Potentials and Practical Proposals for the Use of Solar Thermal Energy in a Chosen Region in Croatia

Martin Felix Pichler

Master Thesis

submitted in fulfilment of the requirements for the degree of Mag. rer. nat.
at the Department of Natural Sciences Karl-Franzens-University Graz

Supervisor and Assessor:

Ao.Univ.-Prof. Dr.phil. Peter Knoll
Department of Experimental Physics, Karl-Franzens-University Graz

Supervisors:

Univ.Prof. Dipl.-Ing. Dr.techn. Wolfgang Streicher
Department of Civil Engineering Sciences, University of Innsbruck

Red.Prof. dr.sc. Bernard Franković, dipl.ing.
Department of Thermodynamics and Energy Engineering, University of Rijeka

2010

Acknowledgments

My sincere thanks go to:

Bernard Franković – for providing me with a working environment in his group at the Technical University of Rijeka during my five-month stay.

Peter Knoll and Wolfgang Streicher for trusting my research method.

Branko Bošnjaković – for his guidance and fruitful feedback on my work.

Paolo Blecich, Sanjin Fućak, Igor Wolf, Aleksandar Božunović, Igor Bonefačić and Christian Lenić for consultations regarding theoretical and practical issues.

Ana Chytil for inspiring me to write about solar thermal energy in Croatia and begin this research.

Abstract

This thesis analyses low-temperature solar thermal potential for Primorje-Gorski kotar County, located in Croatia on the upper Adriatic coast. Of specific interest are applications for heating and domestic hot water preparation for private housing, and in particular, for tourist accommodations. An analysis and surveillance of energy supply and consumption on a global scale, with a focus on Croatia, provides a basis for discussion of relevant renewable sources, consumption sectors, and prices. The requirements for suitable climate data sets for computer simulations of solar systems are discussed. Three different data sets are analysed and evaluated. The hourly useful heat demand profiles for private housing and domestic hot water preparation in tourist accommodations are also examined. Three standard single-family houses with different thermal insulations are defined. Heat demand profiles for tourist accommodations are derived for three different consumer classes from statistical data showing annual overnight stays. Accommodation types show various degrees of utilisation, making it necessary to invent a facility utilisation factor that reflects how much of the available bed capacity is used. Of special interest here is the period from May to September, which contains 91.0% of the annual overnight stays in 2008. For this period, eight annual heat demand profiles for domestic hot water with facility utilisation factors from 0.25 to 0.94 are derived: the average independent facility utilisation factor is 0.51. Four solar thermal systems for private housing and three systems for domestic hot water preparation in tourist accommodations are defined using the above data. Sensitivity analyses are conducted to optimise system parameters and efficiencies. The key figure, solar coverage ratio (SCR), is used to compare systems for a set of collector orientations. Average SCR are used to estimate total final energy savings for certain degrees of solar thermal penetration. This term is illustrated with an example: 10% penetration stands for installation of solar thermal systems in 10% of all single family houses or 10% of all tourist accommodations throughout the county. A realistic scenario that combines installations for private housing and the tourism branch showed a potential 1% decrease of total final energy consumption for Primorje-Gorski kotar County in the subsector Households and 0.6% in the subsector Public Services. Demand for steam and hot water in households could be lowered by 13%. Two similar scenarios with 30% and 60% solar thermal penetration lead to accordingly higher values. The research concludes by providing the most relevant figures regarding energy production, supply and consumption with special attention paid to the electricity market. This was done to underline the viability of solar thermal energy for tackling electricity supply problems. Progress in the installation of solar thermal systems, however, will require a systematic plan for subsidies in order to attract customers.

Zusammenfassung

Ziel und Zweck dieser Arbeit ist die Analyse des solar thermischen Energie Potentials für niedrig-Temperatur Anwendungen für die Region Primorje-Gorski kotar an der oberen Adria in Kroatien. Dafür werden Solaranlagen zur Heizungs-Unterstützung und für reine Brauchwasserbereitung für Einfamilienhäuser als auch für Touristenunterkünfte betrachtet. Die Analyse der Energieversorgung und des -konsums sowohl weltweit als auch mit Fokus auf Kroatien bieten den Hintergrund für die Diskussion von erneuerbaren Energieträgern und Energiepreisen. Benötigte stündliche Klimadaten von drei unterschiedlichen Quellen werden verglichen und bewertet. Der nächste Schritt besteht in der Studie des Wärmebedarfs für private Zwecke und auch für Brauchwasser in Tourismusunterkünften. Das führt zur Definition von Wärmebedarfsprofilen für Brauchwasser und von drei Einfamilienhäusern mit unterschiedlichem Heizwärmebedarf. Brauchwassserbedarfsprofile für Touristenunterkünfte werden auf der Basis von statistischen Daten und drei Gäste-Verbrauchsklassen definiert. Verschiedene Unterkünfte weisen unterschiedliche Belegungen auf, was die Definition eines Unterkunfts-Nutzungsfaktors erfordert. Insbesondere interessant sind die Monate Mai bis September die für 91.0% der jährlichen Übernachtungen verantwortlich sind. Insgesamt werden acht jährliche Verbrauchsprofile für Touristenunterkünfte ausgearbeitet mit Nutzungsfaktoren zwischen 0.25 und 0.94. Die durchschnittliche Unterkunft-unabhängige Belegung im Sommer ist 51% was einem Nutzungsfaktor von 0.51 entspricht. In weiterer Folge wurden vier thermische Solaranlagen für Einfamilienhäuser, und drei thermische Solaranlagen für Brauchwasseraufbereitung in Touristenunterkünften definiert und mittels Sensitivitätsanalysen optimiert. Schließlich wurden für jede optimierte Anlage für eine Reihe von Kollektororientierungen Simulationen durchgeführt um einen durchschnittlichen jährlichen solaren Deckungsgrad (SCR) zu erhalten, welcher den Vergleich von unterschiedlichen System Lösungen erlaubt. Der solare Deckungsgrad, liefert das Potential für die Einsparung von Endenergie für bestimmte solar-thermische Durchdringungen. Die Idee hinter dieser letzten Bezeichnung ist wie folgt: 10% Durchdringung stehen für die Installation von Solaranlagen in 10% der Einfamilienhäuser oder analog für 10% der Touristenunterkünfte im betrachteten Bundesland. Die Kombination der einzelnen Potentialstudien führt zu einem realistischen Szenario für das sowohl 10% der Einfamilienhäuser als auch 10% der Touristenunterkünfte mit Solaranlagen ausgestattet sind. Diese Fallstudie zeigt eine potentielle Reduktion des Endenergiekonsums in Primorje-Gorski kotar County um 1% im Subsektor Haushalte und um 0.6% im Subsektor Öffentliche Einrichtungen. Weiters könnte der Endenergieeinsatz für Dampf und Heiß(Warm)wasser im privaten Bereich um 13% gesenkt werden. Zusätzlich wurde das Potential für Endenergieeinsparung für 30% und 60% solar-thermische Durchdringung untersucht. Die Arbeit schließt mit der Zusammenfassung der wichtigsten Zahlen im Umkreis von Energieerzeugung, -versorgung und -konsum unter Hervorhebung des Elektrizitätsmarktes in Kroatien. Solarthermie könnte schließlich für die Probleme bei der Elektrizitätsversorgung, speziell im Sommer, eine Abhilfe darstellen, was vermutlich aber nur mit einem Plan für finanzielle Unterstützungen praktisch umsetzbar ist.

Sažetak

Tema ovog magistarskg rada je proučavanje niskotemepraturnog solarnog termalnog potencijala na području Primorsko-goranske županije na sjeveru jadranske obale u Hrvatskoj. Promatra se pripremanje potrošne tople vode za privatan smještaj, a posebno za smještaj turista. Analiza opskrbe energijom i njene potrošnje u svijetu, s naglaskom na Hrvatsku, daje podlogu za diskusiju o obnovljivim izvorima energije i troškovima. Osim toga, razmatraju se i uvjeti za dobivanje primjerenih klimatskih podatka za kompjutersku simulaciju solarnih sistema. Tri vrste podataka su analizirane i procijenjene. Sljedeći korak bila je studija potražnje za potrošnom toplom vodom u privatnom i komercijalnom turističkom smještaju. Iz nje su proizašli profili potrebne potrošne tople vode za tri različita tipa obiteljskih kuća. Za turistički smještaj su takvi profili definirani na osnovi statističkih podataka u tri razreda turističkog smještaja. Različiti tipovi smještaja pokazuju različit stupanj korištenja energije, za što je potrebno ispitati faktor korištenja koji ukazuje koliko je od ukupnog krevetnog kapaciteta trenutačno u uporabi. Ovdje su od posebnog značaja mjeseci između svibnja i rujna tijekom kojih je u 2008. godini realizirano 91% godišnjih noćenja. Sveukupno je izvedeno osam godišnjih profila potrošnje za domaći smještaj s faktorima korištenja od 0,25 do 0,94. Prosječno zauzeće neovisno o smještajnim objektima ljeti je 51%, što odgovara faktoru korištenja od 0,51. Nadalje se definiraju četiri solarno-termalna sustava za obiteljske kuće i tri za pripremu potrošne tople vode u turističkom smještaju, te su optimirani pomoću analize osjetljivosti sustava. Zaključno se za svaki optimirani sustav vrše simulacije niza orijentacija solarnih kolektora kako bi se dobio prosječni godišnji stupanj solarne pokrivenosti (SCR), koji omogućava usporedbu raznih izvedbi sustava. Stupanj solarne pokrivenosti označava potencijal uštede potrošnje energije za određeni stupanj tržišnog prodora solarnih izvora energije. Primjer za 10% prodora znači postavljanje solarnih instalacija u 10% svih obiteljskih kuća ili analogno u 10% svih turističkih smještaja promatrane županije. Realističniji scenarij koji kombinira instalacije za privatnu i turističku potrošnju je pokazao potencijal za 1% smanjenja ukupne konačne potrošnje energije u privatnim, i 0,6% u javnim objektima za smještaj Primorsko-goranske županije. Potražnja za energijom potrošenom za stvaranje tople vode i pare u domaćinstvima mogla bi se smanjiti za 13%. Dva slična scenarija s tržišnim prodorom solarne termalne energije od 30% i 60% pokazuju prikladno više vrijednosti uštede. Istraživanje se završava pokazivanjem relevantnih brojki vezanih uz proizvodnju, dostavu i potrošnju energije s posebnim naglaskom na tržište električne energije. To je učinjeno kako bi se naglasila potreba za korištenjem solarne termalne energije u borbi s problemima opskrbe električnom energijom. Ipak, tržišni napredak u postavljanju solarnih termalnih sustava vjerojatno zahtijeva sistematicniji plan subvencija kojim bi se privuklo mušterije.

Contents

Abbreviations

3D	Three Dimensional
A_{Field}	Net collector field size $[m^2]$
A_{Coll}	Net collector size $[m^2]$
a	annum (year)
AM	Air Mass (factor)
AU	Astronomical Unit (=149,598,000 km), mean distance Earth - Sun
ave	average value
CD	Compact Disc
CERA	Croatian Energy Regulatory Agency
CIS	Commonwealth of Independent States
CSP	Concentrating Solar Thermal Power (Plants)
DHMZ	Drzavni Hidrometeoroloski Zavod (Meteorological and Hydrological Service)
DHW	Domestic Hot Water
d_{Hflow}	Pipe diameter for High-Flow design, if not stated otherwise given in [m]
d_{Lflow}	Pipe diameter for Low-Flow design, if not stated otherwise given in [m]
Δ	Indicates either an estimated error or a difference.
ΔT	Any temperature difference (hysteresis) [K]
e.g.	for example, from the Latin 'exempli gratia'
EIHP	Energy Institute Hrvoje Pozar
EJ	Exa Joules
electr.	electric or electrical
$\bar{\eta}_{Coll}$	Average collector efficiency [unity] or [%]
$\eta_{Coll}(t)$	Current collector efficiency [unity] or [%]
η_{con}	Conversion efficiency [unity] or [%]
η_{sys-e}	Average conversion efficiency for electrical boilers [unity] or [%]
$\eta_{sys-oil}$	Average conversion efficiency for fuel oil heating systems [unity] or [%]
$\bar{\eta}_{sys-priv}$	Average conversion efficiency for private heating systems [unity] or [%]
η_{System}	System (Plant) efficiency [unity] or [%]
F_s	Solar fractional savings (SCR) [unity] or [%]

GDP	Gross Domestic Product [US$]
GEC/GDP	Gross Electricity Consumption/Gross Domestic Product [GWh/US$]
GHP	Geothermal Heat Pump
GW	Giga Watt
H	Height of a storage [m]
H_{large}	Height of a storage, for large storages [m]
H_{small}	Height of a storage, for small storages [m]
HRK	Croatian kuna – national currency, 1 HRK = 0,1376 EUR (May 2010)
I_{bh}	Beam irradiance on a horizontal surface [W/m^2]
I_{bT}	Beam irradiance on a tilted surface [W/m^2]
I_g	Global irradiance on a collector surface [W/m^2]
I_b	Beam irradiance [W/m^2]
IAM	Incidence Angle Modification-factor [unity]
LV	Low Voltage
Max	Maximum
Mtoe	million tonnes of oil equivalent
$\dot{m}$	Mass flow rate, if not stated otherwise [kg/s]
OPEC	Organization of Petroleum Exporting Countries
OPL	Optical Path Length [length]
p.a.	per annum (per year)
PGC	Primorje-Gorski kotar County
PhD	Doctor of Philosophy
PV	Photovoltaic
PWh	Peta Watt hours
P_{nom}	Nominal power [Watt]
Q_{demand}	Heat demand [J]
$Q^{(i)}_{f_{rep}}$	Replaceable final energy (for the facility type (i)) [Wh]
$Q^{(i)}_{f_{new}}$	New value for the final energy (for the facility type (i)) [Wh]
$Q^{(i)}_{f_{use}}$	Useful energy heat demand (for the facility type (i)) [Wh]
$Q_{aux(i)}$	Auxiliary heat supply from source i [Wh]
$Q_{dem(S)}$	Nominal heat demand in summer [Wh]
$Q_{fSFH_{10\%}}$	Final energy demand for SFH [Wh]
$Q_{SFH_{10\%}}$	Total useful heat energy demand for 10% penetration [Wh]
Q_{SFH}	Useful heat demand for SFH [Wh]
$Q^{(i)}_{f_{new}}$	Remaining final energy [Wh] (for the facility type (i))
QP	Qatar Petrol
$\dot{Q}_{Coll}$	Current collector power [W]
$\dot{Q}_{Field}(t)$	Power of the collector field [W]
$\dot{Q}_{losses}(t)$	Power of the heat losses [W]

RES	Renewable Energy Sources
SA	Sensitivity Analysis
SCR	Solar Coverage Ratio [%] or [unity]
Sen.	Sensor
SER	Survey of Energy Resources
SFH	Single Family House
SFH I	Single Family House with high specific heat load (50 W/m^3)
SFH II	Single Family House with medium specific heat load (35 W/m^3)
SFH III	Single Family House with low specific heat load (20 W/m^3)
SH	Space Heating
SHGC	Solar Heat Gain Coefficient [Unity]
SRF	Short Rotation Forestry
strat.	stratification, in connection with a heat storage
T_{Coll}	Collector temperature [°C]
T_{flow}	SH outlet temperature [°C]
T_{max}	Maximum temperature [°C]
T_{ret}	SH inlet or return temperature [°C]
TFC	Total Final Energy Consumption [J]
TPES	Total Primary Energy Supply [J]
TPES/GDP	Total Primary Energy Supply/Gross Domestic Product [J/US$]
TREC	Trans-Mediterranean Renewable Energy Cooperation
U	Specific overall heat transfer coefficient [$W/(m^2 K)$]
VAT	Value Added Tax
V_{aux}	Auxiliary volume in a storage for DHW heat reserve [m^3]
V_S	Volume of the storage [m^3] or [litres]
w_η	Assumed real weight for the efficiency η.

Introduction and Chapter Overview

Energy supply and consumption has become an important concern in recent decades. There are two main reasons for this: energy scarcity and climate change. Consider this situation as it affects a country within a multi-national network; Croatia, from a political point of view, is a valuable case study. Croatia, as a candidate for the European Union (EU), must fulfil the EU entry requirements, but also – once a part of the EU – it will be bound to several laws and objectives. Further, the EU has outlined the EU 2020 programme, making renewable energy sources important in the future policies of the EU and Croatia.

Almost all existing generation technologies for standard energy production are mature. However, analysts must give special attention to the sustainability of future resources upon which respective technologies depend. Most of the resources consumed by society are eternal. Solar energy, for example, is the principal 'infinite' energy source for human life on Earth. Estimating the utilisation potential for solar energy, however, is a complex task. It depends on climate, geographical location and energy consumption processes or applications.

Given the focus of this thesis, an important question is how Croatia can meet the goals outlined in the EU 2020 programme. The supply and demand of energy must be regarded in this matter. Croatia has high levels of solar radiation. This means solar energy may become an important alternative to fossil energy consumption, which would decrease CO_2 emissions.

The goal of this work is to find an answer to the low ratio of installed collector area in Croatia, compared to other European countries and to elaborate the solar thermal potential for a region. This work focuses on low temperature solar thermal energy potential. More precisely it designs, calculates and simulates, on an hourly basis, solar thermal systems for domestic hot water (DHW) preparation and heating for SFHs. Ultimately, results should contribute to policy and practical decision-making in the context of solar thermal energy development.

DHW demand profile schemes for private housing and facilities in tourism sectors are provided as is the consideration of the evaluation of solar-supported heating via 'combined solar systems'. This study concentrates only on the climate conditions of Rijeka, located on the upper Adriatic coast. Although this limitation exists, a more extended study concerning the whole country could readily be conducted using alternate climate data sets and tourism statistics. Major results from this work were published and presented at Eurosun2010 conference in Graz, for which a similar analysis extended to Croatia's islands and coastal regions and including economical aspects was conducted [1].

Chapter Overview

Part I *contains a general introduction to energy resources, sources and energy consumption. It begins with the relevant nomenclature for the consideration of energy (re)sources, supply and consumption. Subsequent to this is a discussion of the present world energy mix and Croatian energy supply and consumption with a focus on renewable energy. Finally, solar energy, the fusion process in the Sun and other relevant topics linked to solar energy consumption unfold in detail.*

Chapter 1

The first chapter defines important terms pertaining to energy production and supply. It also introduces several keywords and technical terms with regard to (solar) energy utilisation including relevant energy units, conversion factors and physical and practical taxonomies.

Chapter 2

The purpose of this chapter is to quantify and summarise the global energy resources and sources presently in use. The data presented is based on the 2007 Survey of Energy Resources published by the World Energy Council. Renewable and fossil fuels provide the scaffolding for this discussion. It includes, for example, the explanation of the production of biofuels and the disadvantages of its use compared to ordinary wood cultivation. In addition, this chapter provides a global overview of the Total Primary Energy Supply and the Total Final Consumption.

Chapter 3

This chapter provides an overview of Total Primary Energy Supply and Total Final Consumption for Croatia. This data is in accordance to the Annual report for the year 2007 and to Energy in Croatia 2007, annual energy report. The provision of key development indicators, with respect to energy consumption (TPES/GDP, GEC/GDP, ...), along with the time evolution for TPES, TFC and primary energy self supply falls in this chapter. Analysis of energy production, import and export habits, and consumption sectors provides context for the end prices for final energy, such as heat energy, electricity, coal and coke, oil and natural gas.

Chapter 4

The final chapter of Part I sketches and describes the constitution of the Sun. The main data includes important parameters and derivations such as the solar constant. Of further relevance is the fusion process and heat transfer from the Sun to the Earth, with consideration of the attenuation of solar radiation in the atmosphere. The concept of measuring attenuation using the relative airmass factor is briefly illustrated. Finally, discussion of practical topics in the context of low-temperature solar energy collection, such as Tilt and Azimuth angle of the collector, conclude the chapter.

Part II *concentrates on Primorje-Gorski kotar County (PGC), located on the upper Adriatic coast, south-east of Istria and provides general statistical and climatic data for Croatia and PGC. Analysis of tourist statistics, standardised accommodation facilities and private houses along with their respective DHW and heat demand profiles constitute the majority of Part II. Finally, three different climate data sets for Rijeka are analysed and assessed, in terms of their suitability for the intended simulations.*

Chapter 5

This chapter estimates the number of single family houses of PGC. Tourism is important for Croatia and, therefore, this chapter pays specific consideration to the number of overnight stays in tourist accommodation and private places of residence. The elaboration of standard buildings and heat consumption profiles involved is along the structure as follows: for three distinct single family houses, DHW and heating demand is analysed, while tourist accommodation facilities are considered with respect to the DHW demand only.

Chapter 6

This chapter aims to evaluate different climate data sets for Rijeka, the capital of PGC. It was selected as the location for solar thermal system analysis. Initial discussion begins with the climate in Rijeka followed by assessment of particular hourly climate data required for solar thermal system analysis. Two suitable climate data sets were available for Rijeka. Consequently, three different data sets were compared, including one data set which does not provide hourly data, but serves as a comparison set on a monthly basis.

Part III *is the most relevant part of this work: it describes the simulation software used in this research, by incorporating technical design concepts and calculations connected with solar thermal energy systems into the text. Further system designs and simulation results for domestic hot water systems and combisystems for private housing and tourist accommodations are provided. The solar thermal potential for the regarded region completes the thesis.*

Chapter 7

This chapter discusses the software SHWwin and general topics, including technical concepts related to solar thermal plants. First, is a discussion of software input parameters. This includes simulation related parameters but also solar system related input parameters. The calculation models, used as part of the software, are described and discussed, followed by the output variables and the simulation result form sheet generated by said software.

Chapter 8

This chapter describes the design and the simulations elaborated using SHWwin; their meaning and their outcome for a number of solar thermal systems. The systems concerned here incorporate characteristics of defined standard tourist accommodations and private housing facilities. For defined template systems a number of sensitivity analyses (SA) are conducted. Subsequent one-dimensional SA, aiming to a maximum solar yield, are conducted using the parameter set for the template system: for which parameters are only changed if it is important to guarantee a proper operation of the system. Finally, the vital results such as annual solar coverage ratio (SCR), appear graphically, and the solar thermal system efficiency and other simulation results are discussed. Detailed results of these simulations appear in the Appendix and on an appended CD.

Chapter 9

The last chapter addresses the solar thermal potential estimation. Research was developed using a case scenario for which a solar thermal penetration of 10% is assumed. This solar thermal penetration level represents a scenario wherein 10% of the private houses and buildings providing tourist accommodation are endowed with solar thermal systems, respectively. The number of solar thermal systems installed, along with the obtained simulation results, lead to potential final energy savings in private housing and tourist accommodation facilities, respectively. Outworked tourist statistics explained in Chapter 5 are applied for this purpose. Based on this scenario, other similar situations with a higher solar thermal penetration may be calculated. Eventually, the replaceable final energy and the remaining auxiliary energy are calculated using SCR outcomes from Chapter 8 for the according plants. A summary and a conclusion isolate the main results and findings in this research.

Part I

Energy Resources and Sources

Chapter 1

Nomenclature

This chapter defines important terms pertaining to energy production and supply. It also introduces several keywords and technical terms with regard to (solar) energy utilisation including relevant energy units, conversion factors and physical and practical taxonomies. More detailed explanations with graphical support are provided in Chapter 4, Solar Energy.

1.1 General energy terms

Except for the division of thermodynamic systems, the first and second laws of thermodynamics and the Carnot process, which are general basics of the theory of thermodynamics, the following definitions are based on those given in [2] and [3]. With regard to physics, in order to perform work, a force is needed. The origin of the force arises from an interaction: i.e. gravitational-, electromagnetic-, weak- or strong interaction. In every man-made process involving the production of useful energy, one of these interacting forces must be the impetus. Thermodynamic systems, as shown in *Figure* 1.1, can be divided into three categories:

1. **Open systems**, which can exchange matter and energy with the environment.
2. **Closed systems**, which can exchange only energy with the environment.
3. **Isolated systems**, which can exchange neither matter nor energy with the environment.

For many applications, thermal energy is converted into mechanical energy. Clausius (1857) established the concept that heat is statistically distributed energy among particles. The **first law** of thermodynamics

$$dU = \delta W + \delta Q \tag{1.1}$$

allows dU to describe the change of the internal energy of the system of interest. δW represents mechanical energy, and δQ is heat energy. The first law implies there exists no perpetuum mobile of the first kind. It also describes the connection between thermal and mechanical work.

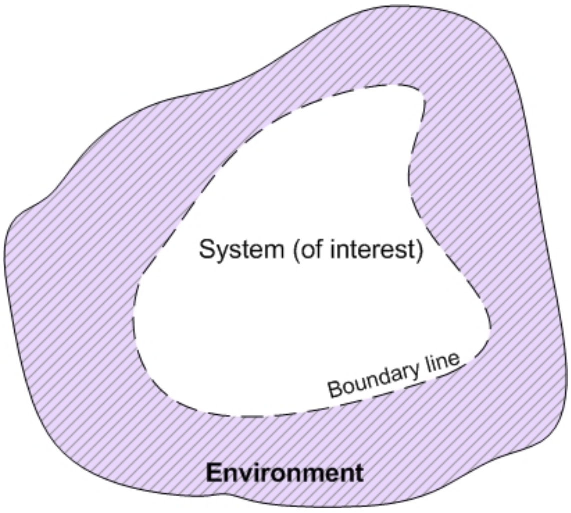


Figure 1.1: Thermodynamic system within an environment

The **second law** reads

$$\begin{aligned} \text{isolated systems in equilibrium satisfy:} \quad & dS = 0, \quad S = S_{max} \\ \text{for irreversible processes:} \quad & dS > 0, \quad \text{holds.} \end{aligned} \tag{1.2}$$

The state quantity S represents entropy and is defined by $dS = \delta Q_{rev} \;/\; T$. Any real process where heat is exchanged leads to an increase of the total entropy. The conversion from thermal into mechanical energy can only be done with a thermodynamic machine.

The **Carnot heat engine** is an ideal engine that converts heat into mechanical energy. The efficiency of this machine is defined by:

$$\eta = \frac{W}{Q} = \frac{T_h - T_c}{T_h} \,, \tag{1.3}$$

where W refers to the mechanical work and Q to the heat energy applied. T_h and T_c are the temperatures of the two heat reservoirs – the hot and the cold, respectively. Carnot's theorem states that no other engine operating between two heat reservoirs can be more efficient than a Carnot engine. This theory is vital when considering heat as a generator for mechanical energy, such as the case for solar thermal driven steam power plants.

If one neglects the mass transfer from the Sun to the Earth, and vice versa, one must consider the Earth as a closed system. The Earth's atmosphere becomes a system boundary, and taking into account the energy conservation law, one finds that **solar radiation** and **gravitational interaction** are the **only two energy flows across the system boundary**. Therefore, these two sources nearly supply the Earth with infinite energy. Moreover, we may gain useful energy supplies via selective usage of geothermal energy. Consequently we can rely only on three energy sources which can be harvested via several methods. The structural diagram in *Figure* 1.2 demonstrates this statement.

1.1.1 Energy carriers

For practical reasons, the term **energy carrier** refers to a substance that could be used to produce useful energy either directly or by one or more conversion processes, synonyms are energy commodity, energy vector or energyware [1]. According to the degree of conversion,

[1] The word *production* or *produce* in the context of energy always means the conversion from one form of energy into another.

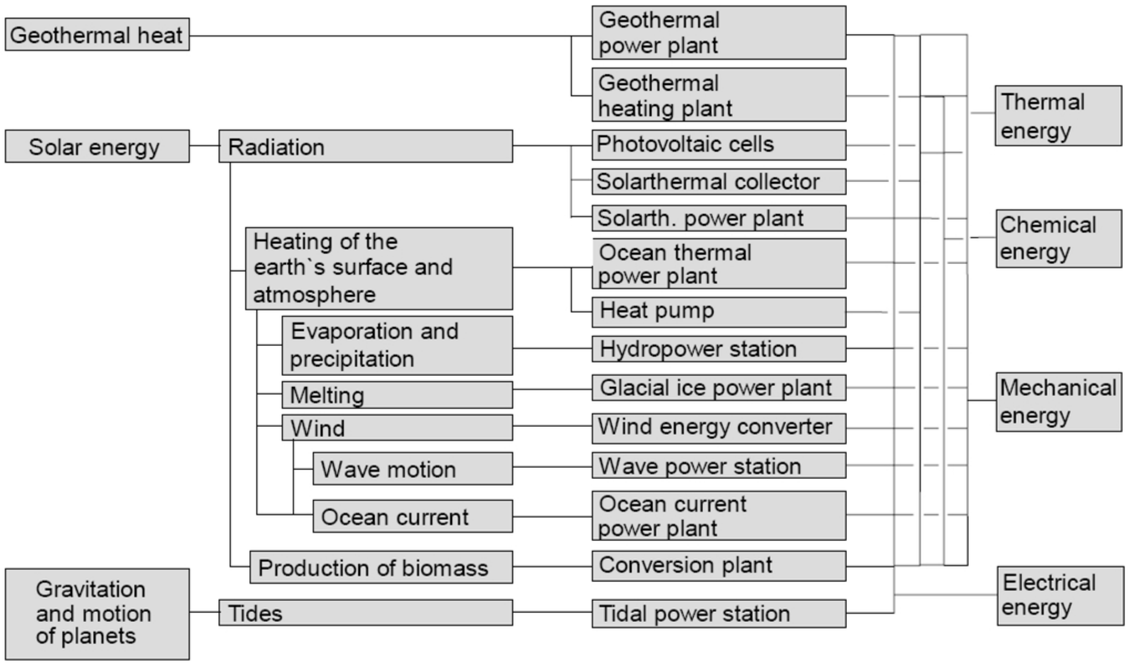


Figure 1.2: Energy sources structure; taken from [2] with permission from Wolfgang Streicher.

energy carriers are classified as **primary**-, **secondary**- or **final energy** carriers. In *Figure* 1.3, the energy conversion chain progresses from left to right. Each conversion is subject to losses.

- Primary energy carriers are energy bearing substances which have not been subjected to man-made processes. The term, therefore, means the amount of energy stored in a primary energy carrier or in a primary energy flux. As shown in *Figure* 1.3, lignite and crude oil are primary fossil energy carriers. With regard to renewable energy sources (RES), wind power and solar radiation are considered to be primary energy fluxes. Solar thermal energy is captured heat from the primary energy flux emitted by the Sun. Other examples for primary energy are hard coal, uranium, hydropower and biomass.

- Secondary energy carriers, or secondary energy, can be obtained by one or several conversion stages. In addition, secondary energy means the amount of energy stored in a secondary energy carrier or in a secondary energy flux. All energy carriers directly derived from primary energy carriers are termed secondary energy carriers. By contrast, branches from secondary energy carriers (refined crude oil) can either be other secondary energy carriers (heating oil) or final energy carriers (light heating oil).

- Characteristic of final energy and final energy carriers is a suitability for change into useful energy consumed by the final user. Final energy carriers are produced from secondary and possibly from primary energy carriers. Due to conversion and distribution losses, and self consumption of the conversion system, these carriers lack a specific amount of energy when compared to the primary resource. Heat energy, in a heat storage gained from solar absorbers, is an important form of final energy relevant to this research.

- Useful energy refers to the different forms of energy directly consumed by humans. It can satisfy the needs of daily life as space heating, food preparation, transportation and illumination. Useful energy is directly derived from final energy carriers or final energy. The amount that can be consumed decreases due to losses during this last conversion process: e.g. losses of the heating system providing heat for space heating.

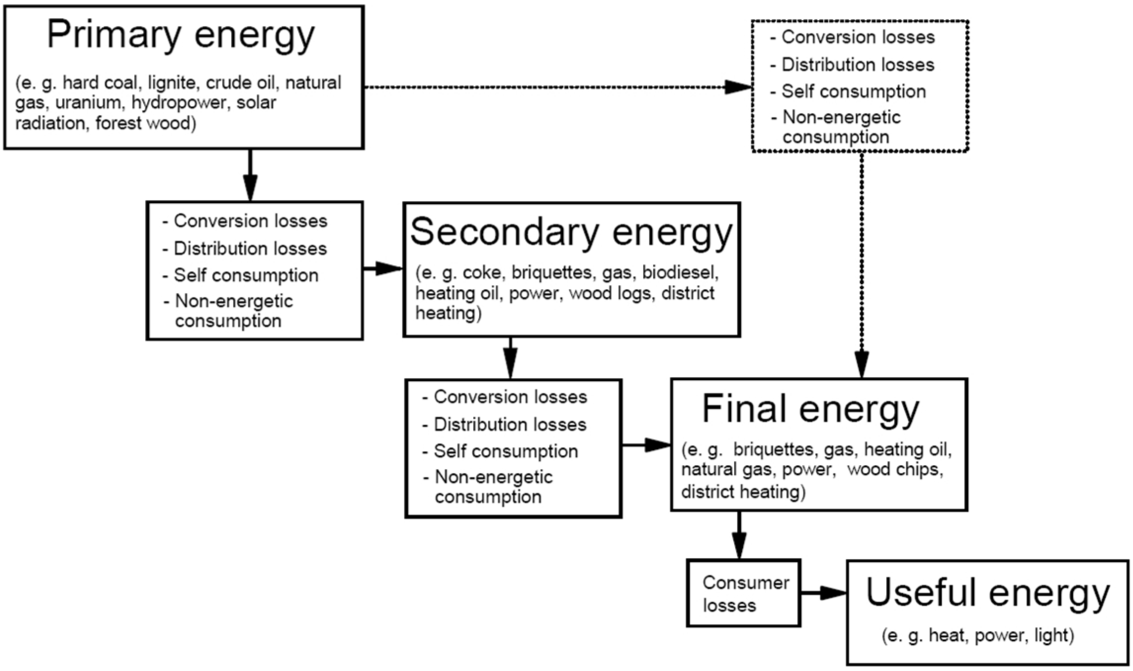


Figure 1.3: Energy conversion chain, taken from [2] with permission from Wolfgang Streicher.

1.1.2 Fossil versus recent (re)sources

A **resource** is something of limited availability while **source** refers to something that is almost inexhaustible and generally refers to a stream over a long period of time [2]. Resources are divisible according to the time it takes to generate them into **recent-** and **fossil resources**.

- Fossil energy resources are stocks of energy that were formed in previous eras [3]. In detail, we classify fossil biogenous resources, which are stocks of biological origin (lignite, hard coal, natural gas and crude oil deposits), and fossil mineral resources, which are stocks wherein the origin of the energy carrier is mineral or non-biological (deposits and resources to be used for nuclear fusion or fission processes).

- Recent energy resources are energy stocks, biologically formed during a human lifespan. If one generation harvests a fire wood forest, the following generation may harvest another fire wood forest cultivated by the former generation. Therefore, we speak about renewable or recent energy resources if the building process for the energy carrier falls within a human lifespan. The energy content of biomass and the potential energy of a natural reservoir, such as a lake in a mountainous region, are part of renewable energy resources.

[2] More precisely it is inexhaustible at least in terms of human time frame.
[3] During a time up to 100 million years ago.

To summarise, renewable energy (carriers) stem from **almost inexhaustible streams** or from **recent biogenous resources**. The following sources are responsible for the streams: the Sun, the Earth's core and gravitational interaction. These yield streams of solar radiation, heat flow from geothermal energy, and tidal flow of water, respectively. In addition, the Sun provides energy for the production of biomass, and it drives renewable streams for so-called **renewable energies** like wind and hydropower. The **energy basis** is the total quantity of energy available to humans [4]. The most reliable distinction between any renewable and common energy (re)sources is the character of regeneration within a human time frame.

1.2 Energy units

The most common units for energy are Joules (J) and Watt-hours (Wh). In the statistical data of the WEC and the IEA, however, mainly kilogram of oil equivalent (oe) appears. Various scaled units can be derived when combined with the appropriate decimal prefixes.

1.2.1 Relevant decimal prefixes

The most important decimal prefixes in use when referring to energy consumption and supply shows the next table.

Table 1.1: Relevant SI decimal prefixes for scaling the energy units

Prefix	Abbreviation	Factor
Hekto	h	10^2
Kilo	k	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}
Zetta	Z	10^{21}
Million	m	10^6
Billion	bn	10^9
Trillion		10^{12}

1.2.2 Conversion factors

Some conversion factors between different scaled units are provided in Table 1.2.

Table 1.2: Conversion factors between scaled energy units

	kJ	kWh	kg oe	m^3 gas
1 Kilo joule (kJ)	1	0.000 278	0.000 024	0.000 032
1 Kilo watt hour (kWh)	3600	1	0.086	0.113
1 kg oil equivalent (kg oe)	41 868	11.63	1	1.319
1 m^3 natural gas	31 736	8.816	0.758	1

The conversion factors refer to the net calorific value.

[4] The World Energy Council (WEC) provides slightly different definitions. Energy resources are present, known and potentially accessible stocks. There is further differentiation of finite and perpetual, or everlasting resources. In this sense, RES are perpetual resources.

1.3 Sun energy utilisation

1.3.1 Solar radiation

The following definitions explain important terms in the context of Sun energy utilisation. Detailed description and graphical support follow in Chapter 4.

- **Radiation** means heat, energy, etc. that travels in the form of rays. For instance, solar radiation emanates from the Sun.
- **Irradiance** is a radiometry term for the power of electromagnetic radiation at a point **r** normal through a unit surface. The dimension in use is W/m^2.
- **Intensity** describes an area density and can refer to power or energy i.e. W/m^2 or kWh/m^2.
- **Insolation** is the amount of radiation from the Sun which reaches a particular surface within a given time frame. Therefore, insolation is a time average of irradiance in W/m^2. However, it can also be given in kWh/m^2.
- The **solar constant**, in general, refers to the average solar irradiance at the top of the Earth's atmosphere in W/m^2.
- **Air mass** (AM) provides a measure to calculate the attenuated value for the solar constant at an altitude close to the ground.
- **Global radiation** is the sum of diffuse and direct radiation either in W/m^2 or kWh/m^2.
- **Diffuse radiation** is the amount of radiation coming from all directions but the Sun, which reaches a surface under shadow of a cover that prevents the incidence of direct radiation. It is given in W/m^2 or kWh/m^2.
- **Direct radiation**, or beam radiation, in W/m^2 or kWh/m^2, is the amount of radiation from the Sun passing through a clear atmosphere and reaching a surface without any attenuation.

1.3.2 Practical context

For the utilisation of solar energy, the following terms must be understood.

- Latitude and the longitude define **geographical location**.
- **Latitude**, range 0-90° from the equator (per definition lat.=0°) to the north pole counted positive; and 0-90° to the south pole with a negative sign.
- **Longitude**, range 0-360° counted with respect to the so-called prime meridian that passes through Greenwich, England.
- **Tilt**, or slope, is the angle that a global radiation collecting surface makes with the horizontal plane at a site.
- **Azimuth** is the angle of orientation of an inclined surface ($tilt \neq 0°$) – in the northern hemisphere, it is given with respect to southern direction.
- **Absorber** stands for the surface that collects solar radiation. A selective absorber has a surface especially adapted for the solar spectrum and is more efficient than any black painted surface. This means it has an absorption coefficient close to one ($\alpha \approx 1$) for short wavelength radiation and an emissivity close to zero ($\epsilon \approx 0$) at any wavelength.
- A **storage tank** functions as an energy storage normally filled with plain water, which sometimes contains additives.
- The term **termosyphon** refers to a simple solar thermal system operating on the base of natural circulation driven by the density differences of hot and cold water.

Chapter 2

World Energy

The purpose of this chapter is to quantify and summarise the global energy resources and sources presently in use. The present data is based on the 2007 Survey of Energy Resources published by the World Energy Council. Renewable and fossil fuels provide the scaffolding for this discussion. It includes an explanation of the production of biofuels and the disadvantages of their use compared to ordinary wood cultivation. In addition, this chapter provides a global overview of the Total Primary Energy Supply and the Total Final Consumption.

2.1 Fossil resources

It is important to know where energy resources are, in what form, and in what quantities when considering energy policy. With the Survey of Energy Resources 2007 (SER) [5], the **World Energy Council** (WEC) published an assessment that provides the latest information in answer to these questions. It is very difficult to collate the collected data regarding energy resources from around the world under a common denominator [4]. Finite reserves are divided into amounts in reserve and quantities recoverable – both proven and non-proven. Data stems from national agencies and underlie different definitions or separations. The highest degree of homogeneity among the different divisions exist for **Proved Recoverable Reserves**.

2.1.1 Coal

Industrialisation was driven by coal, and, as it was then, it is still invaluable. Coal remains a principal force in world energy and was the fastest growing resource in use worldwide in recent years. Because of the long history, the location, size and characteristics of most countries, coal resources are well established. **Economically recoverable** reserves exist in some 70 countries and amount to **850 billion tonnes** – what is approximately **25 000 EJ** [1]. The current annual primary energy consumption of the world ($\approx$ 500 EJ) could be covered for a period of 50 years with this amount of energy.

[1]One billion = 10^9. In the 'statistical review of world energy' published by BP one can find a figure of 826 001 million tonnes for proved reserves at the end of 2008; this is slightly less than the amount provided here. The sometimes claimed 500 years for which coal would provide the current world energy consumption is a misunderstanding. This 500 years is the so called reserves-to-production ratio and refer only to a few regions, which hold a marginal share of 1.3% of the total reserves.

2.1.2 Oil

Oil, as assessed in the mentioned survey, continues to play a major role in future. According to information from WEC member committees and supplementary sources, **proved reserves** of conventional oil stood at **1215 billion barrels** (160 billion tonnes) at the end of 2005 [2]. This amount is 7% higher than it was in the previous study in the year 2002. Expressed in joules it is **6720 EJ**.

Until the end of 2005, the cumulative global crude oil production reached 143 billion tonnes, half of which was produced within the last 23 years. Adding the produced and the proved reserves and calculating the share of this 143 billion tonnes from the total, one gets 47%, which is the percentage value of consumed conventional oil out of the total global reserves discovered so far. The ascending straight line in *Figure* 2.1 clearly shows the direction of oil production since 1980. The horizontal lines show certain reserves. In the Middle East, what remains a major resource location, reserves amount to 61% of the global total. It is followed by Africa with 11%, South America with 8%, Europe, including the whole of the Russian Federation, with 8% and finally by North America where the reserves amount to less than 5%. The assessment from the German Federal Institute for Geosciences and Natural Resources refers to the **Estimated Ultimate Recovery** (EUR) of conventional oil, which amounts to some 387 billion tonnes (**16 300 EJ**) [3].

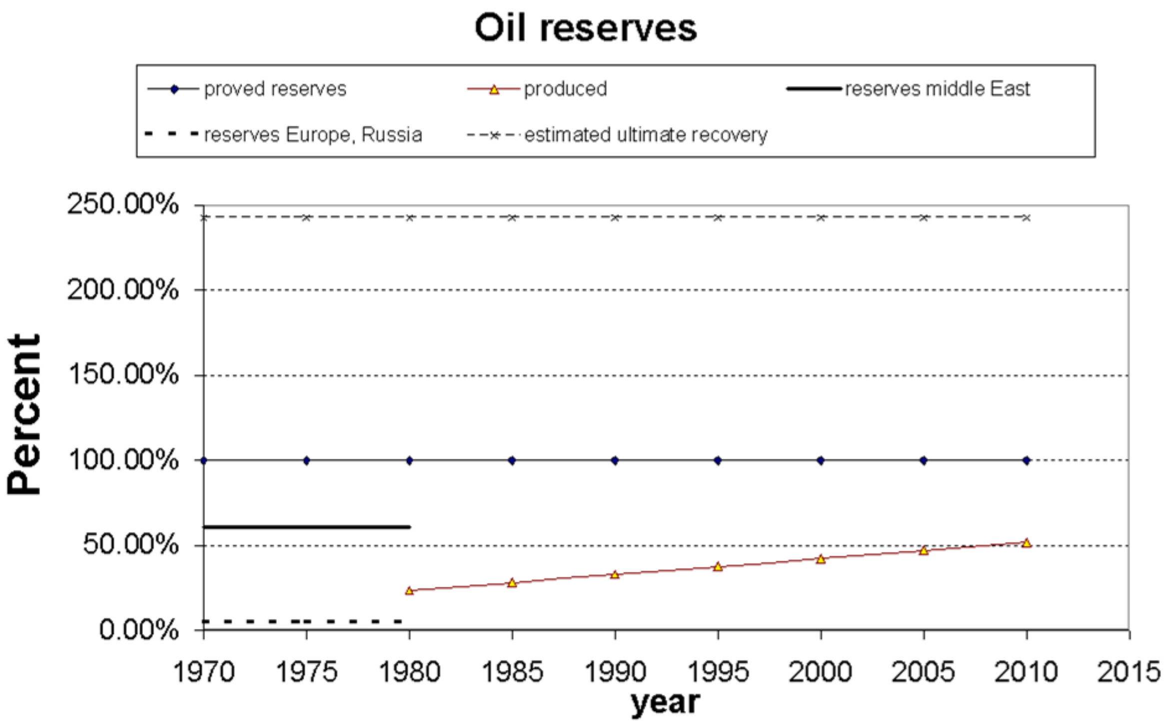


Figure 2.1: Oil reserves and cumulative production

2.1.3 Oil shales

Oil shales are sedimentary rocks from which significant amounts of shale oil and combustible gas can be extracted. A conservative estimation of the world's global resource leads to 2.8 trillion barrels (16 110 EJ) [4]. Because of the extensive extraction process and high costs, only a few deposits are presently exploited. Extraction in 1999 amounted to 600 million tonnes – equivalent to 866 TJ of oil worldwide. Depending on the market price

[2] Conventional means that oil from coal, shale, bitumen and extra-heavy oil are excluded.
[3] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in Hannover
[4] trillion = 10^{12}

for oil, some extraction sites are temporarily stopped or restarted. Only three locations are currently active.

2.1.4 Natural bitumen and heavy oil

Natural bitumen, which refers to tar or oil sands and heavy oil, are characterised by their high density and viscosity and other peculiarities regarding composition. With respect to the predominant location for each of these categories one country accounts for the majority of the global reserve. Canada, in the case of natural bitumen, provides over 70% of worldwide reserves. In the case of extra-heavy oil, Venezuela takes the first place with nearly 98% of recorded reserves. Exact figures of the **reserves** are not available, but it is **suggested** to take the same amount of oil originally in place, i.e. some 300 billion tonnes or **12 600 EJ**.

2.1.5 Global gas reserves

In the current energy mix, **natural gas** has a substantial share of 23.5% of the total primary energy supply (TPES), therefore, it ranks third behind oil and coal. The actual **proved recoverable** reserves at the end of 2005 amount to **176 462 billion cubic metres**, which is equal to approximately **6350 EJ**. This amount, with the current share of natural gas, would provide supply for further 56 years – assuming continued present energy consumption.

Approximately 73% of gas reserves are concentrated in two areas: the Middle East and the Commonwealth of Independent States (CIS). Reserves are distributed similar as oil reserves. The OPEC countries have about half of total reserves, compared with 75% for oil. The CIS enjoys a more advantageous situation for gas, with 33% of total reserves against only 10% of total oil reserves. The world's largest gas field is in Qatar. According to Qatar Petrol (QP), this field holds approximately 90% of the total proved recoverable reserves of Qatar – 26 740 billion cubic metres of natural gas. Qatar has proved recoverable reserves that amount to 923 EJ, approximately twice the annual total world energy consumption.

In addition to the proved recoverable reserves, CEDIGAZ, which is an international association dedicated to natural gas information, suggests that the abundance of gas reserves already discovered and the prospects for a large yet-to-find potential, give natural gas a lifetime probably in excess of 130 years at the current rate of consumption.

2.1.6 Uranium ^{238}U

This is the most common isotope of Uranium found in nature. The Total Reasonably Assured Resources, in comparison with the above nomenclature, is the same as 'proved recoverable' reserves, which reach nearly 3.3 million tonnes of Uranium recoverable at less than \$ US 130/ kgU. This amount is equal to approximately **1400-2220 EJ** [5].

Thorium, similar to Uranium and plutonium, can also be used as fuel in a nuclear reactor. Although not fissile itself, ^{232}Th will absorb slow neutrons to produce ^{233}U, which is fissile. **Thorium** is three times as abundant as Uranium in the Earth's crust. A conservative assumption gives some **4.5 million tonnes** for reserves and, since exploration trials were low, additional resources may exist. The energy potential of Thorium can be assumed to be at least the same as that for Uranium.

At the beginning of 2007, there were 435 nuclear power reactors in operation, which were able to generate 367 GW_e. Identified Uranium resources could last 85 years if utilised in the once-through mode, a state-of-the-art technology with enrichment practices. Closed

[5] One tonne of Uranium (light-water reactors, open cycle) = 10 000 - 16 000 toe

fuel-cycles and pure fast breeder reactor technology, however, could make the resources last for up to 6000 years. The current amount of electricity production was assumed for both technologies.

The question of whether a mineral is economically-producible is a function of concentration, exploration and production technology, demand and market price. For Uranium raw material price pertains with 3% to the electricity price. Uranium resources themselves are seen to be plentiful and should not hinder the development of nuclear power. The limiting factor is untimely investment in new production facilities.

2.1.7 Peat

With reference to the definition of renewable energy carriers, peat lies at the edge between renewable sources and finite resources. It is, therefore, named as an intermediate fuel, halfway between the biomass of which it was originally composed and coal, which it would develop given the appropriate geological conditions.

Resources for peat are enormous; the total area of peat lands approaches 3 million km^2, which is about 2% of the total land surface. The **peat reserve base** in major producing countries, with reserves currently under active cultivation or economically recoverable under current market conditions, was assessed as **5267 million tonnes** (air-dried) in 1993 [6]. This gives approximately **50 EJ**.

2.2 Renewable sources

Sources in this section are renewable energy (carriers), which stem from almost inexhaustible streams or from recent biogenous resources. Energy amounts are given with respect to the period of one year. Underdeveloped countries get one fifth of the primary energy supply from renewables in industrialised countries, the fraction is, on average, only one twentieth [6]. In Austria, however, the respective share varied between 20% and 23% since 1980 [7].

2.2.1 Geothermal

In the SER, this source was classed as an intermediate energy resource although, for most practical purposes, it can be regarded as perpetual. The temperatures at the base of the continental crust are believed to range from 200°C to 1000°C. The Earth's crust has an average thickness of approximately 6.5 km, however, it can reach up to some 30 km. The according temperature range provides heat for several purposes such as electricity production or direct heat usage.

Worldwide data relating to geothermal heat pump (GHP) applications were presented at the World Geothermal Congress in Antalya, Turkey, 2005. GHP accounts for 54.4% of the worldwide geothermal direct-use capacity. The reported annual energy use was **87.5 PJ** with a capacity factor of 0.18 in heating. For space heating, its market penetration is highest in Iceland where it amounts to approximately 90%.

2.2.2 Hydropower

In 2005, RES had a share of one-fifth of the total power generation, of which hydropower contributed the major share, namely 87%. The total global hydropower capacity is 778 GW and generates 2.8 PWh. At the end of 2005, another 124 GW of hydropower capacity

[6] 1 tonne of peat = 0.2275 toe

was under construction; this amounts to approximately 16% of the installed capacity. Hydro-electric generation in 2005 was more than 2.8 PWh, or approximately **10 EJ**.

The stipulated 2.8 PWh annually produced represents 17% of the world's **technically exploitable capability** for hydro sites, approximately **16.5 PWh** or **59.4 EJ** p.a. [7]. The 'gross theoretical capability' amounts to 41.2 PWh p.a. [8]. Although the economically exploitable capability is considerably less than the corresponding technical potential, the International Hydropower Association **estimates** that only **one-third** of the realistic potential has been **developed** thus far.

2.2.3 Bioenergy

Bioenergy indicates the use of vegetable matter as a source of energy for a variety of fuels. Wood makes the largest share in the category bioenergy – about half of the estimated total world supply of **combustible renewables and waste**, approximately **48 exajoules** [6]. Global wood consumption for energy purposes in 2005 was approximately 22 EJ; 17.9 EJ was used as fuelwood. As a primary source, wood provides the production of 1.4 EJ of charcoal and 2.7 EJ of black liquor [9].

The next-largest secondary transformation of biomass is electricity generation. Estimated electricity production from biomass amounted to about 183 TWh (659 PJ) in 2005 nearly three-quarters of which were produced from solid biomass and the remaining from biogas and municipal solid waste. The world's production of **ethanol** in 2006 was approximately equivalent to **1.1 EJ** (USA 40%, Brazil 37%). The controversy surrounding the production of fuel from food resources is justified. For Brazilian sugar-cane one has a ratio of about 8 units of renewable liquid fuel to 1 unit of fossil-fuel input. By contrast the production of ethanol from corn is only marginally energy-positive, the ratio is about 1.4:1.

Biofuel from Rape

The following calculation example should underline the very low efficiency of biofuel production from rape. This comparison is reasonable unless the burning of fossil fuels for heating purposes is suspended.

One hectare of **rape** for the production of agrodiesel, with a conventional cultivation assumed, leads to a peak output of three tonnes/(hectare year). The output can be devided into one tonne plant-oil (unethereal agrodiesel) and two tonnes rape-cake. The energy amount of a yield of one tonne plant-oil is equal to 10 000 kWh or 36 GJ. Two tonnes of rape-cake account for the same amount of energy since the energy density is half that of the rape-oil. This gives a combined total of 20 000 kWh, or 72 GJ. Yields were based on annual harvesting. Inputs were the conventional tractor, N-fertiliser and plant-protection substances [8].

This calculation is now compared with a scenario where the same area of land is dedicated to grow biomass for heating purposes. **Woodlike biomass** produced in Short Rotation Forestry (SRF) cultivation, once planted, leads to a yield of 80 tonnes per hectare each second year for a period of 20 years without any additional fertilisers. The moisture content is approximately 50%. The annual figures for one hectare of land are as follows:

---

[7] This is the amount of the gross theoretical capability that can be exploited within the limits of current technology.

[8] This is the potentially available annual energy if all natural flows were turbined down to sea level, with 100% efficiency. Flows are estimated on the basis of atmospheric precipitation and water run-off.

[9] Black liquor is a by-product in the pulp and paper industry, and it can be used to produce biogas or be burned directly, however, the high yield of sulfur is a problem.

$$80 \text{ tonnes}/(2 \text{ years}) \rightarrow 40 \text{ tonnes/year} \overset{50\%\ water\ content}{\rightarrow} 20 \text{ tonnes/year}.$$

Assuming an energy content of 5 kWh/kg for dry wood, this yield is equal to 100 000 kWh or 360 GJ p.a., per hectare. The energy input for SRF is one tenth of that for rape cultivation.

To summarise, if provided a land area of **one hectare** suitable for agro-cultivation, two different harvesting strategies may be compared. The annual **energetic outcome** for rape (**rapeoil and rape-cake**) is **72 GJ** – with a specific energy input not provided here. By comparison, the yield for **SRF**, with only 10% of the needed energy input, is approximately five times higher – namely **360 GJ**. These two pathways are illustrated in *Figure* 2.2. The tractors represent the energy input, and the oil dropping in the barrel is the energy equivalent yield.

Assuming an average annual solar yield of 1000 kWh/m^2, the incident energy on one ha (=10 000 m^2) is 10 GWh, or 10 000 000 kWh. The **net photosynthetic efficiencies** are **0.2% for rape** and **1% for biomass** cultivation. By contrast, state-of-the-art PV cells, or solar thermal systems, can achieve efficiencies above 10% or approximately 40%, respectively.

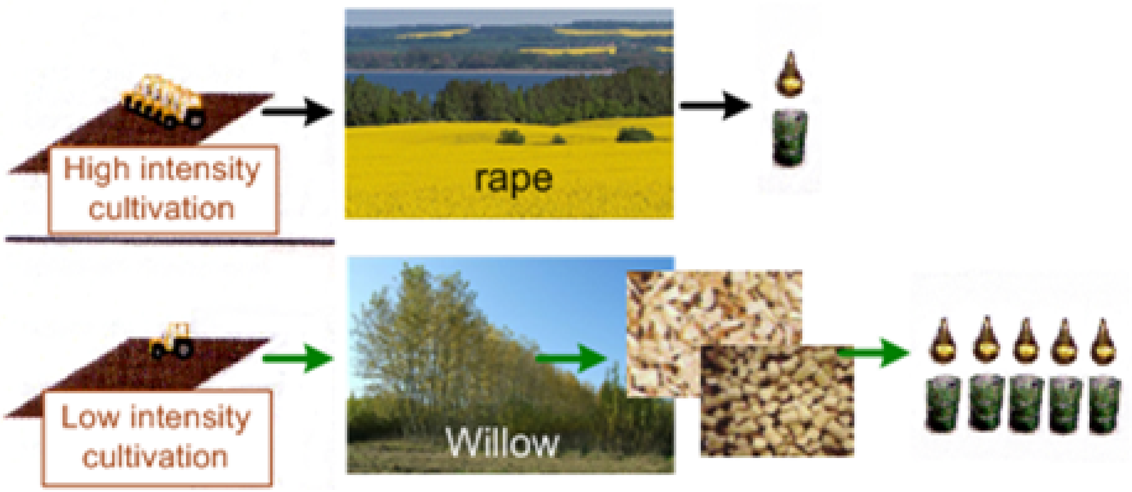


Figure 2.2: Comparison of energy output between generation of agrodiesel and woodlike biomass on the same land area – pictures provided by [9].

2.2.4 Solar energy

The annual solar radiation reaching the Earth is over 7500 times the world's annual total primary energy consumption (450 EJ). It is, therefore, the most abundant perpetual energy source on Earth. The average annual level of irradiance is 170 W/m^2. This amount can be easily harvested to produce heat energy at temperature levels up to 100°C and has applications in the heating and cooling of buildings and the provision of domestic hot water. Concentrating collectors provide medium temperatures of 100 - 400°C, which has applications in process heat, refrigeration and electricity generation. Much of the heat used in industrial processes is less than 250°C.

The installed capacity has been analysed in [10] for 49 countries representing 4 billion people or 60% of the world's population [10]. It was estimated that the analysed countries represent 85 - 90% of the solar thermal market worldwide. The found collector area in operation was 209.7 million m^2, or 146.8 GW_{th}, at the end of 2007. During the same year, the additionally installed power amounted to approximately 7.4% of the existing power. The **specific power in operation**, per 1000 inhabitants, is highest in Cyprus

[10] Croatia was not included.

(651), followed by Israel (499), Austria (252) and Greece (224), where figures are in kW_{th}, respectively. The amount of heat energy generated was found to be 88 845 GWh (**319.841 TJ**), or 12.09 million tonnes expressed in oil equivalent. This eventually avoids 39.3 million tonnes of CO_2.

By contrast to solar thermal applications, photovoltaic devices convert the short-wave solar radiation directly into electricity. The principal advantage is this operation as stand-alone systems, providing power in a range from micro- to megawatts. A drawback is the relatively high costs and the energy-intense production technology of the modules. The global market in modules for terrestrial applications, however, is growing by 35% p.a..

2.2.5 Wind energy

Wind as a source could provide us with a huge amount of energy; **estimations** suggest around **a million gigawatts** for total land coverage [5]. If only **1% of the area was utilised**, and allowance was made for the lower load factors of wind plants (15 - 40%, compared to 75 - 85% for thermal plants), the wind power potential – 13 - 35 million GWh, or **4.68 - 12.48 EJ** – would still equal approximately the total worldwide capacity of all electricity-generating plants [11]. Offshore wind sources could contribute a huge amount to electricity production. European sources up to 30 km from land, for example are capable of satisfying all the European Union's electricity needs. Market development shows doubled capacity every 3.5 years since 1990. By the end of 2006, it reached 72 000 MW, giving rise to an annual output of 160 TWh, or **576 PJ**. The nominal plant power ranges from 2 MW up to 5 MW.

Calculation for policy makers shows that 20% of total electricity consumption could be covered by wind energy. Beyond this point, some plants may need to be stopped when high winds coincide with low levels of demand, unless special electricity storage devices or pump storage hydropower plants can compensate for lower demand.

2.2.6 Tidal

Tidal refers to the cyclic variations in sea and ocean levels due to gravitational interaction. Water currents accompany these variations in sea level, which, in some locations, can be extreme. People residing near the ocean know the influence of gravity on sea level. Few know the Earth's crust moves vertically – up to 20 - 30 cm.

Harvesting water movement means high capital costs due to tidal barrage systems, which will likely restrict the development of tidal power utilisation in the near future. **Economically exploitable resources** range from 140 to 750 TWh p.a. (**504 - 2700 PJ**) for current designs. Design improvements could triple this figure to approximately 2000 TWh p.a. (7200 PJ).

2.3 Data collection of worldwide resources

Table 2.1 provides an overview of resources and sources and their respective reserves in EJ. Coal has the highest share among the considered resources followed by oil and global gas. Below the table acronyms are given indicating the type of respective amounts. Most attention must be drawn to proved recoverable resources (pro), economically recoverable/exploitable (eco) and annual generation (ag). For RES the given values always refer to current or potential annual generation.

[11] Load factor is the average power divided by the peak power over a period of time.

The 25 000 EJ for *Coal* are regarded as proved economically recoverable reserves. The values for *Oil* refer to conventional oil that can be produced under current conditions. The extensive and expensive extraction process of oil from *Oil shales* restrains present exploitation from deposits. In 1999, an amount equal to 866 TJ of oil was extracted. This gives the estimated recoverable reserves little meaning. The estimated value for *Hydropower* refers to technically exploitable energy. For the estimated *Wind* potential an utilisation of 1% of the suitable area for wind energy usage is assumed. Estimations for *Tidal* energy refer to economically exploitable levels.

The present annual generation and utilisation of solar thermal energy is marginal compared to other resources and sources. The theoretical potential is huge. It is vital to estimate the solar thermal potential in detail – applying calculations or simulations. Since the respective process or application of interest and heat demand requires analysis, and a solar thermal system design is also required, this process can be cumbersome.

Table 2.1: Energy resources and sources worldwide in EJ, the world wide annual energy demand is 450 EJ: all numbers are according to [5].

Type	Name	**Reserves**	
Fossil	Coal	25 000 **eco**	
	Oil	6720 **pro**	16 300 **eur**
	Oil shales		16 110 **est**
	Natural bitumen, heavy oil		12 600 **est**
	Global gas	6350 **pro**	
	Uranium	1400 - 2220 **pro**	
	Thorium		1400 - 2220 **est**
	Peat	50 **eco**	
		annual generation	
Renewable	Geothermal	0.09 **ag**	
	Hydropower	10 **ag**	59.4 **tec**
	Bioenergy – total	48 **ag**	
	Solar – total	0.0003 **ag**	
	Wind	0.6 **ag**	4.68 - 12.48 **est**
	Tidal	0.5 - 2.7 **eco**	7.2 **est**

eco ... economically recoverable/exploitable
pro ... proved recoverable
eur ... estimated ultimate recovery
est ... estimated recoverable
ag ... annual generation
tec ... technically exploitable
total ... refers to thermal and electric

2.4 TPES and TFC

An objective comparison of primary energy (re)sources is only possible if the linked final energy consumption is regarded parallel. This is due to varying efficiencies among different processes.

According to the definitions in General energy terms and the diagram in *Figure* 1.3, it can easily be seen that, between the primary energy (re)source and the final energy usage, several conversion steps must be applied. To generate one and the same final energy, different (re)sources require unequal transformation steps, which show different conversion efficiencies. This leads to different shares in total primary energy supply (TPES) for the same amount of total final energy consumption (TFC).

The definition of primary energy suggests consideration of the potential energy of a water reservoir of pump and storage hydropower plants as the primary energy for hydropower. One could also start at the evaporation stage, taking all flows and inputs from sun radiation into account: the calculation would look different. To get an objective picture about the importance of fuel shares of primary energy (re)sources for the different fuels, TPES and TFC always must be regarded in parallel.

Table 2.2: Short energy balance of the world, TPES and TFC for 2006, cf. [11]. TPES expresses the cumulative values of production, import (=transfer from the past year), export (=transfer in the following year, a negative value) and stock changes.

Supply Consu. **TPES**	Coal/ peat	Crude oil	Petrol. prod.	Gas	Nucl.	Hydro	Cobust. Renew. waste	Other	**Total**
EJ	127.9	172.0	-3.3	100.8	30.5	10.9	49.6	3.2	**491.5**
Mtoe	3053.5	4107.1	-78.4	2407.8	728.4	261.1	1184.9	75.5	**11740.0**
Transfers between consumers and losses									
EJ	-98.6	-171.5	148.6	-49.2	-30.5	-10.9	-6.1	65.1	-153.1
Mtoe	-2355.3	-4096.0	3549.0	-1174.4	-728.4	-261.1	-144.8	1555.8	-3655.5
TFC									
EJ	29.2	0.5	145.3	51.6	-	-	43.6	68.3	**338.5**
Mtoe	698.2	11.1	3470.3	1233.4	-	-	1040.1	1631.3	**8084.4**

TPES and the respective TFC of the world are shown in Table 2.2 for 2006. All amounts are given in million tonnes of oil equivalent (Mtoe) and exa joules (EJ), for which the conversion factors are as follows:

$$\mathbf{1\ Mtoe} = 41868\ \text{TJ} = \mathbf{0.041868\ EJ} = 11630\ \text{GWh}\ .$$

In 2006, the **TPES** was **491.5 EJ**, and the according **TFC** numbered **338.5 EJ**.

2.4.1 Total primary energy supply

TPES is the amount of energy that meets all needs for energy, including those of the energy sector: the energy sector own use, energy conversion losses and losses in transport and distribution of energy, the non-energy use and the total final energy consumption are included.

To calculate the contributions from nuclear power, hydropower and other electricity-producing renewables in terms of primary energy inputs, **notional plant efficiencies** are used to convert TFC in TPES. The share on the TPES would be much smaller if the primary energy contributions of hydroelectricity and other electricity-producing renewables was considered equivalent to their actual electricity output, cf. [6]. Comparison of the TFC reflects the relevant shares.

TPES development over the last 33 years is shown in *Figure* 2.3. It **increases** on average by **7.14 EJ p.a.**, or 2.8% p.a., since 1973. From 1973 to 2006, the share of fossil fuels, such as coal, peat, oil and gas, **increases** on average by 5.36 EJ p.a., which equals a gradient of 3.0% p.a. with respect to the base year 1973. During the same time, the share of nuclear power increased by an overall gradient of 0.86 EJ p.a., or 38.6% p.a., and the share of hydropower increases by an average amount of 0.19 EJ p.a. (4.6 Mtoe p.a.), or by 4% p.a., with respect to the base year, 1973. **Combustible renewables increase** by 0.68 EJ p.a., or **2.5% p.a.** on average between 1973 and 2006. The high increase of

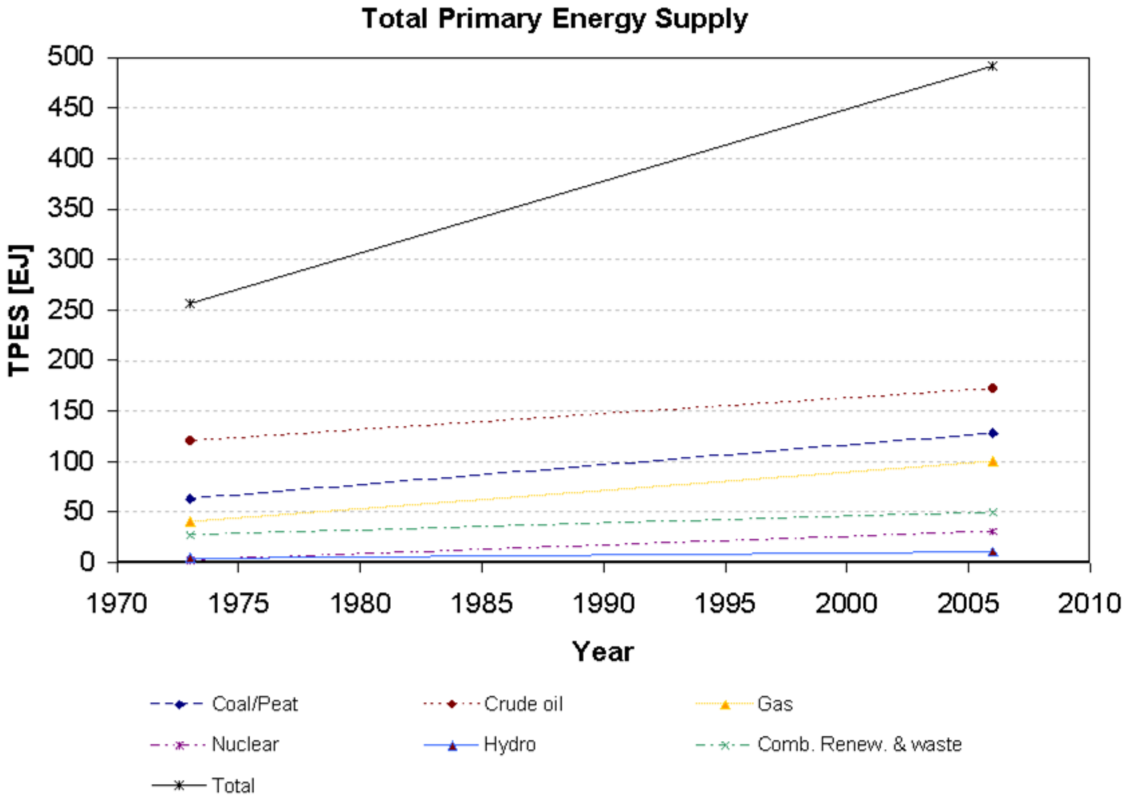


Figure 2.3: Total primary energy supply of the world – 1973 to 2006 [11]

nuclear power can be explained by large commercial usage soaring between 1970 and 1987. The capacity initially rose relatively quickly – from less than 1 GW in 1960 to 100 GW in the late 1970s.

2.4.2 Total final consumption

By contrast to the primary energy input, the TFC reflects the pure contribution of each fuel on total consumption.

TFC including nuclear and hydropower, amounts to 202 EJ (4835.37 Mtoe) in 1973. It is 380 EJ (9073.99 Mtoe) thirty three years later. The average **increase** of TFC was **5.38 EJ p.a.** (128.4 Mtoe p.a.), or 2.7% p.a. with respect to the base year. The shares for different fuels are as follows; fossil fuels increase on average by 2.4 EJ p.a. (56.8 Mtoe p.a.), or by 1.6% p.a. within that time frame; the increase for nuclear power amounts to 0.9 EJ p.a. (20.5 Mtoe p.a.), or 38.6% p.a.; hydropower developed according to the data from 1973 and 2006 by an average rate of 0.2 EJ p.a. (4.6 Mtoe p.a.), or 4.1% p.a.. Combustible renewables increased by 0.5 EJ p.a. (12.84 Mtoe p.a.), or by 2.1% p.a.. The renewable (re)sources hydropower, combustible renewables and others amount to a significant share of 15.2% on the TFC. The same collection of fuels amounts to only 8.1% in terms of their contribution to the TPES.

Chapter 3

Croatia – Supply and Consumption

This chapter provides an overview of Total Primary Energy Supply and Total Final Consumption for Croatia. This data is in accordance with the Annual Report for the Year 2007 [12] and Energy in Croatia 2007, annual Energy Report [13]. Key development indicators, with respect to energy consumption (TPES/GDP, GEC/GDP, ...), are provided along with the time evolution for TPES, TFC and primary energy self supply. Analysis of energy production, import and export habits, and consumption sectors provides context for the end prices of final energy such as heat energy, electricity, coal and coke, oil and natural gas. These are presented at the end of this chapter.

3.1 Total primary energy supply and production

The TPES per gross domestic product (GDP) **TPES/GDP** is an indicator of the energy intensity of production processes. It has decreased significantly since 2004 by an average of 4% p.a.. Approximately half was the rate of decrease for gross electricity consumption per GDP; i.e., **GEC/GDP** decreased p.a. by 2% since 2002.

Of further importance is the time evolution of TPES from 1988 to 2007 – provided by *Figure* 3.1. TPES is given in PJ on the vertical axis. The sharp drop in 1990 falls during the Croation War of Independence. Since 1992, TPES continuously rises. From 2002 to 2007, it increases by approximately 2.1% p.a.. Since 2004, it deviates only slightly from 416.78 PJ. Conversion factors are as follows:

$$\mathbf{1\ Mtoe} = \mathbf{41.868\ PJ} = 11630\ \text{GWh}\ .$$

The fuel shares of TPES in Croatia, which was **416.78 PJ** (9.955 Mtoe) in 2007, are listed in Table 3.1. It increased by 1.5% compared to the previous year. The average increase since 2002 is 2.1% p.a.. Electricity is an important topic in primary energy supply because the import (export) of electricity is regarded as a primary energy import (export) for the country. The values in the column 2007 represent the shares of the respective fuel in PJ. The last column shows the percentage change with respect to the period between 2002 and 2007. Coal and coke shares increase by 8.1% p.a.. Natural gas consumption increases, on average, by 2.5% p.a.. Outstanding is the noticeable high increase of electricity, 12.6% p.a.. The marginal amount of renewable energy sources becomes clear within this table.

Total primary energy production

Total primary energy production for the period 2002 to 2007 is described by Table 3.2. The last column shows the average change across of 5 years, from 2002 to 2007. With respect

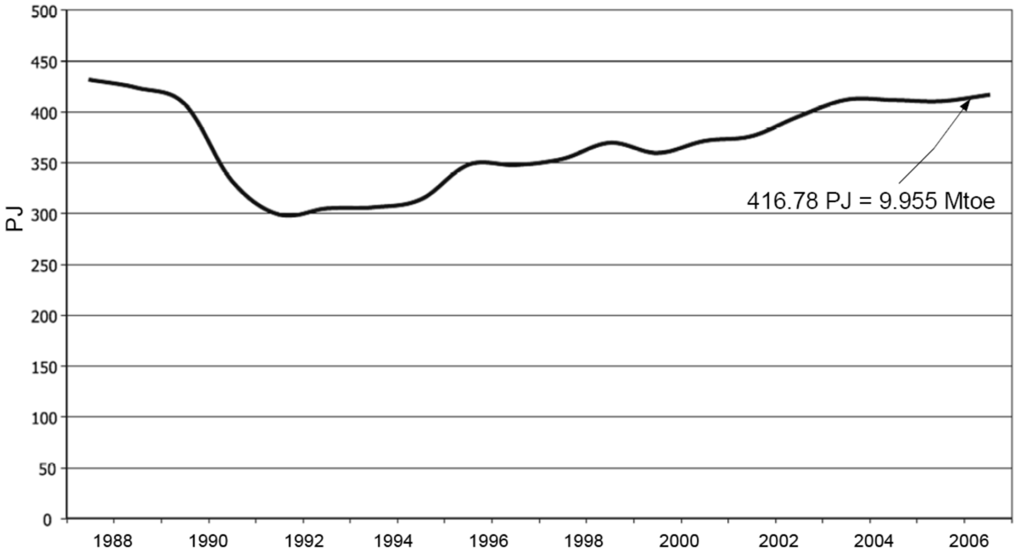


Figure 3.1: Time evolution of TPES in Croatia – 1988 to 2007 cf. [13]

Table 3.1: Shares on TPES in Croatia – years 2002, 2007.

Fuel PJ	**2002**	**2007**	**average change**
Coal and Coke	22.89	33.74	8.1% p.a.
Fuel wood	12.39	13.31	1.4% p.a.
Liquid fuels	175.16	189.70	1.6% p.a.
Natural gas	101.10	114.22	2.5% p.a.
Hydropower	52.01	42.21	-4.1% p.a.
Electricity	12.68	22.90	12.6% p.a.
Renewables	0.0	0.69	-
Total	376.23	416.78	2.1% p.a.

to 2002, **production increases** on average by **1.0% p.a.** which can not cover half of the increase of the TPES. Fuel wood production increases by 4.1% p.a. with respect to the last 5 years. Crude oil production decreases by 4.5% p.a.. The average annual production increase of natural gas is no less than **6.1% p.a.**. Hydropower production droppes by 4.1% p.a.. Energy production from other renewables, such as wind energy and landfill gas, contributes marginally [1]. By 2030, however, renewables should play a principal role in the future energy mix of Croatia, with a share of approximately one fifth of the total production, cf. [13].

3.2 Total energy import and export

3.2.1 Total energy import

In 1990, energy import dropped sharply because of the war. In 2007, there was a change in total energy import by 5.2% from the previous year. From 2002 to 2007, imports increased on average by 3.3% p.a.. Coal and coke increased by 7.3% p.a., petroleum products increased by 8.3% p.a. and **electricity** imports increased significantly by **14.7%** p.a..

[1] Data published in the factsheet of Trans Solar indicate a growth rate of the national collector field installed of ≈ 8600 m^2 p.a. since 2003.

Table 3.2: Total primary energy production in Croatia – 2002, 2007 [13]

Fuel PJ	**2002**	**2007**	**average change p.a.**
Fuel wood	12.39	15.11	4.1% p.a.
Crude oil	47.00	37.27	-4.5% p.a.
Natural gas	74.53	100.12	6.1% p.a.
Hydropower	52.01	42.21	-4.1% p.a.
Renewables	0.00	0.71	-
Total	185.94	195.44	1.0% p.a.

3.2.2 Total energy export

The most important energy forms exported from Croatia are petroleum products. Overall energy exports increased p.a. by 7.4% since 2002. Export of natural gas changed noticeable on average by 15.7% p.a.. Similarly electricity increased on average by 29.0% p.a..

3.2.3 Energy supply in Croatia – review

This summary includes data for the period between 2002 and 2007. Absolute values normally refer to 2007. Data about the world's TPES and TFC in Chapter 2, however, are given for the period from 1973 to 2006.

In reference to energy efficiency on a large scale, according to the main indicators of development, energy intensity of TPES decreased by 3.8%. TPES in the republic of Croatia amounts to 416.78 PJ in 2007. It is mainly comprised by liquid fuels and natural gas: together they amount to more than two thirds of the total supply. National energy production covers slightly less than half of the total primary energy supply. TPES increased on average by 2.1% p.a. within a period of 5 years since 2002. The p.a. increase of TPES within a periode of 33 years is slightly below 2.8% for the TPES of the world.

Putting fuel wood (3.2%) and hydropower (10.1%) in the class of renewable (re)sources, together with other renewables (0.17%), yields a share of 13.5% on the TPES for the year 2007. In contrast, the same bundle for the world's TPES gives a share of 15.2%. The share of other renewables, which include geothermal, solar thermal and photovoltaic energy is marginal.

Referring to the origin of primary energy, one finds that natural gas is the major national (re)source, amounting to half of the national production of total primary energy, followed by hydropower and crude oil. Total national primary energy production amounts to 195.44 PJ. The five-years average change of production is 1.0% p.a.. The annual change of TPES was 7.9 PJ, but national production increased only by 1.86 PJ p.a. since 2002.

Total imports of energy amount to **341.89 PJ**. The biggest share is provided by crude oil, which amounts to more than half of the total import. The five-year **average change** of imports amounts to **3.3% p.a.**. Within this 5 years, imports of the fuels coal and coke, petroleum products and electricity increased noticeably faster than the fuel mix. **Export** of energy (re)sources in Croatia is approximately one third of the total imports of energy, **119.3 PJ**. The biggest export share have petroleum products, which amount to more than two thirds of the total exports. Between 2002 and 2007 the **annual average change** of exports was **7.4%**. The graph in *Figure* 3.2 represents the unfavourable situation of Croatia in terms of independent energy **self supply**. Imports increased by 9.61 PJ p.a. since 2002 whereas exports increased only by 6.18 PJ. Dependency on foreign resources is steadily increasing and self supply is diminishing.

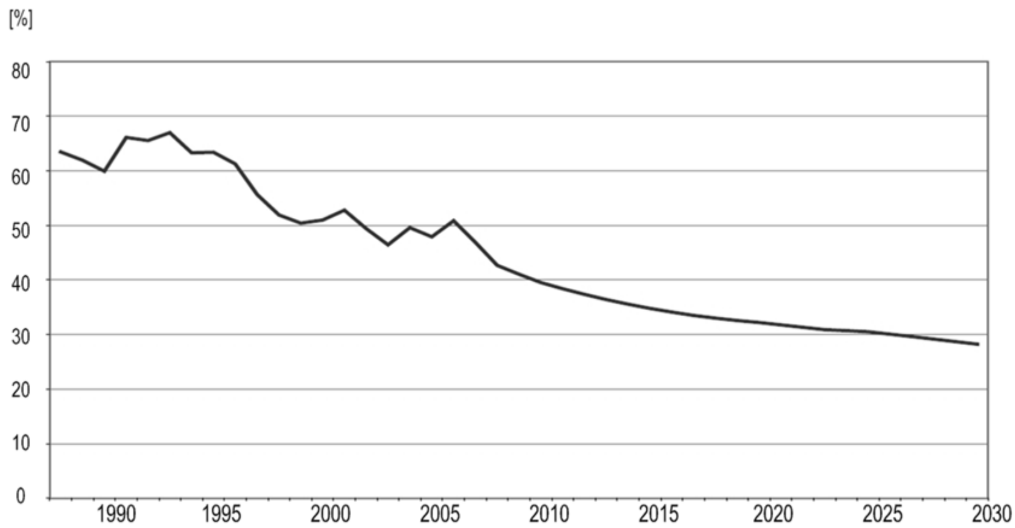


Figure 3.2: Primary energy self supply in (%) in Croatia – 1988 to 2007, prospectively to 2030, cf. [13]

3.3 Total final consumption and prices

The TFC for Croatia is given in Table 3.3 – amounts are in PJ. The value in 2007 is 269.07 PJ. The average annual increase within five years equals 3.0%. The biggest share on the total consumption is Liquid fuels: it amounts to nearly half of the total consumption. Within five years, the consumption of Coal grow by a rate of 29.8% p.a..

Table 3.3: Total final energy consumption in Croatia – 2002 to 2007 [13]

Fuel PJ	2002	2007	average change
Coal	3.23	11.92	29.8% p.a.
Fuel wood	10.37	11.54	2.2% p.a.
Liquid fuels	114.65	128.02	2.2% p.a.
Gaseous fuels	36.36	40.62	2.2% p.a.
Electricity	45.69	55.32	3.9% p.a.
Steam and hotwater	21.71	21.65	-0.1% p.a.
Total	232.02	269.07	3.0% p.a.

The **TFC per inhabitant** for Croatia is 1607 kg of oil equivalent (**67.3 GJ** or 18.7 MWh), which is 38.4% lower than the EU27 average, approximately 2600 kgoe/inhabitant. Prospects indicate a TFC of 410 PJ in 2030, which is 152% of the current consumption.

3.3.1 Consuming sectors

The TFC can be classified in two major sectors. The remaining consumers are summed up in Other sectors.

- Industry (59.60 PJ or 22.2%)
- Transport (91.67 PJ or 34.1%)
- Other Sectors (117.68 PJ or 43.7%)

For transport, the amount of diesel consumed is approximately 1.5 times the amount of normal gasoline. The class Other Sectors includes the energy consumption in households, public services, agriculture and construction. The according fuel shares for Other Sectors are shown in Table 3.4 for 2002 and 2007. The total consumption has a growth rate of 1.1% p.a. with respect to the period of 5 years. The share of Renewables that includes geothermal energy and solar energy is marginal.

Table 3.4: Total final energy consumption in other sectors by fuels in Croatia – 2002, 2007 [13]

Fuel PJ	2002	2007	average change
Coal	0.45	0.18	-16.7%
Fuel wood	10.37	10.71	0.7%
Liquid fuels	34.96	31.50	-2.1%
Gaseous fuels	23.99	26.97	2.4%
Electricity	34.27	40.87	3.6%
Steam and hotwater	7.53	7.28	-0.7%
Renewables	-	0.17	-
Total	111.57	117.68	1.1%

Data in Table 3.5 are important for this work. It breaks-down the overall consumption of 117.68 PJ of Other Sectors into sub-sectors. The biggest share is the sub-sector Households. The continuous high annual growth rate of the sub-sector Construction beginning in 2002, is noticeable. This steep increase underlines activities in the Croatian building and construction sector.

Table 3.5: Final energy consumption of other sectors by sub-sectors in Croatia, for 2002 and 2007, cf. [13]

Fuel PJ	2002	2007	average change
Households	71.98	71.84	-0.04%
Services	24.32	27.88	2.8%
Agriculture	10.54	10.27	-0.5%
Construction	4.73	7.69	10.2%
Total other sectors	111.57	117.68	1.1%

Households amount to nearly **two thirds** of the final consumption of Other Sectors, which is shown in *Figure* 3.3. The respective percentage values refer to the cumulated final consumption of Other Sectors 117.68 PJ. For 2007, the consumption of households amounted to **71.84 PJ**. The average annual change, with respect to a period of five years, is close to zero (-0.04%).

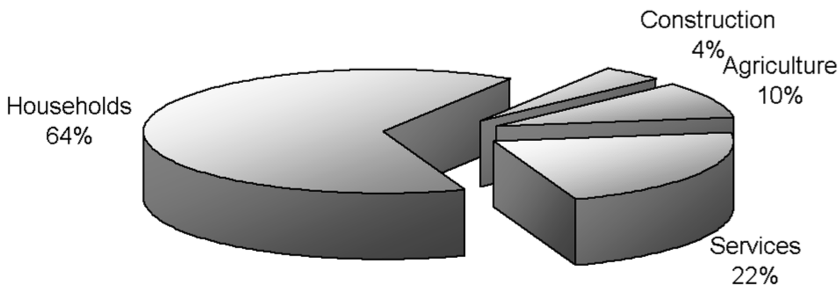


Figure 3.3: Final energy consumption in Other Sectors and shares of sub-sectors in Croatia with respect to the total of 117.68 PJ – 2007. [13]

Bearing in mind the TFC value for 2007 in Croatia (269.07 PJ) and the final consumption for **Households** (**71.84 PJ**), this number turns into nearly 27% , with resepect to the TFC. This means households contribute nearly **one third** on the TFC.

3.3.2 Heat energy and traded heat by district heating networks

The heating season in Croatia lasts from October to April. More details on heating-related circumstances are provided in Table 3.7. The Croatian Energy Regulatory Agency (**CERA**) is the only legal institution that can grant, heat energy producers a valid license, which is needed for selling district heat [13]. This law introduces a number of terms related to domestic heating business. Officials aim to extend the set of rules in future. In Table 3.6, the number of current licenses (2007) for three different energy activities are shown.

Table 3.6: Licenses for energy activities in Croatia, end 2007, cf. [12].

Energy activity	**Licenses standing at end 2007**
Thermal energy production	17 companies
Thermal energy distribution	12 companies
Thermal energy supply	18 companies

HEP Group, a state owned company, is the most powerful energy company. It supplies heat to more than 80% of the total customers, connected to district heating networks in Croatia. Their activities also cover production, transmission, distribution and supply of electricity. Hrvatska elektroprivreda d.d. (HEP d.d.) is the mother company of HEP Group [12].

The company Energo d.o.o. is the main supplier in the city of Rijeka. Its ownership is mainly in the hands of the local municipality. The number of heat consumers is 9845 households. The installed thermal capacity amounts to 112 MW_{th}. In 2006, 88 GWh were distributed on the network with a total length of 16 km to the 9845 customers. In total, 19% of the households, equal to a surface of 600 000 m^2, are connected to the district heating network. The used fuel sources are natural gas, fuel oil and extra light fuel oil. The distributed heat energy of 88 GWh in 2006, together with the installed power of 112 MW_{th}, leads to **786 full load hours**, which is a very low number in this context. The category Steam and hot water an element of the class Other Sectors is analysed in

Table 3.7: Climate data and heating days for cities in Croatia [13]

Location	Average outside Temperature^a during heating season [°C]	Average number of heating days^b	Average number of heating degree days^c
Karlovac	4.03	206	3326
Osijek	5.75	200	3134
Rijeka	9.64	178	2053
Slavonski Brod	6.19	192	2769
Split	11.78	162	1578
Varaždin	5.40	196	2970
Zagreb	6.85	197	2892

^{a}) based on hourly values

^{b}) T_{indoor}=20°C, $T_{outdoor}$=15°C

^{c}) Heating season from 1^{st} Oct. until 30^{th} Apr.

more detail: steam and hot water production, in 2007 amounts to 32.447 PJ. The average p.a. change between 2002 and 2007 was 0.9%. Nearly half of the production is provided by industrial cogeneration plants. Roughly 9000 PJ are provided by public cogeneration plants; the rest is produced by ordinary public and industrial heating plants.

A graphic overview of the production and consumption is given in Appendix Steam and Hot Water in Croatia in *Figure* O.2. The total consumption in this category was 30.700 PJ, 11.4% with respect to TFC. The energy sector itself amounts to nearly one third of this total. Final consumption, therefore, amounts to 21.653 PJ, or 8% of the TFC. This is approximately two thirds of the total consumption. Half of the total consumption (14.377 PJ) is demanded by the Industry sector.

Heat energy **demand in households** amounts to **5.785 PJ** in 2007. Compared to 2006 there was a remarkable change of -5.5%. Across the five years, the annual change was, on average, -1.2%.

3.3.3 Heat energy prices

The tariff system for price regulation of the district heating sector in Croatia sets revenue caps in the regulation year within a specific regulation cycle. This kind of regulation is suitable for **regulated monopolies**. It assures that the price is not to high. The prices are deduced from allowed annual revenues of an energy company by performing regulated energy activities.

Depending on the measurement equipment, accounting is subdivided into consumption categories. These categories with prices excluding Value Added Tax (**VAT**) are given for Rijeka in Table 3.8. Industry and customers without any measuring equipment are accounted on an area base price. Rijeka Energo d.o.o. charged a monthly rate of 5.86 HRK/m^2 in 2007. Industry and commercial customers with installed meters are accounted according to heat consumed and an allocation fee, on an area base. The prices were 406.98 HRK/MWh and 1.9 HRK/m^2 per month in 2007. The same scheme is applied to other customers with installed meters. The price is slightly below that of commercial customers; 319.29 HRK/MWh and 1.13 or 1.47 HRK/m^2 per month, respectively [2].

Table 3.8: Tariff amounts ENERGO d.o.o., Rijeka, 2007 [13]

Tariff amounts, Energo d.o.o. Rijeka	
Consumption category	**Tariff item** (VAT excl.)
Industry and commercial customers **without meters**	5.86 HRK/m^2 monthly
Industry and commercial customers **with meters**	406.98 HRK/MWh
plus allocation fee	1.9 HRK/m^2 monthly
Other customers **with** installed **meters**	319.29 HRK/MWh
plus allocation fee	1.13 or 1.47 HRK/m^2 monthly
Sanitary hot water per month per consumption	19.74 HRK/m^3

Tariffs among counties vary highly: energy prices for thermal energy in accordance with consumption range between 108.8 (Osijek) and 319.3 (Rijeka) HRK/MWh for the category Households and 197.0 (Zagreb) and 773.0 (Karlovac) HRK/MWh for the category Economy. As for Rijeka, in some locations, sanitary hot water is sold directly; the price is 19.74 HRK/m^3.

[2]Here is a contradiction between two sources, in [13] one finds the price 1.47 HRK/m^2, whereas in [12] the price is 1.13 HRK/m^2 per month respectively.

3.3.4 Electricity prices

Croatia ranks among the countries with the lowest tariffs, compared to prices in the EU. Although fourteen registered companies undertake energy activities in the Republic of Croatia, only two may supply so-called eligible customers [3]. This is due to HEP's low-priced electricity supply compared to the wholesale markets across the border. Eligible Customers are all customers excepting residential customers and small customers, [12] [4]. According to HEP-Trgovina d.o.o., purchase of electricity on the **wholesale market** costs, on average, **56,6 EURO/MWh** in 2007 [12]. This explains why there has not been much new supplier interest in entering the market in the Republic of Croatia. It is expected that the situation may look different in future.

Electricity consumption in 2007 was 0.55 PJ (6392.5 GWh) for Households. The five-year trend, beginning in 2002, amounts to 1.4% [13]. According to the EUROSTAT categories, the average electricity selling prices for Croatia in 2007 ranged between 0.4 and 0.9 HRK/kWh (VAT excluded). The household consumer class **Dc** (medium households) has an annual consumption of 3500 kWh, of which 1300 kWh are used during night tariffs. For this category, the price was **0.56 HRK/kWh** (VAT excl.) in 2007. Consumer categories, according to HERA, and the respective prices are listed in Table 3.9.

Table 3.9: Average electricity sales price for end customers, [12], 1 HRK = 0,1376 EUR (May 2010)

Electricity sales prices in [HRK/kWh] for 2007	
Customer category	sales price
Customers using high voltage	0,31
Customers using medium voltage	0,45
Total customers using high and medium voltage	0,43
Customers using LV - entrepreneurs, without public lighting	0,59
Customers using LV - public lighting	0,49
Customers using LV - entrepreneurs total	0,58
Customers using LV - households	0,58
Total customers using LV	0,58
Total tariff customers	0,54

3.3.5 Coal and coke prices

The consumption of coal and coke in households is decreasing at a high rate. In 2002, it amounted to 20 700 metric tons and, in 2007, less than half of that, namely 9000 metric tons. The five-year average annual change was -15.3%. The total consumption of coal is satisfied by imports from countries in the former Yugoslavia. Import prices, therefore, determine final customer prices. Import prices were 3.5, 4.2 and 9.1 US $/GJ for hard coal, brown coal and lignite, and coke, respectively in 2007. Since the consumption trend for Households is highly declining this fuel is not regarded important in future; final consumer prices are not essential for this work.

[3] One of which has not properly been activated yet.

[4] These are legal entities with less than 50 employees and annual income of up to 70 million HRK.

3.3.6 Oil and oil derivatives prices

INA Industrija nafte was responsible for 100% of the production of oil products in Croatia in 2007. Lower and upper price limits between 1996 and 2007 for light fuel oil are **2.09 and 4.66 HRK/litre** – taxes included. Table 3.10 refers to oil derivatives sold by INA: fuel prices are given for the 5^{th} of June 2009.

Table 3.10: Fuel price list INA Croatia, taxes included, Date: June 05 2009

Fuel type	**Short cut**	**Price HRK/litre**
INA Super 95	BMB 95	7,39
INA Eurosuper 95	BMB EURO 95	7,54
INA Super plus 98	BMB 98	7,60
INA Diesel	DG	6,44
INA Eurodiesel	DG EURO	6,64
INA Diesel Blue	DG PLAVI	3,47
INA Auto Gas	INA UNP A	3,69
Heating oil extra light	LUEL	3,88

3.3.7 Biofuels

The official gazette Narodne novine (No. 43/07) prescribes that 0.9% (22 000 tonnes of biodiesel) of the total quantities of energy fuel consumption in 2007 should be covered by biodiesel or any other biofuel. In 2007, however, only 4334 tonnes of biodiesel were produced in Croatia. Approximately 1300 tonnes originated from domestic rapeseed, 320 tonnes stem from collected waste cooking oil and the rest of the required feedstock was imported [13].

3.3.8 Natural gas prices

INA d.d. is the only natural gas supplier in Croatia. In 2007, households consumed 622.5 million m^3 of natural gas (20 MJ). The five-year trend, beginning in 2002, is an increase of 2.6%. Natural gas prices for end customers in Croatia are set up by several elements. There are three buyer categories in accordance with the market position cf. [12]:

- Energy operators for gas who buy gas
- Wholesale buyers
- End customers

Customers may be divided according to the right to free selection of the supplier. Of note are Tariff Customers mainly households, for which free selection of a gas supplier is not allowed. The price is determined by the tariff system, and Eligible Customers may freely select their gas supplier. The status of 'eligible' is granted to the customers buying gas for their own purposes only and whose annual consumption is higher than 25 million m^3. In August 2007, all customers became eligible customers except for those belonging to the household category. In August 2008, all households shall be entitled the rights of eligible customers [12]. The average retail price of natural gas for three different customer categories is given by Table 3.11.

Table 3.11: Natural gas prices for Croatia 2007, in HRK/m^3, (VAT included), [12]

Customer category	sales price [HRK/m^3] 2007
Households	2.05
Services	2.07
Industry	2.04

Prices in Croatia are very low compared to other countries and the EU-15 average. In 2007, the price of natural gas of **EU-15 was twice** the price in **Croatia**. The high differences between the countries are mainly because of different taxes. Furthermore, since 2005, the natural gas price was highly unstable. Due to turbulences such as in winter of 2009 between Ukraine and Russia, it is unlikely that gas prices will become stable or decrease. Another reason for unstable supply are the very old pipelines, which must be renewed, making projects such as the construction of the Nabucco pipeline, which will start in 2011, very urgent. The first gas through the pipeline should flow in 2014.

3.4 Summary

The TPES in Croatia, in 2007, was 416.78 PJ. TPES/GDP has a diminishing trend of 4% since 2004, which indicates an improved industry production. The highest fuel shares have liquid fuels, natural gas and hydropower. The TFC per inhabitant is 61.8% of the EU27 average value, however, it is currently increasing.

The five-year trend for total primary energy production is 1.0%, whereas the TPES increased on average by 2.1% since 2002. The share of renewables is 13.5% in total. Fuel wood and hydropower are the main renewable sources with a share of 3.2% and 10.1% of the total TPES. By contrast, the share of other renewables is only 0.17%. Only one fifth of the national goal for biofuel contribution is currently achieved while the consumption trend for coal in private households is decreasing. Natural gas has a share of 26.97% on the TFC at a cost only half the EU-15 price for natural gas.

The analysis of the TFC fuel shares showed 22.2%, 34.1% and 43.7% for the sectors Industry, Transport and Other Sectors. Households are responsible for nearly two thirds of the consumption in other sectors. The subsector construction showed an annual increase of 10.2% – indicating a great deal of work.

The heat energy business is mainly controlled by the State or legal representatives of the State. There is no market competition, and prices follow a special tariff system. A similar situation hinders market competition for the electricity. HEP, the leading company for electricity supply, dictates a relatively low price on the market compared to wholesale market prices across the border. This difference is explained by the lower income-level of the residents. The increase of electricity imports, at 15.7% p.a. on average from 2002 to 2007, sharpens the situation. It affirms that, sooner or later, the international price-level from northern Europe, which is approximately 1.7 times higher, must be reflected in national electricity prices unless the national production increases significantly or subsidies are established.

Chapter 4

Solar Energy

Chapter 4

This chapter sketches and describes the constitution of the Sun. It contains important parameters and the derivation of the solar constant. Of further relevance is the fusion process and heat transfer from the Sun to the Earth, with special attention made to the attenuation of solar radiation in the atmosphere. The concept of measuring attenuation using the relative airmass factor (AM) and the energy radiation balance of the Earth are briefly illustrated. Discussion of practical topics in the context of low-temperature solar energy collection, such as tilt and azimuth angle of the collector conclude the chapter.

4.1 The Sun

The Sun is the ultimate source of life on our planet. The main reaction responsible for the energy radiated by the Sun is the proton-proton cycle, see *Figure* 4.2. In brief , two hydrogen nuclei are converted into helium by fusion and energy is released. The sub-section The fusion process describes this further.

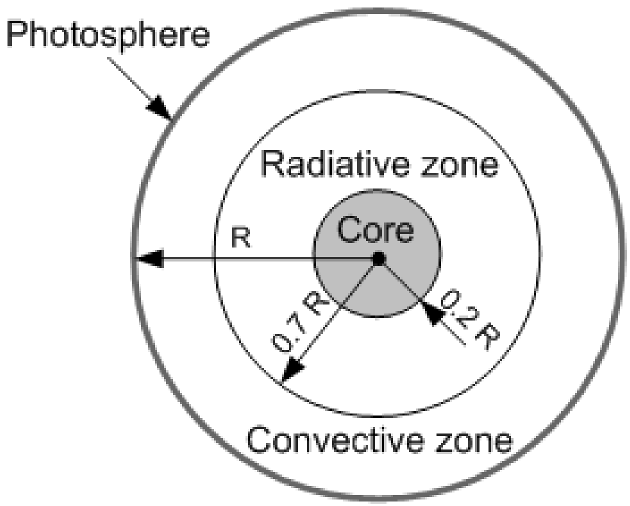


Figure 4.1: Composition of the Sun

4.1.1 Composition of the Sun

Key data referring to the Sun provides Table 4.1. The Sun radiates energy via its high surface temperature, approximately 6000°C, 150 million km from the Earth; expressed in the speed of light: 8 minutes and 19 seconds. The indication G2 V, which stands for the spectral class, means (G2 ⇒) the Sun has a surface temperature of approximately 5780 K and (V ⇒) that it is a main sequence star.

Table 4.1: Key data of the Sun [14]

The Sun - G2 V	
Mass	$1.9891\ 10^{30}$ kg
Solar radius	$6.9599\ 10^{5}$ km
Mean density	1.410 kg/dm^3
Mean distance from Earth	1 AU = $149.598\ 10^{6}$ km
Solar constant (1980)	1368 W/m^2
Effective temperature	5770 K
Central density	140-180 kg/dm^3
Central temperature	14.9-15.7 million K
Specific mean power	$1.937\ 10^{-7}$ W/g

The Sun, a yellow dwarf, is a gaseous sphere with a diameter of approximately 1.39 million km. As seen in *Figure* 4.1, it can be subdivided into a core, a radiative and a convective zone. The radius is measured from the centre to the edge of the photosphere. At this point, the density and 'low' temperature of the gases do not amount to a significant radiation of light. It is this edge, or shell, of the Sun which is mostly seen by our eyes.

The core is considered an extension of 20% of the solar radius. The second 'shell', the radiative zone, ranges up to 0.7 solar radii. The outer most and very tiny shell, the **photosphere**, is between 10 and 100 km thick. It amounts to approximately 0.014% of the radius and is opaque to visible light. It is composed by approximately 74% hydrogen, 24% helium and trace quantities of other heavier elements, which amount to 2%.

The Sun itself accounts for approximately 99% of the total mass of the solar system, whereas 99% of the total angular momentum is covered by the movement of the planets.

4.1.2 The fusion process

The fusion process is described in detail here, in addition to the reaction given, there are others converting hydrogen to helium. The mentioned process in our Sun, however, is leading and it is subdivided into three major stages. Additional energies on the right side of the equations account for kinetic energy of generated particles:

$$p + p \rightarrow d + e^{+} + \nu_e + 0.42\ \text{MeV} \tag{4.1}$$
$$d + p \rightarrow {}^{3}He + \gamma + 5.49\ \text{MeV} \tag{4.2}$$
$${}^{3}He + {}^{3}He \rightarrow {}^{4}He + p + p + 12.86\ \text{MeV} \tag{4.3}$$

The **first stage** is the fusion of two hydrogen nuclei ${}^{1}H$ or p (proton) into *deuterium* (built on $p+n$), releasing a positron e^{+} and an electron neutrino ν_e as one proton changes into a neutron. This stage is extremely slow because protons repel each other. To fuse two protons, their speed must be very high to overcome the repelling force. According to Maxwell's velocity distribution, this is very unlikely, hence the tunnelling process must

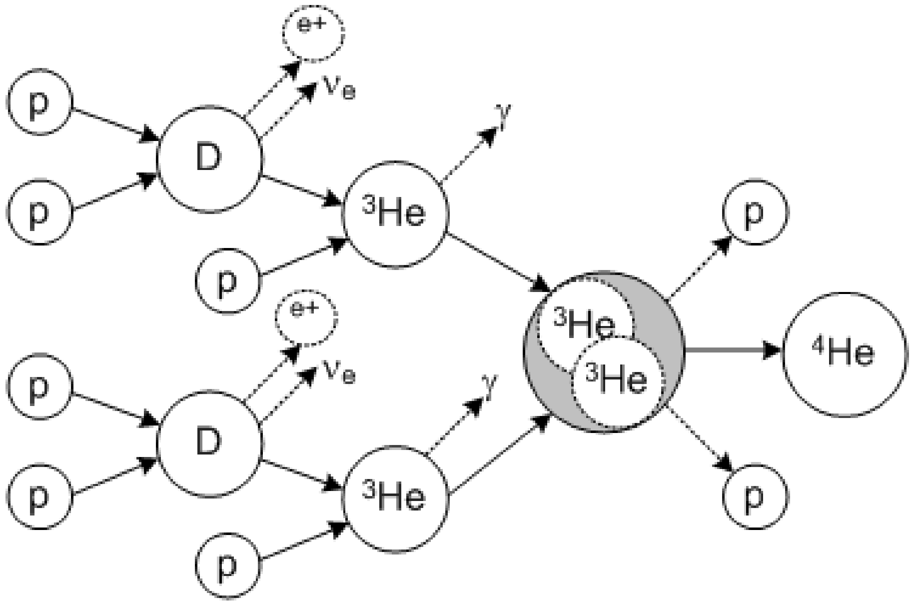


Figure 4.2: Proton proton chain reaction [15]

come into play. This quantum mechanical phenomenon allows some protons to go through the coulomb barrier. The produced positron e^+ immediately annihilates with an electron e^-. Their mass energy is carried off by two gamma ray photons (γ). This part of the reaction is not sketched in *Figure* 4.2.

$$e^- + e^+ \quad \rightarrow \quad 2\gamma + 1.02 \text{ MeV} \tag{4.4}$$

The **second** major reaction stage is the fusion of the deuterium produced with another proton to form the light helium isotope ^3He. To generate the most common helium isotope, ^4He, there are three optional paths. The process with the highest probability in our Sun is the fusion of two ^3He nuclei to form ^4He, this is the **third stage**.

Approximately 5 million tonnes of hydrogen are burned this way during one second. ^4He accumulates in the core of the Sun, therefore the density in the core increases. The core density amounts to 158 tonnes/m^3 and the temperature is approximately 16 million °C. The described energy generating fusion process leads to energy radiation at the surface. The power of the fusion process is 3.85 $\cdot 10^{26}$ W. Assuming isotropic radiation from the surface, and taking into account the distance between the Earth and the Sun, one can calculate the extraterrestrial solar constant, S_0. The result is approximately 1369 W/m^2.

4.2 Heat transfer from the Sun to the Earth

From the **core** of the Sun generated heat is transferred outwards through radiation. This is why the second shell is called the **radiative zone**. The temperature is so high that radiation is effective enough to carry out the heat and, therefore, no convection takes place. The process of radiation consists of continuous emission and absorption. At approximately 0.7 radii the solar plasma is not hot nor dense enough to transport the heat energy via radiation; this is when the convection process comes into play. Convection, in the **convective zone**, within 0.7 to 1.0 radii, gives rise to a dynamo producing north and south poles all over the surface. The rotating and gaseous Sun leads to a complex magnetic field distribution.

Finally, the Sun radiates energy by virtue of its high surface temperature, 5770 K. According to the model of radiating black body, the surface temperature leads to a spectrum that generates the white colour. Due to scattering of shorter wavelengths in the blue region of the spectrum, which occurs in the atmosphere, the colour of the Sun appears yellow. This scattering is also responsible for the bluish colour of the sky.

4.2.1 Solar constant – extraterrestrial

The most important property of the Sun, in terms of solar energy utilisation, is the **solar constant** at the boundary of the atmosphere or the ground of the Earth. It describes the irradiance and has the dimension W/m^2. Calculation is as follows: first, one has to calculate the total power of the Sun:

$$\begin{aligned} \text{Total power} &= \text{Mass} \cdot \text{Specific mean power} \\ &= 1.9891 \cdot 10^{33}\ \text{g} \cdot 1.937 \cdot 10^{-7}\ \text{W/g} \approx 3.85 \cdot 10^{26}\ \text{W}. \end{aligned} \tag{4.5}$$

To be precise, to calculate the solar constant, one must take into account the elliptical orbit of the Earth. This would lead to a time dependent extraterrestrial solar constant S_{ext}(t), with an annual period and some tiny variations. Since the variation of S_{ext}(t) during a period is small, a mean value for one year is satisfying enough for our purpose [1]. This mean value:

$$\bar{S}_{ext} = \frac{1}{T}\int_0^T S_{ext}(t) \cdot dt\ , \tag{4.6}$$

often named S_0, can also be calculated in a simplified way. We make the assumption that the radiation is emitted isotropically. Then, it is enough to divide the total power of the Sun by the area of the spherical shell, with radius equal to the mean distance between the Sun and the Earth:

$$\begin{aligned} S_0 &= \frac{\text{Total power}}{\text{area of the spherical shell}} \\ S_0 &= \frac{3.85 \cdot 10^{26}\ \text{W}}{4 \cdot (149.598 \cdot 10^9\ \text{m})^2 \cdot \pi} = 1369\ \text{W/m}^2\ . \end{aligned} \tag{4.7}$$

The amount S_0 is equal to the energy flux originating from the Sun to the Earth; this flux is indicated by the yellowish arrows in *Figure* 4.3.

4.2.2 Solar constant – terrestrial

The value for the solar constant at an altitude close to the ground must account for attenuation, hence a further reduction factor must be introduced. For this reason, the notion of **airmass** (AM) provides a proper parameter.

AM=1 corresponds to the shortest optical path length (OPL) through the atmosphere of the Earth that light must travel, from a heavenly source, to reach the ground. Along this path, light can be attenuated by scattering and absorption. Hence, the longer its path, until it reaches the ground, the greater its attenuation. The spectrum of the light is given in *Figure* 4.4 for some AM values. Each spectrum corresponds to a radiation-power. The

[1] Within the 11 years lasting Sun cycle the variation is roughly ± 0.1%. Within the 100 years lasting cycle the variation is approx. 0.3%. The changes in solar irradiance since the pre-industrial era, are estimated to have caused a small warming effect (+0.12 [+0.06 to +0.30] W/m^2) [16]. This warming is by far less than one tenth of the contribution from GHG increase.

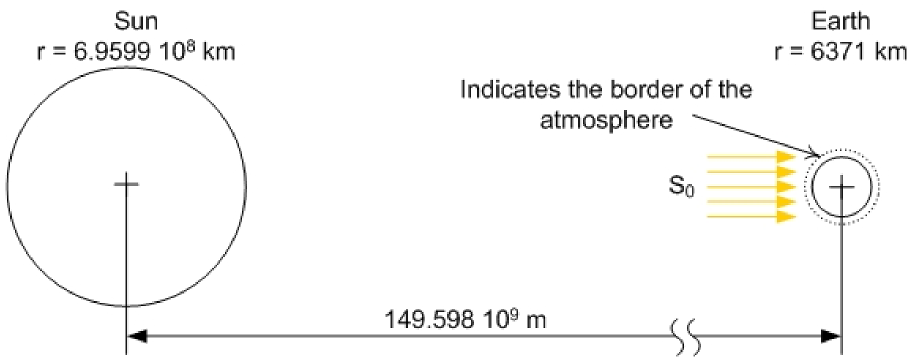


Figure 4.3: Calculation of the extraterrestrial solar constant

'new' average value of the solar constant under the respective conditions can be calculated by integrating over the wavelength of the corresponding spectrum.

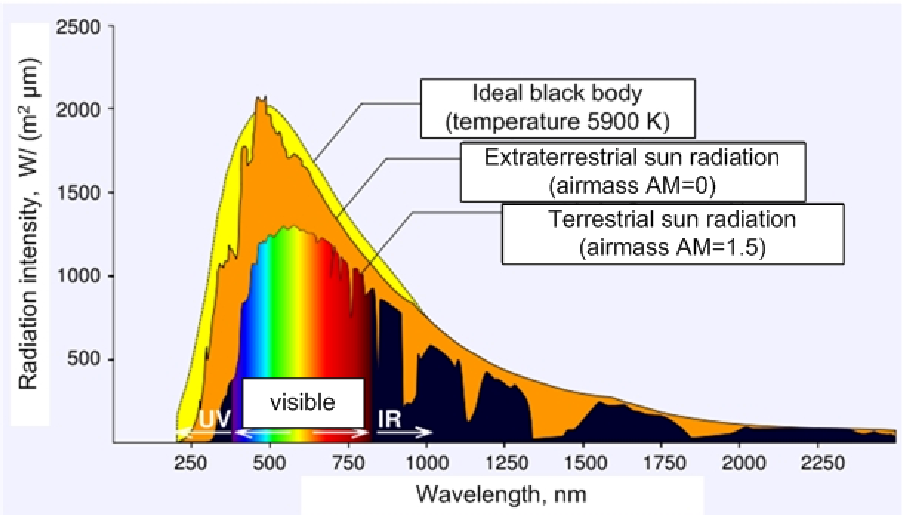


Figure 4.4: Sun spectrum for different conditions

The irradiance calculated in the sub-section Solar constant – extraterrestrial corresponds to AM=0. This means no attenuation since the radiation has not travelled through any layers of the atmosphere. Values for AM apart from zero normally indicate the ratio between the actual OPL and that at the zenith at sea level. According to this, AM is a relative measure, and, by definition, the sea level airmass at the zenith is one. The airmass increases as the angle between the source and the zenith increases, which is the case for higher latitudes and shown in In *Figure* 4.5.

For AM=1.5 the spectrum gives a solar constant of $S_{1.5}$= 1000 W$/m^2$ [2]. This value is used for measuring solar modules. Taking $S_{1.5}$ times the cross sectional area of the Earth and dividing by the surface area of the Earth one gets an estimation for the average solar

[2] This spectrum is defined in IEC 904-3 (1989) part III.

irradiance on Earth ground level:

$$\begin{aligned}\bar{I}_g &= S_{1.5} \cdot \frac{r_{Earth}^2 \cdot \pi}{4 \cdot r_{Earth}^2 \cdot \pi} \\ &= 250 W/m^2 \\ &> 170 W/m^2 \ . \end{aligned} \quad (4.8)$$

Because $S_{1.5}$ is only valid for straight incidence, this average is still too high; in reality it is approximately 170 W/m^2. Measurements in the past show that a variation of ± 1.5% for the solar constant can be taken into account.

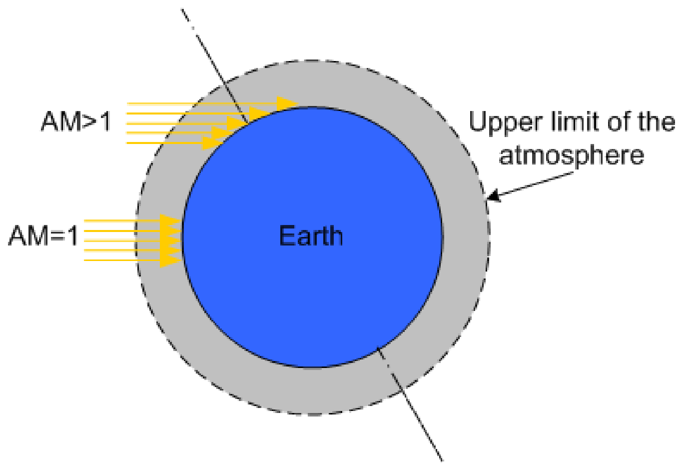


Figure 4.5: Airmass values at different latitudes

Sun radiation balance at the Earth

In *Figure* 4.6, a simplified short wave solar radiation balance is pictured. One can see where the direct reflection takes place and how the reflected 30% are split. 51% are absorbed by the surface and 19% are absorbed by the clouds. Only 0.022% of the incoming annual Sun energy is absorbed via photosyntheses by plants.

Apart from the reflected short-wave radiation, energy is also radiated towards space by long wave radiation originating from the surface of the Earth and the atmosphere. The average atmospheric temperature amounts to -20°C, and the average temperature at the Earth's surface, thanks to the GHG-effect, amounts to 15°C. More details on this topic can be found in any so-called 'zero order climate model'.

4.3 Solar energy utilisation

In any of the following applications, the utilisation of solar energy is provided by the gain of heat from the primary energy flux emitted by the Sun. Solar energy utilisation can be divided into **passive solar usage** and **active solar usage**. Active refers to the use of special devices such as a collector, a heat storage and control system to gather solar energy. Within this category, solar thermal applications, which collect and redistribute heat, and photovoltaic cells, which directly generate electricity from solar radiation, appear. Passive solar heating refers for example to solar space heating by means of special adapted building parts. For more details, cf. [2] Chapter 3-6.

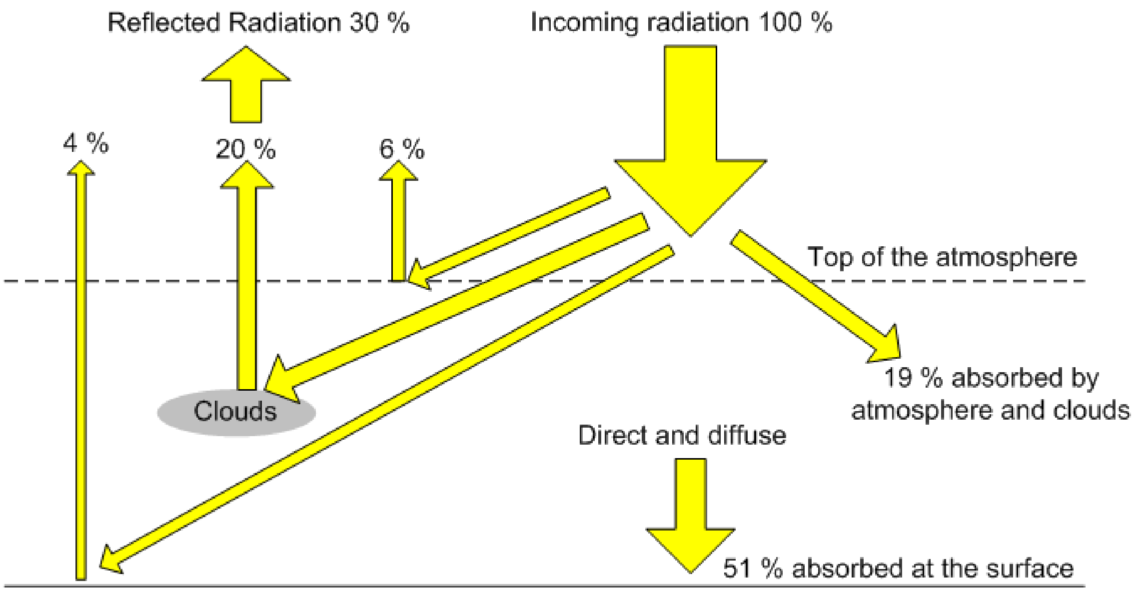


Figure 4.6: Radiation balance for short-wave radiation

4.3.1 Passive solar heating

- This stands for the direct absorption of solar energy in a building, to partially provide the energy required for space-heating. The installed systems mostly use air to circulate the collected energy – usually without pumps or fans. Solar radiation passes through the windows (collectors) and is absorbed by heat storage mass in rooms. Conservatory, or **sunspace**, and **trombe wall** are special constructions that gather solar energy and distribute heat by air flow.

- Passive solar heating, in the broad sense, describes the whole process of integrated low-energy building design; i.e., passive solar architecture is characterised by the use of the building envelope as absorber and the building structure as heat store. The purpose is to significantly reduce the heat demand of the building to benefit from small, passive solar gains during the winter.

4.3.2 Active solar thermal usage

Active solar usage normally includes extra devices and controlled flows to collect and redistribute solar energy. A common application is the solar preparation of **domestic hot water** (DHW).

DHW can be heated simply by the installation of a black coloured storage tank in a bright place. For this system, the DHW is heated directly by means of heat conduction with the storage tank. A further development is the **open thermosyphonic system** where heating takes place in an inclined collector and, by virtue of natural convection, the hot water flows to a storage tank mounted at the top of the collector. It should be stressed that the last two systems make no use of a pump or heat exchanger. In both cases, the heat transfer medium is pure water, therefore, these systems are not applicable in regions where the temperature goes below 0°C. These simple and cheap systems, however, could be used if the devices were discharged during cold seasons, to prevent damage.

A further development is the so-called **closed thermosyphonic system**, which is also suitable for frost climates since the heat transfer medium flows in a separated cycle to which frost protection is added. No pumps are used, and the system has a relatively low price.

The storage tank for the open and the closed thermosyphonic systems was only for DHW and always mounted above the collector. The size of these systems can widely vary. A typical application for a single family house would consist of a total collector surface of 4 m^2 and a storage tank between 120 and 200 litres. Larger systems can be assembled from a combination of smaller ones, and the storage tanks can be equipped with an electrical support heater, with accordant control, to function as a hot water preparation system during all four seasons.

Using a pump, in combination with temperature measurement and a control, the storage tank can be put somewhere else; i.e., in the basement. Thus, different designs and a better insulation become possible. The heat transfer medium flows in a separate cycle – allowing temperatures below 0°C. In contrast to the former systems, these models have a higher price, but are still common for hot water preparation although sometimes a larger heat storage volume is provided.

A more complex system is a combination of a solar energy collector with the **domestic space heating system**. This requires a large heat storage and an extensive collector area. The control is more complex because a complementary heat source; i.e., a fuel oil boiler and a second heat sink, are involved and must be coordinated with the solar thermal heat source. This system costs more, and certain conditions for the installed domestic heat sources must be fulfilled to guarantee a reasonable solar contribution for the heating.

Except for the usage of vacuum collectors, the temperatures for the described systems are normally below 100°C. In additional to the mentioned systems, another technology makes use of concentrated direct Sun radiation, and leads to temperatures of approximately 400°C: the heat can either be used as process heat or could drive a steam turbine for electricity generation. Construction of such **Concentrating Solar Thermal Power (CSP)-Plants** on a commercial scale are recent and only a few are already in operation. The plant in the Mojave desert, in California, has been operating since the end of the 1980s. More recent projects were built in Spain.

4.3.3 Active solar photovoltaic usage

Another active solar usage is the direct generation of electricity from solar radiation. **Photovoltaic** (PV) power generation offers a way to directly utilise solar radiation energy. In contrast to solar thermal electricity generation by CSP-plants, PV power generation employs direct conversion of solar into electrical energy. The key physical effect is the 'internal photo effect'; it is the basis for the photovoltaic effect and thus of the solar cell. **Table** 4.7 lists materials of different PV-cells, their type and the corresponding efficiency. This technology retains disadvantages.

1. PV cells are very expensive.

2. The production technology is energy intense.

The **energy payback time** for PV-cells varies between one third and one half of their lifetime, cf. German original of [2]. This means, assuming that a PV-cell module is thirty years in operation, it must generate electricity for ten or fifteen years in order to compensate for so-called **grey energy** required during the production of the cell. Thus, the energetic footprint is poor. In **stand alone operation**, this technology, in combination with a battery, can be reasonable. Furthermore, some **niche applications** owe their economic efficiency to the use of PV.

Table 4.7: Efficiencies of solar cells – taken from [2], with permission from Wolfgang Streicher.

Material	Type	Efficiency Lab.	Manufac. in %	State of technology[a]
Silicon	monocrystalline	24.7	14.0 – 18.0	1
Polysilicon, simple	polycrystalline	19.8	13.0 – 15.5	1
MIS inversion layer (silicon)	monocrystalline	17.9	16.0	2
Concentrator solar cell (silicon)	monocrystalline	26.8	25.0	2
Silicon on glass substrate	transfer technol.	16.6		3
Amorphous silicon, simple	thin film	13.0	8.0	1
Tandem 2 layers, amorphous silicon	thin film	13.0	8.8	2
Tandem 3 layers, amorphous silicon	thin film	14.6	10.4	1
Gallium indium phosphate / Gallium arsenide[b]	tandem cell	30.3	21.0	2
Cadmium-telluride[c]	thin film	16.5	10.7	2
Copper indium di-selenium[d]	thin film	18.4	12.0	2

Lab. Laboratory; Manufac. Industrial manufacturing; technol. technology; [a] 1 large scale production, 2 small scale production, 3 pilot production, 4 development on a laboratory scale; [b] GaInP/GaAs; [c] CdTe; [c] $CuInSe_2$

Studies from the **Trans-Mediterranean Renewable Energy Cooperation** (TREC) have shown that electricity generation with concentrated solar power plants in sunny regions of the world and the distribution of this electricity up to 5000 km is still more efficient than production of electricity by PV close to the energy sink. Current research, however, promises a new generation of PV-cells that should be able to produce cheap electricity in vast amounts. The Austrian physicist **Niyazi Serdar Sariciftci** is an influential researcher in the field of **organic photovoltaic cells**. For more details cf. [58], [2] or [6].

4.3.4 Technical terms and practical topics

A technical challenge when collecting **low-temperature** solar energy is the use of surfaces with selective properties that highly absorb short-wave solar radiation but block long-wave infrared re-radiation [3].

What we normally call sunshine is known as **direct radiation**. On a clear day one Sun is equal to S_1. Practical peak power in north and south Europe ranges between 900 and 1000 W/m^2. The other part of the spectrum, scattered solar radiation which finds its way to an absorber, is called **diffuse radiation** [4]. The sum of direct and diffuse radiation is defined as **global radiation**.

Global radiation is the key value for low-temperature solar energy collection to calculate or estimate yields. In contrast, for high temperature applications, which use focusing, only direct radiation counts. In northern Europe, the **ratio** between **direct** and **diffuse** radiation is approximately **40:60** [2]. In southern Europe the amounts from direct radiation are usually higher. For **Rijeka**, according to EIHP, the ratio of direct to diffuse radiation is roughly **60:40**.

The radiation on a horizontal surface is measured with for example **pyranometers**. To measure direct and diffuse parts, two devices are needed; one measures the global

[3] Concentrating mechanisms by usage of complex mirrors are to be challenged for high-temperature applications in industry or power generation.

[4] Some authors distinguish between direct, diffuse and reflected radiation where reflected stands for distracted direct radiation, which is reflected for example from snow in the surroundings towards the collector. By contrast, diffuse stands for reflection in the air.

radiation, the other is shadowed – to keep away direct radiation. In conclusion, diffuse radiation is measured directly, and direct radiation is calculated by subtraction of the diffuse from the global radiation. Measurements are highest at the equator, where the annual solar yield is approximately 2000 kWh/m^2. In middle Europe, one typically receives only half of this. An overview of the annual yields in different regions at different latitudes provides Table 4.2.

Table 4.2: Annual yields on a horizontal surface [6]

Overview about annual yields on a horizontal surface in kWh/m^2	
Southern US	2500
Near the equator	2000
Middle Europe	1000
France or south Spain	1500

4.3.5 Solar yields in Croatia

According to **Rijekas** geographic location, it is estimated that the theoretical potential annual yield is approximately 1250 kWh/m^2. A **proper orientation** of the collector assumed, according to EIHP, the annual yield should be **nearly 1500** kWh/m^2.

The usable final heat of a solar system is reduced by the efficiency of the collector and the utilisation rate of the system, leading to a practical yield of approximately 500 kWh/m^2. Since the density of measurement stations with the equipment to measure solar radiation around Croatia has been very low, insolation maps were reconstructed using other data [5]. EIHP eventually published the Solar Radiation Handbook of Croatia. This atlas is based on sunshine duration measurement and cloud-cover observations dating back to 1961. Mathematical models were used to derive the required data. The reconstruction of solar radiation data from long-term measurements instead of real, measured values from the recent past is reasoned as follows: an analysis carried out by the University Oregon physics department lead to a conclusion that high statistical reliability requires long-term measurement series [18].

- Average measurement results over five years compared to twenty years can differ for up to 20%.
- Extending the base measurement period to fifteen years can cut the variation in half.
- Finally, thirty years' measurement can guarantee substantial reliability.

4.3.6 Collector azimuth and tilt angle

Solar radiation at a geographic location is different in summer and winter. An overview of solar radiation is provided by so-called **insolation maps** where lines, called **isosuns**, indicate areas of equal solar yields for a **horizontal surface**. These maps exist for different seasons. July, in Rijeka, provides a daily yield between the 6.0 and the 6.2 kWh/(m^2 day) line. On the contrary, for Austria, the yield is roughly 5.6 kWh/(m^2 day). En route through Dalmatia to Dubrovnik, the daily yield approaches 7.0 kWh/m^2. In winter, the amount of solar radiation is far lower. In northern Europe, it can be only one tenth of

[5]"In order to provide reliable solar radiation data for the design of solar energy conversion systems, Energy Institute Hrvoje Pozar and the Ministry of Economy, Labour and Entrepreneurship with the cooperation of the State Meteorological Service initiated development of Solar Radiation Atlas of Republic of Croatia based on existing solar radiation data and knowledge" [17].

the corresponding value during summer, roughly 0.5 kWh/(m^2 day). In southern Europe, even during winter, the daily yield can be appreciable – between 1.5 to 2.0 kWh/m^2. Hence, in southern Europe, conditions may be satisfactory enough to consider year-round applications, cf. [6].

The mentioned insolation maps allow only initial imprecise estimations and solar radiation is only regarded with respect to a horizontal surface. In order to maximise the yield, perpendicular incidence of the direct radiation is needed. The solar radiation collecting surface, therefore, is tilted against the horizontal, rising the question as to which direction the tilted surface should face. This is described in terms of the **azimuth** angle. In the northern hemisphere, the collecting surface should face south but any surface direction within ± 45 degree functions well without significant losses for simple DHW applications. The optimal **tilt** angle depends on the geographical latitude and on the purpose of the solar energy system. Aside from a few concentrating-solar systems, dynamic adjustment is not common for economic reasons.

Vertical and horizontal orientation of the collector will be major parameters for the simulation of designed solar thermal systems. In part III of this work, the movement of the Sun with respect to a geographical location will be described in detail because it is the pivot of the simulation software in terms of climate data input. The hourly climate data to be used is data for a horizontal surface. The according models then transform the data according to the collector orientation.

In *Figure* 4.8, the plane of rotation of the Earth, known as the ecliptic, is shown. The direct radiation strikes at different angles in different seasons. S_0 is maximal on the second of January at the Perihelion and minimal on the second of June when it reaches the Aphelion. Perpendicular incidence on the northern hemisphere requires a lager tilt in winter than in summer, but the optimal tilt angle for different geographical locations depends also on the purpose of the solar thermal energy system. Since the

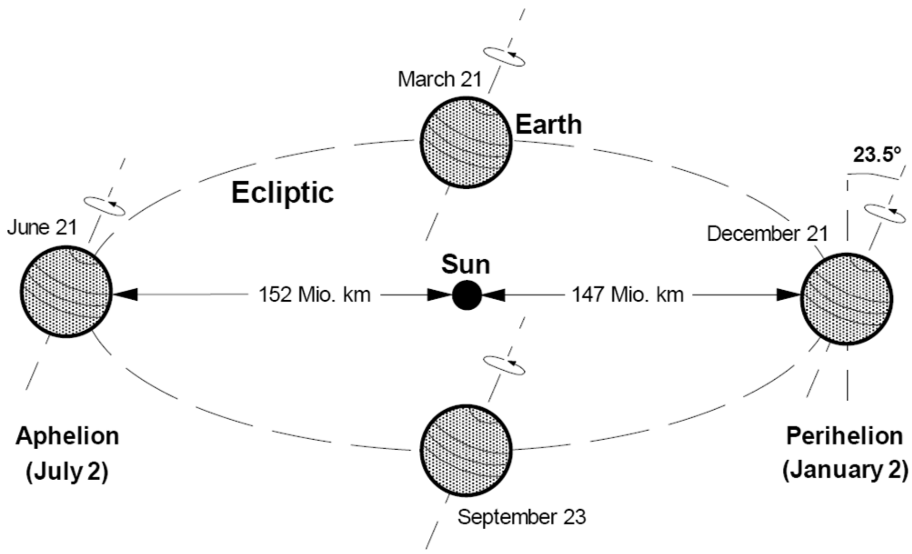


Figure 4.8: Ecliptic of the Earth – taken from [2], with permission from Wolfgang Streicher.

Earth's axis is not perpendicular with respect to the plane of the ecliptic, the Sun seems to have different heights, with respect to the Earth year-round. A tilt less than the latitude gives a higher yield during summer. A more vertical position of the collector is an adaptation that promises a higher yield in winter. A tilt according to the latitude leads to perpendicular incidence in spring and autumn. Most applications allow a wide range of collector orientations, and this flexibility assures the suitability of existing roof surfaces for solar energy systems [6].

4.4 Summary of Part I

Chapter 1 provided an introduction of the topic energy utilisation. General terms and the nomenclature in the context of solar energy utilisation were defined. Furthermore energy units, the relevant decimal prefixes and diverse conversion factors between different units were explained.

In Chapter 2 the world energy resources were discussed and the respective estimated potentials were calculated and summarised. Eventually TPES and TFC of the world were provided. The TPES in 2006 amounted to 491.5 EJ, the TFC amounted to 338.5 EJ. In the last 30 years TPES increased on average by 7.37 EJ p.a.. For fossil fuels the respective gradient amounted to 5.32 EJ p.a.. In the current energy mix crude oil (172.0 EJ), coal/peat (127.9 EJ) and gas (100.8 EJ) contribute the largest distinctive shares. Taking into account only economically viable resources, at current state of knowledge and energy consumption, the energy supply security is as follows: coal reserves alone would provide energy for approximately 50 years. Oil and heavy oil together are estimated to provide energy for approximately the same period, i.e. another 50 years. Known gas resources could cover the world energy supply for about 12 years. Eventually nuclear resources, when utilised in the once-through mode, are seen to cover the world TPES for approximately 8 years [6]. Hence, current TPES assumed, non renewable resources guarantee supply for approximately 120 years.

The utilisation of renewable sources at present lead to a contribution of slightly more than one tenth to the present TPES. Bioenergy (48 EJ) and hydropower (10 EJ) have the highest shares. It was shown that cultivation of rape, for biofuel production, is by far less efficient than cultivation of willow for heating purposes. Unless burning fossil fuels for heating purposes is suspended completely, interchange of fossil fuels in heating applications with biomass and intensive biomass cultivation is five fold more efficient than direct biofuel production.

The annual direct energy generation from solar energy is marginal (0.0003 EJ). Theoretically the solar energy potential is huge. However, no estimations dealing with technical or economical viable potentials exist, therefore, when considering only solar thermal energy generation, it is important to analyse industrial processes and private needs for heat energy.

Chapter 3 described the situation in terms of energy supply and consumption for Croatia. In 2007 TPES was 416.78 PJ, with respect to the last five years before 2007, the mean annual increase was 7.9 PJ or 2.1%. Liquid fuels (189.70 PJ), natural gas (114.22 PJ) and hydropower (42.21 PJ) contribute the majority to the TPES. Energy production in 2007 amounted to 195.44 PJ and increased since 2002 p.a. by 1.0%. This reflects the unfavourable situation of Croatia in terms of independence or energy self supply, which is at present less than 40%. The TFC per inhabitant is 38.4% lower than the EU27 average. The analysis of consumption sectors showed that in 2007 the sub-sector households (71.84 PJ) had a share of 27% on the TFC (269.07 PJ). Noticeable is the continuous high annual growth rate (10%) of the sub-sector construction, with respect to the last five years. This increase underlines the actions in the building and construction sector in Croatia.

The part energy prices of this chapter showed still existing rudimentary structures from the past political system. The regulation of the district heating sector works on the basis of revenue caps within a specific regulation cycle. Thermal energy costs between 108.8 to 319.29 HRK/MWh for the category households and between 197.00 to 773 HRK/MWh for the category economy, VAT excluded. Lower and upper price limits between 1996 and

[6] Utilisation in closed fuel-cycles and pure fast breeder promise much higher yields.

2007 for light fuel oil are 2.09 and 4.66 HRK/litre, taxes included.

Compared to electricity prices in the EU, prices in Croatia rank among the countries with the lowest prices. However, the increase of electricity imports, 15.7% p.a. on average from 2002 to 2007, sharpens the situation. It shows evidence, that sooner or later the international price level from northern Europe, that is approximately 1.7 times higher, need to be reflected in the national electricity price unless the national production increases significantly or subsidies are established.

Chapter 5 focussed on solar energy. First the physical base of heat generation in the Sun by fusion was described. Then the concept of the solar constant and air mass was explained. Next the ways passive and active energy utilisation were described. Finally the movement of the sun during one year and the relevant aspects for the solar collector orientation were discussed in short.

Part II

Croatia – Primorje-Gorski kotar County (PGC)

Chapter 5

Statistical Data, Heat Demand and Standardisation

This chapter discusses the building area of Primorje-Gorski kotar County (PGC) and estimates the number of single family houses. For the Croatian county PGC, tourism is important and, therefore, this chapter pays specific attention to the number of overnight stays in tourist accommodation and private places of residence. Standard buildings and heat consumption profiles are introduced and elaborated along the following structure: three distinct single family houses DHW and heating demand are analysed, while tourist accommodation facilities are considered with respect to the DHW demand only.

5.1 General statistical data

A geographic overview and economic data for **Croatia** provides Table 5.1. Croatia has 4.44 million inhabitants and a land area of 56 594 km^2. Population density is 78.5 per km^2 and the GDP per capita amounts to 11 546 US $. The country is subdivided into 20 counties.

Table 5.1: General statistical data of Croatia, cf. [51]

Land area	56 594 km^2
Surface area of territorial sea and interior sea waters	31 067 km^2
Population, 2006 mid-year estimate	4.44 million
Population density	78.5 per km^2
General economic data	
Gross domestic product per capita (estimate at current prices)	11 546 US $
Average monthly paid net earning	4 841 HRK
Average monthly gross earning	7 047 HRK

Primorje-Gorski kotar County (PGC) is located in western Croatia, east of Istra. It has **305 505 inhabitants** and a land area of 3582 km^2, which is 6.3% of the total land area of Croatia. The most populated city is the **capital Rijeka** – the third largest city in Croatia. It is famous for its big port, the country's principal seaport. The two largest islands are Cres and Krk, their respective areas are approximately the size of Vienna (415 km^2). The highest mountain peak reaches 1534 m. PGC contributes 5.9% of the total revenue of Croatia. More geographic and economic data are provided in Table 6.1. A map of Croatia and PGC is given in the Appendix Maps.

5.1.1 Building area

Building area is the amount of land area on which buildings are situated, the Croatian keyword for this is *izgrađanost*. It was not possible to get an official document or published data concerning building area at the responsible national local body, **PGC's, Public Institution – Institute of physical planning** [1]. Since this figure is only used in this research to estimate the roof surface available for installing solar thermal collectors, an approximate number is satisfactory. After enquiring several times, discussions on the phone, and two personal meetings at the institution the author was able to acquire an estimation. A number of **4%** with respect to the whole **land area** of the county was mentioned to be **covered with buildings**. Furthermore, it was estimated that the 4% percent are divided as follows [20].

- 1% is used for industrial purposes
- 3% is used for private housing or accomodation facilities

Table 5.2: General statistical data of Primorje-Gorski kotar County, [19]

GENERAL DATA	
Total population	305 505 (6.9%)
Most populated – City of Rijeka	144 043
Cities	14
Municipalities	21
Settlements	536
TERRITORY	
Area	3582 km^2 (6.3%)
Sea surface	4398.64 km^2
Coast length	1065 km
Largest islands – Cres and Krk	each 405.78 km^2
Highest mountain peak – Bjelolasica-Kula	1534 m
ECONOMY	
Share in total revenue of the Republic of Croatia	5.9%
Exports	217 million US $
Imports	639 million US $
STRUCTURE OF REVENUE BASED ON ECONOMIC BRANCHES	
Trade	44.9%
Processing industry	21.1%
Transport, warehousing and communications	9.9%
Construction industry	7.2%
Sale and lease of real estate and business services	5.57%
Hotels and restaurants	**5.20** %

Around 45% of the counties' territory is land area, namely 3582 km^2, 4% of which is under roofing; this gives an area of **143** km^2. Approximately 35.75 km^2 are dedicated to industry, and the rest, 107.25 km^2, is the share built for living or other purposes. This number, divided by the total population, yields 351 m^2 per inhabitant.

5.1.2 Single family houses in Croatia and PGC

To estimate the solar thermal potential for family houses, the total number of single family houses (SFH) is needed. Unfortunately, [29] does not provide the number of SFH for

[1] Javna ustanova Zavod za prostorno uređenje Primorsko-goranske županije

PGC. Also the Institute of Physical Planning in Rijeka could not provide any information about the existing number of SFH. A statistic for Croatia, however, found in the public domain provides useful data [21]. As will become clear later, several estimations for certain solar thermal potential scenarios will be needed. Therefore, it is sufficient to work with approximate data based on reasonable assumptions since the preceding estimations are errors-prone.

The relative data for private houses with one and two flats will be used to derive the respective absolute number of SFH for PGC based on the total number of inhabitants and the number of households. The distribution for Croatia does not change rapidly, hence it is acceptable to combine statistical data referring to different years.

The distribution for **Croatia** is provided in Table 5.3 where four different construction periods and the total number in 2001 are listed in columns. The lower part of the table provides the relative figures. It can be seen that more than one half of all flats in Croatia are SFH. Grouping the houses with one and two flats leads to approximately two thirds, which makes the majority of accommodation in one or two flat unit houses. In Chapter 9, the construction periods will be used to justify the derivation of overall conversion efficiencies of the installed heating systems.

Table 5.3: Private buildings with one or two flats in Croatia, [21]

Type	**# of SFH for certain construction periods**				**Total**
	before	81-90	91-95	1996 or later	
One flat	...	129 390	29 838	47 166	796 388
Two flats	...	24 842	5154	6301	167 110
Others	...	...	...	...	...
Total # of flats					**1 453 074**
	Relative figures				
One flat	...	**0.162 471**	**0.037 467**	**0.059225**	**0.548 071**
Two flats	...	0.148 657	0.030 842	0.037 706	**0.115 004**
Others	...	...	...	...	0.336 924
Total					1

Table 5.4 shows the number of flats for **PGC** consisting of three, four, or five and over rooms. Approximately one fourth of the total number of flats belongs to the categories which fit the size of SFH. It could be assumed that the relative number of SFH for PGC is not greater than 25%. However, if a so-called SFH for four people comprises two flats, the category of flats with three rooms is reasonable; 3.2 persons per houshold has been given in [22]. According to the afore mentioned approach, the total number of SFH is

Table 5.4: Private flats with three, four and five or more rooms for PGC in 2008 [29]

	# of flats according to room number for PGC				
	Less than 3	3	4	5 and more	Total
Total # of flats	...	35 054	21 677	5530	**108 662**
Relative #	0.427 021	0.322 597	0.199 490	0.050 892	1
	0.427 021	0.322 597	**0.250 382**		1
	0.427 021	**0.572 979**			1

given by the sum of the flat categories 'four rooms', 'five and more rooms' and half of 'three rooms'. Hence the estimated number of SFH for PGC is 44 734, which corresponds to approximately 41%.

The total number of SFH for PGC for four different construction periods is provided in Table 5.5. The numbers were derived from the assumed relative numbers 15.0, 4.0 and 4.0% for the construction periods 1981-90, 1991-95 and 1996 or later, respectively, and the total number of SFH (44 734), that was previously assembled using data from Table 5.4.

Table 5.5: Estimated number of SFH for PGC for four construction periods

	# of SFH for certain construction periods				
	Before 1980	81-90	91-95	1996 or later	Total
SFH [%][a]	77.0	15.0	4.0	4.0	100.0
Total # of SFH	34 445	6710	1789	1789	44 734

[a]) The relative numbers were estimated (derived) from statistics for Croatia.

5.1.3 Tourism sector overnight stays in 2008

It was assumed the solar thermal potential of the tourism sector is high. One reason for this is the high correlation of daily sunshine hours and tourist numbers during the summer. To analyse this, the number of overnight stays at the local tourist agency was acquired. This section provides the total number, the monthly breakdown and the distribution of occupancy according to the types of buildings. The need for low-temperature heat in this sector is primarily for hygienic purposes and secondary for cleaning, dish-washing and other activities connected with the facilities.

In 2008 the number of overnight stays in the Republic of Croatia amounted to 57 101 494 [23]; this is slightly less than half of the according number for Austria [24]. The annual index is 102, which means an increase of 2% p.a.. PGC has a share of 19.7% on the total amount, thus ranking second amongst all counties – behind Istria.

In 2008, the number of overnight stays in PGC was 11 263 659; the island Krk, with 30.3%, had the highest share. The annual distribution of overnight stays is provided in Table 5.6.

Table 5.6: Monthly distribution of annual overnight stays in PGC for 2008

Month	**Overnight Stays**	**Percentage**	**Percentage**
January	67 863	0.6	
February	73 682	0.7	
March	151 896	1.3%	
April	269 781	2.4%	
May	655 563	5.8%	5.8%
June	1 409 562	12.5%	12.5%
July	3 488 361	31.0%	31.0%
August	3 596 032	31.9%	31.9%
September	1 103 537	9.8%	9.8%
October	289 770	2.6%	
November	78 507	0.7%	
December	79 201	0.7%	
Total	**11 263 755**	**100.0%**	Summer **91.0%**

'Middle summer occupancy rate of utilisation' is a design-related parameter from practise used to plan individual solar thermal plants with respect to size, cf.[25]. This concept is adapted for this work, where FU_{Summer}, the **average utilisation capacity** in the **summer** period from May to September is used in the same way. By contrast, it is applied using statistical values rather than real occupancy rates of an individual accommodation.

Table 5.7: Tourist Capacity in 2008 for PGC according to facility [23]

Facility	**Objects**	**Units**				
		Rooms	**Apartm.**	**Tent sites**	**Beds**	**Berths**[a]
Hotel	102	9813	381	-	19 365	-
Tourist village	4	1104	77	-	2437	-
Apartment	1+4+5+60	308	1371	-	5012	-
Pension	19	248	11	-	549	-
Rooms for rent	46	1015	18	-	2137	-
Camp (site)	39+3	60	195	12 557	39 050	-
Sanatoria	60	712	115	273	4011	-
Hostel	12	327	-	-	1943	-
Ship tourism	5+11	524	-	-	13 044	2813
Others	...	...	...	...	...	...
Commerc. Acc.	417	15 365	2334	13 000	91 205	-
Private Acc.	**Households**					
	14 739	12 584	22 881	97	90 080	-
Total		27 949	25 215	13 097	**181 285**	2813

[a]) Berths are sleeping places on ships.

The number of accommodation types in 2008 for the respective categories were Hotels (102), Camps (39), Tourist villages (4), Sanatoria (60) and Rooms for rent (46). A shortened overview is provided in Table 5.7. The bed capacities were 19 365, 38 515, 2437, 4011 and 2137, respectively. The bed capacity of commercial establishments amounted to 91 205. The number of beds in private accommodations was 90 080.

Facilities show different occupancy rates, which are represented by the **Facility Utilisation** (FU): it gives the total number of overnight stays for each facility during one year – expressed in days on which all beds are occupied

$$FU_{annual} = \frac{\text{total number of overnight stays}}{\text{bed capacity}} . \tag{5.1}$$

In Table 5.6, it was shown, that 91% of the total annual overnight stays in 2008 refers to the summer season from May to September. Different accommodation facilities show different utilisation rates during the year. To distribute the total number of overnight stays amongst the facilities, and to estimate the related solar thermal potential, a certain variable is needed to characterises the utilisation during summer months.

Figures concerning the respective overnight stays in Table 5.8 refer to the whole year. FU_{annual} is the number of annual overnight stays divided by the total capacity of one type of facility. Given a share of 91.0% overnight stays during summer months (from May to September), the summer facility utilisation ($FU_{(Summer)}$) can be defined on the base of the annual utilisation via multiplication

$$FU_{Summer} = FU_{annual} \cdot 0.91 . \tag{5.2}$$

For example for Hotels it yields 143.5 [2]. This calculation was carried out for all facilities in Table 5.8.

[2]The calculation was done with 0.910 269 71%, otherwise for the rounded number 91.0%, one gets 143.42%.

To contrast these facilities, the vital concept of a **Facility Utilisation Factor** which provides a relative characterisation for the utilisation is invented. It is defined as the facility utilisation during summer divided by the nominal number of summer days (153). This leads to the facility utilisation factor, $FU_{F(S)}$, for each facility

$$FU_{F(S)} = \frac{FU_{Summer}}{153} . \tag{5.3}$$

This factor is used to calculate the nominal daily DHW demand as a function of the bed capacity of a specific facility.

Another interesting value is the average facility utilisation – especially the weighted average facility utilisation

$$\left\langle \prod FU \right\rangle_{95\%} = \frac{1}{N_{Subtotal}} \cdot \sum_{i=Private\ Accom.}^{Hostels} N_F^{(i)} \cdot FU^{(i)} . \tag{5.4}$$

This utilisation takes into account 95% of the annual overnight stays ($N_{Subtotal}$=10 691 789). The $FU_{F(S)}$ related to this **average** utilisation is **0.51**, which is the average **facility independent occupancy** rate in summer.

Table 5.8: Number of overnight stays in PGC for 2008, with respect to accommodation facility, FU ... Facility Utilisation, FU_F ... Facility Utilisation Factor.

Facility	**Overnight Stays**	**Utilisation**		
	N_F	$FU_{(annual)}$	$FU_{(Summer)}$	$FU_{F(S)}$
		[days]	[days]	[%]
Private Accom.	3 726 046	41.4	37.7	0.25
Hotels	3 052 140	157.6	143.5	0.94
Camps	2 675 152	69.5	63.3	0.41
Tourist villages	255 290	104.8	95.4	0.62
Sanatoria	239 547	59.7	54.3	0.36
Rooms for rent	174 926	81.9	74.6	0.49
Berths	157 565	14.0	12.7	0.08
Ships cabins	142 669	79.6	72.5	0.47
Apartments	140 894	141.9	129.2	0.84
Hostels	127 560	65.7	59.8	0.39
Subtotal $N_{Subtotal}$	10 691 789	81.6	$\leftarrow \langle FU \rangle_{95\%}$ Average Util. 95%	
Weighted Average $\langle \prod FU \rangle_{95\%}$:		**85.9**	78.2	**0.51**
Others	571 966	$\cdots$		
Total N_{total}	**11 263 755**	62.1	$\leftarrow \langle FU \rangle$ Average Util.	

5.2 Domestic hot water (DHW) demand

According to VDI 2067 (1982), a medium demand for DHW per person amounts to 20-40 litres of 60°C hot water or 30 to 60 litres of 45°C hot water. Assuming cold water temperature to be 10°C, one gets the useful energy for DHW preparation.

Fresh water continuously brings calcium, therefore, limestone deposits are possible. To avoid such deposition, the temperature of the DHW storage should not exceed 70°C, cf. [2] p.144. With central substations or external heat exchangers for DHW preparation combined with an additional heat storage, this problem is avoidable.

Another hygienic issue that arises is legionella. In Germany, the norm *DVGW W 551, W 552 and W 553* refers to this problem. In Austria, it is *ÖNorm B 5019*. The conditions between 25°C and 50°C are optimal for legionella colonies to form: above 60°C the bacteria is killed quickly. For SFH and multi-family houses, the mentioned norm is not compulsory, but for tourism applications or other buildings that accommodate many people, it has to be taken seriously since special hygiene standards must be fulfilled.

5.2.1 Private housing

The software used for simulation provides detailed definition of the DHW demand.

- Nominal daily consumption = **200** litres/day
- Setpoint temperature = **45**°C
- Mean annual groundwater temperature = 10°C
- Variation of groundwater temperature [3] = 0°C

Furthermore daily, weekly, and yearly distribution characteristics may be adjusted. The daily distribution is defined by a weight for each hour. The value zero refers to no demand whereas 100 would mean consumption of the daily demand in one hour. For weekly and yearly demand, weights can be attributed to each day and each month. These weights scale down the nominal daily consumption to the daily consumption.

In *Figure* 5.1 daily demand from Monday to Thursday is 90%, on Friday 100%, and on Saturday and Sunday 120%. This means for a nominal daily demand for 200 litres, the consumption is 180 litres between Monday to Thursday, 200 litres on Friday, and 240 litres on Saturday and Sunday. With reference to the annual distribution, monthly weights represent a factor in percentage valid for every day of the according month. Values deviating from 100 change the daily DHW demand for the corresponding month. The annual demand profile is especially important in the tourism branch.

A guideline for the specifications of DHW demand was provided by [26] [4]. The used profile for SFH is provided by *Figure* 5.1, which was generated as follows [5].

- The hourly demand profile for one year has been worked out in [26], based on this, the annual and weekly variations were removed using backward calculation. For each day, the demand for the respective hours was added and divided by 365. This lead to an average annual consumption for every hour of the day. Then, the values were standardised, i.e. addition of the daily consumption yields 100.
- Weekly consumption was adjusted according to [26]: 90% Monday to Thursday, 100% on Friday, and 120% on Saturday and Sunday.
- The groundwater temperature variation and seasonal consumption variation were modelled with a shifted *sine* and *cosine* function having an amplitude of ± 5% each [6].

Climate conditions compareable with those along the Dalmatinian coast are prevalent in Barcelona or Madrid, for which data are provided in [27]. Considering a different climate

[3] The annual variation was modelled with varying heat demand.

[4] The DHW profiles were developed within the scope of the Solar Heating and Cooling Programme of the IEA, Task 26: Solar Combisystems.

[5] The German abbreviations in the figure mean: Mo=Monday, Di=Tuesday, Mi=Wednesday, Do=Thursday, Fr=Friday, Sa=Saturday, Su=Sunday. Accordingly for the year: (=Jahr) Jän=January, Feb=February, Mär=March, Apr=April, Mai=May, Jun=June, Jul=July, Aug=August, Sep=September, Okt=October, Nov=November, Dez=December.

[6] In [26] ± 5 K are recommended. Ground water temperature variation was modelled via the heat demand profile, because the SHWwin did not allow to adjust the shift of the overlaid annual variation. This implies some uncertainty since the collector efficiency increases with a lower ground water temperature and vice versa; the real collector efficiencies in summer could be slightly less then the obtained results.

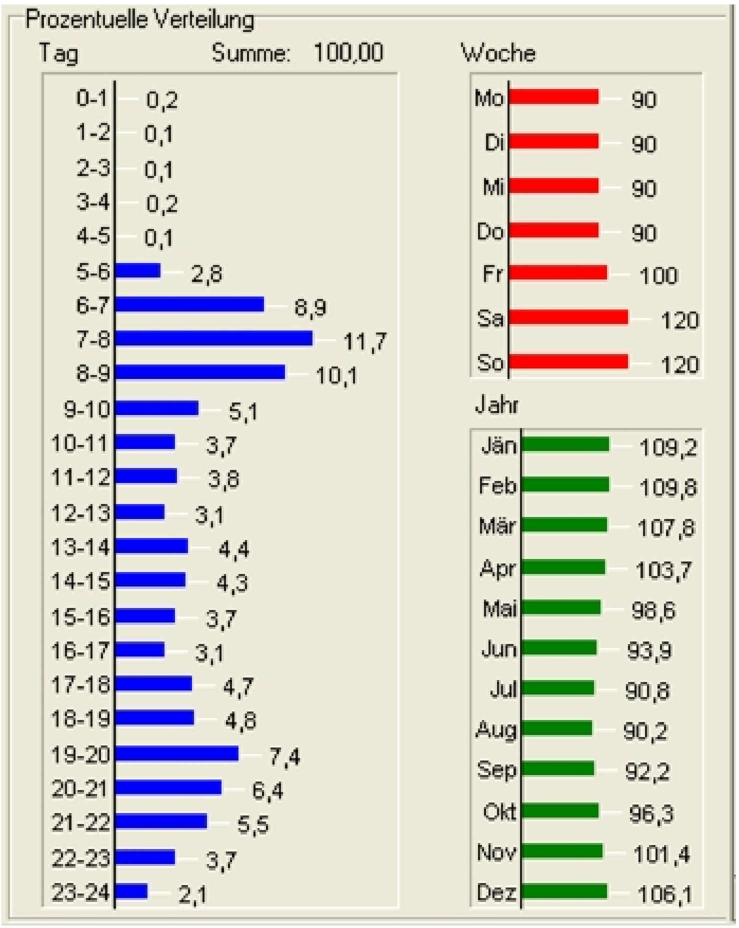


Figure 5.1: DHW-demand profile for SFH; left hourly, right-top weekly, right-bottom yearly.

then PGC, with an average annual radiation approximately 200 kWh/m^2 less, Barcelona and Madrid provided data for orientation [7] [27]. According to [27], the sine-function shift must be adjusted to get the lowest groundwater temperature or the highest consumption demand nineteen days after the first day in January. For Zurich, that number is sixty days. It was chosen to be fourtyfive days in this work. The cosine function that models the consumption variation was shifted by minus thirty days – details are given in the Appendix Demand Profiles. Holiday or visitation periods of less or higher consumption were not taken into account since it was assumed that their effects reconcile each other.

5.2.2 Tourist housing

Defining the DHW demand for accommodation facilities in tourism is slightly more complex than for SFH, it requires some assumptions and estimations. The demand for DHW for different facilities is provided in Table 5.9, according to VDI 2067 (1982) [28].

Practical values for DHW demand in tourism, including rules of thumb for demand for laundry and cooking are listed in Table 5.10. In general, the values given here are less than those in the former table.

[7] In Barcelona design temp. of the space heating system is -1°C, in Madrid it is -7°C.

Table 5.9: Average daily DHW demand per guest in tourism VDI 2067 (1982) [28]

Type of Accomm.	**Demand** [litres 60°C]	**Demand** [litres 45°C]
Rooms with Tub	95 - 138	135 - 196
Rooms with Shower	50 - 95	74 - 135
Other Hotels	25 - 35	37 - 49
Hostels, Bed&Breakfast	25 - 50	37 -74

Table 5.10: Average daily DHW demand per guest of accommodation facilities, according to practise [25].

Type of Accomm.	**Demand** [litres 60°C]
Hotel ***, ****	40 - 60
Apartements	40
Hostels	20 - 25
Bed&Breakfast	30
Camping Sites	20
Additional demand per guest	
Breakfast	2
Noon/ Dinner	4-8
Laundry	3 (litres 60°C)/(1kg dry cloths)

DHW demand profile for accommodation facilities

The **daily** profile was assumed to resemble that for private housing. Every day was given the same weight for the **weekly** profile. The **annual** profile was set up using the structure of overnight stays in 2008, cf. Table 5.6 and ground water temperature variation. A minimal demand for 10% with respect to the demand at maximal occupancy rates was taken for the off-season period to account for repair and cleaning duties.

Each facility has a different annual distribution, which was calculated using the total distribution of overnight stays. This distribution was approximated using a **Gaussian profile** [8]. The relative monthly values were derived from this profile – dependent from the respective $FU_{(S)}$. Finally, each distribution was normalised, that is, 100% for a month refers to the set absolute nominal summer demand, $V_{dem(S)}$.

This led to eight distributions corresponding to the $FU_{F(S)}$'s 0.94, 0.84, 0.62, 0.47, 0.41, 0.39, 0.36 and 0.25, respectively. Comparing the sum of all synthesised distributions in absolute numbers of overnight stays to the real statistical distribution of overnight stays in summer led to a total failure of approximately 4%. Details are provided in the Appendix Annual Demand Profiles. *Figure* 5.2 shows the complete DHW demand profile for Private Accommodations (ACC S) related to the nominal daily summer demand – namely $V_{dem(S)}$. Table 5.7 and Table 5.8 contain results from statistical data and can be used to estimate the solar thermal potential of PGC. To use this data, typical consumer classes for tourist accommodations must be defined from which daily consumption of a particular facility can be inferred. Hence, three consumer classes were defined with a demand for 60, 40 and 20 litres, per guest, per day, respectively, see Table 5.11. It is evident from Table 5.8 that private accommodations, hotels and camps are the facilities with the highest

[8]Another option would be to apply a Cauchy Lorentz distribution, which is slightly sharper at the maximum and might approximate the off-season period more accurately.

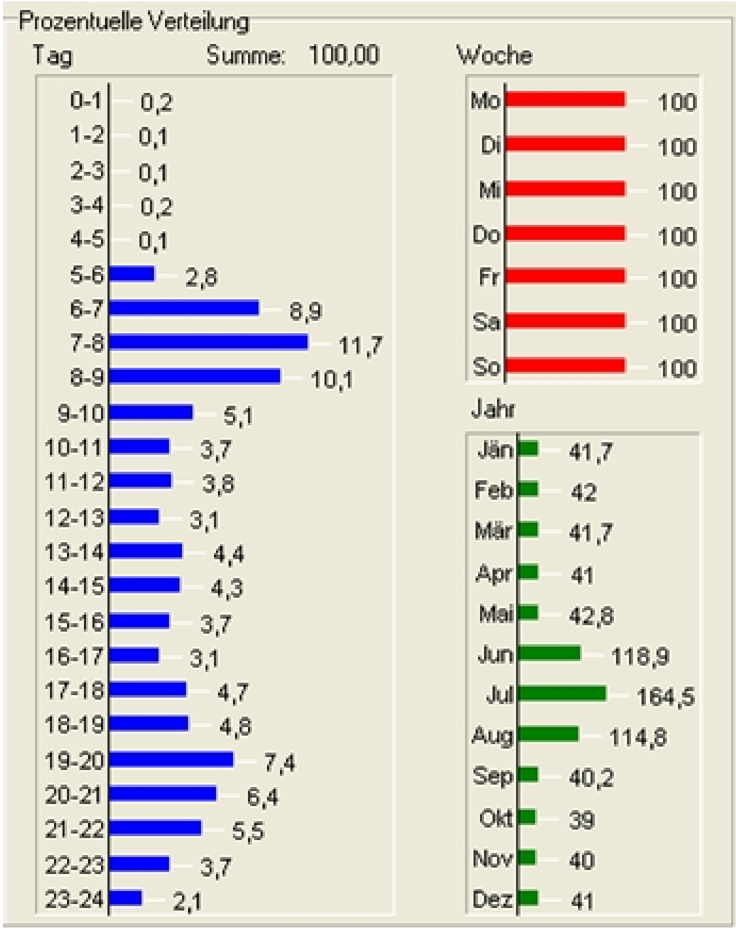


Figure 5.2: DHW-demand profile for a tourist accommodation with $FU_{F(S)} = 0.25$, (left, hourly; top-right, weekly; bottom-right annually)

amount of overnight stays. This is why the according consumer classes were defined [9]. Private accommodations were assumed to include bed & breakfast facilities, apartments and ordinary rooms.

Table 5.11: Fictive consumer classes defined for tourist accommodations.

Position	**Consumption in litres(60°C)/(guest day)**		
	High	**Medium**	**Low**
Typical Accom.	Hotel	Apartement, Rooms	Camp
	Sanatoria	Bed & Breakfast	Hostel
		Tourist Villages	
DHW demand	50	39.4	20
Breakfast	2	-	-
Noon/Dinner	6	-	-
Washing	2	0.6	-
Total [litres/guest]	$V_g = 60$	$V_g = 40$	$V_g = 20$ litres

[9]The solar thermal system design will be applied to these three types of accommodation.

Nominal Daily Summer Demand

This is a measure specific to each type of facility. For the simulation, the respective absolute DHW demand profile is derived from the nominal DHW demand $V_{dem(S)}$ in litres and a relative demand profile, such as the one given in *Figure* 5.2.

Nominal DHW demand for an individual facility (i) is calculated using the maximal bed capacity multiplied by $FU_{F(S)}^{(i)}$ and the DHW consumption per guest. Assuming a hotel with a capacity of 600 guests (600 beds), and applying the consumer class high, the absolute demand is calculated by

$$\begin{aligned} \bar{V}_S &= V_g \cdot n_{beds} \cdot FU_{F(S)}^{Hotels} \\ &= 60\, litres/bed \cdot 600\, beds \cdot 0.94 \\ &= 33\,840\, litres\ . \end{aligned} \tag{5.5}$$

This formula was taken from [25], but the real occupancy rate was replaced by the facility utilisation factor $FU_{F(S)}$. This calculation will be repeated for each individual type of facility that is to be simulated.

The resulting 33 840 litres can be explained from a practical point of view as the absolute, average daily summer consumption from May to September. The meaning in the context of system simulation is different. It is the absolute DHW demand that is combined with the relative numbers of any profile, such as that in *Figure* 5.2.

5.3 Standardised tourist accommodation facilities

Before the definition of prototypical solar thermal systems for DHW preparation for special accommodation facilities, accommodations are classified according to their DHW demand in small-, medium- and large- accommodations – named as ACC S, ACC M and ACC L, respectively. This concept will be used to relate facilities to different DHW-preparation systems for commercial purposes.

Table 5.12 provides an overview of the defined standard accommodation facilities. The parameters, number of beds and nominal daily summer demand provide values for orientation defining theoretical categories only. The relation between the number of beds, the nominal summer demand, the demand per guest of the consumer class and the facility utilisation factor for a certain facility is

$$n_{beds} = \frac{V_{dem(S)}}{V_g \cdot FU_{F(S)}^{i}}\ . \tag{5.6}$$

5.4 Heating and standardised single family houses

Solar combisystems have been considered for the solar heating and cooling programme – Task 26 [10]. They generally consist of five elements; a solar collector loop, a storage subsystem, a control subsystem, an auxiliary subsystem, and a heat distribution subsystem. The most important input parameters required for the used software for simulation are the standard heating design temperature and the average room temperature setpoint (more details follow in the Chapter 7 Simulation Software Description). For the standard heating design temperature for PGC, -6°C was chosen: the average room temperature setpoint should be 20°C.

Table 5.12: Data for the three standard accommodation categories, with '+' referring to additional private demand. Simulation will be worked out for highlighted entries.

Type	$FU_{F(S)}$	**ACC S**	**ACC M**	**ACC L**
Suitable for		No. beds	No. beds	No. beds
Private Accom.	0.25	**16+4**	-	-
Hotels	0.94	-	29	**100**
Camps	0.41	39	**200**	687
Tourist villages	0.62	-	66	227
Sanatoria	0.36	22	114	261
Rooms for rent	0.49	16	-	-
Apartments	0.84	10	49	-
Hostels	0.39	41	210	-
Nominal DHW summer demand, 60°C, litres/day				
Standard		320 L/day	1640 L/day	5640 L/day
Convent.heat source		oil/gas boiler	oil/gas boiler	oil boiler
Summer plant effic.		0.87-0.93	0.60-0.93	0.60-0.93

To define the heat demand linked to space heating in private houses, several estimations and approximations were made. Temperatures are lower in the northern part of the county, however, population density in the coastal part is higher, thus giving more statistical weight to the coastal region and its climate.

Standardised single family houses

In order to estimate the solar thermal potential of a standard SFH, its size must be defined. According to [29], the number of flats in PGC was 159 354 in 2001: the corresponding living space was 10 984 m^2. The average flat size was 72.4 m^2, and the average living space per person was 25.8 m^2. On average, 2.8 people lived in an average flat, which was 72.4 m^2. The SFH however, was **defined** as being occupied by **4 people**. Taking 25.8 m^2 as a measure for one person, living space would be approximately 105 m^2.

Considering a **standard SFH**, some practical assumptions must be made. It was assumed that the reference object has a building area with the dimensions 8 m x 7 m. The building should have two floors, each with a height of 2.6 m, making the volume 291 m^3. The type of construction was assumed to vary among the SFHs that will be defined.

Estimations, with reference to the space heating system, were made considering the requirement to cover a wide range of installed systems and were based on discussions with colleagues from the Department of Thermodynamics at the University of Rijeka [10].

The first artificial building (SFH I) is 'old' and has poor insulation, thus the specific heat load was estimated to be 50 W/m^3. For a second, more recent building (SFH II), specific heat load was assumed to be 35 W/m^3. For a third low- energy house (SFH III), specific heat load was assumed to be 20 W/m^3.

It can be assumed that, for the majority of existing SFH, hot water preparation is done using an electrical boiler – summer and winter operations are distinguished. In that case of winter, the DHW storage, normally with a capacity of one day, is fed by the heating cycle. It is heated electrically during summer nights. Another possible hot water preparation method is the continuous-flow heater where hot water preparation occurs at the time of

[10] Parameters for this work are different than those found in the heating system parameters in [27].

usage. The heat source could use either electrical energy or gas [11].

Because the simulation software takes **passive solar heating** into account, the size, orientation and tilt (normally 90°) of the respective glass fronts and their heat transmission coefficients must be known. A guideline regarding this appears in the Solar Heating and Cooling Programme of the IEA, Task 32 cf. [27].

It was assumed that the building stands free on the mainland and faces the shore, thus most of the windows will face south-west or south-east. The breakdown of the according directions was assumed to be 7% for N-W and N-E and 15% for S-E and S-W, with respect to the facade size. This gives the corresponding **glass surfaces** N-W 2.9 m^2, N-E 2.5 m^2, S-E 6.2 m^2, S-W 5.5 m^2, which amount in total to 17.1 m^2.

The **internal heat sources** are assumed to amount to **550 Watts**, on average [27]. This number incorporates heat dissipation from inhabitants and waste heat generated by electrical appliances. The setpoint room temperature was chosen to be **20°C**, which presents the lower limit according to DIN 1946/2 [27].

Older buildings, SFH I

A specific heat load of 50 W/m^3 was assumed for the older buildings. Taking into account the volume of the building, one acquires the standard heat load of 13 650 W. A heating system consisting of a simple central oil-fired boiler with an overall annual degree of utilisation of 75% was assumed (average annual plant efficiency 0.75). Further characteristics referring to this type of house concern the inlet and outlet temperature of the radiators, which were assumed to be the according heat sources in the rooms. Inlet temperature was estimated to be 90°C, and outlet temperature was estimated to be 70°C. The transmission coefficient for double-glass windows was assumed to be 0.8.

More recent buildings, SFH II

A specific heat load of 35 W/m^3 was assumed for a more recent building. Taking into account the volume of the building, one acquires the standard heat load of 9555 W. A heating system consisting of a central oil- or gas-fired boiler with an overall annual degree of utilisation of 80% was assumed. Further characteristics with reference to this type of house include the inlet and outlet temperature of the radiators, which was estimated to be 75°C, and 55°C. The transmission coefficient for double glass window was assumed to be 0.8.

Low energy houses, SFH III

The low energy house should have a specific heat load of 20 W/m^3. Taking into account the volume of the building, one acquires the standard heat load of SFH III, namely 5460 W. A heating system consisting of a central biomass- or gas-fired boiler with an overall annual degree of utilisation of 85% was assumed. Further characteristics with reference to this type of house include the inlet and outlet temperature of the floor and wall heating, which were assumed to be the according heat sources in the rooms. The temperature was estimated to be 40°C, and 30°C, respectively. The transmission coefficient for triple-glass window was assumed to be 0.7 [12].

[11] The option to use directly thermal heat stored in a storage tank exists also.

[12] The glass transmission for SFH III might be too high compared to praxis, but smaller values will not effect the outcome considerably.

Overview

Table 5.13 provides an overview of the defined standard single-family houses (SFH I, SFH II and SFH III) that will be used to acquire the according solar fractions. The DHW demand is the same for each house, which is why the pure DHW solar fraction analysis in the context of single family houses will be indicated with SFH. The demand profile of the required 200 litres of hot water is provided by *Figure* 5.1. The annual plant efficiency given in the table refers to heat production for either DHW preparation or for SH purposes; this will be used to estimate the current final energy consumption in Chapter 9.

Table 5.13: Technical data for the defined standard buildings.

Type	**SFH I**	**SFH II**	**SFH III**
Occupancy	4 people	4 people	4 people
DHW demand	45°C; 200 L/day	45°C; 200 L/day	45°C; 200 L/day
Living space	105 m^2	105 m^2	105 m^2
Height	2.6 m	2.6 m	2.6 m
Room temp.	20°C	20°C	20°C
Specific heat load	50 W/m^3	35 W/m^3	20 W/m^3
Total heat load	13 650 W	9555 W	5460 W
SH-type °C/°C	radiator 90/70	radiator 75/55	floor&wall 35/30
Conventional heater	oil boiler	oil/gas boiler	gas/biomass boiler
Annual plant effic.	0.75	0.80	0.87
Glass trans. coeff.	0.8	0.8	0.7
Glass surfaces for all buildings, vertical			
N-W 2.9 m^2	N-E 2.5 m^2	S-E 6.2 m^2	S-W 5.5 m^2

Chapter 6

Hourly Climate Data

This chapter aims to evaluate different climate data sets for Rijeka, the capital of PGC, and the location for which solar thermal system analyses were conducted. Initial discussion begins with Rijeka's climate followed by an assessment of particular hourly climate data required for solar thermal system analysis. Two suitable climate data sets were available for Rijeka. Consequently, three different data sets were compared, including one data set that does not provide hourly data but serves as a comparison set on a monthly basis.

6.1 Climate of PGC

The Appendix Maps, provides a map of the territory of PGC (No.VIII. on the map of Croatia). The two islands Krk and Cres, with a respective area of 405.78 km^2, stand out. The capital, Rijeka, is located in the north along the sea and land boundary. All subsequent designed, simulated systems use the coordinates: 45° 19' N, 14° 25'E for Rijeka.

According to **Köppen climate classification** [30], the climate in this region belongs to Group C – temperate/mesothermal climates [1]. More precisely, it ranges between the two types, Cfa and Cfb. **Cfa** stands for a humid subtropical climate and **Cfb** for a maritime temperate or oceanic climate. The meaning of the according letters is as follows:

- The average temperature for **group C** is above 10°C in the warmest month, and the coldest monthly average lies between -3°C and 18°C.
- The second letter **f** sub-divides the climate zone according to the precipitation pattern. While the other subcategories in group C have either low precipitation during the summer -s- or during the winter -w-, **-f-** indicates significant precipitation in all seasons.
- The third letter is an indicator of the temperature for summer heat. The letter **- -a** indicates the highest degree of summer heat. The average temperature at least for one month is above 22°C, and at least four months have an average temperature above 10°C. By contrast, - -b indicates the warmest monthly average below 22°C with at least 4 months averaging above 10°C.

Unlike Mediterranean climates (Csa, Csb) which have dry summers, the precipitation for Cfa and Cfb is significant during all seasons [2]. This can be seen also in Table 6.1,

[1] The concept is established on the basis that native vegetation is the best expression of climate; thus, climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures, precipitation, and the seasonality of precipitation.

[2] These climates usually occur on the western sides of continents between the latitudes of 30° and 45° N.

which provides general climate data for Rijeka. *Figure* 6.1 shows the climate diagram for Rijeka according to Table 6.1. Precipitation is relatively high with a slight drop in July. Other sources, however, describe the climate in Rijeka as 'mediterranean'.

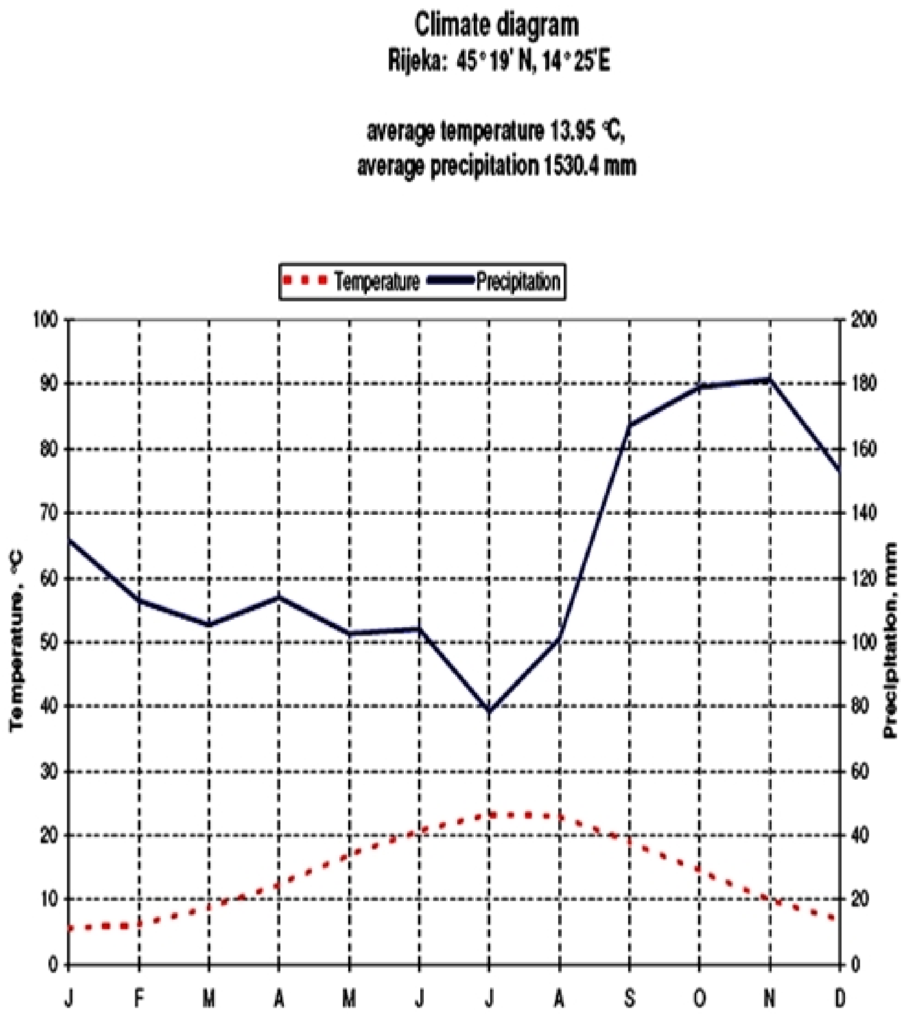


Figure 6.1: Climate diagram for Rijeka according to Table 6.1

6.2 Data sources

Hourly climate data is needed for the computer simulation of proposed solar thermal plants. The climate conditions in Rijeka provide a good sample suitable to estimate the overall potential including all possible locations in the county. This approach is reasonable with respect to the inhabitants, because Rijeka accounts for approximately half of the total inhabitants – for population density cf. Appendix Maps. In addition, slightly higher and lower solar yields to the south and to the north of Rijeka, have opposite effects on the total potential, which offers some balance.

The used software **SHWwin** [32] requires direct or **global** and **diffuse** radiation values on a horizontal surface of 1 m^2 with **outside temperature** [3]. All data must be **average hourly values**. Optional sources were climate data generated by the software Meteonorm or a Test Reference Year (TRY) – sometimes also called Synthetic Reference Year.

[3]Free Software provided by the Technical University Graz, http://lamp.tu-graz.ac.at/ iwt/downloads/swdownload/shwindlgo.html (Oct. 2010)

Table 6.1: General climate data of Rijeka over a period of more than 30 years, cf. [31]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temperature [°C]											
5.6	6.2	8.8	12.4	17.0	20.7	23.3	23.0	19.0	14.5	10.0	6.9
Sunshine duration [h]											
109.6	123.6	150.3	173.6	234	251.9	297.3	270.5	202.6	162.8	103.0	97.3
Precipitation [mm]											
131.6	112.8	105.3	113.8	102.6	104.0	78.4	101.1	167.2	179.1	181.5	153.0
Maximum snowcover [cm]											
28	10	52	-	-	-	-	-	-	-	8	5
Days with				-Rain							
10	9	10	12	12	11	9	9	10	11	13	11
				-Frost							
8	6	4	1	0	0	0	0	0	0	4	8
				-Minimum temperature<0°C							
7	6	2	0	0	0	0	0	0	0	1	4

The TRY-data is the result of a PhD-thesis [33] performed at the faculty of engineering in Rijeka. Details about the software Meteonorm can be found on the according web page or in [35] and [36] [4]. It is based on twenty-three years experience in the development of meteorological databases for energy application estimations. Unfortunately, the Solar Radiation Handbook of Croatia does not provide hourly data [5].

This research, however, does compare all three databases. Therefore, average monthly values of radiation, temperature, and humidity must be calculated from hourly values. Humidity data is not needed for simulation with SHWwin though, because it was provided by all climate data sets, the average monthly humidity was also compared. Therefore the humidity mixing ratio (mr_w), the fraction of water in g or kg with respect to one kg of dry air in the TRY-data, had to be converted to relative humidity (RH). Thus, it will be possible to compare mean monthly values from all three data-sources.

6.2.1 Meteonorm

This is a software that produces climate data for a site location on the basis of measurement data and special algorithms. Data for Rijeka was generated on the basis of measurements for the periods 1996-2005 and 1981-2000 for temperature and radiation data, respectively. In the software description each of these optional choices of periods is referred to as ‘new period’. The sequence of generation is as follows, cf.[35].

1. Space-dependent interpolation of radiation on a horizontal surface and temperature, based on weather data taking altitude, topography, region, etc. into account.

2. Stochastic generation of **time-dependent global** horizontal radiation and **temperature** data, having a quasi-natural distribution and an average monthly value equal to the average value over 10 years. This scheme is applied twice, monthly values lead to daily values and daily values lead to hourly values.

3. Resolution of *global horizontal radiation* into **diffuse** and **direct** components.

[4] The newest Version 6.1 [34] with Single license costs Euro 410,-. Single data sets can be ordered for Euro 50,-. http://www.meteonorm.com/pages/en/meteonorm/what-is-it.php

[5] Meteonorm allows to generate hourly climate data also from external monthly data. This information was brought to attention of the author at a late stage of work only.

According to stage 2 of the above procedure, all hourly values are offered on an average basis. For the generation of global radiation data for Rijeka, the stations on which the interpolation was based are; Koper, 62 km; Trieste, 65 km; and Portoroz, 73 km. The calculation of the outside temperature for the corresponding stations were; Rijeka/Omisalj, 17 km; Senj, 53 km; and Portoroz-Secovlje, 68 km. Other stations in the upper Adriatic region, providing data for the software, are shown in the Appendix Climate Data. Table 6.2 provides a summary of the climate data for Rijeka generated by the software Meteonorm.

Table 6.2: Cumulative monthly insolation Wh/ m^2 on a horizontal surface, average outside temperature and relative humidity generated by Meteonorm 6.1. Database periodes: Temperature: 1996-2005, Radiation: 1981-2000

Location Rijeka
Latitude 45.33 N **Longitude** 14.45 E
Height 0 m

cumulative insolation Wh/m² Temp. Humidity

Source: **meteonorm_6.1**

	global	diffuse	direct		Ta [°C]	RH [%]
january	37996	19948	18048		7.3	61.0
february	54817	31580	23237		7.3	56.4
march	99644	49371	50273		10.2	57.9
april	131526	67544	63982		12.8	62.7
may	173712	87799	85913		18.6	60.8
june	183232	85724	97508		22.3	58.7
july	194764	86832	107932		24.6	54.1
august	168163	67913	100250		25.4	54.0
september	115907	53017	62890		19.9	60.2
october	76447	41481	34966		16.7	65.5
november	42117	26438	15679		11.9	64.9
december	30892	17579	13313		8.4	61.1
hourly average	149	73	77	**mean**	15.5	59.8
total	**1309217**	**635226**	**673991**			

6.2.2 Test reference year (TRY)

The TRY-data is the results of a PhD-thesis [33] from the Department for Thermodynamics, Faculty of Engineering, in Rijeka. The synthetic year is built up of 12 months selected from a period of 10 years. For each month, a distribution function was calculated using the 10 samples from 1971-1980. The February samples were February 1971, February 1972, ... February 1980. The sample that was closest to the mean value of the calculated distribution was selected for the synthetic year.

In order to compare the data with Meteonorm results, the 29^{th} of February was deleted because the February in TRY-data stems from a leap year. The base data has been provided by the Meteorological and Hydrological Service (DHMZ). These values are based on measurements, and therefore, some adaptations were needed to make a comparison with average hourly values. The provided hourly values are average outside temperature, direct radiation, the percentage of sunshine, diffuse radiation and the (humidity) mixing ratio in [g/kg].

An average hourly value for direct radiation was calculated from direct radiation and the percentage of sunshine. Furthermore, the given mixing ratio was converted to relative humidity. This was done using the Ideal Gas Law, Dalton's Law, and the Arden Buck Equation to calculate the saturation pressure of water at a given temperature. This calculation holds until the air is saturated and not above. **Arden Buck Equation:** [37]

$$p_s(T) = 6.1121 \cdot \exp\left(\frac{(18.678 - T/234.5) \cdot T}{257.14 + T}\right) \tag{6.1}$$

Given an ideal gas, in a volume V, at a specific temperature T, and with one atmosphere pressure, one can derive a relation between the mass mixing rate mr_w and the fractional pressure p_w :

$$\begin{aligned} p \cdot V &= n \cdot R \cdot T \ldots \text{ is valid for each fraction.} \\ \Leftrightarrow p_i &= (n_i \cdot R \cdot T)/V \ldots \text{ R is the same for each fraction.} \\ \Rightarrow \frac{p_w}{p_d} &= \frac{n_w}{n_d} \, . \end{aligned} \tag{6.2}$$

Daltons law for two fractions: dry air and water

$$\begin{aligned} p &= p_1 + p_2 \\ \Rightarrow p_d &= p - p_w \, . \end{aligned} \tag{6.3}$$

Inserting (6.3) in equation (6.2) yields:

$$\frac{p_w}{p - p_w} = \frac{n_w}{n_d} \, . \tag{6.4}$$

The mass (humidity) mixing ratio mr_w is defined as the fraction of water with respect to 1 kg of dry air. Its dimension is g/kg or kg/kg

$$mr_w = \frac{m_w}{m_d} \, . \tag{6.5}$$

The advantage of this expression is its consistency with respect to temperature above the dew point. Multiplied with the fraction of the according mol masses (M_d=28.97 g/Mol, M_w=18.015 g/Mol), the mass mixing ratio leads to the Mol mixing ratio (MR_w);

$$\begin{aligned} mr_w \cdot \frac{M_d}{M_w} &= \frac{m_w/M_w}{m_d/M_d} \\ \Rightarrow MR_w &= \frac{n_w}{n_d} \, . \end{aligned} \tag{6.6}$$

The fraction between the molar mass of dry air and that of water is known, MR_w can be calculated using mr_w. Replacing the molar fraction in (6.6) by (6.4) one derives a relation that gives $p_w(MR_w)$. Hence, we have the partial pressure for the fraction of water in a gas mixture at a pressure of one atmosphere

$$\begin{aligned} p_w &= \frac{p \cdot MR_w}{1 + MR_w} \\ \text{or } p_w &= \frac{p \cdot mr_w}{\frac{M_w}{M_d} + mr_w} \\ \Rightarrow p_w &= \frac{1013.25 \text{ mbar} \cdot mr_w}{0.62198 + mr_w} \, . \end{aligned} \tag{6.7}$$

Relative humidity is defined as

$$RH = \frac{p_w}{p_s(T)} \cdot 100\% \, . \tag{6.8}$$

With the result of equation (6.7), relative humidity RH can be calculated from (humidity) mass mixing ratio and p_s at the according temperature

$$RH = \frac{(1013.25 \text{ mbar} \cdot mr_w)/(0.62198 + mr_w)}{p_s(T)} \cdot 100\% \, . \tag{6.9}$$

The climate data of the TRY is summarised in Table 6.3 on an average monthly basis.

Table 6.3: Cumulative monthly insolation in Wh/m^2 on a horizontal surface, average outside temperature and relative humidity from TRY, base data DHMZ, period: 1971-1980 [33].

Location	Rijeka					
Latitude	45.33 N	**Longitude**	14.45 E			
Height						
	cumulative insolation Wh/m²				Temp.	Humidity
Source:	**Test reference year Rijeka, Vilicic 1992**					
	global	diffuse	direct		Ta [°C]	RH [%]
january	36184.5	22647	13537.5		7.33	69.33
february	67946.1	25968	41978.1		7.34	55.69
march	94114.8	36982	57132.8		10.20	64.54
april	137504.5	42965	94539.5		12.83	59.28
may	164940.6	48941	115999.6		18.55	65.06
june	184594.4	48942	135652.4		22.30	63.87
july	216079.4	49458	166621.4		24.60	61.09
august	167921.6	45462	122459.6		25.44	62.38
september	124740.5	37484	87256.5		19.95	62.62
october	92967.6	30818	62149.6		16.71	62.89
november	40783.6	23024	17759.6		11.89	63.16
december	38160.9	20456	17704.9		8.40	71.25
hourly average	156	49	106	**mean**	15.46	63.43
total	**1365939**	**433147**	**932791.5**			

6.2.3 Solar radiation handbook of croatia

EIHP, the Ministry of Economy, Labour and Entrepreneurship, and the State Meteorological Service, have initiated the development of the Solar Radiation Atlas of the Republic of Croatia to support design of solar energy conversion systems. Data is provided for several locations in Croatia. Among the climatological data are the required radiation values but on an average monthly basis only. Data was derived from sunshine duration measurements and cloud cover observations since 1961. Mathematical models were used to derive the required data. A data overview is provided in Table 6.4.

Table 6.4: Cumulative monthly insolation in Wh/m^2 on a horizontal surface, average outside temperature and relative humidity, database periodes; Radiation: 1961-1980, Temperature and RH: 1961-1990 [38].

Location	Rijeka					
Latitude	45° 20' N	**Longitude**	14° 27' E			
Height	120 m					
	cumulative insolation Wh/m²				Temp.	Humidity
Source:	SOLAR RADIATION HANDBOOK OF CROATIA					
	global	diffuse	direct		Ta [°C]	RH [%]
january	39990	23560	16430		5.3	64.00
february	62440	30800	31640		6.1	63.00
march	100130	51770	48360		8.5	61.00
april	136500	65100	71400		12.2	62.00
may	173910	80600	93310		16.6	64.00
june	183600	82500	101100		20.1	63.00
july	195920	79360	116560		22.8	57.00
august	162130	72230	89900		22.3	58.00
september	120000	52800	67200		18.9	64.00
october	84010	39990	44020		14.4	66.00
november	42900	25800	17100		9.8	67.00
december	33790	20460	13330		6.5	65.00
hourly average	152	71	81	**mean**	**13.63**	**62.83**
total	**1335320**	**624970**	**710350**			

6.3 Comparison and conclusion

Climate data reliability for simulation and prediction of long term results is subject to the following issues:

- High statistical reliability requires long term measurement series. Average measurement results over five years, compared to twenty years, can differ up to 20%. Extending the base measurement period to 15 years can half the variation. Thirty years' measurement guarantees substantial reliability [18].
- It has been found that the variation of global radiation from one year to another is larger than 10%, and thus greater than the inaccuracy of Meteonorm synthetic climate data. Hence, a measurement series for one or more years cannot compensate for a lack of proper data; it involves a higher risk of inaccuracy than the predictions from Meteonorm, which are accurate within 10%, cf. Energy and the Environment Congress of 2006 [39], [40].

In conclusion, annual weather conditions can lead to variations in the according climate data, which differ up to 10% or more within a typical year. The base period of measurement data, therefore, should be greater than or at least 15 years long in order to insure accuracy within 10% of the synthetic climate data.

The so called 'new period' of Meteonorm's base radiation data provides measurement data for a period of twenty years. Other base data consist mainly of 1961-1990 and 1996-2005 means. Extensive tests lead to the conclusion that **the error** in interpolating the monthly radiation data values is **9%** with an according value of **1.5°C** for **temperature**.

The available TRY-data was drawn from twelve months selected from the years from 1971-1980. The measurement period is ten years, but the corresponding time frame dates back more than thirty years. In this study the standard outdoor design temperature is given to be -8°C, however, the value given in the solar radiation handbook is -3.9°C [6]. According to experts in the Department of Thermodynamics at the Technical University Rijeka, the standard outdoor design temperature for Rijeka is -6°C [7]. This value can vary from place to place and is mainly dependent on the micro-climate: a **standard value for PGC** of **-6°C** was chosen.

Since the base periods of the measurement data are different, a comparison is of limited validity because climate change. Data from former periods would need to be weighted less than more recent data. **Climate change** is **visible** in the average temperature increase of **1.83°C** between the last two data sets in Table 6.2 where data from Solar Radiation Handbook dates back ten years.

Global radiation – the most important parameter for non-concentrating solar systems – is very similar for all three sources as seen in Table 6.2. The breakdown into direct and diffuse radiation is very different, though. The **annual average hourly yield** calculated from the three different sources gives **152 Wh/m^2**. Multiplied by 8760 hours, this leads to the annual average **cumulative solar yield**, which is **1 334 440 Wh/m^2**.

[6] This is the lowest two-day mean value outside temperature that occurs, at minimum, ten times in a period of 20 years.

[7] Proposed by Wolf, Lenić, Blecich

Table 6.2: Climate data set comparison for Rijeka

Source	**Meteonorm**	**TRY**	**SOLAR RAD. HANDBOOK**
Radiation	Annual hourly average [Wh/m^2]		
-direct	77	106	81
-diffuse	73	49	71
-global	149	156	152
Mean	152 ±3		
Measuring time frame	1981-2000	1971-1980	1961-1980
Length of base period	20 years	10 years	20 years
Ta, RH	Annual mean values of Ta [°] and RH [%]		
Ta	15.5	15.46	13.63
Heating design temp.		-8°C	-3.9°C
RH	59.8	63.43	62.83
Measuring timeframe	1996-2005	1971-1980	1961-1990
Data resolution	hourly	hourly	monthly

Conclusion

The selection of which data should be considered for simulations with the software SHWwin was made by Meteonorm. The main reasons for this are; first, the longer base period; and second, base data in use is more current. However, a few simulations will also be carried out with the adapted TRY-data, thus outcomes with different climate data can be compared. One can see that the average monthly values of the three sources, with respect to global radiation, do not vary appreciably. Average monthly values can be used to estimate annual yields using annual mean values for the efficiency of the collector and the plant, respectively. In aid of this analysis, solar systems will be elaborated in detail, yielding average hourly values, via hourly climate data input.

Part III

Solar Thermal System Simulation

Chapter 7

Simulation Software Description

This chapter discusses the software SHWwin and general topics including technical concepts related to solar thermal plants. First, software input parameters are discussed. These include simulation related parameters and solar system related input parameters. The calculation models, used as part of the software, are described and discussed followed by the output variables and the simulation results sheet generated by said software.

7.1 General software related topics

The software concerned SHWwin, was developed between 1993 and 1999 at the Technical University Graz in order to support various research projects. It can be used to simulate simple DHW solar thermal systems or more complex so-called 'combisystems', as well as solar systems that feed a heat provider's distribution network.

It provides a restricted number of previously-defined hydraulics for solar thermal systems. It is not possible to assemble an arbitrary system from so-called device modules. The set of parameters, however, does provide some freedom for configuration. The software was validated by comparing measurement data from more than three combisystems with the according simulation results. Comparisons of the simulation results of similar solar systems, from SHWwin and TRNSYS [41], showed good consistency [42].

SHWwin functions using a single collector characteristic curve. This means the technician must design a suitable connection for the respective collectors to ensure turbulent flow in each. Small fields are normally connected in parallel to reduce pump power. For larger fields, a mixture between parallel and serial connection is common. Low-Flow concepts are often realised with a serial connection, but each additional collector in the series increases loss by the specific pressure-loss of one collector; this must be taken into account for the pump power. If the flow rate is too low, the temperature increase is high, and therefore, the efficiency of the collector drops. A practical installation is determined by the following parameters

- The producer recommended flow rate, e.g. **40 - 70 $\mathbf{l/(m^2 \cdot h)}$**, to ensure turbulent flow in the pipes
- The chosen concept, Low-Flow or classical High-Flow
- The collector type (flat plate, vacuum, unglazed absorber,...)
- The available area on the roof and its shape
- The available pump power

7.1.1 Classical High-Flow system

In order to keep the efficiency of the collector high, any temperature rise in the collector field should not increase 10 K, i.e. $\Delta\vartheta_{Fluid} \leq 10$ K. Therefore, the critical situation is given at the highest global irradiance; this is approximately $I_g = 1000$ W/m^2. The fluid related parameters are provided in the Appendix Properties of Materials. Other relevant parameters that must be assumed are

- $\bar{\eta}_{Coll} = 0.5$ (standard flat plate collector)
- $A_{Coll} = 2$ m^2
- $A_{Field} = 12$ m^2

From these parameters, the maximum flow rate can be calculated

$$\begin{aligned} \dot{V}_{Field} &= \frac{I_g \cdot \bar{\eta}_{Coll} \cdot A_{Field}}{\Delta\vartheta_{Fluid} \cdot c_{pFluid} \cdot \rho_{Fluid}} \\ &= \frac{1000W/m^2 \cdot 0.5 \cdot 12m^2}{10K \cdot 3810J/(kg \cdot K) \cdot 1021kg/m^3} \\ &= 0.1542 \cdot 10^{-3}\frac{m^3}{s} \approx 555.3\frac{litres}{hour}\ . \end{aligned} \tag{7.1}$$

The total flow rate leads to the specific flow rate ($\dot{v}$), which is **46.28** litres/(hour $\cdot m^2$), and since one collector has a surface area of two square meters, the flow rate of one collector is $\dot{v}_{Coll} = 92.55$ litres/hour. This value is high enough to ensure turbulent flow, even for a parallel connection of all collectors.

For all High-Flow applications, specific flow rates of **50** litres/(hour $\cdot m^2$) are sufficient. Analysis in [43] demonstrates, that specific flow rates above 20 litres/(hour $\cdot m^2$) do not lead to higher solar fractional savings.

7.1.2 Low-Flow system

The Low-Flow concept is designed to yield high temperature increases in the collector field ($\Delta\vartheta_{Fluid} = 40$ K) in order to provide quick, useful energy on a high- temperature level. This concept leads to higher exergy even if the sunshine lasts for a short time [1]. On the other hand, it also implies a lower efficiency.

Highest global irradiance is taken to be, I_g=1000 W/m^2 for the example calculation. The fluid related parameters are provided in the Appendix Properties of Materials. Other relevant parameters are

- $\bar{\eta}_{Coll} = 0.45$ (standard Flat plate collector)
- $A_{Coll} = 2$ m^2
- $A_{Field} = 12$ m^2

With these parameters, the flow rate of the field can be calculated

$$\begin{aligned} \dot{V}_{Field} &= \frac{I_g \cdot \bar{\eta}_{Coll} \cdot A_{Field}}{\Delta\vartheta_{Fluid} \cdot c_{pFluid} \cdot \rho_{Fluid}} \\ &= \frac{1000W/m^2 \cdot 0.45 \cdot 12m^2}{40K \cdot 3810J/(kg \cdot K) \cdot 1021kg/m^3} \\ &= 0.0347 \cdot 10^{-3}\frac{m^3}{s} \approx 124.9\frac{litres}{hour}\ . \end{aligned} \tag{7.2}$$

[1] It must be stressed that this concept, in general, depending on the field and storage size, needs a special stratification unit for the heat storage.

From this total flow rate through the field, the specific flow rate ($\dot{v}$) can be derived. It is **10.41** litres/(hour $\cdot m^2$) and, since one collector has a surface area of two square meters, the flow rate of one collector is $\dot{V}_{Coll} = 20.82$ litres/hour. Because neither the specific nor the collector specific value lies within the recommended range, a special connection of serial subunits of the collectors is needed to reach a flow rate of at least 40 litres/(hour $\cdot m^2$).

The temperature increase for the 2 m^2 collector, taking into account a minimum specific flow rate of 40 litres/(hour $\cdot m^2$), is

$$\begin{aligned} \Delta\vartheta_{Fluid_{Coll}} &= \frac{I_g \cdot \bar{\eta}_{Coll} \cdot A_{Coll}}{\dot{V}_{Coll}/(1000 \cdot 3600) \cdot c_{pFluid} \cdot \rho_{Fluid}} \\ &= \frac{1000W/m^2 \cdot 0.45 \cdot 2m^2}{80l/h/(1000 \cdot 3600) \cdot 3810J/(kg \cdot K) \cdot 1021kg/m^3} \\ &= 10.41K \, . \end{aligned} \tag{7.3}$$

Connecting two series of three collectors in parallel formation, yields a total temperature increase of 31.23 K. The other possibility would be to connect all six collectors in the series; this would give a theoretical temperature increase of 62.47 K, but efficiency and pressure losses in that case are very high. In reality, the first choice is preferable.

7.1.3 Matched-Flow system

A third flow type is called Matched-Flow wherein the fluid speed can be varied according to prevailing conditions. The additional requirements, compared to the former systems, is the installation of a flow rate sensor and an adjustable pump speed. More sophisticated solar thermal systems employing pump speed control can assure a higher overall collector efficiency. One set value to control the pump could be the temperature rise in the collector field. This is an available option of the software SHWwin, and it will be selected for solar thermal plants for tourism accommodation facilities.

7.1.4 Collector characteristic – efficiency

The simplified collector characteristic shows only quadratic terms of ΔT

$$\bar{\vartheta}_{Fluid} = \frac{\vartheta_{Fluid\_inlet} + \vartheta_{Fluid\_outlet}}{2} \tag{7.4}$$

$$\eta_{Coll} = c_0 - c_1 \cdot \frac{\bar{\vartheta}_{Fluid} - T_a}{I_g} - c_2 \cdot \frac{(\bar{\vartheta}_{Fluid} - T_a)^2}{I_g} \, . \tag{7.5}$$

The constants c_i are recorded during standard **collector tests**. This equation was derived using the fraction between the useful thermal heat flow from the collector and the incident global radiation power [2]. The constant c_0 incorporates the transmission coefficient of the absorber cover and the absorption rate of the absorber. By contrast, c_1 and c_2 are the coefficients for the first and second order temperature difference terms. The original equation includes a fourth order term from Stefan Boltzmann's radiation law, but that equation can be approximated fairly well using a Taylor expansion which results in equation (7.5).

7.2 Input parameters

Each of the following subsections refer to a tab of one data card in the project view of the software SHWwin. Unfortunately, the software uses German only.

7.2.1 Simulation related parameters

Simulation related data (Simulationstechnische Daten)

This data defines relevant parameters for the simulation process. Given figures represent recommended values for medium size solar thermal systems [2]. The output form provides a summary of the results for each of the twelve months.

Due to undefined initial conditions in the storage tank, an **overlap** in the **simulation period** starting at the month with the least energy consumption is recommended. The overlap is especially important for systems with a large seasonal heat storage. In the list below First month = 8, Last month = 21 means start in August of the first year with simulation through the end of September of the second year.

The number of stratification layers in the storage is limited to ten. When the temperature difference between two neighbouring layers is below, Min. ΔT between two layers, they merge to one layer. Max. allowed ΔT for iteration in the collector loop, gives the precision for the collector loop, until this temperature difference is reached, iteration during one time step is repeated.

- First month (Anfangsmonat) = ***8*** [unity]
- Last month (Endmonat) = ***21*** [unity]
- Steps per hour (Schritte je Stunde) = ***10*** [1/h]
- Max. no. of layers in the storage (Maximale Schichten im Speicher) = ***10*** [unity]
- Min. ΔT between two layers (Minimale ΔT der Schichten im Speicher) = ***0.5***°C
- Geographic latitude (Geograph. Breitengrad) = ***45.33***° *for Rijeka*
- Max. allowed ΔT for iteration in the collector loop (Max. Erlaubte ΔT für die Iteration im Kollektorkreis) = ***0.1***°C

Type of DHW-Consumption (Art des WW Verbrauches)

Since the DHW consumption profile is provided hourly, two optional consumptions are possible. For the first option, hourly consumption occurs at the first time step of the according hour; for the second option, consumption is distributed over one hour.

- Completely at the first step (Vollständig am ersten Simulationsschritt) – this option is recommended for small solar thermal systems.
- Distributed equally over one hour (Gleichmäßig über die Stunde) – recommended for large systems.

Test data (Testdaten)

The two options refer to detailed output data; the first option, ‘Nicht ausgeben’, means no detailed data output; the second option, ‘Ausgeben’, leads to detailed output within a specified time frame into a file with the extension .xl5.

[2]This does not mean that these values always lead to the best results.

7.2.2 Collector parameters

Collector Data

The collector parameters c_0, c_1, and c_2 describe the characteristic of the collector with respect to the absorption of the incident global irradiance as described in equation (7.5). For normal incidence (0°), the transmission coefficient through glass is one and, until the range of 40°, this coefficient does not change significantly. For greater angles, the incident angle factor describes the reduction of transmission [3].

The specific absorber mass, the heat capacity of the absorber material, and the specific fluid content are needed to account for the thermal inertia when the collector is heated.

- Conversion factor c_0 (Konversionsfaktor) [Unity]
- Heat transmission coefficient c_1 (Wärmedurchgangswert) [W/(m^2 K)]
- Quadratic coefficient c_2 (3.Parameter der Kollektorkennlinie) [W/(m^2 K^2)]
- Specific absorber mass (Spezifische Absorbermasse) [kg/m^2]
- Specific heat capacity of the absorber (Spez. Wärmekap. d. Absorbermaterials) [J/(kg K)]
- Incident angle modification factor (IAM) (Winkelfaktor) [Unity]
- Specific fluid-content (Spezifischer Flüssigkeitsinhalt) [m^3 /m^2]
- Collector field area (Fläche) [m^2]
- Tilt angle (Neigung) [°]
- Azimuth angle (Azimut), west negative, east positive [°]

Type of Controlling the mass flow (Regelungsart des Kollektormassenstromes)

For the first option, Constant Mass Flow, High- or Low-Flow systems can be distinguished depending on what flow rate is realised. The second and the third options 'Constant ΔT ... allow so-called matched flow systems. For the second choice, the controller adjusts the power of the pump to ensure a constant ΔT between the inlet and the outlet of the collector field. In the third option, the controller regulates the power of the pump in order to ensure a constant ΔT between the outlet of the collector field and the outlet with the highest T from the storage tank. The according temperature differences can be ensured only if the mass flow does not reach its upper limit. Only the first and the second options are used in this work.

- Constant Mass Flow (Fixer Massendurchfluß)
- Constant ΔT in the collector field (Fixe TempSpreizung im Kollektor)
- Constant ΔT between collector-outlet and highest sink temperature in the storage (Fixe TempSpreizung zwischen Kollektor-Vorlauftemperatur)

Flow related Parameters

Since three different types of controlling are possible, three different parameter masks exist. **Constant Mass Flow** through the collector field is one parameter that applies for the respective storage. The parameters are:

- Hot water storage (Warmwasserspeicher) [kg/s]
- Heat storage (Pufferspeicher) [kg/s]
- Both (Beide) [kg/s]

[3] During collector tests, this factor is measured for incident angles of 50°.

- Share hot water storage when feeding both (Anteil Warmwasser glz. Ladung) [%]
- Solution density
- Solution heat capacity

For the two matched flow controlling types only single heat storage concepts can be simulated. The parameter Controllable range defines the bandwidth from the maximum flow rate downwards with respect to the maximum flow rate. The parameters for **Constant ΔT in the collector field** (Matched-Flow, Variante 1), while loading the heat storage are

- ΔT collector field (TempSpreizung im Kollektor) [°C]
- Max. flow rate (Maximaler Durchfluß) [kg/s]
- Controllable range (Regelfähigkeit des Durchflusses) [%]
- Solution density
- Solution heat capacity

Solution in the Collector Loop

The density and heat capacity of the solution are parameters relevant for each type of controlling. In order to prevent the liquid in the collector loop of closed systems from freezing, a propylene glycol-water solution (40% glycol and 60% water) is used. The freezing point of this solution is -25.3°C. Further details are provided in the Appendix Properties of Materials.

- Solution density (Dichte sole) = ***1021*** [kg/m^3]
- Solution heat capacity (Wärmekapazität Sole) = ***3810*** [J/(kg K)]

Pipe related Parameters (Rohrleitungen)

Two columns exist for these parameters, the first refers to the connection from the collector to the heat exchanger (Kol-WT) and the second to the connection from the heat exchanger to the collector field (WT-Kol). The length of the pipes is important to calculate their losses. Figures given refer to entries in both columns.

- Length (Länge) [m]
- Diameter (Durchmesser) [m]
- Thickness pipe wall (Wandstärke) [m]
- Insulation thickness (Dämmstärke) = ***0.03*** [m]
- Insulation thermal conductivity (Leitwert Dämmung) = ***0.04*** [W/(m K)]
- Density pipe material (Dichte Rohrmaterial) , (Cu) = ***8900*** [kg/m^3]
- Heat capacity pipe material (Wärmekap. Rohrmaterial) , (Cu) = ***394*** [J/(kg K)]

The **pipe diameter** is calculated for a fluid speed v, which is about 0.6 m/s; this value was chosen according to [27]. Setting equal $\dot{V} = A \cdot v$ and $\dot{V} = \dot{m}/\rho$, replacing A with $A = r^2 \cdot \pi$ and solving for r one gets

$$r = \sqrt{\frac{\dot{m}}{\rho \cdot v \cdot \pi}} . \qquad (7.6)$$

Taking $\rho = 1021\ kg/m^3$, inserting for v, and using the factor 2 to get the diameter leads to

$$d = \sqrt{\frac{4 \cdot \dot{m}}{1021 kg/m^3 \cdot 0.6 m/s \cdot \pi}} . \tag{7.7}$$

Assuming the specific flow rate and the collector field area are given

$$d = \sqrt{\frac{4 \cdot \dot{m}_{spec} \cdot A_{Field}}{1021 kg/m^3 \cdot 0.6 m/s \cdot \pi}}$$

$$d = \frac{\sqrt{\dot{m}_{spec} \cdot A_{Field}}}{21.935} \cdot \sqrt{\frac{m^2 \cdot s}{kg}} . \tag{7.8}$$

The specific flow rate for classical **High-Flow** systems was calculated to be 46.28 litres/(h m^2), which is equivalent to 47.25 kg/(h m^2), or 0.013 1 kg/(s m^2). For **Low-Flow** systems, the according values are 10.41 litres/(h m^2), 10.63 kg/(h m^2), or 0.003 0 kg/(s m^2). With these specific values one can set up a formula for the pipe diameter for High- and Low-Flow systems that depends on the collector field area only

$$d_{Hflow} = \frac{\sqrt{A_{Field}}}{191.4260} , \tag{7.9}$$

$$d_{Lflow} = \frac{\sqrt{A_{Field}}}{400.4726} . \tag{7.10}$$

Collector standstill

In addition to switching the circulation pump according to the control device, the pump must be switched off if the temperature in the storage tank reaches an upper limit. The upper temperature limit prevents the deposition of limestone in the tank (for DHW applications), which is continuously supplied by incoming freshwater – deposits occur at levels over 70°C [2].

In such situations a so-called **collector standstill** occurs. The temperature a collector reaches is then called a **standstill temperature**. In the case of a selectively coated absorber it can be significantly above 140°C [2]. Since the volume in the collector circuit rises significantly, special constructive precautions are required.

One simple and often applied method is the integration of an expansion tank in the collector circuit. This tank consists of two spaces, one is directly in contact with the liquid of the heat transfer medium from the solar circuit and the other space, which is separated from the aforementioned by a flexible membrane, is filled with air at a pressure equal to the normal working pressure of the solar circuit. In case of evaporation, the pressure in the solar circuit increases; the collector fills with steam, and the expansion storage air space volume reduces until the whole heat transfer medium from the collector is discharged.

7.2.3 Domestic hot water (DHW) storage (WW-Speicher)

The most important parameters of the DHW storage are its volume, height, insulation- and heat exchanger-related parameters, and the respective heights of inlets and outlets. For a proper design, the annual average losses including any thermal bridges are 10 - 15% of the solar yield released to the heat storage. In addition to conventional thermal losses,

losses in the storage tank occur because of badly insulated inlets and outlets, natural convections in the connection pipes, and vertical heat conduction through the wall [4].

The fifth parameter in the list below accounts for this vertical heat conduction ($\bar{\lambda}_{Storage}$). According to [28], it is calculated by giving weights according to the share of crosssection on the total, to the respective heat conduction coefficients. Assuming a steel wall with a thickness of $t_{Wall} = 3$ mm with $\lambda_{Wall} = 50$ W/(m·K) and $\lambda_{H_2O} = 0.6W/(m \cdot K)$ for the heat conduction coefficients for steel and water, respectively, and a storage diameter of $d_{Storage}$ one gets

$$\begin{aligned} \bar{\lambda}_{Storage} &= \frac{4 \cdot t_{Wall} \cdot \lambda_{Wall}}{d_{Storage}} + \lambda_{H_2O} \\ &= \frac{4 \cdot 0.003m \cdot W/(m \cdot K)}{d_{Storage}} + 0.6W/(m \cdot K) \\ &= \frac{0.6W/K}{d_{Storage}} + 0.6W/(m \cdot K)\ . \end{aligned} \tag{7.11}$$

Storage (Speicher)

The value of the fourth parameter in the list was chosen to be greater than the one attributed to the used insulation material. The reason is higher losses in praxis than ordinarily expected due to weak insulated storage connections.

- Volume (Volumen) [m^3]
- Height (Höhe) [m]
- Insulation thickness (Dämmdicke) [m]
- Insulation thermal conductivity (Leitwert der Dämmung) = ***0.05*** [W/(m K)]
- $\bar{\lambda}_{Storage}$ mean vertical heat conductivity (Mittl. vert. Wärmeleitwert) [W/(m K)]

DHW-loop connections (Brauchwasserentnahme)

The next three parameters refer to the height of the connections of the DHW-loop, i.e. inlet and outlets.

- Inlet height 1 (Zufluß1) [m]
- Outlet height 1 (Abfluß 1) [m]
- Outlet height 2 (Abfluß 2) [m]

Auxiliary electrical heating (E-Patrone)

The auxiliary electrical heater provides the first additional heat source for DHW storage.

- Height of the auxiliary heater (Einbauhöhe) [m]
- Sensor height (Fühler) [m]
- Power (Leistung) [W]

Auxiliary heating from the space heating (SH)-System (Kesselwärmetauscher)

The second auxiliary heat source for the DHW storage is provided by an external or internal heat exchanger, which is supplied by the space heating heat source.

[4] More precisely, the vertical heat conduction represents losses of exergy.

External heat exchanger (Extern)

- Inlet height (Zufluß) [m]
- Outlet height (Abfluß) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Mass flow (Massenstrom) [kg/s]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

Internal heat exchanger (Intern)

- Mean height of the heat exchanger (Mittlere Einbauhöhe) [m]
- Construction height of the heat exchanger (Bauhöhe) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

Solar heat exchanger (Solarwärmetauscher)

Three options exist for the solar heat exchanger external, internal, and stratification units. The control referring to the loop connected to the heat exchanger includes a sensor.

External heat exchanger (Extern)

- Inlet height 1 (Zufluß 1) [m]
- Outlet height 1 (Abfluß 1) [m]
- Sensor height 1 (Fühler 1) [m]
- Surface area (Oberfläche) [m^2]
- Mass flow (Massenstrom) [kg/s]
- Inlet height 2 (Zufluß 2) [m]
- Outlet height 2 (Abfluß 2) [m]
- Sensor height 2 (Fühler 2) [m]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

Internal heat exchanger (Intern)

- Mean height of the heat exchanger (Mittlere Einbauhöhe) [m]
- Construction height of the heat exchanger (Bauhöhe) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

External heat exchanger, stratification unit (Schichtlader)

- Outlet height (Abfluß) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Mass flow (Massenstrom) [kg/s]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

7.2.4 Heat storage (PU-Speicher)

What was mentioned for the DHW storage mostly holds for the Heat storage. In comparison, the heat storage has a higher volume in general, more optional connections, and consequently, more heat exchangers. The same rules can be considered as for the DHW storage when referring to heat losses – equation (7.11) holds.

Proper heights of inlets and outlets of directly-connected heat sources and sinks are very important to avoid mixing in the storage; this would lead to losses in exergy. Therefore, height will be subjected to sensitivity analyses.

Storage (Speicher)

The **thickness** of the **insulation** was chosen to be 0.15 m for most of the systems. In [43], a conducted sensitivity analysis (SA) has shown that, for volumes below 10 m^3, no significant increase of solar fractional savings can be achieved with thicker insulations. For sizes of 50 m^3 to 100 m^3, this threshold lies around 0.5 m. The insulation conductivity was chosen to be greater than that attributed to the used material to account for higher losses of the storage in praxis due to weak insulated storage connections.

- Volume (Volumen) [m^3]
- Height (Höhe) [m]
- Insulation thickness (Dämmdicke) = ***0.15 m***
- Insulation thermal conductivity (Leitwert der Dämmung) = ***0.05*** [W/(m K)]
- $\bar{\lambda}_{Storage}$ Mean vertical thermal conductivity (Mittl. vert. Wärmeleitwert) [W/(m K)]
- Percentage of heat loss attributed to room heating (Anteil Wärmeverluste der den Innenwärmen zugerechnet wird) [%]

DHW - heat draw off (Warmwasser- Energieentnahme)

The next three parameters refer to the connections of the draw-off loop for DHW purposes

- Inlet height (Rücklauf) [m]
- Outlet height DHW-loop 1 (Vorlauf 1) [m]
- Outlet height DHW-loop 2 (Vorlauf 2) [m]

Auxiliary electrical heating (E-Patrone)

The auxiliary electrical heater provides the first additional heat source for the heat storage

- Height of the auxiliary heater (Einbauhöhe) [m]
- Sensor height (Fühler) [m]
- Power (Leistung) [W]

Second auxiliary heating (Kesselladung)

The second auxiliary heat source for the heat storage is provided by a boiler. The connection is direct, via pipes. In order to increase SCR, the sensor height should be as high as possible [43], but it must be below the outlet of the SH loop. The height, however, also depends on the power of the auxiliary source; the higher the power, the smaller the needed auxiliary volume. The coverage ratio for DHW and SH provides a measure to check whether the auxiliary volume is sufficient.

- Inlet height (Zufluß) [m]
- Outlet height (Abfluß) [m]
- Sensor height (Fühler) [m]

SH draw-off loop (Heiz-Energieentnahme)

The SH draw-off loop is directly connected to the storage via pipes.

- Inlet height SH-loop (Rücklauf) [m]
- Outlet height SH-loop 1 (Vorlauf 1) [m]
- Outlet height SH-loop 2 (Vorlauf 2) [m]

Solar heat exchanger (Solarwärmetauscher)

Three options are available for the solar heat exchanger: external, internal, and stratification units. A SA in [43] shows that a heat transfer coefficient of 50 W/K per m^2 collector field is sufficient. This value of orientation can be applied to internal and external heat exchangers.

External heat exchanger (Extern)

- Inlet height 1 (Zufluß 1) [m]
- Outlet height 1 (Abfluß 1) [m]
- Sensor height 1 (Fühler 1) [m]
- Surface area (Oberfläche) [m^2]
- Mass flow (Massenstrom) [kg/s]
- Inlet height 2 (Zufluß 2) [m]
- Outlet height 2 (Abfluß 2) [m]
- Sensor height 2 (Fühler 2) [m]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

Internal heat exchanger (Intern)

- Mean height of the heat exchanger (Mittlere Einbauhöhe) [m]
- Construction height of the heat exchanger (Bauhöhe) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

External heat exchanger, stratification unit (Schichtlader)

- Outlet height (Abfluß) [m]
- Sensor height (Fühler) [m]
- Surface area (Oberfläche) [m^2]
- Mass flow (Massenstrom) [kg/s]
- Specific heat transfer coefficient (K-Wert) [W/(m^2 K)]

The external heat exchanger separates the solution in the collector loop from the water in the heat storage. It is defined according to boundary conditions. The maximal total power on the primary side is given by the power of the collector field at maximal global irradiance. It was assumed that the external heat exchanger will be operating in counter flow mode. The required overall heat transfer coefficient (cf. [27]) $UaHX_C$ [kJ/(h K)] is provided by

$$\begin{aligned} UaHX_C &= 3.6 \cdot (88.561 \cdot A_{Field} + 328.19) \\ UaHX_{C[kW/K]} &= \frac{88.561 \cdot A_{Field} + 328.19}{1000} \ . \end{aligned} \tag{7.12}$$

If we assume a specific overall heat transfer coefficient of 1000 W/(m^2 K) we get the needed surface

$$A = \frac{UaHX_C}{1kW/(m^2 \cdot K)} \ . \tag{7.13}$$

The mass flow on the secondary side, where the fluid is water (c_{pH_2O}=4171 J/(kg K)) was calculated assuming the same capacity flow-rate as the primary side

$$\begin{aligned} \dot{m}_{sec} &= \dot{m}_{pri} \cdot \frac{c_p}{c_{pH_2O}} \\ \dot{m}_{sec} &= \dot{m}_{pri} \cdot \frac{3810J/(kg \cdot K)}{4171J/(kg \cdot K)} \ . \end{aligned} \tag{7.14}$$

7.2.5 Control parameters (Steuerung)

In addition to the parameters described in the subsection Collector, which refer to the mass flow control, the data card Control provides a range of control parameters.

It has four sub data cards: Collector, DHW storage, Heat storage and Auxiliary heater. The respective parameters concern temperature limits and differences linked with simple on-off controls for the purpose of loading a certain heat storage. In addition, some parameters refer to percentage values that influence flow control mechanisms – such as three-way valves. Some parameters might lead to different effects for different systems.

The following rules apply for a simple control: a pump control parameter set provides a maximum temperature T_{max} (refers to the storage temperature T) and a hysteresis for turning on, ΔT. The control characteristic is

$$\begin{aligned} T &\leq (T_{max} - \Delta T) \Rightarrow \text{switch ON} \\ T &= T_{max} \Rightarrow \text{switch OFF} \ . \end{aligned} \tag{7.15}$$

The solar loop control pump parameter set for on-off control provides a maximum temperature T_{max} (refers to the storage temperature T), one hysteresis ΔT_{on}, and a second hysteresis ΔT_{off}. The control characteristic in connection with the collector temperature T_{Coll} is

$$\begin{aligned} T_{Coll} - T &\geq \Delta T_{on} \Rightarrow \text{switch ON} \\ T_{Coll} - T &\leq \Delta T_{off} \Rightarrow \text{switch OFF} \ . \end{aligned} \tag{7.16}$$

For the matched flow control concepts, the pump power is regulated to realise the set temperature difference ΔT as long as no maximum temperature limit is reached.

Control Parameters (Steuerung)

Collector (Kollektor)

↪ ΔT to start solar energy supply (Temperaturdifferenz für Beginn der solaren Energiezufuhr) is only relevant for the option Constant mass flow. Standard values of ΔT between the collector and the storage sensor, for simple **on-off controls** in solar thermal applications, are 5-7 K for the on signal and approximately 3 K for the off signal, cf. [2].

- ΔT Collector – DHW storage sensor (Kollektor – Warmwasserspeicherfühler) = 5 K
- ΔT Collector – heat storage sensor (Kollektor – Pufferspeicherfühler) = 5 K
- Hysteresis for turning off (Hysterese für Beenden) = 2 K

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)

According to an analysis in [43], no preference leads to the highest solar coverage ratio for systems with two storages.

- Preference DHW storage (Vorrang Warmwasserspeicher)
- Preference heat storage (Vorrang Pufferspeicher)
- No preference, the collector charges the storage with the current lowest temperature (Gleichrang)

DHW Storage (Warmwasserspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1) = 67°C
- Max. storage temp. Sensor 2 (Max. Speichertemp. Fühler 2) = 67°C
- Hysteresis (Hysterese) = 1 K

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Max. storage temp. (Max. Speichertemperatur) = 60°C
- Hysteresis (Hysterese) = 2 K

↪ Auxiliary heating, electrical (Zufuhr von elektrischer Energie)

- Max. storage temp. (Max. Speichertemperatur) = 60°C
- Hysteresis (Hysterese) = 2 K

The next parameters are viable for big buildings, where the DHW preparation is far away from the according taps. In order to prevent a long time-lag and water waste when switching on the hot water tap, a circulation should ensure that the DHW in the pipes is instantly hot.

↪ DHW circulation (Warmwasserzirkulation)

⊗ On (Ein) or ⊘ Off (Aus)
For On the following parameters are available.

- Operation interval 1 (Betrieb 1) start and end time 0-24 h
- Operation interval 2 (Betrieb 2) start and end time 0-24 h
- Operation interval 3 (Betrieb 3) start and end time 0-24 h
- Mass flow rate (Massenstrom) [kg/h]
- Temperature drop (Delta T) [°C]
- Inlet height [m]
- Circulation off during off-heating period (Pumpe aus in heizfreier Zeit)

Heat Storage (Pufferspeicher)

The following parameters control the supply of the various heat sources, which load the heat storage

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1) = 80°C
- Max. storage temp. Sensor 2 (Max. Speichertemp. Fühler 2) = 80°C
- Hysteresis (Hysterese) = 1 K
- Δ T between heat storage and DHW storage to start loading the DHW storage (Temperaturdifferenz zum Laden des WW-Speichers) [K]

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Max. storage temp. (Max. Speichertemperatur) = 65°C
- Hysteresis (Hysterese) = 5 K

↪ Auxiliary heating, electrical (Zufuhr von elektrischer Energie)

- Max. storage temp. (Max. Speichertemperatur) = 0°C
- Hysteresis (Hysterese) = 4 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW preparation (Kesselenergie zur Warmwasserversorgung)

- Indirectly via the heat storage, DHW provision elsewhere (In den Pufferspeicher, WW-Erzeugung über eigenen Kreis)
- Directly in the DHW storage (Direkt in den WW-Speicher)
- Indirectly via the heat storage, DHW provision with continuous flow heat exchanger (In den Pufferspeicher, WW-Erzeugung über Durchlauferhitzer)

7.2.6 DHW consumption (Warmwasserverbrauch)

Parameters on this data card are described in detail above *Figure* 5.1 on page 52.

7.2.7 Building and heating (Gebäude + Heizung)

Heating (Heizung)

This data card defines the building, its heat load, window characteristics for passive solar gain, and heating system related parameters that influence their control. The **radiator exponent** was chosen according to [44].

- Total heat load (Heizlast) [W]
- SH design inlet temperature (Vorlauftemperatur) [°C]
- SH design outlet temperature (Rücklauftemperatur) [°C]
- SH standard design temperature (Auslegungstemperatur) = ***−6 [°C]***
- Room set temperature (Raumtemperatur) = ***20 [°C]***
- SH-start mean outside temperature (Heizbeginntemperatur) = ***12 [°C]*** according to VDI2067 [45]
- Internal heat gain (Innere Wärmeleistung) [W]
- Heat load of unheated rooms (Heizlast unbeheizter Gebäudeteile) [W]
- Room temperature for night setback (Raumtemp. bei Nachtabsenkung) = ***14 [°C]***

- Time frame for night setback (Nachtabsenkung Zeitraum) = ***21 / 5***, [Time of day]/ [Time of day]
- 1^{st} off-heating period (1. heizfreie Zeit) [date]/ [date]
- 2^{nd} off-heating period (1. heizfreie Zeit) [date]/ [date]
- Radiator exponent (Radiatorexponent) = ***1.35*** (radiator)/ ***1.1*** (floor, wall) [Unity]

Building (Gebäude)

Six glass fronts can be defined; the according parameters are

- Glass-surface (Glasfläche) [m^2]
- Tilt (Neigung) [°]
- Azimuth (Azimut) [°]
- SHGC or g-value(Gesamtenergiedurchlassgrad) [Unity]

The according parameters for SFH are provided in Table 5.13, page 58.

Connection to a district heating network
(Solaranlage speist in ein Fernwärmenetzwerk)

The option No (Nein) is always chosen here since no connection to a district heating network is intended.

7.2.8 Heater (Kessel)

The data sheet Heater provides boiler- and flow-related parameters. The boiler-related parameters are

- Power (Leistung) [W]
- Minimum heater temperature (Minimale Kesseltemperatur) [°C]
- **Type** of heater, continuous/constant Temperature (Kesselart Gleitende-/Feste Kesseltemperatur)

Boiler mass flow while feeding... (Kesselmassenstrom bei Ladung von...)

Flow related parameters refer to mass flow while feeding different heat storages. Apart from the first parameter, these parameters are only for the heater type constant Temperature. Relevant parameters are

- DHW storage (Warmwasserspeicher) [kg/s]
- Heat storage (Pufferspeicher) [kg/s]
- Both (Gleichzeitige Ladung) [kg/s]
- Share DHW storage when feeding both (Anteil zur WW-Ladung) [%]

Flow rate calculations were based on the assumption that the provided heat flow (the power of the heater) can be interchanged by the heat fluid, which is water ($c_{pH_2O} = 1.16$ kWh/(m$^3 \cdot K$). For the following example, we take P_{nom}=15 000 W.

$$\begin{aligned} \dot{V}_{aux} &= \frac{P_{nom}}{\Delta\vartheta_{pH_2O} \cdot c_{pH_2O}} \\ &= \frac{15000W}{10K \cdot 1.16kWh/(m^3 \cdot K)} \\ &= 1.2931\frac{m^3}{h} \approx 0.36\frac{litres}{s} \approx 0.36\frac{kg}{s} \end{aligned} \tag{7.17}$$

From this total flow rate, the specific mass flow rate related to the power can be calculated $\Rightarrow \dot{m}_{aux} = 0.024$ kg/(s kW).

7.3 Calculation and applied models

In this section, some of the most important algorithms of the software are either described in words or their underlining formula is provided – see [43] for more details. A step size of **10 steps per hour** (6 minutes) was chosen for the simulation. Since climate data is on a hourly base, data points required in-between two hourly values are evaluated using linear 'intelligent' interpolation [5].

7.3.1 Heat capacities

In reality, prior to effective heat energy transfer to the storage, any heat capacities of devices involved in the collector loop must be heated. The software operates as though all these heat capacities were concentrated in the collector itself, i.e. for all pipes in the solar loop, the heat transfer medium, and any other devices, the respective heat capacity is added to the heat capacity of the absorber, and eventually this cumulative heat capacity is regarded as the heat capacity of the collector.

While heating the collector through the Sun, its temperature increases according to this overall heat capacity. If ΔT between the collector field and the sensor in the storage is high enough, the pump is turned on. In reality, the pump is often turned on and turned off until all the pipes and other parts in the solar loop are heated accordingly.

7.3.2 Direct radiation incident angle

The provided incident angle factor gives the reduction of transmittance for an angle of 50°, which is acquired from standard tests. This parameter is used to derive a curve of 6^th order that models the transmittance at various incident angles.

7.3.3 Radiation on tilted azimuthal twisted surface

In *Figure* 7.1, the relevant angles for modelling the movement of the Sun with respect to an azimuthal twisted and tilted surface at a particular geographical location are drawn. Table 7.1 lists all angles needed for the simulation of the whole annual period.

The declination, the angle between the plane of the equator and the Sun when it is at the highest position during a day, is given by

$$\delta = 23.45 \sin\left(360 \, \frac{284+n}{365}\right) \,, \tag{7.18}$$

where n is the day of the year such that n=1 ⇔ $1st$ of January.

The relation between the angle of incidence θ (see *Figure* 7.2 right sketch) of direct radiation on a surface to the other angles is given by

$$\begin{aligned} \cos\theta &= \sin\delta\cdot\sin\Phi\cdot\cos\beta - \sin\delta\cdot\cos\Phi\cdot\sin\beta\cdot\cos\gamma \\ &+ \cos\delta\cdot\cos\Phi\cdot\cos\beta\cdot\cos\omega + \cos\delta\cdot\sin\Phi\cdot\sin\beta\cdot\cos\gamma\cdot\cos\omega \\ &+ \cos\delta\cdot\sin\beta\cdot\sin\gamma\cdot\sin\omega \,. \end{aligned} \tag{7.19}$$

For a horizontal surface ($\theta \rightarrow \theta_z$) the former equations simplifies to

$$\cos\theta_z = \sin\delta \cdot \sin\Phi + \cos\delta\cdot\cos\Phi\cdot\cos\omega \,. \tag{7.20}$$

For the last two equations, the hour angle $\omega = 180° - h \cdot 15°$, where h is the hour of the day [6].

[5] Intelligent means that sunrise and sunset for the radiation data are taken into account.

[6] This is a sufficiently accurate approximation.

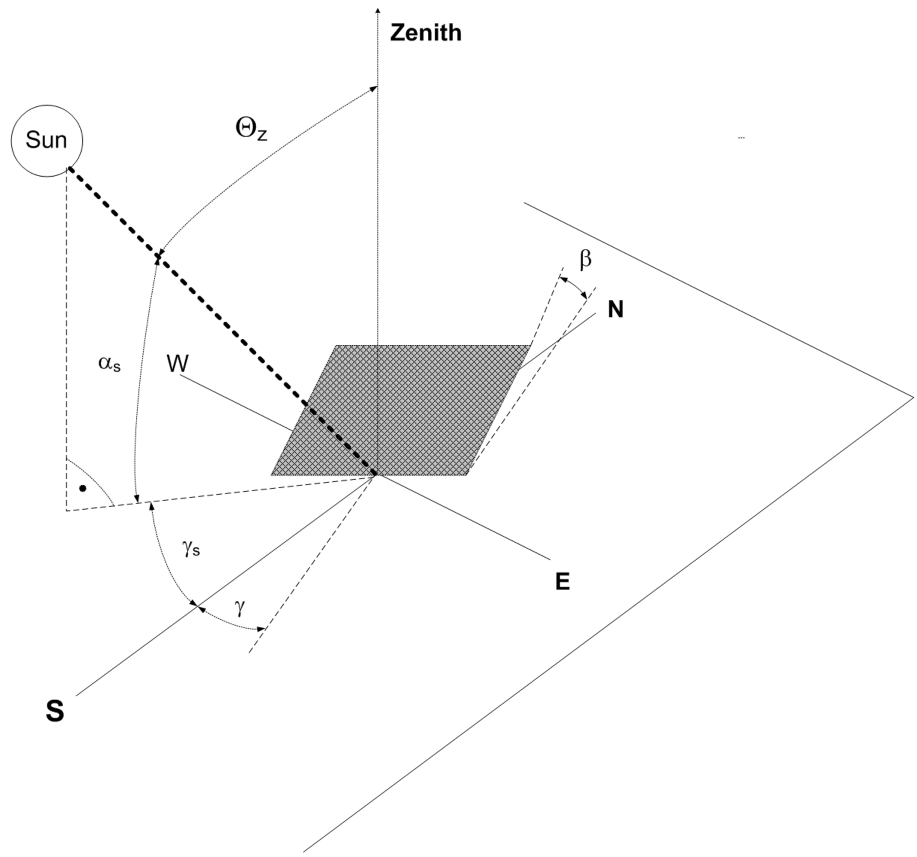


Figure 7.1: Zenith angle θ_Z, surface azimuth angle γ, and solar azimuth angle γ_S for a surface with tilt β, cf. [46]

Table 7.1: Relevant angles to describe the geometric relationship between a plane of any particular orientation with respect to the Earth and the incoming direct solar radiation.

Φ	**Latitude**, location north(+) or south(–) of the equator; $-90° \leq \Phi \leq 90°$
δ	**Declination**, angular position of the Sun at solar noon (i.e. when the Sun is on the local meridian) relative to the plane of the equator; (south) $-23.45° \leq \delta \leq 23.45°$ (north).
β	**Tilt** angle, slope between the plane of the surface in question and the horizontal; $0 \leq \beta \leq 180°$, where $\beta > 90°$ indicates a downward facing surface.
γ	**Surface azimuth angle**, angle between the line $l_{S\perp}$ and southerly direction. Where $l_{S\perp}$ is the orthogonal projection of a normal on the surface, on the horizontal plane. west negative, east positive; $-180° \leq \gamma \leq 180°$.
ω	**Hour angle**, angular displacement of the Sun east or west of the local meridian due to rotation of the Earth on its axis at 15° per hour, morning negative, afternoon positive.
θ	**Angle of incidence**, angle between the direct radiation on a surface and the normal to that surface.
	Additional angles that describe the position of the Sun.
θ_z	**Zenith angle**, angle between the vertical and the line to the Sun, i.e. direct radiation incidence angle on a horizontal surface.
α_S	**Solar altitude angle**, i.e. complement of the zenith angle.
γ_S	**Solar azimuth angle**, angular displacement from south of the orthogonal projection of direct radiation on a horizontal plane.

Beam radiation, or irradiance (I_b), measurement data are generally with respect to a horizontal surface. In *Figure* 7.2, two sketches are drawn. The left one refers to the relation between beam irradiance I_b of the Sun and the respective fraction I_{bh} normal to a horizontal surface. By contrast, the right drawing shows the relation between beam irradiance of the Sun and the respective fraction I_{bT} normal to a tilted surface.

Since the software allows for a tilted surface and the used climate data set provides I_b on a horizontal surface, a formulae is needed that transforms I_{bh} to I_{bT}. For the left drawing

$$\cos\theta_z = \frac{I_{bh}}{I_b} \text{ holds.} \tag{7.21}$$

For the tilted surface, the relation between I_b and I_{bT} is given by

$$\cos\theta = \frac{I_{bT}}{I_b} \,. \tag{7.22}$$

Consequently, I_{bT} can be written as a function of I_{bh} and the two angles θ and θ_z such that

$$I_{bT} = \frac{\cos\theta}{\cos\theta_z} \cdot I_{bh} \,. \tag{7.23}$$

Finally, with the equations (7.18), (7.20), (7.23) and the respective beam irradiance on a horizontal surface I_b and the diffuse irradiance, the corresponding irradiance on a tilted surface can be calculated.

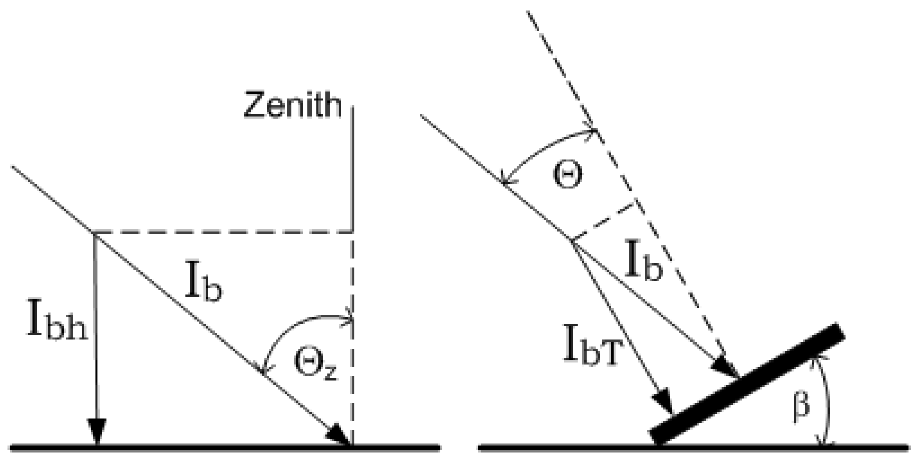


Figure 7.2: Orthogonal fraction of beam irradiance on a horizontal (left) and on a tilted (right) surface.

7.3.4 Temperature layers in the heat storage

Temperature layers in the heat storage and the DHW storage are modelled in the same way. Ten different layers in the storage are possible. Vertical mixing in the storage due to conduction and convection is taken into account by a vertical heat conduction coefficient, $\bar{\lambda}_{Storage}$, which is given in equation (7.11). Additional mixing in the storage can be modelled by an increased coefficient. Also thermal losses of the storages' surface are embraced in the model.

The model used is called a **plug flow model**. It has been realised by a finite element method and represents a modular approach. The respective height of heat exchangers, flow inlets and outlets, and temperature sensors can be chosen with only a few restraints. When an internal heat exchanger supplies the storage with heat, the layer surrounding the bottom end of the heat exchanger is split at the lower edge of the heat exchanger; only the above remaining volume is heated. Layers are created, deleted or merged during this process.

Heat energy inputs directly via pipes work as follows: the layer around the outlet position is split. The flow between inlet and outlet is downward because the inlet position should always be above the flow outlet position for energy delivery to the tank. Also, this heat supply leads to creation or extinction of layers.

As heat is removed from the storage, the layers are shifted to the top, and new layers are created at the bottom. Hence, removal or support of heat leads to the creation or extinction of layers; this means the number of layers is variable.

The losses to the environment at ambient temperature are calculated considering the insulation thickness and its thermal conductivity. Each layer is calculated separately. The vertical heat conduction coefficient is a mean weighted value of the tank material and the thermal conductivity of water multiplied by a stratification factor. This factor must be estimated or found experimentally. More details are provided in [43], page 131, or [47].

7.3.5 Collector- and system efficiency

The collector efficiency η_{Coll}(t) is defined by the ratio of useful thermal energy flow transported by the heat transfer medium in the collector and the global irradiance on the collector at a given time. Of practical relevance is the time average of this value – the mean collector efficiency $\bar{\eta}_{Coll}$

$$\begin{aligned} \text{For } I_g(t) = 0 \quad &\Rightarrow \quad \frac{\dot{Q}_{Coll}(t)}{I_g(t)} = 0 \\ \text{and } \bar{\eta}_{Coll} \quad &= \quad \frac{1}{T}\int_T \frac{\dot{Q}_{Coll}(t)}{I_g(t)}\, dt\ . \end{aligned} \tag{7.24}$$

An upper theoretical limit for the collector efficiency of covered flat plate collectors, selectively and non-selectively coated, lies at approximately 75%, cf. [28]. In [46], 65-78% are given with respect to the net collector area. A daily average value for this key data, using theoretical calculations, is 38% [46]. In [2], for different systems analysed it ranges between 18.6% and 38.4%.

By contrast, η_{System} is a measure of efficiency for the whole solar thermal system. It gives the ratio of the integral of useful thermal energy flow transported by the heat transfer medium (from the collector field) within a given time frame and the integral of the global irradiance onto the collector field within the same time frame, that is, the percentage of available solar energy that was supplied to any heat storage within a certain time period. We could also name it the degree of utilisation with respect to the collector

$$\eta_{System} = \frac{\int_T \dot{Q}_{Field}(t)\ dt}{\int_T I_g(t)\ dt \cdot A_{Field}} . \tag{7.25}$$

System efficiency data on an annual basis gained from simulations of systems used for SFH (DHW plus heating) are 20%, 27%, 37% and 42% for a collector field and total heat load of 105 m^2 and 25.8 MWh, 55 m^2 and 25.3 MWh, 30 m^2 and 24.8 MWh, and 10 m^2 and 24.1 MWh, respectively, cf. [46]. Since SHWwin calculates using one collector and takes the yield multiplied by the collector field area, equation (7.25) reduces to a simpler form

$$\eta_{System} = \frac{\int_T \dot{Q}_{Coll}(t)\ dt}{\int_T I_g(t)\ dt \cdot A_{Coll}} . \tag{7.26}$$

While $\bar{\eta}_{Coll}$ characterises the quality of the collector, η_{System} provides a characteristic value for the quality or **efficiency** of the whole **solar thermal plant**.

7.3.6 Solar coverage ratio or fractional savings

Solar Coverage Ratio (SCR), often also called solar fractional savings (F_s), gives the solar contribution to the total heat energy demand in percentage. While the useful solar thermal energy flow leaving the collector was taken for the calculations of the collector and the system efficiency, here we take only the useful solar thermal energy available in the storage. $\dot{Q}_{Field}(t)$ must be reduced by the losses in the pipes of the solar loop and the losses in the storage. All losses in the storage are attributed to the solar thermal energy, which leads to a reduction of useful solar energy [7].

$$SCR = \frac{\int_T \left(\dot{Q}_{Field}(t) - \dot{Q}_{losses}(t)\right)\ dt}{Q_{demand}} , \tag{7.27}$$

or, when $Q_{aux(i)}$ is the supplied energy by the auxiliary source no. i,

$$SCR = 1 - \frac{\sum_i Q_{aux(i)}}{Q_{demand}} . \tag{7.28}$$

The software provides SCR purely for DHW, purely for heating, or with respect to a combisystem, i.e. the SCR of the whole plant.

7.4 Output variables

The described variables refer to the first page of the automatically generated output form of the Software SHWwin. Some forms are attached in the Appendix; all generated output forms can be found on the attached CD.

On the first page of this form there are four tables which provide the simulation results. Each of the next subsections refer to one table.

[7]Theoretically, if one auxiliary heat source requires a storage, some amount should also be attributed to this source. This is not taken into account however, by the software.

7.4.1 Entire system (Gesamtanlage)

The following variables refer to the entire system. The original German abbreviation is provided in brackets.

- **Month** (Monat) [unity] – according month of the year
- **Glob.Rad.** (Global) [kWh] – global solar radiation on the tilted and azimuthal twisted collector field
- **Op.time Coll.** (BeDauKoll) [h] – total operation time of the collector
- **Q usef. Coll.** (NutzKol) [kWh] – useful heat energy transported by the heat transfer medium from the collector, i.e. solar yield of the field
- **Coll loop loss.** (ZirkVer) [kWh] – heat losses of the collector loop pipes
- **Q Sol. Stor.** (SolSpei) [kWh] – total solar energy supply to all existing heat storages
- **Coll. Eff.** (KolWiGr) [%] – efficiency of the collector
- **Syst. Eff.** (KolNuGr) [%] – efficiency of the solar thermal system
- **SCR** (DeckGr) [%] – Solar Coverage Ratio, i.e. solar contribution to the total heat energy demand

7.4.2 DHW system (Warmwasserbereitungsanlage)

Variables in the next list refer to the DHW system. If only a heat storage is designed, most of the variables are empty.

- **Month** (Monat) [unity] – according month of the year
- **Op.Coll.DHW** (BeDauKoll) [h] – total operation time of the collector for feeding the DHW storage
- **Tmax DHW** (WaSpTmax) [°C] – maximal temperature at the top of the DHW storage that was reached
- **Q remov. DHW** (WaSp+Zi) [kWh] – heat energy removed from the DHW storage, this includes possible circulation losses
- **Q loss. DHW stor.** (WaSpVerl) [kWh] – heat losses of the DHW storage
- **Q aux. DHW** (Kessel) [kWh] – heat supply by the second auxiliary source to the DHW storage
- **Q aux.el.DHW** (Elektr) [kWh] – heat supply by the electrical (first) auxiliary source to the DHW storage
- **Q Sol. DHW** (SolSpei) [kWh] – total solar energy supply to the DHW storage
- **SCR DHW** (DeckWa) [%] – Solar Coverage Ratio for DHW, solar contribution to the DHW energy demand

7.4.3 Heat provision system (Heizenergiebereitungsanlage)

Variables in this list refer to the heat provision system for space heating purposes.

- **Month** (Monat) [unity] – according month of the year
- **Op.Coll.heat** (BeDauKoll) [h] – total operation time of the collector for feeding the heat storage
- **Tmax Stor.** (HeiSpTmax) [°C] – maximal temperature at the top of the heat storage that has been reached
- **Q remov.heat** (HeSpent) [kWh] – heat energy removed from the heat storage
- **Q loss. heat stor.** (HeiSpVerl) [kWh] – heat losses of the heat storage

- **Q aux. heat** (Kessel) [kWh] – heat supply by the second auxiliary source to the heat storage
- **Q aux.el.heat** (Elektr) [kWh] – heat supply by the electrical (first) auxiliary source to the heat storage
- **Q Sol.heat** (SolSpei) [kWh] – total solar energy supply to the heat storage
- **SCR heat** (DeckHei) [%] – Solar Coverage Ratio for SH, solar contribution to the space heating energy demand

7.4.4 Further available results (Weitere Daten)

Variables in the next list provide additional data referring either to the DHW supply or to space heating.

- **Month** (Monat) [unity] – according month of the year
- **Glob.Rad.Op.** (BetrStr) [kWh] – global solar radiation on the tilted and azimuthal twisted collector field during operation of the collector loop
- **Tmin DHW** (WEntTmin) [°C] – minimal temperature of provided hot water in order to check the reliability of DHW provision
- **Q Circ. DHW**(Wa-Zi) [kWh] – heat energy losses because of circulation in the DHW loop
- **Cov.ratio DHW** (WW-Deckg) [%] – coverage ratio of the DHW needs by the entire system
- **Cov.ratio heat** (HZ-Deckg) [%] – coverage ratio of the heating needs by the entire system
- **Q SH** (Heizung) [kWh] – heat energy needed for space heating
- **Q DHW** (Warmwas) [kWh] – heat energy needed for DHW purposes
- **Q Sol.pass.** (Passiv+Sp) [kWh] – passive solar energy gain for SH, provided through solar radiation through the windows plus the defined amount of losses from the heat storage attributable to SH

7.5 Reliability of results – comparison with measurements

The software SHWwin has been validated by comparing simulation results with practical measurement data. In addition simulation results of similar solar systems generated by TRNSYS have been compared. The respective comparisons show good consistency, cf.[42].

The described heat storage tank model has been tested in two ways. First, data from two tests of a tank test bed have been compared with the tank model data; the computer model results were in good agreement with the measured data. Second, real-time data from a solar combisystem have been compared with data generated from the program SHWwin over one month. A primary simulation run produced excellent agreement, and a second run proves the program can reproduce realistic results over a long period.

In summary, it has been validated that results of the simulation program SHWwin show high agreement to measured data.

Chapter 8

Solar Thermal System Analyses

This chapter describes the simulations elaborated using SHWwin, their design, meaning and outcome for various solar thermal systems. Systems concerned here include the defined standard tourist accommodations and private housing facilities (ACC S, ACC M, ACC L, SFH). A number of sensitivity analyses (SA) were conducted for defined template systems. Subsequent one dimensional SA, aiming to a maximum solar yield were conducted using the parameter set for the template system; parameters were only changed if it was important to guarantee a proper operation of the system. Finally, the vital results, such as annual solar coverage ratio (SCR), appear graphically, and the solar thermal system efficiency and other simulation results are discussed. Detailed results of these simulations are provided in the first six Appendices and on an appended CD.

8.1 General topics – simulation procedure

Figure 8.1 illustrates the abstract principle of $\mathbf{y}_{ij} = \mathbf{f}(\mathbf{x}(t), t_i, t_f)$, where $\mathbf{x}$ stands for a set of input parameters of a system with a vector valued transfer function $\mathbf{f}$ that maps the input to a set of output variables $\mathbf{y}_{ij}$. t_i and t_f characterise the start (initial) and end (final) time of the simulation interval. The grey square shows the core of the simulation, the system $\boldsymbol{f}$, which consists of the Solar thermal System Description and the Heat Demand Profile; this is composed by the DHW profile and the SH heat demand. The input parameters $\mathbf{x}$ refer to hourly climate data. The output variables gathered during a certain simulation period are represented by the right square and include all generated results.

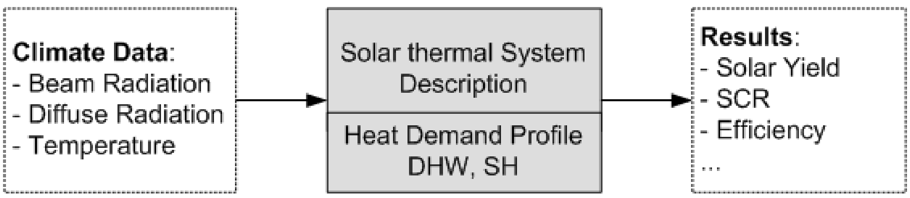


Figure 8.1: Sketch of the applied simulation procedure

8.1.1 Detailed angle analysis

This subsection describes the outcome of two simulation series providing an overview of how annual yields depend on the orientation of the solar radiation collecting surface. One simulation series refers to the variation of the azimuth- the other to the variation of the tilt angle.

Azimuth=0° and *tilt*=45° were assumed the optimal angles for an analysis using a simple solar thermal system with pure DHW demand. The optimal tilt angle for a system with additional SH heat demand is investigated later.

In comparison with a pure theoretical finding of the optimum, this simulation analysis reflects the behaviour of a solar system in operation. The outcome of the simulation can be different from simple estimations. One reason for this is the temperature-dependant efficiency. Furthermore, a difference of global radiation between two subsequent months can influence the solar coverage ratio for systems with large storage [1]. Another striking difference to any purely theoretical calculation based on general assumptions is the detailed heat demand profile with relation to accommodation facilities.

Solar thermal system description for SFH, DHW purpose

The system used for these two analyses is described in Table 8.1. The given collector surface is composed of three collector exemplars (1.915 m^2 each). The storage is a 300 litres tank, and additional heating is provided electrically. The heat demand depends solely on DHW demand and it matches the needs of a SFH, i.e. 200 litres at 45°C per day, cf. Table 5.13 [2]. DHW consumption of the hourly demand occurs at the beginning of each hour.

Table 8.1: DHW One Storage Solar Thermal System description for SFH for supply of a SFH with four people (200 litres/day)

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 5.75 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Storage tank	Tehnomont_SB302	300 litres	add. source: electr.
Heat exchanger	internal		
Coll.loop: pipes	Cu: 1.5 mm	d= 18 mm	
Coll.loop	length 20 m	insulation	30 mm, 0.04 W/(m^2 K)

Azimuth analysis

Variation of *azimuth* was between -90° (west) and 90° (east) in steps of 10° while the **tilt** angle was constant at **45°**.

As seen in *Figure* 8.2, the annual SCR is highest for the months between April and September. Among the twelve months, July provides the highest and December the lowest SCR. Average annual SCR in the context of DHW is nearly 70% for the used collector from Tehnomont. Any *azimuth* in the range between -30° and 30° leads to an annual SCR above 67%. All outcome details are provided in Table B.1 in Appendix: Angle Analyses for SFH DHW Purposes.

[1] For example, if at the end of March, the storage has a medium temperature but the first days in April lead to a high storage temperature, the solar fraction from April is increased. By contrast, a July with high global radiation cannot contribute further to an increase of the solar coverage ratio if the storage temperature is already maximal at the beginning of the month (if radiation in June was also high).

[2] The detailed consumption profile is slightly different from that provided by *Figure* 5.1 because the profile was elaborated a second time after the simulation. Nevertheless, the modification is marginal having nearly no effect on the outcome.

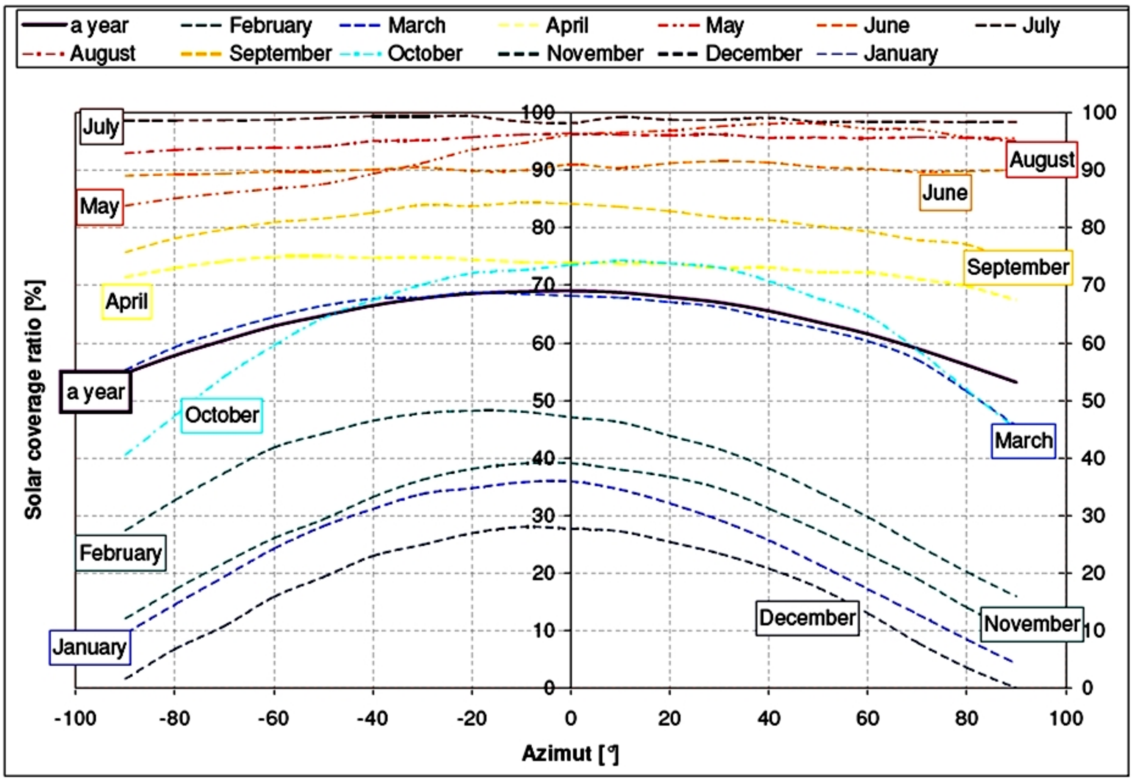


Figure 8.2: Azimuth analysis at *tilt*=45° for Rijeka; SCR for DHW supply of a single family house (45°C; 200 litres/day) at various azimuth angles

Tilt analysis

Variation of *tilt* was between 0° (horizontal) and 90° (vertical) in steps of 5°, whilst the **azimuth** angle was constant at **0°** [3].

As can be seen in *Figure* 8.3, the annual SCR is highest for the months between April and September. Among the twelve months, July provides the highest and December the lowest SCR. Average annual **SCR** in the context of DHW is nearly 70% for the used absorber when south facing at a tilt angle of 45°. Deviations from theoretical assumptions, especially for summer months that do not show a cosine-shaped coverage ratio, are caused by saturation effects. As can be seen in Table B.2 in Appendix: Angle Analyses for SFH DHW Purposes, any *tilt* in the range between 25° and 65° leads to an annual SCR above 66%. This appendix includes another illustration that shows the dependency of the the optimal tilt on the off-season/summer demand ratio.

8.1.2 Mixed-angle analysis

A mixed-angle analysis shows the SCR for various combinations of azimuth and tilt angles on a two-dimensional contour plot. This type of graph will be used to compare the simulation outcomes for the different solar thermal systems.

The original plot is a 3D plot where the z-axis gives the SCR. If a colour scheme is applied to different intervals on the z-axis, and the resulting surface is viewed from above, one gets the **top view** presented in *Figure* 8.4. It allows at first sight to estimate the performance of a system depending on the collector orientation. The legend left of the contour plot links the annual coverage ratio classification scheme with the according colours. A subset of angle pairs from this plot will be selected to finally evaluate average SCR's for each system.

[3]Around 45° in one degree steps.

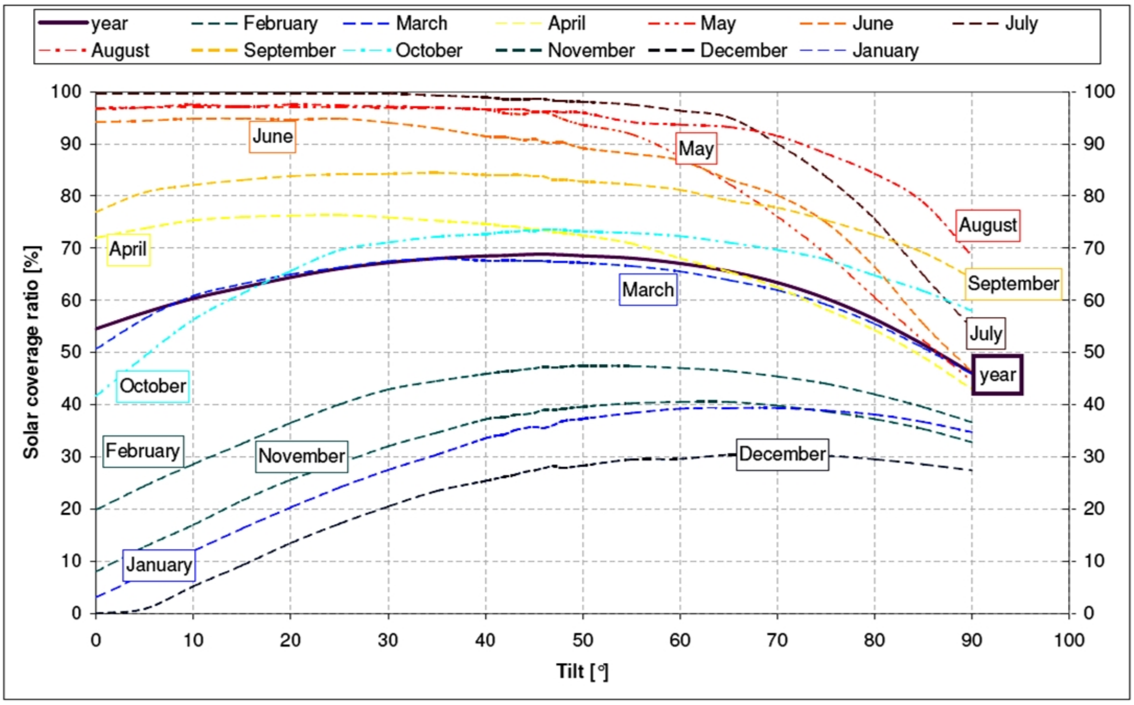


Figure 8.3: Tilt analysis at *azimuth*=0° for Rijeka; SCR for DHW supply of a single family house (45°C; 200 litres/day) at various tilt angles

The analysis in *Figure* 8.2 shows a nearly symmetrical characteristic with respect to the azimuth angle. Hence, in *Figure* 8.4, this angle can be understood as an absolute value, and the coloured contour plot is valid for **positive and for negative azimuth** values. Nevertheless, the simulation was conducted for positive azimuth angles; that is, orientation towards east for which the coverage ratio in *Figure* 8.2 is slightly below the corresponding negative values – indicating a westerly orientation.

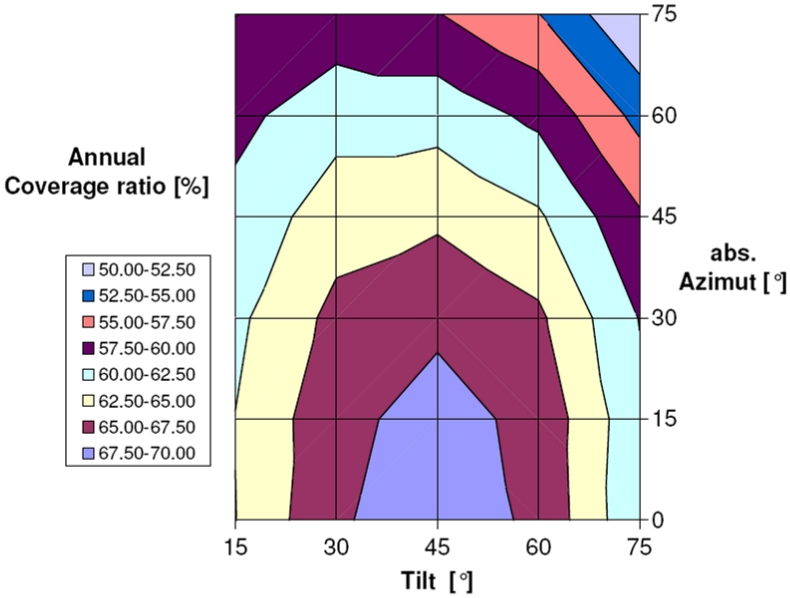


Figure 8.4: Mixed-angle analysis principle demonstration – contour plot of SCR for a number of angle combinations where *azimuth*: 0°-75° and *tilt*: 15°-75°

8.1.3 Sensitivity analyses (SA)

The most relevant output of a solar thermal application is the SCR. In addition, the specific annual yield is a meaningful key number for any solar thermal system.

There exists a number of guidelines for designing solar systems. Using these rules, models or so-called 'prototypical template systems' can be defined. However, particular heat demand profiles, as for tourist facilities and the local climate conditions, demand different system parameters. Collector field and the heat storage size are the principal parameters that must be optimised. The simulation results **Q Sol. Stor.** (the total solar energy supply to all heat storages), the collector and system efficiency, storage losses, auxiliary heat demand and eventually the SCR allow validation of the optimal set of parameters for a system.

The method of SA, where an internal system parameter is changed iteratively and the resulting outputs are compared, will be applied to optimise template systems. For the majority of SA conducted, all parameter values, such as the template system, will be used. However, this rule must be occasionally broken, because the main objective for any SA is to guarantee a real system operation. That is, linked individual parameters must correlate with each other, and therefore, it is necessary to change one parameter or the other.

Orientation of the collector surface for the **net collector field** and the **storage size SA** will be *azimuth*=0° and *tilt*=45° for purely DHW systems. For other applications, the tilt angle may be different, but the azimuth angle will always be 0°.

8.2 Simulations for single family houses (SFH)

Type of DHW-consumption (Art des WW Verbrauches)

For the hourly DHW consumption profile the software allows for two optional ways of consumption; see Chapter 7 Input parameters. For all applications in private housing, the first choice, with consumption at the first time step, will be applied.

- **Completely at the first step** (Vollständig am ersten Simulationsschritt), this option is recommended for small solar thermal systems
- Distributed equally over one hour (Gleichmäßig über die Stunde), this option is recommended for large systems to account for less simultaneity

8.2.1 DHW system 'natural' circulation for SFH

The software SHWwin provides concepts for DHW systems that must be obeyed. However, parameter variation is possible for all used parts that comprise the according solar system. The predefined solar thermal system that will be used for purely DHW provision in private housing is shown in *Figure* 8.5. The relevant parameters will be described in the following subsections. A short German description of the coming system is also provided in Appendix: System Plans.

DHW One Storage With Stratification Unit
(Solare Brauchwassererwärmung mit Pufferspeicher und Durchlauferhitzer)

Natural circulation solar thermal systems, or thermosyphonic systems, are promoted and in operation in south European countries for DHW preparation. The advantages of this compact system are its simplicity, efficiency and low cost. However, it can operate with a tilted collector only.

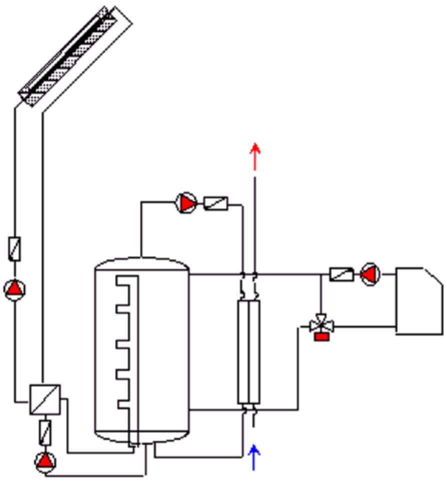


Figure 8.5: Hydraulic design of a solar thermal system for DHW provision with one storage, stratification unit, and counter current heat exchanger for DHW provision [45].

There exist two different system types, the open and the closed cycle system, the last of which is protected against freezing. In order to simulate such a system with the used software, a set of parameters was needed that allow the system to operate as though natural circulation would take place.

Higher losses for an externally located DHW storage were taken into account using an increased thermal conductivity for the storage insulation (0.1 W/(m K)). All parameters for which the mixed angle analysis was conducted are described in the subsection Control parameters and in Table 8.2 – no additional SA was carried out.

Control parameters

The listed control parameters indicate the relevant parameters to simulate natural circulation.

Collector

↪ ΔT to start solar energy supply

- ΔT_{on}, Collector – DHW storage sensor = 1 K
- Hysteresis for turning off = 0.5 K

With this choice, the temperature difference between the upper collector temperature and the storage base temperature is always $\leq$ 1 K.

DHW storage

↪ Solar energy supply

- Max. storage temp. Sensor 1 = 67°C
- Hysteresis turn on = 1 K

↪ Auxiliary heating

- Power (electric) = 5 kW
- Max. storage temp. = 47°C
- Hysteresis turn on = 2 K

Table 8.2: DHW One Storage 'Natural' Circulation System optimised for a SFH with four people.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 5.75 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.01-0.015 kg/s
Coll.loop	length 4 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources, **DHW storage** 250 litres, H=1 m $\lambda_{Storage}$= 1.6 W/(m K)			
Coll. loop	in strat. unit	out 0.0 m	Sen. 0.01 m/T_{max}95°C
Ext. heat exch.	1.5 m^2	500 W/(m^2 K)	0.015 kg/s
Aux. electrical	in 0.75 m	5 kW	Sen. 0.8 m/T_{max}47°C
Heat sinks			
DHW	in 0.0 m	out 1.0 m	200 (*litres* 45°*C*)/*day*

Solar Coverage Ratio

The simulation was carried out with the DHW demand profile given in *Figure* 5.1, *Figure* 8.6 illustrates the results. Each range of SCR was given a different colour: the legend on the left side of the figure describes the classification. For an optimal oriented net surface of 5.75 m^2 and a DHW storage size of 250 litres, a SCR of 77.55% is obtained. The specific annual yield for this case is 544.10 kWh/m^2. More details are given in Table 8.4 or in Appendix: Mixed Angle Analyses.

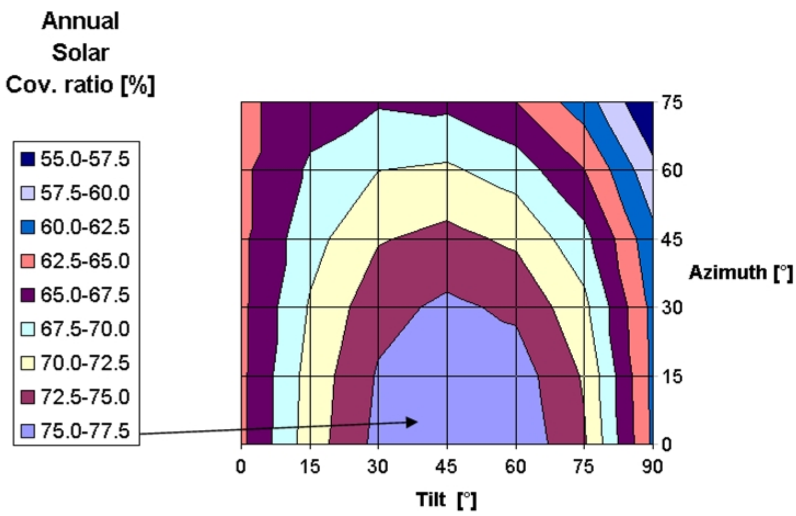


Figure 8.6: Mixed-angle analysis for DHW One Storage 'Natural' Circulation System, optimised for a SFH (45°C; 200 litres/day) in Rijeka.

8.2.2 DHW system forced circulation for SFH

The hydraulic design provided by the software is given in *Figure* 8.7. In addition to the following description of the system, a brief German manual of the system is provided in Appendix: System Plans.

DHW One Storage (Solare Brauchwassererwärmung mit Brauchwasserspeicher)

By contrast to the last system, this system includes a simple on-off control for a pump that manages the heat supply to the DHW storage tank, that is usually located in a building. This is a generic system for DHW preparation found across Europe. In principle the

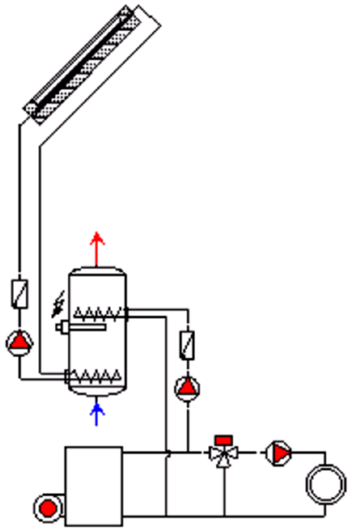


Figure 8.7: Hydraulic design of a solar thermal system for DHW provision with one DHW storage [45].

system can operate in High Flow or Low Flow mode, but the second of these two modes is primary only effective in combination with a stratification unit in the DHW storage.

Here the High Flow rate concept, with a simple internal heat exchanger, will be simulated. Auxiliary energy needs were assumed to be covered by an existing space heating boiler. The given control parameters and Table 8.3 represent the parameters of the template system for which the mixed angle analysis is conducted.

Control parameters

Collector (Kollektor)

↪ ΔT to start solar energy supply

Standard values of ΔT between the collector and the storage sensor for simple **on-off controls** are 5 K to 7 K for the On signal and 3 K for the Off signal, cf. [2]. However, the smaller the difference between the two following temperature values the greater the pump operation time and consequently higher electrical energy required.

- ΔT_{on}, Collector – DHW storage sensor = 4 K
- Hysteresis for turning off = 2 K

DHW storage

↪ Solar energy supply

- Max. storage temp.[4] Sensor 1 = 67°C
- Hysteresis turn on = 1 K

↪ Second auxiliary heating

- Power (thermal via boiler) = 15kW
- Max. storage temp. = 47°C
- Hysteresis turn on = 2 K

[4]Should not exceed 70°C to prevent limestone deposition

Table 8.3: DHW One Storage Forced Circulation System optimised for a SFH with four people.

Collector: Tehnomont SKT-40		net surface 5.75 m^2	
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.045 kg/s
Coll.loop	length 20 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**DHW storage** 300 litres, Tehnomont_SB302, $\lambda_{Storage}$= 1.46 W/(m K)			
Coll. loop	in 0.36 m	out 0.24 m	Sen. 0.3 m/T_{max}95°C
↪Int. heat exch.	1.63 m^2	500 W/(m^2 K)	$\dot{m}$=0.045 kg/s
Aux. loop	in 0.71 m	out 0.59 m	Sen. 1 m / T_{max}47°C
↪ Int. heat exch.	boiler	15 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.0 m	out 1.6 m	200 (*litres* 45°*C*)/*day*

Solar Coverage Ratio

The contour plot for the mixed angle analysis is illustrated in *Figure* 8.8. The legend on the left side of the figure describes the classification of the colour scheme. The simulation was carried out with the DHW demand profile in *Figure* 5.1.

For an optimal oriented net surface of 5.75 m^2 and a storage size of 300 litres, a SCR of 71.05% is obtained. The specific annual yield for this case is 535.62 kWh/m^2. More details are given in Table 8.4 or in Appendix: Mixed Angle Analyses.

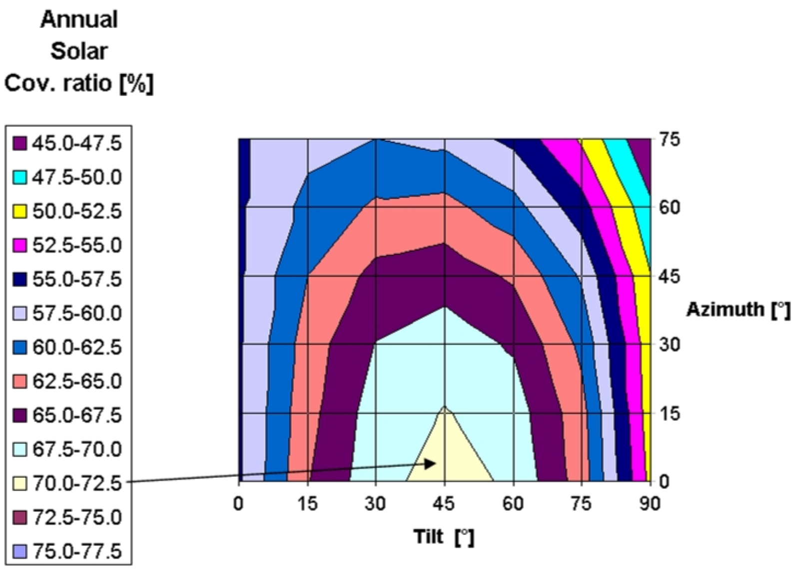


Figure 8.8: Mixed-angle analysis for DHW One Storage Forced Circulation System, optimised for a SFH (45°C; 200 litres/day) in Rijeka.

8.2.3 Comparison of natural and forced circulation

The last two systems are compared in Table 8.4. The simulation was carried out once, for an optimal orientation with the original climate data for Rijeka, and a second time with a modified data set.

The climate data set *Rijeka91* includes solar radiation values lowered by 9% in order to check the outcome for the worst case with regard to the maximal error of solar irradiance values generated by the software Meteonorm [5]. For Forced Circulation, SCR drops by 3.69% and for Natural Circulation by only 3.21%.

[5] Annual variations by natural cause can be approximately 10%.

In conclusion **SCR** changes significantly less than half of the relative change in irradiance. Another elaboration of SCR for different climate data sets is provided at the end of this chapter.

Table 8.4: Comparison of two different DHW One-Storage Systems for a SFH, for original and modified climate data with 91% irradiance; *azimuth*=0°, *tilt*=45°, respectively.

System	Forced Circulation		'Natural' Circulation	
Climate Data	*Rijeka*	*Rijeka91*	*Rijeka*	*Rijeka91*
Results	**Demand**: 200 litres 45°C/day			
Global Radiation [kWh]	8082.70	7355.30	8082.70	7355.30
Operation [h]	2385.10	2385.80	3307.00	3356.30
Q Useful Coll. [kWh]	2907.00	2733.10	3184.20	2996.60
Coll loop loss. [kWh]	228.90	208.80	55.60	49.00
Q Sol. DHW Stor. [kWh]	2678.10	2524.30	3128.60	2947.60
Q aux. DHW Stor. [kWh]	858.00	967.50	665.50	760.50
Q loss. DHW Stor. [kWh]	572.00	527.70	832.70	744.80
Q remov. DHW Stor. [kWh]	2964.10	2964.10	2964.10	2964.10
Q Sol. DHW Stor. spec. [kWh/m^2]	535.62	439.00	544.10	512.63
Coll. Eff. [%]	44.06	44.58	42.22	43.23
Syst. Eff. [%]	35.97	37.16	39.40	40.74
SCR [%]	**71.05**	**67.36**	**77.55**	**74.34**

Remark

Another optional simulation would be the second system, Forced Circulation in combination with a stratification unit and an external heat exchanger. However, it is reasonable to assume approximately the same outcome as the Natural Circulation system yield. This is justified, since the hydraulic design in *Figure* 8.5 would be exactly the same.

Although the pipe losses would increase for a hot water storage tank further displaced from the collector field, i.e. in the basement, the storage losses would slightly decrease in comparison with the storage outside a house.

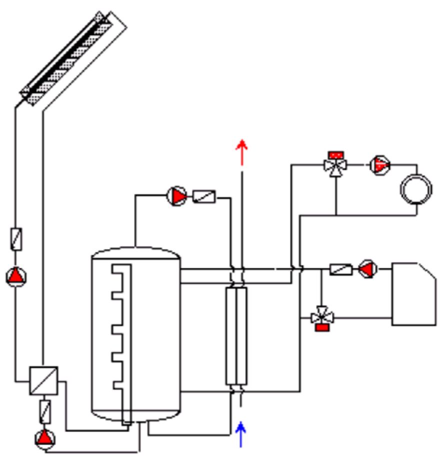


Figure 8.9: Hydraulic design of a solar thermal combisystem with one heat storage, stratification unit, and counter-current heat exchanger [45].

8.3 Combisystem One Storage strat. Unit for SFH

The following solar systems, have previously shown their suitability in real installations.

Combisystem One Storage stratification Unit; DHW preparation with a counter-current heat exchanger (Teilsolare Raumheizung, 1-Speichersystem, Heizkessel in HZ-Speicher, WW-Durchlauferhitzer)

The hydraulic design of this system demonstrates *Figure* 8.9. The fundamental parameters of the template system are provided by Table 8.5. A short German description is provided in Appendix: System Plans.

Since the focus of this work is also on practical topics, the smallest pipe diameter is fixed to be 15 mm. The control strategy of the collector loop is Low Flow, and the diameter of the collector loop pipes will be calculated accordingly. Following this, the closest, practically available standard diameter must be chosen.

Low Flow systems, in general, comprise a stratification unit with an external heat exchanger. The Low Flow rate requires the parallel connection of at least two collectors, to ensure turbulent flow in the collectors. In addition to the formulas provided for certain parameters, design parameters of the template system were based on rules deduced from [43] and practical experience of the author.

Table 8.5: Combisystem One Storage for SFH, solar thermal system description

Collector	Tehnomont_SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Storage tank	1000 litres	aux. source:	SH heater
Heat exchanger	**Stratification Unit**		
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$=0.046 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)

Counter-current heat exchanger in the DHW draw-off loop

The concept 'Combisystem One Storage strat. Unit, DHW preparation with a counter-current heat exchanger', incorporates a counter-flow heat exchanger for just-in-time heating of DHW. For this heat exchanger, the flow rate at the storage side is controlled to achieve the DHW setpoint temperature. In order to size the heat exchanger, some assumptions and calculations are required.

The chosen flow rate corresponds to the action of filling a bathtub, cf.[26].

Inlet temperature storage loop	= 50°C
Arithmetic mean temperature difference	= 10 K
Inlet temperature cold water (DHW loop)	= 10°C
Setpoint DHW temperature	= 40°C
Max. flowrate in the DHW loop	= 14 kg/min (0.23 kg/s)

Given these assumptions, the power required by the heat exchanger can be calculated using the heat capacity of water c_{pH2O}=1.16 kWh/(m^3 K) and its density ρ=1 kg/litre. (14 kg/min $\Rightarrow \dot{V} = 0.840 m^3/h$)

$$\begin{aligned} \dot{Q} &= \dot{V} \cdot c_{pH2O} \cdot \Delta T \\ \dot{Q} &= 0.840\ m^3/h \cdot 1.16\ kWh/(m^3K) \cdot 30\ K = 29.232\ kW \end{aligned} \tag{8.1}$$

Assuming the same capacity flow rate on the primary side, where the fluid is also pure water, and neglecting losses, the above equation yields the supported heat flow from the storage. Using an arithmetic mean temperature difference of 10 K [6] and a specific, overall heat transfer coefficient U of 1000W/(m^2 K), the needed heat exchanger surface becomes

$$\begin{aligned} A &= \frac{\dot{Q}}{U \cdot \Delta T} \\ &= \frac{29.232\ kW}{1000\ W/(m^2K) \cdot 10\ K} \\ &= 2.9232\ m^2\ . \end{aligned} \tag{8.2}$$

For the provision of a secure supply, 4 m^2 for the surface and a maximum flow rate of 0.4 kg/s were chosen. This gives an overall heat transfer coefficient of 4 kW/K . The draw-off loop of the Reference Heating System in [27] has an overall heat transfer coefficient of 5.3 kW/K and a maximum allowed flow rate, on the primary side, of 0.39 kg/s.

External heat exchanger for the stratification unit

Another counter-flow heat exchanger is used, to separate the collector loop and the stratification unit loop. The parameters of this heat exchanger are calculated according to equations (7.13) and (7.14). This yields UaHX$_C$=5963.778 kJ/(h K), or 1656.6 W/K [7]. The assumption of a specific overall heat transfer coefficient of 1000 W/(m^{2}K) leads to the surface A= 1.657 m^2; A= 2m^2 was chosen for the simulation. The secondary mass flow is 0.042 kg/s for a primary mass flow of $\dot{m}_{pri}$=0.046 kg/s.

Heat storage

The storage has a volume of 1.0 m^3, while in [48], the storage volume is 0.75 m^3. The absolute height of the storage is calculated using the equation (8.3), cf. [48]

$$H = Max\left\{Min[2.2, 1.78 + 0.39 \cdot ln(V_S)], 0.8\right\}\ . \tag{8.3}$$

If V_S=1 m^3, this formula leads to H=1.78 m.

In [27], calculation of the value for the absolute height depends only on the volume V and two constants, which are based on data of solar storages sold on the market

$$\begin{aligned} H_{small} &= 0.32 \cdot V_S + 1.65\ , \\ H_{large} &= 0.09302 \cdot V_S + 4.698\ , \\ H &= Min[H_{small}, H_{large}]\ . \end{aligned} \tag{8.4}$$

This set of formulas will be **used for further calculations**. For V_S=1 m^3, the total height is 1.97 m.

When defining the respective pipe connections, it is important to apply a set of general rules. Two fundamentals are:

- Enough auxiliary storage volume for DHW – V_{aux}=200 litres
- In case of a bad SH boiler control enough storage for this heater should be planned to avoid losses in efficiency.

[6] Remark from Supervisor: this is high.

[7] A very simple calculation: UaHX$_C$= $I_g \cdot \bar{\eta}_{Coll} \cdot A_{Field}/\Delta T$, with I$_g$=1000 W/m^2, $\bar{\eta}_{Coll}$=0.45, A$_{Field}$=15m^2 and ΔT=5 K leads to 1350 W/K.

Table 8.6: Heights of in- and outlets and sensors and other parameters for the 1000 litres heat storage.

Description	Parameter values		
Heat sources, **Heat storage** 1000 litres, H=1.97 m			
Solar loop	in strat. unit	out 0.0 m	Sensor 0.1 m
Ext. heat exch.	2 m^2	1000 W/(m^2 K)	0.042 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.75 m
Heat sinks			
DHW loop	in 0.05 m	out 1.97 m	
DHW heat exch.	4 m^2	1000 W/(m^2 K)	0.4 kg/s
SH loop	in 1.0 m	out 1.8 m	

For the specification of the **heights** of the various **out**- and **inlets** it must be considered that the stratification in the heat storage is modelled with a maximum of 10 layers. While defining these parameters, relative heights in [27] and parameters of similar combisystems in [49] were taken as values for orientation.

For V_S=1 m^3 and H≈2 m, any fraction ΔH=0.1 m equals 50 litres. Thus, in order to ensure V_{aux}=200 litres, the second heat sink, the SH draw-off loop, must not be connected above 1.6 m. The volume below the SH inlet is available to store solar thermal energy, and it should be maximised to increase the SCR.

According to [28], SCR should be highest if the SH loop- and the DHW loop inlet are at the bottom of the storage. In fact, simulation results for the 'Combisystem One Storage strat. Unit for SFH' do not support this rule [8]. Placing the inlets below a certain level does not lead to a higher SCR but can even lead to a lower SCR. Table 8.6 summarises the results for all relevant in- and outlets and the respective sensors.

Control parameters (Steuerung)

Collector (Kollektor)

↪ ΔT to start solar energy supply (Temperaturdifferenz für Beginn der solaren Energiezufuhr)
Standard values of ΔT between the collector- and the storage sensor for simple **on-off controls** in solar thermal applications are 5-7 K for the On signal and 3 K for the Off signal, c.f. [2].

- ΔT_{on}, Collector – heat storage sensor (Kollektor - Pufferspeicherfühler) = 5 K
- Hysteresis for turning off (Hysterese für Beenden) = 2 K

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)

- Preference heat storage (Vorrang Pufferspeicher)

Heat storage (Pufferspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 80°C
- Hysteresis turn on (Hysterese)= 1 K

[8] The bottom layer temperature of heat storages is approximately at room temperature if the storage is not heated up completely. This is why space heating return pipe, for which the temperature is in general significantly above room temperature, should not be connected at the bottom of the storage.

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Power (thermal via boiler)SFH I/II/III = 15/12/7 kW
- Max. storage temp. (Max. Speichertemperatur)= 80°C
- Hysteresis turn off (Hysterese)= 5 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW (Kesselenergie zur Warmwasserversorgung)

- Indirectly via the heat storage, DHW provision with continuous flow heat exchanger (In den Pufferspeicher, WW-Erzeugung über Durchlauferhitzer)

8.3.1 Outcome for house type SFH I

The 'Combisystem One storage strat. Unit' will now be applied to a single family house with the particular heat demand for SFH I defined in Table 5.13. The first simulated standard house was SFH II. The results gained from the extensive analyses conducted for SFH II were applied to SFH I, and the following SA are only storage- and field size related. Finally, the requisite angle analysis will also be presented.

Sensitivity analyses

The outcome and graphical support for extensive SA is provided in Appendix: SA Combisystem One Storage. The azimuth angle for the following analyses was 0° and the tilt angle was 45°.

Analysis of the **net collector field area** (Coll. field), which was varied between 5.75-21.1 m^2, shows SCR in the range from 10.91-25.40%, with system efficiency (Syst. Eff.) ranging from 32.06% to 17.52%. The result recommends a size between 9.58 and 15.32 m^2 because up to the first value, the increase of SCR is very steep, and above the second value, the increase of SCR is flat and nearly linear, i.e. the effort/effect ratio is very good within the mentioned range. Notwithstanding the increase of SCR for each collector more is still higher than 1% up to 21.10 m^2, the range above was not analysed. For the optimsed system, a net collector field size of **15.32 m^2** was chosen.

Heat storage size was varied from 0.7 to 1.5 m^3. SCR for the according values ranges from 21.61 to 21.91%. The annual solar yield increases from 4094.40 to 4588.00 kWh and losses of the storage increase parallel. Both changes have linear characteristics and nearly cancel out. This is why an approximately double-sized storage leads to an increase of only 0.31% in SCR. For simplicity, the optimsed system storage size was chosen, as in the template system, to be 1m ^{3}. **700 litres** would be **optimal**.

To keep heat losses minimal, it is vital to choose a storage temperature just high enough to guarantee acceptable working conditions for the SH system. The lowest possible storage temperature, **Max. storage temp.**, for auxiliary heat supply was found to be **75°C** [9].

Optimised system and mixed angle analysis

A mixed angle analysis was carried out for this altered system; the optimised parameters are provided in Table 8.7. The results can be seen clearly in *Figure* 8.10.

The azimuth angle was varied between 0°-75° (0° = south, 90°=east) and the tilt angle between 15°-90°. The scale box on the left side of the plot provides the according

[9] Extensive analysis was not completed.

Solar Coverage Ratio (SCR) for each colour. It decreases from below to the top, and the different colours are in the same order as they appear in the contour plot. SCR is highest for *tilt* between 30° and 80° and *azimuth* between -30° and 30°. Since $SCR(azimuth,tilt)$ is **nearly** a symmetric function with respect to the first argument, the contour plot is also valid for azimuth angles with a negative value, i.e. the *azimuth* variation can be interpreted as a variation of the absolute value.

An optimal orientation leads to a SCR within the range of 22.5-25.0%. The full analysis is summarised in Appendix: Mixed Angle analysis.

Table 8.7: Combisystem One Storage strat. unit, optimised for SFH I.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.046 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 1000 litres, H=1.97m			
Coll. loop	**strat. unit**	out 0.0 m	Sensor 0.1 m, T_{max}=80°C
↪Ext. heat exch.	2 m^2	1000 W/(m^2 K)	$\dot{m}$ =0.042 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.75 m, T_{max}=75°C
↪ direct infusion	boiler	15.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.05 m	out 1.97 m	200 $(litres\ 45°C)/day$
↪Ext.heat exch.	4 m^2	1000 W/(m^2 K)	$\dot{m}$=0.4 kg/s
SH loop	in 1.0 m	out 1.8 m	T_{flow} = 90°C, T_{ret} = 70°C

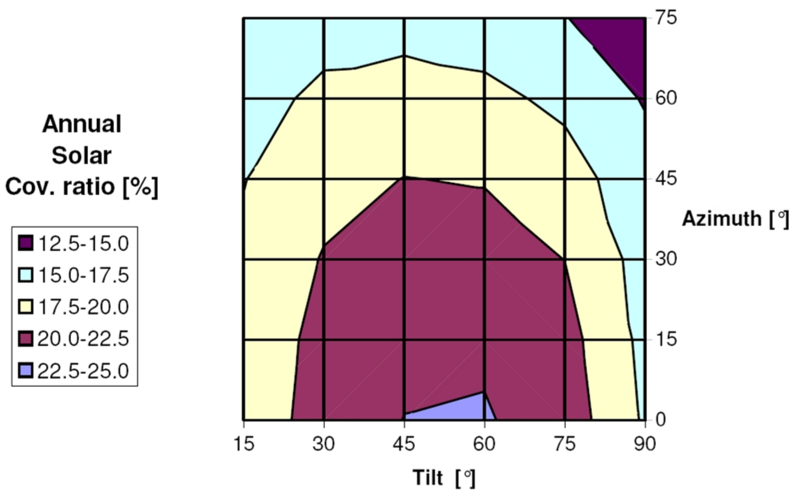


Figure 8.10: Mixed-angle analysis for Combisystem One Storage Strat. Unit, optimised for DHW (45°C; 200 litres/day) and heating need of SFH I in Rijeka.

8.3.2 Outcome for house type SFH II

The first simulation of the defined combisystem with one storage was carried out applying heat demand data of SFH II according to Table 5.13. Consequently, a series of SA were conducted to determine the optimal control parameters and the optimal heights for in- and outlets.

First, the collector field and storage size analyses will be documented. Then, the search for optimal control parameters and ideal SH temperature levels will be presented.

Next, three analyses for a selective coated collector will be shown, and finally, the requisite angle analysis will be presented. The azimuth angle for the following analyses was 0°, and the tilt angle was 45°. The outcome and graphical support for extensive SA is provided in Appendix: SA Combisystem One Storage.

Analysis of the **net collector field area** (Coll. field), which was varied between 5.75-21.1 m^2, shows SCR in the range from 16.29-36.49%. The system efficiency (Syst. Eff.) ranges from 32.36 - 17.33%. The outcome suggests an area between 9.58-15.32 m^2 because, until the first value, the increase of SCR is very steep, and above the second value, the gradient of SCR is nearly linear and not high, i.e. the effort/effect ratio is very good within that range. For the optimsed system, a net collector field size of **15.32 m^2** was chosen.

For the analysis of the **heat storage size**, maximum temperature for second auxiliary supply was 80°C (Max. storage temp.=80°C). The heat storage size was varied from 0.7-1.5 m^3. SCR for the according values range from 31.37 - 32.35%. Annual solar yield increases from 4085.50 to 4616.00 kWh, but also, the losses of the storage increase significantly; both changes have nearly linear characteristics. This is why an approximately double-sized storage leads only to a 0.98% increase in SCR. Above 1 m^3, SCR increases are marginal. A storage size from 0.7 m^3 to 1.0 m^3, therefore, is recommended. The storage size was set as per the template system, **1 m^3**, for the optimsed system.

heating system parameters

To demonstrate how heating system parameters can influence the SCR, the flow- and return temperatures of the SH were investigated. The range was from 55/35°C to 75/55°C.

SCR changes between 32.85% and 31.16%, respectively. Reducing the temperature in the return pipe by 5°C results in an increase of SCR by approximately 0.5%. Details are given in Appendix: SA Combisystem One Storage.

Heating system parameters of SFH II are more advantageous for solar thermal heating compared to the values for SFH I. To minimise the losses, the lowest possible maximum storage temperature, **Max. storage temp.**, for heat supply via the auxiliary heater, must be found iteratively [10]. The optimal value that guarantees a maximum heat coverage ratio (100%) was found to be **67°C**.

For this system, two control parameters of the collector loop were analysed. The first, is the temperature difference between the collector and the heat storage (**ΔT_{on}, Collector – heat storage sensor**) to turn on the pump, and the second is the **hysteresis for turning off** the collector. The analysed ranges were 3.00-7.00 K and 1.00-5.00 K. For both variations, SCR changes only slightly – approximately 0.7%. Because improvements of SCR correspond to parameter values that contradict practical recommendations, the two parameters were not altered for the optimised system.

Selective collector

To demonstrate the alteration of the SCR when using a selective coated absorber, data of the selective reference collector defined in [27] was used. Three simulations were carried out using this fictive collector type. The heat capacity of the absorber was not changed since the given heat capacity in [27] refers to the total collector, i.e. comprises the heat transfer medium, the insulation and the glass cover. Furthermore, the specific fluid content was also unchanged, and it was assumed that the absorber material is copper. The 'new' collector parameters are given in Table 8.8.

[10] Extensive analysis has not been completed.

Table 8.8: Combisystem One Storage for SFH I, solar thermal system description (selective coated absorber)

Collector	Flat-plate selective SHC T32 net surface 15.32 m^2		
Conversion factors	c_0=0.8 , c_1=3.5, c_2=0.015		IAM=0.9
Storage tank	1000 litres	aux. source:	SH heater
Heat exchanger	**Stratification Unit**		
Coll.loop: pipes	Cu: 1.5 mm	d_{Hflow}= 22 mm	d_{Lflow}= 15 mm
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)

Results for the selective coated absorber show nearly no change of SCR in comparison with the Tehnomont SKT-40 collector. The storage size analysis for the system with the selective coated absorber shows an approximately 0.3% higher SCR than that of the system with the Tehnomont SKT-40 collector. Almost the same is true for the net collector field SA, but results were within the range 5.75 to 11.49 m^2, i.e. for very small fields, the selective absorber results in a yield that is 0.54-0.92% higher. The reason for these small differences is the general high efficieny of the absorber from Tehnomont and the low maximum ΔT between collector and storage during the operation [11].

Another analysis carried out with the selective absorber refers to the height of the **SH-loop inlet**. The optimal height variation was set between 0.5 and 1.5 m. SCR decreases as the height increases; it ranges from 33.11 to 31.76%. Plant and collector efficiency stay nearly the same. **0.6 m** was chosen for the optimised system.

Optimised system and mixed angle analysis

Results from all sensitivity analyses were used to alter the system to an optimal system, for which parameters are provided in Table 8.9. For this optimised system, a mixed angle analysis as per SFH I was conducted. The results can be seen in *Figure* 8.11. SCR is highest for *tilt* between 30° and 80° and *azimuth* between –30° and 30°. Optimal orientation leads to a SCR within the range of 32.5-35.0%.

Table 8.9: Combisystem One Storage, optimised for SFH II.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.046 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 1000 litres, H=1.97m			
Coll. loop	**strat. unit**	out 0.0 m	Sensor 0.1 m, T_{max}=80°C
↪Ext. heat exch.	2 m^2	1000 W/(m^2 K)	$\dot{m}$ =0.042 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.75 m, T_{max}=75°C
↪ direct infusion	boiler	12.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.05 m	out 1.97 m	200 (*litres* 45°*C*)/*day*
↪Ext.heat exch.	4 m^2	1000 W/(m^2 K)	$\dot{m}$=0.4 kg/s
SH loop	in 1.0 m	out 1.8 m	T_{flow} = 75°C, T_{ret} = 55°C

Extensive *tilt* analysis

For the optimised system, SCR was examined extensively for various tilt angles. The graphical result can be seen in *Figure* 8.12. The dashed line on the graph refers to the right scale axis – all other lines refer to the left axis.

[11]The incident angle modificator – since it was not given – was chosen to be high.

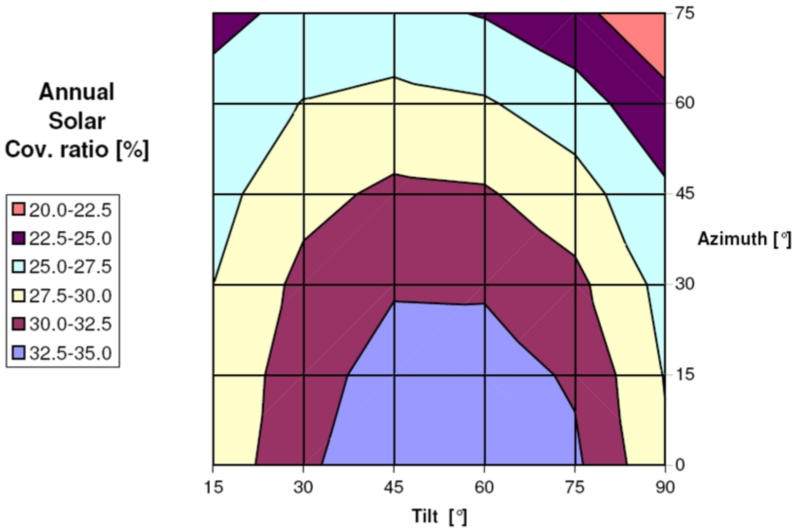


Figure 8.11: Mixed-angle analysis for Combisystem One Storage Strat. Unit, optimised for DHW (45°C; 200 litres/day) and heating need of SFH II in Rijeka.

The highest SCR can be managed with a *tilt* between 50° and 60°. Within a range between 40° and 70° and 35° and 75°, SCR decreases by a maximum 1% point and 2% points respectively, compared to the maximum value at 55°. By contrast, for the system with pure DHW demand, the maximum was at *tilt*=45°.

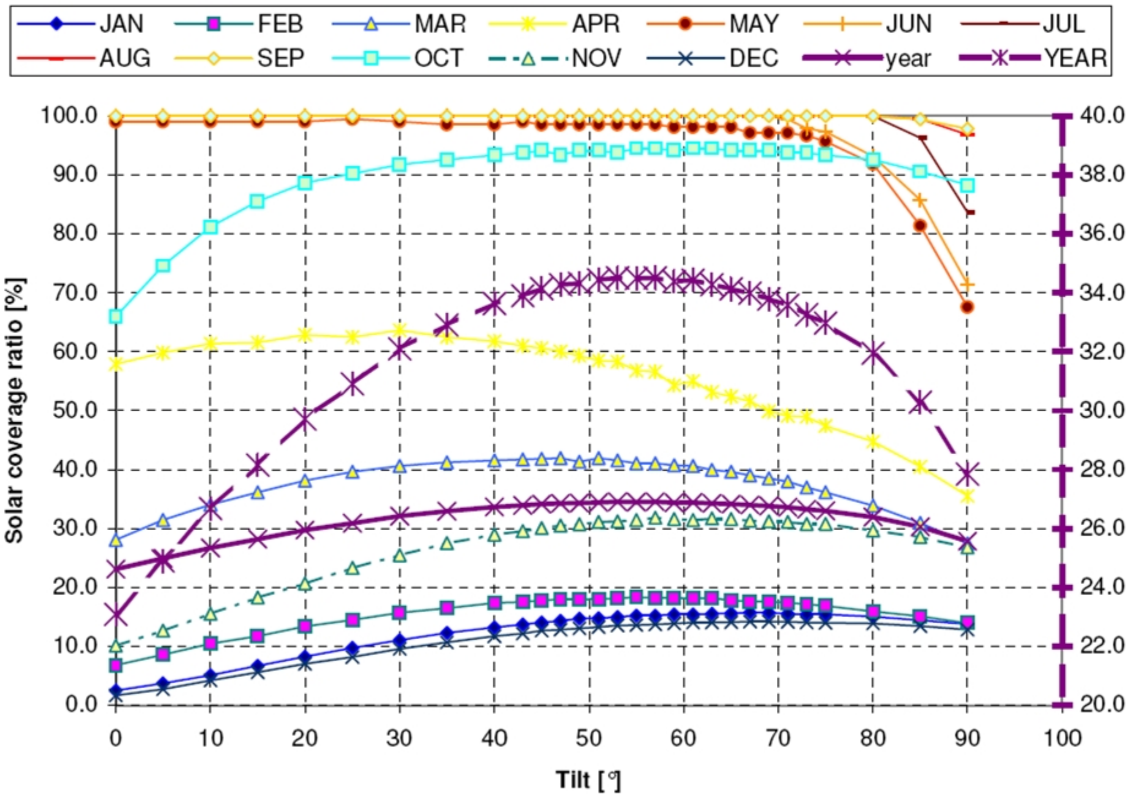


Figure 8.12: Tilt angle analysis for Combisystem One Storage Strat. Unit, optimised for DHW (45°C; 200 litres/day) and heating need of SFH II in Rijeka. The left axis refers to all months and the average SCR over a year. At the right axis, the necessary division to show the annual SCR more clearly is magnified, it refers to the most buckled curve on the graph.

The SCR for various **azimuth** angles was not analysed in detail. From a theoretical point of view, it is clear that a south-facing collector *azimuth*=0° leads to the highest annual yield. *SCR(azimuth)* is nearly a symmetric function, for details see [46].

8.3.3 Outcome for house type SFH III

Important adjustments for SFH III, compared to the standard combisystem with one storage, are different parameters with regard to the SH system, the heat load, the heater (minimum heater temperature = 60°C), and the radiator exponent, (1.1).

In addition, the inlet of the SH loop was altered from 1.0 m to 0.5 m, since the return temperature of the SH is significantly lower than that of SFH I and SFH II, cf. Table 8.6. Trials show a further decrease below 0.5 m does not lead to a significant increase of the SCR. Finally, the better windows have a lower solar heat gain (transmission) coefficient.

Sensitivity analyses

The outcome and graphical support for each SA is provided in Appendix: SA Combisystem One Storage. The azimuth angle for the following analyses was 0°, and the tilt angle was 45°. For the first SA, maximum temperature for the second auxiliary supply was set at 80°C (max. storage temp.=80°C).

Analysis of the **net collector field area** (Coll. field), which varied between 5.75 and 21.1 m^2, shows SCR in the range from 27.85 to 59.23%; the system efficiency (Syst. Eff.) ranges from 33.46 to 17.55%. The outcome recommends a field size between 9.58 and 15.32 m^2. Until the first value, the increase of SCR is very steep, and above the second value, the increase of SCR is nearly linear with a SCR gradient of plus 2.4% for each collector. The effort/effect ratio is very good within the recommended range. For the optimsed system, a net collector field size of **11.49 m^2** was chosen.

For the analysis of the **heat storage size**, maximum temperature for second auxiliary supply was set 70°C (Max. storage temp.=70°C). Heat storage size was varied from 0.7 to 1.5 m^3. SCR for the according values range from 53.56 to 55.80%. The solar yield increases from 4283.50 to 4853.20 kWh, but at the same time, the losses of the storage increase significantly. Both changes have nearly linear characteristics. This explains why an approximately double-sized storage leads to an increase in SCR of only 2.24%. Above $1m^3$, SCR increases are marginal. Therefore, a storage size from 0.7-1.0 m^3 is recommended. For the optimsed system, the storage size was chosen to be the same as for the template system, **$1m^3$**.

It was assumed that a low maximum storage temperature **Max. storage temp.**, when heat supply is provided by the auxiliary heater, could contribute significantly to a higher SCR, and therefore, this parameter was analysed. It was varied within the range from 50 to 80°C. SCR for the according values range from 58.25 to 52.33%. One reason for the diminishing SCR is the increasing storage losses (Q loss Heat) parallel to the temperature of the storage. Another effective reason is a lower solar yield (Q Sol. Stor.) for higher storage temperatures. This can be explained with less low-temperature volume available for solar heating after the auxiliary heater begins operating. Since there are no essential losses in the coverage ratio for heating (Cov.ratio heat), with a low maximum storage temperature for auxiliary heat supply, the optimsed system was chosen such that max. storage temp = **50°C**.

Optimised system and mixed angle analysis

Finally, results from all sensitivity analyses were used to alter the system to an optimal design. For this system, a mixed-angle analysis as per SFH I, was carried out. The results can be seen in *Figure* 8.13.

Table 8.10: Combisystem One Storage, optimised for SFH III.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 11.49 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.046 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 1000 litres, H=1.97m			
Coll. loop	**strat. unit**	out 0.0 m	Sensor 0.1 m, T_{max}=80°C
↪Ext. heat exch.	2 m^2	1000 W/(m^2 K)	$\dot{m}$ =0.042 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.75 m, T_{max}=50°C
↪ direct infusion	boiler	7.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.05 m	out 1.97 m	200 (*litres 45°C*)/*day*
↪Ext.heat exch.	4 m^2	1000 W/(m^2 K)	$\dot{m}$=0.4 kg/s
SH loop	in 0.5 m	out 1.8 m	T_{flow} = 35°C, T_{ret} = 30°C

SCR is highest for a *tilt* between 30° and 80° and an *azimuth* between –30° and 30°. Optimal orientation leads to a SCR within the range of 50.0-52.5%.

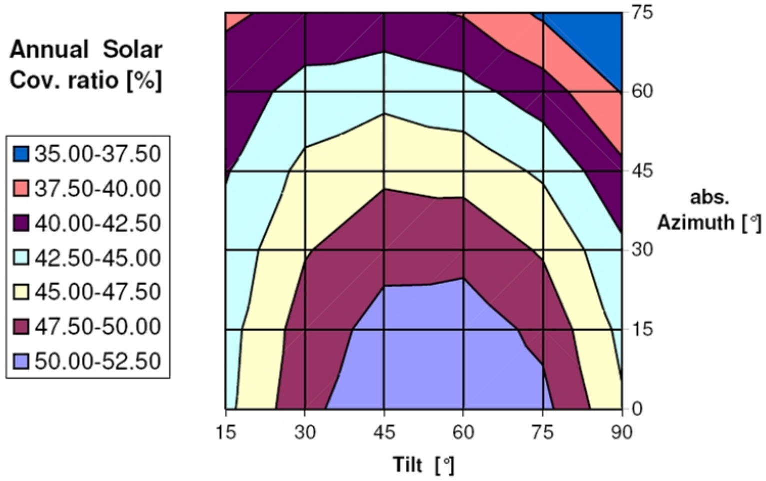


Figure 8.13: Mixed-angle analysis for Combisystem One Storage Strat. Unit, optimised for DHW (45°C; 200 litres/day) and heating need of SFH III in Rijeka.

8.4 Combisystem Two-Storage for SFH

A German description of this system is provided in Appendix: System Plans.

Combisystem Two-Storage, DHW Preparation in DHW Storage

(Teilsolare Raumheizung, 2-Speichersystem, Heizkessel nur in HZ-Speicher)

In *Figure* 8.14, the hydraulic design for the combisystem with a heat storage and additional DHW storage is shown. A secondary auxiliary heat supply from the heater is foreseen for the heat storage only, but the DHW storage allows electrical auxiliary supply. Existing heating systems may incorporate a boiler for heating purposes and a DHW storage with auxiliary heating optional electrical (during summer operation) or employ a boiler during winter. Modernisation measures for such a system, i.e. the installation of a solar system, could lead to a two-storage combisystem very similar to the one proposed here.

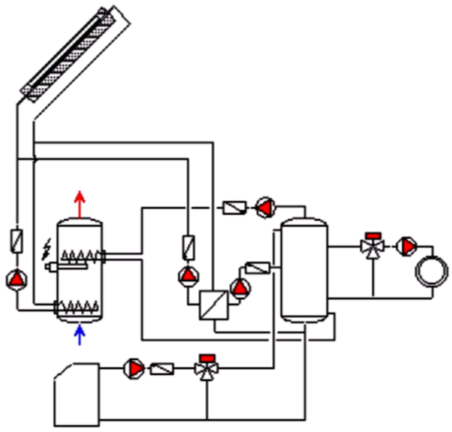


Figure 8.14: Hydraulic design of a solar thermal combisystem with one heat storage and a separate DHW storage [45].

It is a solar combisystem with a DHW storage and a heat storage – each of which can be loaded by solar energy, and there is no priority storage with regard to solar supply. The auxiliary boiler supplies the heat storage only, and therefore, auxiliary supply of the DHW storage is provided by an extra loop connected to the heat storage. Parameters for the heat storage are mainly the same as per the combisystem with one storage. The sensor height for auxiliary supply and the type of heat exchanger in the solar loop, however, are different.

The main parameters for the template system are provided by Table 8.11. Since this work also focuses on practical topics, the smallest pipe diameter was fixed to be 15 mm. The diameter depends mainly on the size of the system and the control strategy of the collector loop (High-Flow or Low-Flow). After the respective calculations of the theoretical value, the closest norm diameter of the pipes must be chosen. The combisystem described here is a **High-Flow** system for the base scenario. Design parameters were based on rules of thumb deduced from [43], and provided in [27], and gleaned from experience of the author.

Table 8.11: Combisystem Two-Storage for SFH, solar thermal system description

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Heat storage	1000 litres, int. heat exch., aux. source: boiler		
DHW storage	250 litres, two int. heat exch., aux. source: Heat storage		
Coll.loop: pipes	Cu: 1.5 mm	d_{Hflow}= 22 mm	$\dot{m}$ =0.20 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)

DHW- and heat storage

According to equation (8.4) the height of the DHW storage is 1.73 m. With the corresponding diameter from equation (7.11), it follows $\bar{\lambda}_{Storage} = 2\ W/(m \cdot K)$. Heat storage vertical conduction coefficient is the same as for the one storage combisystem.

Heat exchangers

This concept involves two internal heat exchangers in the DHW storage and one heat exchanger in the heat storage.

According to [43], a specific overall heat transfer coefficient of 50 W/($m^2_{Coll} \cdot K$) was assumed for the solar loop heat exchangers. If A_{Field} = 15.32 m^2, this gives 766 W/K, and assuming the heat exchanger surface to be 2 m^2, a **specific heat transfer coefficient** of 383 W/($m^2 \cdot K$) is achieved. For the DHW and the heat storage, 400 W/($m^2 \cdot K$) was chosen. The second heat exchanger, in the DHW storage for auxiliary supply, has the same parameters.

First, the position of the collector control sensor was chosen in the middle of the solar heat exchanger. A short SA showed an optimal position for this sensor at a relative height of approximately one third of the heat exchanger height.

Heights of in- and outlets

The heights of in and outlets for the two storages are given in Table 8.12.

Table 8.12: Heights of in-, outlets, and sensors for the 250 litres DHW storage, the 1000 litres heat storage, and other parameters.

Description	**Parameters and respective values**		
Heat sources – **Heat storage**: 1000 litres, height 1.97 m			
Coll. loop	in 0.1 m	out 0.4 m	Sensor 0.15 m
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$ =0.20 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.70 m, $\dot{m}$=0.38 kg/s
Heat sinks			
DHW storage	in 0.05 m	out 1.97 m	
SH loop	in 1.0 m	out 1.8 m	
Heat sources – **DHW storage**: 250 litres, height 1.73 m			
Coll. loop	in 0.3 m	out 0.1 m	Sensor 0.16 m
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.20 kg/s
Aux. loop	in 0.8 m	out 0.6 m	Sensor 0.80 m
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW loop	in 0.10 m	out 1.73 m	

Control parameters (Steuerung)

Subsequently, the control parameters that switch the respective pumps for heat energy supply on and off will be described for the case of the two-storage combisystem.

Collector (Kollektor)

↪ ΔT to start solar energy supply (Temperaturdifferenz für Beginn der solaren Energiezufuhr), Standard values of ΔT between the collector- and the storage sensor for simple **on-off controls** in solar thermal applications are 5-7 K for the On signal and approximately 3 K for the off signal, cf. [2].

- ΔT_{on}, Collector – DHW storage sensor (Kollektor – Warmwasserspeicherfühler) = 5 K
- ΔT_{on}, Collector – heat storage sensor (Kollektor – Pufferspeicherfühler) = 5 K
- Hysteresis for turning off (Hysterese für Beenden)= 2 K

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)
An analysis in [43] demonstrates no preference leads to the highest total solar coverage ratio for systems with two storages.

- No preference (Gleichrang)

DHW storage (Warmwasserspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)
- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 50°C
- Hysteresis turn on (Hysterese) = 1 K

↪ Second auxiliary heating (Zufuhr von Kesselenergie)In this case, second auxiliary heating refers to the energy transfer from the heat storage to the DHW storage [12].

- Max. storage temp. (Max. Speichertemperatur) = 45°C
- Hysteresis turn off (Hysterese) = 1 K

Heat storage (Pufferspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 95°C
- Hysteresis turn on (Hysterese) = 1 K
- Δ T between heat storage and DHW storage to start loading the DHW storage (Temperaturdifferenz zum Laden des WW-Speichers)[°C] = 2 K

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Power (thermal via boiler)SFH I/II/III = 15/12/7 kW
- Max. storage temp. (Max. Speichertemperatur)= 75°C
- Hysteresis turn off (Hysterese)= 5 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW(Kesselenergie zur Warmwasserversorgung)
- Indirectly via the heat storage, DHW provision elsewhere (In den Pufferspeicher, WW-Erzeugung über eigenen Kreis)

8.4.1 Outcome for house type SFH I

Sensitivity analyses

The detailed outcome and graphical support for the SA is provided in Appendix SA Combisystem Two-Storage. The azimuth angle for the following analyses was 0°, and the tilt angle was 50°.

Analysis of the **net collector field area** (Coll. field), which was varied between 5.75-21.1 m^2, shows overall SCR in the range from 9.28 to 23.19%. SCR for DHW ranges from 31.31 to 60.13%, and the according SCR for SH has the range 3.80-14.01%. The system efficiency is between 32.94 and 18.44%. The result recommends a size between 9.58 and 15.32 m^2 because, the effort/effect ratio is very good within that range. The increase of

[12]The German label is not completely correct.

SCR for each collector up to 21.10 m^2 is still higher than 1%: the range above was not analysed. For the optimsed system a net collector field size of **15.32 m^2** was chosen.

Heat storage size was varied from 0.7 to 1.5 m^3. Overall SCR for the according values range from 19.31 to 19.53%. SCR for DHW ranges from 53.01 to 53.93%, and the according SCR for SH stays nearly constant at 11%. Solar yield increases from 4242.00 to 4718.60 kWh, but losses of the storage increase significantly. Both changes have close to linear characteristics and nearly cancel out. This is why an approximate double-sized storage leads to an increase in SCR by only 0.22%. The storage size was chosen to be the same as per the template system, **1m^3**, for the optimsed system. The slight increase and decrease of the SCR at 1 m^3 is assumed to be connected with the required parameter adaption needed to guarantee a consistent set of parameters; there is no reasonable explanation for this behaviour.

DHW storage

Variation of the **DHW storage size** was between 200 litres and 500 litres. The SA showed what is stated in [28], the greater the volume the higher SCR. Since it was assumed that this system is installed in line with modernisation measures, the DHW storage volume for the optimised system will not be changed. However, for a new system, DHW storage volume should be within 300 and 500 litres, since SCR increases significantly up to 500 litres.

The optimal height for the internal **auxiliary heat exchanger** is, according to [28], approximately 2/3 of the storage height. Since auxiliary heat supply implies some time-delay sufficient auxiliary volume in the DHW storage needs to be planned for the case of high flow rates in the drain-off loop.

Optimised system and mixed-angle analysis

Since the conducted analyses brought no change, the optimised system is as per the template system. Parameters for this optimised system are summarised in Table 8.13.

Table 8.13: Combisystem Two-Storage, optimised for SFH I.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Hflow}= 22 mm	$\dot{m}$ =0.20 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
***Heat sources*–heat storage** 1000 litres, H=1.97m			
Coll. loop	in 0.1 m	out 0.4 m	Sensor 0.15 m, T_{max}=95°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$ =0.20 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.70 m, T_{max}=75°C
↪ direct infusion	boiler	15.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW storage	in 0.05 m	out 1.97 m	
SH loop	in 1.0 m	out 1.8 m	T_{flow} = 90°C, T_{ret} = 70°C
***Heat sources* –DHW storage**: 250 litres, H= 1.73m, aux. supply via heat storage			
Coll. loop	in 0.3 m	out 0.1 m	Sensor 0.16 m, T_{max}=50°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.20 kg/s
Aux. loop	in 0.8 m	out 0.6 m	Sensor 0.80 m, T_{max}=45°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW loop	in 0.10 m	out 1.73 m	200 $(litres\ 45°C)/day$

The results for the mixed-angle analysis can be seen clearly in *Figure* 8.15. The azimuth angle was varied between 0° and 75° (0° = south, 90°=east) and tilt angle between 15° and 90°. The legend on the left side of the plot describes each colour according to the SCR. SCR decreases from below to the top, and the different colours are in the same order as they appear in the contour plot. SCR is highest for *tilt* between 30° and 80° and *azimuth* between –30° and 30°.

An optimal orientation leads to an overall SCR within the range of 17.5 and 20.0%. The full analysis is summarised in Appendix: Mixed Angle Analysis. In contrast to the one storage combisystem, overall SCR is on average approximately 2% points less. The reason for this might be the different equipment mainly the simpler internal heat exchanger in use. The one storage system comprised a special stratification unit with an external heat exchanger.

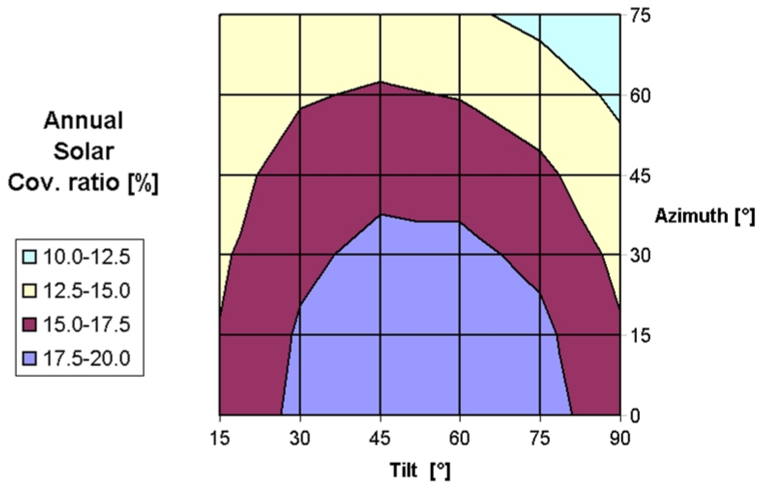


Figure 8.15: Mixed-angle analysis for Combisystem Two-Storage, optimised for DHW (45°C; 200 litres/day) and heating need of SFH I in Rijeka.

8.4.2 Outcome for house type SFH II

The combisystem with one storage was analysed extensively for this type of house, therefore, some parameters, such as SH loop inlet height, and T_{max} for auxiliary supply, which was set to 67°C (Max. storage temp.=67°C), may be copied for the two-storage combisystem. The collector field and storage size analyses, however, will be conducted as usual. The azimuth angle for the coming analyses was 0°, and the tilt angle was 50°.

Sensitivity analyses

The outcome and graphical support for extensive SA is provided in Appendix SA Combisystem Two-Storage. Analysis of the **net collector field area** (Coll. field), which was varied between 5.75 and 21.1 m^2, shows overall SCR in the range from 14.05 to 33.70%. The system efficiency (Syst. Eff.) ranges from 18.80 to 33.43%. The outcome suggests a surface area between 11.49 and 19.15 m^2, because until the first value, the increase of SCR is very steep, and until the second value, the gradient of SCR is reasonable – even between 19.15 and 21.10 m^2, SCR changes by 1.50%. The effort/effect ratio is good within the recommended range. For the optimsed system, a net collector field size of **17.24 m^2** was chosen.

For the analysis of the heat storage size, the field area of 15.32 m^2 was chosen. Heat storage size was varied from 0.7 to 1.5 m^3. SCR for the according values range from 27.59 to 28.98%. Annual solar yield increases from 4292.70 to 4834.80 kWh, but the losses of the storage also increase. Both changes have nearly linear characteristic and partly cancel out. An approximate double sized storage leads to an increase in SCR by 1.27% only. Above 1 m^3, SCR does not change, a storage size between 0.7 m^3 and 1.0 m^3 is recommended. The storage size was set as per the template system, for the optimsed system **1 m^3**.

Optimised system and mixed-angle analysis

Finally, the results from the former sensitivity analyses were used to alter the combisystem to an optimal system for which parameters are provided in Table 8.14. For this optimised system, a mixed-angle analysis, following the same angle variations as per SFH I, was carried out. The results can be seen in *Figure* 8.16.

SCR is highest for *tilt* between 30° and 80° and *azimuth* between –30° and 30°. Optimal orientation leads to a SCR within the range of 30.0 to 27.50%. Although the collector surface was increased for this system, the SCR is slightly smaller than for the combisystem with one storage and stratification unit.

Table 8.14: Combisystem Two-Storage, optimised for SFH II.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 17.24 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Hflow}= 22 mm	$\dot{m}$ =0.20 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 1000 litres, H=1.97m			
Coll. loop	in 0.1 m	out 0.4 m	Sensor 0.15 m, T_{max}=95°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$ =0.20 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.70 m, T_{max}=67°C
↪ direct infusion	boiler	12.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW storage	in 0.05 m	out 1.97 m	
SH loop	in 0.6 m	out 1.8 m	T_{flow} = 75°C, T_{ret} = 55°C
Heat sources –**DHW storage**: 250 litres, H= 1.73 m, aux. supply via heat storage			
Coll. loop	in 0.3 m	out 0.1 m	Sensor 0.16 m, T_{max}=50°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.20 kg/s
Aux. loop	in 0.8 m	out 0.6 m	Sensor 0.80 m, T_{max}=45°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW loop	in 0.10 m	out 1.73 m	200 $(litres\ 45°C)/day$

8.4.3 Outcome for house type SFH III

Important adjustments for SFH III, compared to the other single family houses, are different parameters with regard to the SH system, heat load, heater – minimum heater temperature = 60°C, max. storage temp.=50°C for second auxiliary supply to lower the storage losses – and the radiator exponent (1.1). As for the one-storage combisystem, the inlet of the SH loop is 0.5 m instead of 1.0 m (as in Table 8.6), because the return temperature for SH is significantly lower than that for SFH I and SFH II. Finally, the better windows have a lower solar heat gain (transmission) coefficient. The azimuth angle for the following analyses was 0°, and the tilt angle was 50°.

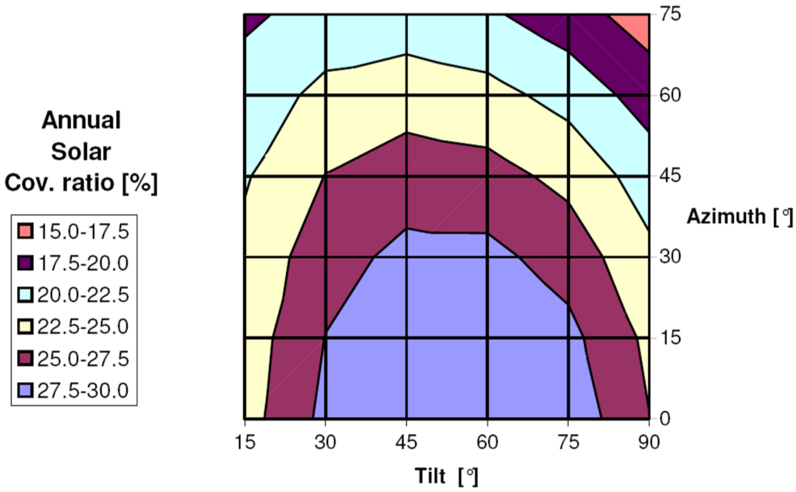


Figure 8.16: Mixed-angle analysis for Combisystem Two-Storage, optimised for DHW (45°C; 200 litres/day) and heating need of SFH II, in Rijeka.

Sensitivity analyses

The outcome and graphical support for each SA is provided in Appendix: SA Combisystem Two-Storage. Analysis of the **net collector field area** (Coll. field), which was varied between 5.75 and 21.1 m^2, shows SCR in the range from 26.94 to 57.99%; the system efficiency (Syst. Eff.) ranges from 34.37 to 19.04%. The outcome recommends a field size between 9.58 and 19.15 m^2. Up to the first value, the increase of SCR is very steep, and above the second value the increase of SCR becomes more constant. The effort/effect ratio is very good within that range. A net collector field size of **15.32 m^2** was chosen for the optimsed system.

For the analysis of the **heat storage size**, storage size was varied from 0.7 to 1.5 m^3. SCR for the according values range from 48.85 to 51.26%. The solar yield increases from 4419.40 to 4959.80 kWh, but parallel heat losses in the storage increase at approximately the same rate. This explains why an approximate double-sized storage leads to an increase in SCR of only 2.19%. The sudden jump in the SCR when the storage size is altered from 0.9 to 1 m^3, is due to parameter adaptions of in- and outlets at the heat storage, required to assure a consistent set of parameters; above 1m^3, SCR stays nearly constant. Therefore, a storage size between 0.7 and 1.0 m^3 is recommended. The storage size was chosen to be the same as per the template system, **1m^3**, for the optimsed system.

Optimised system and mixed-angle analysis

Finally, results from all sensitivity analyses were used to alter the system toward an optimal system. For this, a mixed-angle analysis following the same angle variations as per SFH I was carried out; parameters follow Table 8.15. The results of the angle analysis can be seen in *Figure* 8.17. SCR is highest for a *tilt* between 30 and 80° and an *azimuth* between –30° and 30°. Optimal orientation leads to a SCR of approximately 50.0%.

8.5 Sim. for tourist accommodations (ACC)

In order to define the typical DHW consumption profiles for these applications, the general annual distribution of tourist traffic in PGC was analysed. This distribution is shown in

Table 8.15: Combisystem Two-Storage, optimised for SFH III.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 15.32 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d$_{Hflow}$= 22 mm	$\dot{m}$ =0.20 kg/s
Coll.loop	length 30 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 1000 litres, H=1.97m			
Coll. loop	in 0.1 m	out 0.4 m	Sensor 0.15 m, T$_{max}$=95°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$ =0.20 kg/s
Aux. loop	in 1.9 m	out 1.55 m	Sensor 1.70 m, T$_{max}$=50°C
↪ direct infusion	boiler	7.0 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW storage	in 0.05 m	out 1.97 m	
SH loop	in 0.5 m	out 1.8 m	T_{flow} = 35°C, T_{ret} = 30°C
Heat sources –**DHW storage**: 250 litres, H= 1.73 m, aux. supply via heat storage			
Coll. loop	in 0.3 m	out 0.1 m	Sensor 0.16 m, T$_{max}$=50°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.20 kg/s
Aux. loop	in 0.8 m	out 0.6 m	Sensor 0.80 m, T$_{max}$=45°C
↪Int. heat exch.	2 m^2	400 W/(m^2 K)	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW loop	in 0.10 m	out 1.73 m	200 (*litres* 45°*C*)/*day*

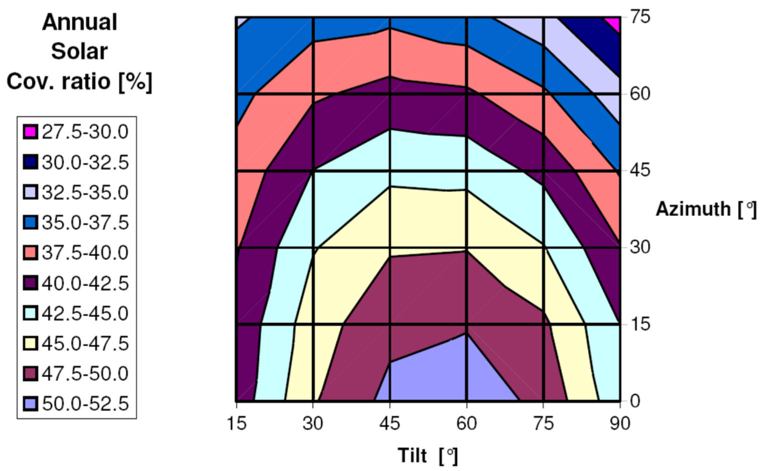


Figure 8.17: Mixed-angle analysis for Combisystem Two-Storage, optimised for DHW (45°C; 200 litres/day) and heating need of SFH III, in Rijeka.

Table 5.6. In 2008, the absolute number of overnight stays is 11 263 755: the island Krk is responsible for one third of this total. The months between May and September account for 91.0% of the annual overnight stays. The months July and August have the highest share; in 2008, this is 31.0% and 31.9%, respectively.

For the DHW demand analysis in the tourism sector analysed and discussed in the first chapter of Part II, three fictive consumer classes for tourist accommodations, with a daily demand per guest of 60, 40 and 20 litres of 60°C hot water, respectively, were defined, cf. Table 5.11, p.54. Furthermore, the concept of nominal daily summer demand was introduced. Technical data referring to DHW preparation for the three defined standard tourist accommodation facilities ACC S, ACC M and ACC L are listed in Table 5.12, cf. p.56.

The daily, weekly, and monthly demand profiles for different accommodations deviate with respect to the monthly distribution. This is due to different facility utilisation factors

$FU_{F(S)}$, or FU_F. The relative annual DHW demand and the monthly demand profiles for eight different facility utilisation factors are provided in Appendix: Annual Demand Profiles.

In order to analyse the characteristics of solar thermal systems in tourism branches for DHW preparation, two template systems will be designed. The main difference between these is the heat storage concept.

Type of DHW-consumption (Art des WW Verbrauches)

For the hourly DHW consumption profile provided, two optional consumptions are possible. The second, highlighted option will be chosen for any applications in tourist housing.

- Completely at the first step (Vollständig am ersten Simulationsschritt)– this option is recommended for small solar thermal systems
- **Distributed equally over one hour (Gleichmäßig über die Stunde)**

8.5.1 DHW One-Storage System – general

The software SHWwin provides concepts for DHW systems that must be obeyed. Parameter variation, however, is possible for all parts used that set up the according system. A short German description of the following system is provided in Appendix: System Plans. *Figure* 8.18 shows the hydraulic design for the selected system. In principle, it is the same as the 'natural' circulation system.

DHW One-Storage System with counter-current heat exchanger for DHW preparation (Solare Brauchwassererwärmung mit Pufferspeicher und Durchlauferhitzer)

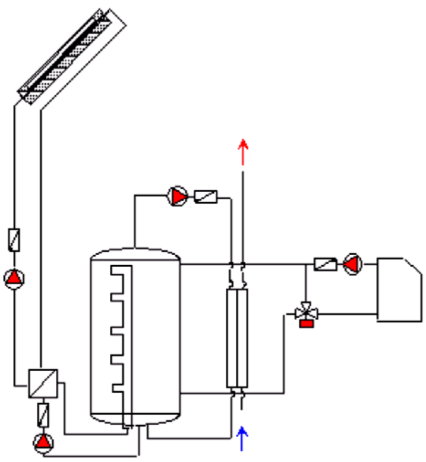


Figure 8.18: Hydraulic design of a solar thermal system for DHW preparation with one heat storage, stratification unit, and counter-current heat exchanger [45].

This template system is assumed to be used for commercial purposes, it is similar to the one-storage combisystem with counter-current heat exchanger, although the only heat sink is the DHW draw-off loop.

For the counter-current heat exchanger in the DHW draw-off loop, surface area and flow rate values must be chosen according to the maximum expected demand. However, since it is very unlikely that all guests consume DHW at the same time, a simultaneity factor, which lowers the maximal flow rate at a given time, can be taken into account (Verbrauch=Gleichmässig über die Stunde).

The auxiliary heat supply was assumed to be covered with an existing oil or gas boiler with parameters similar to the SFH I one-storage combisystem. The system concept, one-storage with a counter-current heat exchanger, does not bear any danger of legionella colony formation because hot water heating is at the time of consumption.

Control parameters (Steuerung)

Collector (Kollektor)

↪ ΔT to start solar energy supply (Temperaturdifferenz für Beginn der solaren Energiezufuhr)
Standard values of ΔT between the collector- and the storage sensor for simple **on-off controls** in solar thermal applications are 5-7 K for the On signal and 3 K for the Off signal, cf. [2].

- ΔT_{on}, Collector – heat storage sensor (Kollektor - Pufferspeicherfühler)= 5°C
- Hysteresis for turning off (Hysterese für Beenden)= 2°C

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)

According to an analysis in [43] no preference leads to the highest solar coverage ratio for systems with two storages.

- **No preference** (Gleichrang)

Heat storage (Pufferspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 80°C
- Hysteresis turn on (Hysterese)= 1 K

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Max. storage temp. (Max. Speichertemperatur) = 65°C
- Hysteresis turn on (Hysterese)= 5 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW (Kesselenergie zur Warmwasserversorgung)

- Indirectly via the heat storage, DHW provision with continuous flow heat exchanger (In den Pufferspeicher, WW-Erzeugung über Durchlauferhitzer)

8.5.2 DHW One-Storage System for small-size ACC

This template system was designed for private accommodation – local residents who rent out apartments or rooms to tourists – where $FU_{F(S)} = 0.25$. In addition to the DHW demand of the guests (here maximum 16), the private DHW demand of four residents is taken into account. Hence, the nominal summer demand ($Q_{dem(S)}$) of the standard solar thermal system was projected to be 16 · 40 litres · 0.25 + (4 · 40 litres) which yields 320 litres. According to the **nomograph** [25] for tourist facilities that provides $SCR_{(May-Sept)}$ as a function of the specific collector load, it is reasonable to assume 25 $(litres\ 60°C)/m^2$.

With this choice considering the Austrian climate, $SCR_{(May-Sept)}$ would be approximately 58%. Furthermore, 60 litres/ m^2 for the storage are projected [25]. This yields

$$A_{Field} = \frac{320\ litres}{25\ litres/m^2} = 12.8\ m^2 \quad (8.5)$$

$$\Rightarrow V_{Storage} = 12.8\ m^2 \cdot 60\ litres/m^2 = 768\ litres\ . \quad (8.6)$$

For the counter-current heat exchanger in the DHW draw-off loop, surface area and flow rate values are chosen to be 1.5 times higher than the combisystem with single storage for SFH use.

Table 8.16: DHW One-Storage System, prototypical for small-size accommodations (ACC S) $FU_{F(S)}$=0.25.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 13.41 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.040 kg/s
Coll.loop	length 40 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 800 litres, H=1.9 m, $\lambda_{Storage}$= 1.5 W/(m K)			
Coll. loop	in strat. unit	out 0.0 m	Sen. 0.1 m/T_{max}80°C
↪Ext. heat exch.	2.0 m^2	1000 W/(m^2 K)	$\dot{m}$=0.037 kg/s
Aux. loop	in 1.8 m	out 1.40 m	Sen. 1.73 m/T_{max}65°C
↪ direct infusion	boiler	15 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.05 m	out 1.9 m	320 (*litres* 60°*C*)/*day*
↪Ext. heat exch.	6 m^2	1000 W/(m^2 K)	$\dot{m}$=0.60 kg/s

8.5.3 Outcome for type ACC S – $FU_{F(S)}$=0.25

Sensitivity analyses

A brief report on the following SA is provided in Appendix SA tourist DHW – One Storage. The azimuth angle for the following analyses was 0°, and the tilt angle was 45°.

The net collector field area was varied between 5.75 and 22.98 m^2 to analyse the SCR, which ranges from 54.13 to 98.03%, respectively. The according system efficiency ranges from 36.50 to 17.59%. For the summer term, SCR is even higher; $SCR_{(May-Sep)}$ ranges from 63.72 to 99.95%. System and collector efficiency decrease as the collector field increases. The outcome recommends a net collector field size between 9.58 and 13.41 m^2, because until the first value, the increase of SCR is very steep, and above the second value, the gradient of SCR is only 0.5% per m^2, therefore, the effort/effect ratio is very good within that range. A net collector field size of **11.49 m²** was chosen for the optimised system.

The heat storage size was varied between 0.3 and 1.9 m^3. Meanwhile, the collector field size was altered to **11.49 m²**. SCR ranges from 85.10 to 88.96%, that is, it varies only sligthly. Any size above 700 and up to 1300 litres leads to a SCR of 88%. Storage sizes above 1300 litres show higher losses that compensate for the additional gain. $SCR_{(May-Sep)}$ is highest for 700 and 900 litres storage, namely 96%. DHW coverage ratio is above 99.90% for any storage size, though up to 1100 litres the minimum draw-off temperature is below 50°C. The storage size was chosen to be **0.8 m³** for the optimised system. This ensures a specific annual yield of 400 kWh/m^2 in connection with a net field of 11.49 m^2.

Angle analysis for ACC S

In *Figure* 8.19, the annual SCR is illustrated for various *tilt* and *azimuth* combinations for a net collector field of $A_{Field} = 11.49m^2$. This two-dimensional plot is less smooth compared to *Figure* 8.13. One reason for this could be the large grid-size of 15°, however, the essential information is contained. The legend on the left demonstrates the ranges to which each colour of the contour refers. $\text{SCR}_{(May-Sep)}$ is expected to show a more advantageous contour plot for angle combinations near the optimum.

Compared to the outcome from the nomograph provided by [25], SCR for Rijeka is about

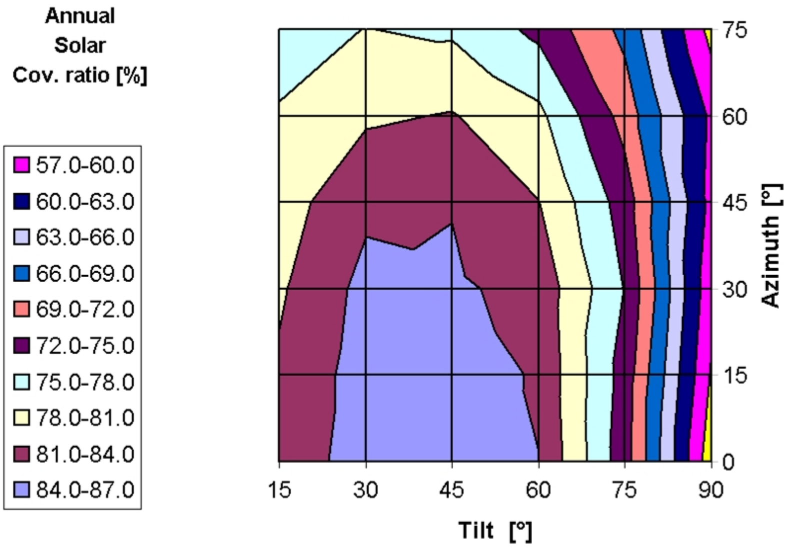


Figure 8.19: Mixed-angle analysis for DHW One-Storage System, optimised for DHW demand (60°C; 320 litres/day) provided for ACC S with $\text{FU}_{F(S)}$=0.25 in Rijeka; V_S=0.8 m^3, $A_{Field} = 11.49$ m^2.

25% higher for the according DHW load/ m^2 [13]. The parameters for the optimised system are provided in Table 8.17.

Table 8.17: DHW One-Storage System, optimised for small-size accommodations (ACC S), $\text{FU}_{F(S)}$=0.25.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 11.49 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 1.5 mm	d_{Lflow}= 15 mm	$\dot{m}$ =0.040 kg/s
Coll.loop	length 40 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 800 litres, H=1.9 m, $\lambda_{Storage}$= 1.5 W/(m K)			
Coll. loop	in strat. unit	out 0.0 m	Sen. 0.1 m/T_{max}80°C
↪Ext. heat exch.	2.0 m^2	1000 W/(m^2 K)	$\dot{m}$=0.037 kg/s
Aux. loop	in 1.8 m	out 1.40 m	Sen. 1.73 m/T_{max}65°C
↪ direct infusion	boiler	15 kW	$\dot{m}$=0.38 kg/s
Heat sinks			
DHW	in 0.05 m	out 1.9 m	320 (*litres* 60°*C*)/*day*
↪Ext. heat exch.	6 m^2	1000 W/(m^2 K)	$\dot{m}$=0.60 kg/s

[13] The nomograph may be shifted by 25% along the y-axis.

8.5.4 DHW Two-Storage System – general

A short German description of the following system is provided in Appendix: System Plans.

DHW Two-Storage System with heat storage and small DHW storage [Solare Brauchwassererwärmung mit 2 Speichern (Pufferspeicher und kleiner Brauchwasserspeicher)]

Figure 8.20 illustrates the hydraulic design of the DHW Two-Storage System. Auxiliary heat supply is provided via the electrical immersion heater included in the DHW storage.

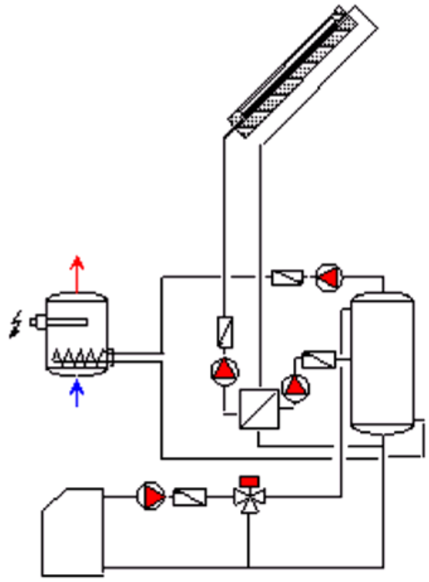


Figure 8.20: Hydraulic design of a solar thermal system for DHW preparation with one heat storage and a small DHW storage [45].

8.5.5 DHW Two-Storage System for medium-size ACC

This template system is assumed for commercial use. Camps, hostels, sanatoria, or small hotels could install such a system – accommodations where the DHW demand is already significantly higher than for private purposes.

The system comprises of one heat storage with an internal heat exchanger for the solar loop and one small DHW storage with an auxiliary electrical immersion heater. It was assumed that there is no additional heater available, therefore, auxiliary heat supply is provided only in the DHW storage. This storage has ordinary thermal insulation. By contrast, the insulation of the heat storage is 0.3 m, which decreases heat loss, cf. [43].

A matched flow control concept was chosen, namely a constant ΔT=6 K in the collector field. DHW consumption with respect to the defined demand profile is assumed to occur with equal distribution over one hour.

The system was designed and simulated for a camp with a capacity of 200 beds. With the DHW demand of 20 litres per guest and $FU_{F(S)}$=0.41, the nominal summer demand is $V_{dem(S)}$ = 1640 litres. Furthermore 60 litres storage volume per square metre were projected, using the **nomograph** cf. [25]. The DHW demand profile differs with respect to the monthly distribution shown in *Figure* 5.2 because the $FU_{F(S)}$ is different. The monthly distribution is provided in Appendix: Annual Demand Profiles.

The following calculations were carried out for the collector field and the storage capacity design;

$$\begin{aligned} A_{Field} &= \frac{1640\, litres}{25\, litres/m^2} \\ &= 65.6\, m^2 \qquad (8.7) \\ \Rightarrow V_{Storage} &= 65.6\, m^2 \cdot 60\, litres/m^2 \\ &= 3936\, litres\,. \qquad (8.8) \end{aligned}$$

All parameters for the prototypical template system are provided in Table 8.18.

Table 8.18: DHW Two-Storage System, prototypical for medium-size accommodations (ACC M).

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 65.11 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 2.0 mm	d_{Hflow}= 42 mm	$\dot{m}$ =0.26-0.85 kg/s
Coll.loop	length 40 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 3936 litres, H=2.9 m, $\lambda_{Storage}$= 1.2 W/(m K)			
Coll. loop	in 1 m	out 0.1 m	Sen. 0.15 m/T_{max}93°C
↪ Int. heat exch.	6 m^2	543 W/(m^2 K)	$\dot{m}$ =0.26-0.85 kg/s
Heat sinks			
DHW storage	in 0.1 m	out 2.9 m	on if Δ T≥2 K
Heat sources –**DHW storage**: 500 litres, H= 1.8m, $\lambda_{Storage}$= 1.8 W/(m K)			
Heat storage	in 0.1 m	out 0.6 m	Sen. 0.15 m/T_{max}60°C
↪Int. heat exch.	1.5 m^2	500 W/(m^2 K)	
Aux. electrical	in 0.7 m	10 kW	Sen. 0.8 m/T_{max}60°C
Heat sinks			
DHW loop	in 0.10 m	out 1.80 m	1640 (*litres* 60°*C*)/*day*

Control parameters (Steuerung)

The following bullet points give relevant parameters for the solar thermal system design with reference to the control of the system.

Collector (Kollektor)

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)
The DHW storage is not loaded directly with solar energy from the collector field for this system but indirectly through the heat storage.

- Preference heat storage (Vorrang Pufferspeicher)

DHW storage (Warmwasserspeicher)

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 0°C

↪ Second auxiliary heating

In this context, the next set of parameters refer to the energy supply of the DHW storage from the heat storage.

- Max. storage temp. (Max. Speichertemperatur)= 60°C
- Hysteresis turn on (Hysterese)= 2 K

↪ Auxiliary heating, electrical (Zufuhr von elektrischer Energie)

The maximum temperature here should prevent from any problems with legionella and assure a hygienic DHW supply .

- Max. storage temp. (Max. Speichertemperatur)= 60°C
- Hysteresis turn on (Hysterese)= 2 K

↪ DHW circulation (Warmwasserzirkulation)

⊗ Off (Aus)

Heat storage (Pufferspeicher)

Auxiliary heating was assumed to happen in the DHW storage only. This is reflected in the last two bullet points where the maximum storage temperature for a certain heat source is set to zero.

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 93°C
- Hysteresis turn on (Hysterese)= 2 K
- Δ T between heat storage and DHW storage to start loading the DHW storage (Temperaturdifferenz zum Laden des WW-Speichers)=2 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW preparation(Kesselenergie zur Warmwasserversorgung)

- Indirectly via the heat storage, DHW provision elsewhere (In den Pufferspeicher, WW-Erzeugung über eigenen Kreis)

8.5.6 Outcome for type ACC M – FU$_{F(S)}$=0.41

Sensitivity analyses

Estimations were needed regarding the system design. Some rules applied are based on experience with solar thermal systems already installed in Austria. These rules, however, might be slightly different when applied to the Croatian climate. It is reasonable, therefore, to carry out sensitivity analyses with respect to the principal parameters. Each analysis is described in detail in Appendix: SA Tourist DHW Two-Storage. In addition, other less extensive simulations were also performed but not recorded.

The net collector field area was varied between 36.39 and 88.09 m^2. Annual SCR ranges from 69.67 to 92.55%, and SCR$_{(May-Sep)}$ is, on average, about 2.5% higher. The system efficiency ranges from 30.45 to 16.56%. The outcome recommends an area below 59.37 m^2, because until this value, the increase of SCR is relatively steep, whereas above the SCR-gradient is not considerably high, i.e.: the effort/effect ratio is very good within that range. SCR at this upper limit is 85.81% and SCR$_{(May-Sep)}$ is 88.25%. A net collector field size of **47.88 m^2** was chosen for the optimsed system.

The surface area of the internal heat exchanger of the DHW storage was increased from 1.5 to 4 m^2, for supply from the heat storage. The **heat storage size** was varied from 1.8 to 4.5 m^3, while the DHW storage was taken to be a constant of 500 litres. SCR ranges from 79.46 to 81.66%, that is, it varies only sligthly. $SCR_{(May-Sep)}$ is, on average, 3% higher. The specific yield ranges from 343.06 to 363.60 kWh/m^2. An optimal size is 3 m^3 since for lower volumes auxiliary heat supply rises significantly. The system efficiency here is 26.54%, therefore, the optimsed system consists of a **3 m^3** heat storage.

Table 8.19: DHW Two-Storage System, optimised for medium-size accommodations (ACC M), $FU_{F(S)}$=0.41.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 47.88 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 2.0 mm	d_{Hflow}= 42 mm	$\dot{m}$ =0.60-0.85 kg/s
Coll.loop	length 40 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 3000 litres, H=2.9 m, $\lambda_{Storage}$= 1.2 W/(m K)			
Coll. loop	in 1 m	out 0.1 m	Sen. 0.15 m/T_{max}93°C
↪ Int. heat exch.	6 m^2	543 W/(m^2 K)	$\dot{m}$ =0.85 kg/s
Heat sinks			
DHW storage	in 0.1 m	out 2.9 m	on if Δ T≥2 K
Heat sources –**DHW storage**: 500 litres, H= 1.8 m, $\lambda_{Storage}$= 1.8 W/(m K)			
Heat storage	in 0.1 m	out 0.6 m	Sen. 0.15 m/T_{max}60°C
↪Int. heat exch.	4 m^2	500 W/(m^2 K)	
Aux. loop electrical	in 0.7 m	10 kW	Sen. 0.8 m/T_{max}60°C
Heat sinks			
DHW loop	in 0.10 m	out 1.80 m	1640 (*litres* 60°*C*)/*day*

Angle analysis for ACC M

Table 8.19 provides an optimal set of parameters for the ACC M system incorporating the SA outcome. The results for the mixed angle analysis are drawn in *Figure* 8.21. The legend on the left side of the figure gives the ranges to which each colour of the contour refers.

This system is characterised by the **highest SCR** for a **tilt** angle of approximately **30°**. The reason may lie in the annual consumption profile. Since the heat demand for this system is highest during the summer, where the incidence angle of direct solar radiation with respect to an orthogonal on the horizontal surface is very low (Θ_z in Figure 7.1 is low), collector fields with less *tilt* are more beneficial.

Orientations include *azimuth* $\in \{0°, ..., 30°\}$ combined with *tilt* $\in \{15°, ..., 45°\}$, ensure a maximal SCR very close to or even above 80%. For 68% of the whole simulated range of angles SCR is greater than 72%.

8.5.7 DHW Two-Storage System for large-size ACC

This template system was designed to be used for DHW preparation in hotels, however, it could also operate in sanatoria, tourist villages or camps. The system will be simulated for a hotel with a capacity of one hundred beds.

The nominal summer demand is $V_{dem(S)}$ = 5640 litres, calculated with a DHW demand of 60 litres 60°C per guest, and a facility utilisation factor in summer of $\mathbf{FU_{F(S)}}$=**0.94**. The outcome of the previous system led to the assumption of a specific collector load

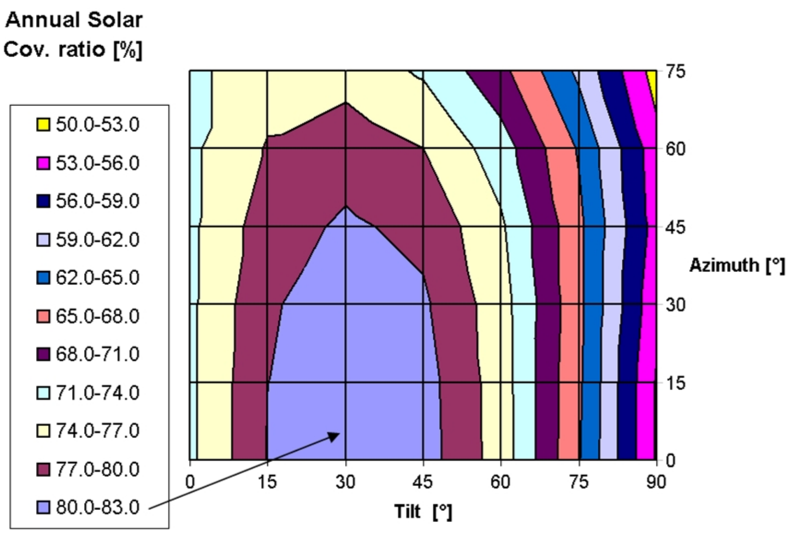


Figure 8.21: Mixed-angle analysis for DHW Two-Storage System, optimised for DHW demand (60°C; 1640 litres/day) provided for ACC M with $\mathrm{FU}_{F(S)}$=0.41 in Rijeka; V_S=3 m^3, $V_{S_{DHW}}$=0.5 m^3, $A_{Field} = 47.88\ m^2$.

of 35 $(litres\ 60°C)/m^2$ rather than 25. Furthermore, 60 litres/m^2 are projected for the prototypical system storage. Hence

$$A_{Field} = \frac{5640\ litres}{35\ litres/m^2} = 161.1\ m^2 \tag{8.9}$$

$$\text{and} \Rightarrow V_{Storage} = 161.1\ m^2 \cdot 60\ litres/m^2 = 9666\ litres\ . \tag{8.10}$$

A **matched flow control** concept was chosen, namely a constant ΔT=10 K in the collector field.

DHW consumption with respect to the defined demand profile is assumed to occur equally over one hour. The DHW demand profile is the same as in *Figure* 5.2, except for the annual distribution. The annual demand distribution is provided in Appendix: Annual Demand Profiles ($\mathrm{FU}_{F(S)}$=0.94).

Auxiliary supply is electrical-directly in the DHW storage and by means of an oil or gas boiler in the heat storage. This concept, and the appropriate temperature limits, rule out any danger of legionella growth.

A hot water circulation was projected for this system to ensure faster hot water provision from the taps. It was assumed that 3% demand is adequate to keep the water in the pipes on an appropriate temperature level.

Hot water circulation (Warmwasserzirkulation)

↪ DHW circulation (Warmwasserzirkulation)

For the selection ⊗ On (Ein), the following available parameters were adjusted to the given value

- Operation interval 5-6 h
- Operation interval 12-13 h

- Operation interval 17-18 h
- Mass flow rate = 170 kg/h
- Temperature drop = 20 K
- Inlet height = 0.35 m

The heat exchanger in the DHW storage is very important. The external heat exchanger did not function and consequently, the internal option was chosen.

Since it is very unlikely that all guests consume a maximum amount of DHW at the same time, the simultaneity of DHW consumption is limited. The software reflects this reduced simultaneity in the optional choice for 'equally distributed' DHW consumption over one hour. Hence, for certain system parts, the boundary values reduce.

Type of DHW-consumption (Art des WW Verbrauches)

- Distributed equally over one hour (Gleichmäßig über die Stunde)

Table 8.20: DHW Two-Storage System, prototypical for large-size accommodations (ACC L).

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 161.1 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 3.0 mm	d_{Hflow}= 66 mm	$\dot{m}$ =1.1-2.2 kg/s
Coll.loop	length 100 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 10000 litres, H=4.75 m, $\lambda_{Storage}$= 1.0 W/(m K)			
Coll. loop	in strat. unit	out 0.3 m	Sen. 0.4 m/T$_{max}$88°C
↪Ext. heat exch.		8250 W/K	$\dot{m}$=2 kg/s
Aux. loop	in 4.6 m	out 4.0 m	Sen. 4.42 m/T$_{max}$67°C
↪ direct infusion	boiler	100 kW	$\dot{m}$=2.4 kg/s
Heat sinks			
DHW storage	in 0.5 m	out 4.75 m	on if Δ T≥2 K
Heat sources –**DHW storage**: 1000 litres, H= 1.97 m, $\lambda_{Storage}$= 1.4 W/(m K)			
Heat storage	in 1.5 m	out 0.1 m	Sen. 0.15 m/T$_{max}$62°C
↪Int. heat exch.		6000 W/K	
Aux. electrical	in 1 m	10 kW	Sen. 1.1 m/T$_{max}$60°C
Heat sinks			
DHW loop	in 0.10 m	out 1.97 m	5640 (*litres* 60°*C*)/*day*

Control parameters (Steuerung)

The relevant parameters and the respective values for the control of the solar thermal system design are listed below.

Collector (Kollektor)

↪ Preference for solar energy supply (Vorrang für solare Energiezufuhr)Only the heat storage is supplied with solar energy.

- Preference heat storage (Vorrang Pufferspeicher)

↪ Second auxiliary heating

Given this context, this set of parameters refers to the energy supply of the DHW storage from the heat storage.

- Max. storage temp. (Max. Speichertemperatur)= 62°C
- Hysteresis turn on (Hysterese)= 2 K

↪ Auxiliary heating, electrical

- Max. storage temp. (Max. Speichertemperatur)= 60°C
- Hysteresis turn on (Hysterese) = 2 K

↪ DHW circulation (Warmwasserzirkulation)
⊗ On (Ein)

Heat storage

↪ Solar energy supply (Zufuhr von Solarenergie)

- Max. storage temp. Sensor 1 (Max. Speichertemp. Fühler 1)= 88°C
- Hysteresis turn on (Hysterese)= 1 K
- Δ T between heat storage and DHW storage to start loading the DHW storage (Temperaturdifferenz zum Laden des WW-Speichers)=2 K

↪ Second auxiliary heating (Zufuhr von Kesselenergie)

- Max. storage temp. (Max. Speichertemperatur)= 67°C
- Hysteresis turn on (Hysterese) = 5 K

Auxiliary heater (Kessel)

↪ Auxiliary energy supply for DHW preparation (Kesselenergie zur Warmwasserversorgung)

- Indirectly via the heat storage, DHW provision elsewhere (In den Pufferspeicher, WW-Erzeugung über eigenen Kreis)

8.5.8 Outcome for type ACC L – $\mathbf{FU}_{F(S)}$=0.94

Sensitivity analyses

A number of estimations were needed for the system design, and rules applied are based on experience with solar thermal systems installed in Austria. Each SA conducted is described in detail in Appendix: SA Tourist DHW Two-Storage. In addition, other, less extensive simulations performed were not recorded.

The **net collector field area** was varied between 84.26 and 199.16 m^2. Parallel to the size of the field, the annual SCR steadily increased from 53.09 to 86.72%. SCR$_{(May-Sep)}$ is, on average, 3.26% lower. This is surprising, but considering the system was designed for the summer period and recalling the low off-seaoson demand that can contribute positively to the SCR, it is justified. The specific annual yield decreases from 406.00 to 278.92 kWh/m^2. Above 160.86 m^2, SCR increases only slightly; on average 0.17%/m^2 whereas, below 160.68 m^2, the increase is significantly higher – between 0.48 and 0.24% per m^2. The system efficiency ranges from 30.74 to 20.89%. A net collector field size of **145.54 m^2** was chosen for the optimsed system. SCR is, therefore, 76.81%, and SCR$_{(May-Sep)}$ is 73.52%. The collector efficiency for this field size is 39.32%, and the system efficiency is 25.40%. A total annual solar yield of 49 159.30 kWh leads to the specific annual yield of 337.77 kWh/m^2.

For analysis of the **heat storage size** the previously reduced field size (145.54 m^2) was used, the storage size was then varied between 8 and 12.5 m^3. SCR varies only marginally from 75.79 to 77.39%. The specific yield ranges from 331.43 to 342.92 kWh/m^2. SCR$_{(May-Sep)}$ varies from 72.56 to 74.10%. Collector and system efficiency are nearly constant at a level of 39% and 25%, respectively, as the storage size varied. A size of **10 m^3** was retained for the template system of the optimised system. Therefore, all results of the key variables remain as described for the collector field variation.

Table 8.21: DHW Two-Storage System, optimised for large-size accommodations, (ACC L) $FU_{F(S)}$=0.94.

Description	**Parameters and respective values**		
Collector	Tehnomont SKT-40, net surface 145.54 m^2		
Conversion factors	c_0=0.759 , c_1=3.768, c_2=0		IAM=0.9
Coll.loop: pipes	Cu: 3.0 mm	d_{Hflow}= 66 mm	$\dot{m}$ =1.1-2.2 kg/s
Coll.loop	length 100 m	insulation	30 mm, 0.04 W/(m^2 K)
Heat sources–**heat storage** 10000 litres, H=4.75 m, $\lambda_{Storage}$= 1.0 W/(m K)			
Coll. loop	in strat. unit	out 0.3 m	Sen. 0.4 m/T_{max}88°C
↪Ext. heat exch.		8250 W/K	$\dot{m}$=2 kg/s
Aux. loop	in 4.6 m	out 4.0 m	Sen. 4.42 m/T_{max}67°C
↪ direct infusion	boiler	100 kW	$\dot{m}$=2.4 kg/s
Heat sinks			
DHW storage	in 0.5 m	out 4.75 m	on if Δ T≥2 K
Heat sources –**DHW storage**: 1000 litres, H= 1.97 m, $\lambda_{Storage}$= 1.4 W/(m K)			
Heat storage	in 1.5 m	out 0.1 m	Sen. 0.15 m/T_{max}62°C
↪Int. heat exch.		6000 W/K	
Aux. electrical	in 1 m	10 kW	Sen. 1.1 m/T_{max}60°C
Heat sinks			
DHW loop	in 0.10 m	out 1.97 m	5640 (*litres* 60°*C*)/*day*

Angle analysis for ACC L

Table 8.21 provides the optimal set of parameters, which vary with respect to the field area from the prototypical system only. In *Figure* 8.22 the angle analysis results are drawn. The legend on the left side of the figure provides the ranges to which each colour of the contour refers.

Such as the former system, this system is characterised by the **highest SCR** for a **tilt angle of 30**°. The reason, therefore, may lie in the annual consumption profile. Since the heat demand is highest during the summer, where the zenith angle Θ_z in Figure 7.1 is low, collector fields with a lower tilt angle are more beneficial.

Orientations of *azimuth* $\in \{0°, ..., 45°\}$ combined with *tilt* $\in \{15°, ..., 45°\}$ ensure a maximal SCR between 77 and 80%.

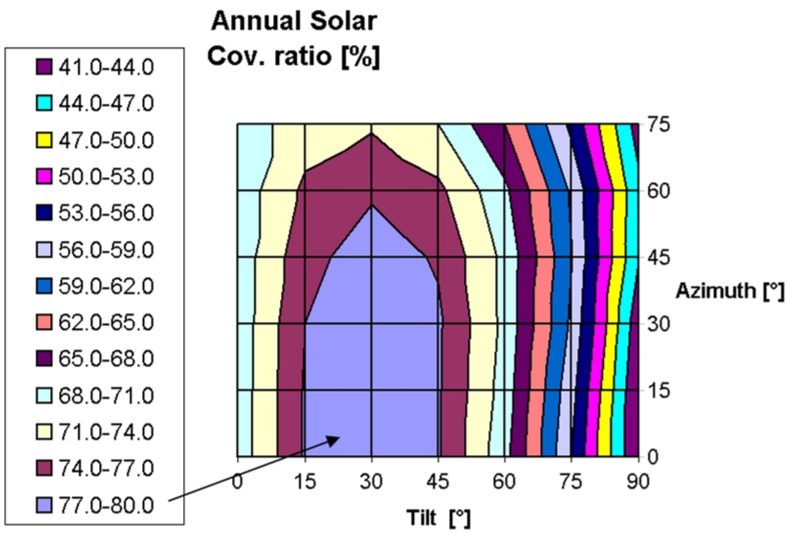


Figure 8.22: Mixed-angle analysis for DHW Two-Storage System, optimised for DHW demand (60°C; 5640 litres/day) provided for ACC L with $FU_{F(S)}$=0.94 in Rijeka; V_S=10 m^3, $V_{S_{DHW}}$=1 m^3, $A_{Field} = 145.54\ m^2$.

Angle analysis with Gluatmugl GS Collector for ACC L

The angle analysis was repeated using another collector type. Data for this collector is provided in Appendix: Components. The outcome differs only slightly from that attained with the Tehnomont SKT-40 collector. The test results from the collector test protocol for this collector, however, are more recent than that of the Tehnomont SKT-40 collector.

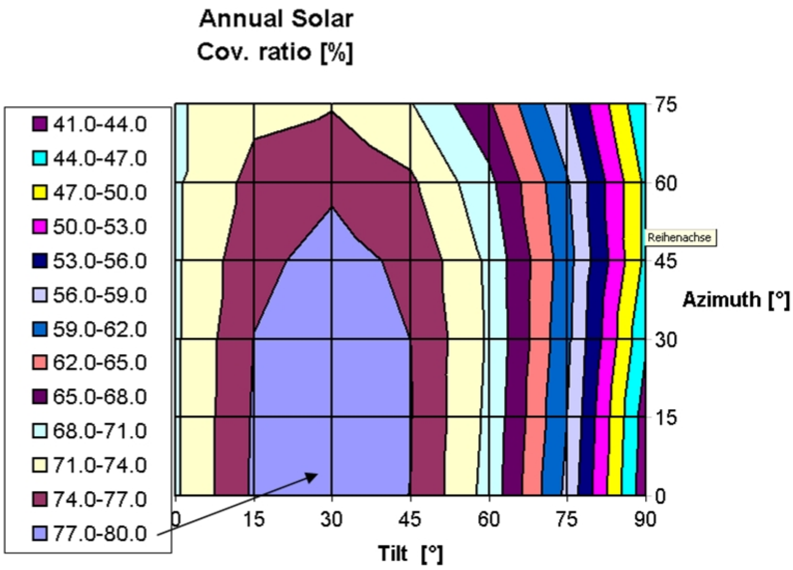


Figure 8.23: Mixed-angle analysis for DHW Two-Storage System, optimised for DHW demand (60°C; 5640 litres/day) provided for ACC L with $FU_{F(S)}$=0.94 in Rijeka; V_S=10 m^3, $V_{S_{DHW}}$=1 m^3, Collector: Gluatmugl GS $A_{Field} = 145.54\ m^2$.

8.6 Summary and results for other climate data

In order to estimate the solar thermal potential, it is important to gather representative values of SCR or specific solar yields, for various sites. It was assumed that average values of the respective mixed-angle analysis satisfy this requirement. Therefore, a subset of angle pairs will be used to calculate average values.

All simulation results used for averaging in this section refer to simulations with optimal parameter sets.

Slightly smaller systems with higher efficiencies and higher specific solar yields were used by Pichler et al. for the solar thermal potential analysis along the Croatian coast including also an economical analysis for the systems [1].

8.6.1 Systems for domestic hot water purposes

All results within the range of *tilt* $\in \{15°, ..., 60°\}$ and *azimuth* $\in \{0°, ..., 60°\}$ were taken into account for the evaluation and comparison of the outcome of the designed and simulated solar thermal systems for DHW purposes. This gives in total twenty pairs of angles, and therefore, twenty values for each evaluated average variable.

In Table 8.22, the annual SCR, and the total and the specific annual yields for all simulated systems with purely DHW heat demand are listed. The values refer to the optimised system. The system's name in the left column are abbreviated – followed by the total annual yield and the respective collector field area. The total annual solar yield that defines the size of the system ranges from 2508 to 47 866 kWh. The collector field area for the smallest system is 5.8 m^2 and 145.5 m^2 for the largest. SCR average values range from 66.1 to 84.7%; the systems designed for tourist accommodation show very high numbers due to nearly pure summer operation.

The specific annual yield varies between 328.5 and 509.1 kWh/m^2. The specific annual yield decreases with the system size due to the heat demand profile. The larger a facility, the smaller the relative off-season heat demand, which entails less utilisation and a smaller annual yield.

Graphic support for all data is provided in *Figure* 8.24 and *Figure* 8.25 for DHW systems for tourism for all ACC systems and *Figure* 8.28 and *Figure* 8.29 for all SFH systems. The dot indicates the average value, and the upper and lower bar show the range given for the simulated set of angle combinations.

Table 8.22: Summary of annual average values over various collector orientations, for SCR and (specific) solar yield for all simulated systems for DHW preparation. System names include total annual yield and collector area in m^2.

	SCR [%]			**Solar yield [kWh]**			**sp.yield [kWh/m²]**		
System	max	min	**ave**	max	min	**ave**	max	min	**ave**
SFH forc. 2508, 5.8	71.2	60.7	66.1	2678	2311	2508	461.7	398.4	432.4
SFH nat. 2953, 5.8	77.6	67.9	73.0	3129	2740	2953	539.5	472.4	509.1
ACC S, 4397, 11.5	88.4	80.2	84.7	4605	4162	4397	400.4	361.9	382.3
ACC M, 16440, 47.9	82.8	72.4	78.7	17288	15125	16440	360.9	315.8	343.2
ACC L, 47866, 145.5	80.0	68.6	75.4	50852	43510	47866	349.5	299.0	329.0
ACC L, 47799, 145.5	79.5	68.8	75.4	50486	43565	47799	347.0	299.4	328.5

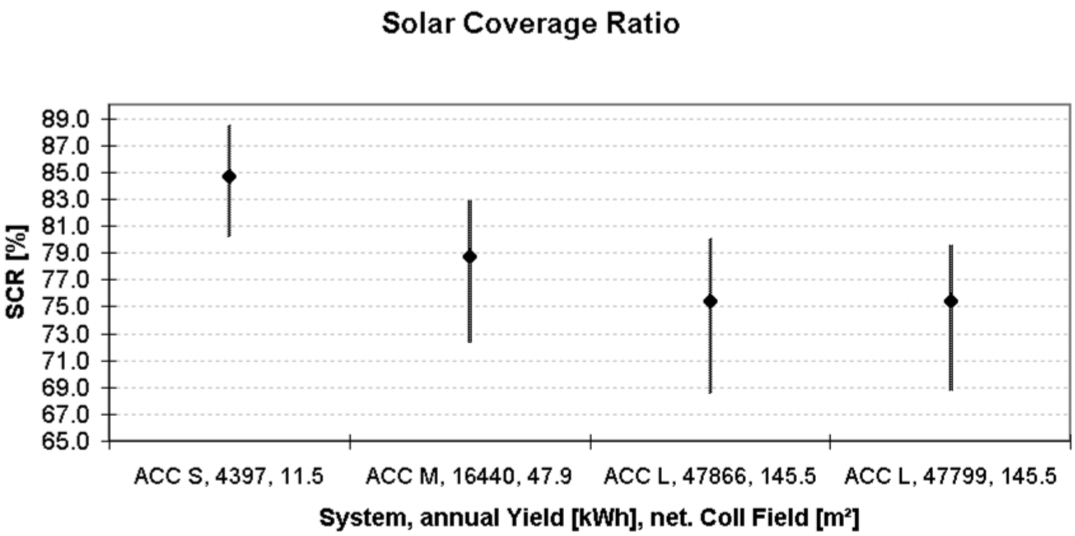


Figure 8.24: Summary and comparison of minimum, average, and maximum SCR of four systems for DHW preparation for tourist accommodation in Rijeka

Table 8.23 reaccounts simulation results with respect to efficiency and the operation time for all simulated systems with pure DHW heat demand. The system efficiency average is minimal 25.5% and maximal 38.5%. There is a pattern wherein the larger the system, the smaller the respective efficiency. Further analysis is required to explain this trend. One reason is the design and optimisation for the summer period. Low off-season heat consumption and system operation result in a relatively small nominator in equation (7.26).

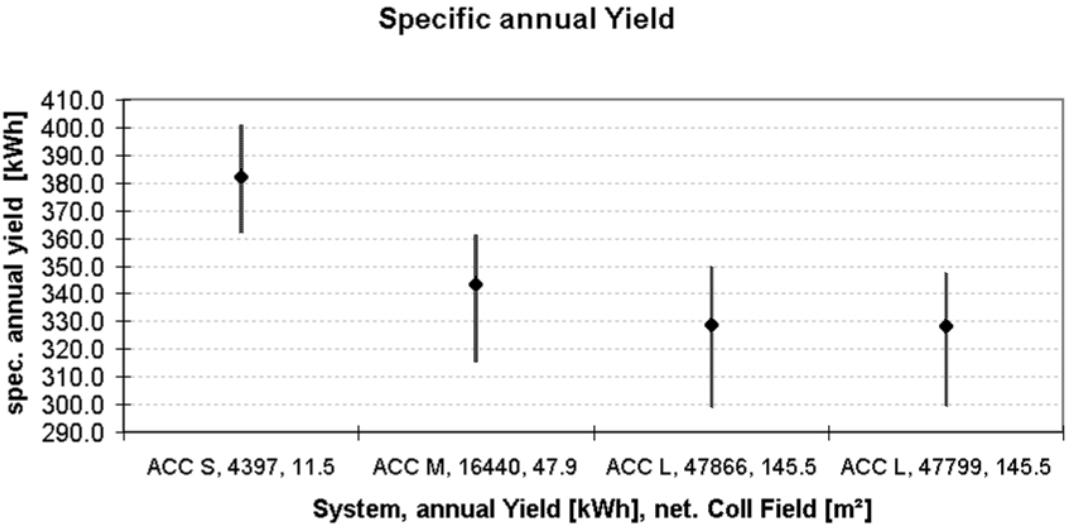


Figure 8.25: Summary and comparison of minimum, average, and maximum specific solar yield of four systems for DHW preparation for tourist accommodation in Rijeka

The values for the collector efficiency range from 39.1 to 48.1% and the operation time lies between 1484 and 2286 hours on average.

For comparison, [2] demonstrates the system efficiency between 14 and 28% and the collector efficiency between 18.6 and 38.4% for a collector area range between 7.4 and 620 m^2.

In *Figure* 8.26 and *Figure* 8.27, the system and the collector efficiency are drawn in a diagram. The dot indicates the average value, and the upper and lower bar demonstrate the range, given for the simulated set of angle combinations.

Table 8.23: Summary and results of annual average values over various collector orientations for all simulated systems for DHW preparation; System names include total annual yield and collector area in m^2.

	Syst. efficiency [%]			**Coll. efficiency [%]**			**Operation time [h]**		
System	max	min	**ave**	max	min	**ave**	max	min	**ave**
SFH forc. 2508, 5.8	37.3	32.8	34.9	45.6	41.9	43.8	2385	2051	2286
SFH nat. 2953, 5.8	40.9	36.5	38.5	43.2	39.8	41.6	-	-	-
ACC S, 4397, 11.5	31.8	28.6	30.1	49.6	46.6	48.1	1584	1461	1514
ACC M, 16440, 47.9	27.3	26.0	26.5	41.9	38.7	40.0	1609	1394	1538
ACC L, 47866, 145.5	26.3	24.4	25.6	40.9	38.5	39.4	1560	1338	1484
ACC L, 47799, 145.5	26.2	24.7	25.5	40.8	38.4	39.1	1558	1339	1487

Remark

Depending on the purposes of heat supply and the annual heat demand profile, different systems require different favourable tilt angles. For **private applications** for purely solar heat provision for DHW, the maximum SCR is achieved with a tilt angle of **45°**. Systems for **tourist facilities** show a maximum SCR at a tilt angle of approximately **30°**, as long as the base heat demand off-season is significantly less than the demand during summer. This holds for the ACC M and ACC L systems, whereas for the small ACC S system, the optimum tilt angle lies between 45° and 30°; see also Appendix: Angle Analyses for SFH DHW Purposes, *Figure* B.1.

The concept of facility utilisation was used to design and adapt a solar thermal system for a respective accommodation and its average 'tourist load'. Hence, an analysis of how SCR changes with FU is not needed since, during the design, optimisation of the system for the real average number of overnight stays was attempted.

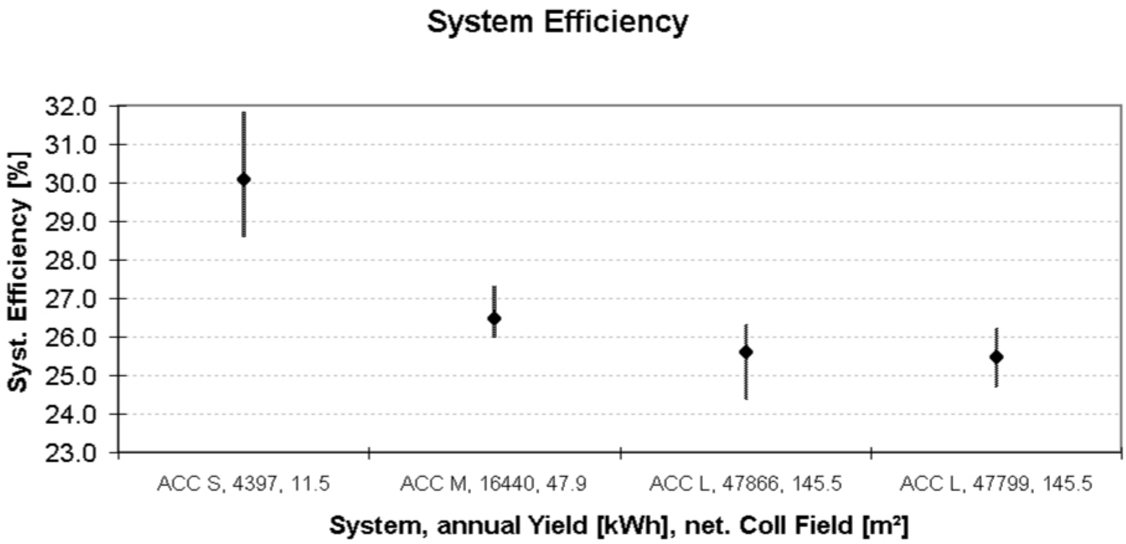


Figure 8.26: Summary and comparison of minimum, average, and maximum system efficiency of four systems for DHW preparation for tourist accommodation in Rijeka

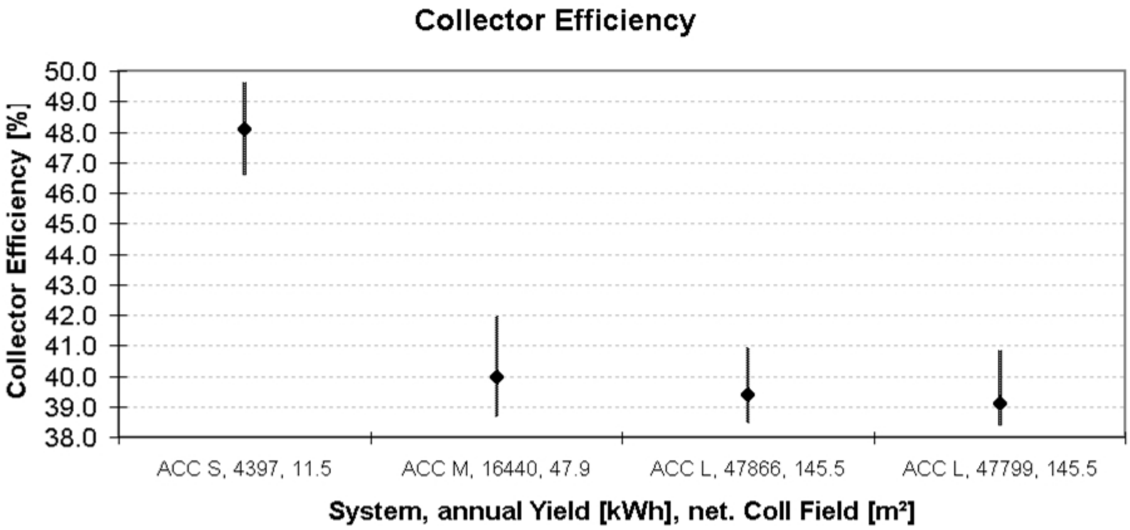


Figure 8.27: Summary and comparison of minimum, average, and maximum collector efficiency of four systems for DHW preparation for tourist accommodation in Rijeka

8.6.2 Combisystems for private housing

For evaluation and comparison of the outcome of the designed and simulated solar thermal combisystems, all results within the range of $tilt \in \{15°, ..., 75°\}$ and $azimuth \in \{0°, ..., 60°\}$ were taken into account. This gives, in total twenty five pairs of angles, and therefore, twenty five values for each evaluated variable. Each average was calculated using twenty five individual values.

SCR and solar yield

Table 8.24 provides maximum, minimum, and average values for SCR, total and specific annual yield for all simulated combisystems. The system's name in the left column is abbreviated, followed by the total annual yield, in kWh, and the respective collector field area.

Table 8.24: Summary and results of annual average values for various collector orientations for SCR and (specific) solar yield for all combisystems; System names include total annual yield and collector area in m^2.

System	**SCR [%]**			**Solar yield [kWh]**			**sp.yield [kWh/m^2]**		
SFH	max	min	**ave**	max	min	**ave**	max	min	**ave**
I, 3939, 15.3	22.7	16.6	19.8	4392	3455	3939	287.1	225.8	257.5
II, 4051, 15.3	34.4	25.7	30.2	4503	3570	4051	294.3	233.3	264.8
III, 3821, 11.5	52.3	41.2	46.8	4213	3368	3821	366.3	292.9	332.3
I 2stor, 3971, 15.3	19.8	13.4	16.7	4452	3469	3971	291.0	226.7	259.5
II 2stor, 4239, 17.2	30.8	21.0	26.0	4773	3681	4239	277.5	214.0	246.5
III 2stor, 4187, 15.3	51.4	36.8	44.2	4687	3675	4187	306.3	240.2	273.7

SCR lies between 19.8 and 46.8%. The average annual solar yield lies between 3821 and 4239 kWh, and the range for the specific values is between 246.5 and 332.3 kWh/m^2. The specific annual yield clearly increases from SFH I to SFH III. This becomes evident with recollection that SFH III reflects low energy architecture and a heating system optimised for solar thermal heating.

Figures 8.28 and 8.29 provide a graphic demonstration of the SCR and the specific annual yield. Note that the results of the DHW systems for single family houses are also drawn.

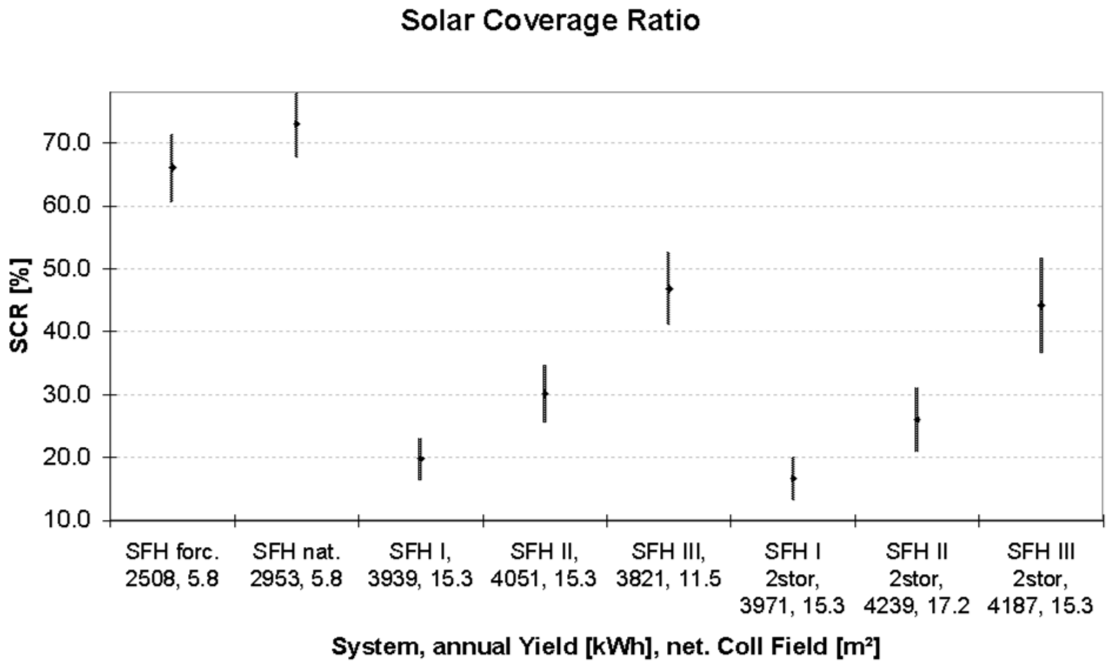


Figure 8.28: Summary and comparison of minimum, average and maximum SCR of two DHW systems and six combisystems for SFH in Rijeka.

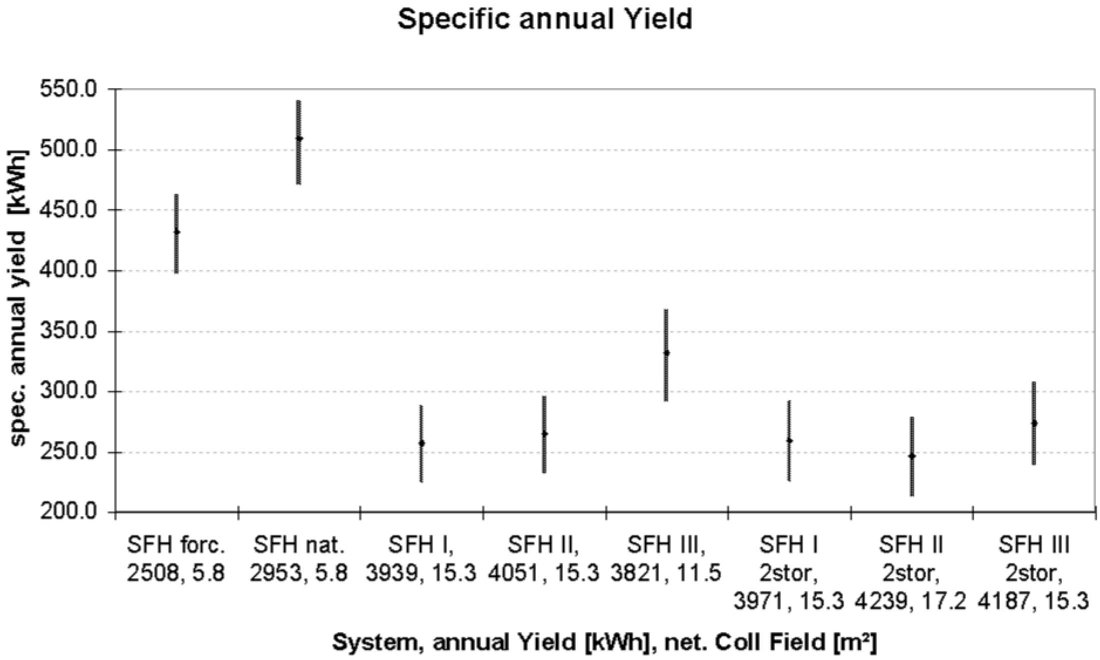


Figure 8.29: Summary and comparison of minimum, average and maximum specific solar yield of two DHW systems and six combisystems for SFH in Rijeka

Efficiencies and operation time

Table 8.25 provides maximum, minimum, and average values for system and collector efficiency, and the operation time for all simulated combisystems.

The system efficiency ranges from 20.1 to 26.9% and is, therefore, significantly lower than the systems with pure DHW heat demand. The collector efficiency, however, is nearly the same; the range for combisystems is between 39.0 and 45.7%. The average operation time for the combisystems is, in general, lower (1333 - 1484 hours) compared to the range of systems for pure DHW preparation. In *Figures* 8.30 and 8.31, a graphic demonstration of the respective system and collector efficiency is provided. These graphs also include the DHW system results for single family houses.

Table 8.25: Summary and results of annual average values for various collector orientations for system and collector efficiency and operation time for two DHW systems and six combisystems for SFH in Rijeka; System names include total annual yield and collector area in m^2.

System	**Syst. efficiency [%]**			**Coll. efficiency [%]**			**Operation time [h]**		
SFH	max	min	**ave**	max	min	**ave**	max	min	**ave**
I, 3939, 15.3	24.8	17.8	20.9	41.0	37.2	39.6	1486	1168	1333
II, 4051, 15.3	25.6	18.4	21.5	41.6	37.6	40.2	1527	1206	1370
III, 3821, 11.5	31.5	23.6	26.9	46.9	43.2	45.7	1629	1325	1484
I 2stor, 3971, 15.3	25.3	18.0	21.3	42.1	38.3	40.1	1521	1156	1368
II 2stor, 4239, 17.2	24.2	17.0	20.1	41.0	37.0	39.0	1538	1149	1369
III 2stor, 4187, 15.3	26.6	19.0	22.4	43.2	39.2	41.2	1559	1195	1410

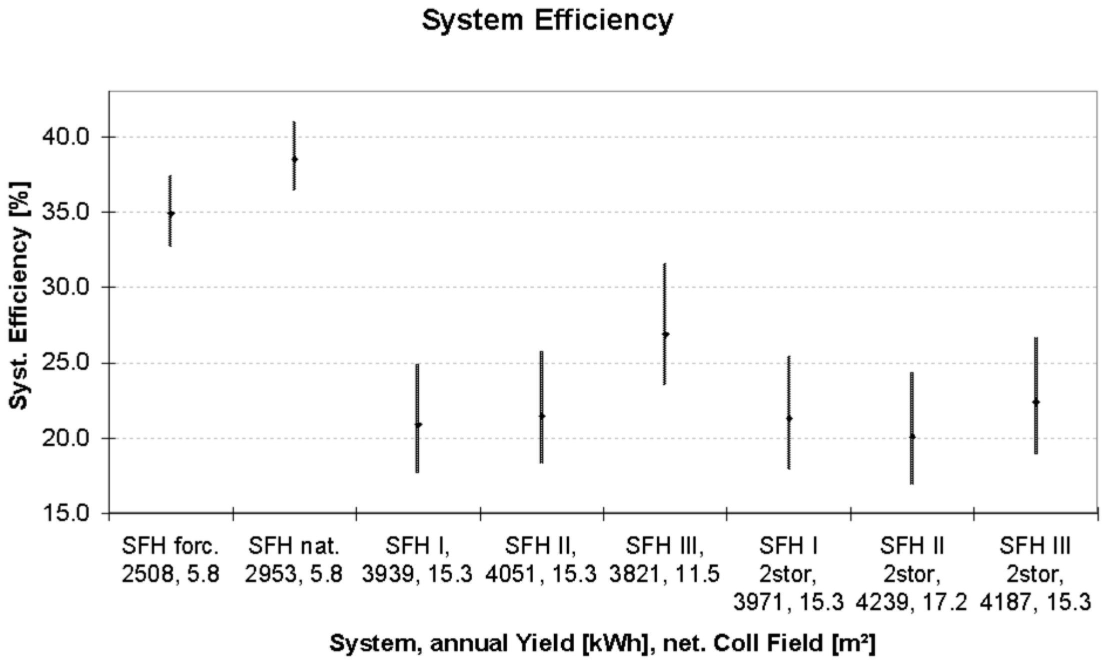


Figure 8.30: Summary and comparison of minimum, average, and maximum system efficiency for two DHW and six combisystems for SFH in Rijeka

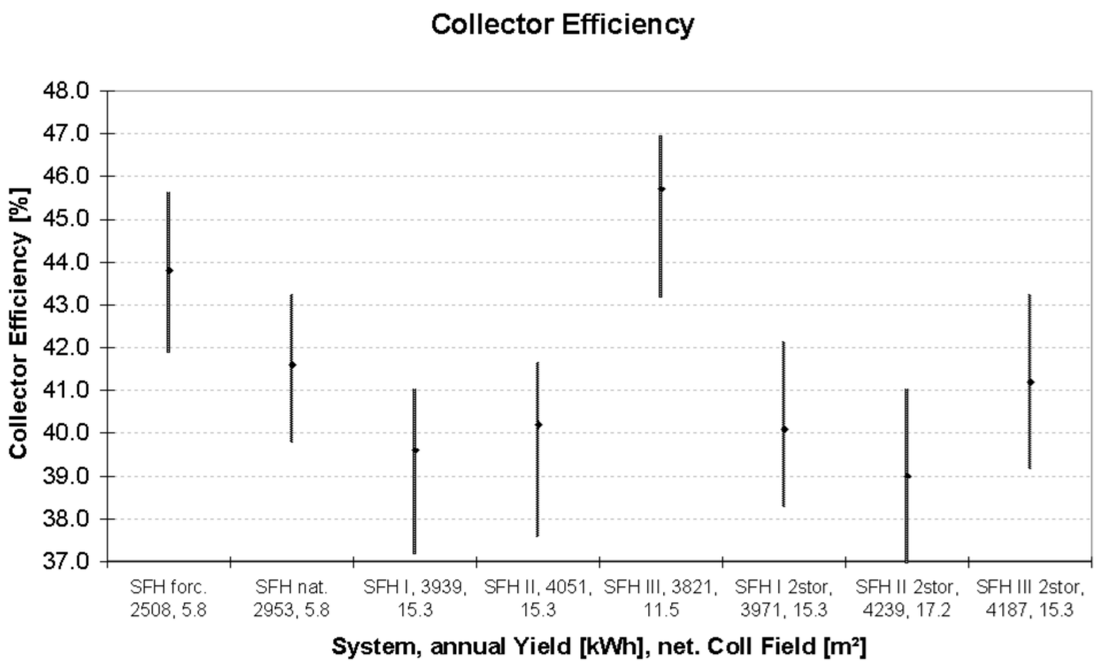


Figure 8.31: Summary and comparison of minimum average and maximum collector efficiency for two DHW systems and six combisystems for SFH in Rijeka

Heat demand for DHW and SH

Table 8.26 provides a summary for the outcome of the combisystem simulation. Given are the annual heat demand for domestic hot water and space heating and the passive solar yield due to radiation through the windows. The SFH II and SFH II 2stor result in terms of space heating is not the same, because heat load was differently. For the two-storage solar system, the simulation was carried out for a heat load of 10 000 W rather than 9555 W. This was not on purpose, but human error during parameter setting before the simulation. The result is a 6.8% higher annual heat demand than that originally defined for SFH II. The simulations, however, were not repeated.

The heat demand for SH will be used in the following chapter to estimate the final energy consumption for SH.

Table 8.26: Summary of results for DHW and SH heat demand and passive solar yield for six combisystems for SFH in Rijeka; System names include total annual yield and collector area in m^2.

System	**Annual useful heat demand in [kWh]**		
SFH	**Q DHW**	**Q SH**	**Q Sol.pass.**
I, 3939, 15.3	2964	12045	2356
II, 4051, 15.3	2964	7328	2079
III, 3821, 11.5	2964	3510	1364
I 2stor, 3971, 15.3	2964	12045	2356
II 2stor, 4239, 17.2	2964	7824	2123
III 2stor, 4187, 15.3	2964	3510	1364

8.6.3 Results for other climate data

In this work, all simulations that were carried out refer to the climate conditions prevalent in Rijeka. Thinking about other tourist destinations along the Adriatic coast but further in the south, it becomes clear, that there are more favourable sites for solar thermal applications in Croatia.

The establishment of a nationally funded policy for subsidies requires an approximate picture of the SCR or the specific yield for the whole country. Also a lower bound for the SCR of systems, with reference to an atypical year with significantly lower radiation values is required. The following sources do not yield a detailed analysis but rather a simple simulation run for a constant collector orientation ($azimuth$=0°, $tilt$=45°).

To demonstrate how the yield can vary with the location, simulations were conducted for a set of different climate data. The climate data source for the locations Rijeka, Zadar, Split and Hvar was the software Meteonorm. The data set *Rijeka91* refers to the data set *Rijeka* were all radiation values were lowered by 9%, and the data set *TRY* refers to the test reference year created in 1992, at the Technical University of Rijeka, from measurement data within the period between 1971 and 1980 [33]. The Meteonorm and TRY climate data sets were analysed previously in Chapter 6 Hourly Climate Data. Finally, the data set *Grazhour* refers to a proprietary climate data set used at the TU Graz generated from measurement data between 1960 and 1990 [14]. In Table 8.27, SCR is provided for nearly all designed systems with the respective optimised set of parameters for seven different climate data sets.

The data set *Rijeka91* provides a lower bound for natural atypical years with low radiation values for Rijeka. SCR is highest for Hvar. The mean deviation compared to

[14] Amendment from supervisor Wolfgang Streicher; *Gr10hour* (1990-1999) refers to a more recent period than the used data set, *Grazhour* (1960-1990).

Table 8.27: Results of annual average values for SCR, at *azimuth*=0°, *tilt*=45° for seven climate data sets

Climate	DHW nat.	DHW forc.	SFH I	SFH I 2stor	SFH II	SFH III	ACC S	ACC M	ACC L
Hvar	93.02	88.82	39.85	37.6	57.1	77.89	97.62	91.06	88.5
Split	90.28	86.29	33.54	30.96	49.4	69.73	97.83	91.68	89.39
Zadar	89.44	85.12	27.44	25.29	41.16	60.16	95.62	90.23	88.13
TRY	81.17	74.55	25.69	23.09	38.42	55.31	92.24	87.57	85.63
Rijeka	77.55	71.05	22.54	19.58	34.14	51.95	88.27	81.34	76.81
Rijeka91	74.34	67.36	20.67	17.72	31.47	48.72	84.48	76.06	69.9
Grazhour	63.88	55.72	9.7	7.58	14.52	24.56	75.45	68.2	60.29

Rijeka is 16.5 ± 5.7%; the outcome for all systems listed in Table 8.27 was taken into account.

Further deviations, in percentiles, with respect to the data set *Rijeka* are; *Split*, 12.9 ± 2.7; *Zadar*, 8.8 ± 3.0; *TRY*, 4.5 ± 1.9; *Rijeka91*, -3.6 ± 1.6; *Grazhour*, -15.9 ± 4.9. *Figure* 8.32 demonstrates how SCR is different for varying climate conditions. Each line in the graph represents a climate data set and connects the outcome for SCR for various solar thermal systems.

Results for climate data Rijeka, Zadar and Hvar for four different systems for DHW preparation are also provided in the publication for the EuroSun2010 conference [1].

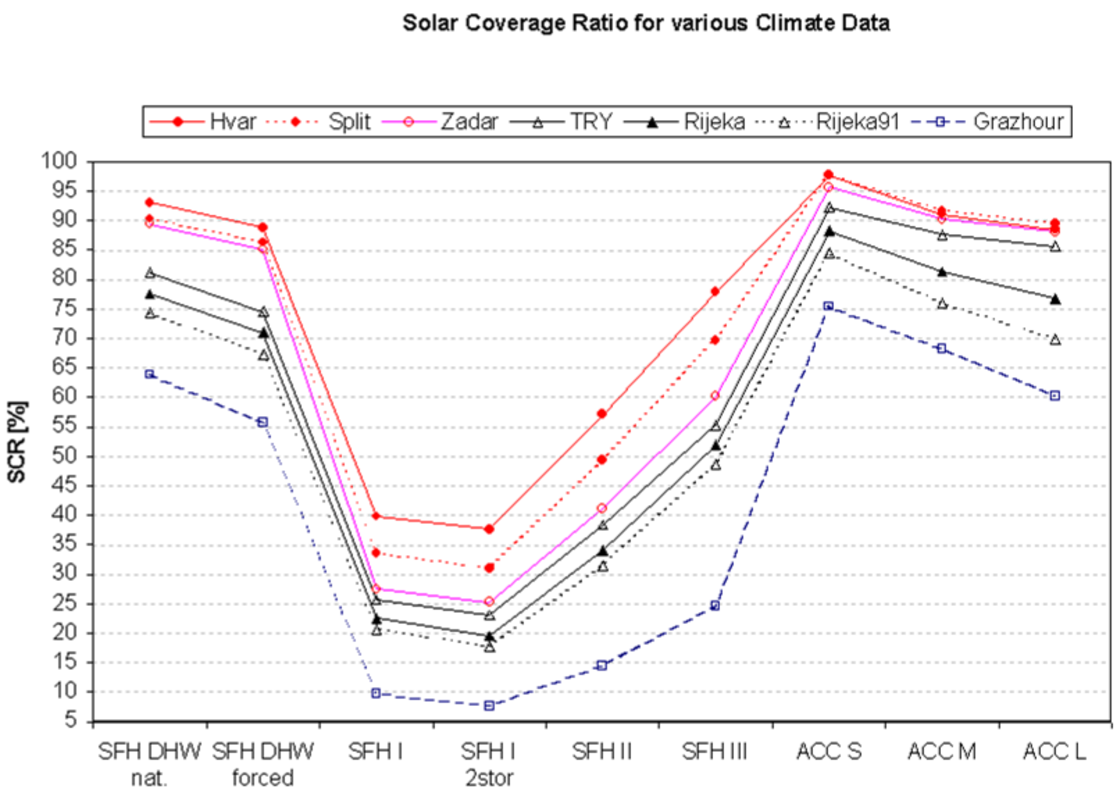


Figure 8.32: Comparison of SCR for all systems for seven climate data sets, (*azimuth*=0°, *tilt*=45°).

Table 8.28 provides the specific solar yield for seven different climate data sets and nearly all designed solar thermal systems for a constant collector field orientation *azimuth*=0° and *tilt*=45°. The parameters of the systems are optimised parameters. The mean deviation and the according standard deviation from the data set *Rijeka* are; *Hvar*, 68.9 ± 29.5; *Split*, 67.9 ± 22.7; *Zadar*, 72.5 ±22.6; *TRY*, 33.0 ± 6.9; *Rijeka91*, -23.2 ± 5.1; *Grazhour*, -57.4 ± 24.5 – in kWh/m^2, respectively.

Table 8.28: Results for specific annual yield for all simulated systems at *azimuth*=0° and *tilt*=45° for seven climate data sets

Climate	DHW nat.	DHW forc.	SFH I	SFH I 2stor	SFH II	SFH III	ACC S	ACC M	ACC L
Hvar	668.35	580.56	339.29	357.25	344.53	427.95	452.69	401.28	389.94
Split	654.87	567.81	344.51	356.44	349.33	430.37	453.05	403.07	393.42
Zadar	646.42	560.09	363.79	373.86	371.54	450.83	442.27	397.11	388.20
TRY	590.70	498.96	319.01	326.98	324.84	392.51	425.45	384.09	376.37
Rijeka	544.10	465.76	286.61	290.44	293.90	366.64	400.77	355.95	337.77
Rijeka91	512.63	439.01	268.44	271.61	275.76	345.62	379.96	332.57	307.52
Grazhour	447.13	375.95	252.94	249.97	262.45	330.97	340.49	298.88	266.46

Figure 8.33 provides the graphical aid for Table 8.28. It clearly shows how the specific annual yield is different for various climate conditions. Each line in the graph represents a climate data set and connects the outcome for the specific annual yield for various solar thermal systems. The range of results is highest for the two smallest systems, whereas for all the other systems, the range of results is nearly the same width.

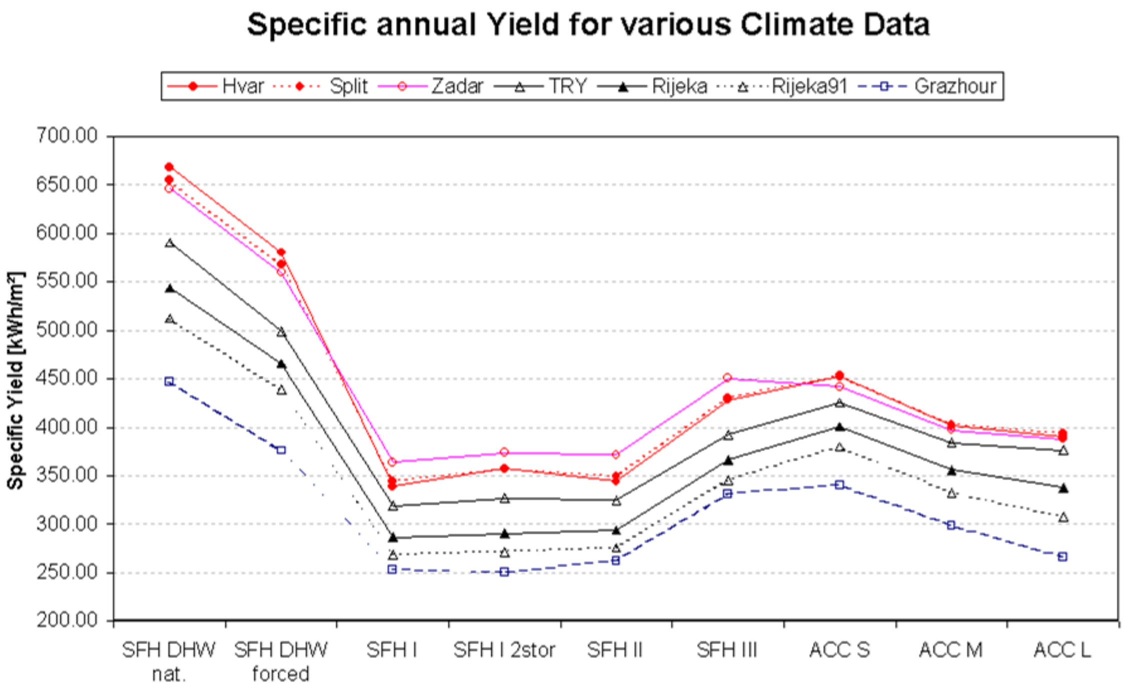


Figure 8.33: Comparison of the specific annual yield for all systems for seven climate data sets (*azimuth*=0°, *tilt*=45°)r

Chapter 9

Solar Thermal Potential & Conclusion

The last chapter addresses the solar thermal potential estimation. This is developed using a case scenario for which a solar thermal penetration of 10% is assumed. That is 10% of the single-family houses (SFH) and buildings providing tourist accommodation are endowed with solar thermal systems. The number of installed systems, along with the obtained simulation results, lead to potential final energy savings. The tourist statistics calculated in Chapter 5 are applied for this purpose. Eventually, the replaceable final energy and the remaining auxiliary energy are calculated using SCR outcomes from Chapter 8 for the according plants. The final conclusion follows at the end of this chapter.

9.1 Description of the procedure

A detailed potential analysis would begin with a theoretical potential and continue to decrease the respective number to establish the technical potential; in a third stage, due to economical restraints from the last potential, the (present) economical potential could be estimated. Finally, all practical limitations and influences would lead to an economically exploitable, or just practical, potential. The sketched, extensive potential analysis is beyond the focus of this work.

The theoretical solar thermal potential for private housing could be estimated using the available roof area, that is, the building area in private housing; and similar for tourist accommodation facilities. The analysis of the building area in Chapter 5, Statistical Data and Heat Demand, yields 351 m^2 building area per inhabitant for living purposes. This number intuitively appears too large. In addition, a set of assumptions and approximations is needed to derive a reasonable practical potential. Since this approach also involves various uncertainties, a different, more theoretical and direct way will be chosen to derive a solar thermal potential.

The applied potential analysis uses three different scenarios. The keyword for these scenarios is the **penetration** of solar thermal systems in private housing and tourist accommodation facilities throughout PGC. For example, a penetration of 50% within one hundred SFHs and ten hotels means installation of fifty plus five solar thermal systems for private and commercial purposes, respectively. Which simulation results are to be applied depends on the type of building: this is deduced using statistical data.

While calculating final energy savings, the additional electricity consumption of pumps, which operate the solar systems, is neglected. According to [2], electricity demand differs between 0.008 and 0.03 kWh per gathered solar thermal kilowatt hour. This equals 1.9 $\pm$1.1 % with respect to the total solar thermal yield of a plant.

General assumption

A general assumption in this context must be stressed: simulation results for the climate conditions in Rijeka were considered a good sample, suitable for establishing the overall potential, including all possible locations in the county. This approach is reasonable as Rijeka accounts for approximately half of the county's total inhabitants. In addition, slightly higher and lower yields to the south and to the north of Rijeka, respectively, have opposite effects on the total potential, and hence will give some balance.

9.2 Potential calculations

9.2.1 DHW in tourism branch

The tourist accommodation capacity, the monthly distribution of the total number of overnight stays, and the breakdown of overnight stays with the real facility utilisation for 2008 is provided in Table 5.7, 5.6, and 5.8. Relevant data from these tables are summarised in Table 9.1. The annual final heat energy demand is subsequently calculated for the categories Hotel, Apartment, Camp Site and Private Accommodation, however, the useful energy demand must be calculated beforehand.

The specific heat demand for preparation of one litre DHW (1 dm^3) from 10 to 60°C is given by

$$\begin{aligned} Q &= c_{pH_2O} \cdot \Delta T \cdot 1\,dm^3 \\ &= 1.16\,Wh/(dm^3K) \cdot 50K \cdot 1\,dm^3 \;= 58\,Wh\,. \end{aligned} \tag{9.1}$$

This result, applied to the respective consumption classes (V_g) 20, 40, and 60 litres, leads to: 1160, 2320, and 3480 Wh per day and guest, respectively. This multiplied again by the bed capacity and the facility utilisation factor during summer, $FU_{F(S)}$ leads to the useful heat demand for the summer season, from May to September.

The useful heat demand for DHW for the rest of the year, was assumed as for the annual tourist profiles, cf. Appendix: Annual Demand Profiles: the average is 0.10229 with respect to full occupation [1]. This demand should cover maintenance or other work and low occupation.

Table 9.1: Useful energy demand for DHW for relevant accommodations, $FU_{F(S)}$ and beds capacity refer to statistics of PGC for 2008. Summer refers to 153 and off-season to 212 days. The row t'Regarded [%]' reflects the percentile amount of useful energy – it includes the accommodation types Hotel, Apartment and Camp Site and private accommodations.

				Useful heat demand [**MWh**]		
Facility	V_g	$FU_{F(S)}$	# of Beds	Summer	Off season	annual
Hotel	60	0.94	19365	9692	1461	11153
Apartment	40	0.84	5012	1494	252	1747
Camp Site	20	0.41	39050	2842	982	3824
Subtotal			63427	14028	2696	**16724**
Regarded [%]			69.5433	81.5590	72.5399	79.9565
Neglected	diverse	diverse	27778	3172	1021	4192
Private Accom.	40	0.25	90080	7994	4532	**12526**
Regarded **Total**			153507	22022	7228	**29250**
Regarded [%]			84.6772	87.4102	87.6276	87.4638

[1] That is approximately 10% of the consumption at maximal occupancy. It is approximately 11%, 12%, 25%, and 41% for Hotel, Apartment, Camp Site and Private Accommodation, respectively, with respect to the nominal daily summer rate of consumption.

Summer and off-season demand is provided separately in Table 9.1. It should be noted that summer demand calculation is based on real figures, whereas for the rest of the year, it is based on an assumption taking into account self-consumption and low occupation.

The total useful heat demand of 29 250 MWh was calculated using overnight stays of four types of facility, and corresponds to approximately 87.5% of the total useful heat demand consumed, in terms of DHW, in the tourism sector in PGC. The row 'Neglected' includes all other types of accommodation for which the guest DHW consumption and $FU_{F(S)}$ were taken into account in order to calculate the useful heat demand.

Potential substitution of final energy consumption

As concerns the 10% penetration rate the total useful energy consumption of this 10% is given in Table 9.2, along with the respective conversion efficiencies of existing heating systems and the theoretical final energy consumption in the case of commercial energy provision. The amount of final energy consumption that can be substituted using a solar thermal system depends on the SCR of the system suitable for the corresponding type of accommodation.

Table 9.2: Useful heat energy demand and final energy consumption in MWh for DHW for relevant tourist accommodations with different conversion efficiencies of existing heat sources for a scenario with 10% penetration throughout the county.

Facility	Heat energy for a penetration of 10% in **MWh**						
	Useful heat	Final energy consumption for various η_{conv}					
Replaced energy carrier		Electricity		Fuel Oil			
and respective conversion efficiency		0.93	0.87	0.93	0.8	0.7	0.6
Hotel	1115	1199	1282	1199	1394	1593	1859
Apartment	175	188	201	188	218	250	291
Camp Site	382	411	440	411	478	546	637
Private Accom.	1253	1347	1440	1347	1566	1789	2088
Regarded Total	2925	3145	3362	3145	3656	4179	4875

Conversion efficiencies in Table 9.2 are assumed potential efficiencies in practise. It is difficult to state to what degree these efficiencies are prevalent in existing installations: it mainly depends on the age and quality of the systems and on the care taken during installation. An estimation of a reasonable weight, w_η, reflecting the practical relevance to calculate a weighted **average conversion efficiency** is required for the respective efficiencies. A weight of $w_{0.93}$=0.30 and $w_{0.87}$=0.70 was assumed for electrical boilers, leading to an average efficiency of η_{sys-e}=0.888 ± 0.03. For oil-fired boilers, the efficiency is, in general, lower [50]. This holds especially during partial-load operation in summer. The weights were assumed to be $w_{0.93}$=0.05, $w_{0.80}$=0.15, $w_{0.70}$=0.50, and $w_{0.60}$=0.30, leading to an average efficiency of $\eta_{sys-oil}$=0.6965±0.0849.

For Hotel, Apartment, and Camp Site, the average efficiency η_{conv}=$\eta_{sys-oil}$ = 0.6965± 0.0849 will be used. For private accommodations, a conversion efficiency with equal weights for $\eta_{sys-oil}$ and η_{sys-e} that gives η_{conv}=$\bar{\eta}_{sys-priv}$ = 0.7923 ± 0.0962, will be applied to calculate the final energy consumption from the useful heat demand. An overview of the useful and final energy demand for tourist accommodations is given in Table 9.3. The

Table 9.3: Total useful and final energy demand calculated with the average conversion efficiencies for four types of accommodation standing for 87.5% of the DHW energy consumption in tourism in PGC.

	Private	Commercial	Total
Hotel		11153	
Apartment		1747	
Camp Site		3824	
Private Accom.	12526		
$Q_{use}^{(total)}$ [MWh]	12526	16724	29250
η_{conv}	0.7923±0.0962	0.6965 ± 0.0849	
$Q_f^{(total)}$ [MWh]	15810±1712	24011±2608	39822±3120

weighted efficiencies and their margins of error will also be used to elaborate the replaceable final energy consumption for the 10% solar thermal penetration scenario. In addition, this calculation step involves the SCRs, which bear another potential uncertainty. The amount of replaceable final energy $Q_{f_{rep}}^{(i)}$ for 10% solar thermal penetration for accommodation type i, with the appropriate system characterised by $SCR^{(i)}$ is given by

$$Q_{f_{rep}}^{(i)} = \left(0.01 \cdot Q_{use}^{(i)} \cdot SCR^{(i)}\right) \cdot \frac{1}{\eta_{con}} . \tag{9.2}$$

The respective uncertainties are calculated as follows, where $Q_{use}^{(i)}$ was treated with zero error, and the superscript i refers to the according facility and the suitable solar system

$$\pm\Delta Q_{f_{rep}}^{(i)} = \left(\left(\frac{0.01 \cdot Q_{use}^{(i)} \cdot \pm\Delta SCR^{(i)}}{\eta_{con}}\right)^2 + \left(\frac{0.01 \cdot Q_{use}^{(i)} \cdot SCR^{(i)}}{-\eta_{con}^2} \cdot \Delta\eta_{con}\right)^2\right)^{\frac{1}{2}} . \tag{9.3}$$

The attributed average SCRs for Hotel, Apartment, Camp Site, and Private Accom. are 75.4, 75.4, 78.7 and 84.7%, respectively. Only for Apartment ($FU_{F(S)} = 0.84$) was SCR not achieved from the exact annual demand profile. The outcome of the system with the closest value was Hotel $FU_{F(S)} = 0.94$.

The remaining final energy, $Q_{f_{new}}^{(i)}$, needed for 10% solar thermal penetration for accommodation type i is given by

$$Q_{f_{new}}^{(i)} = \left(Q_{use}^{(i)} - 0.01 \cdot Q_{use}^{(i)} \cdot SCR^{(i)}\right) \cdot \frac{1}{\eta_{con}} . \tag{9.4}$$

The respective uncertainties are given by

$$\pm\Delta Q_{f_{new}}^{(i)} = \left(\left(\frac{-0.01 \cdot Q_{use}^{(i)} \cdot \pm\Delta SCR^{(i)}}{\eta_{con}}\right)^2 + \left(\frac{Q_{use}^{(i)} - 0.01 \cdot Q_{use}^{(i)} \cdot SCR^{(i)}}{-\eta_{con}^2} \cdot \Delta\eta_{con}\right)^2\right)^{\frac{1}{2}} . \tag{9.5}$$

The total replaced final energy consumption (in MWh) for a solar thermal penetration of 10% in tourism is shown in Table 9.4. For this scenario, the total final energy replaced is, on average 3352 MWh. Although only certain types of accommodation were taken into account, the total amount of useful heat energy shows responsibility for 87.5% of the total useful heat demand for DHW preparation in tourism throughout PGC, cf. Table 9.1.

The replaced final energy consumption per facility type and upper and lower bounds were calculated according to (9.2) and (9.3): these results were added. All numbers linked to solar thermal penetration were calculated for 10% penetration. However, any **other penetrations** can simply be achieved by taking the results times the ratio given by the intended penetration and 10%. This holds also for the lower and upper bounds and the reason is the linearity of all equations involved. Table 9.5 provides replaced final energy and the remaining final energy needed for several solar thermal penetrations.

Table 9.4: Replaced final energy for 10% solar thermal penetration for four types of accommodation standing for 87.5% of the DHW energy consumption in tourism in PGC.

Facility	Replaced final energy in **MWh**		
	Max	Min	Average
Hotel	1416	984	1207
Apartment	222	154	189
Camp Site	503	357	432
Private Accom.	1724	1318	1523
Total[a]	**3652**	**3037**	**3352**

[a]) The values Max and Min were calculated using the individual uncertainties and average values and the total average,rather than by simply adding Max and Min values.

The replaced final energy for a penetration of 10% for the four accommodation types analysed is clearly shown in *Figure* 9.1. Private accommodations, followed by hotels, have the largest share.

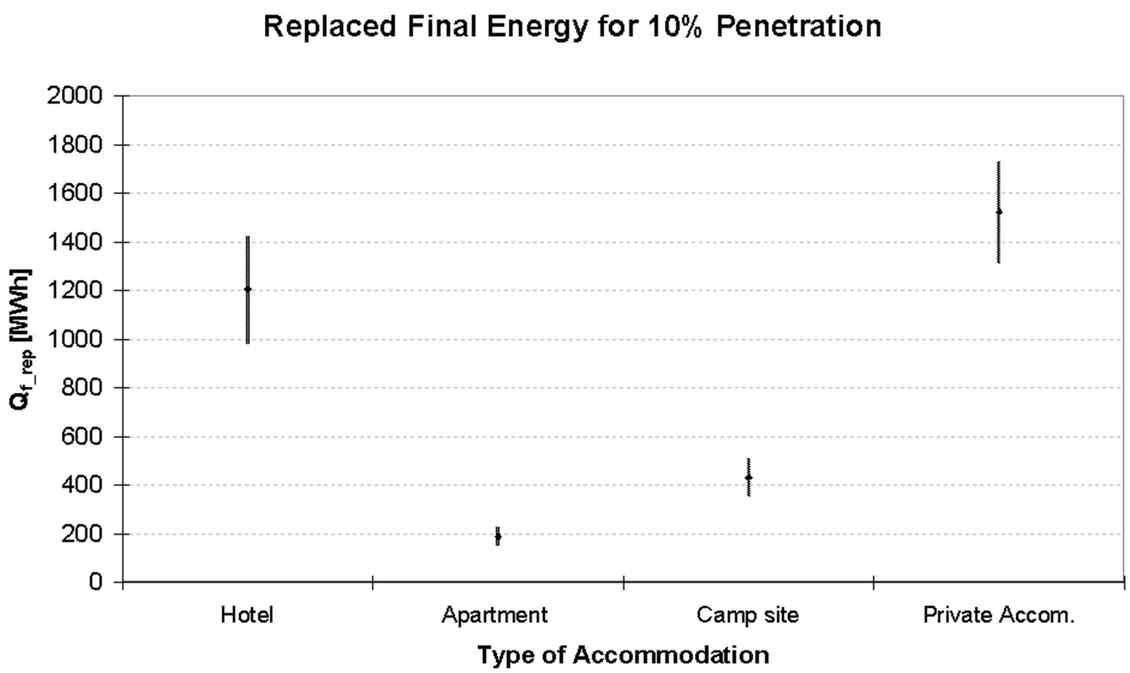


Figure 9.1: Replaced final energy for 10% solar thermal penetration for four types of accommodation standing for 87.5% of the DHW energy consumption in tourism in PGC

Table 9.5: Replaced and remaining final energy for certain solar thermal penetrations, for four types of accommodations standing for 87.5% of the DHW energy consumption in tourism in PGC.

Penetration	Energy in [**MWh**]					
↓	Replaced final energy			Remaining final energy		
	Max	Min	Average	Max	Min	Average
10%	3652	3037	**3352**	36 785	36 170	**36 470**
30%	10 955	9112	**10 055**	30 710	28 867	**29 767**
60%	21 909	18 225	**20 111**	21 597	17 913	**19 711**

A solar thermal penetration of 10% leads to a reduction of final energy by 8.4% – with respect to the total amount of final energy required. Hence, in Table 9.5 the final energy consumption diminishes by 25.2 and 50.4% for the second and third row.

Average Objects

To understand what 10% solar thermal penetration means practically, an average object-size was calculated. For the categories Hotel, Apartment, Camp Site, and Private Accommodation, the values are given in Table 9.6, along with the number of objects corresponding to 10% solar thermal penetration.

Table 9.6: Average bed capacity, and number of objects for 10% solar thermal penetration, for the relevant accommodation facilities

Facility	Total # of objects	Bed capacity total	Bed capacity 10%	**Average** size [Bed]	10% # of objects
Hotel	102	19 365	1937	190	10
Apartment	70	5012	501	72	7
Camp Site	42	39 050	3905	930	4
Private Accom.	14 739	90 080	9008	6	1474

9.2.2 Combisystems in private housing

The heat demand in private housing consists of the needs for DHW preparation and space heating (SH). SH heat demand is different among the individual buildings, whereas the demand for DHW preparation is the same. By contrast to tourist housing, the DHW demand of 200 litre per day refers to hot water at a temperature of 45°C. The specific heat demand for preparation of one litre DHW is the energy required to heat 1 litre DHW from 10 to 45°C: it is given by

$$\begin{aligned} Q &= c_{pH_2O} \cdot \Delta T \cdot 1\, dm^3 \\ &= 1.16\, Wh/(dm^3 K) \cdot 35\, K \cdot 1\, dm^3 = 40.6\, Wh\,. \end{aligned} \tag{9.6}$$

Consequently, the useful energy required to prepare 200 litres daily over one year becomes 2964 kWh. This heat demand is also given in Table 8.26.

Solar thermal combisystems for SH purposes were applied to three different buildings (SFH I, SFH II and SFH III). Each SFH meets certain criteria with respect to architecture, insulation and heating system. To estimate the replaceable final energy consumption for a certain solar thermal penetration, the existing absolute number of SFH must be categorised, i.e. subdivided into the number of houses for SFH I, SFH II, and SFH III. The figures given in Table 5.5 partially explain the division that must be chosen. It is claimed that 80% of the buildings concerned are old buildings, however, it was assumed that one fourth of them were renovated (from SFH I to SFH II), thus giving only 60% old buildings (SFH I). For construction after 1996, the optimistic figure of 2% was chosen for the category SFH III. The rest was added for category SFH II, which carries a responsibility for 38% of the existing SFH. The total number of SFH in PGC was estimated to be 44 734. For a penetration of 10%, a total of 4473 SFH would be endowed with a solar thermal combisystem. The respective absolute numbers for each building category are provided in the last row of Table 9.7.

Table 9.7: Division of the total number of SFH in PGC within the categories SFH I, SFH II and SFH III for 10% solar thermal penetration

	SFH I	SFH II	SFH III	Total
Share on total	60%	38%	2%	100%
Absolute number	26 840	16 999	895	44 734
10% penetration	2684	1700	89	4473

The annual demand for useful heat for each category of house is provided in Table 9.8. The first three columns sum up the useful heat demand of each house. The penultimate column provides the overall heating system efficiencies of the according buildings applied to calculate the total final energy demand given in the last column.

Table 9.8: Total annual useful heat and final energy demand for SFH I, SFH II and SFH III, respectively, in PGC; an error of ±0.05 was taken into account for the conversion efficiency.

	Useful and final heat demand in [**MWh**] for 10% penetration						
	Q DHW	Q SH	Q_{SFH}	# SFH	Q_{use}	η_{con}	Q_f[MWh]
SFH I	2.964	12.045	**15.009**	26 840	402 848	0.75	537 130± 33571
SFH II	2.964	7.328	**10.292**	16999	174 953	0.80	218 691±12 864
SFH III	2.964	3.510	**6.474**	895	5792	0.87	6658 ±362
Total				44734	**583 593**		**762 479** ±35 953

The total final energy replaced for a solar thermal penetration of 10% for SFHs is given in Table 9.9. The formulae for the calculation of the final energy and the error calculations are analogous to equations (9.2) through (9.5). Figure 9.2 provides a pictorial representation of this table. The old building, SFH I clearly has the highest saving potential, that does not mean, however, that thermal renovation is a lesser priority. In principal, thermal renovation should be thought of first and foremost, since it leads to the avoidance of energy consumption.

Table 9.9: Replaced final energy for 10% solar thermal penetration with respect to SFH in PGC.

Building	Replaced final energy in **MWh**		
	Max	Min	Average
SFH I	14 540	6663	10 635
SFH II	8251	4920	6604
SFH III	365	258	312
Total[a]	**21790**	**13 237**	**17 551**

[a]) The values Max and Min were calculated using the individual uncertainties and the total average, rather than simply adding the Max and Min values.

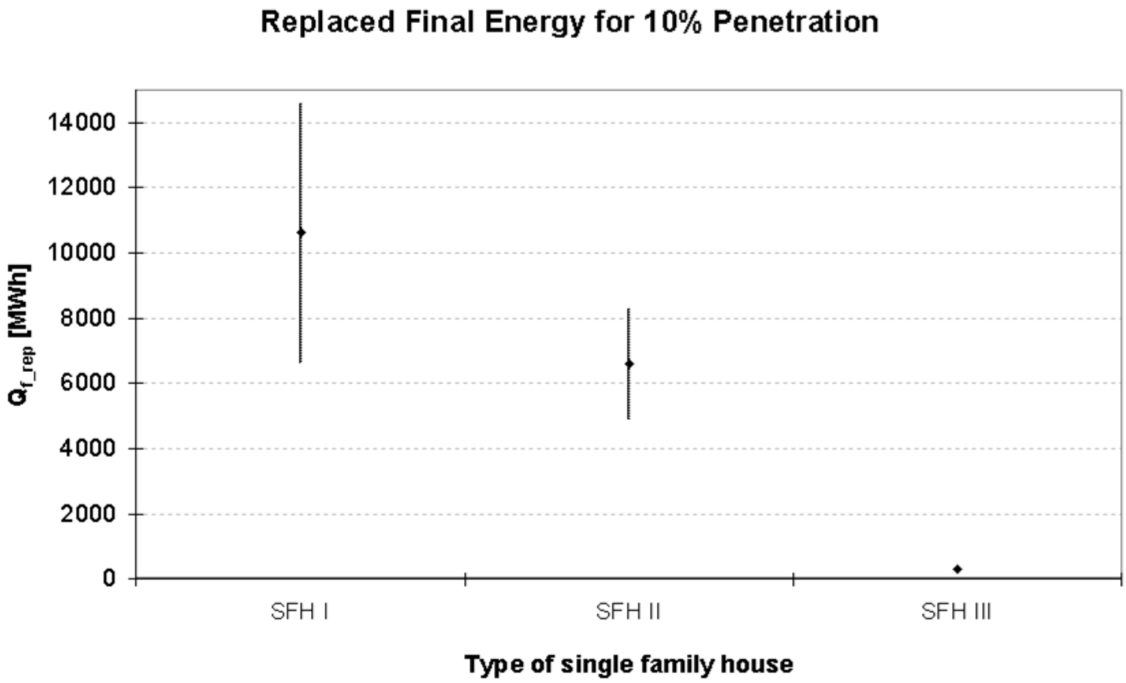


Figure 9.2: Replaced final energy for 10% solar thermal penetration for three types of buildings for single families.

Any other **penetration** can simply be derived by taking the given results multiplied by the ratio given by the intended penetration and 10%. This also holds for the lower and upper bounds due to the linearity of all equations involved. Table 9.10 lists the replaceable and the remaining total final energy demand for a number of different solar thermal penetrations throughout PGC.

Table 9.10: Replaced and remaining final energy for certain solar thermal penetrations for single-family houses endowed with combisystems in PGC.

Penetration	Energy in [**MWh**]					
↓	Replaced final energy			Remaining final energy		
	Max	Min	Average	Max	Min	Average
5%	10 895	6618	8776	789 720	717 688	753 703
10%	21 790	13 237	**17 551**	781 139	708 726	**744 928**
20%	43 579	26 473	35 102	764 351	690 438	727 377
30%	65 369	39 710	**52 654**	748 037	671 690	**709 825**
40%	87 158	52 946	70 205	732 155	652 525	692 274
50%	108 948	66 183	87 756	716 651	632 989	674 723
60%	130 737	79 419	**105 307**	701 475	613 134	**657 172**
70%	152 527	92 656	122 859	686 575	593 007	639 620
80%	174 317	105 892	140 410	671 910	572 649	622 069
90%	196 106	119 129	157 961	657 438	552 100	604 518
100%	217 896	132 365	175 512	643 130	531 388	586 967

9.2.3 Pure DHW in private housing

The useful energy needed for pure DHW preparation for SFH and the respective energy demand for 10% solar thermal penetration are given in Table 9.11. In addition, the last column lists the conversion efficiency.

Table 9.11: Particular annual useful heat demand and demand for 10% penetration for pure DHW preparation for SFH, in PGC, η_{con} was calculated as mean value from η_{con}=0.80 and η_{con}=0.93 for winter (via an existing SH) and summer (electrical) operation, respectively.

Useful and final heat demand for DHW preparation in SFH in [**MWh**]					
	Q DHW	# SFH	Q_{use}	η_{con}	Q_f
				± 0.069	
SFH	2.964	4473	132 592	0.865	153 285±11 250
Total			**13 259**		**153 285**±11 250

The total final energy replaced and the total final energy remaining for a number of solar thermal penetrations for pure DHW preparation for single-family houses is given in the next table.

Table 9.12: Replaced and remaining final energy for certain solar thermal penetrations for single-family houses endowed with pure DHW systems in PGC

Penetration	Energy in [**MWh**]					
↓	Replaced final energy			Remaining final energy		
	Max	Min	Average	Max	Min	Average
5%	6042	4602	5330	159 229	136 682	147 955
10%	12 085	9204	**10 661**	153 968	131 284	**142 624**
20%	24 169	18 409	21 322	143 585	120 358	131 963
30%	36 254	27 613	**31 983**	133 371	109 268	**121 302**
40%	48 339	36 817	42 644	123 311	98 031	110 641
50%	60 423	46 022	53 305	113 382	86 667	99 980
60%	72 508	55 226	**63 966**	103 565	75 193	**89 319**
70%	84 593	64 430	74 627	93 842	63 628	78 658
80%	96 677	73 635	85 288	84 195	51 988	67 997
90%	108 762	82 839	95 949	74 612	40 285	57 336
100%	120 847	92 043	106 610	65 081	28 529	46 675

9.2.4 Half combisystems half DHW systems for SFH

It was assumed that the respective solar thermal penetration is achieved via installation of combisystems and pure DHW solar thermal systems for the results given in Table 9.13. The ratio was assumed to be 50:50.

9.2.5 Real scenario

Another scenario that could provide a base for policy makers and combines former simulation results was considered. For this case, it was assumed that half of the considered private houses install combisystems and the second half install pure DHW systems as outlined above. Further results for saving final energy from the installation of solar thermal systems in tourism branches were used to calculate the total savings of final energy. That is, this scenario assumes private houses and tourist accommodation facilities are endowed with solar thermal systems. The study is presented for 10, 30, and 60% solar thermal penetration.

The results for this scenario are shown in Table 9.14, the potential final energy savings for private housing and tourist accommodation facilities are provided for three different solar thermal penetrations. The upper part of the table is in TJ followed by the same outcome in units of tonnes of oil equivalent and MWh.

Table 9.13: Replaced and remaining final energy for certain solar thermal penetrations, for half SFHs throughout PGC endowed with combisystems and half with pure DHW systems.

Penetration	Energy in [**MWh**]					
↓	Replaced final energy			Remaining final energy		
	Max	Min	Average	Max	Min	Average
5%	8171	5914	7053	469 699	431 960	450 829
10%	16 342	11 829	**14 106**	462 749	424 808	**443 776**
20%	32 683	23 658	28 212	449 049	410 311	429 670
30%	49 025	35 488	**42 319**	435 600	395 569	**415 563**
40%	65 366	47 316	56 425	422 380	380 607	401 457
50%	81 708	59 146	70 531	409 361	365 449	387 351
60%	98 050	70 975	**84 637**	396 514	350 122	**373 245**
70%	114 392	82 804	98 743	383 814	334 651	359 139
80%	130 733	94 633	112 849	371 236	319 059	345 033
90%	147 075	106 462	126 955	358 761	303 366	330 927
100%	163 417	118 291	141 061	346 372	287 588	316 821

Table 9.14: Total final energy substitution for three solar thermal penetrations, for installations in private housing for DHW and heating purposes (ratio 50:50) and in tourist accommodation for DHW preparation; additional consumption of electrical energy was neglected. Values are given in three different units: TJ, toe, and MWh.

Penetration	Replaceable (substituted) final energy in **TJ**			
↓	Max	Min	Average	Application
10%	59	43	51	combisystem : DHW = (50 : 50)
10%	13	11	12	DHW tourism
30%	176	128	152	combisystem : DHW = (50 : 50)
30%	39	33	36	DHW tourism
60%	353	256	305	combisystem : DHW = (50 : 50)
60%	79	66	72	DHW tourism
	Substituted final energy in **toe**			
10%	1412	1022	1219	combisystem : DHW = (50 : 50)
10%	316	262	290	DHW tourism
30%	4236	3066	3656	combisystem : DHW = (50 : 50)
30%	947	787	869	DHW tourism
60%	8471	6132	7313	combisystem : DHW = (50 : 50)
60%	1893	1575	1738	DHW tourism
	Substituted final energy in **MWh**			
10%	16 342	11 829	14 106	combisystem : DHW = (50 : 50)
10%	3652	3037	3352	DHW tourism
30%	49 025	35 488	42 319	combisystem : DHW = (50 : 50)
30%	10 955	9112	10 055	DHW tourism
60%	98050	70975	84637	combisystem : DHW = (50 : 50)
60%	21 909	18 225	20 111	DHW tourism

Results of the former table are illustrated in *Figure* 9.3. In order to show the significance of the respective replaceable amount of total final energy, percentage figures are given along with data points in the graph. These figures were derived using TFC in Croatia for households (71.84 PJ), subsector public services (27.88 PJ), and steam and hot water demand in households (5.785 PJ). These shares were first scaled down to 4956.96 TJ for households, 1923.72 TJ for public services and 399.165 TJ for steam and hot water demand in households, thus accounting for the share of inhabitants in PGC (6.9%).

As can be clearly seen, with reference to 10% solar thermal penetration, TFC in the subsector households drops by 1%, and TFC in the subsector public services decreases by 0.6%. The demand for steam and hot water demand in households could be lowered by 12.7%. The according figures for 30 and 60% solar thermal penetration are 3, 1.9, and 38.2% , and 6, 3.8 and 76.3%, respectively. A deviation from the strict linear relation is due to round-off errors.

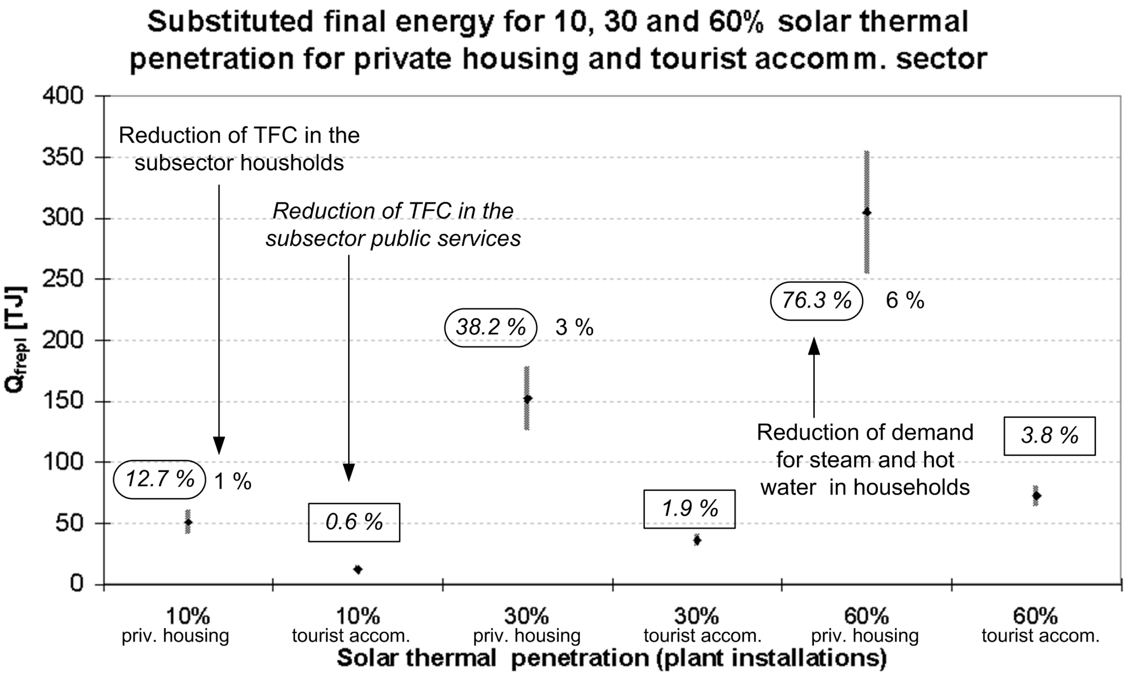


Figure 9.3: Substituted final energy for 10, 30 and 60% solar thermal penetration for DHW and SH purposes (ratio 50:50) in private housing and DHW preparation in tourist accommodations.

9.3 Summary

A detailed introduction to energy, energy resources and sources, with a focus on solar energy, was given in Chapter 2. Present data for proved recoverable, economically recoverable, or exploitable and estimated (ultimate) recoverable resources ensure a world energy supply at current consumption levels for approximately 100 years; according to data from [5]. In addition, slightly more than one tenth of the current energy supply stems from renewable energy sources. Although energy supply from the Sun, the principal energy source of the Earth, is huge, direct utilisation of solar energy in terms of solar thermal or photovoltaic applications, which harvest all or part of the solar radiation spectrum, is rare. This is the case, in general, but also for Croatia where global solar radiation is above the European average.

In 2007, TPES in Croatia was 416.78 PJ. It increased, on average, by 2.1% p.a. since 2002, and the five year trend for total primary energy production is plus 1.0% p.a.. The share of other renewables, including solar thermal energy, is only 0.17% – with respect to TPES in 2002. Energy self supply in Croatia is below 40%, and electricity imports increased, on average, by 15.7% p.a. between 2002 and 2007.

Solar energy, unlike standard fossil energy resources, requires a particular, extended potential analysis because the potential arises amidst processes or applications consuming heat energy. Such an analysis was conducted for a region in Croatia located on the upper Adriatic coast, namely PGC.

Part II

Part II of this research discussed statistical data relevant for the estimation of low-temperature solar thermal potential in private housing and for tourist accommodation. Since statistical data was not available, an approximate number of SFH for PGC was derived using relevant statistics. According to this estimation, the number of SFH is 44 734 units. Assuming an occupancy of four people, this would mean that 58% of the inhabitants of PGC live in SFH. The total number of units was divided into four construction periods: 'before 1980', '1981-90', '1991-95', and '1996 or later'. The shares of buildings with respect to these periods were estimated at 77.0, 15.0, 4.0, and 4.0%, respectively, using available statistics for Croatia. In addition, annual DHW demand profiles for private housing and three standardised SFH, with high (SFH I), medium (SFH II), and low (SFH III) specific heat demand, were defined.

Tourist statistics were analysed extensively in Chapter 5. Overnight stays from May through to September are responsible for 91.0% of annual overnight stays in PGC. Hourly DHW demand profile schemes were devised based on the occupation rate and guest DHW demand classes for a total of eight tourist accommodation facilities. Assuming a Gaussian distribution, synthetic annual demand profiles that refer to typical occupancy rates during summer were generated. The final potential estimation made use of the profiles for Hotels (also used for Apartments), Camp Sites, and Private Accommodations, with facility utilistation factors of 0.94, 0.41, and 0.25, respectively. These types of accommodations stand for 87.5% of the DHW consumption of all tourist accommodation facilities.

Chapter 6 analysed the climate conditions in Rijeka, which was considered to provide a good sample for the PGC region. General climate data was needed for the definition of the SH heat demand, and data for the annual simulation of solar thermal systems was needed on an hourly basis. The standard outdoor design temperature for Rijeka is -6°C. An assessment of available hourly climate data lead to the selection of climate data generated by the software Meteonorm, for which radiation source data refers to the measuring time frame between the years 1981 and 2000. However, the annual average hourly yield for global radiation between the three compared data sets deviates only slightly: 152 ± 3 Wh/m^2.

Part III

In Part III, the simulation software was introduced. In Chapter 8, along with the three systems for tourist accommodation facilities, two solar thermal systems for DHW preparation, two combisystems for DHW preparation, and SH for SFH were defined and optimised using SA. Subsequently, these systems were simulated for the three defined houses for various tilt and azimuth angle combinations in order to generate a contour plot that shows the annual SCR as a function of the two angles. This analysis was named Mixed Angle Analysis.

For the evaluation and comparison of average outcomes for systems with pure DHW demand, twenty pairs of angles, within the range of *tilt* $\in \{15°, 30°, ..., 60°\}$ and *azimuth* $\in \{0°, 15°, ..., 60°\}$, were taken into account. The tilt range for combisystems was $\{15°, 30°, ..., 75°\}$; averaging was over 25 pairs. SCR for pure DHW systems for private purposes ranged, on average, between 66.1 and 73.0%, and the specific annual yield fell between 432.4 and 509.1 kWh/m^2. SCR was between 16.7 and 46.8% for the combisystems: the highest coverage ratio was attained for SFH III in combination with a one storage system with a stratification unit. The specific solar yield ranged from 246.5 to 332.3 kWh/m^2.

Moreover, definition, optimisation, and mixed angle analyses were conducted for three solar thermal systems for DHW preparation for tourist accommodation facilities. The collector area for the small (ACC S), medium (ACC M), and large (ACC L) system ranged between 11.5 and 145.5 m^2. Outcome for SCR was between 75.4 and 84.7%, and specific annual yield was between 328.5 and 382.3 kWh/m^2. The system efficiency average fell between 25.5 and 30.1%.

SA demonstrated that, for auxiliary heat supply, maximum SCR is achieved at a storage temperature as low as possible. Furthermore, a SH system optimised for solar thermal heating, i.e. low temperature wall or floor heating, and the height of the return pipe for SH, bore significant optimisation potential. Favourable tilt angles varied with respect to the purpose of heat supply, and hence, depend on the annual heat demand profile. For pure DHW heat demand, the maximum annual yield was achieved for a south facing collector with a tilt angle of 45°, whereas for additional SH heat demand, the optimal tilt angle was 55°. Systems for tourist facilities showed a maximum SCR at a tilt angle of approximately 30° as so long as the base heat demand off-season is significantly less than the demand during summer. This held for the ACC M and ACC L systems, whereas for the small system ACC S, the optimal tilt angle was approximately 35°.

Simulations using other climate data were conducted with the optimised systems from Chapter 8 with *azimuth*=0° and *tilt*=45°. Taking into account the outcomes for all systems applied to this analysis, the mean deviations of SCR, compared to the climate data set for *Rijeka* were; *Hvar*, 16.5 ± 5.7; *Split*, 12.9 ± 2.7; *Zadar*, 8.8 ± 3.0; *TRY*, 4.5 ± 1.9; *Rijeka91*, -3.6 ± 1.6; and *Grazhour*, -15.9 ± 4.9, in % respectively. *Rijeka91* refers to a modified climate data set for Rijeka with 9% lower radiation values; it was used to estimate the impact of an atypical year.

Potential analyses in Chapter 9 were based on 10% solar thermal penetration, i.e. installation of solar thermal systems assumed for 10% of total SFH, tourist accommodations, or both. Calculations were conducted separately for the DHW scenarios in the tourism branch, combisystems, and pure DHW in private housing. Following this, 10% penetration in private housing, assuming realisation with installation of half combisystems and half pure DHW systems, was calculated. Subsequently, a real scenario, also including 10% penetration in the tourism branch, was derived. Results show a potential decrease of TFC in the subsector households by 1%, and in the subsector public services by 0.6%. Further demand for steam and hot water in households could be lowered by 13%.

9.4 Conclusion

Conventional energy resources at the current rate of consumption, will last for approximately one hundred years worldwide. Technology for solar thermal utilisation for private purposes and in tourist accommodations is in operation in several countries in the EU. High global solar radiation in Croatia, as compared to the European average, justifies this study. The study at so demonstrates how low electricity prices might hinder private incentives in terms of solar thermal installations.

Electricity imports increased, on average, by 15.7% p.a. between 2002 and 2007, and the international price-level was approximately 1.7 times higher than in Croatia. This price must be inevitably reflected in national prices unless national production increases significantly or subsidies are established or increased. These subsidies, however, could also be established for installations of solar thermal systems, which in turn, would lead to a reduction in electricity consumption.

An analysis of tourist statistics showed that overnight stays from May through to September are responsible for 91.0% of annual overnight stays in PGC. In addition to applications for private housing, special attention was given to the summer tourist period. The average facility utilistation factors in summer for Hotels, Apartments, Camp Sites and Private Accommodations, 0.94, 0.84, 0.41, and 0.25, respectively, and the high share of 87.5% on the DHW demand among all tourist accommodations, underline the relevance of these accommodations.

Hourly climate data generated using the software Meteonorm and the collection time 1981 to 2000 proved suitable for system simulations. Another opportunity not taken into account is the generation of hourly climate data from external monthly data as provided by the Solar Radiation Handbook of Croatia [38].

The conducted SA showed the different outcomes for High- and Low-flow concepts, the importance of the right heights for heat storage inlet connections, and maximum temperatures in order to increase the efficiency of solar thermal systems. The natural circulation system for SFH yields the highest *SCR*. The simulated combisystem with a stratification unit yields the best results in terms of *SCR*. Furthermore, a SH system optimised for solar thermal heating, i.e. low temperature wall or floor heating, and a low maximum storage temperature for auxiliary supply, bore optimisation potential. Pure DHW systems for private purposes use the collector field most efficiently. Systems for tourist accommodations show smaller specific collector yields with decreasing off-season/summer demand ratios. Higher specific yields were obtained in [1] for smaller but better optimised systems.

The tilt angle analysis showed maximum annual yields for a south facing collector with a tilt angle of 45° for the SFH systems with pure DHW demand, whereas for additional SH heat demand, the optimal tilt angle is 55°. Systems for tourist accommodations show a decreasing optimal tilt angle as the relative off-season demand falls. The optimal angles are 35, 32, and 30° for ACC S, ACC M, and ACC L, respectively.

Applying different climate data to the defined systems shows a *SCR* increasing significantly southwards. The analysis for an atypical year with 9% less solar radiation data showed a drop of *SCR* by $3.6 \pm 1.6\%$, thus influence on SCR is much less than the reduction of the radiation. The impact on the outcome, however, increases in correlation with the size of the system. A simulation with an azimuth of 45° and a tilt angle of 30° is a suitable replacement for averaging a number of angle combinations to calculate average *SCR*s for statistical purposes. This simulation provides a good sample for the systems SFH and ACC S. The larger systems for commercial purposes ACC M and ACC L require a tilt of 15° to approximate the averaging procedure adequate. The suitable angles are an azimuth of 45° and a tilt of 60° for combisystems.

The potential estimation with 10% solar thermal penetration showed a decrease of

TFC in the Households subsector by 1%, and in the Public Services subsector by 0.6%. This could lower the demand for steam and hot water in households by 13%.

This research demonstrates a significant potential for TFC reduction in terms of low temperature heat, if heat production purely based on fossil fuel or electricity, would be supported by the installation of solar thermal systems for SH and preparation of DHW. Major results from this research are published in [1], which also includes an economical analysis with smaller, more efficient systems. Future developments and progress in the sector of solar thermal cooling could significantly increase potential energy savings, but this would require additional analysis.

List of Figures

List of Tables

Appendix A

Bibliography

Bibliography

[1] Pichler M., Fucak S., Frankovic B. *Low temperature solar thermal domestic hot water potential of Croatia's Islands and Coastal Regions*, Eurosun2010 Conference proceedings, Graz 2010

[2] Kaltschmitt M., Streicher W., Wiese A. *Renewable Energy - Technology, Economics and Environment*, Springer, Berlin Heidelberg New York, 2007

[3] INTERNATIONAL ENERGY AGENCY, *Energy Statistics Manual*, source: HTTP://WWW.IEA.ORG/, OECD/IAE, Paris, 2005

[4] Officers of the World Energy Council, *2007 Survey of Energy Resources* Executive Summary, World Energy Council 2007 London

[5] Officers of the World Energy Council, *2007 Survey of Energy Resources*, World Energy Council 2007 London

[6] Boyle Godfrey, *Renewable Energy, Power for a sustainable future*, Oxford University Press in association with The Open University, 2th edition, 2004

[7] AEA, *Austrian Energy Agency Mariahilfer StraSSe 136, 1150 Wien* website (01.06.2010): http://www.energyagency.at/energien-in-zahlen/erneuerbare-energie.html

[8] Christoph Wegscheider, Kraft und Wärme aus Biomasse GmbH Industriestraße 235, A-8321 St. Margarethen/Raab, 2009

[9] Erwin Stubenschrott, *Vortrag im Rahmen von Alumni Graz*, Kraft und Wärme aus Biomasse, KWB, 2009

[10] Weiss W., Bergmann I., Stelzer R *Solar Heat Worldwide EDITION 2009, IEA Solar Heating & Cooling Programme* , AEE - Institute for Sustainable Technologies, Gleisdorf, 2009

[11] INTERNATIONAL ENERGY AGENCY, *KEY WORLD ENERGY STATISTICS*, source: HTTP://WWW.IEA.ORG/, IAE, Paris, 2008

[12] Energy Regulatory Agency *Annual Report for the Year 2007*, Croatian Energy Regulatory Agency , Ulica grada Vukovara 14, 10000 Zagreb, 2007

[13] Horacek B., *ENERGY IN CROATIA 2007, ANNUAL ENERGY REPORT*, Ministry of Economy, Labour and Entrepreneurship Republic of Croatia Zagreb, Ulica grada Vukovara 78, Zagreb 2008

[14] Zombeck Martin, *Handbook of Space Astronomy & Astrophysics*, Cambridge University Press, Cambridge USA, 2nd edition

[15] Foelsche Ulrich, *Lecturenotes geophysics 2006/2007*, Karl Franzens University Graz, 2006

[16] IPCC, 2007: *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

[17] EIHP, *Introduction to SOLAR RADIATION HANDBOOK OF CROATIA* , http://www.eihp.hr/english/prirucnik.htm
Check

[18] *University of Oregon Solar Monitoring Lab: Pacific Northwest Solar Radiation Data, UO Physics Department, Solar Energy Center, 1999*

[19] Branko Skrobonja, *Statistical Chronicle of the Primorsko-goranska County*, http://www.pgz.hr/eng/index.html , Croatian Chamber of Economy - Rijeka 2002

[20] Vlatko Šuperina, *Personal Meeting on the 06th of July 2009* PRIMORSKO-GORANSKA COUNTY, Public Institution INSTITUTE OF PHYSICAL PLANNING, Rijeka Splitska 2

[21] *Nastanjeni stanovi prema godini izgradnje, vrsti zgrade i broju kuć anstava u stanu , popis 2001*,
http://www.dzs.hr/Hrv/Censuses2001/Popis/H03_04_01/H03_04_01.html

[22] B. Hrastnik, B. Franković, *Solar energy demonstration zones in the Dalmatian region*, Renewable Energy 24, 501-515, Elsevier, 2001

[23] Berislav Tulić, *ANALIZA TURISTIČKE 2008. GODINE NA PODRUČJU PRIMORSKO-GORANSKE ŽUPANJE*, Upravni odjel za turizam, Rijeka January 2009

[24] P. Laimer, *Tourism in figures Austria 2008/09*, STATISTIK AUSTRIA, www.statistik.at, Vienna 2009

[25] G. Tschernigg, *Technical description, sizing and calculation methods of solar systems in tourism*, Arsenal Research, Trans Solar Conference Zagreb, April 2009

[26] U. Jordan, K. Vajen, *Realistic Domestic Hot-Water Profiles in Different Time Scales*, Universität Marburg, FB. Physik, FG. Solar, V.2.0, May 2001

[27] R. Heimrath, M. Haller, *The Reference Heating System, the Template Solar System of Task 32*, Report A2 of Subtask A, International Energy Agency, September 2007

[28] Streicher, W., *Vorlesungsskript Sonnenenergienutzung (307.036), Solare Brauchwasserbereitung und Heizung*, TU GRAZ INSTITUT FÜR WÄRMETECHNIK , 2008

[29] *Statistički ljetopis Primorsko-Goranske Županije 2008.*, Republika Hrvatska Ured državne uprave u Primorsko-Goranskoj Županiji, Rijeka, prosinac 2008.

[30] M.C. Peel, B.L. Finlayson, T.A. McMahon *Updated world map of the Köppen-Geiger climate classification* , University of Melbourne, Australia 2007

[31] , DHMZ, *Climate/monthly values* , DHMZ Meteorological and hydrological service, http://meteo.hr/index.php, June 2009

[32] Streicher W., Schnedl K., Thür A., Vilics A., *SHWwin Version 1.2 Okt. 1999*, Technical University Graz, http://lamp.tugraz. ac.at/iwt/downloads/swdownload/shwindlgo.html, 1999

[33] I. Viličić, *STUDIJSKA ANALIZA UTJECAJA KLIMATSKO-METEOROLOŠKIH FAKTORA NA GRIJANJE I HLAĐENJA OBJEKATA HRVATSKOG PRIMORJA*, Disertacija Sveučilište u Rijeci tehnički fakultet Rijeka, Rijeka , 1992

[34] METEOTEST, *Meteonorm Version 6.1.0.12*

[35] J. Remund, S. Kunz, C. Schilter, *Meteonorm Version 6.0 Handbook part I: Software*, METEOTEST, Fabrikstrasse 14, CH-3012 Bern, Switzerland, Version 6 (software version 6.1 of December 15^{th} 2008)

[36] J. Remund, S. Kunz, C. Schilter, *Meteonorm Version 6.0 Handbook part II: Theory*, METEOTEST, Fabrikstrasse 14, CH-3012 Bern, Switzerland, Version 6 (software version 6.1 of December 15^{th} 2008)

[37] Arden L. Buck, *New Equations for Computing Vapor Pressure and Enhancement Factor*, National Center for Atmospheric Research, Boulder, CO 80307, 1981

[38] EIHP, *EIHP- Solar Radiation Handbook of Croatia* ,

[39] B. Franković, *Energy and the Environment 2006 Vol. I.*, Croatian Solar Energy Association Rijeka, Vukovarska 58, Croatia, 2006

[40] U.V. Desnica, K.Cindric and A.Marki, *Applicability of Meteonorm Computer Program for Quantitative Estimates of Solar Radiation in Croatia*, R. Boskovic Institute - Zagreb, DHMZ Zagreb, Faculty of Science, Department of Geophysics - Zagreb, 2006

[41] *Transient System Simulation Program*, Solar Energy Laboratory, University of Wisconsin-Madison, Version 14.1, 1995

[42] Vilics A., *Erweiterung des Simulationsprogrammes SHW für solare Brauchwasserbereitung und Heizung*, Diplomarbeit an der Technischen Universität Graz, September 1999

[43] Schnedl, K., *Simulation von Systemen zur solaren Raumheizung und Warmwasserbereitung mit Zusatzheizung*, Diplomarbeit am Institut für Wärmetechnik der Technischen Universität Graz, Graz Juni 1994

[44] Recknagel, Sprenger, Schramek, *Taschenbuch für Heizung und Klimatechnik*, R. Oldenburg Industrieverlag GmbH, München, Oldenburg Industrieverlag, 72. Ausgabe, 2004

[45] Streicher W., Schnedl K., Thür A., Vilics A. *Programmbeschreibung von SHWwin, Simulationsprogramm für solare Brauchwasserbereitungs- und Heizungssysteme*, Institut für Wärmetechnik, TU Graz, Version 25. April 2000

[46] Duffie John A., Beckman William A., *SOLAR ENGINEERING OF THERMAL PROCESSES*, JOHN WILEY & SONS, INC, NEW YORK, 2nd edition, 1980

[47] W. Streicher, K., *SIMULATION MODEL OF A VERSATILE WATER STORAGE TANK WITH INTERNAL HEAT EXCHANGERS AND FLOW INLETS/OUTLETS* , Institute of Thermal Engineering, Graz University of Technology, A-8010 Graz, Austria

[48] Louise Jivan Shah, *Generic System #4: DHW Tank as a Space Heating Storage Device*, Technical University of Denmark BYG.DTU Dep. of Civil Engineering, October 2002

[49] Streicher W., *Report on Solar Combisystems Modelled in Task 26 (System Description, Modelling, Sensitivity, Optimisation)*, Institute of Thermal Engineering Graz University of Technology, A Report of IEA SHC - Task 26 Solar Combisystems, April 2003

[50] Brumbaugh, J.E., *HVAC Fundamentals Volume 1 Heating Systems, Furnaces, and Boilers*, Wiley Publishing, Inc., 4th Edition, 1975

[51] Kovač I. *STATISTICAL INFORMATION*, REPUBLIC OF CROATIA CENTRAL BUREAU OF STATISTICS, ISSN 1330-335X, Zagreb 2008

[52] , *official web site Primorsko-goranska County* , http://www.pgz.hr/eng/gradiop.html , 2004

[53] Eduard Cvitković, *TURISTIČKI PROMET U PRIMORSKO-GORANSKOJ ŽUPANIJI, Razdoblje od siječnja do prosinca 2008.*, Republika Hrvatska Ured Državne uprave u PGŽ služba za gospodarstvo odsjek za statistiku, Rijeka 2009, broj:7.1.12, 2009

[54] Scheer Hermann, *The Solar Economy, Renewable Energy for a Sustainable Global Future*, Original title: *Solare Weltwirtschaft* Verlag Antje Kunstmann, Earthscan London Sterling, VA, , 2005

[55] Josip Pažanin , *II SIMPOZIJA O KORIŠTENJU SUNČEVE ENERGIJE, Opatija, 1. i 2. VI 1978*, TEHNICKI FAKULTET RIJEKA; JUGOSLAVENSKO UDREŽENJE ZA KORIŠTENJE SUNČEVE ENERGIJE, Rijeka 1978

[56] B. Franković, *strojarstvo Journal for Theory and Application in Mechanical Engineering*, Croatian Union of Mechanical Engineers and Naval Architects, Volume 49 Number 3, Zagreb 2007

[57] EIHP, *STRATEGIJA ENERGETSKOG RAZVITKA PRIMORSKO-GORANSKA ŽUPANIJE*, EIHP & Sveučilište u Rijeci tehnički fakultet Rijeka, Zagreb, prosinac 2005, 2005

[58] M. Pichler, *Measuring and modelling charge mobility in organic electronic devices*, Imperial College London, Master thesis at the Department of Physics, 2010

Low temperature solar thermal domestic hot water potential of Croatia's Islands and Coastal Regions

Martin Felix Pichler[1*], Sanjin Fućak[2] and Bernard Franković[2]

[1] Physics Department, Karl-Franzens University of Graz, Universitätsplatz 5, A - 8010 Graz, Austria (currently at Physics Department, Imperial College London, London, SW7 2AZ, UK)

[2] Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000, Rijeka, Croatia

[*] Corresponding Author, martin.pichler09@imperial.ac.uk

Abstract

This paper discusses solar thermal energy as a cost-effective alternative to conventional energy sources for the supply of domestic hot water for private housing and tourist accommodation along the Croatian Adriatic coast. The initial analysis concerns domestic hot water system designs and simulation. This includes a brief view on the following topics: simulation software, hourly climate data and simulation procedures. Daily, weekly and annual domestic hot water demand profiles reflect fluctuations in utilization of tourist accommodations. Potential solar yields along the coast significantly increase southwards. Simulation results for annual specific solar yield and solar coverage ratio are summarized for four different solar thermal systems, each with two collector orientations and using climate datasets from Rijeka, Zadar and Hvar. The number of inhabitants and tourist overnight stays are used to estimate current final energy consumption and potentially replaceable amounts, showing that only 10% of ST installations for the proposed applications would nearly double the current share of renewable energy in Croatia. Consequently, economic methods are used to show that investment payback times are significantly shorter than the expected system lifetime.

1. Introduction

The most widely used energy resources for preparing domestic hot water (DHW) in Croatia are fuel oil, gas and electricity. Diverse, ongoing and previous energy crises are signals that highlight existing European dependencies in the energy sector. A viable alternative would be the utilization of free and sustainable sources such as solar energy, which could help to lower this dependency and provide more than two thirds of the energy necessary for providing DHW within reasonable costs. Replacing a share of useful energy obtained from electrical or fuel sources, is expected to have positive side-effects of an ecological as well as logistical nature in regards to the summer peak electricity supply problems – especially on islands with poor grid connectivity. The percentage of international hotel managers (66%) considering solar thermal (ST) energy supports the relevance of this study [1].

An extensive analysis of low temperature ST systems by Pichler [2] has predicted significantly higher annual solar coverage ratios (*SCR*) along the Croatian Adriatic coast than those for middle and northern Europe. The analysis of a ST system for purely private demand (SFH f) and three systems of small (ACC S), medium (ACC M) and large (ACC L) size demand for tourist accommodation facilities show, that the southern part of the country is in the context of this paper nearly as favorable as the proponent Greece.

2. Methods

2.1. Simulation Software and Climate Data

Simulations presented here were performed using SHWwin [3] and synthetic hourly climate data provided by METEONORM [4], whose applicability has been investigated in [2].
SHWwin provides monthly and annual results in a table-like schematic [2, 3]. Thermal stratification of storage tanks is modeled using 10 layers and via the vertical heat conduction coefficient λ. System features from the collector field to the storage such as pipe length, the heat capacity of all parts and various thermal losses are taken into account. The step size of the algorithm is 6 minutes and it uses interpolation between two sequential hourly climate data inputs. Initial boundary condition problems for heat storages are avoided by using a two months overlap in the simulation period: i.e. it starts in August and ends in September of the following year.
This study required average hourly climate data for a base period of at least 10 years, namely global and diffuse solar radiation on a horizontal surface of 1 m², and ambient temperature. Climate data generation was based on measurements from 1996-2005 for temperature and from 1981-2000 for radiation data. Uncertainties were 1.5°C and 9% for monthly solar radiation, less than the natural variations of global radiation between consecutive years [4]. Climate datasets for Rijeka, Zadar and Hvar (designated *Ri* / *Zd* / *Hv*) were used to assess system performances in different latitudes and were assumed to provide representative samples of their surrounding coastal municipalities.

2.2. Control Parameters

All considered ST systems incorporate pumps for heat supply, for which typical parameters of on/off control units were a temperature difference of 5 K and a hysteresis of 1-2 K. Low, high and matched flow rate systems were analyzed. Low flow concepts (~10 ℓ / (m² h)) with stratification units as used in ACC S guarantee a high temperature rise in the collector field (40 K) and rapidly provide high exergy. By contrast, the temperature rise for high flow rate systems (~20 – 50 ℓ / (m² h)), as used in SFH f, should not exceed 10 K to assure high collector efficiencies. The systems ACC M and ACC L use the matched flow concept.

2.3. Statistical Data, Facility Utilization and DHW Demand

Data for tourist overnight stays was obtained from [5] where it was compiled from regular monthly accommodation and agency services' reports. Accommodation facilities in this paper are divided into three categories named after the facility with the highest genuine share: Hotels etc. (later split into Hotels and Apartments), Camps and Private Accommodations.
The analyzed tourist traffic statistics showed that 91% of annual overnight stays in Primorje-Gorski kotar County (PGC) fall into the summer season between May and September. Different accommodation facilities vary with respect to facility utilization (FU), which is the total number of overnight stays in a year divided by bed capacity (n_{beds}) [2]. The average summer season FU , abbreviated $FU_{(\mathrm{S})}$, is expressed in days as 143.5, 129.2, 63.3 and 37.7 for Hotels, Apartments, Camps and Private Accommodations, respectively. These numbers, divided by the number of summer days (153), lead to the facility utilization factors $FU_{\mathrm{F(S)}}$ which are 0.94, 0.84, 0.41 and 0.25, respectively. A nominal daily summer demand for DHW ($V_{\mathrm{dem(S)}}$) in tourist accommodations is given by [6, 7]:

$$V_{\mathrm{dem(S)}} = V_{\mathrm{G}} \cdot n_{\mathrm{beds}} \cdot FU_{\mathrm{F(S)}} \quad (1)$$

where V_G is the daily demand in ℓ at 60°C (over 45° for hygienic reasons) per guest, which was estimated to be 60 for Hotels, 40 for Apartments and Private Accommodations and 20 for Camps, [2]. $V_{dem(S)}$ is the key parameter in sizing of ST systems for summer tourism accommodations. All systems in use have been defined for certain standard accommodations [2]; $V_{dem(S)}$ was calculated at 320 ℓ / day for ACC S (Private Accommodation n_{beds}= 16), 1640 ℓ /day for ACC M (Camp n_{beds}= 200) and 5640 ℓ / day for ACC L (Hotel n_{beds}= 100). For a single family of 4 persons the assumed annual daily DHW demand (V_{dem}) is 200 ℓ at 45°C per day.
The actual daily DHW consumption results from folding $V_{dem(S)}$ or V_{dem} with respective demand profiles, see Fig. 1. Anticipated hourly demand for each day has been deduced in [2] from demand profiles for the IEA solar heating and cooling Task32. Daily demand for private housing was set to 90% during the week, 100% on Fridays, and 120% over the weekend but was assumed constant at 100% for tourist accommodations. Annual demand reflects variations of ground water temperature (set 10°C), demand variations for private housing, and the annual distribution of overnight stays for the respective accommodation facilities combined with minimum demand for the off-season months [2].

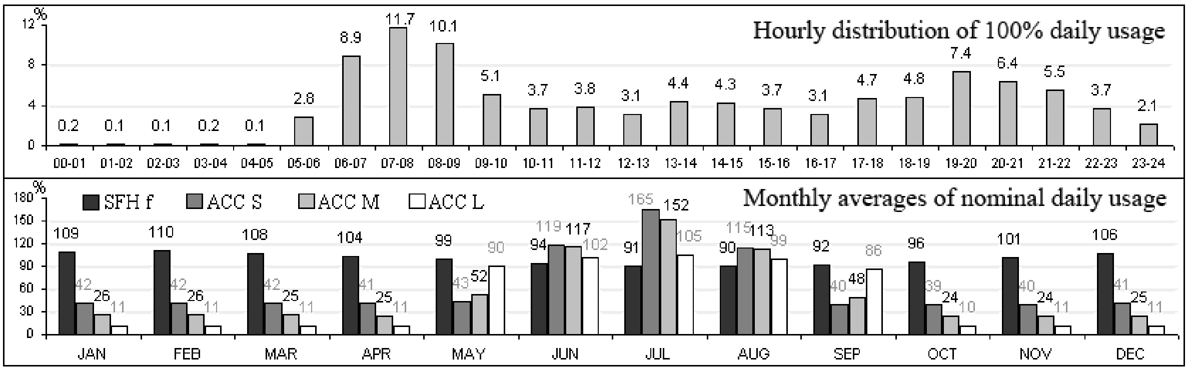


Fig. 1. Daily (above) and annual (below) DHW demand profiles relative to the nominal daily demand [2]. Monthly averages have been derived from data for PGC in 2008.

2.4. Solar Thermal System Analysis and Optimization

The system description includes the collector field, storage, pipe, insulation and flow related parameters and along with the DHW demand profile constitutes the main part of the model in Fig. 2.

Fig. 2. System analysis procedure, with most relevant parameters and available results.

The solar coverage ratio is an important simulation result characterizing the performance of a system, and is generally used to compare different system designs for the same application. It is given by:

$$SCR = 1- [\Sigma_i (Q_{aux(i)}) / Q_{demand}], \quad (2)$$

where Q_{demand} is the total heat demand and $Q_{aux(i)}$ the auxiliary heat demand of the *i*-th auxiliary source. For the optimization, it was assumed that systems with a *SCR* of approximately 70% for tilt $\beta = 45°$ and azimuth $\gamma = 0°$ represent a good balance of performance, ecological and economical optima [6] . This was applied to the climate datasets for Rijeka, Zadar and Hvar.

3. Solar Thermal Systems

Hydraulic designs of the investigated systems are illustrated in Fig.3 and their defining parameters are given in Table 1. Certain adjustments were needed in aiming for a *SCR* of 70% for templates previously defined in [2, 7] – mainly smaller collector fields and storages appropriate for the climate.

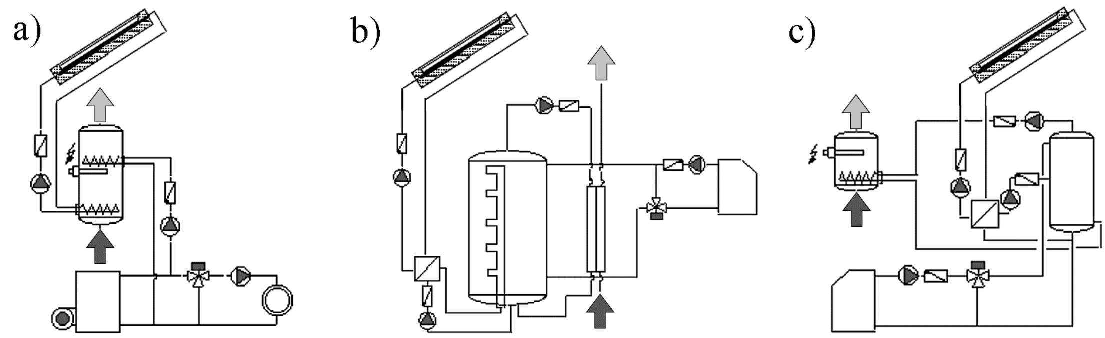


Fig. 3. Hydraulic design of three ST systems for DHW provision **a)** SFH f **b)** ACC S and **c)** ACC M / ACC L. Auxiliary heating for all designs is either electrical, via a boiler or both. Light and dark arrows indicate hot water draw-off and cold water inlet, respectively [3].

Table 1: Technical parameters for simulated systems; varying collector field and storage sizes separated with a slash refer to climate data *Rijeka* / *Zadar* / *Hvar*. All simulations were performed using a flat-plate collector.

Description	**Parameters and respective values**	
Collectors (at 1.92 m²):	Conversion factors: c_0=0.759, c_1=3.768, c_2=0.0	Incidence angle modifier = 0.9
SFH f: 200 (liter 45°C)/ day,	**Collector field**: net. surface 5.75 m² / 3.83 m² / 3.83 m²	
Collector loop, pipes	1.5 mm Cu, *d* =15 mm, *L* = 20 m; insul.: 30 mm, 0.04 W/(m² K), mass flow = 0.045 kg / s	
DHW Storage	300 ℓ / 300 ℓ / 250 ℓ , λ = 1.46 W/(m K); $T_{\text{max solar}}$ = 67°C, $T_{\text{max aux}}$ = 50°C	
ACC S: $FU_{F(S)}$ = 0.25, 320 (ℓ 60°C) / day;	**Collector field**: net. surface 7.66 m²/ 5.75 m²/ 5.75 m²	
Collector loop, pipes	1.5 mm Cu, *d* = 15 mm, *L* = 40 m, insul.: 30 mm, 0.04 W/(m² K), mass flow = 0.04 kg / s	
Heat Storage (stratif.)	500 ℓ / 500 ℓ / 350 ℓ , λ = 1.5 W/(m K); $T_{\text{max solar}}$ = 80°C, $T_{\text{max aux}}$ = 65°C	
ACC M: $FU_{F(S)}$ = 0.41, 1640 (ℓ 60°C) / day;	**Collector field**: net. surface 36.39 m²/ 28.75 m²/ 26.83 m²	
Collector loop, pipes	2 mm Cu, *d* = 42 mm, *L* = 40 m; insul.: 30 mm, 0.04 W/(m² K), mass flow = 0.6-0.85 kg / s	
DHW Storage	500 ℓ, λ = 1.8 W/(m K), $T_{\text{max heat storage}}$ = 65°C, $T_{\text{max aux elect}}$ = 60°C	
Heat Storage	1500 ℓ / 1000 ℓ / 1000 ℓ , λ = 1.2 W/(m K); $T_{\text{max solar}}$ = 93°C, $T_{\text{max aux boiler}}$ = 67°C	
ACC L: $FU_{F(S)}$ = 0.94, 5640 (ℓ 60°C) / day;	**Collector field:** net surface 130.22 m²/ 99.58 m²/ 95.74 m²	
Collector loop, pipes	2 mm Cu, *d* = 66 mm, *L* = 100 m; insul.: 30 mm, 0.04 W/(m² K), mass flow=1.1-2.2 kg / s	
DHW Storage	1000 ℓ , λ = 1.4 W/(m K); $T_{\text{max heat storage}}$ =62°C, $T_{\text{max aux elect}}$ = 60°C	
Heat Storage (stratif.)	7000 ℓ / 5000 ℓ / 5000 ℓ , λ = 1.0 W/(m K), $T_{\text{max solar}}$ =88°C, $T_{\text{max aux boiler}}$ = 67°C	

3.1. Simulation Results

Unless explicitly stated otherwise, all results refer to annual values. Hourly DHW consumption for SFH f and ACC S was taken at the first simulation step of each hour while ACC M and ACC L distribute consumption continuously within the hour. Results for each system and the three different climate datasets are provided in Table 2. Annual useful energy demand for DHW preparation in kWh equals to 2964, 4353, 19099 and 55995 for SFH f, ACC S, ACC M and ACC L, respectively. System size decreases significantly towards south for the same DHW demand, and parallel the operation time increases. Q_{losses} incorporates all losses connected to the ST equipment installed.

Table 2: Result overview of three climate datasets for all systems, $\gamma = 0°$ and $\beta = 45°$. System names are given in the leftmost column along with the net collector field size and total volume of storages involved. Columns with the suffix ***Sample*** refer to $\gamma = 45°$ and $\beta = 30°$ for SFH f and ACC S or $\beta = 15°$ for ACC M and ACC L.

Annual mean values **System: [m²], [ℓ]**	***Rijeka/ Zadar/ Hvar***	**Global radiation [MWh]**	***SCR* [%]**	***SCR Sample* [%]**	**Operation time [h]**	**Q_{useful} Coll. [kWh]**	**Q_{losses} sol. loop & Storage [kWh]**	**Specific solar yield in storage [kWh/ m²]**	**Specific solar yield in storage *Sample* [kWh/ m²]**	**System Efficiency [%]**	**Coll. Efficiency [%]**
SFH f: 5.75, 300	*Ri*	8.1	68.3	63.3	2214	2655	631	**434**	**407**	32.8	47.5
SFH f: 3.83, 300	*Zd*	6.7	72.5	65.6	2491	2803	655	**685**	**628**	42.1	53.1
SFH f: 3.83, 250	*Hv*	6.8	72.1	67.4	2510	2758	620	**673**	**633**	40.3	52.6
ACC S: 7.66, 500	*Ri*	10.8	74.1	72.1	1722	3775	737	**462**	**448**	35.1	53.5
ACC S: 5.75, 500	*Zd*	10.0	72.0	70.7	1797	3681	760	**597**	**583**	36.8	56.8
ACC S: 5.75, 350	*Hv*	10.3	76.0	75.6	1939	3718	695	**602**	**595**	36.2	56.0
ACC M: 36.39, 2000	*Ri*	51.1	71.7	69.2	1652	15421	1828	**404**	**388**	30.2	43.9
ACC M: 28.75, 1500	*Zd*	50.0	72.2	69.3	1842	15835	2182	**521**	**497**	31.7	46.3
ACC M: 26.83, 1500	*Hv*	47.9	71.9	69.6	1923	15806	2207	**557**	**535**	33.0	46.9
ACC L: 130.22, 8000	*Ri*	183.0	71.2	70.0	1533	47945	5330	**347**	**339**	26.2	40.3
ACC L: 99.58, 6000	*Zd*	173.3	69.6	68.3	1766	46942	5367	**439**	**429**	27.1	41.9
ACC L: 95.74, 6000	*Hv*	170.9	69.8	69.8	1820	47198	5463	**458**	**456**	27.6	42.1

3.2. Result Analysis

A specific storage volume of 60 ℓ / m² is suggested for Austria [6], while a study focusing on economical viability of DHW systems proposes 55 ℓ / m² for Greece [8], however, it ranges from 52 ℓ / m² to 78 ℓ / m² in this paper. System efficiencies are between 26.2% and 42.1%.

Increasing the storage volume for **SFH f** to 350 ℓ for climate data *Ri* would increase *SCR* to 70.2%, while a 200 ℓ storage for *Zd* would decrease *SCR* to 59.6%. For *Hv,* a storage of 200 ℓ leads to *SCR* = 63.1%, while for 250 ℓ the *SCR* rises to 72.1%. The maximum *SCR* for *Ri* is achieved with $\gamma = 0°$, $\beta = 45°$ (Fig. 4); for *Zd* and *Hv* the angle β changes marginally. Actual specific outputs of a slightly smaller system in Greece were found to range from 350 to 800 kWh/m² [9].
For **ACC S** and climate data *Ri,* a storage smaller than 500 ℓ sometimes cannot maintain a set DHW temperature value. A similar problem occurs for *Hv* even though a storage of 300 ℓ would lead to a *SCR* of 77.5%. Reducing the collector field for *Hv* by one panel to 3.83 m² leads to a *SCR* of 52.1%. For systems like **ACC M**, with off-season demand equal or less than one quarter of the nominal demand, $\gamma = 0°$, $\beta = 30°$ lead to maximum annual performance, see Fig. 4. The average *SCR* over the summer period for **ACC L** is surprisingly ~3.3% lower than the annual values. This can be explained by the high *SCR*s off-season because of low demand, which is approximately only 11% of the nominal demand. The parametrized DHW circulation for this system, with three circulation periods per day, resulted in 4323 kWh losses in the draw-off loop per year.

By contrast to the wide range of specific annual yields of the four systems, average specific yields from May to September vary only between 342 and 360 kWh/m² (given for *Zd*). Another investigation in [2] showed an average drop in *SCR* of 3.6 ± 1.6% for atypical years with 9% lower global radiation. These numbers increase for larger systems, while *SCR* proportionally decreases.

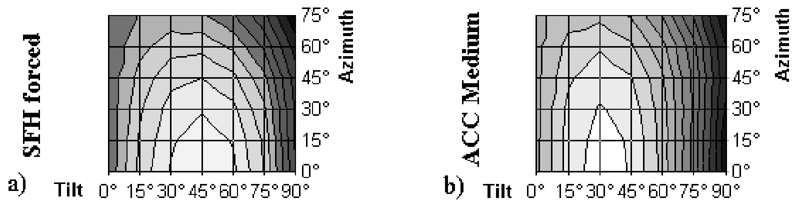


Fig. 4. Collector orientation contour plots of *SCR*, performed for the *Ri* climate. Azimuth refers towards the east and the grayscale map for category values is divided in 2.5% steps, with higher values shown brighter. **a)** SFH f, DHW demand: 200 ℓ 45°C /day, and **b)** ACC M, DHW demand: 1640 ℓ 60°C /day [2];

For evaluation of actual average values of ST systems for DHW purposes when installed, simulation results within the range of $\beta \in \{15°, \dots, 60°\}$ and $\gamma \in \{0°, \dots, 60°\}$ have been taken into account for each averaged variable [2]. Comparing the average values with individual results, the angle combinations $\gamma = 45°$ and $\beta = 30°$ (SFH f, ACC S) and $\gamma = 45°$ and $\beta = 15°$ (ACC M, ACC L) provide representative samples that were used as surrogates for the averaging procedure. Uncertainties of 3% and 15 kWh / m² can be attributed to the *SCR* and specific ST yield, respectively.

4. Potential Estimation and Economical Aspects along the Croatian Adriatic Coast

Seven coastal Croatian counties were considered for estimates of ST potential. Simulations using climate datasets of Rijeka (lat. 45.33°, long. 14.45°), Zadar (lat. 44.10°, long. 15.36°) and Hvar (lat. 43.16°, long. 16.45°) were assumed as representative for their surrounding coastal mainland and island municipalities. Municipalities were grouped across counties to form, with their respective datasets: the northern group (counties Istria, PGC and Lika-Senj); central group (counties Zadar and Šibenik-Knin); and southern group (counties Split-Dalmatia and Dubrovnik-Neretva) used in Table 3.

4.1. Annual Bed Capacities and Overnight Stays

Table 3. Total useful energy demand, and replaceable and auxiliary final energy demand for DHW preparation in SFHs and four accommodation categories. Data from Hotels (etc.) was split into Hotels (75%) and Apartments (25%), according to the PGC data distribution [2]. Total bed capacities for accomodations and the number of SFHs ±10% are given for each group of municipalities. *SCR Sample* is taken from Table 2.

Annual energy demand	**Hotels (etc.)**	**Apartments**	**Camps**	**Priv ACC**	**# of SFH**
Northern group (*Ri*): Bed capacity I #SFH	94311		148801	178869	81346
Central group (*Zd*): Bed capacity I #SFH	21869		32704	113973	36803
Southern group (*Hv*): Bed capacity I #SFH	51672		17818	143909	73396
$FU_{F(S)}$	0.94	0.84	0.41	0.25	-
Daily demand ℓ / unit	60	40	20	40	200
Qspecific [Wh/ ℓ]	58	58	58	58	40.6
Demand for DHW, for seaside resorts of coastal counties and SFHs in [MWh]					
Quseful total	**76303**	**15467**	**22261**	**63430**	**237968**
Demand for DHW, for seaside resorts of coastal counties and SFHs for 10% share; in [MWh]					
Quseful for 10%	**7630**	**1547**	**2226**	**6343**	**23797**
Conversion Efficiency	0.70 ± 0.08			0.79 ± 0.10	
SCR Sample [%] ± 3% for *Ri* / *Zd* / *Hv*	70/ 68/ 70	70/ 68/ 70	69/ 69/ 70	72/ 71/ 76	63/ 66/ 67
Qfinal replaceable [MWh]	**7630**±589	**1547**±119	**2201**±191	**5789**±449	**19068**±1934
Qfinal auxiliary [MWh]	3270±314	663±63	979±104	2240±216	11055±1206

Annual overnight stays in counties considered in this paper amount to 54.63 million – 52.66 million of which (~96.4%) refers to seaside resorts, including coastal mainland and islands, where the season from May to September accounts on average for 93.5% of the total seaside resort overnight stays. Official data was not available for the number of single-family houses (SFH) in relevant counties; it was estimated at 40% ± 10% of the total number of households [5].

Bed capacities listed in Table 3 reflect 89% of the total capacity, which includes other types of accommodation. Useful energy demand in Table 3 was calculated for an assumed share of ST system installations, namely 10% of the total bed capacity, for the summer (153 days) using $FU_{F(S)}$ and the off season (212 days) with a factor of 0.1 (low occupation, maintenance, cleaning etc.). Conversion efficiencies [2], together with *SCR Sample*, lead to the potential replaceable final energy of 17.2 GWh (62 TJ). For SFH and a share of 10% ST system installations it is 19.1 GWh (69 TJ).

Results in Table 3 can be extrapolated for other ST installation shares, due to linear dependencies.

4.2 Economical Viability

A net present value (PV) calculation [9] was applied to gauge the competitiveness of ST systems compared to conventional ones. Local suppliers were consulted for investment costs, which incorporate specific collector costs (€ 200±25 per m²), specific storage costs (between € 0.91 and 3.1 per ℓ) and costs for other components and installation [10]. Maintenance and operation costs were 1.5% for SFH f, ACC S and ACC M and 1.0% for ACC L, with respect to the total investments.

PV of savings was calculated using a current price of € 0.077 ± 0.01 per kWh (electricity for SFH f and ACC S) or € 0.060 ± 0.01 per kWh (light fuel oil for ACC M and ACC L).

Table 4: Overview of economic viability for all simulated systems. System names on the left are followed by replaced and auxiliary final energy. Together with *Ri, Zd* or *Hv,* they correlate to the systems in Table 2. Needed subsidies with respect to the total investment costs are given for three investment payback times (*IPBT*) in years (7 a, 10 a and 15 a); *IPBT* is also provided for 0% subsidies in the rightmost column.

System: *Q*final replaced *Q*final aux. [MWh]	***Rijeka/ Zadar/ Hvar***	**Specific costs** [€/m²]	**Subsidy** [%] for 3 *IPBT*			***IPBT*** [a]
			7 a	10 a	15 a	no subsidy
SFH f 2.6 ± 0.4 / 1.1 ± 0.2	*Ri*	570 ± 95	>50	45	10	16.5
	Zd	648 ± 95	50	23	0	12.5
	Hv	609 ± 95	45	17	0	12.0
ACC S 3.9 ± 0.5 / 1.7 ± 0.3	*Ri*	553 ± 100	>50	36	0	14.5
	Zd, Hv	598 ± 103	45	18	0	12.0
ACC M 19.1 ± 2.3 / 8.2 ± 1.2	*Ri*	457 ± 48	>50	47	13	16.5
	Zd, Hv	453 ± 48	45	17	0	11.5
ACC L 56.0 ± 6.8 / 24.0 ± 3.6	*Ri*	426 ± 48	>50	43	6	16.0
	Zd, Hv	425 ± 48	47	22	0	12.5

An inflation rate of 2.9% ± 1.0% was assumed (mean value of the Harmonized Indices of Consumer Prices for EU27 and Croatia for the last 10 years). Average interest rates for 10-year government bonds yielding 4.4% ± 0.4% were assumed for market capital costs. The energy price index is the most important and time sensitive parameter for this assessment. It was set at 7.1% ± 5.1% using the five-year average for Electricity, Gas and other Fuels for EU27. Results obtained for *IPBT* are slightly higher than those achieved in [1], but subsidies between 17% and 47% (depending on the system) could reduce the *IPBT* to 10 years. For comparison, state subsidies between 11% and 30% existed in Greece before 2004 [9] and different counties in Austria offer up to approximately 25% in subsidies.

5. Conclusion

Four DHW ST systems, with net collector fields from 3.83 m² to 130.22 m² and specific annual solar yields between 347 and 685 kWh/m², were analyzed for applications in tourism accommodations and private housing, in three groups of Croatian municipalities on the Adriatic Coast.
System performance was shown to depend on geographical latitude, annual DHW consumption profiles and the heat storage volume. Oversized storages for small scale systems can significantly raise *SCR* and compensate for suboptimal collector field sizes. An alternative to the SFH f system would be a self-sufficient system employing natural circulation with an immersion heater (like 95% of the systems in Greece [9]). Maximum annual yields were achieved with 30° tilt angles for dominating heat demand in summer. Specific annual yields are higher than in Austria [2], where the ST market is well developed. ST systems showed high reliability, even for years with a 9% reduction in global solar radiation. Final energy savings in e.g. fuel oil for a scenario with a 10% share of ST installations for DHW systems in tourist accommodations and private housing would nearly double the current share of renewables in the total final energy consumption of Croatia and lead to CO_2 reductions of 12200 tons. The cost analysis indicated a significantly lower *IPBT* than the expected system lifetime of 20 years. It could drop to 10 years with subsidies but also increase for higher system costs at remote islands.
ST systems for DHW preparation represent a viable opportunity to save energy resources. Rising electricity prices and summer peak demands combined with poor grid connectivity further favor the use of ST systems. Finally, extensive market development would also create new jobs and Croatia's low temperature ST potential could further be extended to cooling and industrial purposes.

References

[1] M Karagiorgas, T. Tsoutsos, V. Drosou, et. al., HOTRES: renewable energies in the hotels. Renewable & Sustainable Energy Reviews 10 (2006) 198-224, Elsevier

[2] M. Pichler, (2010). Potentials and practical Proposals for the use of Solar Thermal Energy in a chosen Region in Croatia, Master thesis at the Karl Franzens University Graz, Graz – Rijeka 2009, London 2010

[3] W. Streicher, K. Schnedl, A. Thür, A. Vilics (1999). SHWwin V. 1, 2 Okt. 1999, Programmbeschreibung von SHWwin, Version 25. April 2000, Technical University Graz, http://lamp.tu-graz.ac.at/~iwt/

[4] J. Remund, S. Kunz, C. Schilter (2008). METEONORM Version 6.0 Handbook part I: Software; Software Version 6.1.0.12 METEOTEST, CH-3012 Bern, Switzerland

[5] I. Kovač, (2009). Statistical Reports 2009, ISSN 1332-0297, Editor-in-Chief: Jasna Crkvenčić-Bojić, Central Bureau of Statistics of the Republic of Croatia – Archive and Publications Division, stat.info@dzs.hr

[6] G. Tschernigg, Technical description, sizing and calculation methods of solar systems in tourism, arsenal research, Trans Solar Conference, Zagreb April 2009

[7] M. Pichler, S. Fućak, B. Franković (2009). Low temperature solar thermal potential for DHW purposes on the islands of Primorsko-goranska county, Third conference on marine technologies 2009, 176-194, Rijeka

[8] J.K. Kaldellis, K. El-Samani, P.Koronakis, Feasibility analysis of domestic solar water heating systems in Greece, Renewable Energy 30 (2005) 659-682, Elsevier

[9] J.K. Kaldellis, K. A. Kavadias, G. Spyropoulos, Investigating the real situation of Greek solar water heating market, Renewable & Sustainable Energy Reviews 9 (2005) 499-520, Elsevier

[10] M. Kaltschmitt, W. Streicher, A.Wiese (2007). Renewable Energy - Technology, Economics and Environment, Springer, Berlin Heidelberg New York

Appendix B

Angle Analyses for SFH DHW Purposes

Table B.1: Auxiliary heat demand, solar yield and SCR for DHW supply of a SFH (45°C; 200 litres/day), at various azimuth angles for *Tilt*=45°

Azimut	**Electr**	**SolStor**	**CovDHW**
[°]	[kWh]	[kWh]	[%]
-90	1353.9	2117	54.73
-80	1261.5	2220.6	57.82
-70	1182.9	2309.1	60.46
-60	1109.6	2389.8	62.92
-50	1055.3	2450.6	64.74
-40	1003.3	2508.6	66.49
-30	965.1	2552.5	67.77
-20	940.8	2580.8	68.59
-10	930.9	2594.4	68.92
0	927	2598.7	69.05
10	935.8	2589.6	68.76
20	959.4	2565.1	67.97
30	987.5	2532.1	67.03
40	1031.5	2481.7	65.56
50	1089.8	2415.4	63.61
60	1150.9	2343.8	61.56
70	1226.9	2257.3	59.01
80	1312.5	2161.8	56.15
90	1401.9	2060.1	53.15

Table B.2: Auxiliary heat demand, solar yield and SCR for DHW supply of a SFH (45°C; 200 litres/day), at various tilt angles for *Azimuth*=0°

Tilt	Electr	SolStor	CovDHW
[°]	[kWh]	[kWh]	[%]
0	1359.5	2117.8	54.55
5	1266.6	2221.8	57.66
10	1186	2312.7	60.36
15	1123.9	2383.8	62.45
20	1065.6	2448.6	64.4
25	1016.1	2502.8	66.06
30	981.6	2541.9	67.22
35	957.7	2568.2	68.02
40	943.8	2583.2	68.49
45	933.9	2591.2	68.82
50	942.8	2578.8	68.53
55	956.1	2558.6	68.08
60	986.4	2518.3	67.07
65	1031	2458.9	65.58
70	1096.5	2376.5	63.4
75	1187.4	2267	60.36
80	1306.2	2130.3	56.39
85	1452	1967.7	51.52
90	1616.1	1788.8	46.04

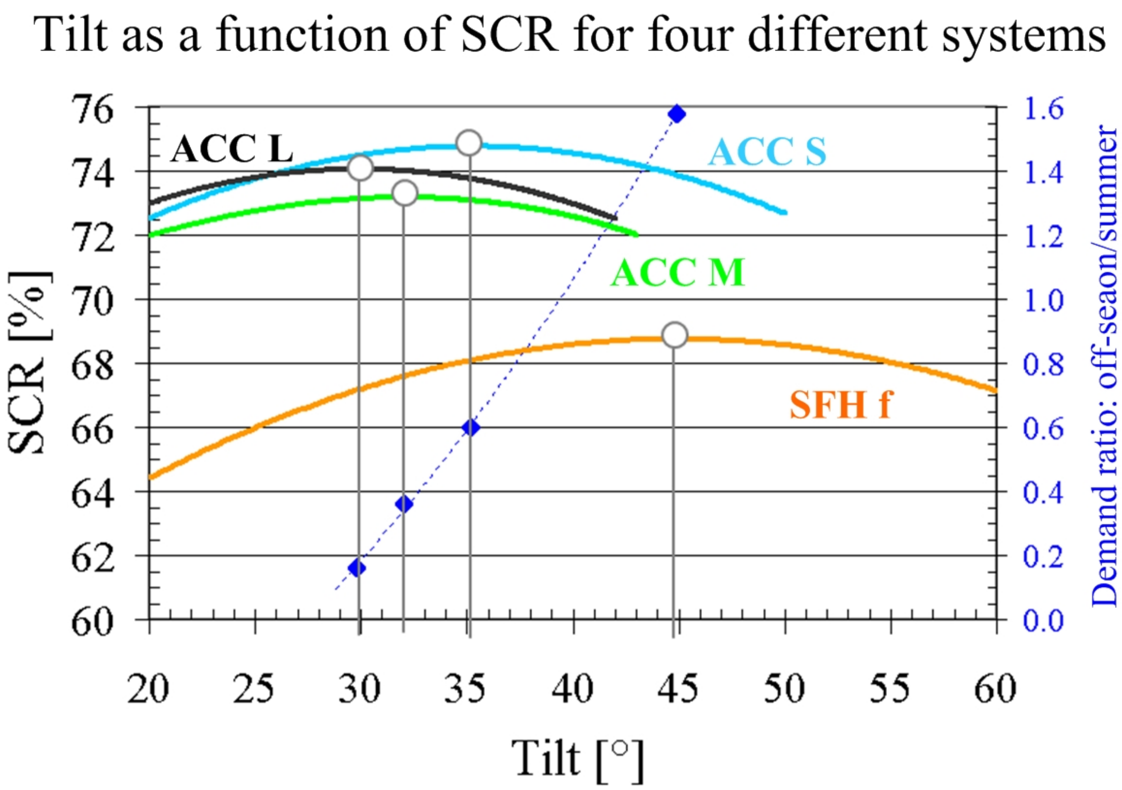


Figure B.1: Tilt analysis for four pure DHW systems

Appendix C

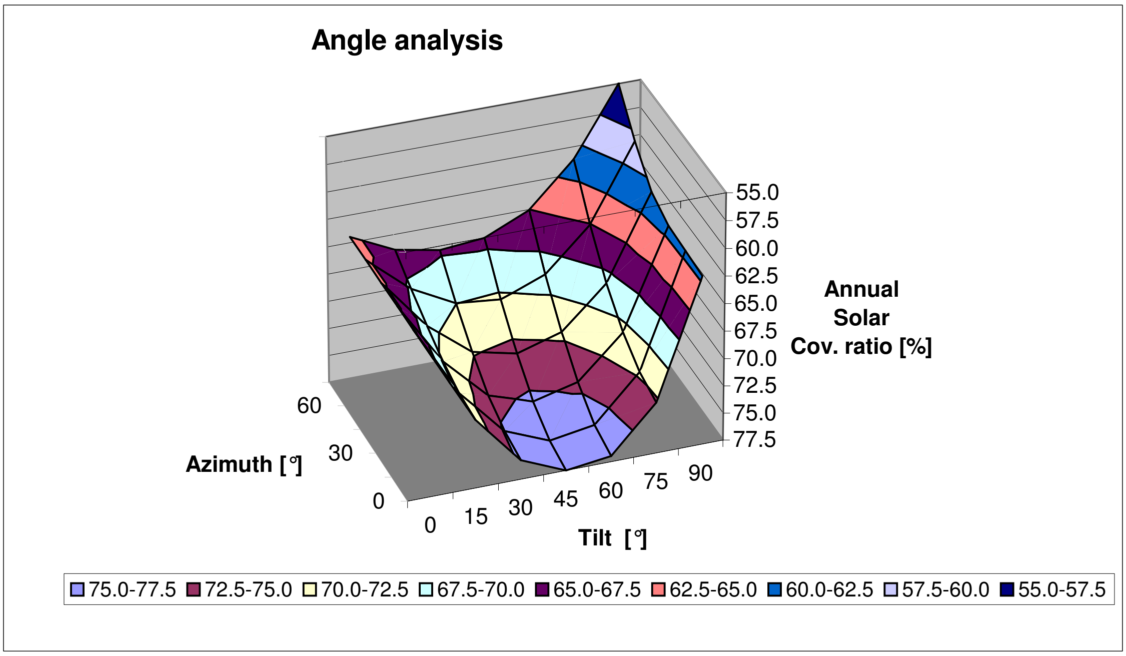
Mixed Angle Analyses

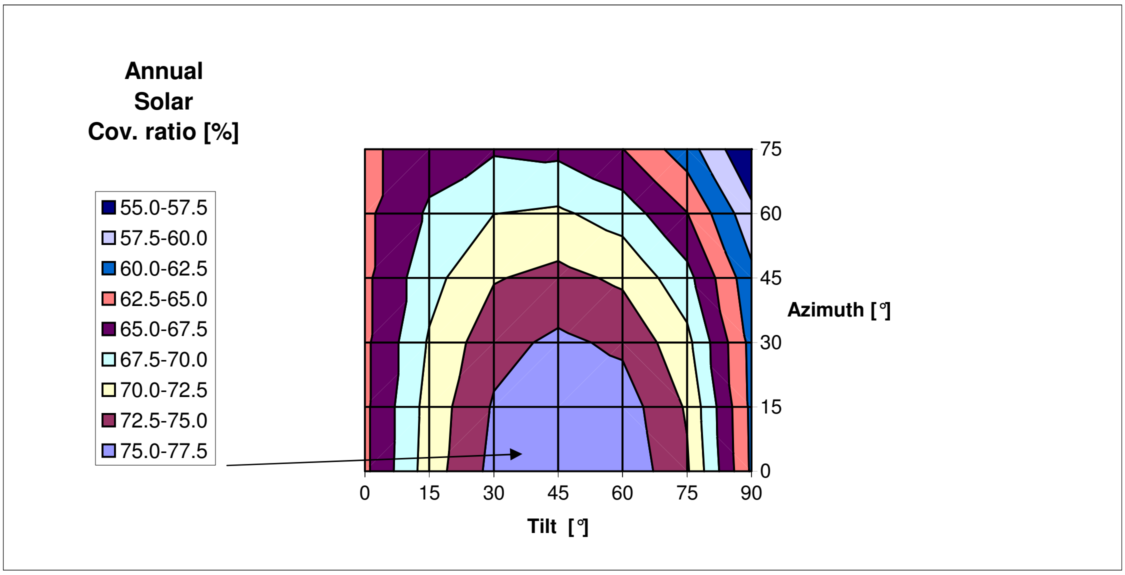
Analysis of **annual solar coverage ratio** at various tilt- and azimuth angles. The solar thermal system consits of one storage and is designed for DHW heat provision for a single family house. DHW demand 45°C/200 litre/day, auxiliary supply: Max. storage temp. =47°C. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka SFH DHW natural** optimised system **simulated:** 03.10.2009
Collector: Tehnomont_SKT-40
Net Coll. Field 5.750 m² **Storage:** .250 m³
Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	0	15	30	45	60	75	90
0	64.5	71.3	75.8	77.6	77.0	72.8	62.1
15	64.5	71.0	75.3	76.9	76.3	72.2	61.9
30	64.5	70.3	74.2	75.5	74.5	70.7	61.7
45	64.5	69.2	72.3	73.3	72.1	68.4	60.7
60	64.5	67.9	70.0	70.4	68.9	65.1	58.2
75	64.5	66.4	67.2	66.9	65.1	61.1	54.7



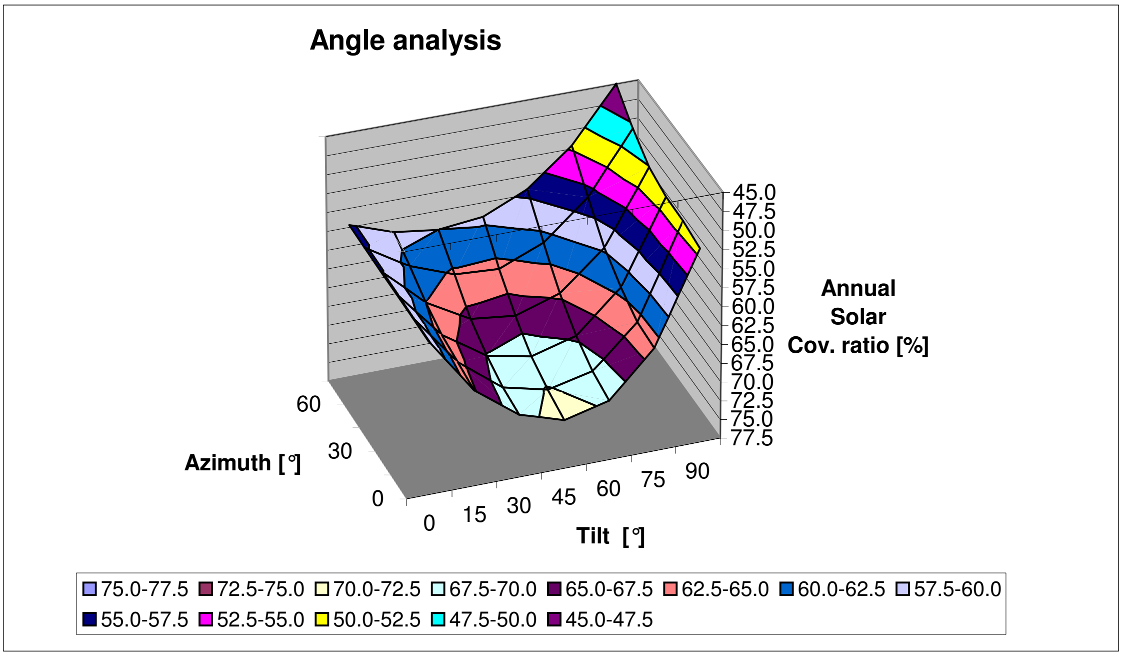


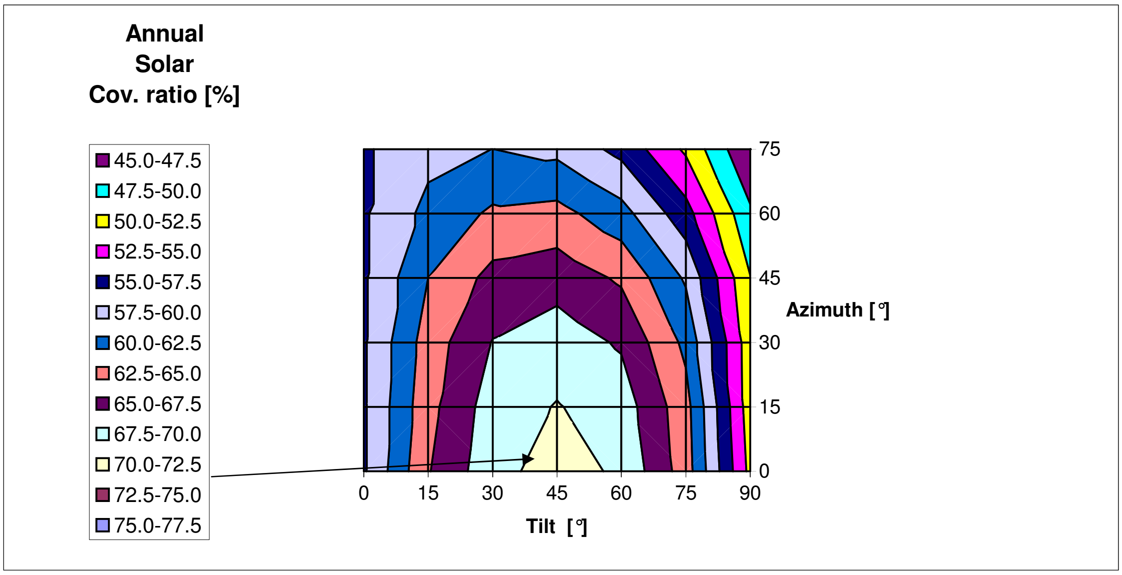
Analysis of annual **solar coverage ratio** at various tilt- and azimuth angles. The solar thermal system consits of one storage and is designed for DHW heat provision for a single family house. DHW demand 45°C/200 litre/day, auxiliary supply : Max. storage temp.=47°C. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka SFH DHW forced** optimised system **simulated:** 03.10.2009
Collector: Tehnomont_SKT-40
Net Coll. Field 5.750 m² **Storage:** .300 m³
Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**0**	**15**	**30**	**45**	**60**	**75**	**90**
0	57.2	64.8	69.2	71.1	69.6	63.8	51.8
15	57.2	64.2	68.7	70.1	68.8	63.4	51.2
30	57.2	63.7	67.6	68.8	67.2	61.9	51.0
45	57.2	62.5	65.8	66.5	64.6	59.7	50.1
60	57.2	60.7	62.9	63.3	60.9	56.0	47.9
75	57.2	59.2	60.0	59.4	56.8	52.1	44.2



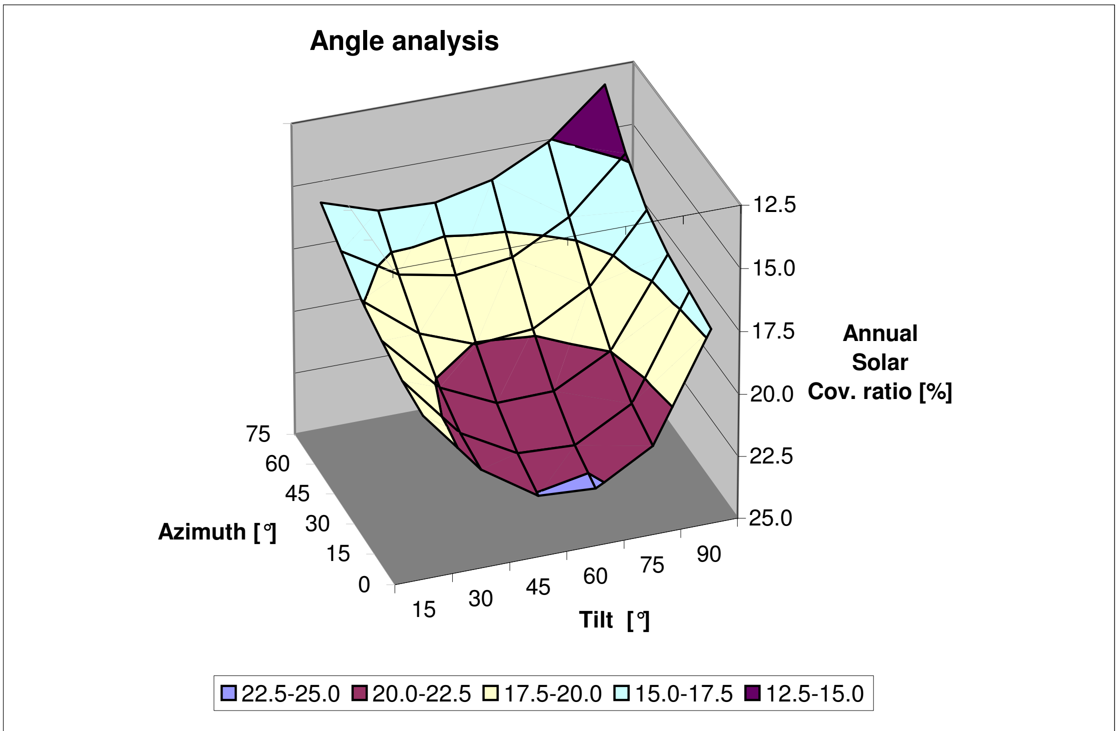


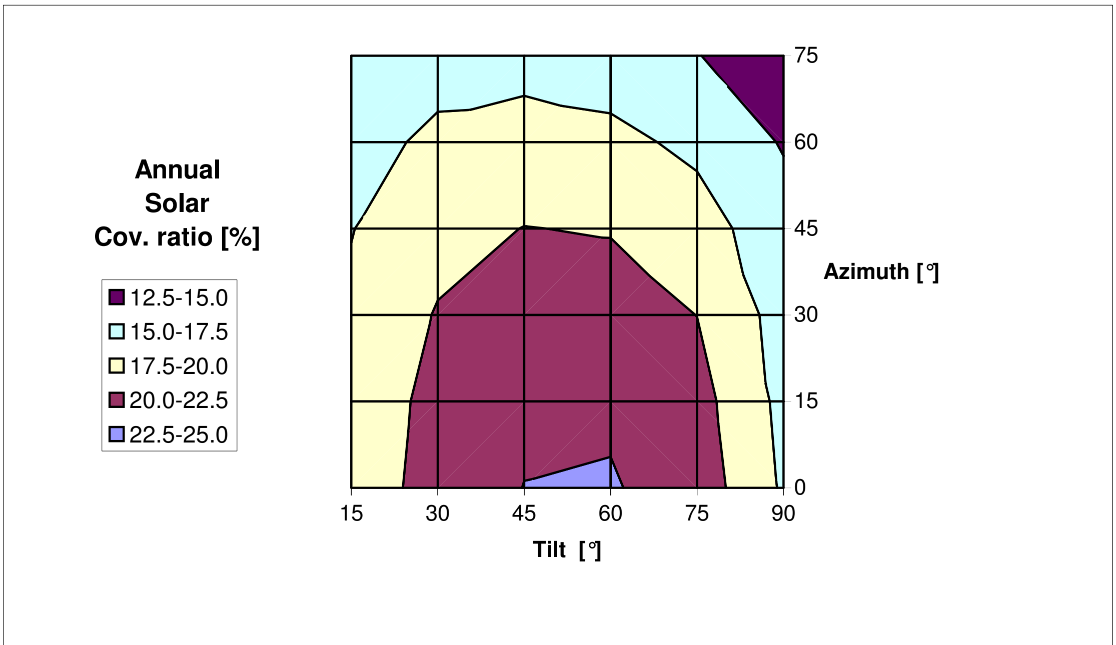
Analysis of annual **solar coverage ratio** for a Combisystem with 1 storage at various tilt- and azimuth angles. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=75℃. Provided are a 3D plot and the according top view surface plot below.

Project : **Rijeka SFH I** optimised system **simulated:** 24.08.2009
Collector: Tehnomont_SKT-40
Net coll. Field 15.320 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**15**	**30**	**45**	**60**	**75**	**90**
0	18.5	21.1	22.5	22.7	21.4	17.2
15	18.3	20.8	22.0	22.2	20.9	16.9
30	17.9	20.2	21.2	21.2	20.0	16.5
45	17.4	19.2	20.1	19.9	18.6	15.9
60	16.6	18.0	18.5	18.2	17.0	14.8
75	15.9	16.6	16.7	16.2	15.1	13.2



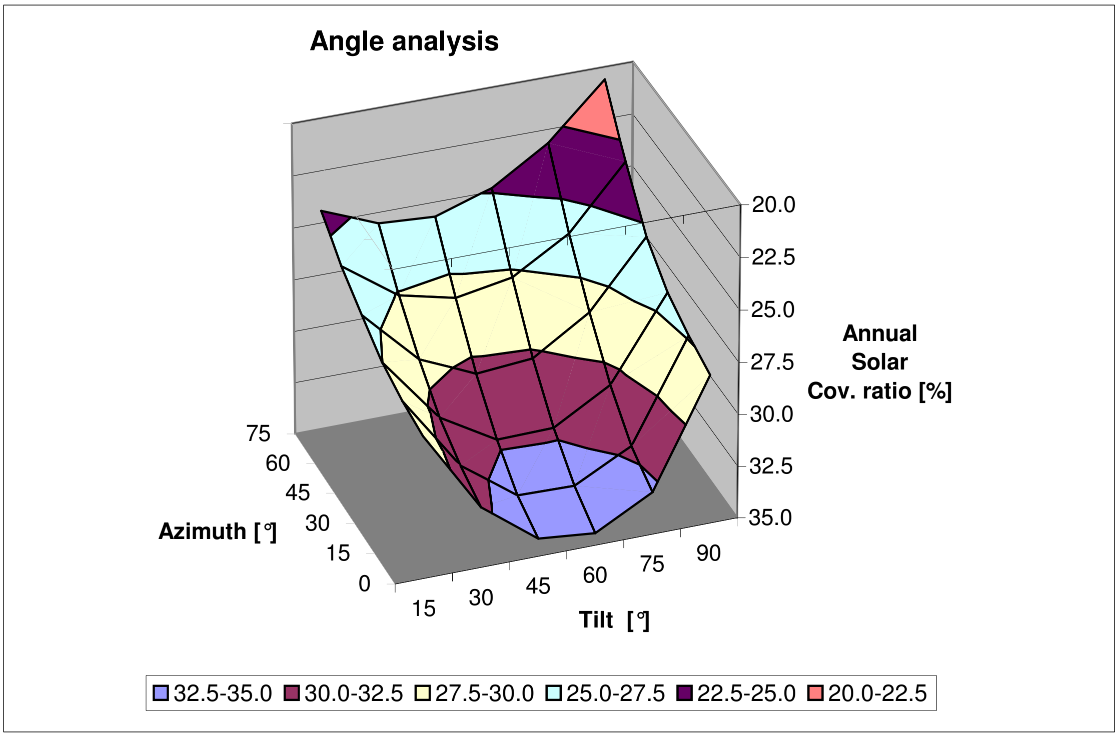


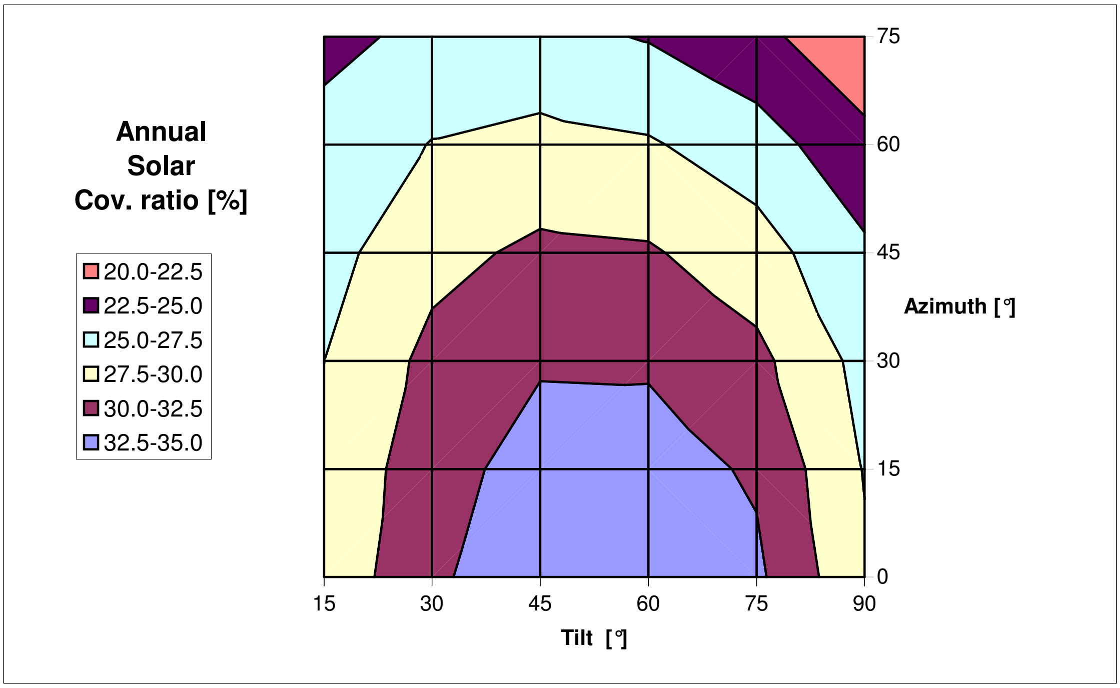
Analysis of annual **solar coverage ratio** for a Combisystem with 1 storage at various tilt- and azimuth angles. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=67℃. Provided are a 3D plot and the according top view surface plot below.

Project : **Rijeka SFH II** optimised system **simulated:** 24.08.2009
Collector: Tehnomont_SKT-40
Net coll. Field 15.320 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**15**	**30**	**45**	**60**	**75**	**90**
0	28.2	32.1	34.1	34.4	33.0	27.8
15	27.9	31.5	33.5	33.6	32.2	27.4
30	27.5	30.7	32.3	32.2	30.7	26.7
45	26.7	29.3	30.5	30.3	28.6	25.4
60	25.7	27.6	28.2	27.8	26.2	23.2
75	24.4	25.5	25.7	24.8	23.2	20.6



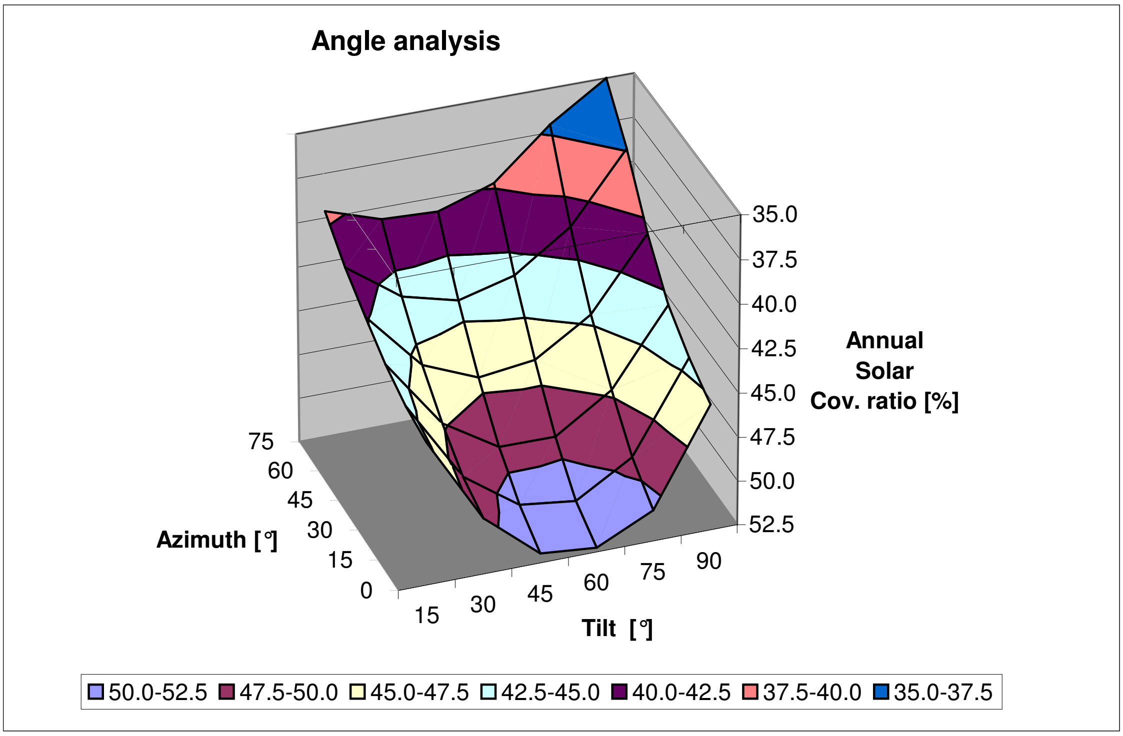


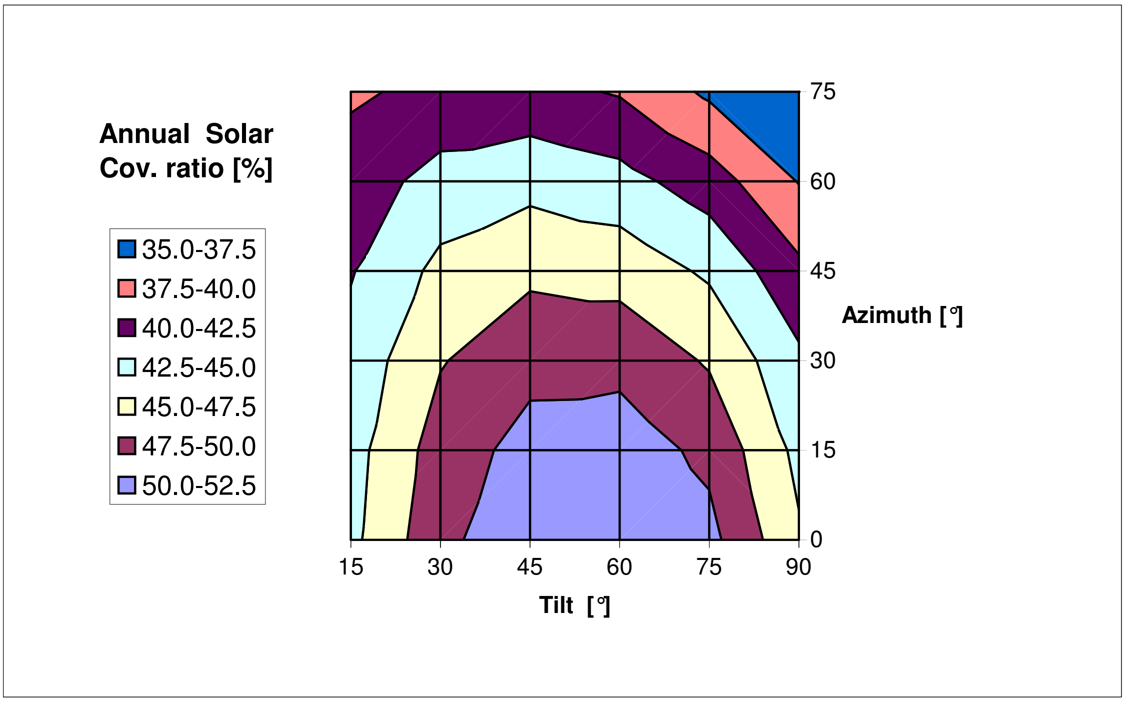
Analysis of annual **solar coverage ratio** for a Combisystem with 1 storage at various tilt- and azimuth angles. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=50°C. Provided are a 3D plot and the according top view surface plot below.

Project : **Rijeka SFH III** optimised system **simulated:** 16.08.2009
Collector: Tehnomont_SKT-40
Net coll. Field 11.490 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**15**	**30**	**45**	**60**	**75**	**90**
0	44.4	49.3	52.0	52.3	50.7	45.3
15	44.1	48.7	50.9	51.3	49.4	44.4
30	43.4	47.3	49.3	49.3	47.2	43.0
45	42.3	45.7	47.0	46.6	44.6	40.6
60	41.2	43.4	44.3	43.4	41.2	37.4
75	39.6	40.7	40.8	39.8	37.1	33.5



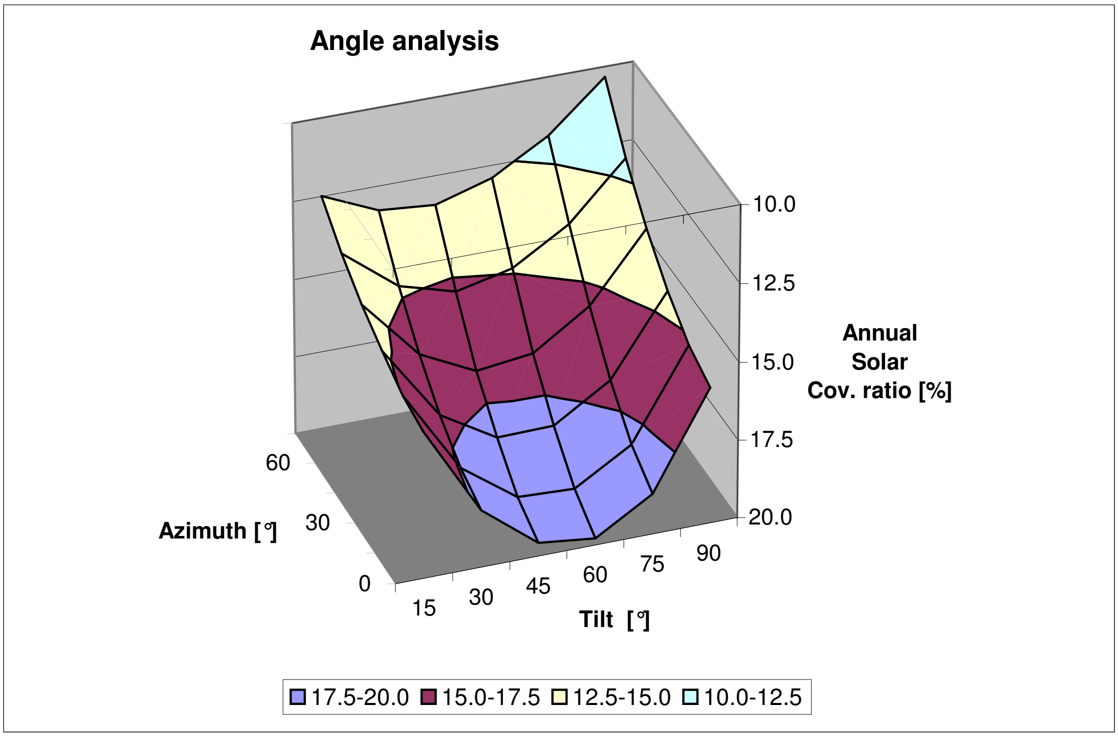


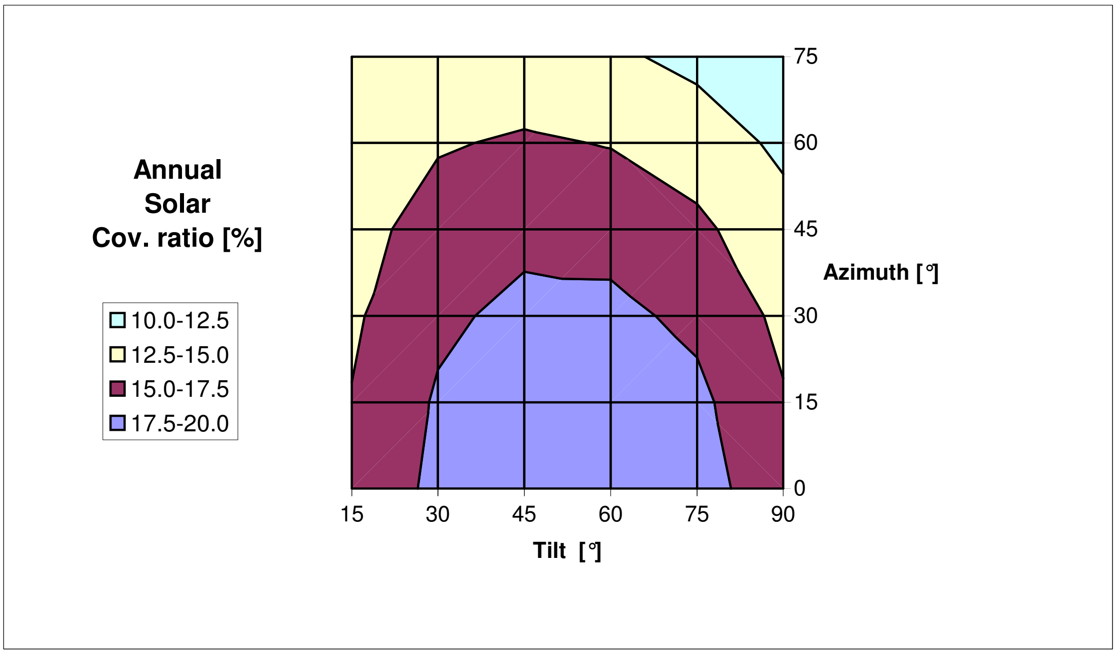
Analysis of annual solar coverage ratio for a Combisystem (heating and DHW) with two storage at various tilt- and azimuth angles. Heat provision for DHW for a single family house with 4 people (daily consumption: 45°C/ 200 litre), is provided via a DHW storage (250 litre). For second auxiliary supply from a gas/oil fired boiler: Max. storage temp.=75°C. Provided are a 3D plot and the according top view surface plot below.

Project : **Rijeka SFH I 2 storages** optimised system **simulated:** 24.10.2009
Collector: Tehnomont_SKT-40
Net coll. Field 15.320 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	15	30	45	60	75	90
0	15.3	18.2	19.6	19.8	18.7	15.6
15	15.1	17.8	19.1	19.2	18.1	15.2
30	14.6	17.0	18.1	18.1	17.0	14.4
45	14.1	16.0	16.9	16.7	15.5	13.4
60	13.4	14.8	15.3	14.9	13.8	12.0
75	12.5	13.3	13.4	12.9	11.9	10.3



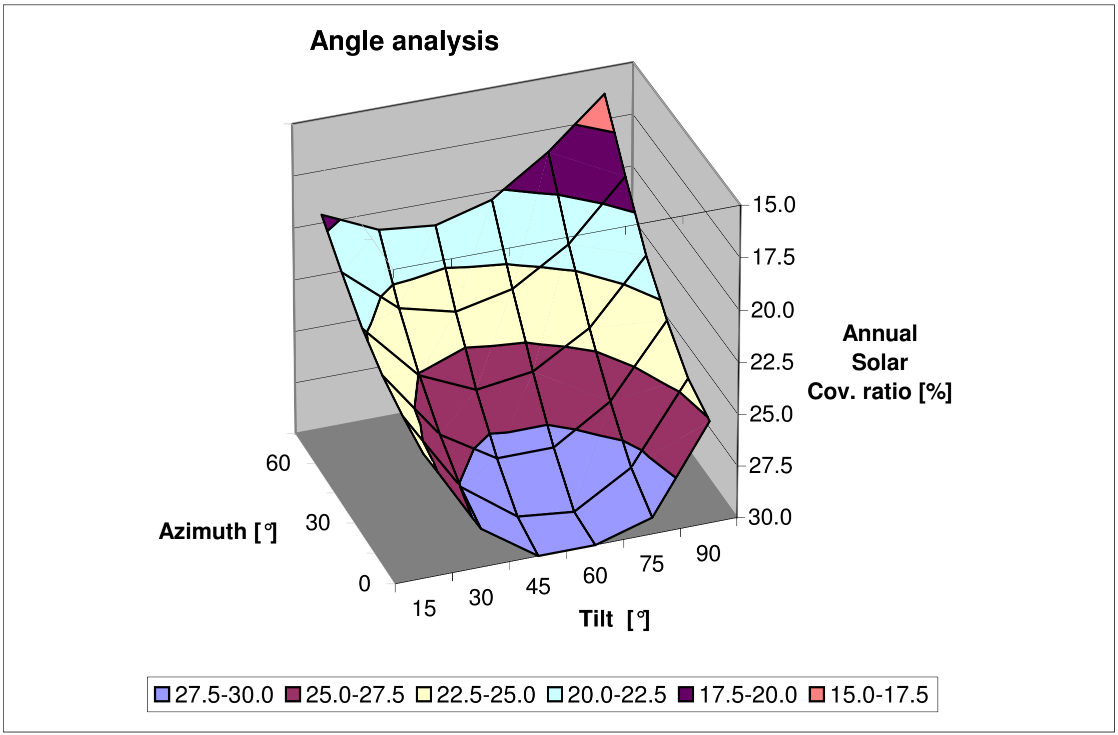


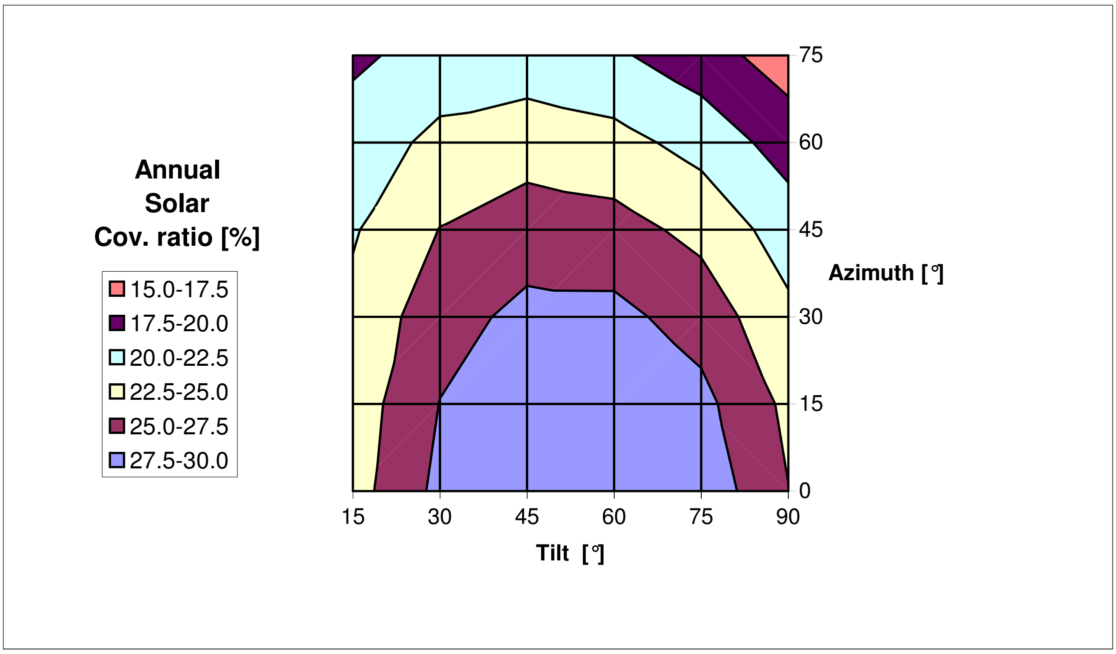
Analysis of annual **solar coverage ratio** for a Combisystem (heating and DHW) with two storage at various tilt- and azimuth angles. Heat provision for DHW for a single family house with 4 people (daily consumption: 45°C/ 200 litre), is provided via a DHW storage (250 litre). For second auxiliary supply from a gas/oil fired boiler: Max. storage temp.=67°C. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka SFH II 2 storages** optimised system **simulated:** 26.01.2010
Collector: Tehnomont_SKT-40
Net coll. Field 17.240 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	15	30	45	60	75	90
0	24.0	28.2	30.3	30.8	29.2	25.1
15	23.7	27.6	29.6	29.9	28.2	24.4
30	23.1	26.5	28.2	28.2	26.5	23.1
45	22.3	25.1	26.3	25.9	24.3	21.3
60	21.0	23.2	23.9	23.3	21.7	18.9
75	19.6	20.8	21.1	20.4	18.6	16.3



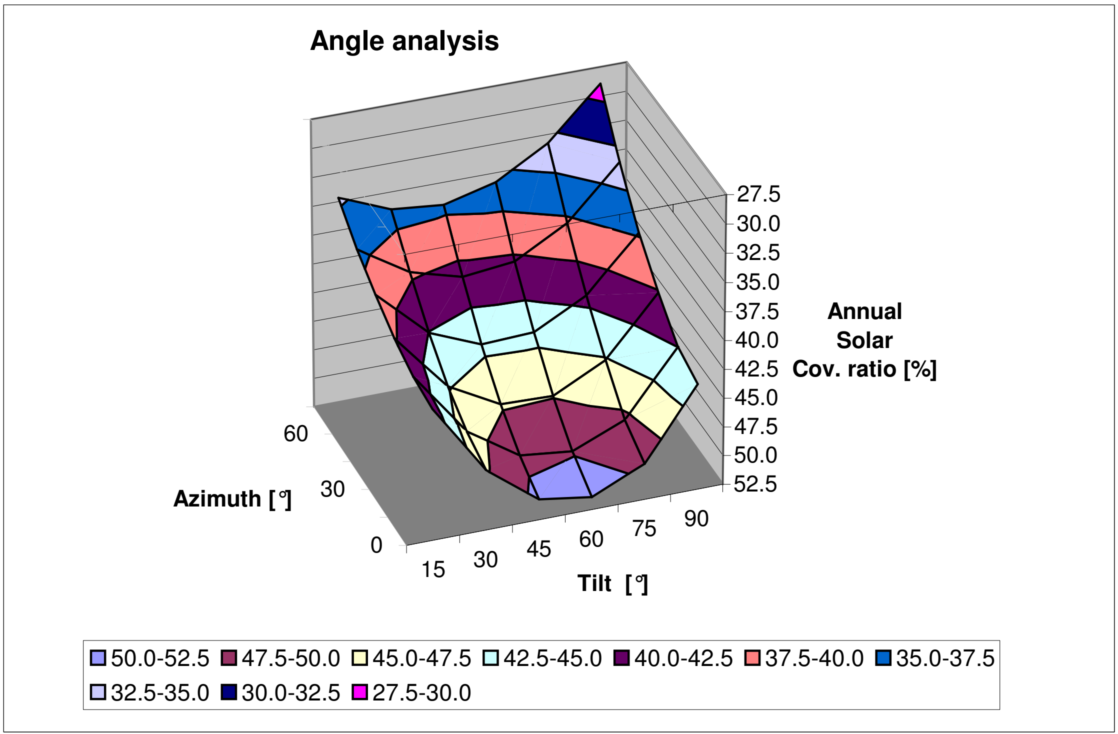


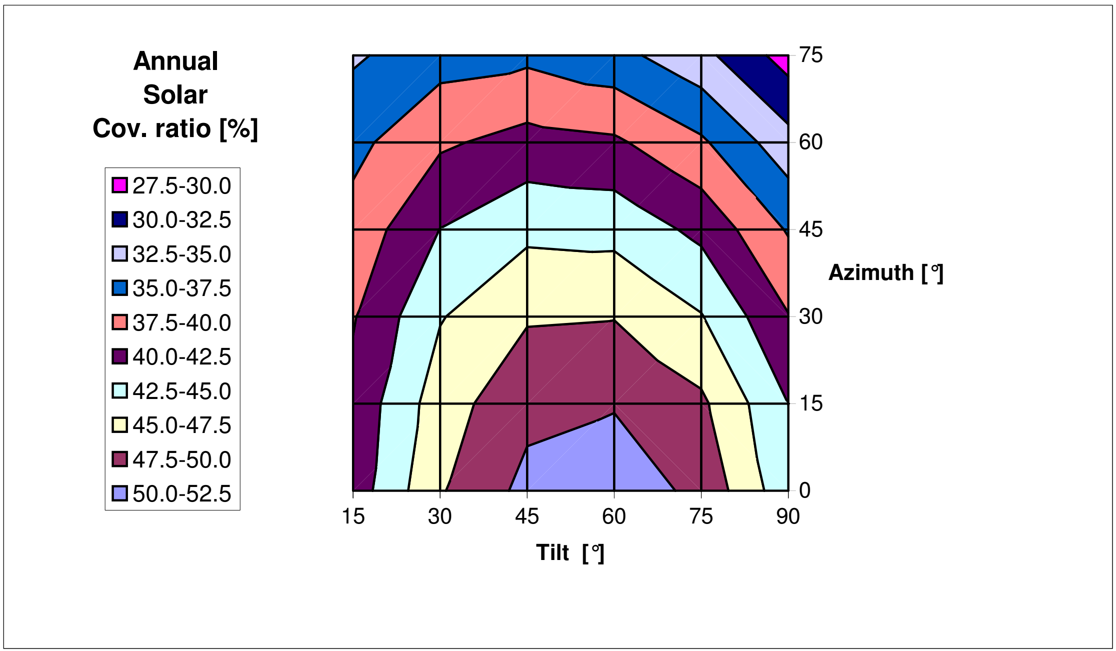
Analysis of annual **solar coverage ratio** for a Combisystem (heating and DHW) with two storage at various tilt- and azimuth angles. Heat provision for DHW for a single family house with 4 people (daily consumption: 45℃/ 200 litre), is provided via a DHW storage (250 litre). For second auxiliary supply from a gas/oil fired boiler: Max. storage temp.=50℃. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka SFH III 2 storages** optimised system **simulated:** 29.01.2010
Collector: Tehnomont_SKT-40
Net coll. Field 15.320 m² **Storage:** 1.000 m³
climate data set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	15	30	45	60	75	90
0	41.1	47.3	50.7	51.4	49.4	43.3
15	40.7	46.3	49.3	49.8	48.0	42.5
30	39.8	44.8	47.3	47.4	45.1	40.1
45	38.4	42.6	44.4	44.2	41.9	37.3
60	36.8	39.6	40.9	40.4	37.9	33.5
75	34.7	36.5	36.9	35.8	33.3	28.9



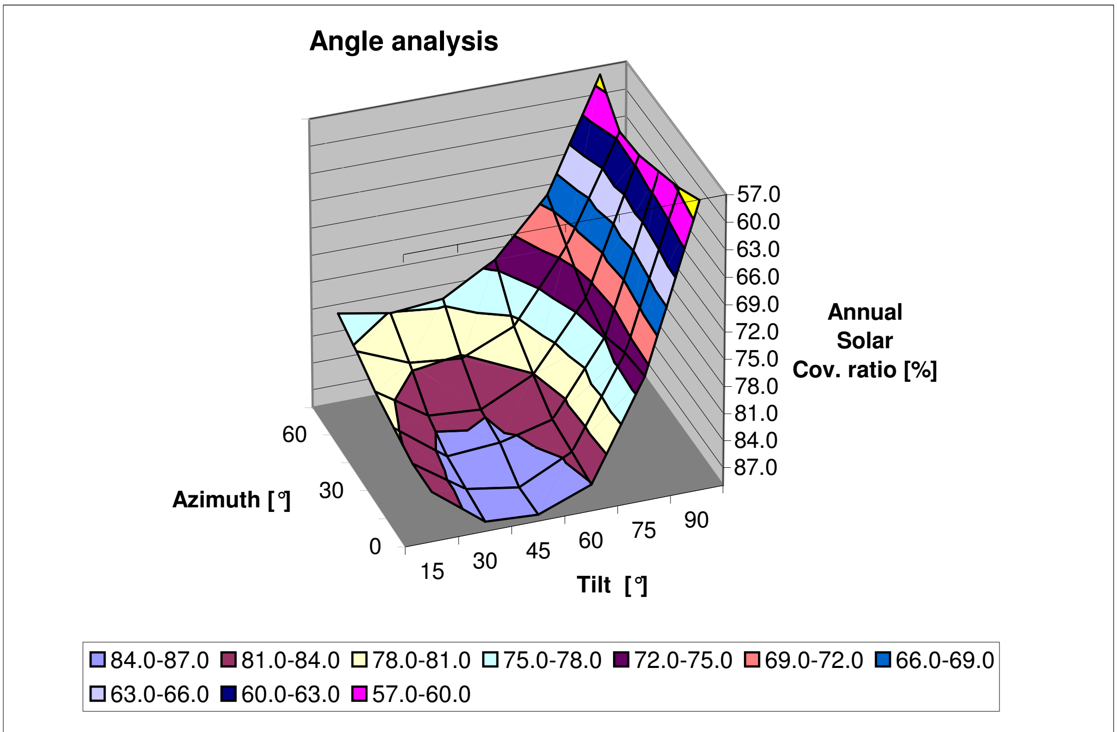


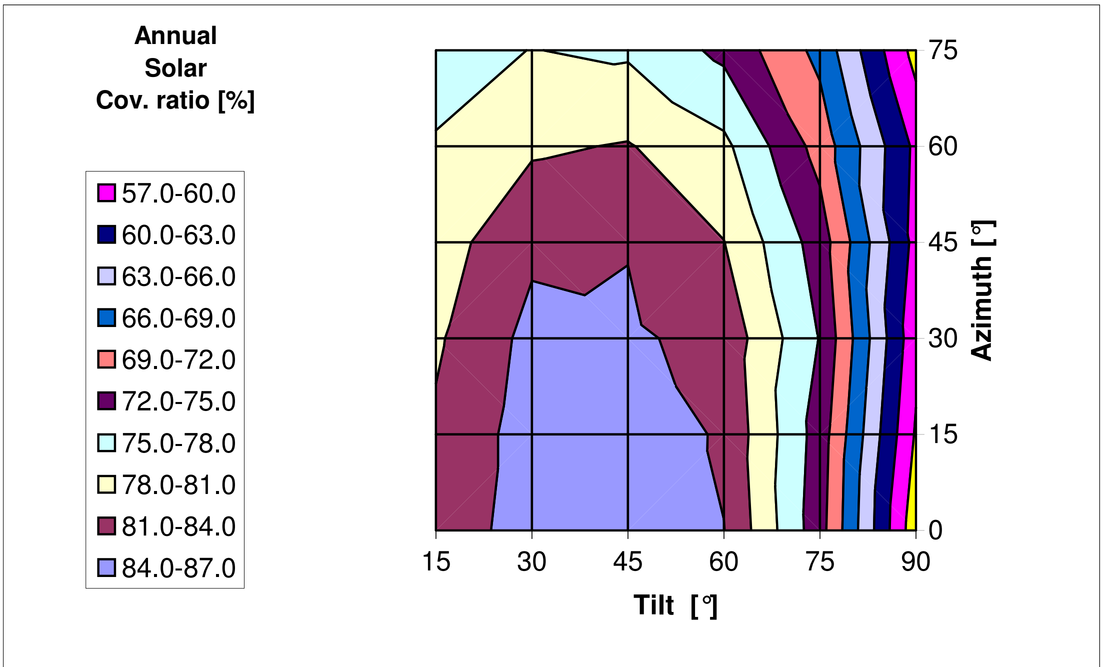
Analysis of annual **solar coverage ratio** for a system with one storage at various tilt- and azimuth angles. Heat provision for DHW for a small size tourist accomodation, where 4 additional people (staff or owners) were taken into account. Demand: notional summer demand of DHW 60℃/(160+160) litre is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=65℃. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka ACC Small** optimised system **simulated:** 30.09.2009
Collector: Tehnomont_SKT-40
Net Coll. Field 11.490 m² **Storage:** .800 m³
Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**15**	**30**	**45**	**60**	**75**	**90**
0	83.5	87.9	88.3	86.1	75.2	57.1
15	83.5	87.4	88.4	85.5	75.7	58.7
30	82.6	86.9	86.5	85.0	76.9	59.9
45	81.6	85.4	85.9	83.1	75.6	61.0
60	80.2	82.6	83.2	80.7	72.9	61.3
75	79.0	80.1	79.6	76.3	70.1	57.9





Analysis of annual **solar coverage ratio** at various tilt- and azimuth angles. The solar thermal system consits of two storage and is designed for DHW heat provision for a medium size tourist accomodation. Demand: notional summer consumption DHW 60℃/1640 litre is provided via a small DHW storage. For electrical auxiliary supply : Max. storage temp.=60℃. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka ACC Medium** optimised system **simulated:** 02.10.2009

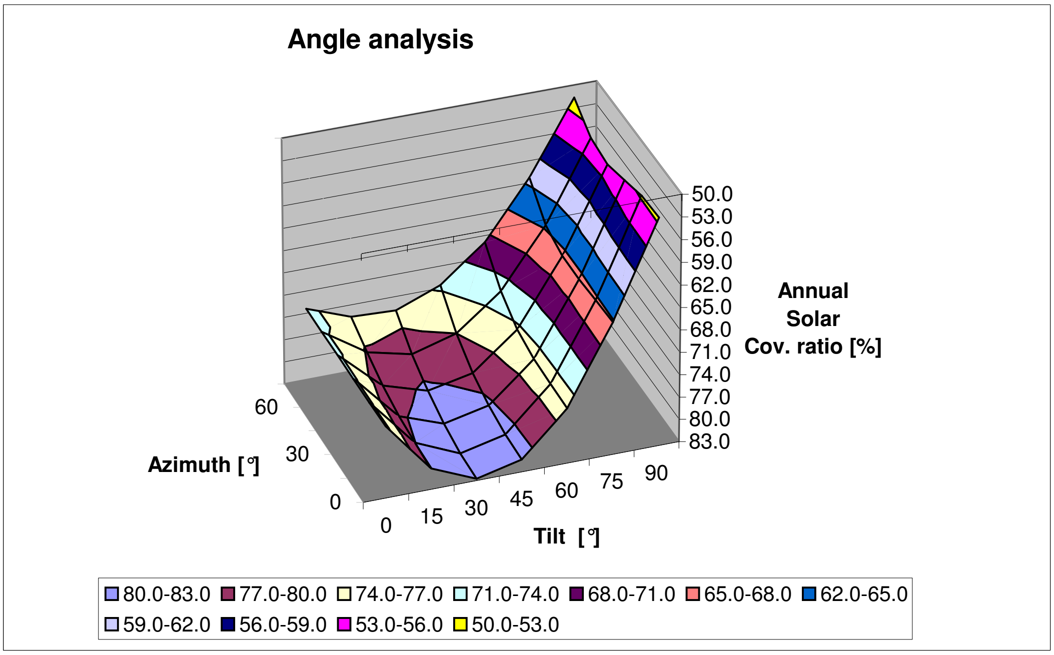
Collector: Tehnomont_SKT-40

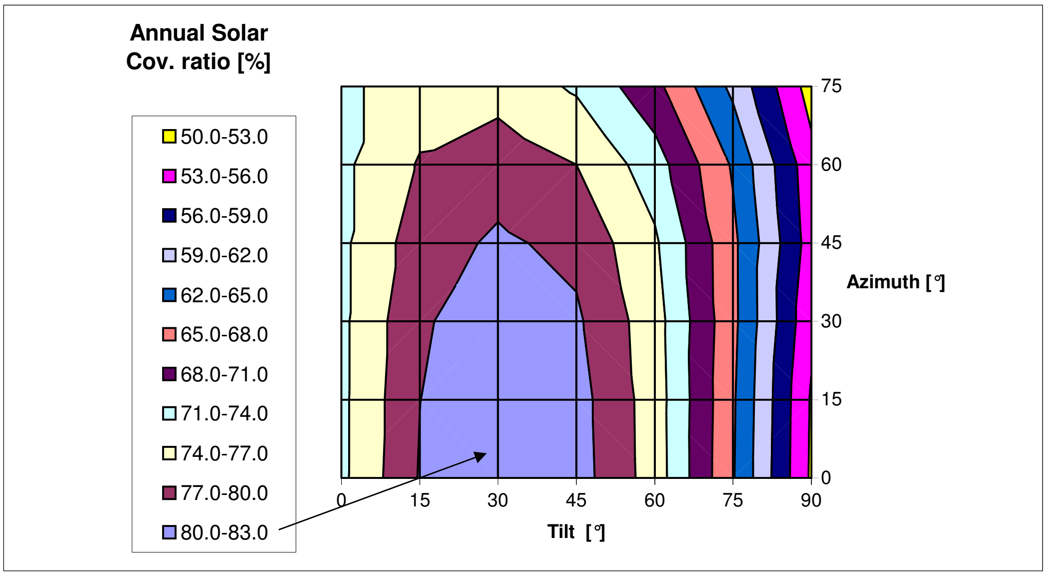
Net Coll. Field 47.880 m² **Storage:** 3.000 m³

Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	0	15	30	45	60	75	90
0	73.4	80.2	82.8	81.3	75.6	65.2	52.5
15	73.4	80.0	82.6	81.2	75.5	65.4	52.7
30	73.4	79.6	81.8	80.5	75.3	65.8	53.7
45	73.4	78.6	80.5	79.2	74.5	65.7	54.6
60	73.4	77.3	78.7	77.0	72.4	64.7	54.0
75	73.4	75.6	75.9	73.6	68.9	61.3	51.7



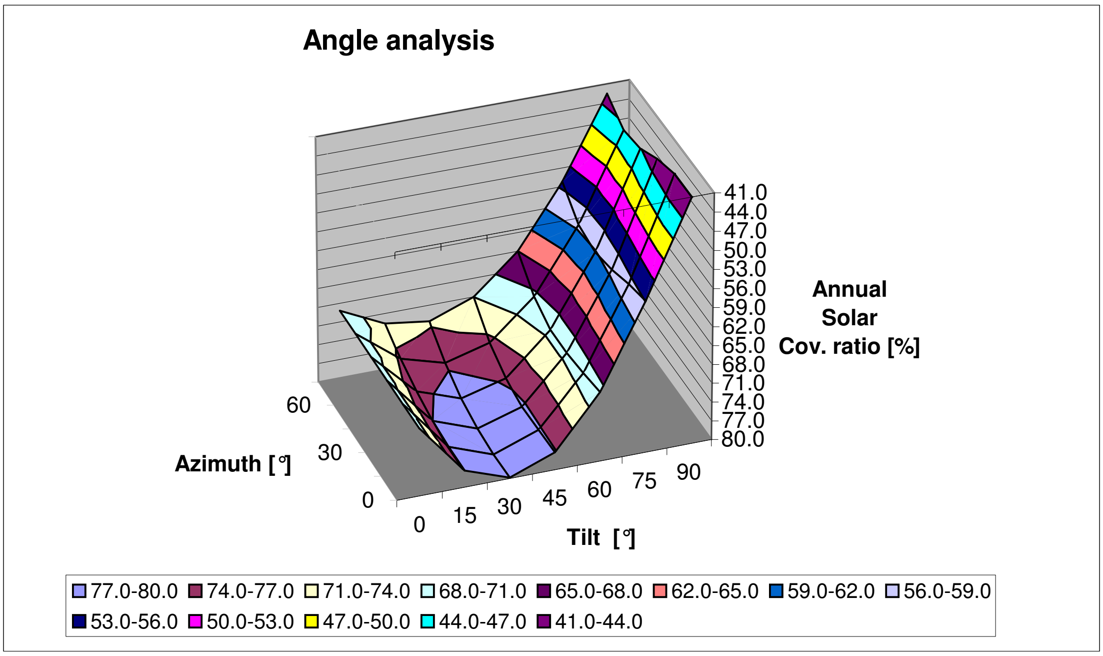


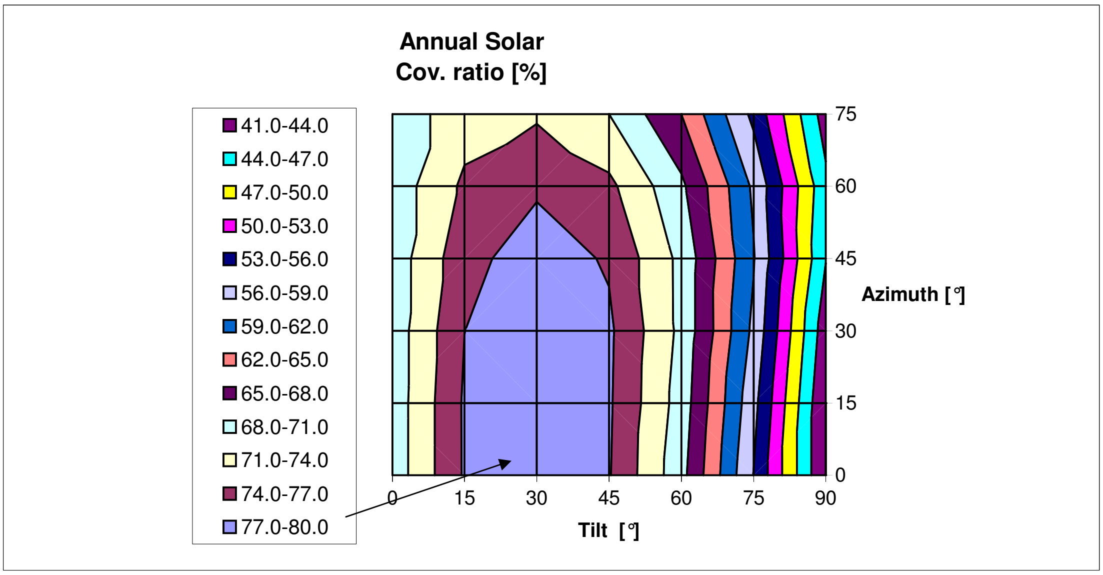
Analysis of annual solar coverage ratio at various tilt- and azimuth angles. The solar thermal system consits of two storage and is designed for DHW heat provision for a large size tourist accomodation. Notional summer consumption DHW 60℃/5640 litre is provided via a small DHW storage (1 m³). Auxiliary supply: into the heat storage: Max. storage temp.=67℃, electrical in the DHW storage Max. storage temp.=60℃. Provided are a **3D plot** and the according **top view surface** plot below.

Project : **Rijeka ACC L** optimised system **simulated:** 16.10.2009
Collector: Tehnomont_SKT-40
Net Coll. Field 145.540 m² **Storage:** 10.000m³
Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	0	15	30	45	60	75	90
0	69.2	77.3	79.9	77.2	69.0	55.9	39.3
15	69.2	77.4	80.0	77.4	69.7	57.0	39.7
30	69.2	77.0	79.6	77.5	70.3	58.4	42.2
45	69.2	76.0	78.5	76.7	70.3	59.2	44.1
60	69.2	74.6	76.6	74.7	68.6	58.5	44.8
75	69.2	72.6	73.6	71.0	65.0	55.2	42.5



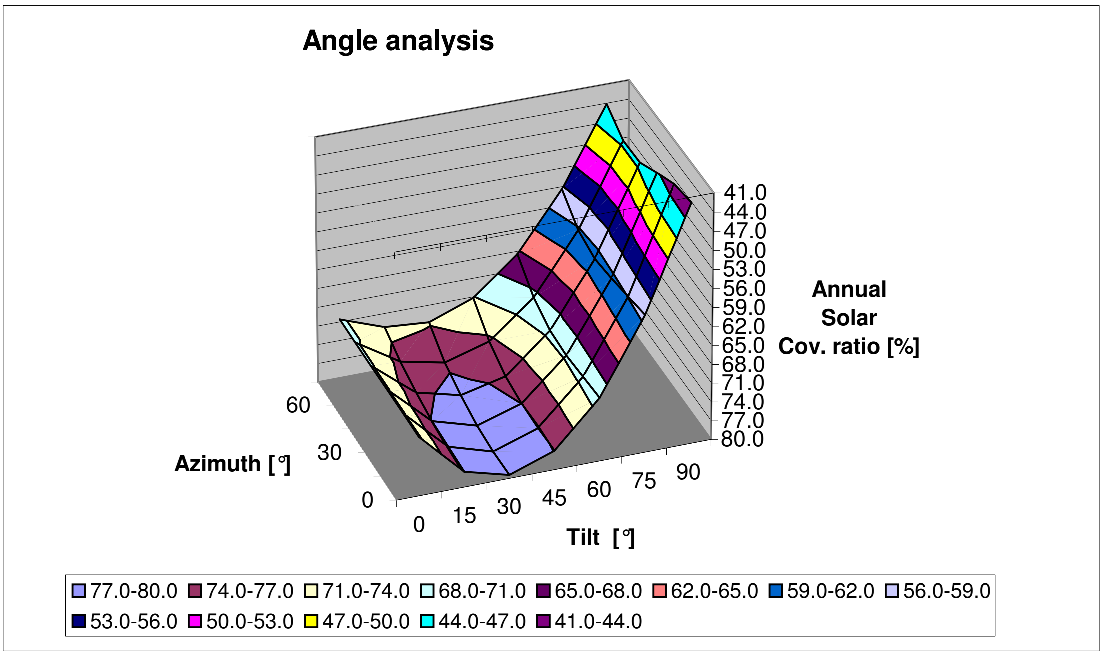


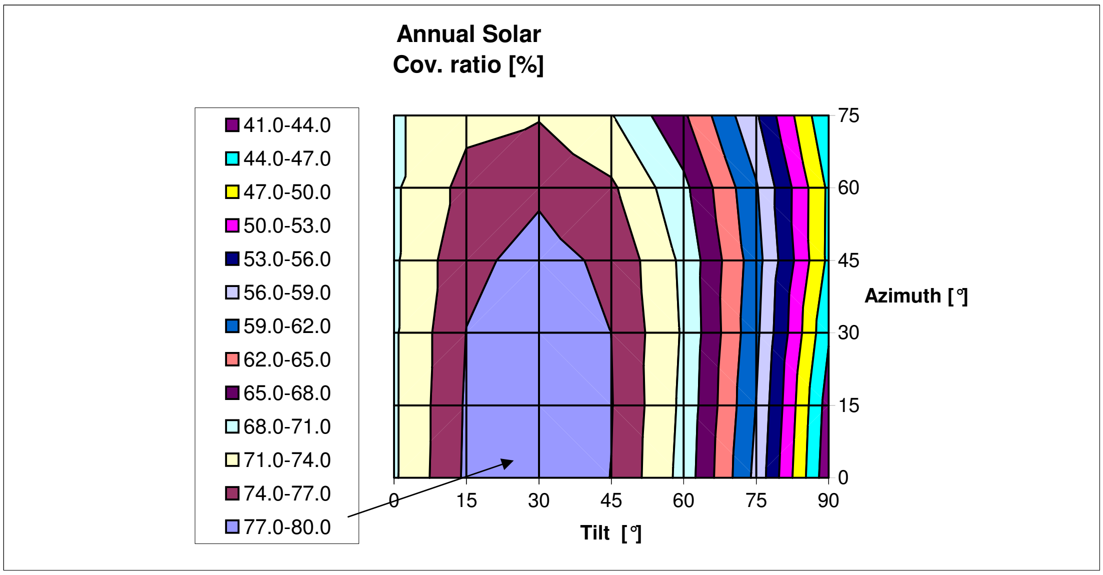
Analysis of **annual solar coverage ratio** at various tilt- and azimuth angles. The solar thermal system consits of two storage and is designed for DHW heat provision for a large size tourist accomodation. Notional summer consumption DHW 60°C/5640 litre is provided via a small DHW storage (1 m³). Auxiliary supply: into the heat storage: Max. storage temp.=67°C, electrical in the DHW storage Max. storage temp.=60°C. Provided are a **3D plot** and the according **top view surface plot** below.

Project : **Rijeka ACC L** optimised system **simulated:** 24.10.2009
Collector: Gluatmugl GS
Net Coll. Field 145.540 m² **Storage:** 10.000m³
Climate Data Set: Rijeka.dat

Solar Coverage Ratio [%]

Azimuth\ Tilt [°]	**0**	**15**	**30**	**45**	**60**	**75**	**90**
0	70.6	77.5	79.5	76.9	69.9	58.2	41.9
15	70.6	77.4	79.5	77.1	70.3	58.9	42.5
30	70.6	77.1	79.2	77.0	70.6	59.7	44.3
45	70.6	76.3	78.1	76.4	70.4	60.3	46.3
60	70.6	75.0	76.5	74.5	68.8	59.3	46.4
75	70.6	73.2	73.8	71.2	65.5	56.4	44.1





Appendix D

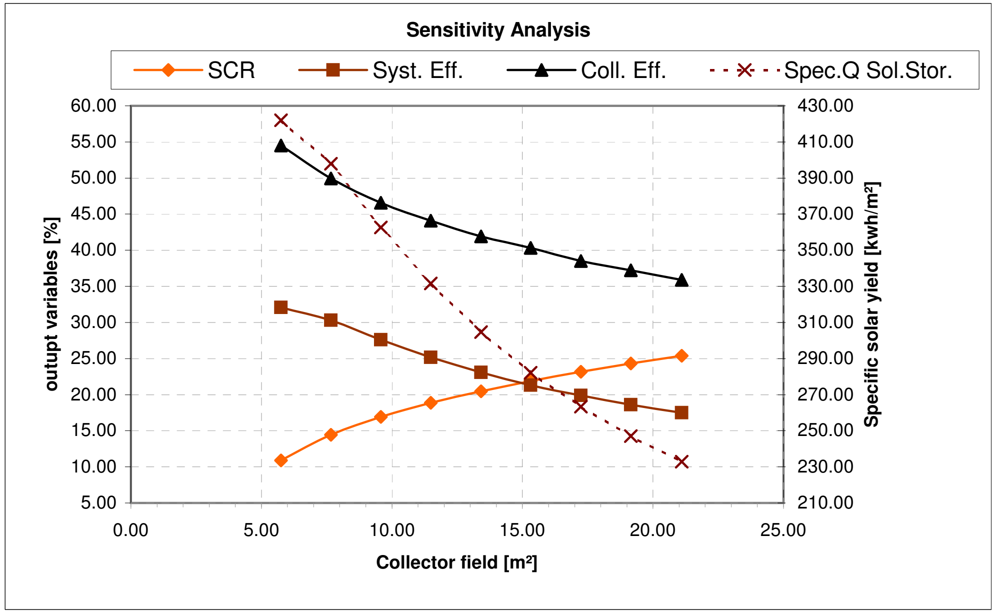
SA Combisystem One Storage

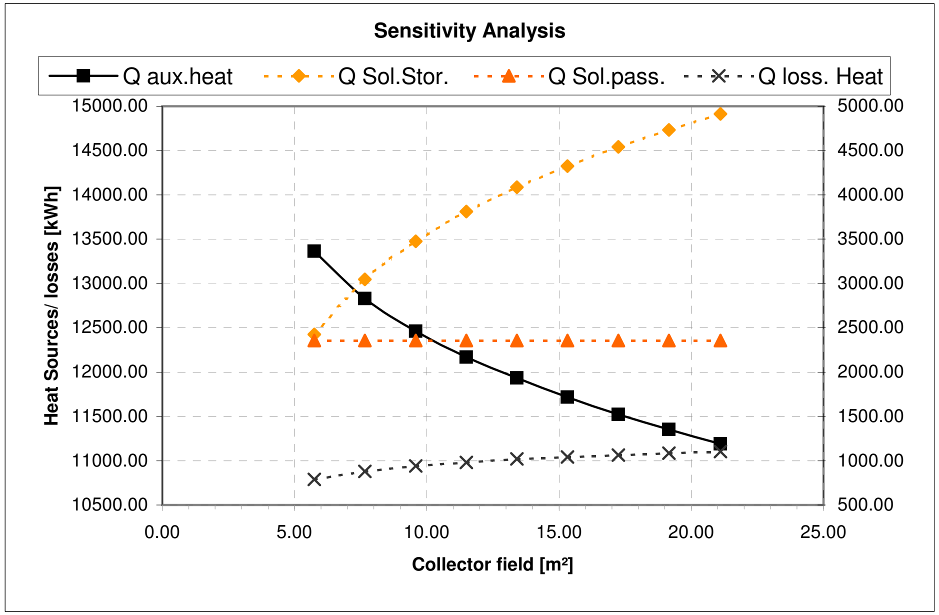
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net collector field**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH I**	**simulated:**	16.08.2009	
Collector:	Tehnomont_SKT-40	**Field:**	5.75 - 21.1	m²
Climate data set:	Rijeka.dat	**storage:**	1.000	m³

	entire plant				**Heat sources**			**Heat sinks**				**Cov.ratio**	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
5.75	10.91	54.52	32.06	422.02	2426.60	13365.00	2356.40	2964.10	12045.40	788.80	15798.30	100.00	99.89
7.66	14.46	49.93	30.32	397.85	3047.50	12828.00	2356.40	2964.10	12045.40	878.50	15888.00	100.00	99.85
9.58	16.92	46.55	27.61	362.69	3474.60	12462.00	2356.40	2964.10	12045.40	939.00	15948.50	100.00	99.87
11.49	18.86	44.10	25.18	331.64	3810.50	12169.50	2356.40	2964.10	12045.40	981.60	15991.10	100.00	99.85
13.41	20.45	41.92	23.09	304.73	4086.40	11932.50	2356.40	2964.10	12045.40	1018.60	16028.10	100.00	99.87
15.32	21.89	40.33	21.33	282.20	4323.30	11718.00	2356.40	2964.10	12045.40	1040.00	16049.50	100.00	99.89
17.24	23.19	38.49	19.89	263.45	4541.80	11521.50	2356.40	2964.10	12045.40	1064.80	16074.30	100.00	99.87
19.15	24.31	37.22	18.62	247.12	4732.40	11353.50	2356.40	2964.10	12045.40	1085.30	16094.80	100.00	99.88
21.10	25.40	35.89	17.52	232.90	4914.10	11191.50	2356.40	2964.10	12045.40	1104.00	16113.50	100.00	99.90



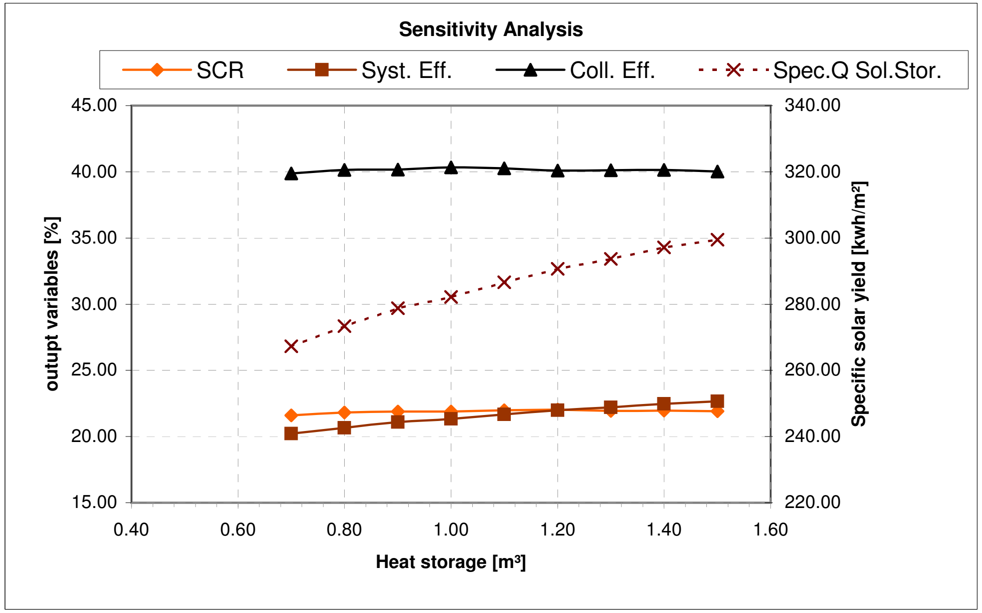


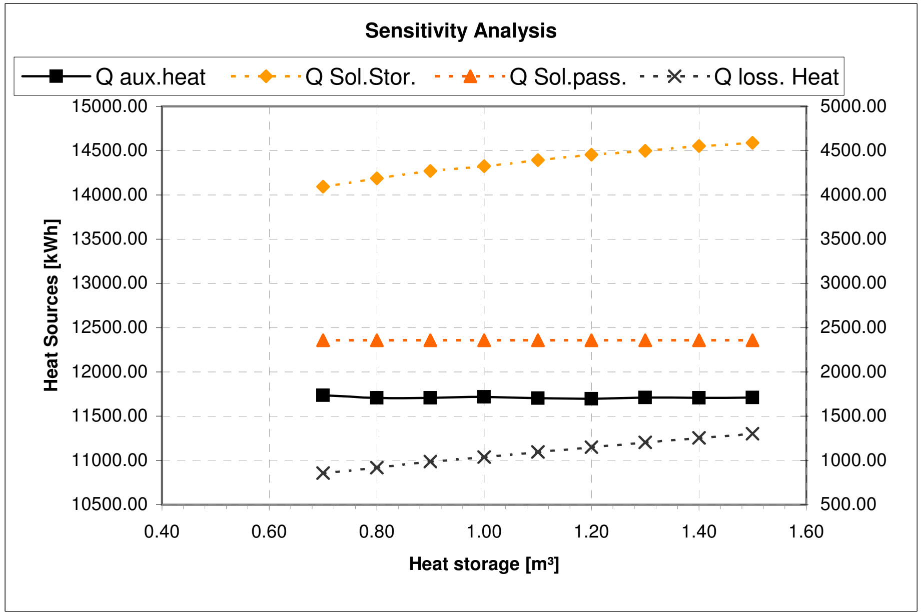
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH I**	**simulated:**	16.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
0.70	21.61	39.87	20.22	267.26	4094.40	11736.00	2356.40	2964.10	12045.40	859.60	15869.10	100.00	99.64
0.80	21.82	40.14	20.66	273.34	4187.60	11706.00	2356.40	2964.10	12045.40	920.80	15930.30	100.00	99.66
0.90	21.90	40.17	21.08	278.77	4270.80	11709.00	2356.40	2964.10	12045.40	987.10	15996.60	100.00	99.81
1.00	21.89	40.33	21.33	282.20	4323.30	11718.00	2356.40	2964.10	12045.40	1040.00	16049.50	100.00	99.89
1.10	21.98	40.26	21.67	286.66	4391.70	11704.50	2356.40	2964.10	12045.40	1095.30	16104.80	100.00	99.89
1.20	22.03	40.10	21.99	290.69	4453.30	11695.50	2356.40	2964.10	12045.40	1151.00	16160.50	100.00	99.87
1.30	21.94	40.12	22.21	293.67	4499.00	11712.00	2356.40	2964.10	12045.40	1203.40	16212.90	100.00	99.91
1.40	21.96	40.13	22.48	297.18	4552.80	11709.00	2356.40	2964.10	12045.40	1256.80	16266.30	100.00	99.90
1.50	21.92	40.03	22.66	299.48	4588.00	11712.00	2356.40	2964.10	12045.40	1302.10	16311.60	100.00	99.87



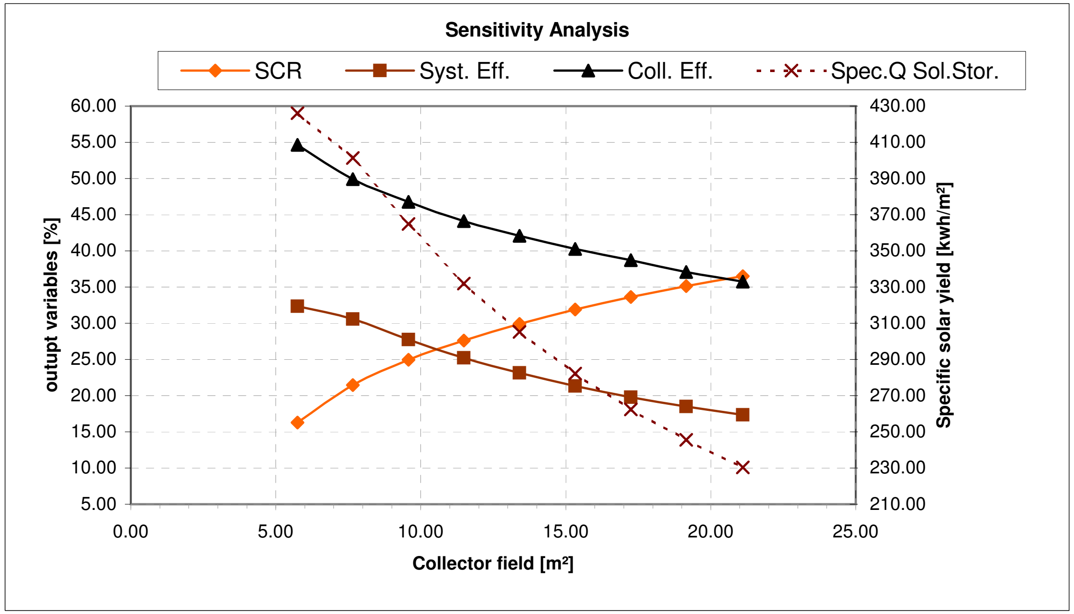


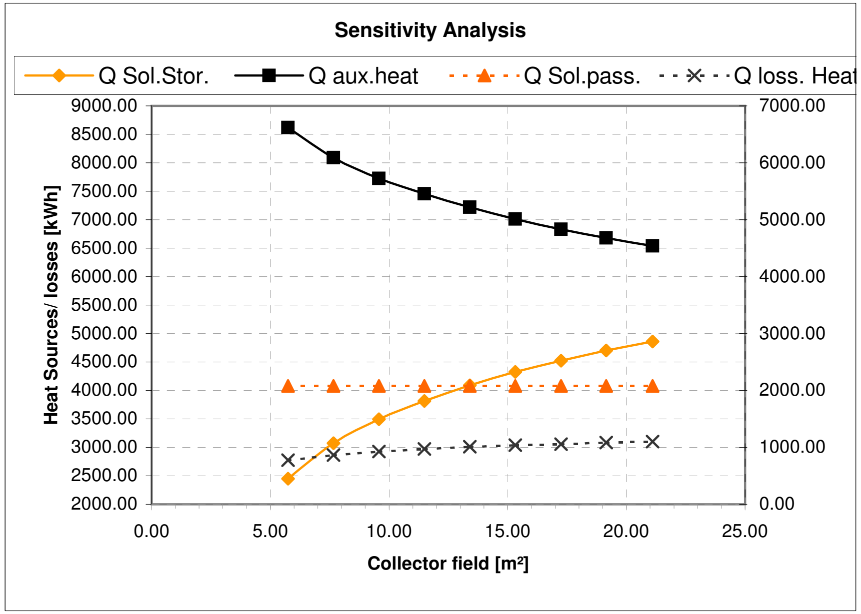
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net collector field**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80℃. Dashed lines refer to the right scale axis.

Project :	**SFH II**	**simulated:**	15.08.2009		
Collector:	Tehnomont_SKT-40	**Field:**	5.75 - 21.1	m²	
Climate data set:	Rijeka.dat	**storage:**	1.000	m³	

	entire plant				**Heat sources**			**Heat sinks**				**Cov.ratio**	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
5.75	16.29	54.65	32.36	426.17	2450.50	8619.60	2078.90	2964.10	7327.60	773.70	11065.40	100.00	100.00
7.66	21.44	49.90	30.58	401.34	3074.30	8089.20	2078.90	2964.10	7327.60	867.70	11159.40	100.00	100.00
9.58	24.96	46.75	27.75	364.83	3495.10	7726.80	2078.90	2964.10	7327.60	925.00	11216.70	100.00	100.00
11.49	27.60	44.11	25.21	332.02	3814.90	7455.60	2078.90	2964.10	7327.60	972.80	11264.50	100.00	100.00
13.41	29.92	42.06	23.12	305.18	4092.50	7216.80	2078.90	2964.10	7327.60	1011.60	11303.30	100.00	100.00
15.32	31.91	40.25	21.33	282.22	4323.60	7011.60	2078.90	2964.10	7327.60	1039.20	11330.90	100.00	100.00
17.24	33.63	38.71	19.79	262.35	4522.90	6834.00	2078.90	2964.10	7327.60	1058.40	11350.10	100.00	100.00
19.15	35.14	37.10	18.51	245.56	4702.40	6679.20	2078.90	2964.10	7327.60	1084.60	11376.30	100.00	100.00
21.10	36.49	35.74	17.33	230.27	4858.80	6540.00	2078.90	2964.10	7327.60	1103.10	11394.80	100.00	100.00



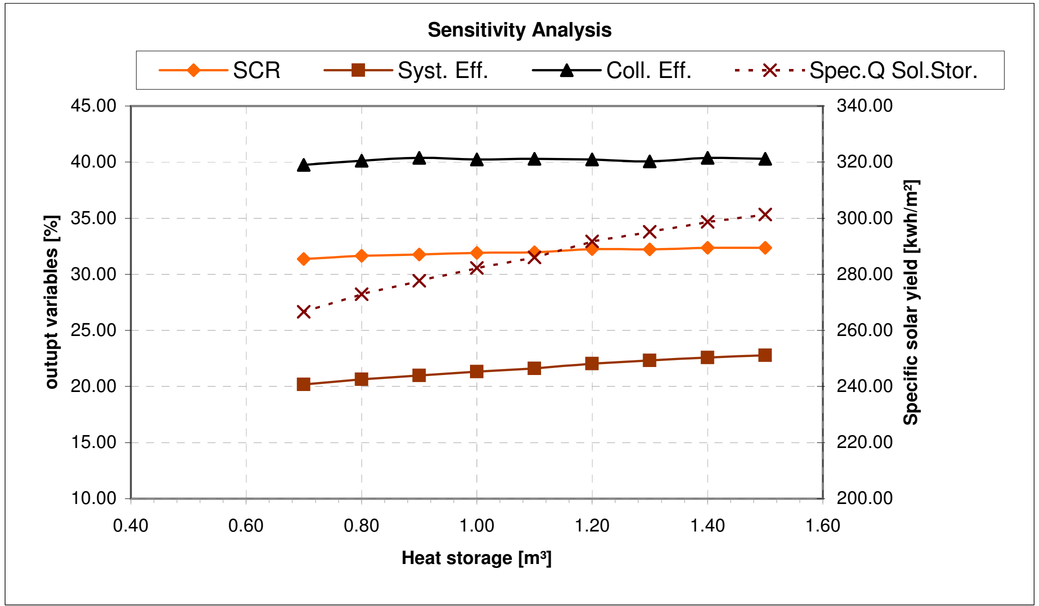


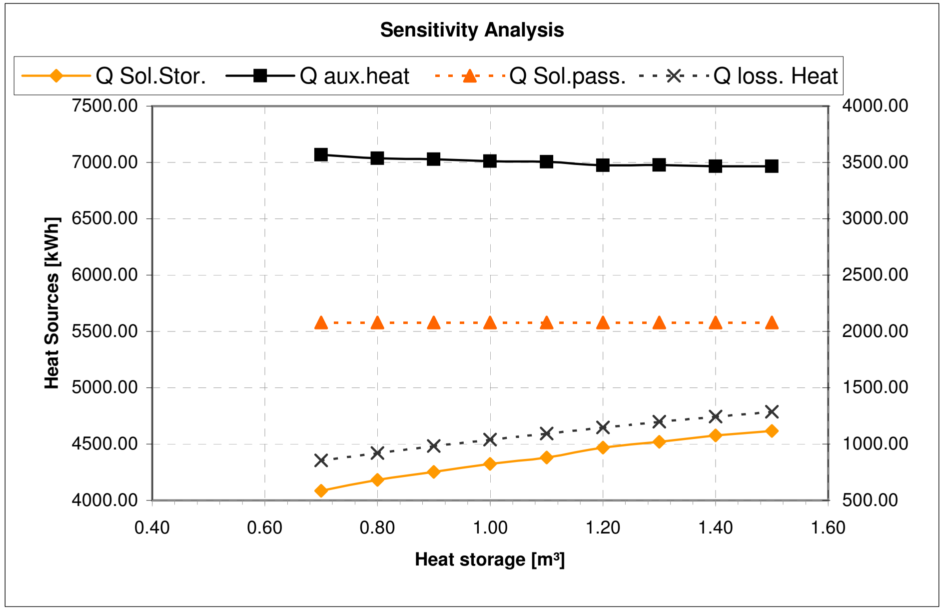
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³

	entire plant				Heat sources			Heat sinks				Cov. ratio	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
0.70	31.37	39.75	20.18	266.68	4085.50	7066.80	2078.90	2964.10	7327.60	856.00	11147.70	100.00	99.99
0.80	31.66	40.11	20.63	272.89	4180.70	7036.80	2078.90	2964.10	7327.60	919.80	11211.50	100.00	100.00
0.90	31.76	40.37	20.98	277.69	4254.20	7027.20	2078.90	2964.10	7327.60	982.80	11274.50	100.00	100.00
1.00	31.91	40.25	21.33	282.22	4323.60	7011.60	2078.90	2964.10	7327.60	1039.20	11330.90	100.00	100.00
1.10	31.97	40.30	21.62	286.03	4382.00	7005.60	2078.90	2964.10	7327.60	1092.90	11384.60	100.00	100.00
1.20	32.26	40.23	22.05	291.69	4468.70	6975.60	2078.90	2964.10	7327.60	1147.10	11438.80	100.00	100.00
1.30	32.23	40.06	22.33	295.12	4521.20	6978.00	2078.90	2964.10	7327.60	1198.70	11490.40	100.00	100.00
1.40	32.36	40.39	22.57	298.65	4575.30	6964.80	2078.90	2964.10	7327.60	1244.90	11536.60	100.00	100.00
1.50	32.35	40.29	22.78	301.31	4616.00	6966.00	2078.90	2964.10	7327.60	1286.60	11578.30	100.00	100.00



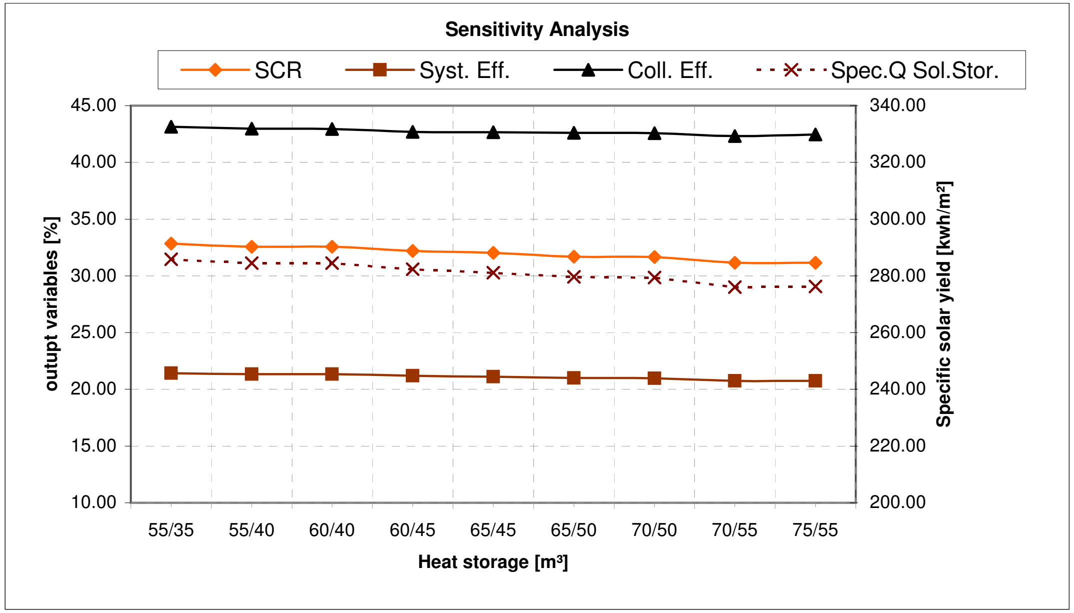


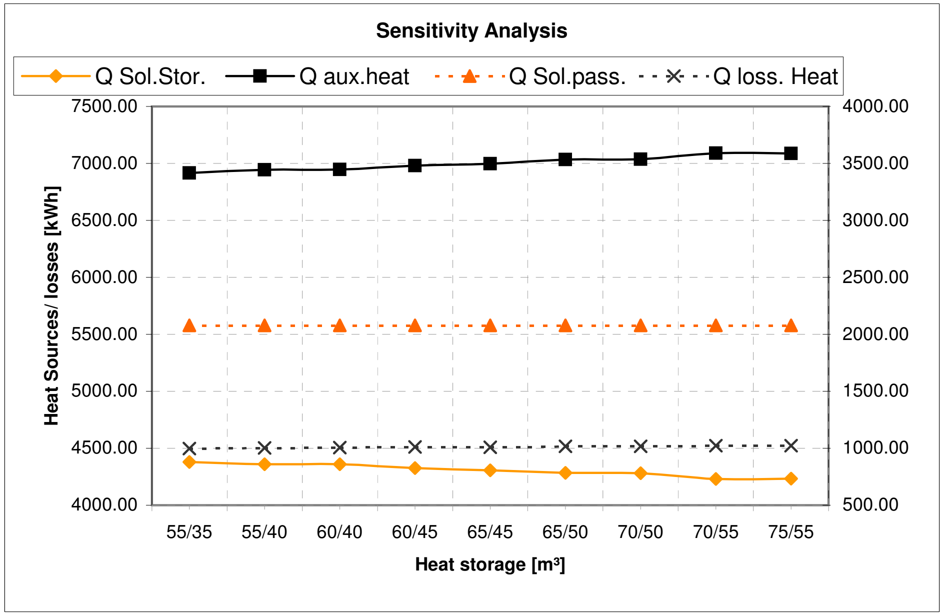
Sensitivity Analysis

Sensitivity Analysis, with respect to different **heating system parameters**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80℃. Dashed lines refer to the right scale axis.

Project :	Rijeka SFH II	**simulated:**	15.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	1 m³

	entire plant				**Heat sources**			**Heat sinks**				**Cov.ratio**	
SH-type	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
℃/℃	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
55/35	32.85	43.14	21.42	285.89	4379.90	6914.40	2078.90	2964.10	7327.60	995.90	11287.60	100.00	100.00
55/40	32.57	42.98	21.33	284.54	4359.20	6943.20	2078.90	2964.10	7327.60	1002.80	11294.50	100.00	100.00
60/40	32.55	42.95	21.33	284.52	4358.90	6945.60	2078.90	2964.10	7327.60	1005.10	11296.80	100.00	100.00
60/45	32.20	42.70	21.19	282.40	4326.40	6981.60	2078.90	2964.10	7327.60	1010.30	11302.00	100.00	100.00
65/45	32.04	42.67	21.10	281.16	4307.40	6998.40	2078.90	2964.10	7327.60	1008.70	11300.40	100.00	100.00
65/50	31.70	42.59	20.99	279.64	4284.10	7033.20	2078.90	2964.10	7327.60	1017.10	11308.80	100.00	100.00
70/50	31.67	42.58	20.97	279.41	4280.50	7035.60	2078.90	2964.10	7327.60	1017.60	11309.30	100.00	100.00
70/55	31.15	42.31	20.74	276.06	4229.20	7089.60	2078.90	2964.10	7327.60	1021.70	11313.40	100.00	100.00
75/55	31.16	42.45	20.75	276.26	4232.30	7088.40	2078.90	2964.10	7327.60	1022.30	11314.00	100.00	100.00



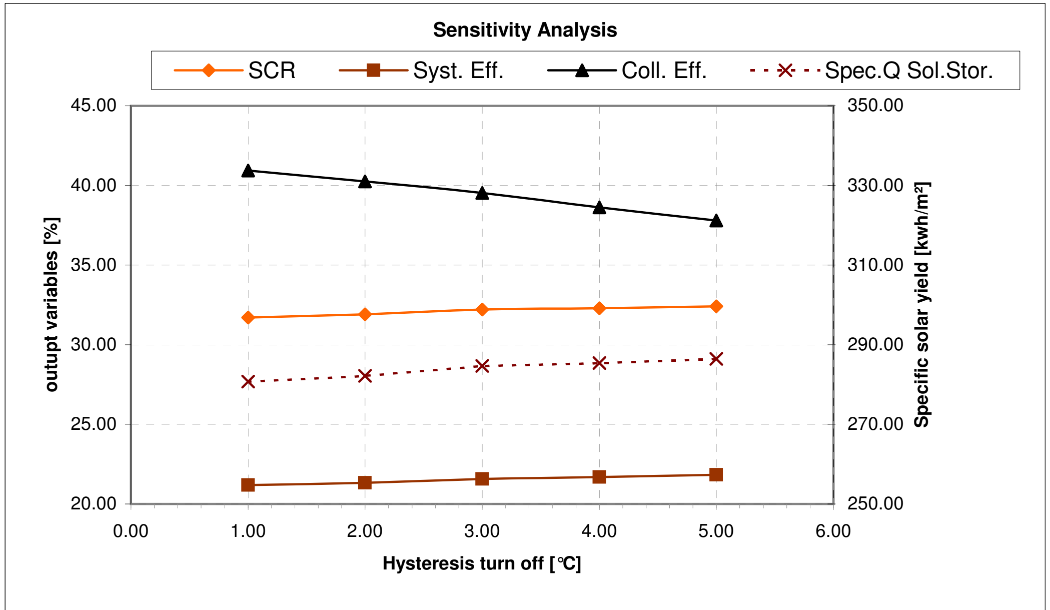


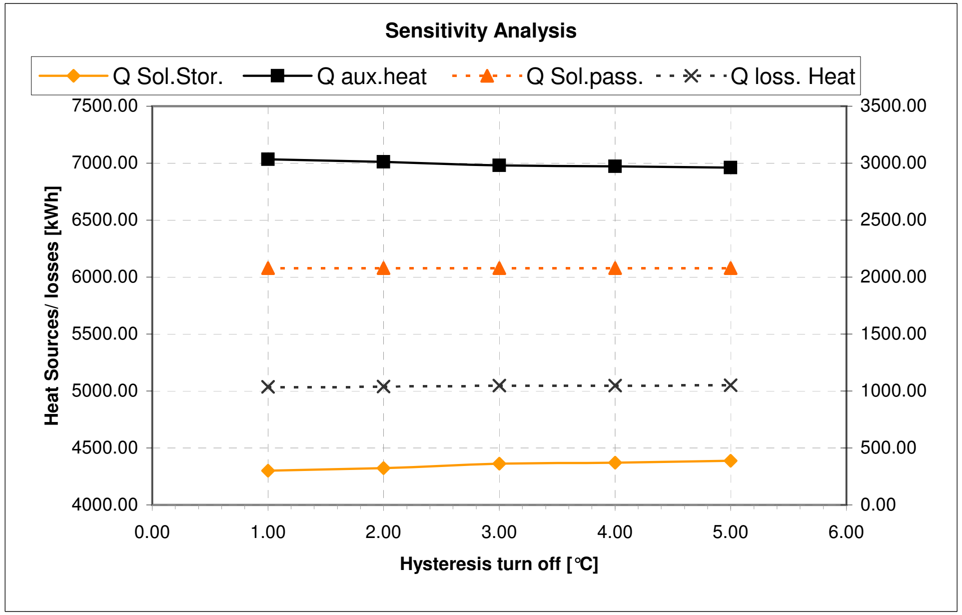
Sensitivity Analysis

Sensitivity Analysis, with respect to the collector loop control parameter "**hysteresis turn off**". The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	1 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Hyst. turn off	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[℃]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
1.00	31.70	40.93	21.18	280.71	4300.50	7033.20	2078.90	2964.10	7327.60	1035.60	11327.30	100.00	100.00
2.00	31.91	40.25	21.33	282.22	4323.60	7011.60	2078.90	2964.10	7327.60	1039.20	11330.90	100.00	100.00
3.00	32.20	39.53	21.57	284.67	4361.10	6981.60	2078.90	2964.10	7327.60	1046.50	11338.20	100.00	100.00
4.00	32.28	38.63	21.69	285.37	4371.80	6973.20	2078.90	2964.10	7327.60	1048.30	11340.00	100.00	100.00
5.00	32.41	37.80	21.83	286.42	4387.90	6960.00	2078.90	2964.10	7327.60	1050.20	11341.90	100.00	100.00



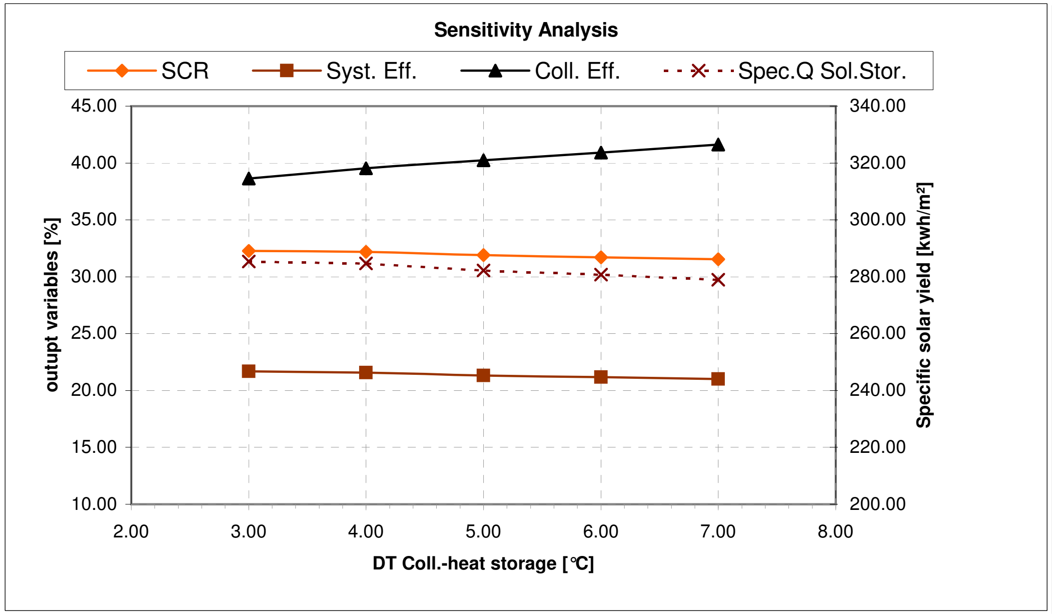


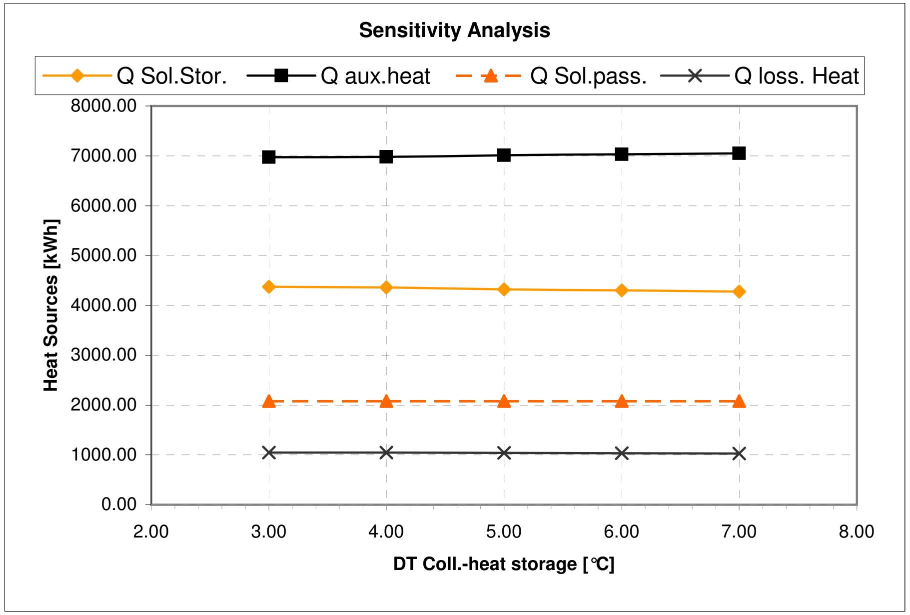
Sensitivity Analysis

Sensitivity Analysis, with respect to the collector loop control parameter "**Δ T Collector - heat storage sensor** ". The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	1 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
ΔT Coll - heat st.	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[℃]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
3.00	32.28	38.63	21.69	285.37	4371.80	6973.20	2078.90	2964.10	7327.60	1048.30	11340.00	100.00	100.00
4.00	32.20	39.53	21.57	284.67	4361.10	6981.60	2078.90	2964.10	7327.60	1046.50	11338.20	100.00	100.00
5.00	31.91	40.25	21.33	282.22	4323.60	7011.60	2078.90	2964.10	7327.60	1039.20	11330.90	100.00	100.00
6.00	31.70	40.93	21.18	280.71	4300.50	7033.20	2078.90	2964.10	7327.60	1035.60	11327.30	100.00	100.00
7.00	31.53	41.62	21.00	278.94	4273.40	7050.00	2078.90	2964.10	7327.60	1027.60	11319.30	100.00	100.00



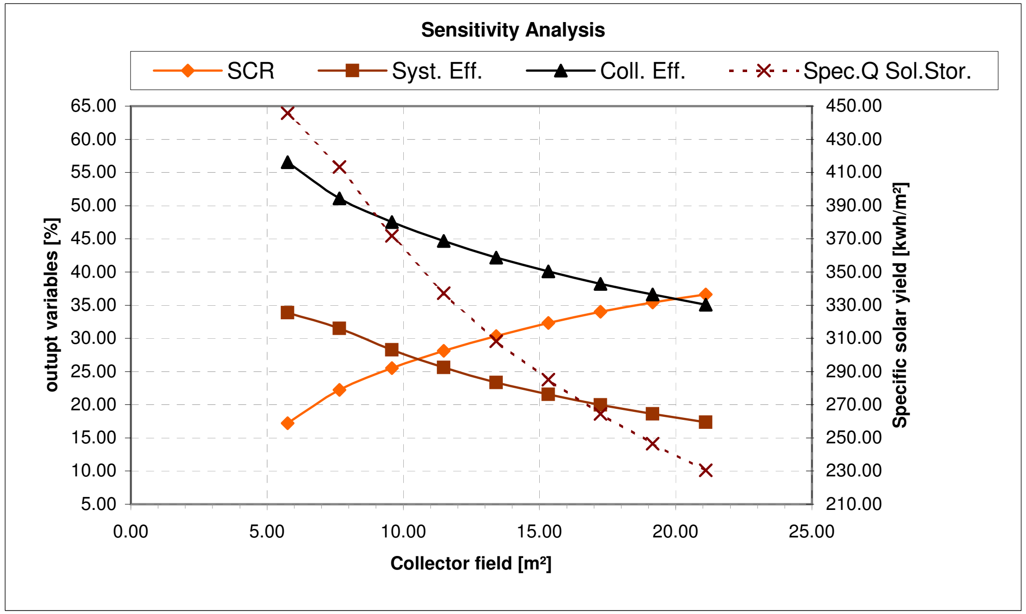


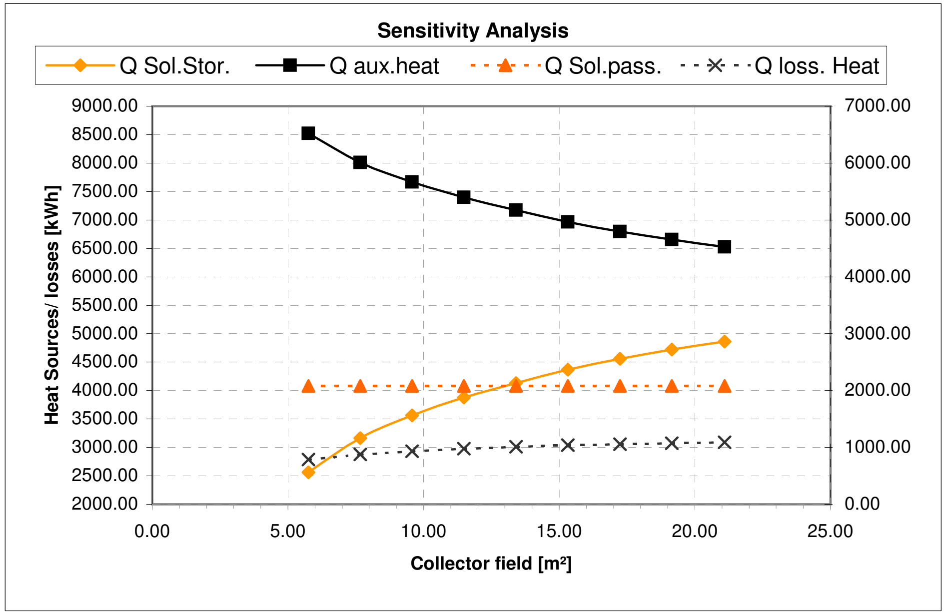
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net collector field**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009	
Collector:	**std. fictive sel. flat plate SHC T32**	**Field:**	5.75 - 21.1	m²
Climate data set:	Rijeka.dat	**storage:**	1.000	m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Coll. field [m²]	**SCR** DeckGr [%]	**Coll. Eff.** KolWiGr [%]	**Syst. Eff.** KolNuGr [%]	**Spec.Q Sol.Stor.** spez. Ertrag [kwh/m²]	**Q Sol.Stor.** SolSpei [kWh]	**Q aux.heat** Kessel [kWh]	**Q Sol.pass.** Pass+Sp [kWh]	**Q DHW** Warmwas [kWh]	**Q SH** Heizung [kWh]	**Q loss. Heat** HeiSpVerl [kWh]	**total** [kWh]	**DHW** WW-Deckg [%]	**heat** HZ-Deckg [%]
5.75	17.21	56.53	33.87	445.70	2562.80	8524.80	2078.90	2964.10	7327.60	788.40	11080.10	100.00	100.00
7.66	22.21	51.08	31.51	413.26	3165.60	8010.00	2078.90	2964.10	7327.60	879.20	11170.90	100.00	100.00
9.58	25.52	47.53	28.29	371.77	3561.60	7669.20	2078.90	2964.10	7327.60	933.20	11224.90	100.00	100.00
11.49	28.14	44.68	25.61	337.34	3876.00	7399.20	2078.90	2964.10	7327.60	976.70	11268.40	100.00	100.00
13.41	30.32	42.16	23.36	308.20	4132.90	7174.80	2078.90	2964.10	7327.60	1011.20	11302.90	100.00	100.00
15.32	32.34	40.09	21.57	285.15	4368.50	6967.20	2078.90	2964.10	7327.60	1039.60	11331.30	100.00	100.00
17.24	33.99	38.21	19.97	264.41	4558.40	6796.80	2078.90	2964.10	7327.60	1059.00	11350.70	100.00	100.00
19.15	35.39	36.62	18.59	246.48	4720.00	6652.80	2078.90	2964.10	7327.60	1075.90	11367.60	100.00	100.00
21.10	36.64	35.05	17.36	230.44	4862.30	6524.40	2078.90	2964.10	7327.60	1089.00	11380.70	100.00	100.00



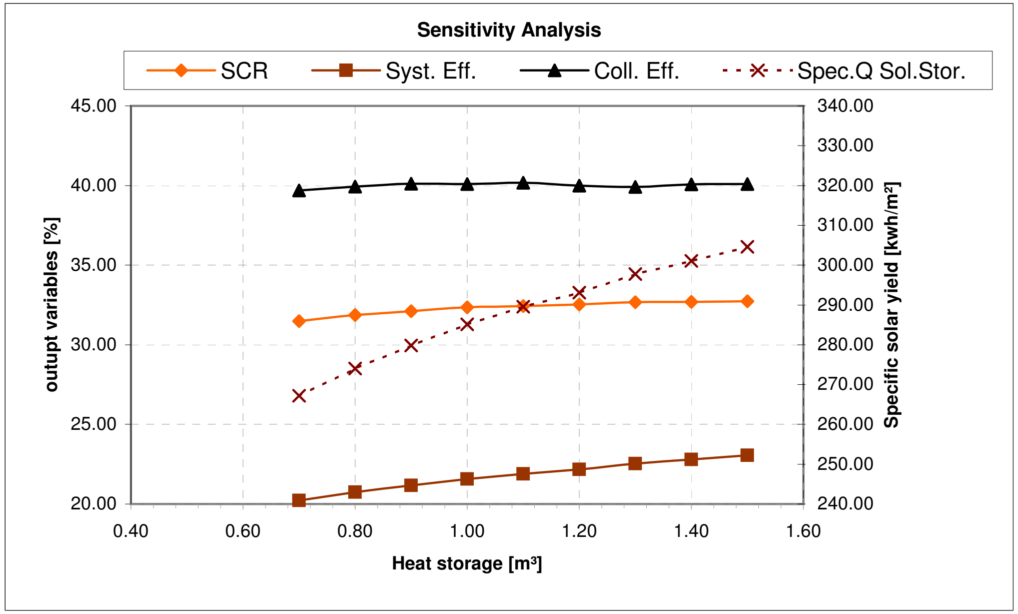


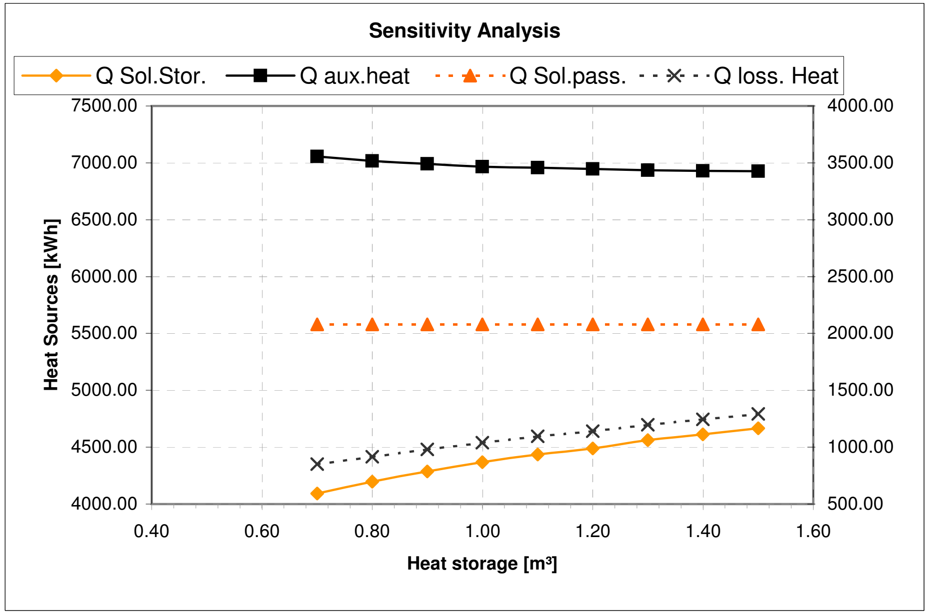
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009
Collector:	**std. fictive sel. flat plate SHC T32**	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deck	HZ-Deckg
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
0.70	31.49	39.70	20.23	267.23	4094.00	7054.80	2078.90	2964.10	7327.60	851.70	11143.40	100.00	99.99
0.80	31.86	39.94	20.74	274.00	4197.70	7016.40	2078.90	2964.10	7327.60	917.30	11209.00	100.00	100.00
0.90	32.10	40.11	21.17	279.80	4286.60	6992.40	2078.90	2964.10	7327.60	981.40	11273.10	100.00	100.00
1.00	32.34	40.09	21.57	285.15	4368.50	6967.20	2078.90	2964.10	7327.60	1039.60	11331.30	100.00	100.00
1.10	32.43	40.17	21.90	289.56	4436.00	6957.60	2078.90	2964.10	7327.60	1094.70	11386.40	100.00	100.00
1.20	32.54	39.99	22.18	293.10	4490.30	6946.80	2078.90	2964.10	7327.60	1141.50	11433.20	100.00	100.00
1.30	32.67	39.92	22.54	297.74	4561.40	6933.60	2078.90	2964.10	7327.60	1196.70	11488.40	100.00	100.00
1.40	32.70	40.08	22.79	301.08	4612.50	6930.00	2078.90	2964.10	7327.60	1246.00	11537.70	100.00	100.00
1.50	32.73	40.10	23.05	304.57	4666.00	6926.40	2078.90	2964.10	7327.60	1293.30	11585.00	100.00	100.00



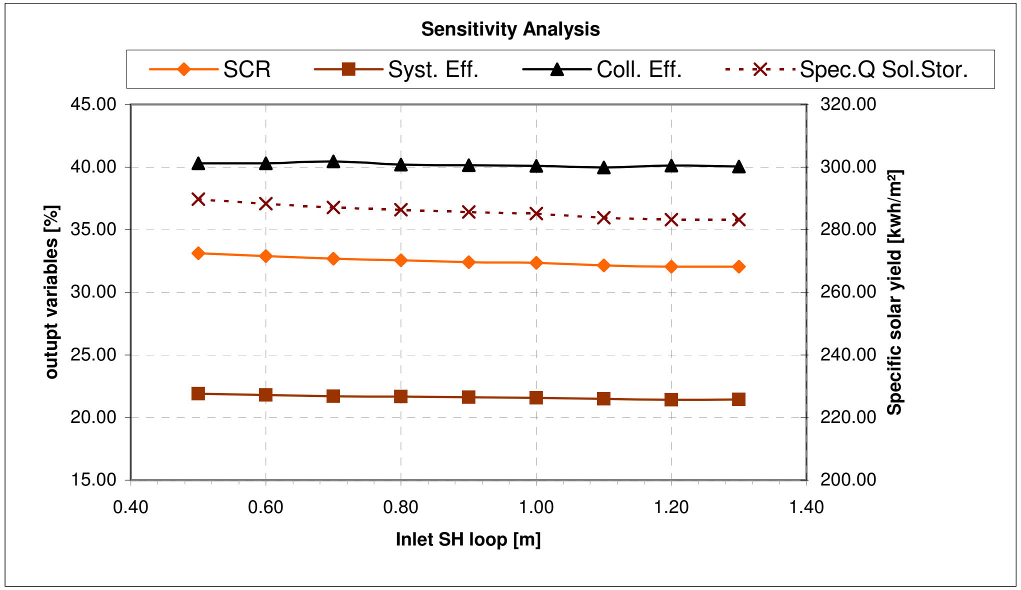


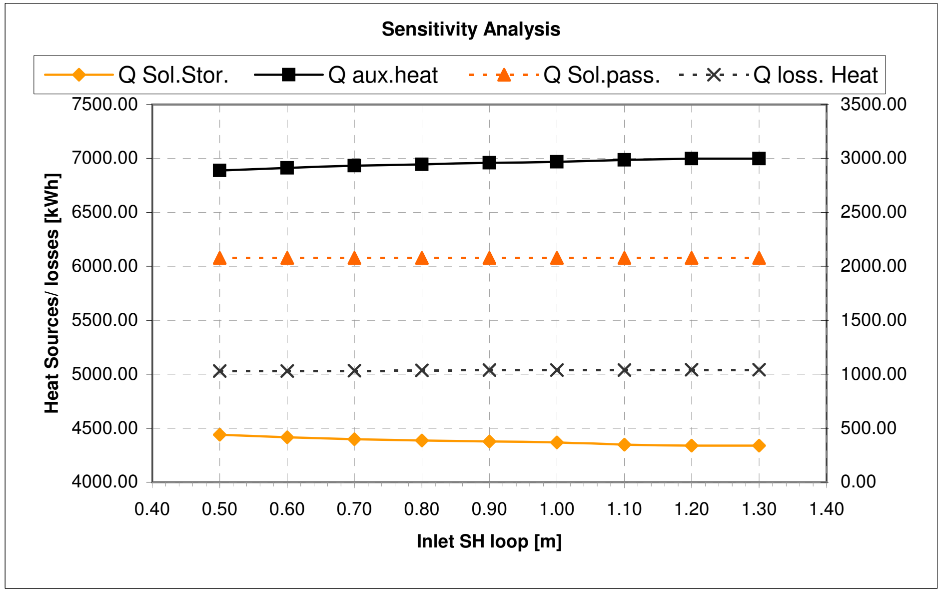
Sensitivity Analysis

Sensitivity Analysis, with respect to **the inlet of the SH-loop**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II**	**simulated:**	15.08.2009	
Collector:	**std. fictive sel. flat plate SHC T32**	**Field:**	15.320	m²
Climate data set:	Rijeka.dat	**storage:**	1.000	m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Inlet SH-loop	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
0.50	33.11	40.31	21.90	289.71	4438.30	6888.00	2078.90	2964.10	7327.60	1031.20	11322.90	100.00	100.00
0.60	32.89	40.30	21.80	288.32	4417.00	6910.80	2078.90	2964.10	7327.60	1031.50	11323.20	100.00	100.00
0.70	32.68	40.44	21.70	287.08	4398.10	6932.40	2078.90	2964.10	7327.60	1034.20	11325.90	100.00	100.00
0.80	32.55	40.19	21.66	286.33	4386.60	6945.60	2078.90	2964.10	7327.60	1036.10	11327.80	100.00	100.00
0.90	32.41	40.14	21.61	285.63	4375.90	6960.00	2078.90	2964.10	7327.60	1039.60	11331.30	100.00	100.00
1.00	32.34	40.09	21.57	285.15	4368.50	6967.20	2078.90	2964.10	7327.60	1039.60	11331.30	100.00	100.00
1.10	32.15	39.97	21.48	283.84	4348.50	6986.40	2078.90	2964.10	7327.60	1038.90	11330.60	100.00	100.00
1.20	32.05	40.11	21.42	283.15	4337.90	6997.20	2078.90	2964.10	7327.60	1040.70	11332.40	100.00	100.00
1.30	32.04	40.05	21.43	283.25	4339.40	6998.40	2078.90	2964.10	7327.60	1041.80	11333.50	100.00	100.00
1.40	31.87	40.11	21.34	282.02	4320.50	7015.20	2078.90	2964.10	7327.60	1040.10	11331.80	100.00	100.00
1.50	31.76	39.84	21.32	281.55	4313.30	7027.20	2078.90	2964.10	7327.60	1044.00	11335.70	100.00	100.00

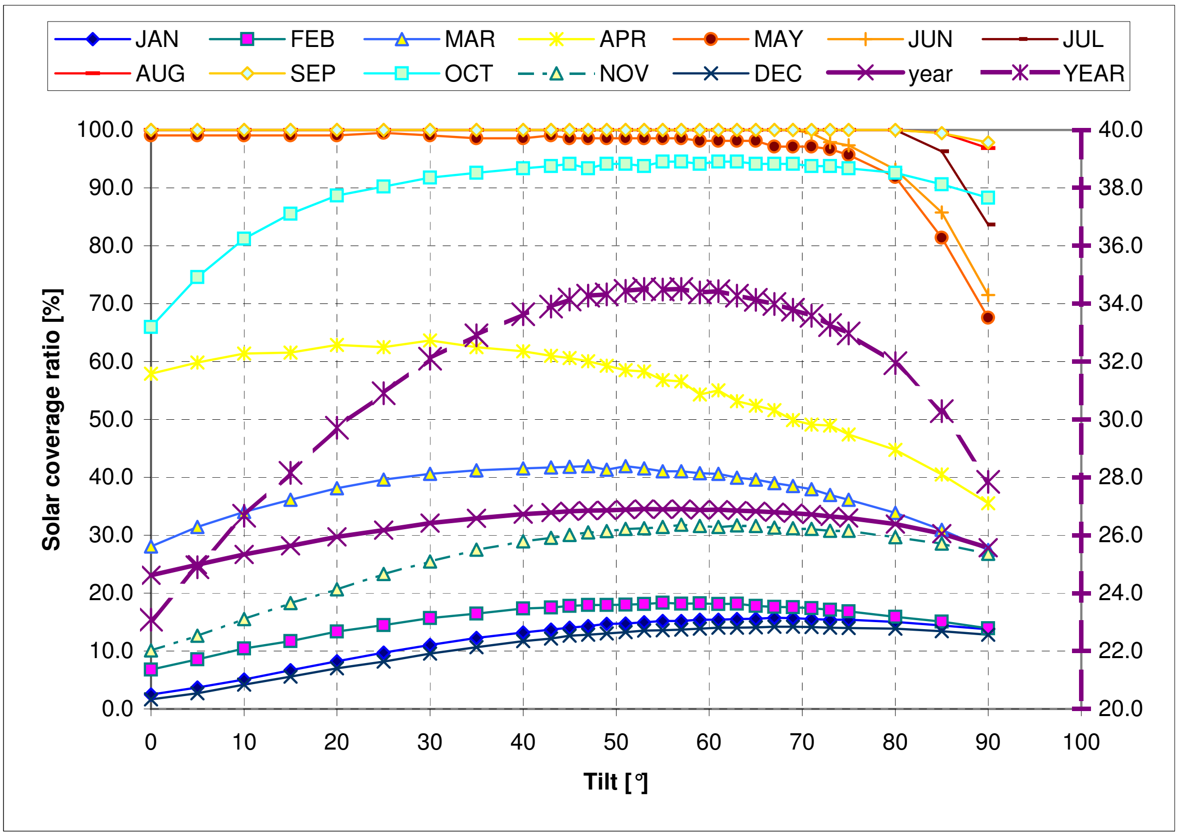




Analysis of Solar Coverage Ratio for **different Tilt angles** (Azimuth=0)°. The dashed line for the annual coverage ratio refers to the right scale axis.

Project : Rijeka SFH II optimised system **simulated:** 17.08.2009
Net collector field: Tehnomont_SKT-40 15.320m² **storage:** **1.000m³**
climate data set: Rijeka.dat

Tilt [°]	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OKT	NOV	DEZ	**year**
	SCR for Different Tilt angles for each month and one year [%]												
0	2.5	6.8	28.1	57.9	99.1	100.0	100.0	100.0	100.0	66.0	10.1	1.6	**23.1**
5	3.7	8.6	31.5	59.8	99.1	100.0	100.0	100.0	100.0	74.6	12.7	2.7	**24.9**
10	5.1	10.5	34.0	61.4	99.1	100.0	100.0	100.0	100.0	81.2	15.5	4.2	**26.7**
15	6.7	11.7	36.1	61.6	99.1	100.0	100.0	100.0	100.0	85.5	18.3	5.6	**28.2**
20	8.3	13.4	38.1	62.9	99.1	100.0	100.0	100.0	100.0	88.7	20.7	7.0	**29.7**
25	9.7	14.5	39.6	62.5	99.5	100.0	100.0	100.0	100.0	90.2	23.3	8.2	**30.9**
30	11.1	15.7	40.6	63.7	99.1	100.0	100.0	100.0	100.0	91.8	25.5	9.6	**32.1**
35	12.3	16.5	41.2	62.5	98.6	100.0	100.0	100.0	100.0	92.6	27.5	10.7	**32.9**
40	13.2	17.4	41.5	61.8	98.6	100.0	100.0	100.0	100.0	93.4	29.0	11.7	**33.6**
43	13.7	17.5	41.7	61.0	99.1	100.0	100.0	100.0	100.0	93.8	29.6	12.2	**33.9**
45	14.0	17.8	41.8	60.6	98.6	100.0	100.0	100.0	100.0	94.1	30.0	12.7	**34.1**
47	14.3	17.9	41.9	60.0	98.6	100.0	100.0	100.0	100.0	93.4	30.5	12.8	**34.3**
49	14.7	18.0	41.3	59.3	98.6	100.0	100.0	100.0	100.0	94.1	30.7	13.0	**34.3**
51	14.7	18.0	41.9	58.5	98.6	100.0	100.0	100.0	100.0	94.1	31.1	13.3	**34.4**
53	15.0	18.1	41.5	58.3	98.6	100.0	100.0	100.0	100.0	93.8	31.2	13.6	**34.5**
55	15.2	18.3	41.0	56.8	98.6	100.0	100.0	100.0	100.0	94.5	31.5	13.6	**34.5**
57	15.2	18.2	41.0	56.6	98.6	100.0	100.0	100.0	100.0	94.5	31.8	13.7	**34.5**
59	15.4	18.3	40.7	54.3	98.1	100.0	100.0	100.0	100.0	94.1	31.6	13.9	**34.4**
61	15.4	18.1	40.6	55.1	98.1	100.0	100.0	100.0	100.0	94.5	31.5	14.0	**34.4**
63	15.6	18.2	39.9	53.1	98.1	100.0	100.0	100.0	100.0	94.5	31.7	14.0	**34.3**
65	15.6	17.8	39.6	52.4	98.1	100.0	100.0	100.0	100.0	94.1	31.6	14.1	**34.1**
67	15.8	17.6	39.0	51.6	97.1	100.0	100.0	100.0	100.0	94.1	31.3	14.2	**34.0**
69	15.7	17.6	38.5	49.9	97.1	100.0	100.0	100.0	100.0	94.1	31.2	14.2	**33.8**
71	15.6	17.4	37.9	49.1	97.1	99.5	100.0	100.0	100.0	93.8	31.1	14.1	**33.6**
73	15.4	17.1	36.9	48.9	96.7	97.9	100.0	100.0	100.0	93.8	30.8	14.1	**33.3**
75	15.4	16.9	36.1	47.4	95.7	97.4	100.0	100.0	100.0	93.4	30.8	14.0	**33.0**
80	15.1	15.9	33.8	44.7	91.9	93.1	100.0	100.0	100.0	92.6	29.7	13.9	**32.0**
85	14.4	15.1	31.0	40.5	81.4	85.7	96.3	99.5	99.5	90.6	28.6	13.5	**30.3**
90	13.8	13.9	27.5	35.5	67.6	71.5	83.6	96.9	97.9	88.3	26.8	12.8	**27.8**

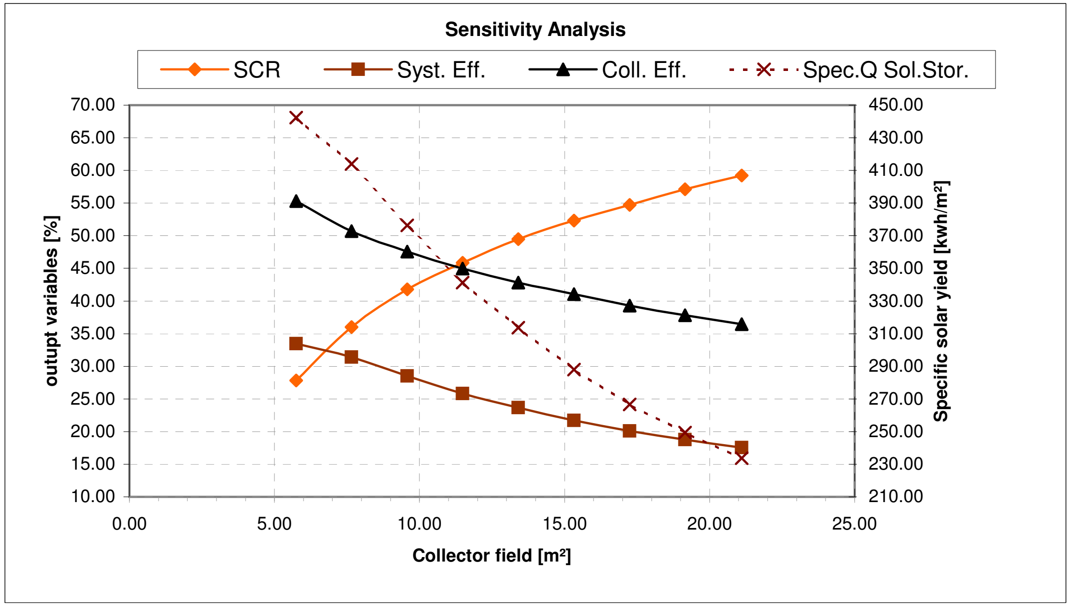


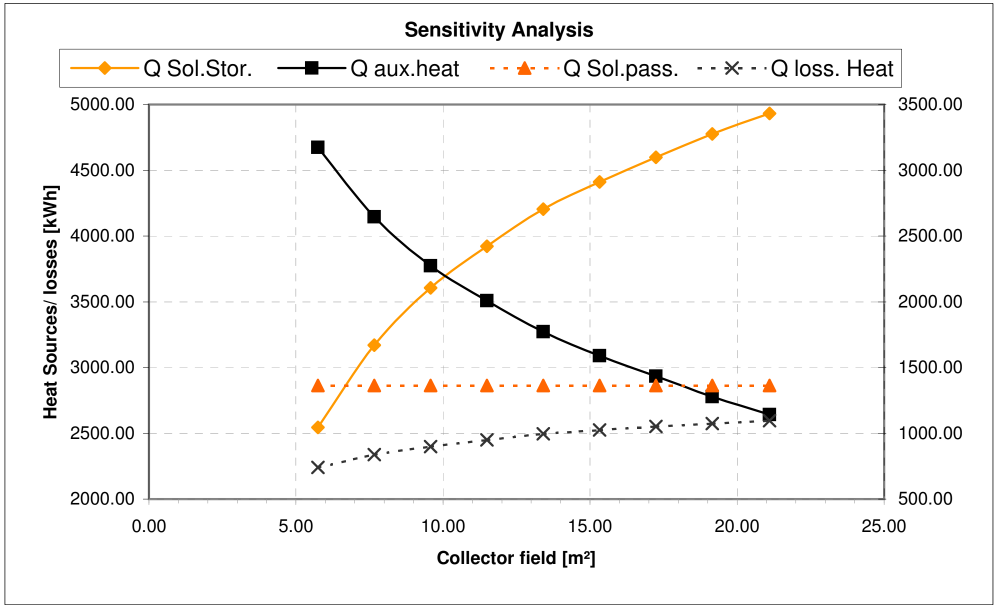
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net collector field**. The solar Combisystem consists of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=80°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH III**	**simulated:**	15.08.2009	
Collector:	Tehnomont_SKT-40	**Field:**	5.75 - 21.1	m²
Climate data set:	Rijeka.dat	**storage:**	1.000	m³

	entire plant				**Heat sources**			**Heat sinks**				**Cov.ratio**	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
5.75	27.85	55.32	33.46	442.45	2544.10	4674.60	1364.10	2964.10	3510.20	740.50	7214.80	100.00	100.00
7.66	36.01	50.72	31.41	413.97	3171.00	4146.10	1364.10	2964.10	3510.20	837.20	7311.50	100.00	100.00
9.58	41.77	47.56	28.51	376.29	3604.90	3773.00	1364.10	2964.10	3510.20	899.40	7373.70	100.00	100.00
11.49	45.84	44.97	25.82	341.30	3921.50	3509.10	1364.10	2964.10	3510.20	951.20	7425.50	100.00	100.00
13.41	49.50	42.82	23.68	313.60	4205.40	3272.50	1364.10	2964.10	3510.20	997.40	7471.70	100.00	100.00
15.32	52.33	41.06	21.70	287.93	4411.10	3089.10	1364.10	2964.10	3510.20	1024.90	7499.20	100.00	100.00
17.24	54.71	39.28	20.08	266.68	4597.50	2934.40	1364.10	2964.10	3510.20	1052.30	7526.60	100.00	100.00
19.15	57.12	37.80	18.75	249.41	4776.20	2778.30	1364.10	2964.10	3510.20	1074.50	7548.80	100.00	100.00
21.10	59.23	36.44	17.55	233.75	4932.10	2641.80	1364.10	2964.10	3510.20	1095.00	7569.30	100.00	100.00



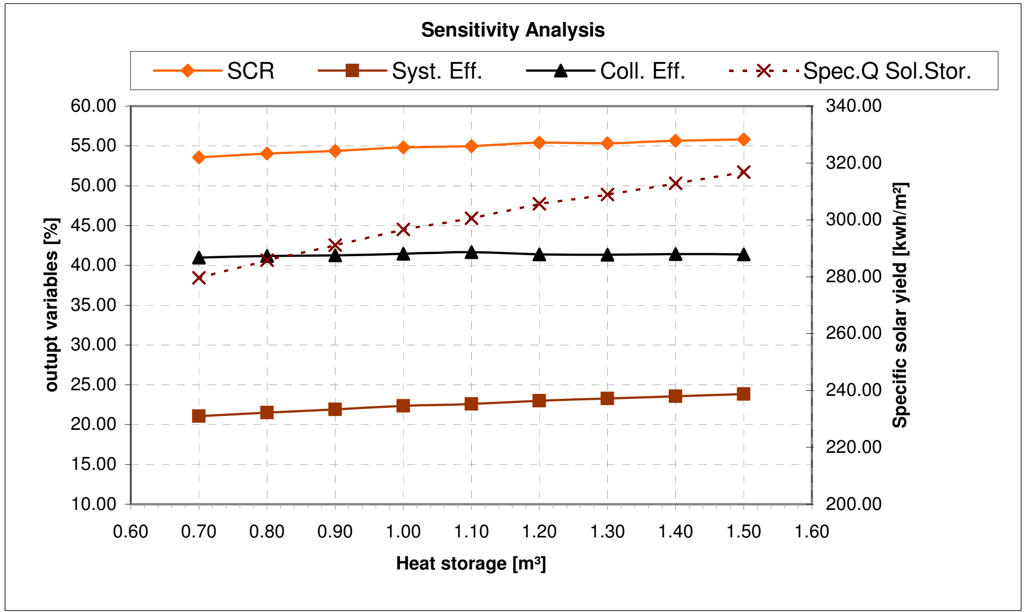


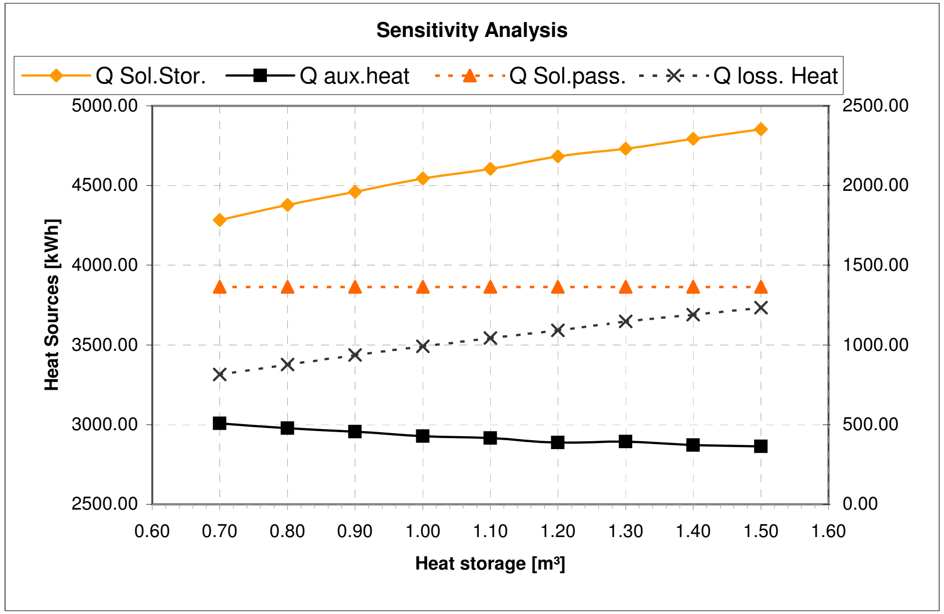
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consist of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45°C/ 200 litre) is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=70°C. Dashed lines refer to the right scale.

Project :	**Rijeka SFH III**	**simulated:**	16.08.2009
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]
0.70	53.56	40.97	21.06	279.60	4283.50	3007.20	1364.10	2964.10	3510.20	814.30	7288.60	100.00	99.97
0.80	54.04	41.18	21.52	285.79	4378.30	2977.10	1364.10	2964.10	3510.20	877.40	7351.70	100.00	100.00
0.90	54.37	41.26	21.92	291.10	4459.60	2955.40	1364.10	2964.10	3510.20	937.30	7411.60	100.00	100.00
1.00	54.81	41.44	22.33	296.66	4544.80	2926.70	1364.10	2964.10	3510.20	991.70	7466.00	100.00	100.00
1.10	54.99	41.66	22.61	300.62	4605.50	2915.50	1364.10	2964.10	3510.20	1043.70	7518.00	100.00	100.00
1.20	55.43	41.39	23.01	305.64	4682.40	2886.80	1364.10	2964.10	3510.20	1091.90	7566.20	100.00	100.00
1.30	55.33	41.35	23.26	308.87	4731.90	2893.10	1364.10	2964.10	3510.20	1146.90	7621.20	100.00	100.00
1.40	55.66	41.42	23.55	312.87	4793.10	2872.10	1364.10	2964.10	3510.20	1189.10	7663.40	100.00	100.00
1.50	55.80	41.38	23.85	316.79	4853.20	2863.00	1364.10	2964.10	3510.20	1233.20	7707.50	100.00	100.00





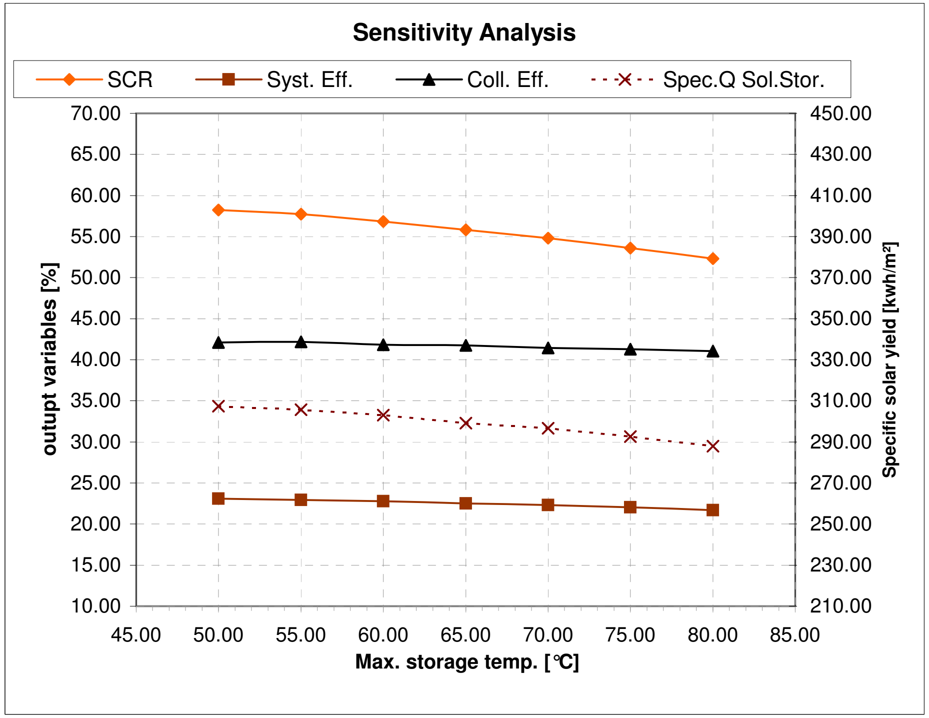
Sensitivity Analysis

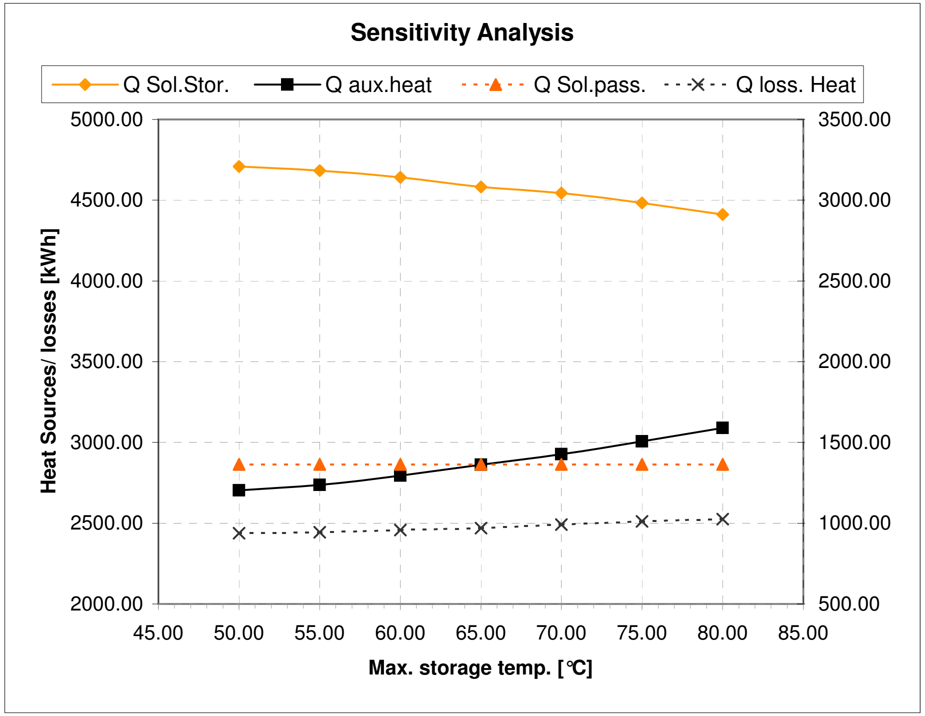
Sensitivity Analysis, with respect to the **maximal storage temperature** when the heat storage is supplied by the **auxiliary heater**. The solar Combisystem consits of 1 storage. Heat provision for DHW usage for a single family house with 4 people (daily consumption: 45℃/ 200 litre) is provided via a continuous flow heat exchanger.
Dashed lines refer to the right scale axis.

Project : **Rijeka SFH III**
Collector: Tehnomont_SKT-40
Climate data set: Rijeka.dat

simulated: 16.08.2009
Field: 15.32 m²
storage: 1.000 m³

	entire plant				Heat sources			Heat sinks				Cov.ratio	
Max. storage temp. (aux. heater) [℃]	**SCR** DeckGr [%]	**Coll. Eff.** KolWiGr [%]	**Syst. Eff.** KolNuGr [%]	**Spec.Q Sol.Stor.** spez. Ertrag [kwh/m²]	**Q Sol.Stor.** SolSpei [kWh]	**Q aux.heat** Kessel [kWh]	**Q Sol.pass.** Pass+Sp [kWh]	**Q DHW** Warmwas [kWh]	**Q SH** Heizung [kWh]	**Q loss. Heat** HeiSpVerl [kWh]	**total** [kWh]	**DHW** WW-Deckg [%]	**heat** HZ-Deckg [%]
50.00	58.25	42.11	23.08	307.41	4709.50	2704.10	1364.10	2964.10	3510.20	938.10	7412.40	100.00	99.99
55.00	57.73	42.18	22.94	305.63	4682.30	2737.70	1364.10	2964.10	3510.20	944.10	7418.40	100.00	100.00
60.00	56.85	41.82	22.77	302.97	4641.50	2794.40	1364.10	2964.10	3510.20	958.70	7433.00	100.00	100.00
65.00	55.81	41.74	22.49	299.13	4582.70	2862.30	1364.10	2964.10	3510.20	970.20	7444.50	100.00	100.00
70.00	54.81	41.44	22.33	296.66	4544.80	2926.70	1364.10	2964.10	3510.20	991.70	7466.00	100.00	100.00
75.00	53.58	41.27	22.03	292.57	4482.10	3007.20	1364.10	2964.10	3510.20	1011.50	7485.80	100.00	100.00
80.00	52.33	41.06	21.70	287.93	4411.10	3089.10	1364.10	2964.10	3510.20	1024.90	7499.20	100.00	100.00





Appendix E

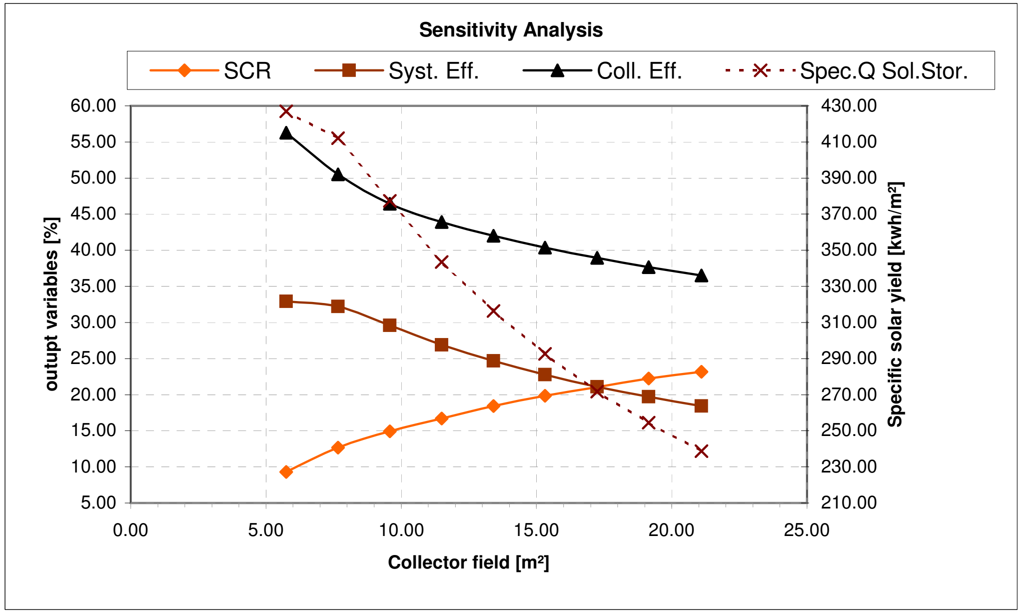
SA Combisystem Two-Storage

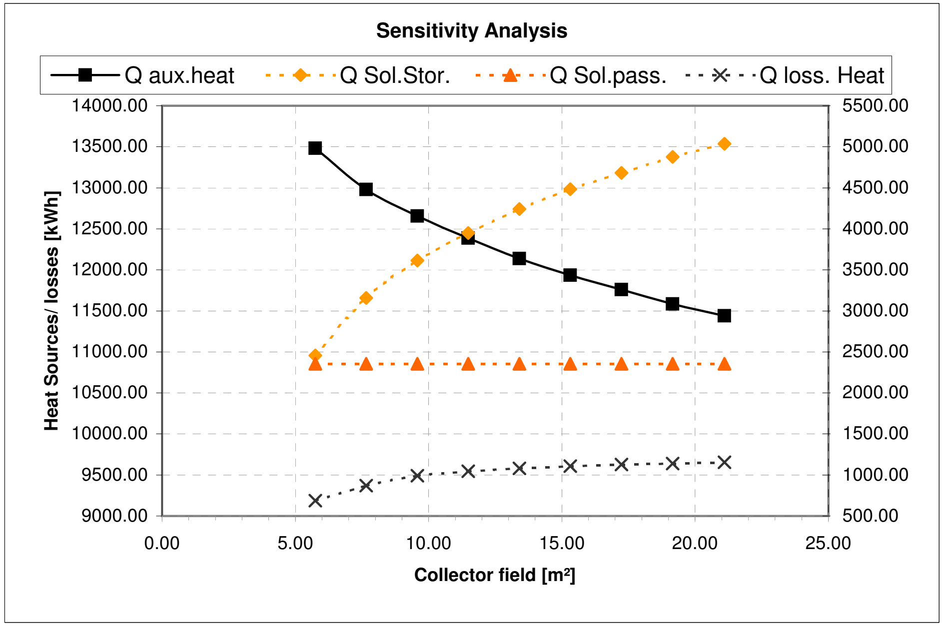
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net Collector field area**. The solar Combisystem consists of 2 storages, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45℃/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=75℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH I 2 storages**	**simulated:**	28.08.2009	**Azimuth:**	0°
Collector:	Tehnomont_SKT-40	**Field:**	5.75 - 21.1 m²	**Tilt:**	50°
Climate data set:	Rijeka.dat	**storage:**	1.000 m³		

	entire plant				Heat sources			Heat sinks				Cov.ratio		SCR	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
5.75	9.28	56.29	32.94	426.96	2455.00	13483.50	2356.40	2964.10	12045.40	688.40	15697.90	100.00	98.79	31.31	3.80
7.66	12.65	50.50	32.20	412.08	3156.50	12978.00	2356.40	2964.10	12045.40	870.90	15880.40	100.00	98.74	38.86	6.12
9.58	14.91	46.44	29.59	377.28	3614.30	12655.50	2356.40	2964.10	12045.40	989.20	15998.70	100.00	98.86	44.07	7.65
11.49	16.72	43.90	26.88	343.53	3947.20	12387.00	2356.40	2964.10	12045.40	1045.50	16055.00	100.00	98.88	48.19	8.89
13.41	18.44	42.01	24.68	316.38	4242.70	12138.00	2356.40	2964.10	12045.40	1081.70	16091.20	100.00	98.94	51.31	10.26
15.32	19.84	40.35	22.77	292.70	4484.10	11935.50	2356.40	2964.10	12045.40	1109.30	16118.80	100.00	99.01	53.70	11.43
17.24	21.03	38.97	21.08	271.66	4683.50	11758.50	2356.40	2964.10	12045.40	1126.60	16136.10	100.00	99.01	55.88	12.37
19.15	22.22	37.67	19.71	254.57	4875.00	11584.50	2356.40	2964.10	12045.40	1140.60	16150.10	100.00	99.03	58.09	13.30
21.10	23.19	36.53	18.44	238.67	5036.00	11440.50	2356.40	2964.10	12045.40	1153.20	16162.70	100.00	99.04	60.13	14.01



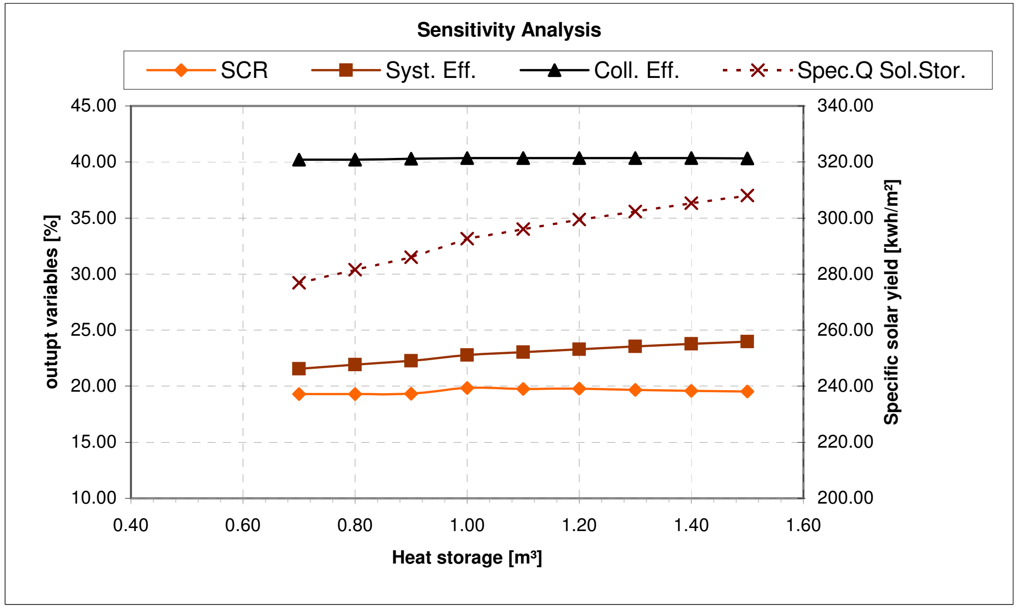


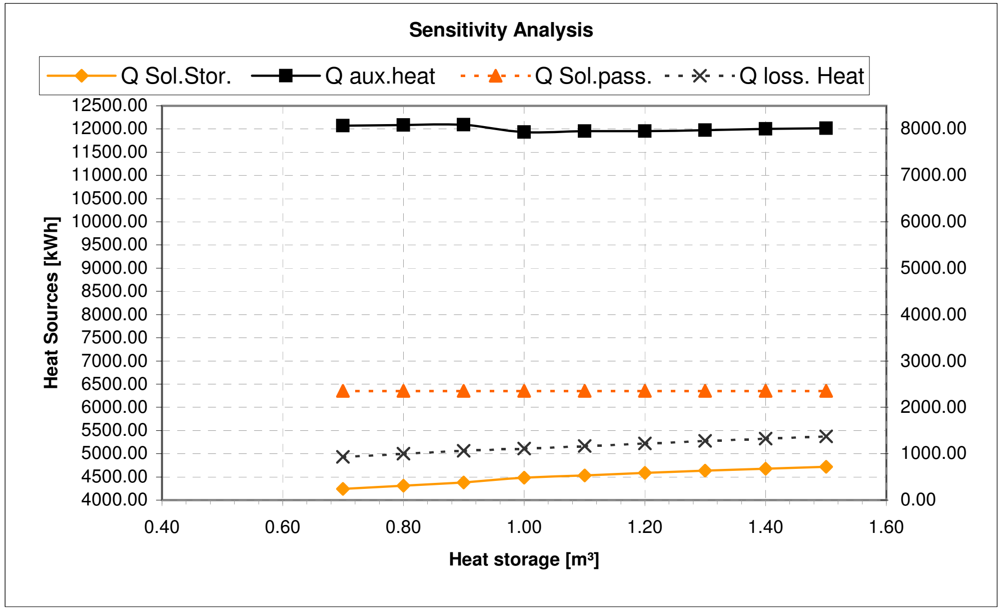
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consits of 2 storages, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45°C/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=75°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH I 2 storages**	**simulated:**	28.08.2009	**Azimuth:**	0°
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²	**Tilt:**	50°
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³		

	entire plant				**Heat sources**			**Heat sinks**				**Cov. ratio**		**SCR**	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
0.70	19.31	40.21	21.55	276.89	4242.00	12069.00	2356.40	2964.10	12045.40	934.60	15944.10	100.00	99.57	53.01	10.98
0.80	19.29	40.21	21.92	281.59	4313.90	12087.00	2356.40	2964.10	12045.40	1003.20	16012.70	100.00	99.72	53.22	10.92
0.90	19.32	40.28	22.26	285.99	4381.40	12096.00	2356.40	2964.10	12045.40	1065.10	16074.60	100.00	99.86	53.39	10.93
1.00	19.84	40.35	22.77	292.70	4484.10	11935.50	2356.40	2964.10	12045.40	1109.30	16118.80	100.00	99.01	53.70	11.43
1.10	19.76	40.36	23.03	296.02	4535.10	11955.00	2356.40	2964.10	12045.40	1166.90	16176.40	100.00	99.08	53.50	11.37
1.20	19.77	40.36	23.30	299.46	4587.70	11955.00	2356.40	2964.10	12045.40	1220.90	16230.40	100.00	99.10	53.84	11.31
1.30	19.66	40.34	23.54	302.37	4632.30	11977.50	2356.40	2964.10	12045.40	1275.70	16285.20	100.00	99.16	53.67	11.22
1.40	19.59	40.35	23.77	305.37	4678.20	12003.00	2356.40	2964.10	12045.40	1326.80	16336.30	100.00	99.31	53.70	11.13
1.50	19.53	40.33	23.98	308.00	4718.60	12016.50	2356.40	2964.10	12045.40	1376.10	16385.60	100.00	99.37	53.93	11.02



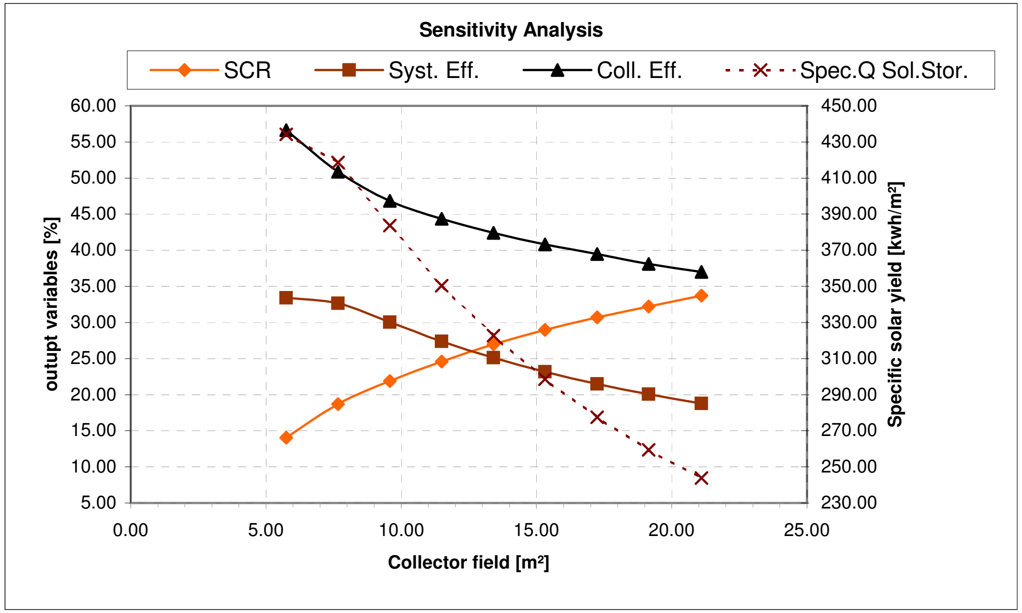


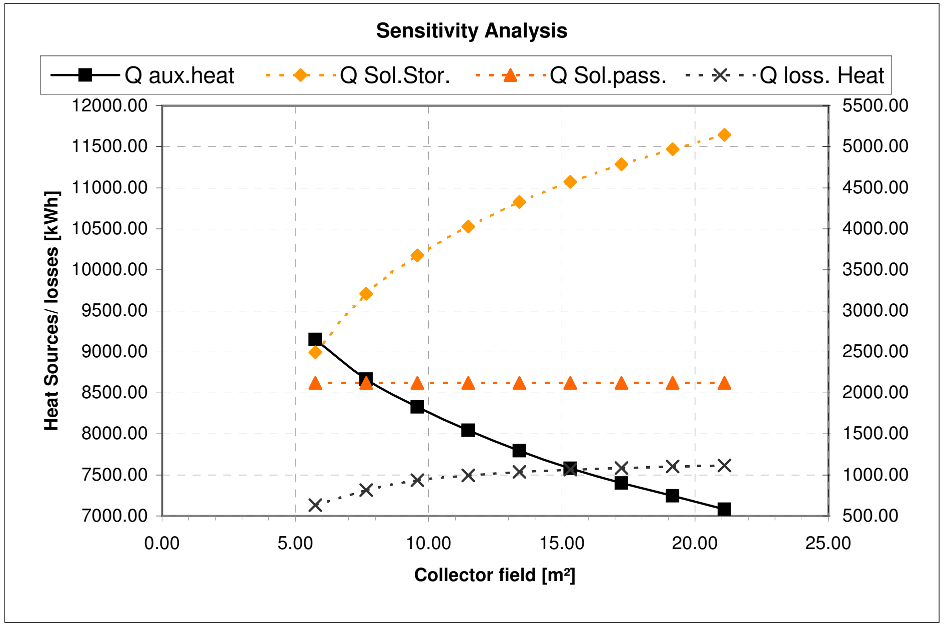
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net Collector field area**. The solar Combisystem consists of 2 storages, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45°C/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=67°C. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II 2 storages**	**simulated:**	25.01.2010	**Azimuth:**	0°
Collector:	Tehnomont SKT-40	**Field:**	5.75 - 21.1 m²	**Tilt:**	50°
Climate data set:	Rijeka.dat	**storage:**	1.000 m³		

	entire plant				**Heat sources**			**Heat sinks**				**Cov.ratio**		**SCR**	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
5.75	14.05	56.62	33.43	434.19	2496.60	9151.20	2123.10	2964.10	7823.80	630.80	11418.70	99.99	98.20	35.25	5.87
7.66	18.69	50.87	32.64	418.63	3206.70	8666.40	2123.10	2964.10	7823.80	816.60	11604.50	100.00	98.34	43.18	9.25
9.58	21.89	46.84	30.03	383.76	3676.40	8329.20	2123.10	2964.10	7823.80	937.10	11725.00	100.00	98.41	48.69	11.58
11.49	24.58	44.35	27.36	350.37	4025.70	8043.60	2123.10	2964.10	7823.80	996.70	11784.60	100.00	98.43	52.98	13.64
13.41	26.97	42.42	25.12	322.66	4326.90	7794.00	2123.10	2964.10	7823.80	1036.10	11824.00	100.00	98.53	56.33	15.69
15.32	28.98	40.82	23.18	298.59	4574.40	7580.40	2123.10	2964.10	7823.80	1064.40	11852.30	100.00	98.53	58.93	17.46
17.24	30.70	39.47	21.49	277.58	4785.50	7402.80	2123.10	2964.10	7823.80	1083.80	11871.70	100.00	98.65	61.34	18.93
19.15	32.20	38.12	20.05	259.46	4968.70	7244.40	2123.10	2964.10	7823.80	1103.00	11890.90	100.00	98.68	63.39	20.22
21.10	33.70	36.99	18.80	243.81	5144.30	7083.60	2123.10	2964.10	7823.80	1115.70	11903.60	100.00	98.67	65.36	21.54



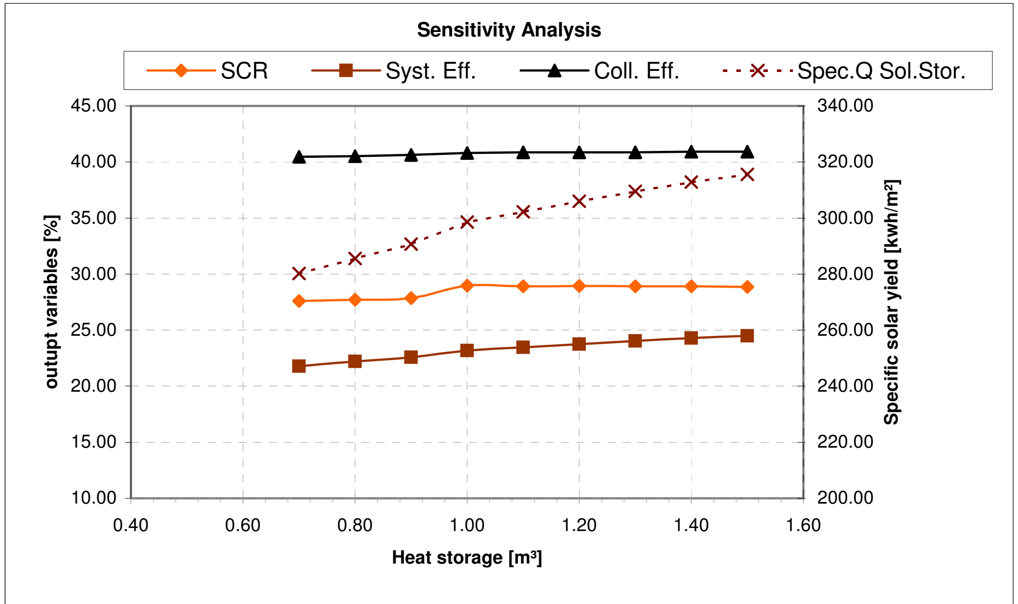


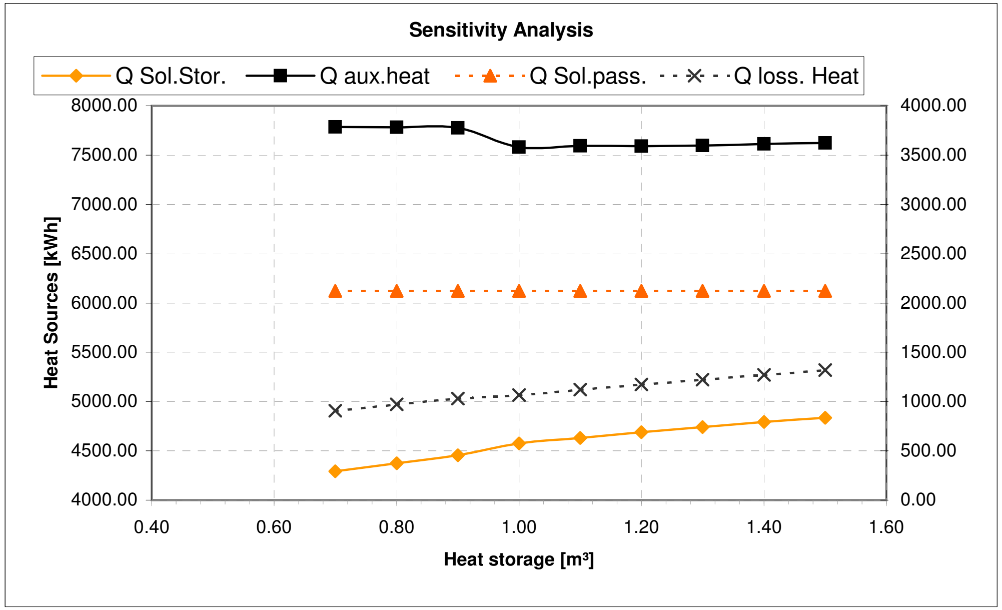
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consists of 2 storages, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45℃/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=67℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH II 2 storages**	**simulated:**	25.01.2010	**Azimuth:**	0°
Collector:	Tehnomont_SKT-40	**Field:**	15.32 m²	**Tilt:**	50°
Climate data set:	Rijeka.dat	**storage:**	0.7 - 1.5 m³		

	entire plant				**Heat sources**			**Heat sinks**				**Cov. ratio**		**SCR**	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
0.70	27.59	40.46	21.78	280.20	4292.70	7786.80	2123.10	2964.10	7823.80	906.80	11694.70	100.00	99.56	57.47	16.21
0.80	27.71	40.51	22.20	285.55	4374.70	7780.80	2123.10	2964.10	7823.80	970.20	11758.10	100.00	99.69	58.04	16.19
0.90	27.85	40.64	22.59	290.74	4454.10	7777.20	2123.10	2964.10	7823.80	1029.50	11817.40	100.00	99.89	58.15	16.36
1.00	28.98	40.82	23.18	298.59	4574.40	7580.40	2123.10	2964.10	7823.80	1064.40	11852.30	100.00	98.53	58.93	17.46
1.10	28.91	40.85	23.46	302.21	4629.90	7593.60	2123.10	2964.10	7823.80	1120.60	11908.50	100.00	98.65	59.06	17.34
1.20	28.95	40.87	23.76	306.05	4688.70	7591.20	2123.10	2964.10	7823.80	1172.10	11960.00	100.00	98.69	59.13	17.37
1.30	28.92	40.87	24.03	309.50	4741.60	7598.40	2123.10	2964.10	7823.80	1222.90	12010.80	100.00	98.76	58.96	17.40
1.40	28.91	40.93	24.29	312.86	4793.00	7612.80	2123.10	2964.10	7823.80	1271.50	12059.40	100.00	98.99	59.30	17.28
1.50	28.86	40.93	24.50	315.59	4834.80	7622.40	2123.10	2964.10	7823.80	1317.80	12105.70	100.00	99.07	59.60	17.11



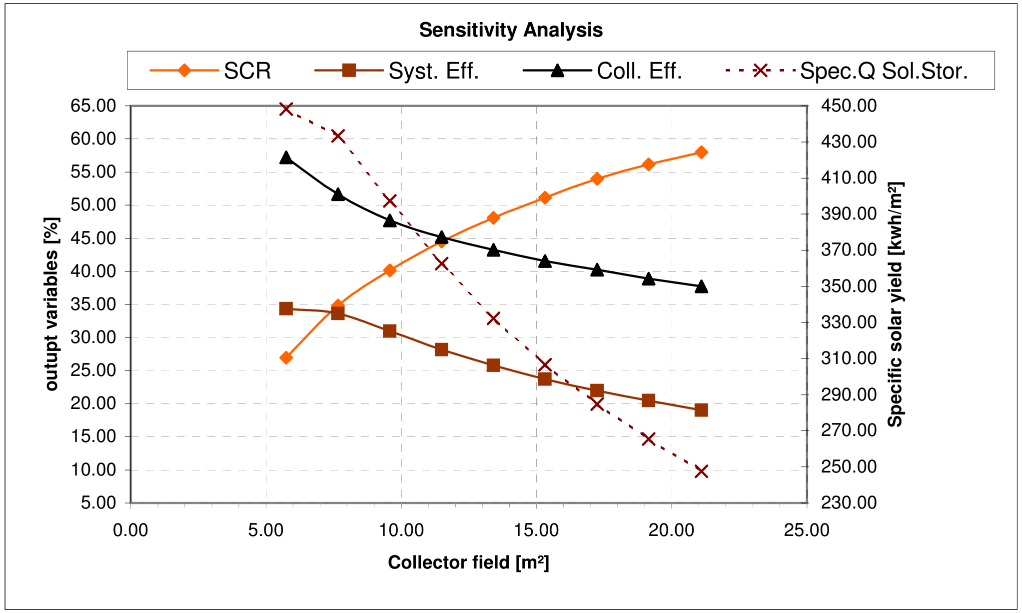


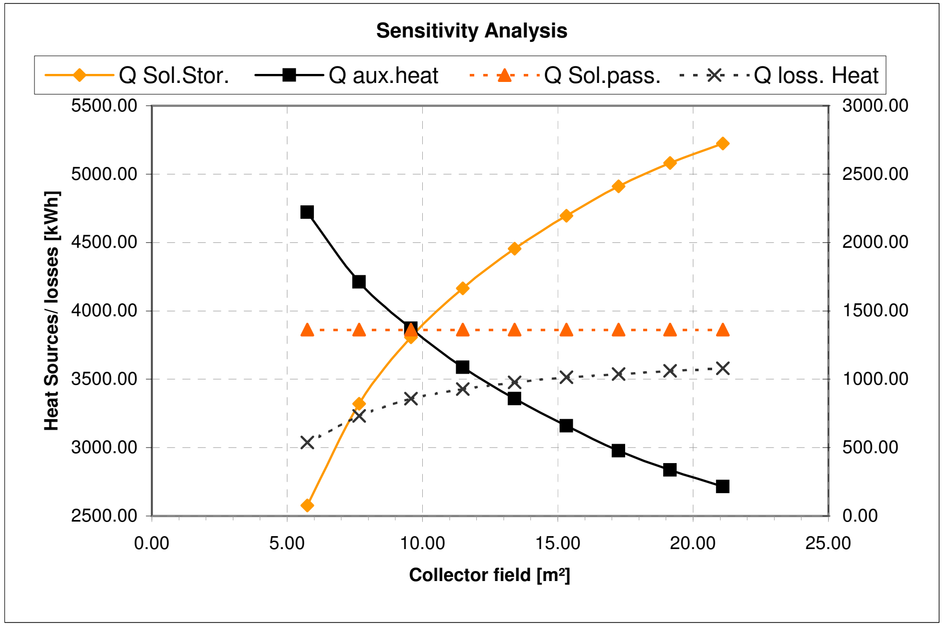
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net Collector field area**. The solar Combisystem consists of 2 storages, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45℃/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=50℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka SFH III 2 storages**	**simulated:**	27.01.2010	**Azimuth:**	0°
Collector:	Tehnomont SKT-40	**Field:**	5.75 - 21.1 m²	**Tilt:**	50°
Climate data set:	Rijeka.dat	**storage:**	1.000 m³		

	entire plant				Heat sources			Heat sinks				Cov.ratio		SCR	
Coll. field	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m²]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
5.75	26.94	57.24	34.37	448.26	2577.50	4721.50	1364.10	2964.10	3510.20	538.70	7013.00	99.97	99.69	45.14	11.53
7.66	34.85	51.66	33.64	433.37	3319.60	4211.90	1364.10	2964.10	3510.20	731.10	7205.40	99.99	99.75	54.86	17.92
9.58	40.13	47.68	30.96	397.43	3807.40	3871.70	1364.10	2964.10	3510.20	859.30	7333.60	99.99	99.80	61.05	22.43
11.49	44.51	45.19	28.18	362.52	4165.30	3587.50	1364.10	2964.10	3510.20	927.20	7401.50	100.00	99.73	65.67	26.59
13.41	48.06	43.23	25.77	332.25	4455.50	3358.60	1364.10	2964.10	3510.20	978.40	7452.70	99.99	99.76	69.05	30.29
15.32	51.12	41.57	23.72	306.54	4696.20	3159.80	1364.10	2964.10	3510.20	1014.20	7488.50	100.00	99.72	71.71	33.68
17.24	53.96	40.24	21.98	284.85	4910.90	2976.40	1364.10	2964.10	3510.20	1038.30	7512.60	99.99	99.75	74.29	36.76
19.15	56.15	38.90	20.45	265.39	5082.20	2835.70	1364.10	2964.10	3510.20	1062.40	7536.70	99.99	99.80	76.30	39.10
21.10	57.99	37.71	19.04	247.59	5224.10	2716.00	1364.10	2964.10	3510.20	1080.10	7554.40	99.99	99.77	78.08	41.00



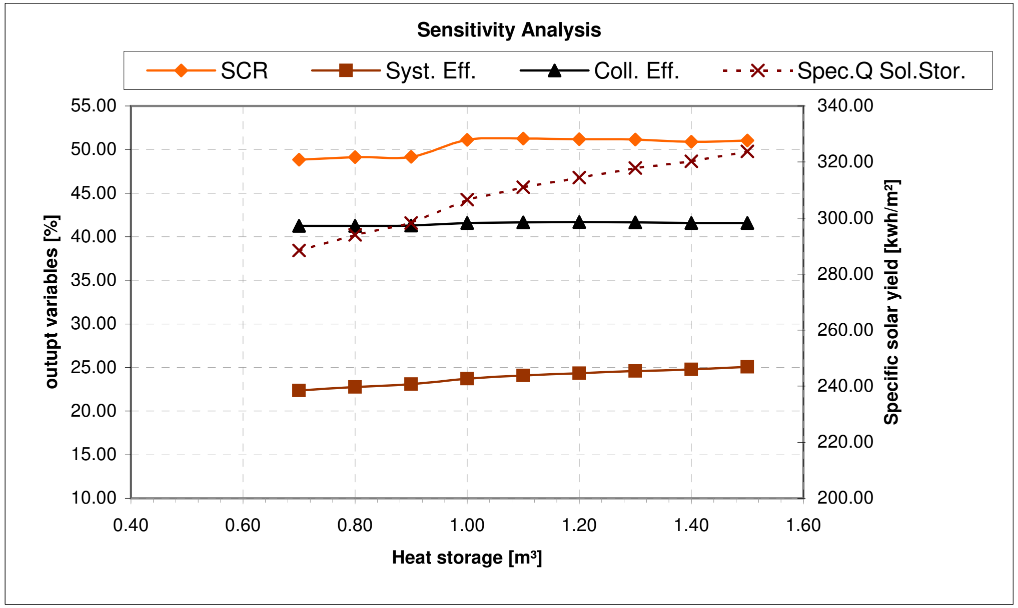


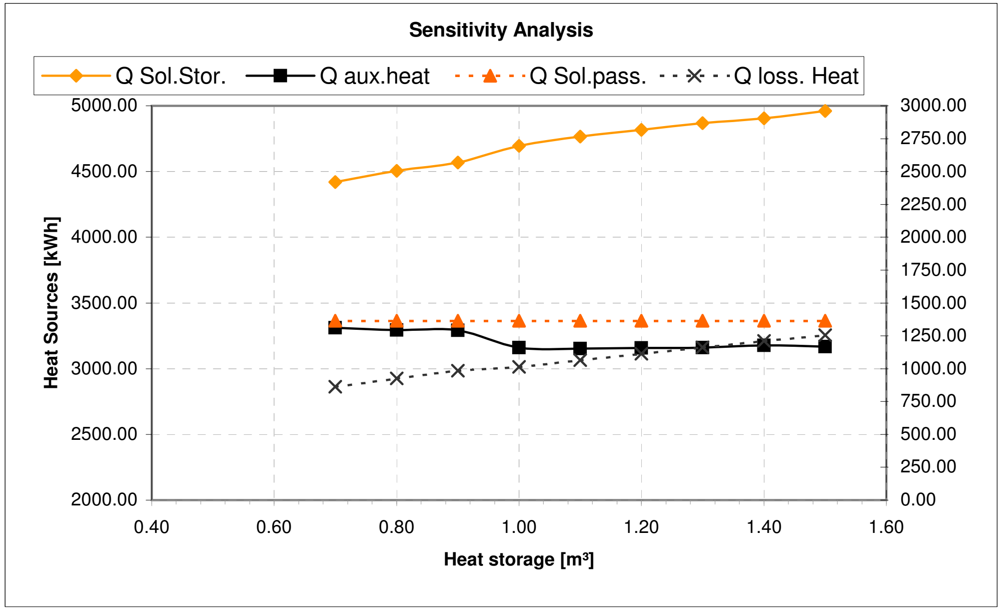
Sensitivity Analysis

Sensitivity Analysis, with respect to the **Heat storage size**. The solar Combisystem consists of 2 storage, the DHW-Storage has a volume of 250 litre - designed for 4 people (daily consumption: 45℃/ 200 litre). Auxiliary supply is provided via a boiler only in the Heat-Storage: Max. storage temp.=50℃. Dashed lines refer to the right scale axis.

Project : **Rijeka SFH III 2 storages** | **simulated:** 29.01.2010 | **Azimuth:** 0°
Collector: Tehnomont_SKT-40 | **Field:** 15.32 m² | **Tilt:** 50°
Climate data set: Rijeka.dat | **storage:** 0.7 - 1.5 m³

	entire plant				Heat sources			Heat sinks				Cov. ratio		SCR	
Heat storage	**SCR**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q Sol.pass.**	**Q DHW**	**Q SH**	**Q loss. Heat**	**total**	**DHW**	**heat**	**DHW**	**SH**
	DeckGr	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Pass+Sp	Warmwas	Heizung	HeiSpVerl		WW-Deckg	HZ-Deckg	DeckWa	DeckHei
[m³]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
0.70	48.85	41.23	22.35	288.47	4419.40	3311.00	1364.10	2964.10	3510.20	863.60	7337.90	100.00	99.96	69.51	31.39
0.80	49.13	41.26	22.78	294.01	4504.20	3293.50	1364.10	2964.10	3510.20	926.30	7400.60	100.00	99.99	70.01	31.49
0.90	49.17	41.29	23.11	298.28	4569.70	3290.70	1364.10	2964.10	3510.20	984.80	7459.10	99.99	100.00	70.12	31.48
1.00	51.12	41.57	23.72	306.54	4696.20	3159.80	1364.10	2964.10	3510.20	1014.20	7488.50	100.00	99.72	71.71	33.68
1.10	51.26	41.65	24.07	311.04	4765.10	3152.80	1364.10	2964.10	3510.20	1064.20	7538.50	99.99	99.86	71.95	33.77
1.20	51.19	41.68	24.33	314.46	4817.60	3158.40	1364.10	2964.10	3510.20	1113.30	7587.60	99.99	99.91	72.07	33.54
1.30	51.15	41.65	24.60	317.83	4869.10	3160.50	1364.10	2964.10	3510.20	1161.70	7636.00	100.00	99.89	72.03	33.51
1.40	50.89	41.56	24.79	320.23	4906.00	3177.30	1364.10	2964.10	3510.20	1211.70	7686.00	99.99	99.89	72.12	32.95
1.50	51.04	41.59	25.06	323.75	4959.80	3168.20	1364.10	2964.10	3510.20	1255.00	7729.30	100.00	99.90	72.42	32.97





Appendix F

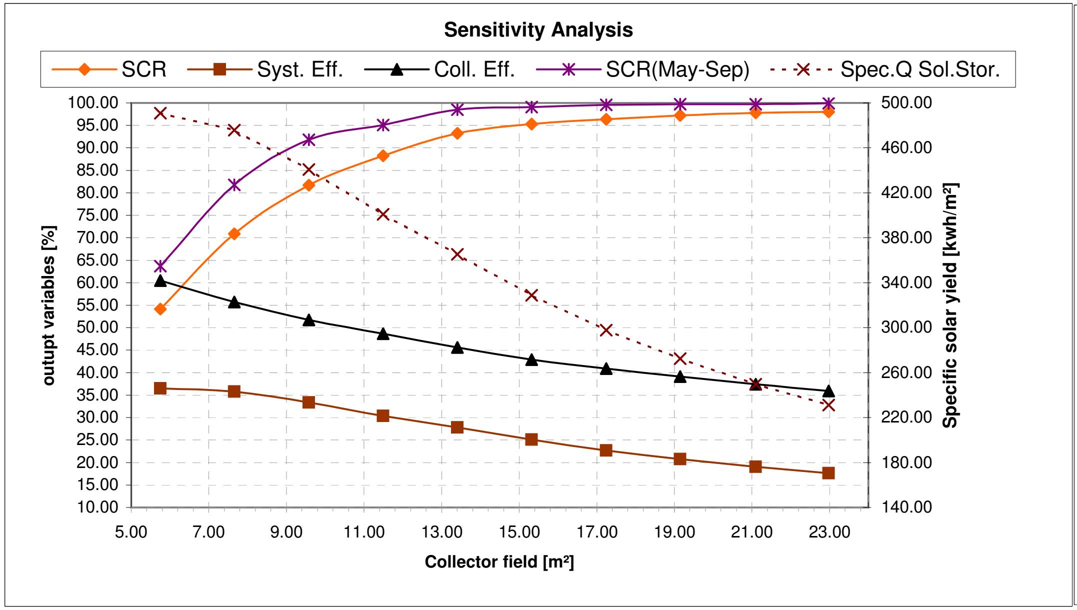
SA Tourist DHW One Storage

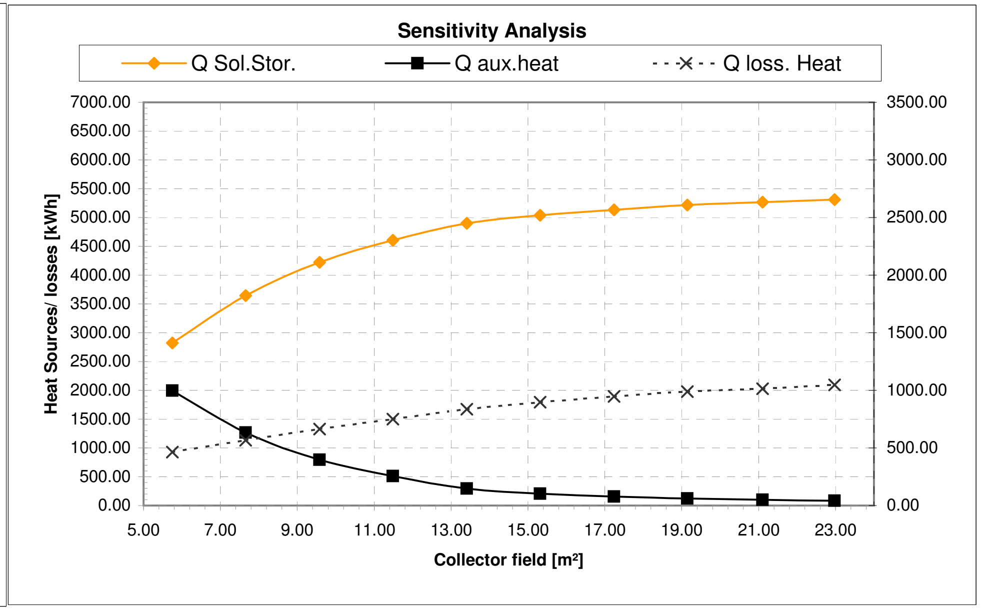
Sensitivity Analysis

Sensitivity Analysis, with respect to the **net collector field**. The solar system consists of 1 storage. Heat provision for DHW for a small size tourist accomodation (FU_F(S)=0.25), where 4 additional people (staff or owners) were taken into account. demand: nominal summer consumption DHW 60℃/(160 +160) litre is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=65℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC Small**	**simulated:**	30.09.2009	
Collector:	Tehnomont_SKT-40	**Field:**	5.75 - 22.98	m²
Climate data set:	Rijeka.dat	**storage:**	.800	m³

	entire plant					Heat sources		Heat sinks			Cov.ratio	
Coll. field	**SCR**	**SCR**$_{(May\text{-}Sep)}$	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q rem. DHW**	**Q loss. Heat**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	WaSp+Zi	HeiSpVerl		WW-Deckg	WEntTmin
[m²]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
5.75	54.13	63.72	60.51	36.50	490.99	2823.20	1995.00	4349.70	464.20	4813.90	99.93	57.92
7.66	70.89	81.76	55.72	35.76	475.84	3644.90	1266.00	4350.30	567.20	4917.50	99.94	51.03
9.58	81.71	91.79	51.75	33.33	440.84	4223.20	795.00	4350.60	663.70	5014.30	99.95	40.86
11.49	88.27	95.05	48.63	30.39	400.77	4604.90	510.00	4350.10	749.30	5099.40	99.94	37.80
13.41	93.24	98.52	45.58	27.79	365.40	4900.00	294.00	4349.70	836.60	5186.30	99.93	53.65
15.32	95.31	99.09	42.86	25.06	328.75	5036.40	204.00	4349.30	898.50	5247.80	99.92	56.74
17.24	96.38	99.54	40.93	22.69	297.82	5134.40	157.50	4349.00	946.90	5295.90	99.92	58.22
19.15	97.21	99.68	39.09	20.75	272.43	5217.10	121.50	4348.70	989.80	5338.50	99.91	59.90
21.10	97.76	99.73	37.43	19.01	249.64	5267.50	97.50	4348.70	1014.10	5362.80	99.91	59.90
22.98	98.03	99.95	35.95	17.59	231.11	5310.90	85.50	4348.60	1047.50	5396.10	99.91	58.89



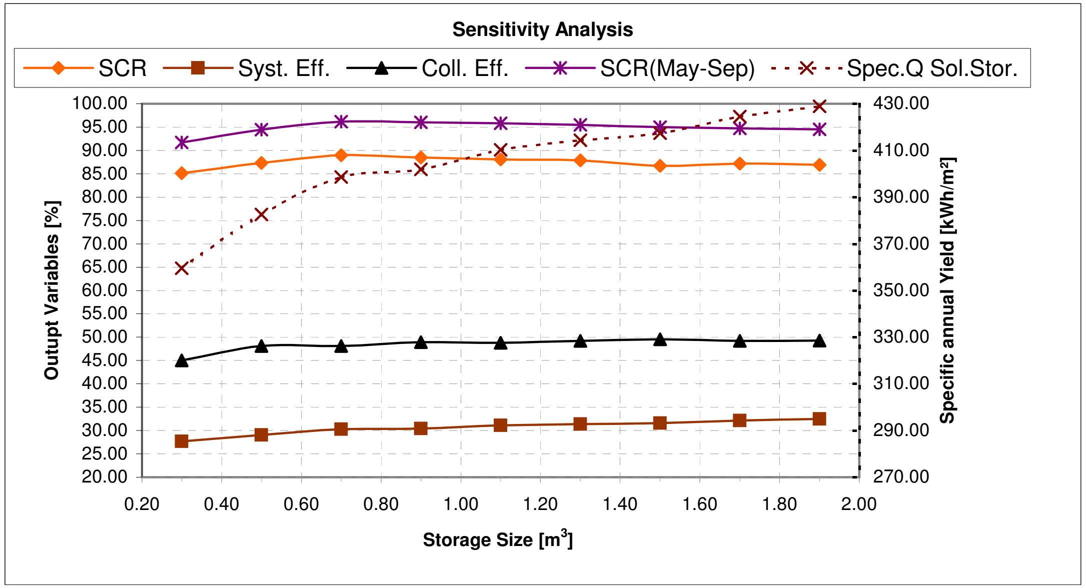


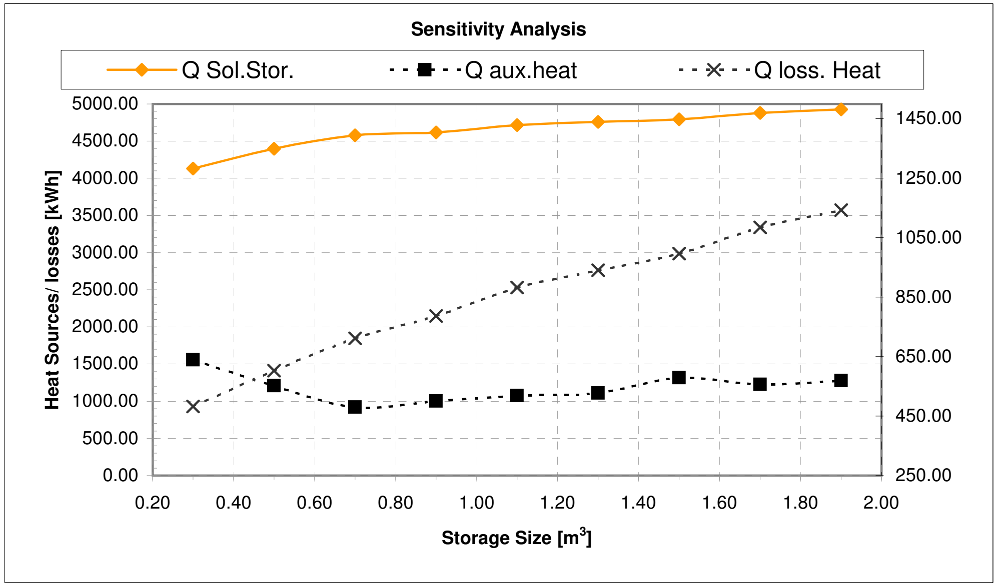
Sensitivity Analysis

Sensitivity Analysis, with respect to the **heat storage size**. The solar system consists of 1 storage. Heat provision for DHW for a small size tourist accomodation, where 4 additional people (staff or owners) were taken into account. demand: nominal summer consumption DHW 60℃/(160+160) litre is provided via a continuous flow heat exchanger. For second auxiliary supply: Max. storage temp.=65℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC Small**	**simulated:**	30.09.2009	
Collector:	Tehnomont_SKT-40	**Field:**	11.490	m²
Climate data set:	Rijeka.dat	**storage:**	0.3 - 1.9	m³

Heat storage	**entire plant**					**Heat sources**		**Heat sinks**			**Cov.ratio**	
	SCR	**SCR** *(May-Sep)*	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q DHW**	**Q loss. Heat**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Kessel	Warmwas	HeiSpVerl		WW-Deckg	WEntTmin
[m³]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
0.30	85.10	91.69	45.01	27.66	359.57	4131.50	639.00	4352.70	482.30	4835.00	99.91	37.87
0.50	87.29	94.44	48.08	29.06	382.59	4396.00	552.00	4352.70	602.70	4955.40	99.95	44.98
0.70	88.96	96.16	48.10	30.29	398.59	4579.80	480.00	4352.70	711.90	5064.60	99.94	49.59
0.90	88.48	96.05	48.96	30.43	401.85	4617.20	501.00	4352.70	786.90	5139.60	99.94	46.07
1.10	88.07	95.81	48.79	31.11	410.26	4713.90	519.00	4352.70	882.30	5235.00	99.95	55.65
1.30	87.86	95.50	49.22	31.37	414.37	4761.10	528.00	4352.70	940.20	5292.90	99.94	58.81
1.50	86.69	94.96	49.57	31.56	417.37	4795.60	579.00	4352.70	996.90	5349.60	99.95	53.95
1.70	87.21	94.73	49.21	32.14	424.53	4877.80	556.50	4352.70	1084.60	5437.30	99.95	58.70
1.90	86.90	94.49	49.24	32.47	428.87	4927.70	570.00	4352.70	1142.60	5495.30	99.95	58.36





Appendix G

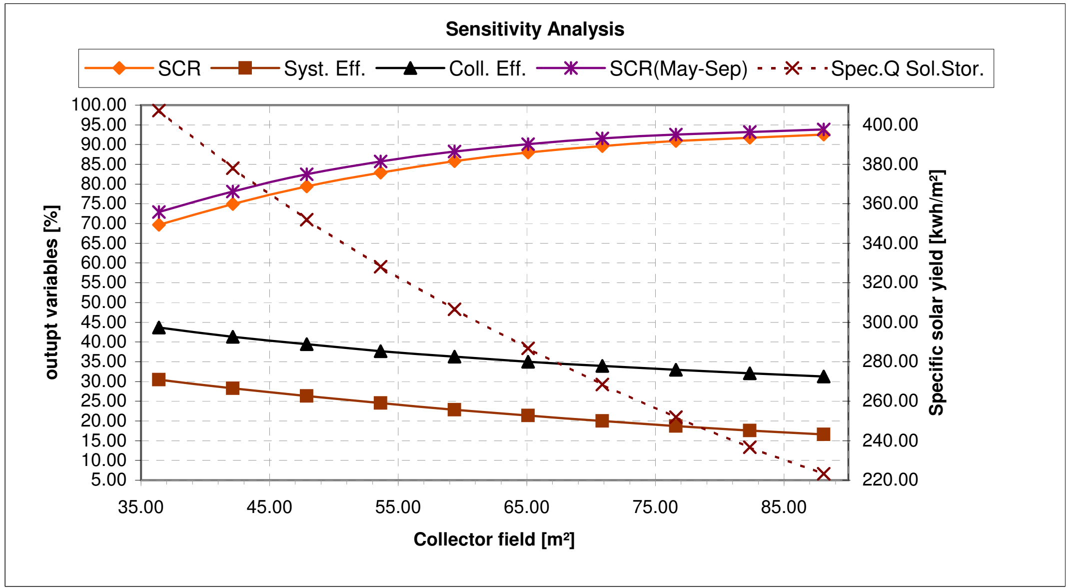
SA Tourist DHW Two-Storage

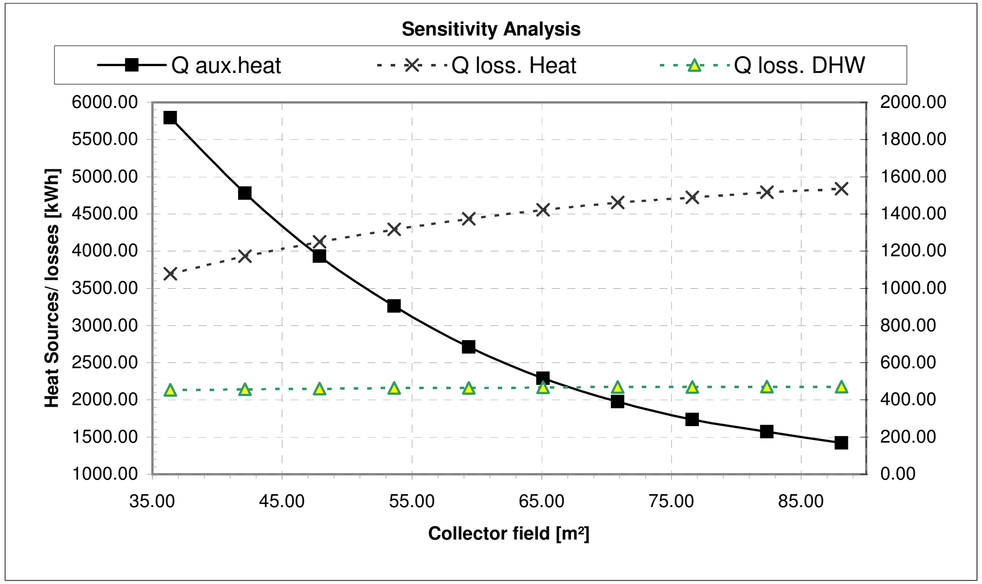
Sensitivity Analysis

Sensitivity Analysis, with respect to the net collector field. The solar system consists of 2 storage and should provide heat for DHW for a medium size tourist accomodation (FU_F(S) = 0.41). The nominal summer demand of DHW 60℃/1640 litre is provided via a separate small DHW storage. Auxiliary supply is provided by an immersion heater: Max. storage temp.=60℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC Medium**	**simulated:**	02.10.2009	
Collector:	Tehnomont_SKT-40	**Field:**	36.39 - 88.09	m²
Climate data set:	Rijeka.dat	**storage:**	3.936	m³

	entire plant					Heat sources		Heat sinks	and Storage losses			Cov.ratio	
Coll. field	**SCR**	**SCR** *(May-Sep)*	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q DHW**	**Q loss. Heat**	**Q loss. DHW**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Elektr	Warmwas	HeiSpVerl	WaSpVerl		WW-Deckg	WEntTmin
[m²]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
36.39	69.67	72.95	43.67	30.45	407.20	14817.90	5792.00	19099.30	1078.90	453.60	20178.20	99.97	58.00
42.13	74.96	78.12	41.35	28.27	378.07	15927.90	4781.00	19099.30	1173.40	458.10	20272.70	99.98	57.45
47.88	79.40	82.46	39.42	26.30	351.99	16853.40	3934.00	19099.30	1250.60	461.10	20349.90	99.98	58.02
53.62	82.93	85.71	37.68	24.50	328.15	17595.20	3260.00	19099.30	1317.00	463.60	20416.30	99.98	58.02
59.37	85.81	88.25	36.27	22.87	306.56	18200.70	2709.00	19099.30	1373.40	464.90	20472.70	99.96	58.01
65.11	88.01	90.14	35.01	21.37	286.81	18673.90	2290.00	19099.30	1422.50	467.20	20521.80	99.98	58.01
70.86	89.65	91.53	33.92	19.99	268.50	19026.10	1977.00	19099.30	1460.90	468.80	20560.20	99.98	58.01
76.60	90.90	92.51	32.99	18.73	251.88	19293.80	1737.00	19099.30	1488.60	469.70	20587.90	99.97	58.03
82.35	91.77	93.20	32.04	17.58	236.66	19488.60	1572.00	19099.30	1516.00	471.40	20615.30	99.98	58.00
88.09	92.55	93.83	31.24	16.56	223.16	19658.40	1422.00	19099.30	1536.10	472.00	20635.40	99.98	58.01



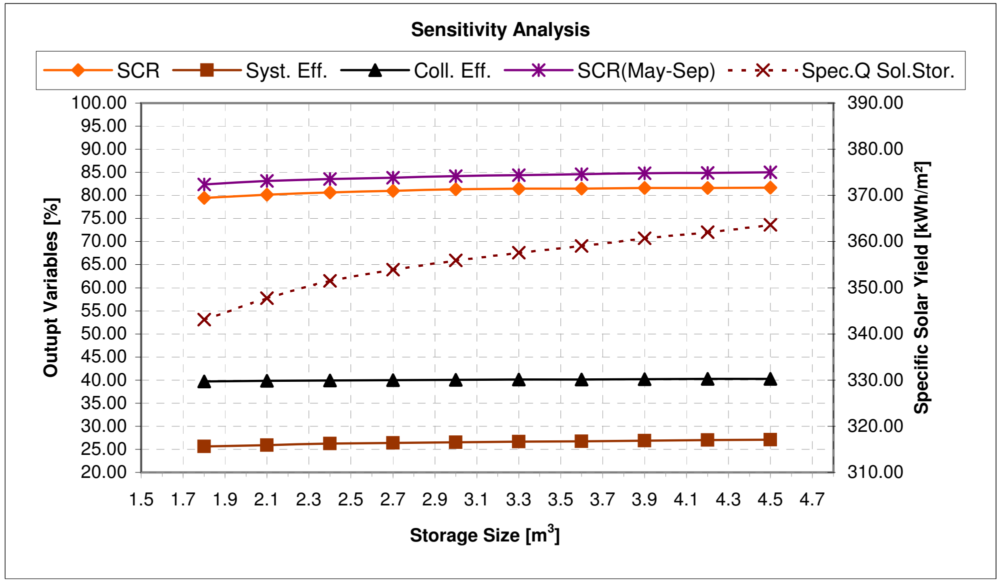


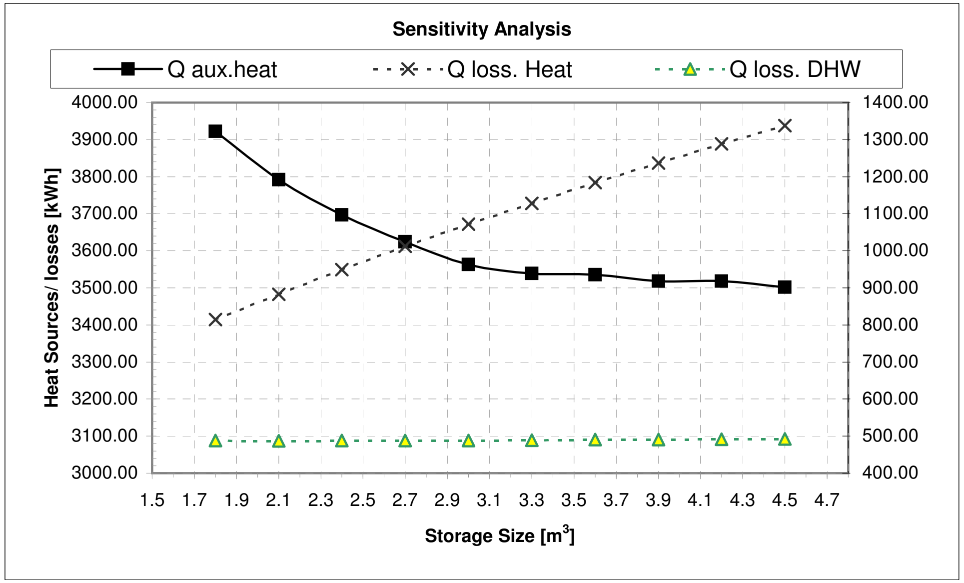
Sensitivity Analysis

Sensitivity Analysis, with respect to the heat storage size. The solar system consists of 2 storage and should provide heat for DHW for a medium size tourist accomodation (FU_F(S) = 0.41). The nominal summer demand of DHW 60℃/1640 litre is provided via a separate small DHW storage. Solar control operates in a matched flow mode ΔT collector - storage= 6K. Auxiliary supply is provided by an immersion heater: Max. storage temp.=60℃. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC Medium**	**simulated:**	02.10.2009
Collector:	Tehnomont_SKT-40	**Field:**	47.880 m²
Climate data set:	Rijeka.dat	**storage:**	1.8 - 4.5 m³

	entire plant					Heat sources		Heat sinks	and Storage losses			Cov.ratio	
Heat storage	**SCR**	**SCR$_{(May-Sep)}$**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.heat**	**Q DHW**	**Q loss. Heat**	**Q loss. DHW**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Elektr	Warmwas	HeiSpVerl	WaSpVerl		WW-Deckg	WEntTmin
[m³]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
1.8	79.46	82.41	39.70	25.60	343.06	16425.80	3922.00	19099.30	814.10	488.40	20401.80	99.99	57.82
2.1	80.14	83.13	39.85	25.93	347.72	16648.80	3792.00	19099.30	883.10	487.40	20469.80	99.99	58.00
2.4	80.64	83.52	39.91	26.21	351.49	16829.50	3697.00	19099.30	949.10	487.80	20536.20	99.99	58.01
2.7	81.02	83.86	39.98	26.39	353.91	16945.00	3624.00	19099.30	1012.20	488.40	20599.90	100.00	58.06
3.0	81.34	84.15	40.04	26.54	355.95	17042.80	3563.00	19099.30	1071.90	487.80	20659.00	99.99	58.01
3.3	81.47	84.38	40.12	26.66	357.63	17123.40	3539.00	19099.30	1128.30	488.80	20716.40	99.99	58.00
3.6	81.49	84.60	40.15	26.76	359.05	17191.10	3535.00	19099.30	1183.70	490.70	20773.70	99.99	58.01
3.9	81.58	84.78	40.18	26.88	360.70	17270.10	3518.00	19099.30	1236.80	490.90	20827.00	99.99	58.01
4.2	81.58	84.84	40.23	26.98	362.01	17333.00	3518.00	19099.30	1288.80	491.40	20879.50	99.99	58.00
4.5	81.66	84.99	40.29	27.09	363.60	17409.20	3502.00	19099.30	1338.00	492.10	20929.40	99.99	58.00



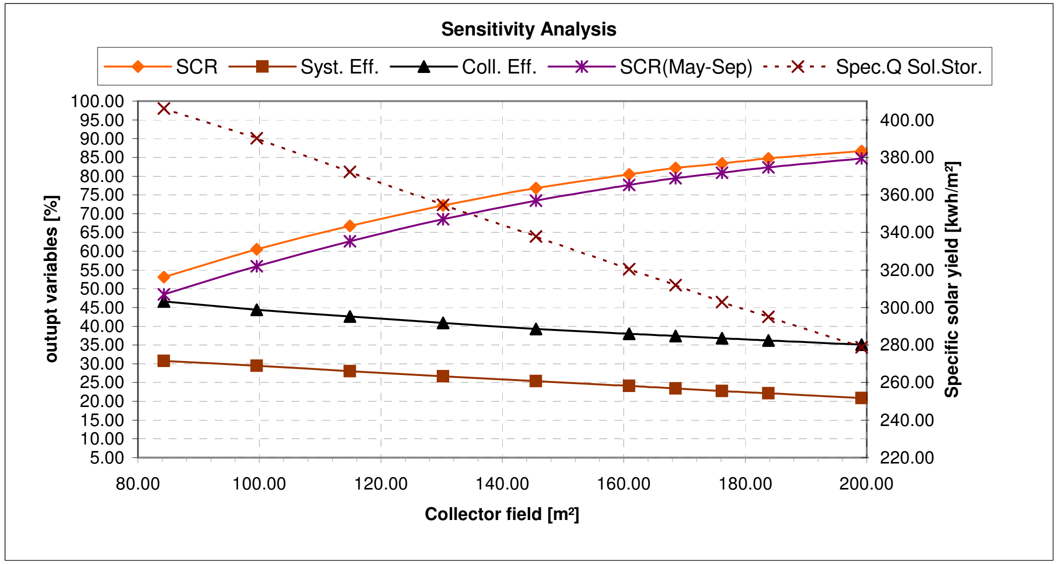


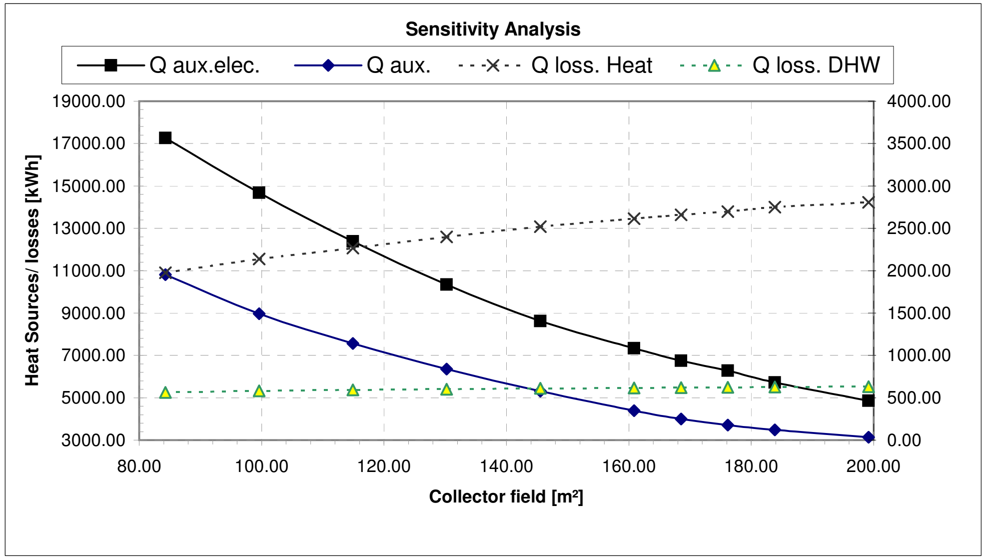
Sensitivity Analysis

Sensitivity Analysis, with respect to the net collector field. The solar system consits of 2 storage and should provide heat for DHW for a large size tourist accomodation (FU_F(S) = 0.94). The nominal summer demand of DHW 60℃/5640 litre is provided via a separate small DHW storage with an auxiliary electrical immersion heater: Max. storage temp.=60℃. Besides the heat storage incorporates a second auxiliary supply from a boiler. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC L**	**simulated:**	12.10.2009		
Collector:	**Tehnomont_SKT-40**	**Field:**	84.26 - 199.16 m²	**Azimuth:**	0°
Climate data set:	Rijeka.dat	**storage:**	10.000 m³	**Tilt:**	45°

	entire plant					Heat sources			Heat sinks	and Storage losses				Cov.ratio	
Coll. field	**SCR**	**SCR**$_{(May-Sep)}$	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.elec.**	**Q aux.**	**Q DHW**	**DHW circ.**	**Q loss. Heat**	**Q loss. DHW**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Elektr	Kessel		Wa-Zir	HeiSpVerl	WaSpVerl		WW-Deckg	WEntTmin
[m²]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
84.26	53.09	48.48	46.60	30.74	406.00	34209.80	17256.00	10810.00	55504.98	4322.82	1976.20	562.90	62366.90	99.13	44.98
99.58	60.51	56.00	44.40	29.48	390.18	38854.60	14679.00	8970.00	55560.88	4322.82	2137.30	580.10	62601.10	99.23	45.49
114.90	66.73	62.66	42.60	28.06	372.22	42768.60	12377.00	7570.00	55626.78	4322.82	2265.00	592.40	62807.00	99.34	47.45
130.22	72.16	68.49	40.91	26.70	354.75	46195.60	10350.00	6360.00	55688.48	4322.82	2397.20	601.70	63010.20	99.45	47.10
145.54	76.81	73.52	39.32	25.40	337.77	49159.30	8619.00	5310.00	55739.88	4322.82	2519.00	610.60	63192.30	99.54	47.01
160.86	80.49	77.62	38.02	24.06	320.45	51547.60	7335.00	4390.00	55784.08	4322.82	2612.30	617.20	63336.40	99.62	48.56
168.52	82.15	79.48	37.38	23.42	312.01	52579.60	6744.00	3990.00	55804.78	4322.82	2657.70	620.40	63405.70	99.66	50.18
176.18	83.38	80.86	36.81	22.72	302.89	53363.90	6284.00	3710.00	55807.68	4322.82	2695.30	622.90	63448.70	99.67	45.35
183.84	84.71	82.38	36.23	22.12	295.03	54237.70	5719.00	3480.00	55828.68	4322.82	2748.60	626.20	63526.30	99.70	45.21
199.16	86.72	84.71	35.13	20.89	278.92	55549.90	4858.00	3130.00	55847.68	4322.82	2806.40	629.70	63606.60	99.74	46.87



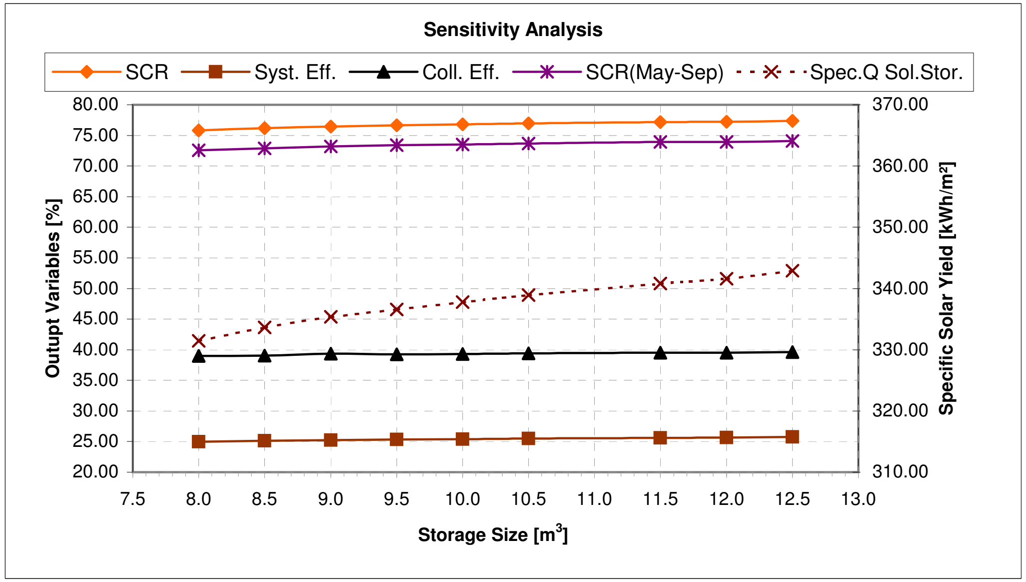


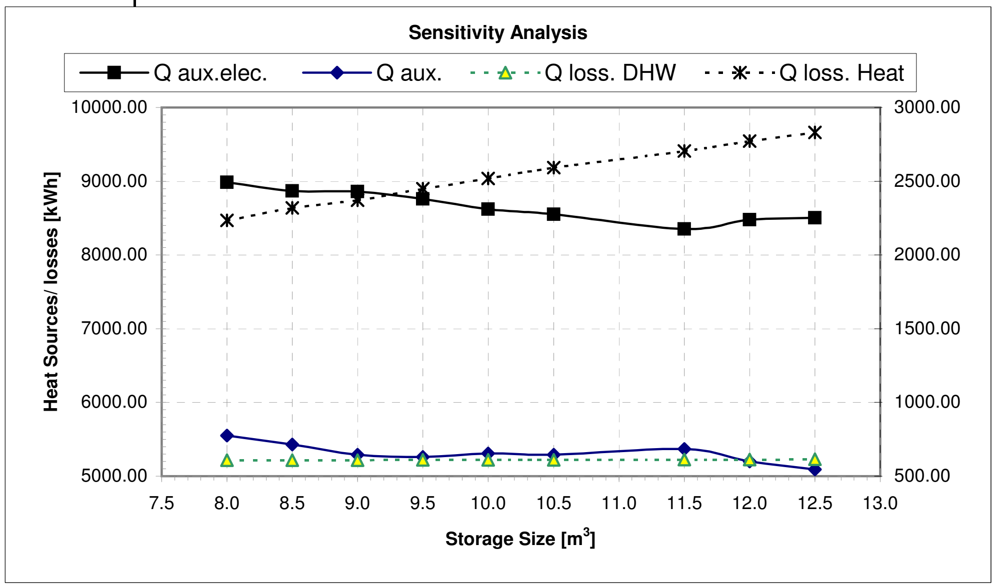
Sensitivity Analysis

Sensitivity Analysis, with respect to the heat storage size. The solar system consists of 2 storage and should provide heat for DHW for a large size tourist accomodation (FU_F(S) = 0.94). The nominal summer demand of DHW 60℃/5640 litre is provided via a separate small DHW storage with an auxiliary electrical immersion heater: Max. storage temp.=60℃. Besides the heat storage incorporates a second auxiliary supply from a boiler. Dashed lines refer to the right scale axis.

Project :	**Rijeka ACC L**	**simulated:**	12.10.2009	**Azimuth:**	0°
Collector:	Tehnomont_SKT-40	**Field:**	145.540 m²	**Tilt:**	45°
Climate data set:	Rijeka.dat	**storage:**	8 - 12.5 m³		

	entire plant					Heat sources			Heat sinks		and Storage losses			Cov.ratio	
Heat storage	**SCR**	**SCR$_{(May-Sep)}$**	**Coll. Eff.**	**Syst. Eff.**	**Spec.Q Sol.Stor.**	**Q Sol.Stor.**	**Q aux.elec.**	**Q aux.**	**Q DHW**	**DHW circ.**	**Q loss. Heat**	**Q loss. DHW**	**total**	**DHW**	**Tmin**
	DeckGr	DeckGr(S)	KolWiGr	KolNuGr	spez. Ertrag	SolSpei	Elektr	Kessel		Wa-Zir	HeiSpVerl	WaSpVerl		WW-Deckg	WEntTmin
[m³]	[%]	[%]	[%]	[%]	[kwh/m²]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[oC]
8.0	75.79	72.56	38.99	24.95	331.43	48235.90	8985.00	5550.00	55726.38	4322.82	2234.20	607.40	62890.80	99.52	48.05
8.5	76.19	72.90	39.06	25.11	333.65	48559.90	8870.00	5430.00	55732.08	4322.82	2319.40	608.80	62983.10	99.53	46.22
9.0	76.44	73.19	39.36	25.22	335.38	48811.50	8858.00	5290.00	55726.18	4322.82	2371.40	608.30	63028.70	99.52	46.65
9.5	76.66	73.41	39.26	25.32	336.60	48988.70	8758.00	5260.00	55729.78	4322.82	2448.80	609.50	63110.90	99.53	48.13
10.0	76.81	73.52	39.32	25.40	337.77	49159.30	8619.00	5310.00	55739.88	4322.82	2519.00	610.60	63192.30	99.54	47.01
10.5	76.96	73.65	39.42	25.48	338.95	49330.30	8550.00	5290.00	55739.28	4322.82	2591.70	611.20	63265.00	99.54	47.57
11.5	77.16	73.91	39.51	25.61	340.83	49604.40	8353.00	5370.00	55772.28	4322.82	2705.60	612.50	63413.20	99.60	47.73
12.0	77.25	73.93	39.53	25.67	341.61	49717.30	8479.00	5200.00	55793.68	4322.82	2772.20	613.40	63502.10	99.64	45.48
12.5	77.39	74.10	39.61	25.77	342.92	49908.60	8504.00	5090.00	55798.48	4322.82	2831.30	614.10	63566.70	99.65	48.12





Appendix H

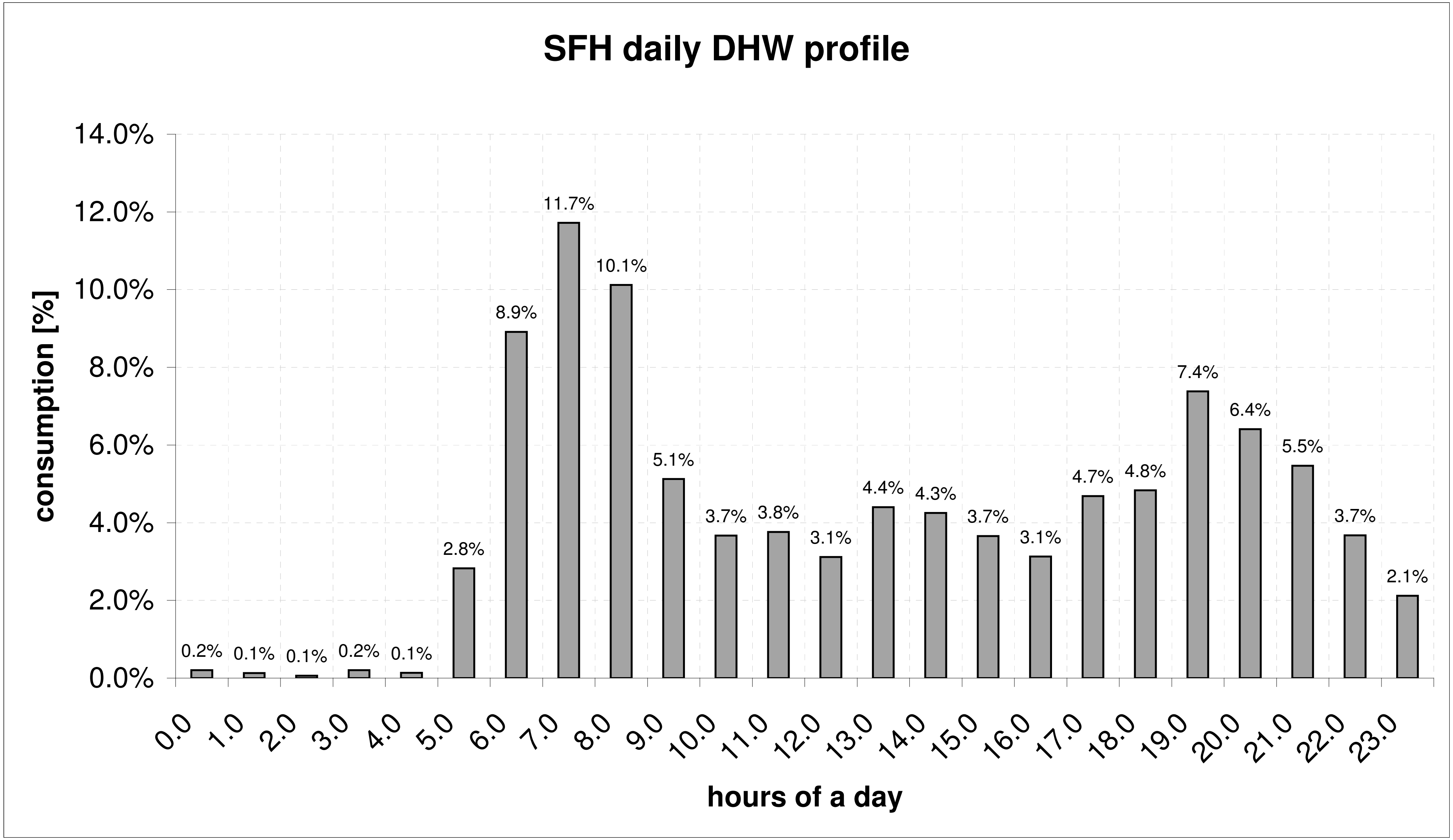
Properties of Materials

Table H.1: Properties of air, water and 60% water / 40% propylenglycol (VDI-Wärmeatlas, 1991) [28]

(alle phys. Stoffwerte bei 1 bar)	Luft	Wasser	60% Wasser, 40% Propylenglykol
spez. Wärmekap. c_p (50°C) [J/kgK]	1020	4171	3810
Dichte ρ (50°C) [kg/m^3]	1,1	988	1021
Dyn. Viskosität η (50°C) [10^{-6} Pas]	19,3	547	1850
Wärmeleitfähigk. λ (50°C) [W/mK]	0,028	0,64	0,421
Gefrierpunkt [°C]	-	0	-25,3
lebensmittelecht	ja	ja	ja
langzeit-/temperaturbeständig	ja	ja	ja (unter 130°C)
brennbar	nein	nein	nein
korrosionshemmend	ja	ja (mit Inhibitoren)	
Preis	gratis	billig	etwas teurer
umweltschonend	ja	ja	ja (Wassergefährdungsklasse 0)

Appendix I

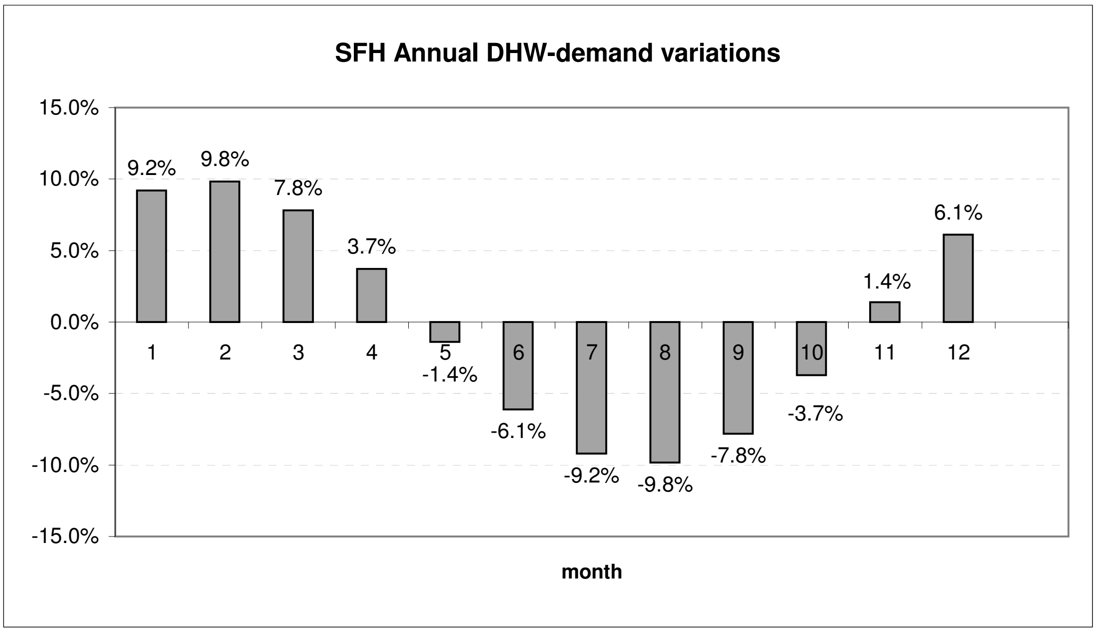
Demand Profiles

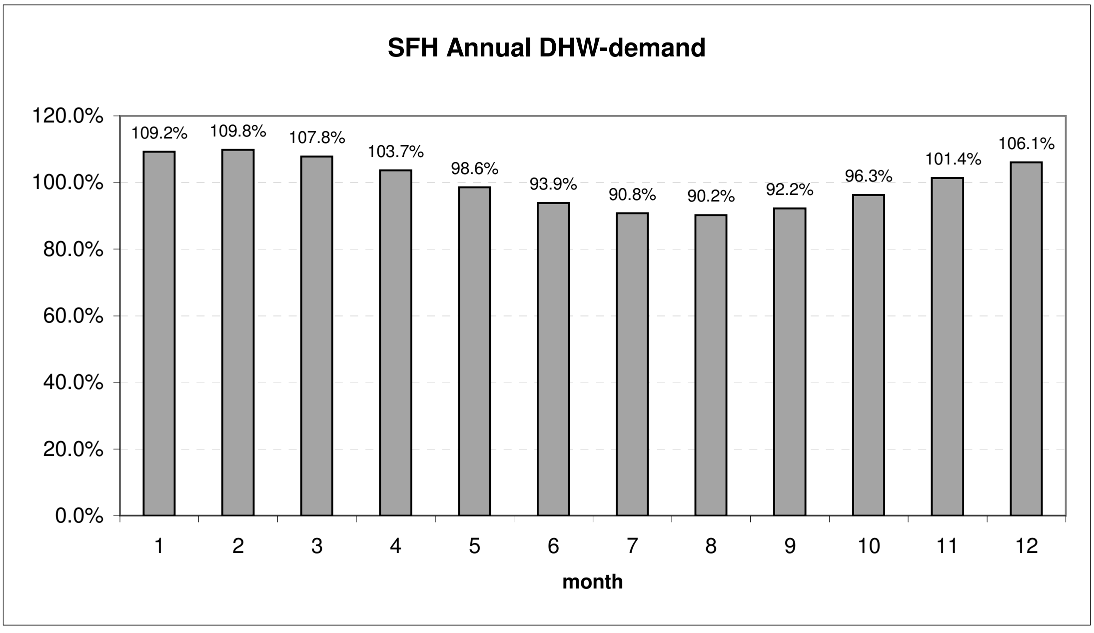

SFH daily DHW profile
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
consumption [%]
0.2%
0.1%
0.1%
0.2%
0.1%
2.8%
8.9%
11.7%
10.1%
5.1%
3.7%
3.8%
3.1%
4.4%
4.3%
3.7%
3.1%
4.7%
4.8%
7.4%
6.4%
5.5%
3.7%
2.1%
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
hours of a day

Modelling annual DHW-demand varations because of less consumption and ground water temperature variations.
Holidays have not been taken into account.

T=365 Sin - max 45. day
Cos - max 30. day

month	t	**f**(*t*)=0.5*Sin((*t+46.25)*2*Pi/T*) +0.5*COS((*t-30)*2*Pi/365*)	var 0.1*f(*t*)	annual demand var*0.1+1
1	15.21	0.92	9.2%	109.2%
2	45.62	0.98	9.8%	109.8%
3	76.04	0.78	7.8%	107.8%
4	106.46	0.37	3.7%	103.7%
5	136.87	-0.14	-1.4%	98.6%
6	167.29	-0.61	-6.1%	93.9%
7	197.71	-0.92	-9.2%	90.8%
8	228.12	-0.98	-9.8%	90.2%
9	258.54	-0.78	-7.8%	92.2%
10	288.96	-0.37	-3.7%	96.3%
11	319.37	0.14	1.4%	101.4%
12	349.79	0.61	6.1%	106.1%





Appendix J

Annual Demand Profiles

Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

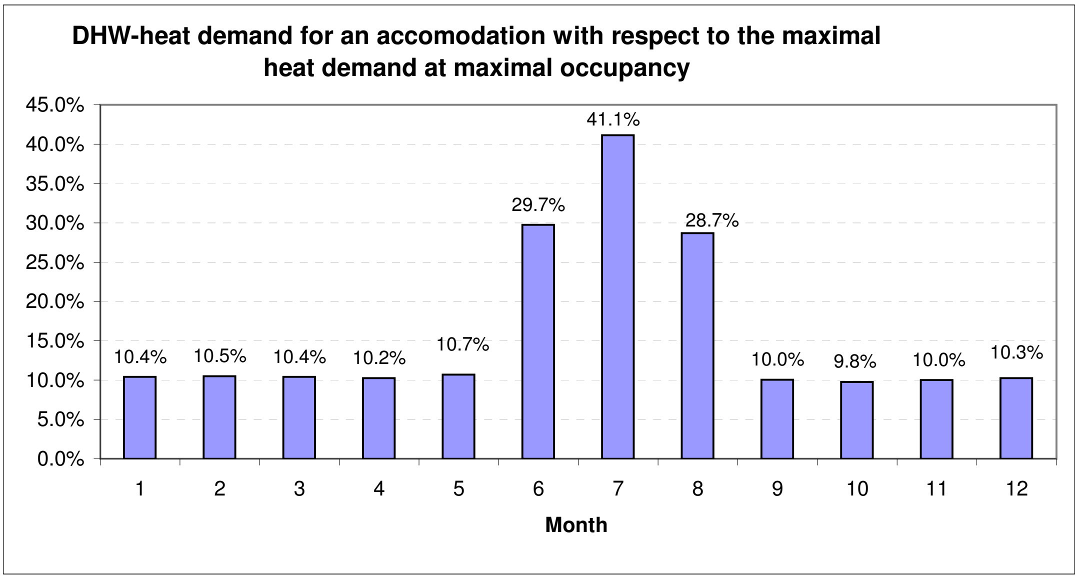
Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

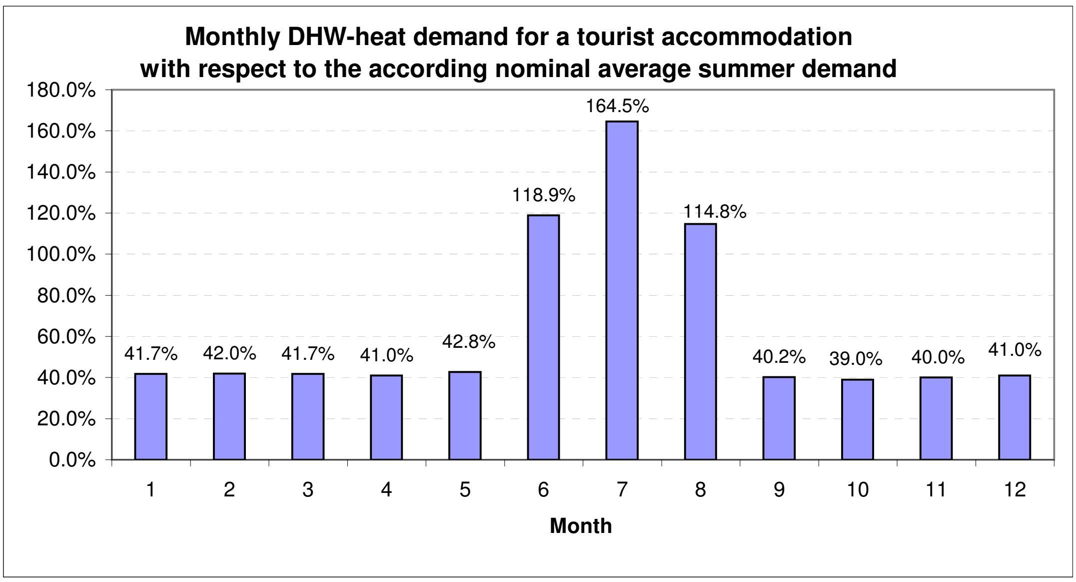
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

***Qdem* (t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.25.

T=365 Sin - max 45. day **$FU_{F(S)}$= 0.25**

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N25(t),10%) ***DHW*** $_{dem}$ (t)	DHW-heat demand related to $Q_{dem(max)}$	 $<Q_{dem(S)}>$
					Q_{dem}(t)=(**f**(t)+1)**DHW* $_{dem}$(t)	
1	15.21	0.044	*0.6%*	10.0%	10.4%	**41.7%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**42.0%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**41.7%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**41.0%**
5	136.87	-0.001	*5.8%*	10.7%	10.7%	**42.8%**
6	167.29	-0.025	*12.5%*	30.5%	29.7%	**118.9%**
7	197.71	-0.044	*31.0%*	43.0%	41.1%	**164.5%**
8	228.12	-0.050	*31.9%*	30.2%	28.7%	**114.8%**
9	258.54	-0.043	*9.8%*	10.5%	10.0%	**40.2%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**39.0%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**40.0%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**41.0%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

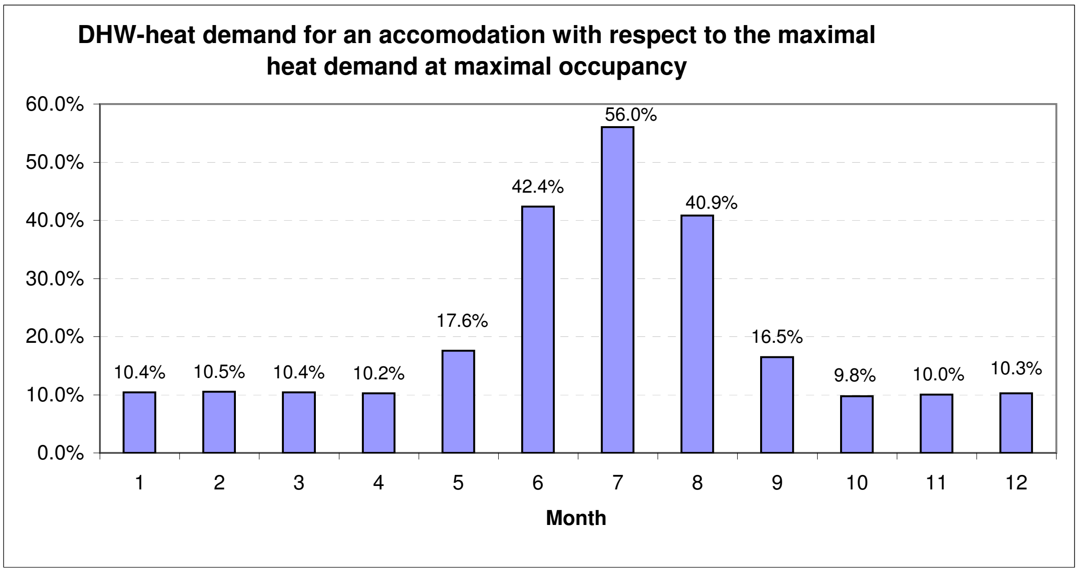
Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

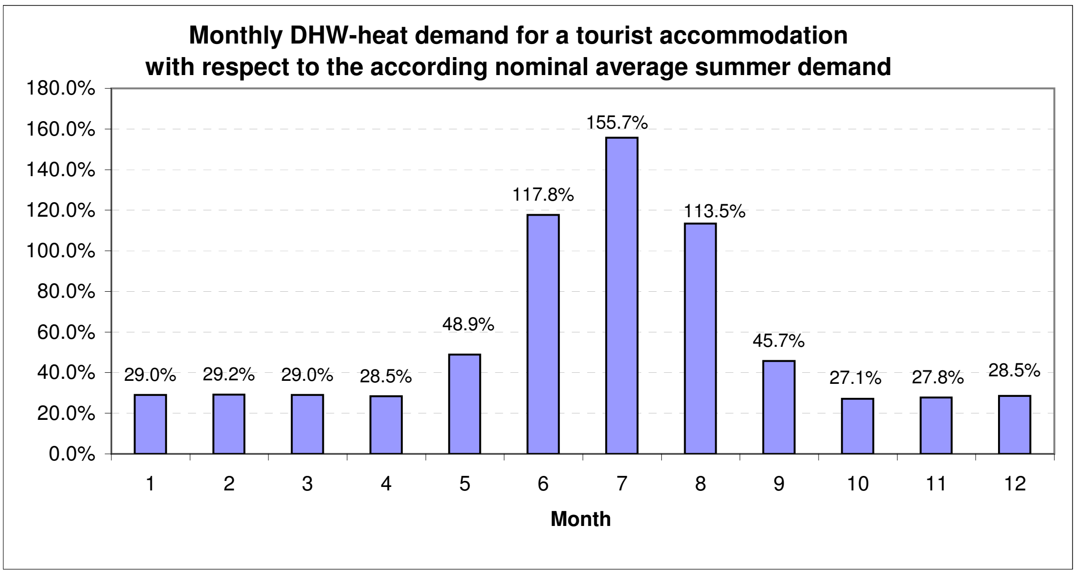
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

***Qdem*(t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.36.

T=365 Sin - max 45. day **$FU_{F(S)}$= 0.36**

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N36(t),10%) ***DHW** dem* (t)	DHW-heat demand related to $Q_{dem(max)}$ Q_{dem}(t)=(**f**(t)+1)*DHW_{dem}(t)	 $<Q_{dem(S)}>$
1	15.21	0.044	*0.6%*	10.0%	10.4%	**29.0%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**29.2%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**29.0%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**28.5%**
5	136.87	-0.001	*5.8%*	17.6%	17.6%	**48.9%**
6	167.29	-0.025	*12.5%*	43.5%	42.4%	**117.8%**
7	197.71	-0.044	*31.0%*	58.6%	56.0%	**155.7%**
8	228.12	-0.050	*31.9%*	43.0%	40.9%	**113.5%**
9	258.54	-0.043	*9.8%*	17.2%	16.5%	**45.7%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**27.1%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**27.8%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**28.5%**
		$<O_S>_{rel}$=	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

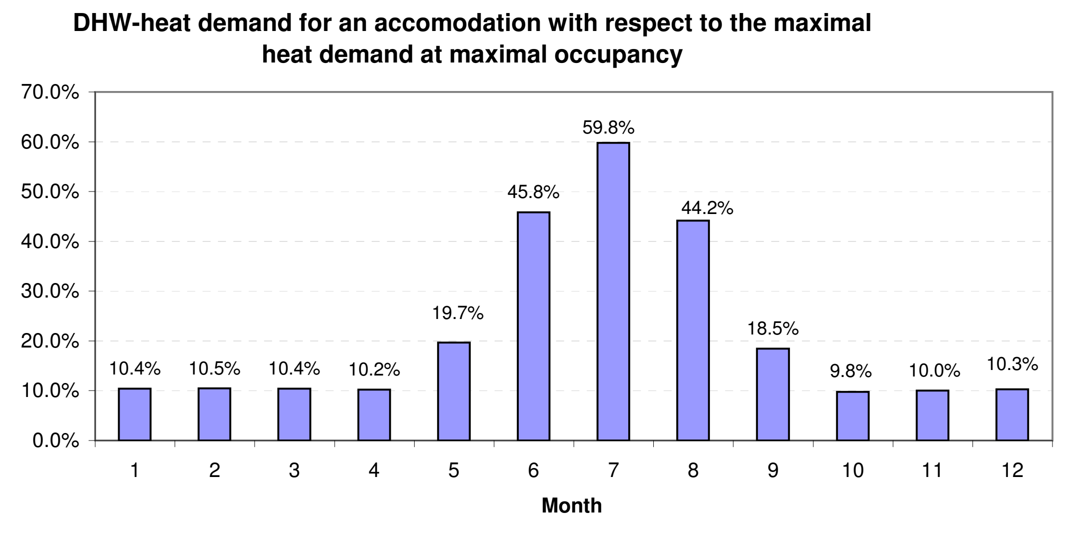
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

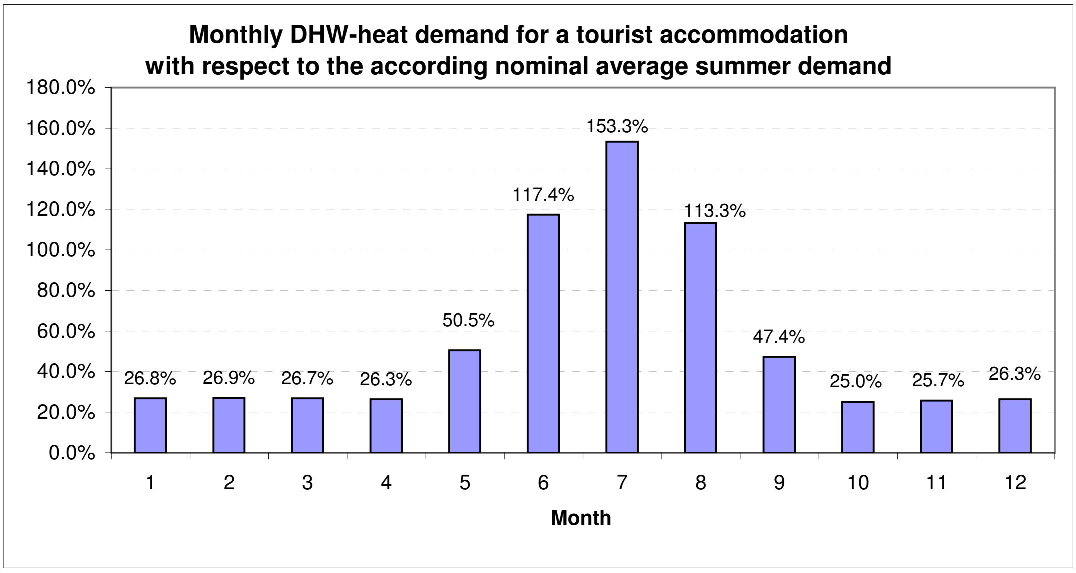
***Qdem* (t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.39.

T=365 Sin - max 45. day

$FU_{F(S)}$= 0.39

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N39(t),10%) ***DHW*** ***dem*** (t)	DHW-heat demand related to $Q_{dem(max)}$ Q_{dem}(t)=(**f**(t)+1)*DHW_{dem}(t)	 $<Q_{dem(S)}>$
1	15.21	0.044	*0.6%*	10.0%	10.4%	**26.8%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**26.9%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**26.7%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**26.3%**
5	136.87	-0.001	*5.8%*	19.7%	19.7%	**50.5%**
6	167.29	-0.025	*12.5%*	47.0%	45.8%	**117.4%**
7	197.71	-0.044	*31.0%*	62.5%	59.8%	**153.3%**
8	228.12	-0.050	*31.9%*	46.5%	44.2%	**113.3%**
9	258.54	-0.043	*9.8%*	19.3%	18.5%	**47.4%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**25.0%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**25.7%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**26.3%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

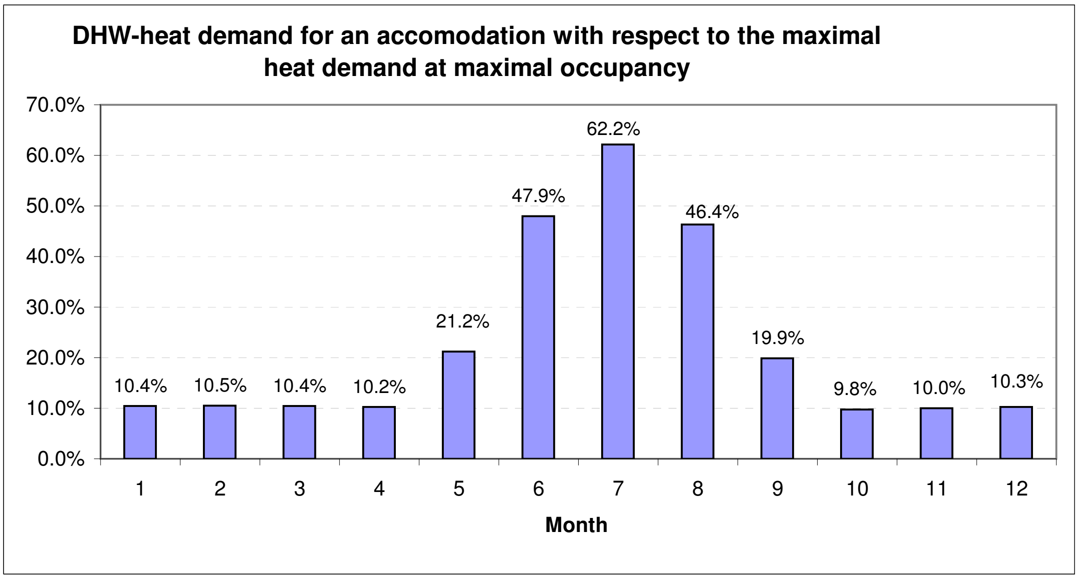
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

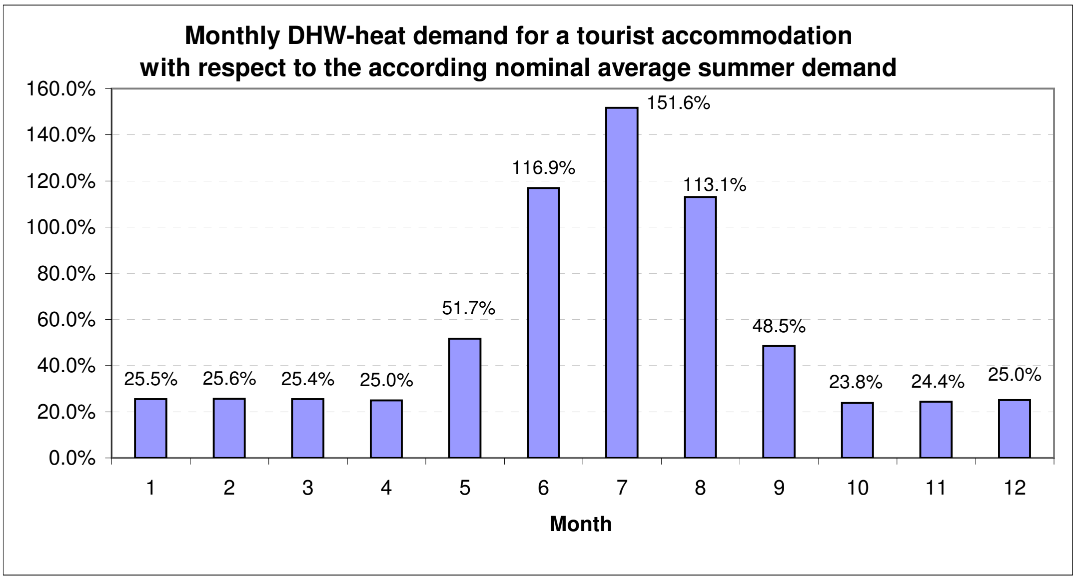
***Qdem* (t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.41.

T=365 Sin - max 45. day

$FU_{F(S)}$= 0.41

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N41(t),10%) ***DHW*** ***dem*** (t)	DHW-heat demand related to $Q_{dem(max)}$ Q_{dem}(t)=(**f**(t)+1)*DHW_{dem}(t)	 $<Q_{dem(S)}>$
1	15.21	0.044	*0.6%*	10.0%	10.4%	**25.5%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**25.6%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**25.4%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**25.0%**
5	136.87	-0.001	*5.8%*	21.2%	21.2%	**51.7%**
6	167.29	-0.025	*12.5%*	49.2%	47.9%	**116.9%**
7	197.71	-0.044	*31.0%*	65.0%	62.2%	**151.6%**
8	228.12	-0.050	*31.9%*	48.8%	46.4%	**113.1%**
9	258.54	-0.043	*9.8%*	20.8%	19.9%	**48.5%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**23.8%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**24.4%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**25.0%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

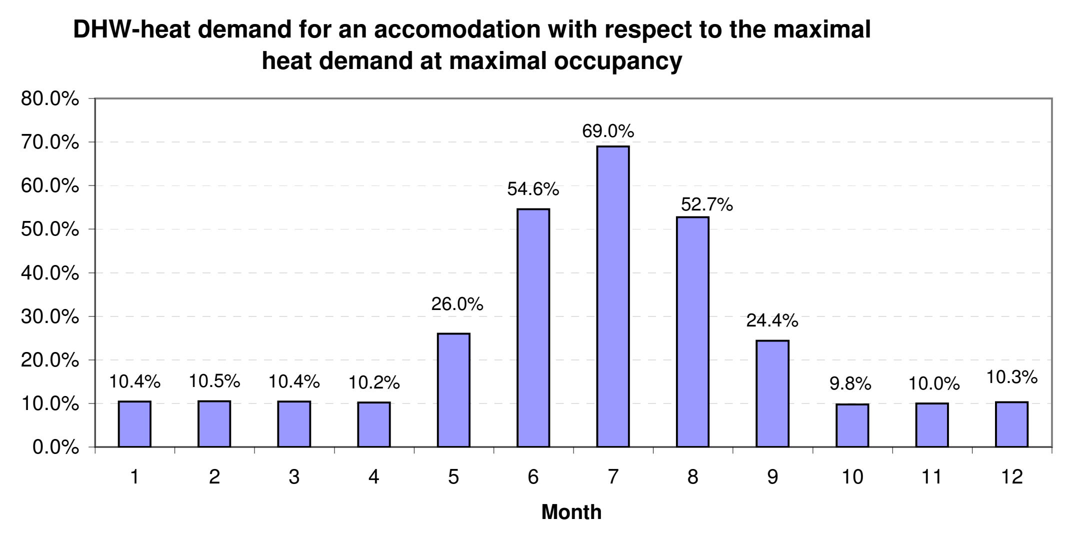
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

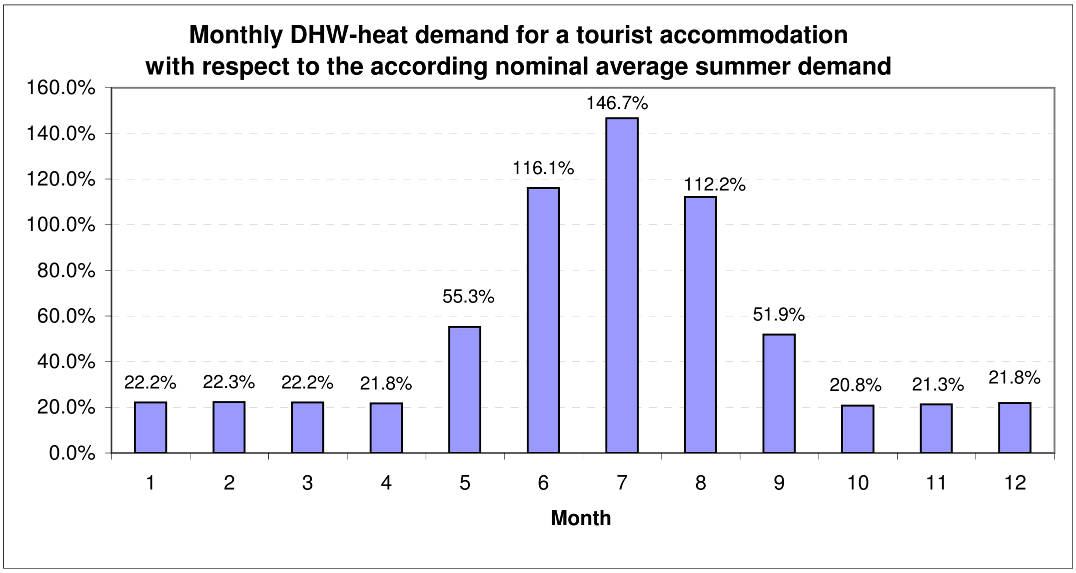
Qdem **(t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.47.

T=365 Sin - max 45. day

$FU_{F(S)}$= 0.47

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N47(t),10%) DHW_{dem}(t)	DHW-heat demand related to $Q_{dem(max)}$	 $<Q_{dem(S)}>$
					Q_{dem}(t)=(**f**(t)+1)*DHW_{dem}(t)	
1	15.21	0.044	*0.6%*	10.0%	10.4%	**22.2%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**22.3%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**22.2%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**21.8%**
5	136.87	-0.001	*5.8%*	26.0%	26.0%	**55.3%**
6	167.29	-0.025	*12.5%*	56.0%	54.6%	**116.1%**
7	197.71	-0.044	*31.0%*	72.1%	69.0%	**146.7%**
8	228.12	-0.050	*31.9%*	55.5%	52.7%	**112.2%**
9	258.54	-0.043	*9.8%*	25.5%	24.4%	**51.9%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**20.8%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**21.3%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**21.8%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

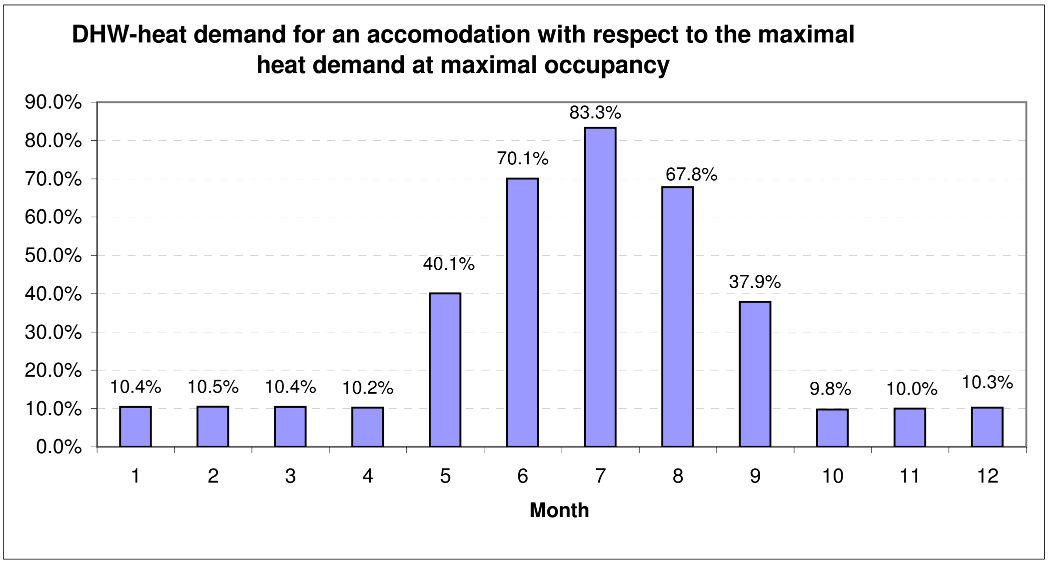
Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

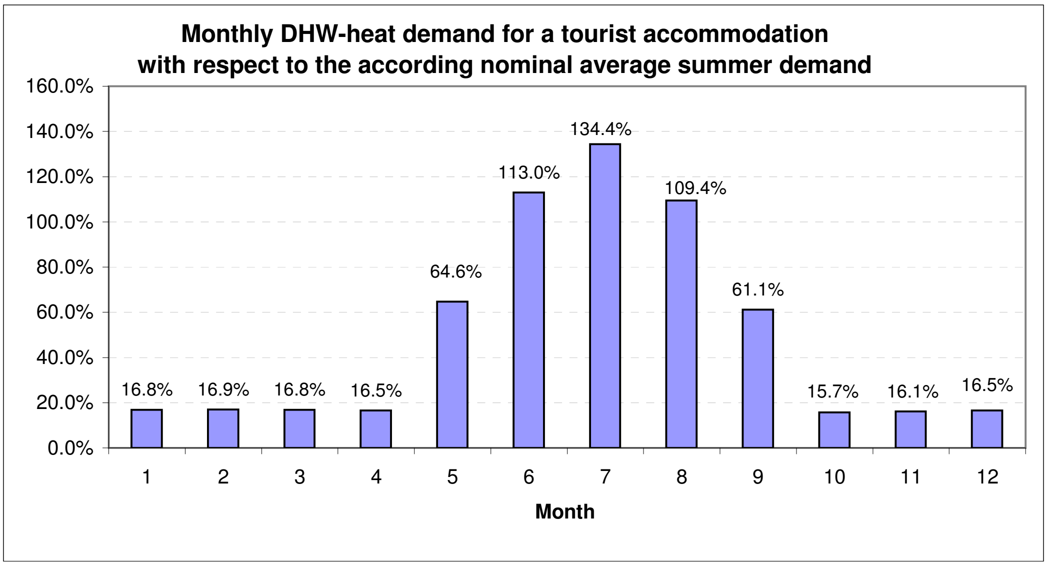
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

***Qdem* (t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.62.

T=365 Sin - max 45. day **$FU_{F(S)}$= 0.62**

month	t	ground water T variation **f**(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)	tourist traffic relativ	relative DHW Demand Max(months0N62(t),10%) ***DHW*** ***dem*** (t)	DHW-heat demand related to $Q_{dem(max)}$	 $<Q_{dem(S)}>$
					Q$_{dem}$(t)=(**f**(t)+1)*DHW_{dem}(t)	
1	15.21	0.044	*0.6%*	10.0%	10.4%	**16.8%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**16.9%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**16.8%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**16.5%**
5	136.87	-0.001	*5.8%*	40.1%	40.1%	**64.6%**
6	167.29	-0.025	*12.5%*	71.9%	70.1%	**113.0%**
7	197.71	-0.044	*31.0%*	87.1%	83.3%	**134.4%**
8	228.12	-0.050	*31.9%*	71.4%	67.8%	**109.4%**
9	258.54	-0.043	*9.8%*	39.6%	37.9%	**61.1%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**15.7%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**16.1%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**16.5%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

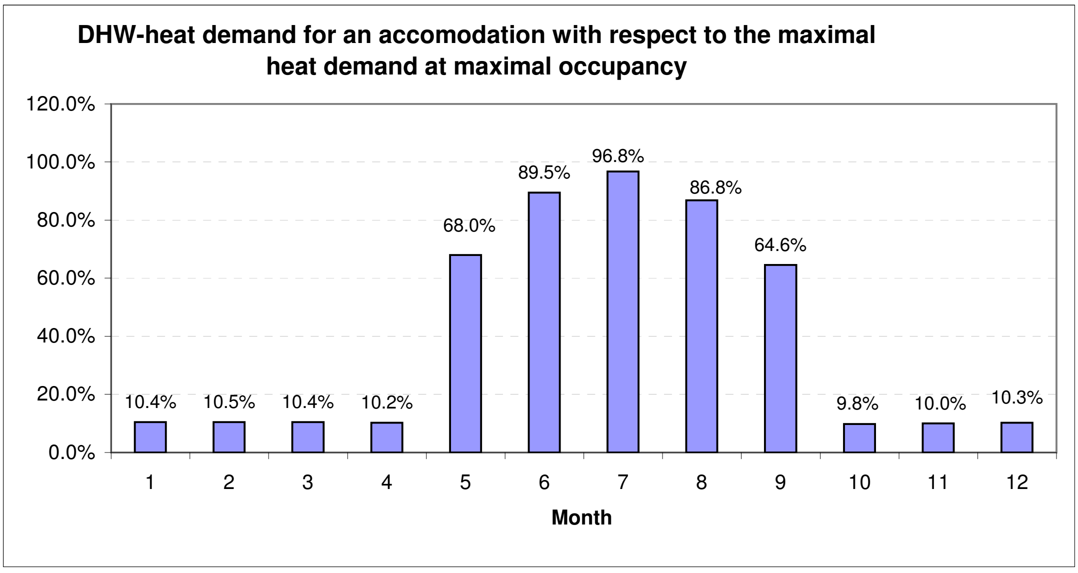
Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

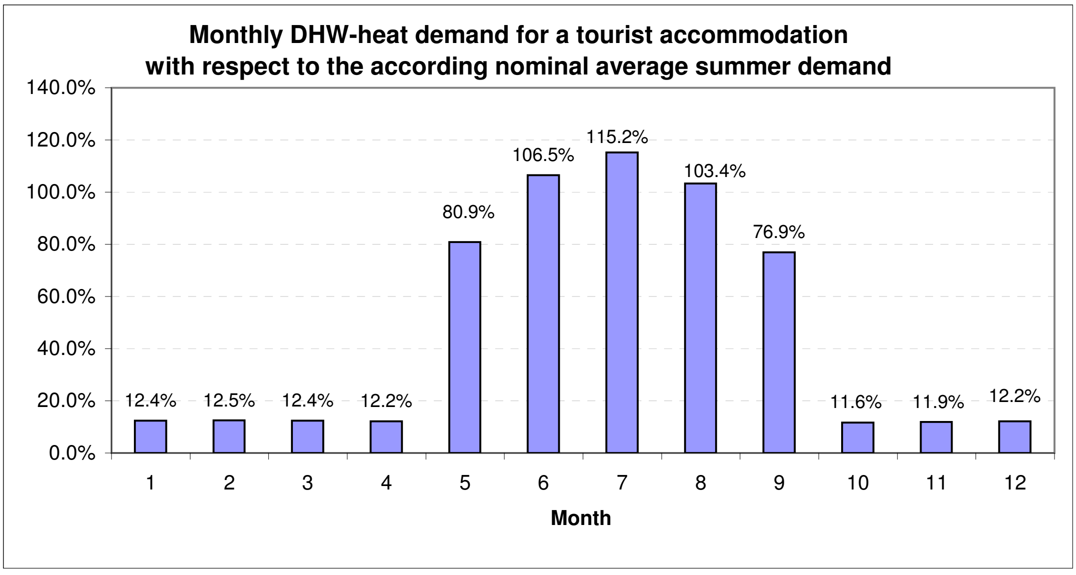
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

Qdem **(t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.84.

T=365 Sin - max 45. day **$FU_{F(S)}$= 0.84**

month	t	ground water T variation $f(t)=0.05*\sin((t+46.25)*2*Pi/T)$	tourist traffic relativ	relative DHW Demand Max(months0N84(t),10%) $DHW_{dem}(t)$	DHW-heat demand related to $Q_{dem(max)}$	$<Q_{dem(S)}>$
					$Q_{dem}(t)=(f(t)+1)*DHW_{dem}(t)$	
1	15.21	0.044	*0.6%*	10.0%	10.4%	**12.4%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**12.5%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**12.4%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**12.2%**
5	136.87	-0.001	*5.8%*	68.0%	68.0%	**80.9%**
6	167.29	-0.025	*12.5%*	91.8%	89.5%	**106.5%**
7	197.71	-0.044	*31.0%*	101.2%	96.8%	**115.2%**
8	228.12	-0.050	*31.9%*	91.4%	86.8%	**103.4%**
9	258.54	-0.043	*9.8%*	67.5%	64.6%	**76.9%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**11.6%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**11.9%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**12.2%**
		$<O_S>_{rel}$ =	**18.2%**			





Modelling annual DHW-demand variations as a function of tourist traffic and ground water temperature variations.

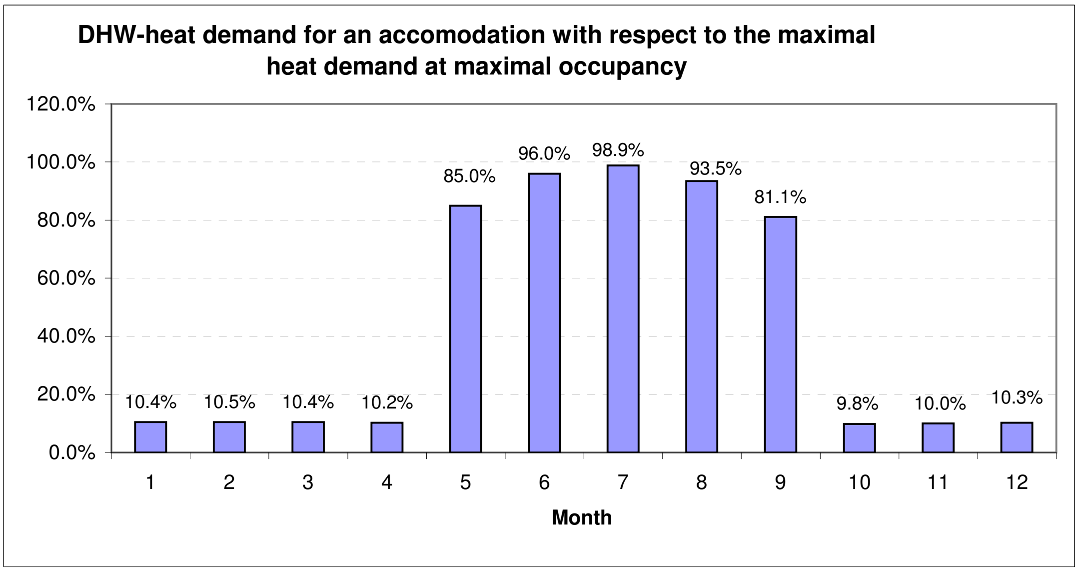
Average general relative summer occupancy $<O_S>_{rel}$, is calculated with the average relative number of overnight stays from May until Septmber.

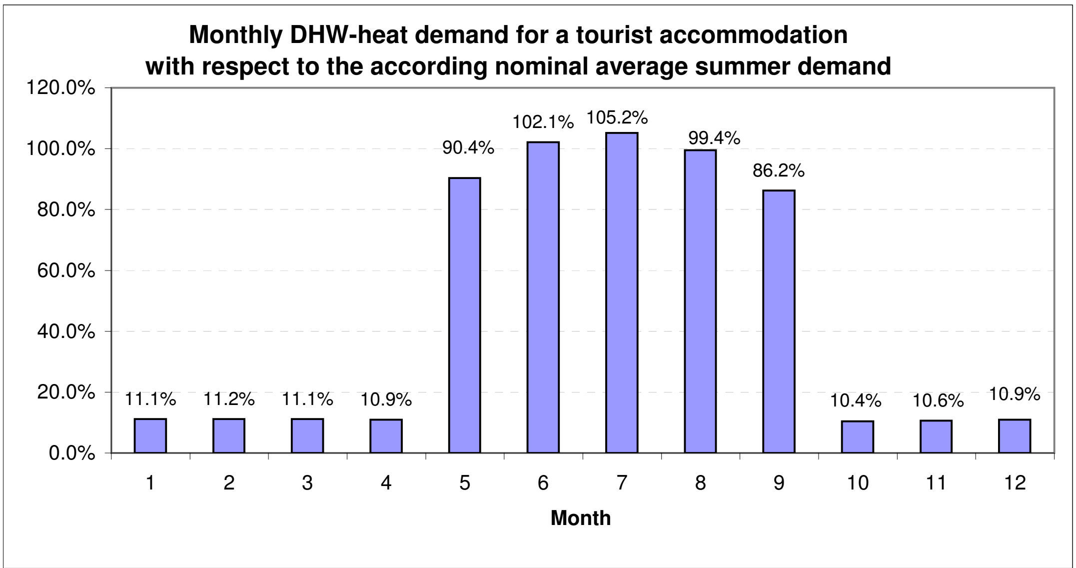
Minimal relative DHW demand was assumed to be at least 10% of the maximal heat demand $Q_{dem(max)}$, that is the bed capacity of an accommodation times DHW demand per guest.

***Qdem*(t)** is the monthly DHW-heat demand for tourism, calibrated to a facility with FU_F(S)=0.94.

T=365 Sin - max 45. day **$FU_{F(S)}$= 0.94**

month	t	ground water T variation	tourist traffic	relative DHW Demand	DHW-heat demand related to	
			relativ	Max(months0N94(t),10%)	$Q_{dem(max)}$	$<Q_{dem(S)}>$
		f(*t*)=0.05*Sin((*t+46.25)*2*Pi/T*)		***DHW*** ***dem*** (t)	$Q_{dem}(t)=(f(t)+1)*DHW_{dem}(t)$	
1	15.21	0.044	*0.6%*	10.0%	10.4%	**11.1%**
2	45.62	0.050	*0.7%*	10.0%	10.5%	**11.2%**
3	76.04	0.043	*1.3%*	10.0%	10.4%	**11.1%**
4	106.46	0.025	*2.4%*	10.0%	10.2%	**10.9%**
5	136.87	-0.001	*5.8%*	85.0%	85.0%	**90.4%**
6	167.29	-0.025	*12.5%*	98.5%	96.0%	**102.1%**
7	197.71	-0.044	*31.0%*	103.4%	98.9%	**105.2%**
8	228.12	-0.050	*31.9%*	98.4%	93.5%	**99.4%**
9	258.54	-0.043	*9.8%*	84.7%	81.1%	**86.2%**
10	288.96	-0.025	*2.6%*	10.0%	9.8%	**10.4%**
11	319.37	0.001	*0.7%*	10.0%	10.0%	**10.6%**
12	349.79	0.025	*0.7%*	10.0%	10.3%	**10.9%**
		$<O_S>_{rel}$ =	**18.2%**			





Annual Distribution of Overnight Stays

In[1607]:=

```
ClearAll[R, σ, μ, x, y, Overall, Dist, P1, P2, P3, P4, P5, P6, height, check, dmax, a,
 b, deltax, Normalisation]
```

Collected number of overnight stays for Primorska - Goranska county

Relative Distribution

In[1608]:=

```
OverallAbsolute = {67 863, 73 682, 151 896, 269 781, 655 563, 1 409 562, 3 488 361,
   3 596 032, 1 103 537, 289 770, 78 507, 79 201};
Overall = (1 / 11 263 755) OverallAbsolute;
```

Fit the Distribution to a Gauß - Distribution

In[1610]:=

```
FindFit[Overall, 1 / (σ √(2 π)) Exp[(-1 / 2) ((x - μ) / σ) ^2], {σ, μ}, x]
```

Out[1610]=

```
{σ → 1.12218, μ → 7.44466}
```

In[1611]:=

```
σ = 1.1221839987759015`;
μ = 7.444658435180731`;
```

In[1613]:=

```
dmax = μ - 7;
```

Defining the relative Overall Distribution and Comparision

In[1614]:=

```
Dist[x_, σ_, μ_] := 1 / (σ √(2 π)) Exp[(-1 / 2) ((x - μ) / σ) ^2];
```

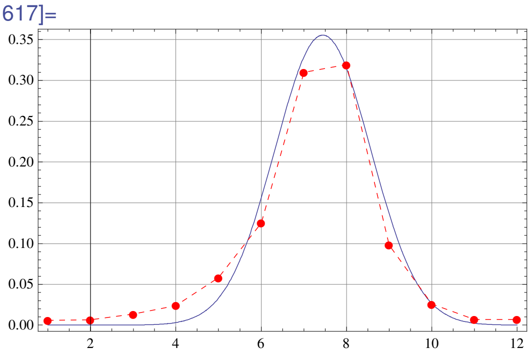
In[1615]:=

```
P1 := ListLinePlot[Transpose[{Range[12], Overall}], PlotStyle → {Red, Dashed},
   DataRange → {0, 5}, PlotMarkers → Automatic];
P2 := Plot[ Dist[y, σ, μ], {y, 1, 12}, Frame -> True, GridLines -> Automatic];
```

In[1617]:=

```
Show[P2, P1]
```

Out[1617]=



Presetting for calculation of various Distributions

In[1618]:=

```
height := Dist[μ, σ, μ]
height
```

Out[1619]=

```
0.355505
```

In[1620]:=

```
Area between the distribution and the rectangle set up by a horizontal at
Max[Dist[ ..]] and the intervall length z
```

Out[1620]=

a and Area at between by distribution horizontal rectangle set the^2 up

In[1621]:=

```
f[z_ ?NumberQ] := 2 NIntegrate[ (height - Dist[y, σ, μ]), {y, μ, μ + z},
   MaxRecursion → 100]
```

Verification

In[1622]:=

```
check[σ_, μ_, z_, deltax_] := (((2 z) height) - ∫_{μ-z+deltax}^{μ+z-deltax} Dist[x, σ, μ] ⅆx);
```

$$check[\sigma\_, \mu\_, z\_, deltax\_] := \left(((2\,z)\ height) - \int_{\mu - z + deltax}^{\mu + z - deltax} Dist[x, \sigma, \mu]\, dx \right);$$

Distribution for a facility with $FU_{F\,(S)}$ = 0.94 in the summer season from May - September

In[1623]:=

```
Clear[a, FUF, z, months, monthsN]
FUF = 0.94;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```

Out[1625]=

```
0.887277
```

In[1626]:=

```
deltax = (dmax 2 z) / 5 / 50
```

Out[1626]=

```
0.00315628
```

Calculation of the monthly values for an average month (30.6 days)

In[1627]:=

$$months = Table\left[\int_{(\mu - z + deltax + i * 2\,z/5)}^{(\mu - z + deltax + (i+1) * 2\,z/5)} Dist[x, \sigma, \mu]\, dx, \{i, 0, 4\}\right]$$

Out[1627]=

```
{0.10322, 0.119674, 0.125648, 0.119463, 0.102856}
```

In[1628]:=

```
Normalisation = Apply[Plus, months] / (5 * FUF)
```

Out[1628]=

```
0.12146
```

Normalisation and Filling the full range

In[1629]:=

```
monthsN = Flatten[{{0.1, 0.1, 0.1, 0.1}, {months / Normalisation}, {0.1, 0.1, 0.1}}];
```

In[1630]:=

```
P3 := ListPlot[monthsN, Filling -> Axis, DataRange -> {1, 12}, AxesLabel → {x, y},
   PlotRange → {{0, 12}, {0, Max[months / Normalisation] + 0.1}} ];
P4 := ListLinePlot[Transpose[ { Table[i, {i, 5, 9}], Table[FUF, {i, 0, 4}]} ],
   PlotStyle -> {Green, Dashed}];
```

Annual DHW demand for a facility with facility utilisation factor in summer FU_F

In[1632]:=

```
(1 - check[σ, μ, z, deltax])
```

Out[1632]=

```
0.938356
```

In[1633]:=

```
monthsN
```

Out[1633]=

```
{0.1, 0.1, 0.1, 0.1, 0.849827, 0.985297, 1.03448, 0.98356, 0.846833, 0.1, 0.1, 0.1}
```

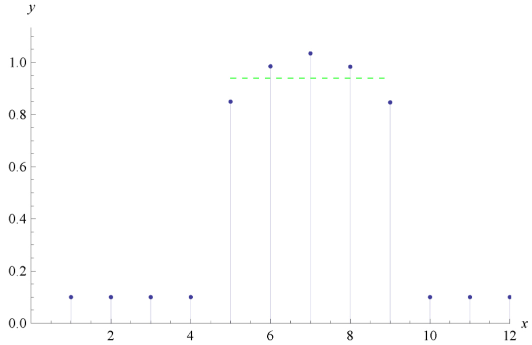
In[1634]:=

```
months0N94 = monthsN;
```

In[1635]:=

```
Show[P3, P4]
```

Out[1635]=



Distribution for a facility with $FU_{F\,(S)}$ = 0.84 in the summer season from May - September

In[1636]:=

```
Clear[a, FUF, z, months, monthsN]
FUF = 0.84;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```

Out[1638]=

```
1.26781
```

In[1639]:=

```
deltax = (dmax 2 z) / 5 / 50
```

Out[1639]=

```
0.00450995
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\,(S)}$

In[1645]:=

```
(1 - check[σ, μ, z, deltax])
```

Out[1645]=

```
0.838302
```

In[1646]:=

```
monthsN
```

Out[1646]=

```
{0.1, 0.1, 0.1, 0.1, 0.68017, 0.917563, 1.01264, 0.914292, 0.67533, 0.1, 0.1, 0.1}
```

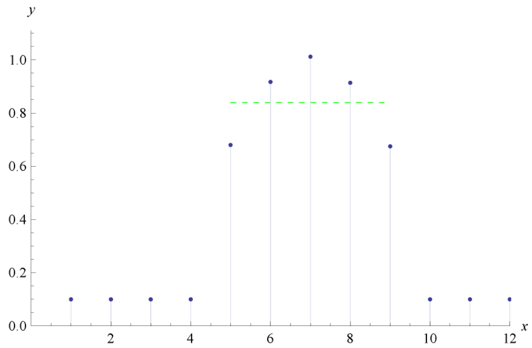
In[1647]:=

```
months0N84 = monthsN;
```

In[1648]:=

```
Show[P3, P4]
```

Out[1648]=



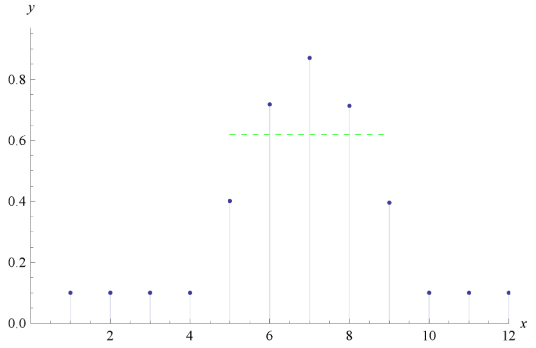
Distribution for a facility with $FU_{F\ (S)}$ = 0.62 in the summer season from May - September

In[1649]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.62;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1651]=
```
1.78335
```
In[1652]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1652]=
```
0.00634385
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\ (S)}$

In[1658]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1658]=
```
0.618718
```
In[1659]:=
```
monthsN
```
Out[1659]=
```
{0.1, 0.1, 0.1, 0.1, 0.401305, 0.718638, 0.870631, 0.713661, 0.395765, 0.1, 0.1, 0.1}
```
In[1660]:=
```
months0N62 = monthsN;
```
In[1661]:=
```
Show[P3, P4]
```
Out[1661]=



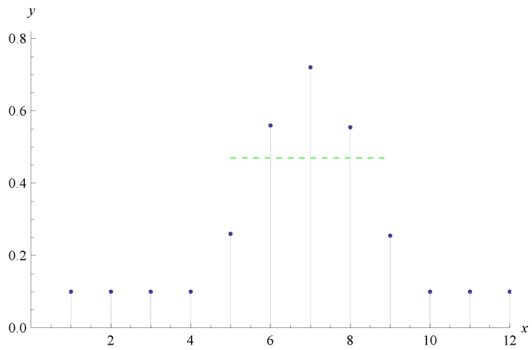
Distribution for a facility with $FU_{F\ (S)}$ = 0.47 in the summer season from May - September

In[1662]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.47;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1664]=
```
2.05813
```
In[1665]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1665]=
```
0.00732132
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\ (S)}$

In[1671]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1671]=
```
0.469026
```
In[1672]:=
```
monthsN
```
Out[1672]=
```
{0.1, 0.1, 0.1, 0.1, 0.25981, 0.559757, 0.720681, 0.554657, 0.255094, 0.1, 0.1, 0.1}
```
In[1673]:=
```
months0N47 = monthsN;
```
In[1674]:=
```
Show[P3, P4]
```
Out[1674]=



Distribution for a facility with $FU_{F\ (S)}$ = 0.41 in the summer season from May - September

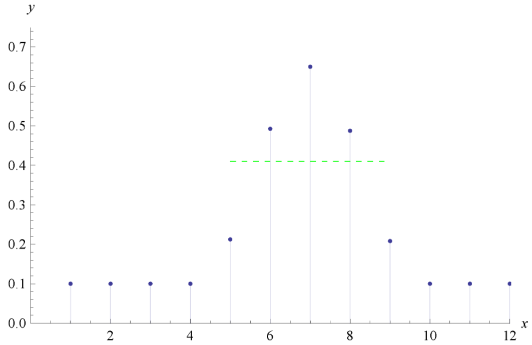
In[1675]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.41;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1677]=
```
2.15994
```
In[1678]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1678]=
```
0.00768349
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\ (S)}$

In[1684]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1684]=
```
0.409137
```
In[1685]:=
```
monthsN
```
Out[1685]=
```
{0.1, 0.1, 0.1, 0.1, 0.212256, 0.492472, 0.649683, 0.487554, 0.208035, 0.1, 0.1, 0.1}
```
In[1686]:=
```
months0N41 = monthsN;
```

In[1687]:=
```
Show[P3, P4]
```
Out[1687]=



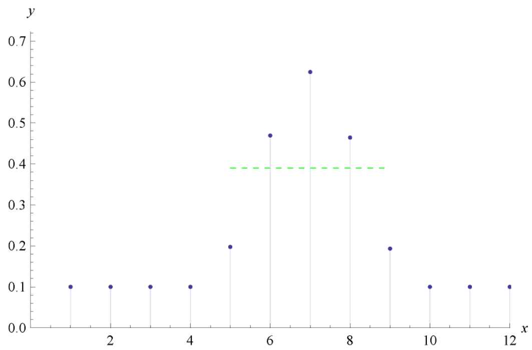
Distribution for a facility with $FU_{F\ (S)}$ = 0.39 in the summer season from May - September

In[1688]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.39;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1690]=
```
2.19313
```
In[1691]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1691]=
```
0.00780155
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\ (S)}$

In[1697]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1697]=
```
0.389173
```
In[1698]:=
```
monthsN
```
Out[1698]=
```
{0.1, 0.1, 0.1, 0.1, 0.197465, 0.469649, 0.62464, 0.464822, 0.193423, 0.1, 0.1, 0.1}
```
In[1699]:=
```
months0N39 = monthsN;
```
In[1700]:=
```
Show[P3, P4]
```
Out[1700]=



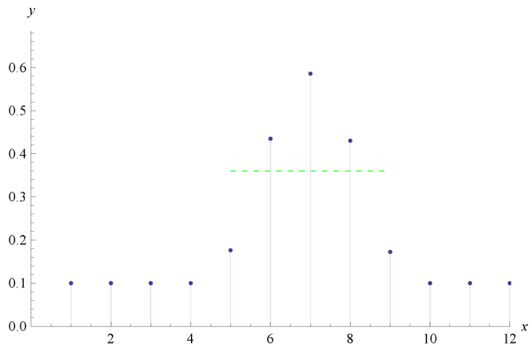
Distribution for a facility with $FU_{F(S)}$ = 0.36 in the summer season from May - September

In[1701]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.36;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1703]=
```
2.2423
```
In[1704]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1704]=
```
0.00797647
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F(S)}$

In[1710]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1710]=
```
0.359224
```
In[1711]:=
```
monthsN
```
Out[1711]=
```
{0.1, 0.1, 0.1, 0.1, 0.176237, 0.435079, 0.58579, 0.430417, 0.172476, 0.1, 0.1, 0.1}
```
In[1712]:=
```
months0N36 = monthsN;
```
In[1713]:=
```
Show[P3, P4]
```
Out[1713]=



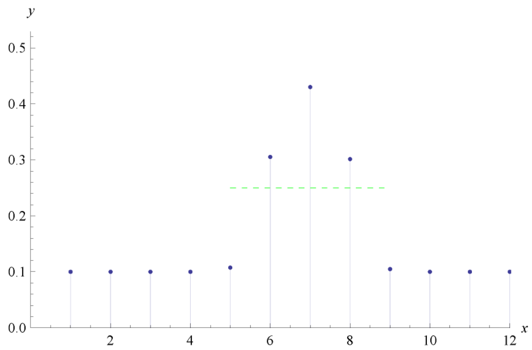
Distribution for a facility with $FU_{F(S)}$ = 0.25 in the summer season from May - September

In[1714]:=
```
Clear[a, FUF, z, months, monthsN]
FUF = 0.25;
z = a /. FindRoot[f[a] == (1 - FUF), {a, μ}]
```
Out[1716]=
```
2.41737
```
In[1717]:=
```
deltax = (dmax 2 z) / 5 / 50
```
Out[1717]=
```
0.00859922
```

Calculation of the monthly values for an average month (30.6 days)

Annual DHW demand for a facility with facility utilisation factor in summer $FU_{F\ (S)}$

In[1723]:=
```
(1 - check[σ, μ, z, deltax])
```
Out[1723]=
```
0.249394
```
In[1724]:=
```
monthsN
```
Out[1724]=
```
{0.1, 0.1, 0.1, 0.1, 0.107751, 0.305363, 0.430186, 0.301595, 0.105104, 0.1, 0.1, 0.1}
```
In[1725]:=
```
months0N25 = monthsN;
```
In[1726]:=
```
Show[P3, P4]
```
Out[1726]=



Overview Relative Distributions for different FU_F(S)

relative Distributions for different facilities

In[1727]:=
```
months0N94
months0N84
months0N62
months0N47
months0N41
months0N39
months0N36
months0N25
```
Out[1727]=
```
{0.1, 0.1, 0.1, 0.1, 0.849827, 0.985297, 1.03448, 0.98356, 0.846833, 0.1, 0.1, 0.1}
```
Out[1728]=
```
{0.1, 0.1, 0.1, 0.1, 0.68017, 0.917563, 1.01264, 0.914292, 0.67533, 0.1, 0.1, 0.1}
```
Out[1729]=
```
{0.1, 0.1, 0.1, 0.1, 0.401305, 0.718638, 0.870631, 0.713661, 0.395765, 0.1, 0.1, 0.1}
```
Out[1730]=
```
{0.1, 0.1, 0.1, 0.1, 0.25981, 0.559757, 0.720681, 0.554657, 0.255094, 0.1, 0.1, 0.1}
```
Out[1731]=
```
{0.1, 0.1, 0.1, 0.1, 0.212256, 0.492472, 0.649683, 0.487554, 0.208035, 0.1, 0.1, 0.1}
```
Out[1732]=
```
{0.1, 0.1, 0.1, 0.1, 0.197465, 0.469649, 0.62464, 0.464822, 0.193423, 0.1, 0.1, 0.1}
```
Out[1733]=
```
{0.1, 0.1, 0.1, 0.1, 0.176237, 0.435079, 0.58579, 0.430417, 0.172476, 0.1, 0.1, 0.1}
```
Out[1734]=
```
{0.1, 0.1, 0.1, 0.1, 0.107751, 0.305363, 0.430186, 0.301595, 0.105104, 0.1, 0.1, 0.1}
```

Individual annual distribution in absolute numbers for summer season

In[1735]:=
```
FUF94 = Take[months0N94, {5, 9}] 3 052 140 × 0.95 / (Apply[Plus, months0N94] - 0.7)
FUF84 = Take[months0N84, {5, 9}] 140 894 × 0.95 / (Apply[Plus, months0N84] - 0.7)
FUF62 = Take[months0N62, {5, 9}] 255 290 × 0.95 / (Apply[Plus, months0N62] - 0.7)
FUF47 = Take[months0N47, {5, 9}] 142 669 × 0.95 / (Apply[Plus, months0N47] - 0.7)
FUF41 = Take[months0N41, {5, 9}] 2 675 152 × 0.95 / (Apply[Plus, months0N41] - 0.7)
FUF39 = Take[months0N39, {5, 9}] 127 560 × 0.95 / (Apply[Plus, months0N39] - 0.7)
FUF36 = Take[months0N36, {5, 9}] 239 547 × 0.95 / (Apply[Plus, months0N36] - 0.7)
FUF25 = Take[months0N25, {5, 9}] 3 726 046 × 0.95 / (Apply[Plus, months0N25] - 0.7)
```

Out[1735]=
```
{524 277., 607 851., 638 196., 606 780., 522 430.}
```

Out[1736]=
```
{21 676.3, 29 241.7, 32 271.9, 29 137.5, 21 522.}
```

Out[1737]=
```
{31 395.7, 56 221.9, 68 113., 55 832.6, 30 962.3}
```

Out[1738]=
```
{14 984.5, 32 283.8, 41 565.1, 31 989.7, 14 712.5}
```

Out[1739]=
```
{263 135., 610 519., 805 415., 604 423., 257 902.}
```

Out[1740]=
```
{12 271.4, 29 186.2, 38 818., 28 886.2, 12 020.2}
```

Out[1741]=
```
{22 281.2, 55 006., 74 060.1, 54 416.6, 21 805.8}
```

Out[1742]=
```
{305 129., 864 726., 1.2182×10^6, 854 056., 297 633.}
```

Distribution according to the sum set up on the reconstructed Distribution of each facility

In[1743]:=
```
yearAbsolute = Apply[Plus, {FUF94, FUF84, FUF62, FUF47, FUF41, FUF39, FUF36, FUF25}];
```

In[1744]:=
```
yearN = Flatten[{{0.0, 0.0, 0.0, 0.0}, {yearAbsolute}, {0.0, 0.0, 0.0}}];
```

In[1745]:=
```
Apply[Plus, yearN]
```

Out[1745]=
```
9.84133×10^6
```

In[1746]:=
```
Take[OverallAbsolute, {5, 9}]
```

Out[1746]=
```
{655 563, 1 409 562, 3 488 361, 3 596 032, 1 103 537}
```

In[1747]:=
```
Apply[Plus, Take[OverallAbsolute, {5, 9}]]
```

Out[1747]=
```
10 253 055
```

- **Comparison**

In[1748]:=
```
Apply[Plus, yearN] / Apply[Plus, Take[OverallAbsolute, {5, 9}]]
```

Out[1748]=
```
0.959844
```

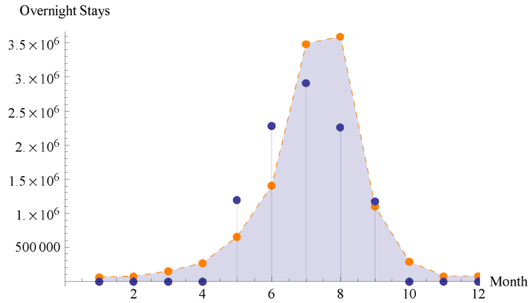
In[1749]:=
```
P3 := ListPlot[Transpose[ { Table[i, {i, 1, 12}], yearN}], Filling -> Axis, DataRange ->
   PlotRange → {{0, 12}}, PlotMarkers → Automatic ];
P4 := ListLinePlot[OverallAbsolute, Filling -> Axis, DataRange -> {1, 12},
   AxesLabel → {Month, Overnight Stays}, PlotRange → {{0, 12}}, PlotStyle ->
    {Orange, Dashed}, PlotMarkers → Automatic ];
```

Comparison of the absolute distribution (number) of overnight stays
to the reconstructed distribution

In[1751]:=

```
Show[P4, P3]
```

Out[1751]=



In[1752]:=

In[1753]:=

```
Take[OverallAbsolute, {5, 9}]
```

Out[1753]=

```
{655 563, 1 409 562, 3 488 361, 3 596 032, 1 103 537}
```

In[1754]:=

```
yearAbsolute
```

Out[1754]=

$\{1.19515\times10^{6}, 2.28504\times10^{6}, 2.91664\times10^{6}, 2.26552\times10^{6}, 1.17899\times10^{6}\}$

In[1755]:=

```
Thread[ Divide[Take[OverallAbsolute, {5, 9}], yearAbsolute ] ]
```

Out[1755]=

```
{0.54852, 0.616866, 1.19602, 1.58729, 0.936004}
```

Appendix K

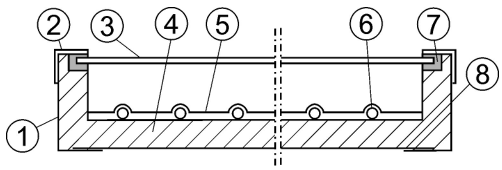
Components

Flat solar collector SKT 40

TECHNICAL DATA:

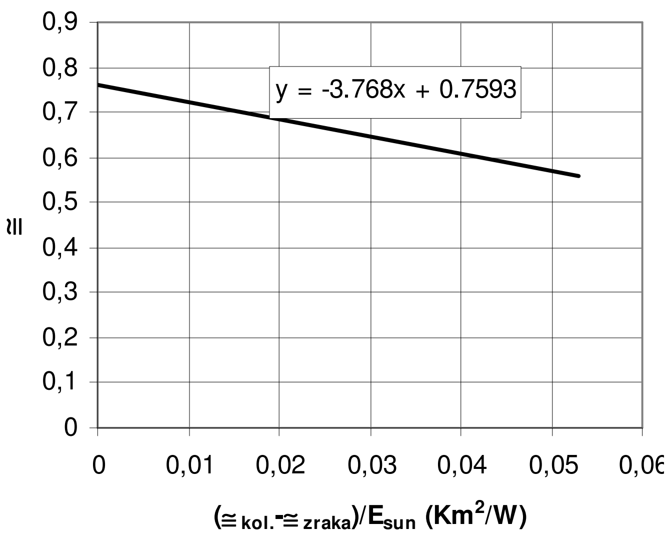
Size.. 1964 x 1034 x 86 mm
Net solar area...1,915 m^2 *
Efficiency..60 to 76%
Utility factor:........................ $\varphi = -3.768x + 0{,}7593$
Local resistance coefficient................................ $\xi = 630$
Fluid content in SKT...1,4 litres
Collector mass..49 kg
Hermetic connection ....Ø 12/10 mm
Solar selective coat:
- absorption coefficient .... $\alpha = 0{,}95$
- temperature steadiness from....................60 to 250 ºC

* Sun collector is certified by the Faculty of Mechanical Engineering and Naval Architecture of Zagreb

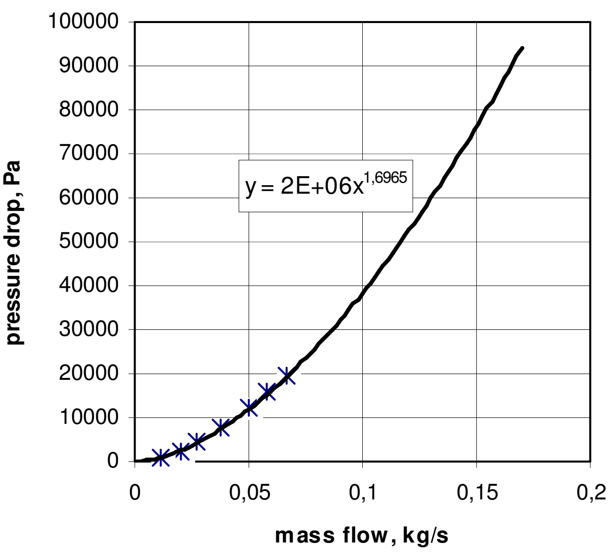


1. Collector housing: Al anodized
2. Collector frame: Al anodized
3. Tempered glass 4 – 5 mm, transmission coeff. 0,9 ± 1%
4. Insulation: polyurethane foam
5. Absorber plate: Cu + selected coat
6. Pipe coils: Cu
7. Rubber seal
8. Protecting plate: Al

Thermal Characteristics–Tehnomont SKT-40



Hydraulic Charact.-Tehnomont SKT-40



Parameters not provided were calculated based on assumptions and according to informations from people who were involved in the development of the collector. The following result is based on the provided fluid content of the absorber, an assumed inner pipe diameter of the Cu pipe of 9 mm, a total pipe length of 22 m and a raw Cu sheet with the dimensions 1 m x 2 m x 3 mm.

$$m_{absorber} = 8780g \tag{K.1}$$

PIZ
1

Vom BMWA mit GZ 92714/237-IV/9/00 akkreditierte Prüf- und Überwachungsstelle
sowie sowie mit BGBl. II Nr. 244/2005 akkreditierte Zertifizierungsstelle für Personen

Prüfbericht / Test Report

AUSTRIAN INSTITUTE OF TECHNOLOGY

Projektbezeichnung
Project Designation

Leistungsprüfung eines abgedeckten Sonnenkollektors gemäß EN 12975:2006

Thermal performance testing of a solar collector according to EN 12975:2006

Produktbezeichnung
Product name

Gluatmugl GS 4,2m^2

Auftraggeber
Client

ökoTech Produktionsgesellschaft für Umwelttechnik mbH
Puchstrasse 85
8020 Graz
Österreich

Auftrag vom / Zahl
Order from / No.

15.12.2008

Projekt Nummer
Project number

2.04.00667.1.0-1 - LT(1)

Sachbearbeiter
Test engineer

DI(FH) Roland Sterrer

Ausstellungsdatum *Date of issue*	Neufassung: 29.6.2009
Ausfertigungen: Anzahl / Nr. *Total number of issures / No.*	1/1
Anzahl der Seiten *Number or pages*	13
Anzahl der Beilagen im Blatt *Annex: number of pages*	1

AUSTRIAN INSTITUTE OF TECHNOLOGY

Inhaltsverzeichnis

1. Allgemeine Angaben
General specifications

Prüfstelle: ÖSTERREICHISCHES FORSCHUNGS- UND PRÜFZENTRUM ARSENAL Ges.m.b.H
test center: *AIT Austrian Institute of Technology*
Giefinggasse 2, A-1210 Wien, Tel: +43 50550-6497, www.ait.ac.at/energy

Eingang des Prüfgegenstandes *receipt of test sample*	17.2.2009
Prüfung im Zeitraum (vom/bis) *test periode (from/to)*	18.05.2009 - 26.06.2009
Durchgeführte Prüfung *performed test*	vollständige Leistungsprüfung nach EN 12975-2 *complete performance test according EN 12975-2*

1.1. Angaben zum Kollektor / *collector details*

Hersteller *manufacturer*	
Anschrift *address*	ökoTech Produktionsgesellschaft für Umwelttechnik mbH Puchstrasse 85 8020 Graz Österreich / Austria
Vertrieb *distributor*	
Anschrift *address*	S.O.L.I.D. Gesellschaft für Solarinstallation und Design GmbH Puchstrasse 85 8020 Graz Österreich / Austria

Bezugsflächen (vom Pürflabor bestimmt) *dimensions of collector unit (determined by test laboratory)*	
Bruttofläche (m²) *gross area (m²)*	4,256
Aperturfläche (m²) *aperture area (m²)*	3,802
Absorberfläche (m²) *absorber area (m²)*	3,714

Angaben zu Kollektor und Gehäuse *technical figures of the collector*	
Bauart * *type of collector **	Flachkollektor *flat plate collector*
Bezeichnung * *brand name **	Gluatmugl GS 4,2m²
Seriennummer * *serial number **	GS ID 002/09 (A)
Serienprodukt oder Prototyp * *serial product or proto type **	Serienprodukt *serial product*
Herstellungsjahr * *year of production **	2009
Länge (mm) *length (mm)*	2050
Breite (mm) *width (mm)*	2076
Höhe (mm) *height (mm)*	121
Leergewicht des Kollektors (kg) *weight of empty collector (kg)*	107,5

Absorber *absorber*	
Absorberbauart * *absorbertype* *	Streifenabsorber (Sunstrip®, Typ 143) *strip absorber (Sunstrip®, type 143)*
Material des Absorberblechs * *material of absorber* *	Aluminium *aluminium*
Stärke (mm) *thickness (mm)*	0,50
Art der Verbindung Absorber-Rohr * *type of connectionabsorber - tube* *	eingewalztes Kupferrohr in zwei Aluminiumbändern *rolling of copper pipe between two aluminum strips*
Absorberbeschichtung * *absorber coating* *	Nickeloxid *nickel oxide*
Absorptionskoeffizient α * *absorptance* α *	0,96 (+/- 2%)
Emissionskoeffizient ϵ * *emittance* ϵ *	0,07 (+/- 2%)
Abmessungen Sammelrohr (mm) *dimensions of the header tube (mm)*	Ø22 x 1
Abmessungen Absorberrohr (mm) *dimensions of absorber tube (mm)*	Ø10 x 1
Art der hydraulischen Verschaltung *kind of hydraulic circuit*	Harfe *harp*
Anzahl der Absorberrohre *number of absorber tubes*	14
Anzahl paralleler Rohrabschnitte *number of parallel tube segments*	2
Anzahl serieller Rohrabschnitte *number of serial tube segments*	7
Anzahl der Anschlüsse *number of connections*	2

Transparente Abdeckung *transparent cover*	
Material & Bezeichnung * *material & identification* *	Solarglas ESG *solar glass ESG*
Anzahl der Abdeckungen * *number of covers* *	2
Transmissionsgrad τ * *transmittance* τ *	0,90
Abmessungen (mm) *dimensions (mm)*	1000 x 2010 x 4
Struktur der Abdeckung (innen/außen) *structure of the cover (inside/outside)*	keine Struktur *no structure*

Kollektor Wärmedämmung *collector thermal insulation*	
Rückseite: Material * *back side: material* *	Steinwolle mit Glasvlies (schwarz) kaschiert *rock wool with glass fleece (black)*
Spezifische Masse (kgm^{-3}) * *specific weight* (kgm^{-3}) *	50
Stärke (mm) *thickness (mm)*	70
Seitenwand: Material * *side wall: material* *	keine *none*
Spezifische Masse (kgm^{-3}) * *specific weight* (kgm^{-3}) *	-
Stärke (mm) * *thickness (mm)* *	-

Gehäusekonstruktion *frame construction*	
Material Rahmen * *material frame* *	Holz *wood*
Material Rückwand * *back board material* *	OSB - Platte *OSB board*
Dichtungsmaterial * *sealing material* *	EPDM
Einbauweise * *collector mounting* *	Indach *in roof*

Betriebsspezifikationen *specifications for operation*	
Wärmeträgerfüllvolumen (l) * *heat transfer fluid content (l)* *	3,00
empfohlener Wärmeträger * *recommended heat transfer fluid* *	Propylenglykol / Wasser Gemisch *propylene glycol / water mixture*
empfohlenes Mischungsverhältnis * *recommended mix ratio* *	≥35% Propylenglykol, (je nach Einsatzort !!)
empfohlener Durchfluss (lh^{-1}) * *recommended flow rate (lh^{-1})* *	10 - 80 l/m²h
empfohlener Betriebsüberdruck (bar) * *recommended operation pressure (bar)* *	3
maximaler Betriebsüberdruck (bar) * *maximum operation pressure (bar)* *	10

* Angaben mit diesem Zeichen sind Herstellerangaben
* *Specifications with this sign are manufacturers instructions*

1.2. Feststellung des Kollektors / *collector identification*

Überprüfung ob folgende Daten, die die ÖNORM EN 12975-1, Kapitel 7 fordert, vorhanden sind.
Check the following informations which ÖNORM EN 12975-1, chapter 7 requires.

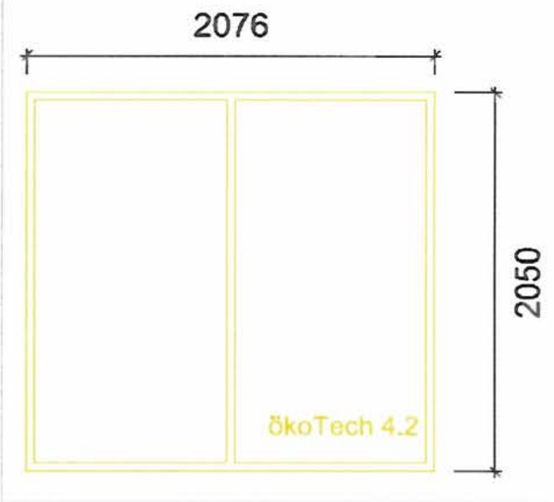
Zeichnungen und Datenblätter *pictures and technical data sheets*	nicht vorhanden / not available	
Zeichnungsnummer *drawing number*	☑ Ja / *Yes*	☐ Nein / *No*
Ausgabedatum *date of issue*	☑ Ja / *Yes*	☐ Nein / *No*
Überarbeitungsdatum *date of revision*	☐ Ja / *Yes*	☑ Nein / *No*
Werkstoffliste *list of materials*	☑ Ja / *Yes*	☐ Nein / *No*
Angabe von Maßen und Struktur *specification of measurements and size*	☑ Ja / *Yes*	☐ Nein / *No*

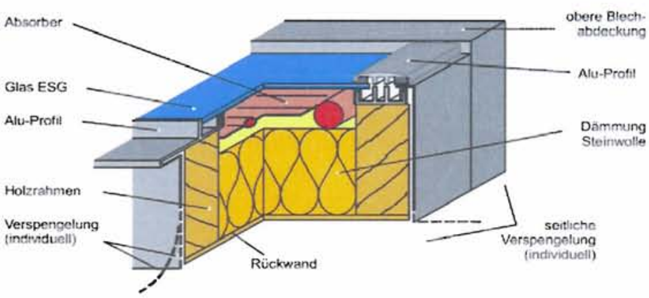
Kennzeichnung *collector label*	vorhanden / available	
Name des Herstellers *name of manufacturer*	☑ Ja / *Yes*	☐ Nein / *No*
Kollektortyp *type of collector*	☑ Ja / *Yes*	☐ Nein / *No*
Seriennummer *serial number*	☑ Ja / *Yes*	☐ Nein / *No*
Herstellungsjahr *year of production*	☑ Ja / *Yes*	☐ Nein / *No*
Brutto Kollektorfläche *gross area*	☑ Ja / *Yes*	☐ Nein / *No*

maximaler Betriebsüberdruck *maximum operation pressure*	☑ Ja / *Yes*	☐ Nein / *No*
Stagnationstemperatur bei 1000 Wm^{-2} und 30°C *stagnation temperature at 1000 Wm^{-2} and 30 °C*	☐ Ja / *Yes*	☑ Nein / *No*
Volumen des Wärmeträgerfluids *volume of the heat transfer fluid*	☑ Ja / *Yes*	☐ Nein / *No*
Leergewicht des Kollektors *weight of the empty collector*	☑ Ja / *Yes*	☐ Nein / *No*
Hergestellt in... *made in...*	☑ Ja / *Yes*	☐ Nein / *No*

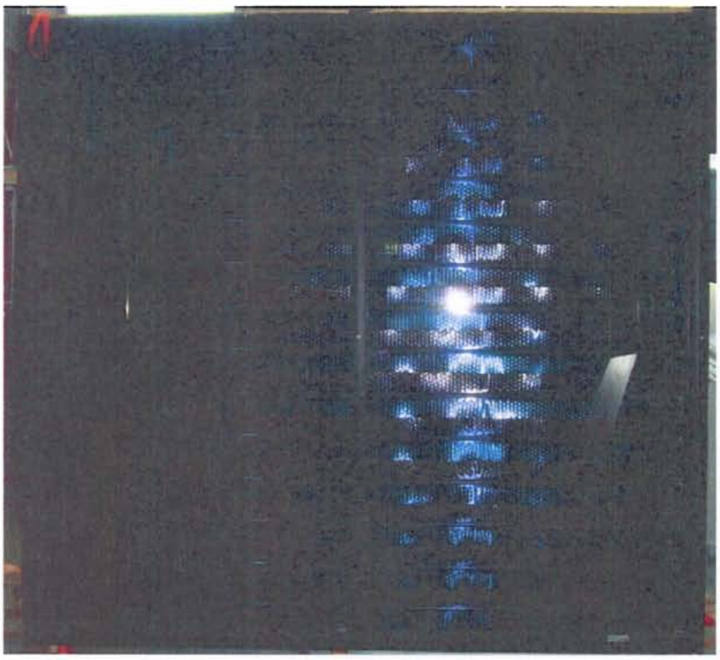
Installationsanweisungen *installer instruction manual*	**vorhanden / available**	
Anweisung für Transport und Handhabung *instructions for transport and handling*	☑ Ja / *Yes*	☐ Nein / *No*
Beschreibung Montageverfahren *description of the mounting procedure*	☑ Ja / *Yes*	☐ Nein / *No*
Empfehlung zum Blitzschutz *recommendation for lighting protection*	☑ Ja / *Yes*	☐ Nein / *No*
Anweisung für die Verbindung und Anschluss des Kollektors an den Wärmeträgerkreislauf *instructions for connection of the collector to the heat transfer circle*	☐ Ja / *Yes*	☑ Nein / *No*
Maße von Rohranschlüssen bei Kollektorgruppen bis 20 m² *dimensions of tube connections for collector arrays up to 20 m²*	☑ Ja / *Yes*	☐ Nein / *No*
Empfehlung der verwendbaren Wärmeträgermedien *recommendation of usable heat transfer fluid*	☑ Ja / *Yes*	☐ Nein / *No*
Vorsichtsmaßnahmen bei Füllung, Betrieb und Wartung *precaution for filling, operating and maintenance*	☑ Ja / *Yes*	☐ Nein / *No*
maximaler Betriebsüberdruck *maximum operating pressure*	☑ Ja / *Yes*	☐ Nein / *No*
maximaler Druckabfall *maximum pressure drop*	☐ Ja / *Yes*	☑ Nein / *No*
größter und kleinster Neigungswinkel *maximum and minimum tilt angle*	☑ Ja / *Yes*	☐ Nein / *No*
Wartungsanforderungen *maintenance requirements*	☐ Ja / *Yes*	☑ Nein / *No*

1.3. Schematische Darstellung des Sonnenkollektors (aus Unterlagen des Herstellers)
Schematic diagramm of the collector (by the manufacturer)





1.4. Fotografie des Kollektors / *Photograph of the collector*



2. Protokoll der Prüfreihenfolge und Zusammenfassung der Hauptergebnisse

Record of test sequence and summary of main results

Test *test*	Teststart *test start*	Testende *end of test*	bestanden *pass*
1. Leistungsprüfung *performance test*	18.5.2009	25.6.2009	**Ja / *yes***
2. Endkontrolle *final inspection*	26.6.2009	26.6.2009	**Ja / *yes***

3. Ergebnisse der Leistungsprüfung

Test results of thermal performance test

Prüfbedingungen *test conditions*	
Prüfverfahren *test methode*	stationär Indoor *steady-state / indoor*
Lampentyp *type of lamps*	Metallhalogen *metal halide*
Schutz vor langwelliger Strahlung *shading of longwave radiation*	ja *yes*
Bestrahlungsstärke G^*_{mittel} (Wm^{-2}) *irradiance* G^*_{mean} (Wm^{-2})	816
G^*_{mittel} bei K 50° - Messung (Wm^{-2}) G^*_{mean} *at K 50° - measurement* (Wm^{-2})	605
Massenstrom (kgh^{-1}) *flow rate* (kgh^{-1})	273,8
Umgebungsluftgeschwindigkeit (ms^{-1}) *ambient air velocity* (ms^{-1})	3+/-1

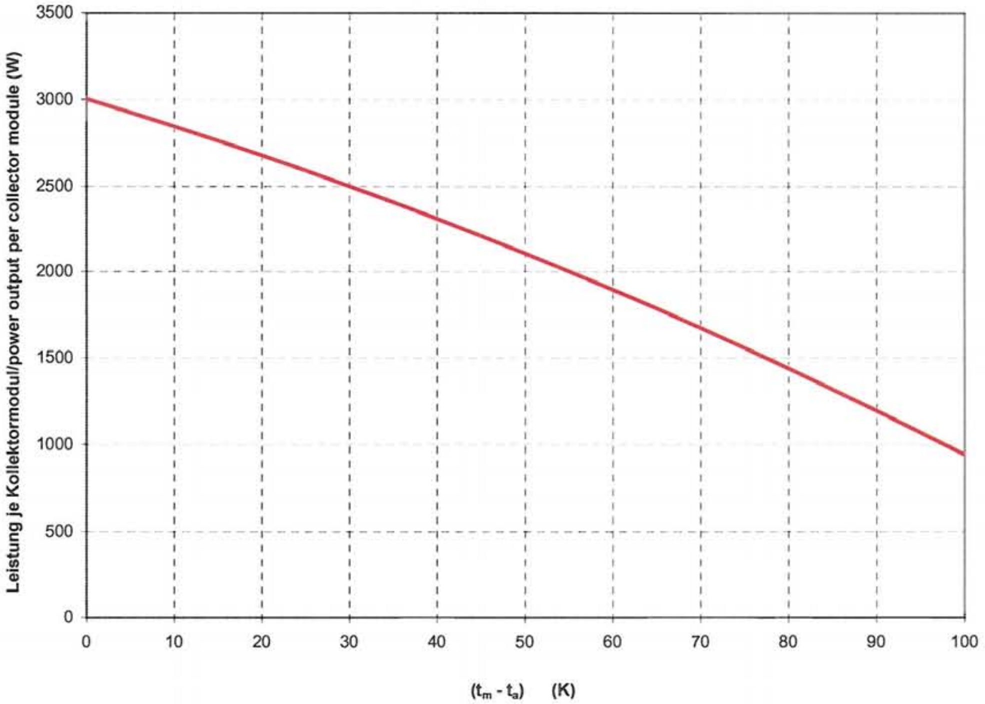
Wirkungsgradgleichung
efficiency equation

$$\eta = \eta_0 - a_1 (T_m - T_a)/G^* - a_2 (T_m - T_a)^2 / G^*$$

Koeffizienten der Wirkungsgradgleichung *coefficients of the efficiency equation*					
bezogen auf die Aperturfläche A_a *based on aperture area A_a*					
η_{0a} =	**0,790**	a_{1a} =	**3,979**	a_{2a} =	**0,014**
bezogen auf die Absorberfläche A_A *based on absorber area A_A*					
η_{0A} =	**0,809**	a_{1A} =	**4,073**	a_{2A} =	**0,015**

4. Leistungskennlinie (G^{*}_{Norm} = 1000 Wm^{-2})

Peformance curve (G^{*}_{Norm} = 1000 Wm^{-2})



Kollektorleistung (W) *performance of collector (W)*		Bestrahlungsstärke (Wm^{-2}) *irradiance (Wm^{-2})*		
		400	700	1000
T_m-T_a (K)	10	1044	1945	2846
	30	728	1599	2500
	50	307	1208	2109
Spitzenleistung (G=1000 W/m²) je Kollektormodul (W_{peak}) *Peak performance (G=1000 W/m²) per collector module (W_{peak})*		**3003**		

5. Einstrahlwinkel - Korrekturfaktor

Incident angle modifier

Winkelkorrekturfaktor K50° *incidence angle modifier*	**0,94**

6. Ergebnisse der Druckabfallmessung

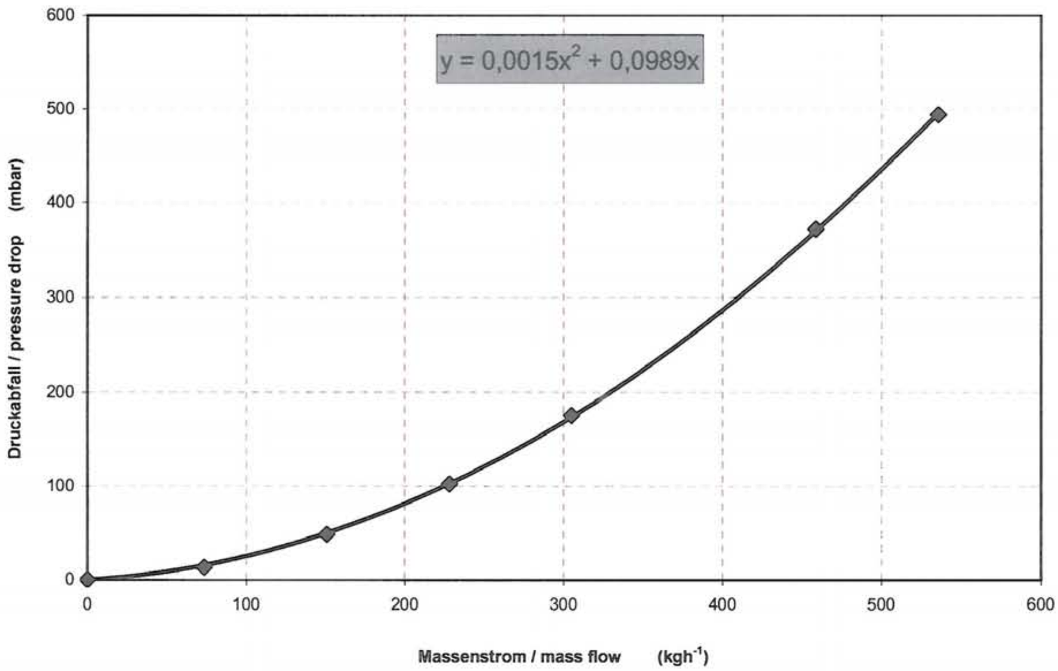
Test results of pressure drop measurement

Durchgeführte Messungen:
conducted measurements:

- Temperatur des Wärmeträgers am Kollektoreintritt
  temperature of heat transfer fluid at collector inlet
- Massenstrom des Wärmeträgers
  mass flow of heat transfer fluid
- Druckabfall des Wärmeträgers zwischen Kollektoreintritts- und -austrittsanschlüssen
  pressure drop of heat transfer fluid between collector inlet and -outlet.

Messung - Nr. *measurement - No.*	Volumenstrom *volume flow* (lh^{-1})	Fluid-Temperatur *temp. heat transfer fluid* (°C)	Massenstrom *mass flow* (kgh^{-1})	Druckabfall *pressure drop* (mbar)
1	0,0	20,5	0,0	0,0
2	73,7	20,4	73,6	13,3
3	151,0	20,3	150,8	48,3
4	228,6	20,3	228,2	102,5
5	305,5	20,3	305,0	175,6
6	459,5	20,4	458,7	371,9
7	536,5	20,4	535,6	493,8

Kennlinie Druckabfall / *pressure drop curve*



7. Effektive Wärmekapazität des Kollektors

Effective heat capacity of the collector

Berechnung der Wärmekapazität *calculation of heat capacity*
$C = \sum_i p_i m_i c_i$

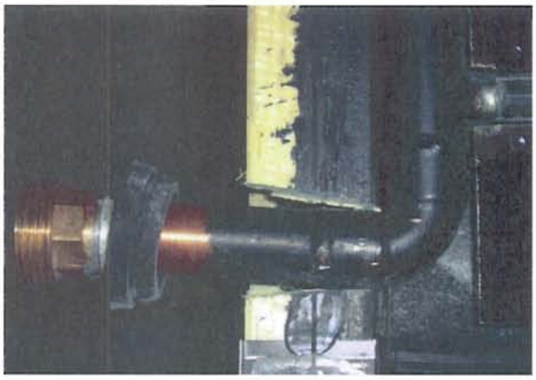
	Absorber *absorber*		Wärmeträger *heat transfer fluid*	Wärmedämmung *thermal insulation*	Abdeckung *cover*
Material *material*	Kupfer *copper*	Alu	H_2O:Glykol (60%:40%)	Steinwolle *rock wool*	Glas *glass*
Masse (kg) *weight (kg)*	5,87	5,38	3,00	13,00	38,90
spez. Wärmekapazität ($kJkg^{-1}K^{-1}$) *specific heat capacity ($kJkg^{-1}K^{-1}$)*	0,39	0,94	3,70	0,84	0,75
Wichtung *weighting*	1,00	1,00	1,00	0,50	0,03
Wärmekapazität d. Bauteils (kJK^{-1}) *components heat capacity (kJK^{-1})*	2,26	5,06	11,10	5,46	0,96

Wärmekapazität des Kollektors c_{eff} (kJK^{-1}) *heat capacity of the collector c_{eff} (kJK^{-1})*	**24,84**
Wärmekapazität c_{eff} bezogen auf die Aperturfläche ($kJK^{-1}m^{-2}$) *heat capacity c_{eff} based on the aperture area ($kJK^{-1}m^{-2}$)*	**6,53**

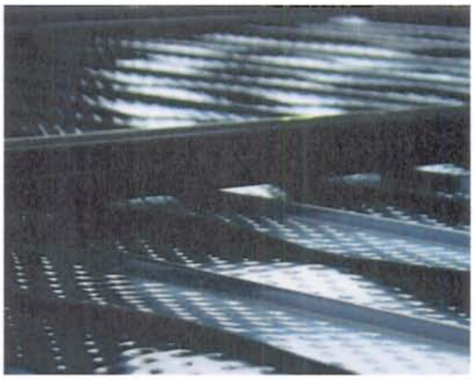
8. Endüberprüfung
Final inspection

8.1. Beobachtung und Dokumentation
Monitoring and documentation

Ansicht des geöffneten Kollektors
view of the opened collector



Ansicht der Gehäusedurchführung des Sammelrohres und des Rohranschlusses
view of frame- feedthrough of header tube and of the tube connection



Ansicht des Mittelsteges
view of the middle bar

Es wurden keine sichtbaren Veränderungen festgestellt.
There have been no visible changes.

9. Bewertung

Evaluation of results

0 kein Problem *0 no problem*	1 geringfügiges Problem *1 marginal problem*	2 gravierendes Problem *2 serious problem*	* Inspektion war nicht möglich ** inspection was impossilble*

Komponente *component*	**mögliche Probleme** *possible problems*	**Bewertung** *evaluation*
1. Kollektorgehäuse *collector casing*	Bruch, Aufwerfung, Korrosion, Eindringen von Wasser *breakage, bendings, corrosion, penetration of water*	**0**
2. Befestigungen / Glashalter *mountings / glass holder*	Materialermüdung/Sicherheit *fatigue of material / security*	**0**
3. Dichtungen *sealings*	Bruch, Adhäsion, Elastizität *breakage, adhesion, elasticity*	**0**
4. Abdeckungen/Reflektoren *covers / reflectors*	Bruch, Riss-, Blasen- und Kondensatbildung, Auflösung *breakage, tearing, lumps, dissolution, condensation*	**0**
5. Absorberbeschichtung *absorber coating*	Bruch, Rissbildung, Blasenbildung *breakage, tearing, lumps*	**0**
6. Absorber-, Verteil- und Sammelrohre *absorber-, distributor- and header-tube*	Deformation, Korrosion, Leckage *deformation, corrosion, leakage, disconnection*	**0**
7. Absorberbefestigung *absorber mounting*	Deformation, Korrosion *deformation, corrosion*	**0**
8. Wärmedämmung *thermal insulation*	Wasseraufnahme, Ausgasung, Degradation *water absorption, emissin of gas, degradation*	**0**

Die Prüfergebnisse beziehen sich ausschließlich auf die geprüften und von uns gekennzeichneten Kollektoren.
Der oben angeführte Kollektor hat die beschriebenen Prüfungen nach EN 12975-2:2006 bestanden.
The test results refer only to the collector which was tested by arsenal research.
The collector which is mentioned above has passed the described tests according to EN 12975-2:2006.

Zeichnungsberechtigter

Ing. Heinrich Huber, BSc

Projektleiter

DI (FH) Roland Sterrer, BSc

Anhang A: Nomenklatur

Appendix A: Nomenclature

A_A	Absorberfläche des Kollektors / *absorber area*	m^2
A_a	Aperturfläche des Kollektors / *aperture area*	m^2
A_G	Bruttofläche des Kollektors / *gross area*	m^2
a_1	linearer Wärmeverlustkoeffizient / *algebraic constant, reference to T*m*	$Wm^{-2}K^{-1}$
a_2	quadratischer Wärmeverlustkoeffizient / *algebraic constant, reference to T*m*	$Wm^{-2}K^{-2}$
C	effektive Wärmekapazität des gesamten Kollektors *effective thermal capacity of collector*	JK^{-1}
c_i	spezifische Wärmekapazität der Kollektorbauteile *specific thermal capacity of collector components*	$Jkg^{-1}K^{-1}$
c_f	mittlere spezifische Wärmekapazität des Wärmeträgers *specific heat capacity of heat transfer fluid*	$Jkg^{-1}K^{-1}$
G^*	globale Bestrahlungsstärke / *global irradiance*	Wm^{-2}
K_θ	Winkelkorrekturfaktor bei Einstrahlwinkel θ / incidence angel modifier	
$\dot{m}$	Massenstrom des Wärmeträgerfluids / *mass flowrate of heat transfer fluid*	kgs^{-1}
m_i	Masse eines Kollektorbauteiles / *mass of collector components*	kg
p_i	Wichtungsfaktor zur Berechnung der effektiven Wärmekapazität *Factor of weighting*	
$\dot{Q}_{Nutz}$	Nutzleistung des Kollektors / *useful power extracted from collector*	W
$\dot{Q}_{zu}$	zugeführte (eingestrahlte) Leistung / *power from irradiance*	W
t_a	Umgebungslufttemperatur / *ambient air temperature*	°C
t_e	Kollektoraustrittstemperatur des Wärmeträgers / *collector outlet temperature*	°C
t_i	Kollektoreintrittstemperatur des Wärmeträgers / *collector inlet temperature*	°C
t_m	mittlere Temperatur des Wärmeträgers im Kollektor *mean temperature of heat transfer fluid*	°C
v	Umgebungsluftgeschwindigkeit / *surrounding air speed*	ms^{-1}
η	Kollektorwirkungsgrad / *collector efficiency*	
η_0	Konversionsfaktor (Wirkungsgrad bei $T_m = T_a$) *zero- loss collector efficiency (efficiency at* $T_m = T_a$*)*	

Appendix L

System Plans

3.1 Solare Brauchwasserbereitung

Mehrere Varianten der solaren Brauchwasserbereitung können gerechnet werden:

3.1.1 Solare Brauchwassererwärmung mit Brauchwasserspeicher

Einspeichersystem mit internen oder externen Wärmetauscher oder einer Schichtladeeinheit. Die Nachheizung kann über einen Heizkessel und/oder eine E-Patrone erfolgen. Das Brauchwasser wird dem Speicher direkt entnommen. Die Beheizung durch den Kessel kann mit *Steuerung/Warmwasserspeicher/ Kesselenergie/max. Speichertemperatur* = 0 unterbunden werden. Dies wäre dann der Fall einer einfachen Solaranlage mit E-Patrone als Nachheizung.

Steuerung/Warmwasserspeicher/Solarenergie/ max. Speichertemperatur	> 20°C
Steuerung/Pufferrspeicher/Solarenergie/max. Speichertemperatur	= 0°C
WW-Speicher/Kesselwärmetauscher, Solarwärmetauscher	Intern oder extern
Steuerung/Kollektor/Vorrang für solare Energiezufuhr	Vorrang Warmwasserspeicher
Steuerung/Kessel/Kesselenergie zur Warmwassererzeugung	Direkt in den WW-Speicher
Gebäude+Heizung/Ferwärmenetz	Nein

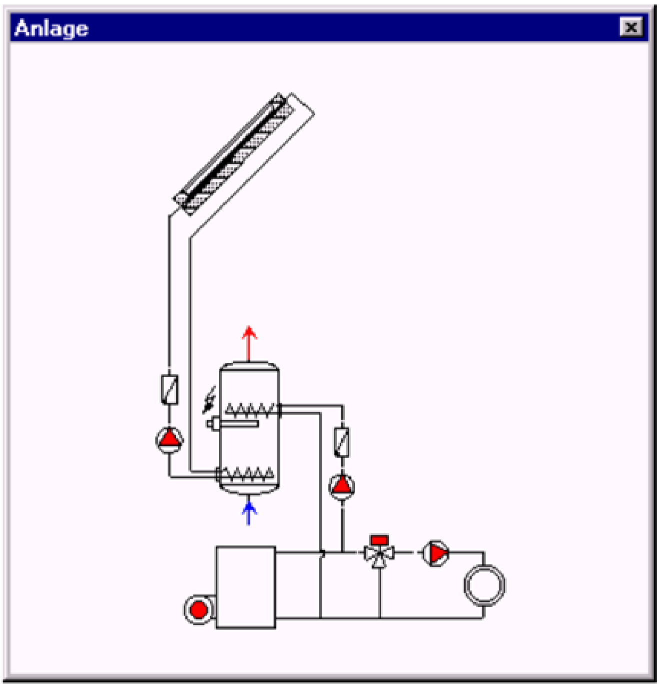


Bild 6: Solare Brauchwassererwärmung mit Brauchwasserspeicher

Figure L.1: DHW system with DHW storage [45].

3.1.2 Solare Brauchwassererwärmung mit Pufferspeicher und Durchlauferhitzer

System wie unter 3.1.1. allerdings unter Verwendung des PU-Speichers und Aufheizen des Brauchwassers in einem externen Durchlauferhitzer (Gegenstromwärmetauscher). Mit einer drehzahlgeregelten Pumpe auf der Speicherseite des Durchlauferhitzers wird immer (falls möglich) die benötigte Brauchwassertemperatur erreicht. Dieses System eliminiert die (ohnehin sehr unwahrscheinliche) Gefahr einer Legionellenbildung im Brauchwasser. Zusätzlich zu der dargestellten Schaltung (Bild 7) kann natürlich auch eine E-Patrone im Pufferspeicher eingesetzt werden.

Steuerung/Warmwasserspeicher/ Solarenergie/max. Speichertemperatur	= 0°C
Steuerung/Pufferrspeicher/ Solarenergie/max. Speichertemperatur	>20°C
PU-Speicher/Solarwärmetauscher	= Schichtlader
	(dies wird bei Durchlauferhitzern empfohlen ist aber im Programm nicht verpflichtend)
WW-Speicher/Kesselwärmetauscher	= extern
Steuerung/Kollektor/ Vorrang für solare Energiezufuhr	= Vorrang Heizenergiespeicher
Steuerung/Kessel/ Kesselenergie zur Warmwassererzeugung	= In den Pufferspeicher (WW-Erzeugung über Durchlauferhitzer)
Gebäude+Heizung/Ferwärmenetz	= Nein
Kessel/KesselArt	= Feste Kesseltemperatur

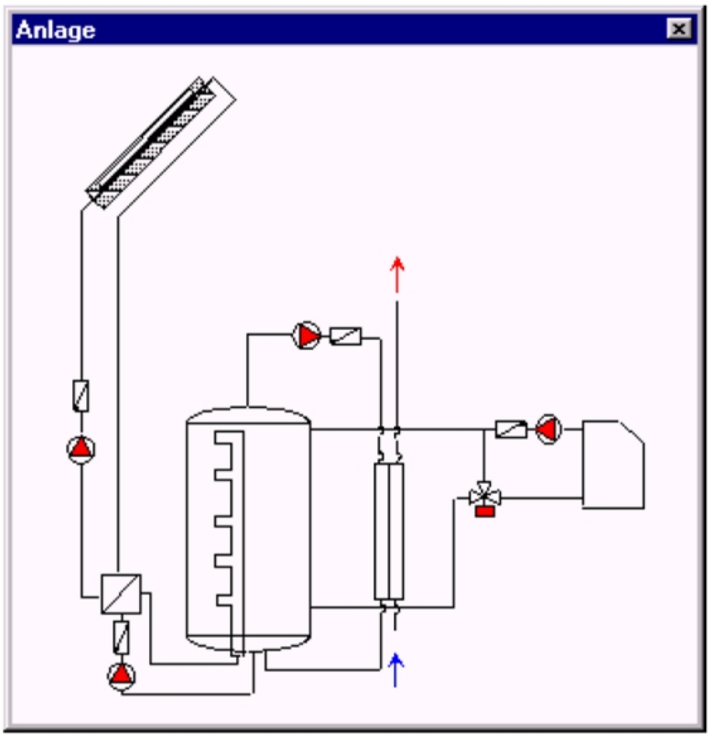


Bild 7: Solare Brauchwassererwärmung mit Pufferspeicher mit Schichtladeeinheit und Durchlauferhitzer

Figure L.2: DHW system with heat storage and continuous flow heater [45].

3.1.3 Solare Brauchwasserbereitung mit 2 Speichern (Pufferspeicher und kleiner Brauchwasserspeicher)

Die folgende Schaltung ist ein Zwei-Speicher System. Die Solaranlage lädt einen Pufferspeicher (wahlweise auch temperturabhängig in 2 Höhen). Dieser kann zusätzlich von einem Kessel und/oder einer E-Patrone nachgewärmt werden. Anschließend wird vom Pufferspeicher ein Brauchwasserspeicher über einen internen oder einen externen Wärmetauscher geheizt. Hier kann eine Nachheizung noch über eine E-Patrone erfolgen. Auch bei dieser Schaltung wird (bei kleinem Brauchwasserspeicher) eine allfällige Legionellenbindung unterbunden. Die Ladung durch den Kessel kann *mit Steuerung/Pufferspeicher/Zufuhr von Kesselenergie/Max. Speichertemperatur* = 0°C unterbunden werden. Dann findet die Nachheizung nur im Brauchwasserspeicher statt.

Steuerung/Warmwasserspeicher/ Solarenergie/max. Speichertemperatur	= 0°C
Steuerung/Pufferrspeicher/Solarenergie/max. Speichertemperatur	> 20°C
Steuerung/Kollektor/Vorrang für solare Energiezufuhr	= Vorrang Pufferspeicher
Steuerung/Kessel/Kesselenergie zur Warmwassererzeugung	= In den Pufferspeicher (WW-Erzeugung über eigenen Kreis)
Gebäude+Heizung/Ferwärmenetz	= Nein
Kessel/KesselArt	= Feste Kesseltemperatur

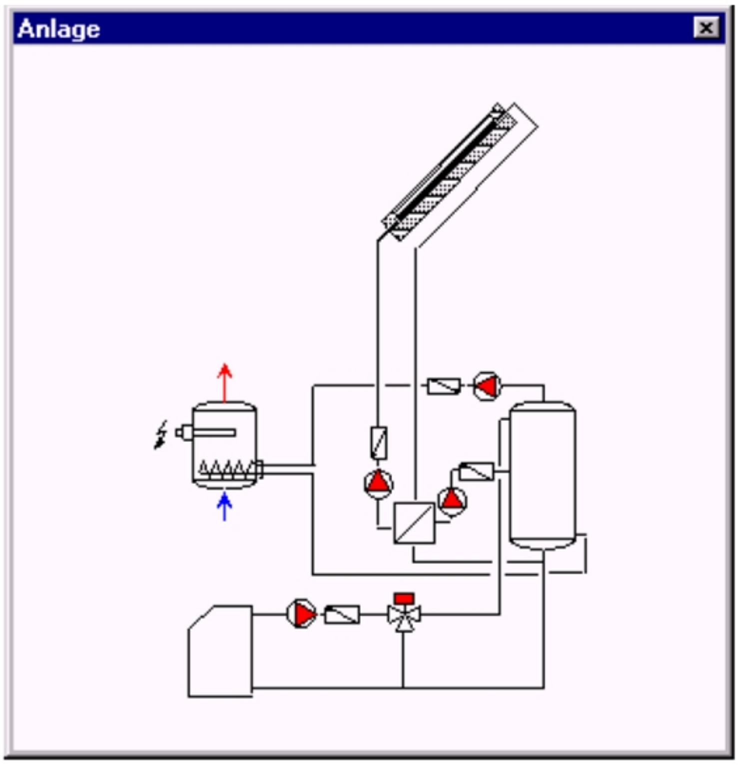


Bild 8: Solare Brauchwasserbereitung mit 2 Speichern (Pufferspeicher und kleiner Brauchwasserspeicher)

Figure L.3: DHW system with heat- and small DHW storage [45].

3.2.4 Teilsolare Raumheizung, 1-Speichersystem, Heizkessel in HZ-Speicher, WW-Durchlauferhitzer

Das folgende System ist ein 1-Speicher-System zur teilsolaren Raumheizung (ähnlich System 3.1.2). Die Warmwassererzeugung erfolgt über den Heizungsspeicher mittels Durchlauferhitzer. Der speicherseitige Massenfluß wird hierbei so drehzahlgeregelt, daß möglichst die gewünschte Brauchwassertemperatur erreicht wird. Der Heizungsspeicher sollte vom Kessel her nachladbar sein. Dieses System wird besonders bei Low-Flow Systemen (großes ΔT im Kollektor) mit Schichtladeeinheit der Solarenergie im Heizungsspeicher eingesetzt.

Steuerung/Warmwasserspeicher/ Solarenergie/max. Speichertemperatur	= 0°C
Steuerung/Pufferrspeicher/ Solarenergie/max. Speichertemperatur	> 20°C
WW-Speicher/Kesselwärmetauscher	= extern
Steuerung/Kollektor/Vorrang für solare Energiezufuhr	= Vorrang Pufferspeicher
Steuerung/Kessel/Kesselenergie zur Warmwassererzeugung	= In den Pufferspeicher (WW-Erzeugung über Durchlauferhitzer)
Gebäude+Heizung/Ferwärmenetz	= Nein
Kessel/KesselArt	= Feste Kesseltemperatur

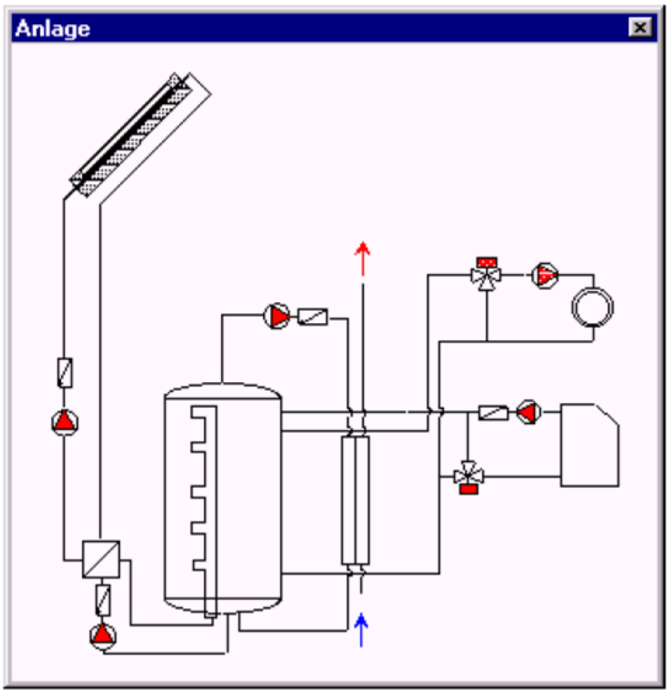


Bild 12: Teilsolare Raumheizung, 1-Speichersystem, Heizkessel in PU-Speicher, WW-Durchlauferhitzer

Figure L.4: Combisystem with one heat storage and continuous flow heat exchanger [45]

3.2.3 Teilsolare Raumheizung, 2-Speichersystem, Heizkessel nur in HZ-Speicher

Dies ist ein ähnliches System wie das unter 3.2.1 beschriebene. Es erfolgt jedoch die Nachheizung des Brauchwasserspeichers über einen internen oder externen Wärmetauscher aus dem Heizungsspeicher heraus. Dieses System funktioniert nur, falls der Heizungsspeicher auch vom Heizkessel aus nachgeladen werden kann.

Als Vorteil gegenüber Variante 3.2.1 und 3.2.2 sei herausgestellt, daß im Sommer ein größeres Wasservolumen für die solare Brauchwassererwärmung zur Verfügung steht. Zudem braucht der Wärmetauscher zum Nachheizen des Brauchwasserspeichers nicht auf die volle Kesselleistung ausgelegt werden und der Kessel kann im Sommer ebenfalls, falls benötigt, beide Volumina nutzen, was zu längeren Laufzeiten führt.

Steuerung/Warmwasserspeicher/Solarenergie/max. Speichertemperatur	> 20°C
Steuerung/Pufferrspeicher/Solarenergie/max. Speichertemperatur	> 20°C
Steuerung/Kollektor/Vorrang für solare Energiezufuhr	(alle Arten möglich)
Steuerung/Kessel/Kesselenergie zur Warmwassererzeugung	In den Pufferspeicher (WW-Erzeugung über eigenen Kreis)
Gebäude+Heizung/Ferwärmenetz	= Nein
Kessel/KesselArt	= Feste Kesseltemperatur

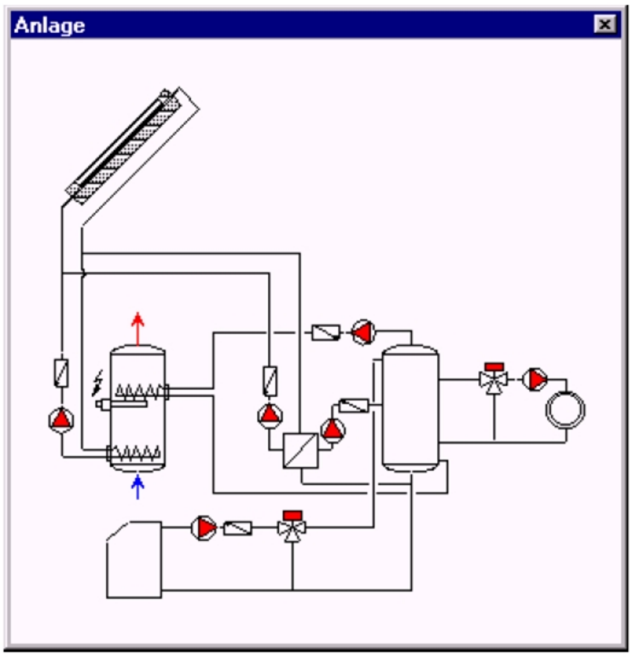


Bild 11: Teilsolare Raumheizung, 2-Speichersystem, Heizkessel nur in HZ-Speicher

Figure L.5: Combisystem with two storages [45]

Appendix M

Energy Reports in Croatia

Data about energy in Croatia are provided by the 'ANNUAL ENERGY REPORT' published from the ministry of economy, labour and entrepreneurship. The data for that report and most of the content are produced by the Energy Institute Hrvoje Požar (EIHP).
The founder of this Institute is the government of the Republic of Croatia. Its goals are to provide expert and scientific support in any sense connected with strategic development of the Croatian energy system, the processes of legislative reform and development and the advancement of economic relations.
The Institute's main challenge lies in the transformation of the Croatian energy system, from the past communist structure, into an open energy market that conform with the legislative, formal and institutional structures as they are defined by the 'Directives of the European Union'. Furthermore a major task is the initiation of 'National Energy Programmes' which aim to create adequate preconditions for an increase in energy efficiency and a more substantial utilisation of renewable energy sources.
As a result, the Institute is ready to undertake a leading role in the field of energy within the entire region.

Appendix N

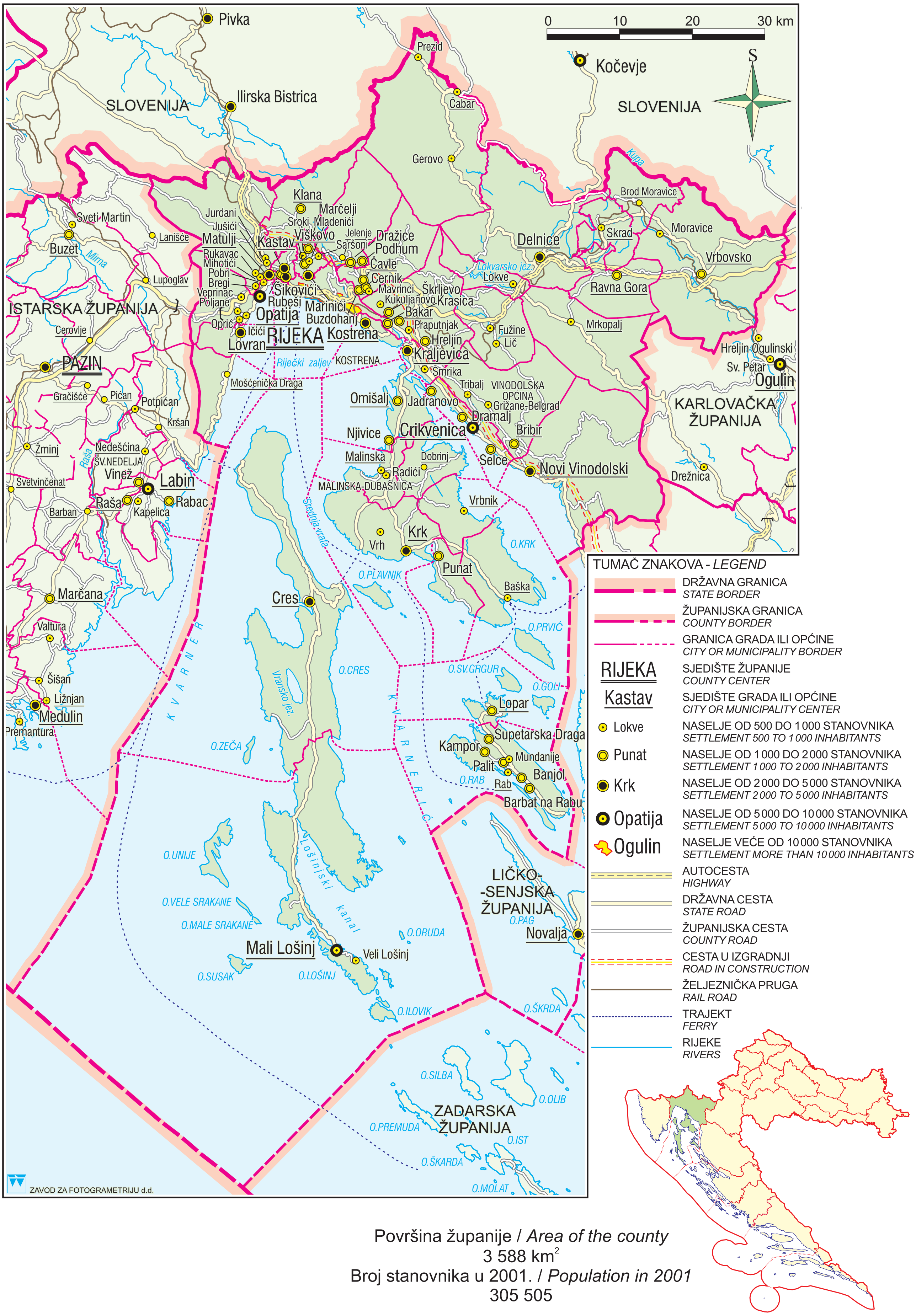
Maps

ŽUPANIJE REPUBLIKE HRVATSKE

COUNTIES OF THE REPUBLIC OF CROATIA

I.	Zagrebačka županija	*I.*	*County of Zagreb*
II.	Krapinsko-zagorska županija	*II.*	*County of Krapina-Zagorje*
III.	Sisačko-moslavačka županija	*III.*	*County of Sisak-Moslavina*
IV.	Karlovačka županija	*IV.*	*County of Karlovac*
V.	Varaždinska županija	*V.*	*County of Varaždin*
VI.	Koprivničko-križevačka županija	*VI.*	*County of Koprivnica-Križevci*
VII.	Bjelovarsko-bilogorska županija	*VII.*	*County of Bjelovar-Bilogora*
VIII.	Primorsko-goranska županija	*VIII.*	*County of Primorje-Gorski kotar*
IX.	Ličko-senjska županija	*IX.*	*County of Lika-Senj*
X.	Virovitičko-podravska županija	*X.*	*County of Virovitica-Podravina*
XI.	Požeško-slavonska županija	*XI.*	*County of Požega-Slavonia*
XII.	Brodsko-posavska županija	*XII.*	*County of Sl. Brod-Posavina*
XIII.	Zadarska županija	*XIII.*	*County of Zadar*
XIV.	Osječko-baranjska županija	*XIV.*	*County of Osijek-Baranja*
XV.	Šibensko-kninska županija	*XV.*	*County of Šibenik-Knin*
XVI.	Vukovarsko-srijemska županija	*XVI.*	*County of Vukovar-Sirmium*
XVII.	Splitsko-dalmatinska županija	*XVII.*	*County of Split-Dalmatia*
XVIII.	Istarska županija	*XVIII.*	*County of Istria*
XIX.	Dubrovačko-neretvanska županija	*XIX.*	*County of Dubrovnik-Neretva*
XX.	Međimurska županija	*XX.*	*County of Međimurje*
	Grad Zagreb		*City of Zagreb*

VIII. PRIMORSKO-GORANSKA ŽUPANIJA
COUNTY OF PRIMORJE-GORSKI KOTAR



Površina županije / *Area of the county*
3 588 km²
Broj stanovnika u 2001. / *Population in 2001*
305 505

Appendix O

Steam and Hot Water in Croatia

Table O.1: Steam and hot water, production, supply, consumption[13]

		2002	2003	2004	2005	2006	2007	2007 /06	2002 -07
		PJ						%	
Proizvodnja	**Production**	**31,025**	**32,507**	**35,093**	**34,418**	**33,224**	**32,447**	**-2,3**	**0,9**
-javne toplane	-public cogeneration plants	8,933	9,653	9,561	9,847	8,888	8,676	-2,4	-0,6
-javne kotlovnice	-public heating plants	3,171	3,470	3,304	3,478	2,984	2,988	0,1	-1,2
-industrijske toplane	-industrial cogeneration plants	12,476	12,503	15,836	15,468	15,576	15,398	-1,1	4,3
-industrijske kotlovnice	-industrial heating plants	6,445	6,881	6,392	5,625	5,775	5,385	-6,8	-3,5
Ukupna potrošnja	**Energy supplied**	**31,025**	**32,507**	**35,093**	**34,418**	**33,224**	**32,447**	**-2,3**	**0,9**
Gubici distribucije	Distribution losses	1,556	1,615	1,564	1,673	1,504	1,746	16,1	2,3
Neto potrošnja	**Total consumption**	**29,469**	**30,892**	**33,529**	**32,745**	**31,719**	**30,700**	**-3,2**	**0,8**
Potrošnja energetike	**Total energy sector**	**7,760**	**7,966**	**9,621**	**9,136**	**9,160**	**9,047**	**-1,2**	**3,1**
-proizvodnja nafte i plina	-oil and gas extraction	0,000	0,000	0,858	0,847	0,669	0,231	-65,5	
-degazolinaža	-NGL plant	0,000	0,000	0,508	0,512	0,512	0,470	-8,2	
-javne toplane	-public cogeneration plants	0,815	0,883	0,891	0,871	0,770	0,798	3,6	-0,4
-rafinerije	-petroleum refineries	6,945	7,084	7,364	6,907	7,209	7,548	4,7	1,7
Neposredna potrošnja	**Final demand**	**21,709**	**22,926**	**23,908**	**23,609**	**22,559**	**21,653**	**-4,0**	**-0,1**
Industrija	**Industry**	**14,179**	**14,478**	**15,625**	**15,072**	**14,956**	**14,377**	**-3,9**	**0,3**
-željeza i čelika	-iron and steel	0,148	0,224	0,164	0,142	0,114	0,010	-91,2	-41,5
-obojenih metala	-non-ferrous metals	0,006	0,006	0,000	0,002	0,000	0,000		
-stakla i nem. minerala	-non-metallic minerals	0,187	0,360	0,091	0,070	0,197	0,185	-6,3	-0,3
-kemijska	-chemical	3,096	3,557	5,115	4,893	4,788	4,776	-0,2	9,1
-građevnog materijala	-construction materials	0,064	0,038	0,036	0,030	0,033	0,019	-43,5	-21,7
-papira	-pulp and paper	1,545	1,637	1,975	2,278	2,207	1,748	-20,8	2,5
-prehrambena	-food production	5,747	5,425	4,726	4,548	4,745	4,740	-0,1	-3,8
-ostala	-not elsewhere specified	3,387	3,232	3,518	3,108	2,872	2,901	1,0	-3,1
Opća potrošnja	**Other sectors**	**7,529**	**8,448**	**8,283**	**8,536**	**7,603**	**7,276**	**-4,3**	**-0,7**
-kućanstva	-households	6,144	6,742	6,587	6,876	6,119	5,785	-5,5	-1,2
-usluge	-services	1,386	1,706	1,696	1,661	1,485	1,491	0,5	1,5

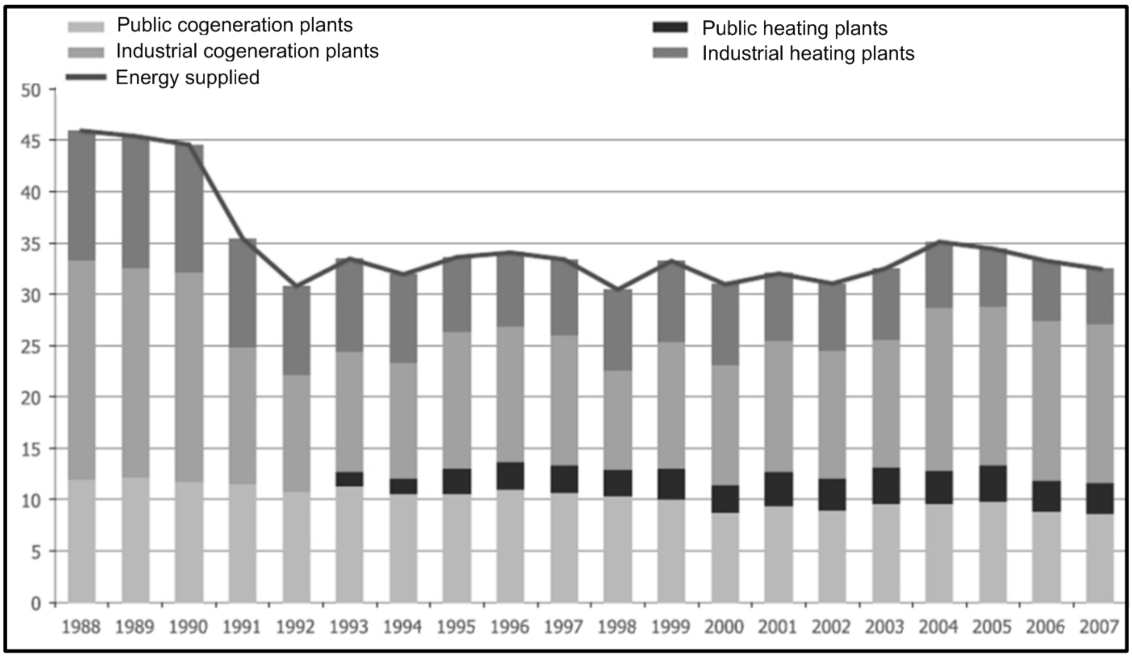


Figure O.2: Steam and hot water, production [13]

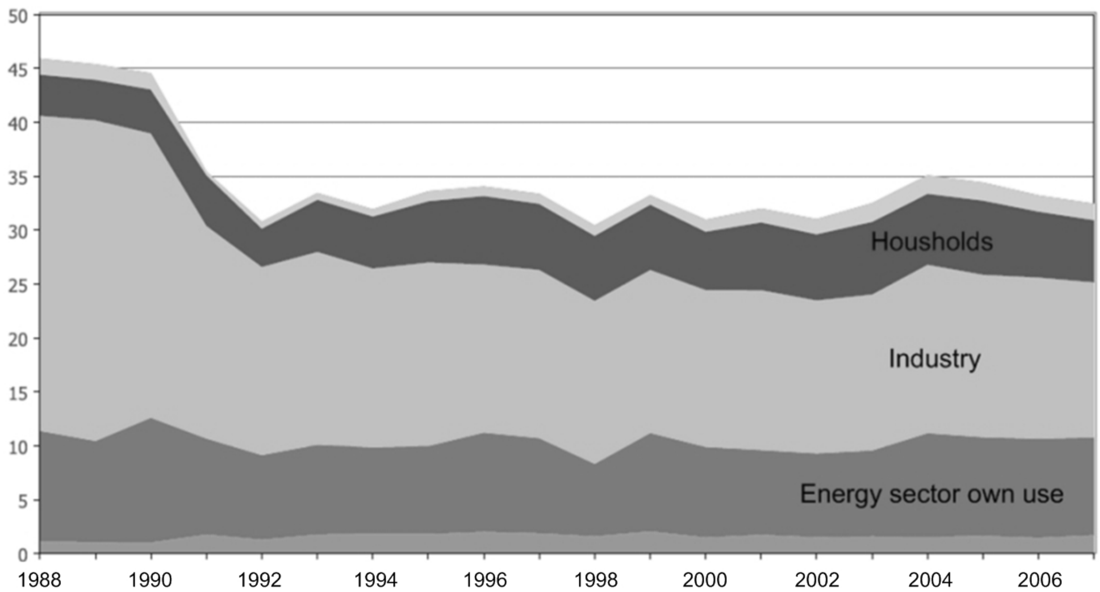
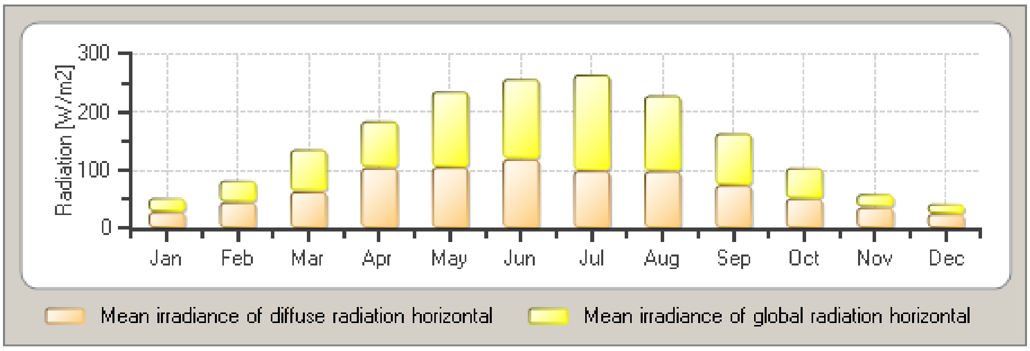


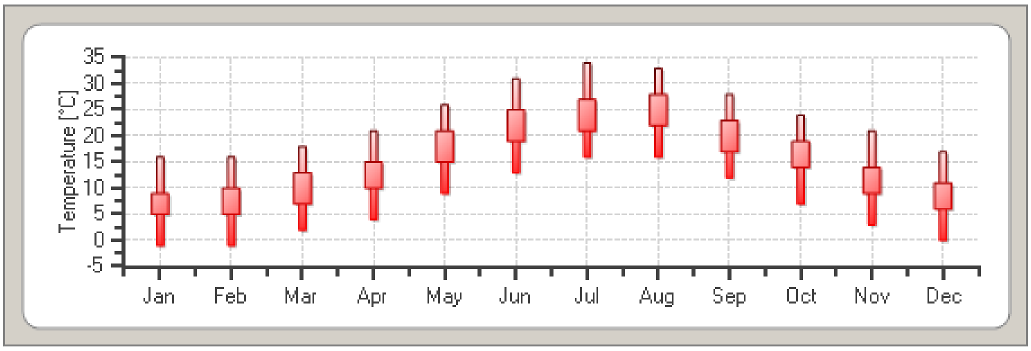
Figure O.3: Steam and hot water, consumption [13]

Appendix P

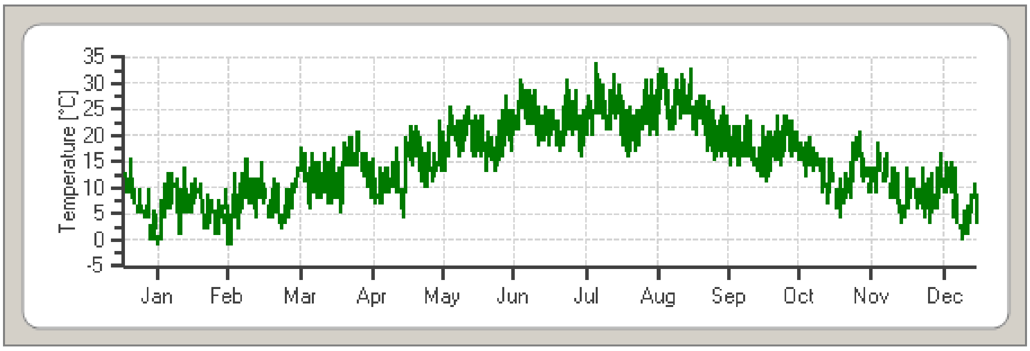
Climate Data Overview



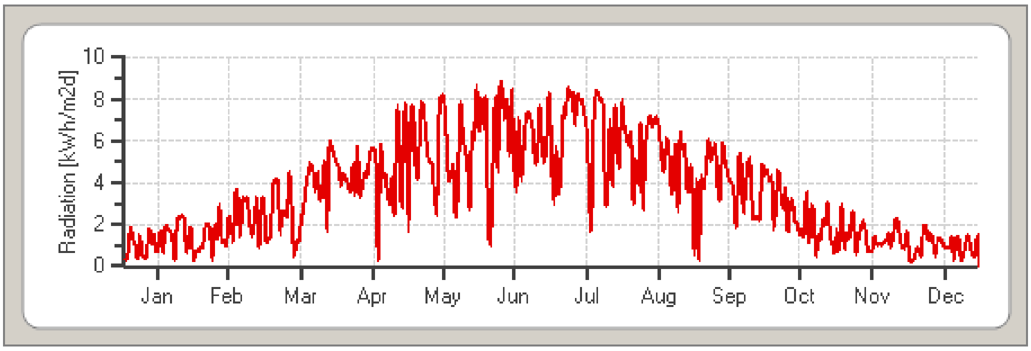
C:\Program Files\Common Files\mn61\output\Fig_ghdh2.png



C:\Program Files\Common Files\mn61\output\fig_tamima2.png



C:\Program Files\Common Files\mn61\output\fig_tadaily2.png



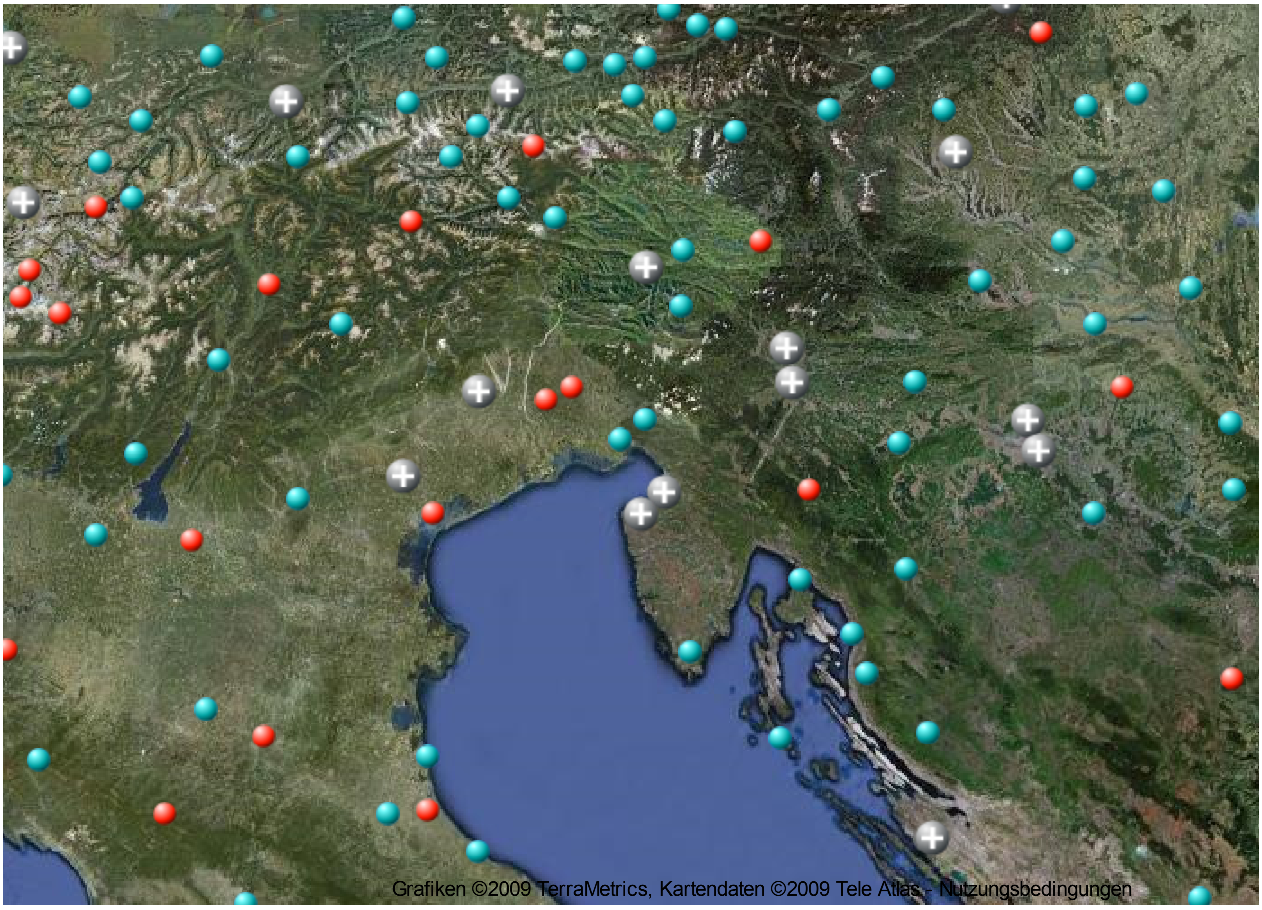
C:\Program Files\Common Files\mn61\output\fig_ghdaily2.png

METEONORM
a product by

Messstationen

Die METEONORM Datenbank hat Messdaten von über 8000 Stationen gespeichert. Die folgende Google Karte zeigt Ihnen diese an. Das Laden aller Informationen benötigt einige Zeit - bitten haben Sie Geduld.

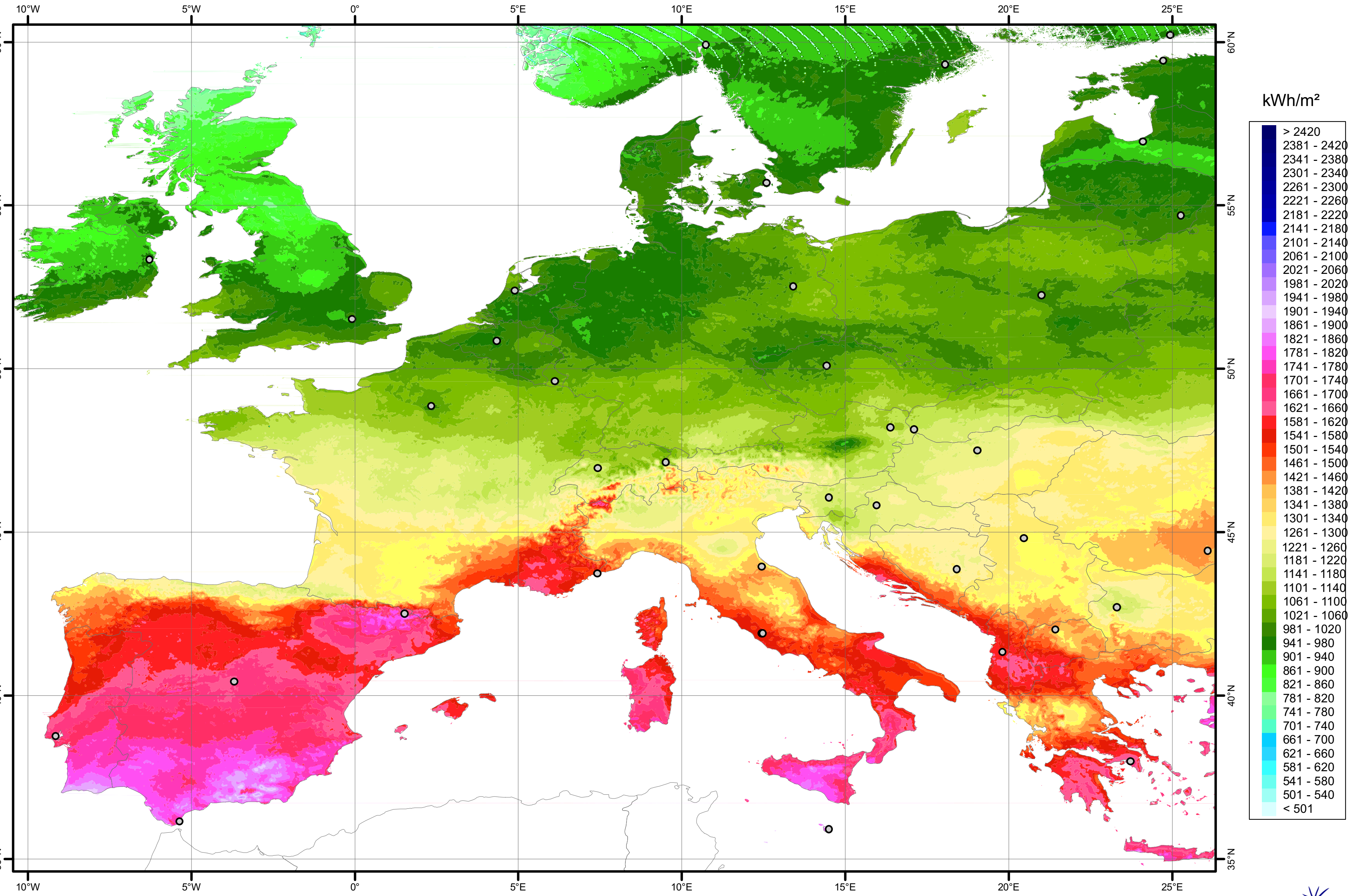
Eine Cluster-Funktion erkennt jegliche Gruppe(n) von zwei und mehr Stationen, dessen Icons sich überlagern. Diese Gruppen werden durch das Zoom Icon ersetzt. Dieses Icon zeigt, wenn angeklickt, die darunter liegenden Stationen und vergrössert den Kartenausschnitt entsprechend. Verweilen Sie mit dem Mauszeiger über einem dieser Icons so wird die Anzahl versteckter Stationen angezeigt.



Legend:
Legende:

●	with irradiation (Gh) measurement mit Einstrahlungsmessung (Gh)	number of stations: Anzahl Stationen:	1422
●	without irradiation (Gh) measurement ohne Einstrahlungsmessung (Gh)	number of stations: Anzahl Stationen:	6633
		total number of stations: Total Anzahl Stationen:	**8055**

Two or more stations whose icons visually intersect when displayed are clustered and displayed with this zoom icon! Hover over these icons to see how many stations are contained or click on it to see all of those stations.



Globalstrahlung: Langjähriges Mittel

2. April 2008/fd

METEOTEST

Afterword

A good introduction to solar thermal energy along the Croatian coast provides [22]. Recommended literature in the context of solar energy in English and Croatian language: [2], [55], [56], [57].

Major results from this research were published at the EuroSun 2010 in Graz [1]. This publication includes also an economical analysis and the systems are smaller in size but more efficient.