AIGUASOL Enginyeria

C/ Palau 4, 2º 2ª
E-08 002 BARCELONA

Tel.: (+34) 93 342 47 55
Fax: (+34) 93 342 47 56
E-Mail: hans@aiguasol.com

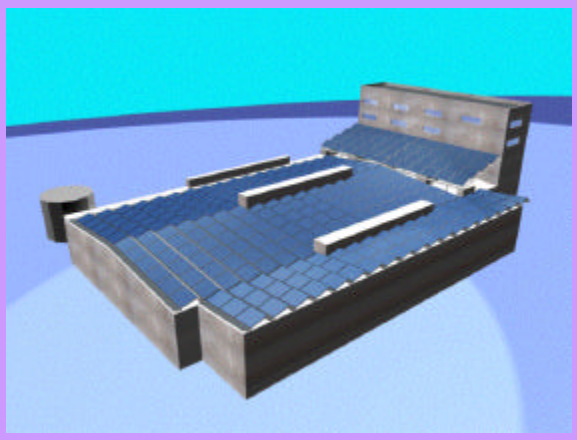
FINAL REPORT

POSHIP

The Potential of Solar Heat for Industrial Processes

Project No. NNE5-1999-0308





ENERGY, ENVIRONMENT
AND SUSTAINABLE DEVELOPMENT

EUROPEAN COMMISSION
DIRECTORATE GENERAL
ENERGY AND TRANSPORT

Project co-ordination and contact address:

AIGUASOL Enginyeria

Hans Schweiger
Palau 4, 2º 2ª
08002 BARCELONA (Spain)

tel.: +34 93 342 47 55
fax: +34 93 342 47 56
e-mail: hans@aiguasol.com
web: www.aiguasol.com

Participating organisations:

Inst. Nacional de Engenharia e Tecnologia Industrial (INETI)

João Farinha Mendes
Estrada do Paço do Lumiar, 22
1649-038 LISBOA (Portugal)

tel.: +351 21 712 71 86
fax: +351 21 712 71 95
e-mail: farinha.mendes@ineti.pt
web: www.ineti.pt

Bayr. Zentrum für angewandte Energieforschung e.V. (ZAE)

Christiane Schwenk
Domagkstr. 11
80807 MÜNCHEN (Alemania)

tel.: +49 89 35 62 50 30
fax: +49 89 35 62 50 23
e-mail: schwenk@
a4.zae.physik.uni-muenchen.de
web: www.zae-bayern.de

Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR)

Klaus Hennecke
Linder Höhe
51147 KÖLN (Alemania)

tel.: +49 2203 601 32 13
fax: +49 2203 669 00
e-mail: klaus.hennecke@dlr.de
web: www.dlr.de

Instituto para la Diversificación y Ahorro de la Energía (IDAE)

Carlos García Barquero
Pº de la Castellana 95, Planta 21
28046 MADRID (España)

tel.: +34 91 456 50 32
fax: +34 91 555 13 89
e-mail: cgbarquero@idae.es
web: www.idae.es

Institut Català d'Energia (ICAEN)

Albert Mitjá i Sarvisé
Av. Diagonal 453 bis, àtic
08036 BARCELONA (España)

tel.: +34 93 622 05 00
fax: +34 93 622 05 01
e-mail: renovables.icaen@menta.es
web: www.icaen.es

Sociedade Portuguesa de Energía Solar (SPES)

Dra. Maria João Carvalho
Edificio M1 – Campus do INETI-DER
Estrada Paço do Lumiar, 22
1649-038 LISBOA (Portugal)

tel.: +351 21 716 69 03
fax: +351 21 715 72 69
e-mail: spes@spes.pt
web: www.spes.pt

Web-site:

www.aiguasol.com/poship.htm

1 INTRODUCTION 9

2 OVERVIEW OF THE POSHIP PROJECT 11
2.1 OBJECTIVES OF POSHIP 12
2.2 INNOVATION AND MAIN RESULTS 14
2.3 STRUCTURE OF THE WORK 15

3 SOLAR THERMAL TECHNOLOGY 17
3.1 INTRODUCTION 18
3.2 SOLAR COLLECTOR TYPES 20
3.2.1 Flat Plate Collectors 20
3.2.2 Evacuated (Tube and Flat Plate) Collectors 20
3.2.3 CPC Type Collectors (Stationary Concentrators) 21
3.2.4 Parabolic Trough Collectors 21
3.2.5 Comparison of Market Available Solar Collectors 23
3.3 SOLAR SYSTEM CONCEPTS 25
3.3.1 Introduction 25
3.3.2 Industrial Solar Systems without Storage 25
3.3.3 Industrial Solar Systems with Heat Storage 26
3.4 SYSTEM THERMAL AND ECONOMICAL EVALUATION 27
3.4.1 System Efficiency 27
3.4.2 Energy Costs 31
3.5 EXISTING SOLAR PROCESS HEAT PLANTS 34

4 CASE STUDIES 38
4.1 OVERVIEW 39
4.2 METHODOLOGY 41
4.2.1 Data Acquisition - Questionnaire 41
4.2.2 Case Studies 44
4.2.3 Detailed Case Studies (Proposals for Demonstration Plants) 59
4.3 RESPONSE TO THE MAILING AND DIRECT INDUSTRY CONTACTS 60
4.3.1 Mailing IDAE (Spain) 60
4.3.2 Mailing ICAEN (Catalonia) 62
4.3.3 Mailing SPES (Portugal) 63
4.3.4 Direct Contacts by AIGUASOL (Spain) 65
4.3.5 Analysis of the Response 65
4.4 CASE STUDIES 67
4.4.1 Spain 67
4.4.2 Portugal 75
4.4.3 Parabolic Trough Technology 77
4.4.4 Response from Industry 82

5 PROPOSALS FOR DEMONSTRATION PROJECTS 83

5.1 MALTING FACTORY: HEINEKEN ESPAÑA S.A., SEVILLA (SPAIN) 86

5.1.1 Description of the Proposed Solar System ... *86*
5.1.2 Optimisation of the System - Step I: Comparison of Solar Collector Types and Parametric Study. ... *90*
5.1.3 Optimisation of the System. Step II: Comparison of Design Alternatives ... *100*
5.1.4 Integration of Solar Thermal System and Heat Recovery ... *102*

5.2 MALTIBÉRICA – SOCIEDADE PRODUTORA DE MALTE S.A. (PORTUGAL) 105

5.2.1 Identification and Location ... *105*
5.2.2 Solar Energy Integration ... *107*
5.2.3 Solar System Design ... *109*
5.2.4 Solar Energy Project Impact ... *113*
5.2.5 Conclusions and Recommendations ... *114*

5.3 BEIRALÃ – *LANIFÍCIOS S.A.* (PORTUGAL) 116

5.3.1 Identification and Location ... *116*
5.3.2 Solar Energy Integration ... *117*
5.3.3 Solar System Design ... *118*
5.3.4 Solar Energy Project Impact ... *122*
5.3.5 Conclusions and Recommendations ... *124*

5.4 BODEGAS MAS MARTINET, TARRAGONA (SPAIN) 125

6 GUIDELINES FOR EVALUATION AND SYSTEM DESIGN 128

6.1 FEASIBILITY ANALYSIS – EVALUATION CRITERIA 129

6.1.1 Selection of Appropriate Interfaces for the Coupling of a Solar System ... *129*
6.1.2 Influence of the Working Temperature ... *130*
6.1.3 Continuity of the Load and Storage ... *130*
6.1.4 Climatic Zones in the Iberian Peninsula ... *131*
6.1.5 Summary of Evaluation Criteria ... *132*

6.2 GUIDELINES FOR SYSTEM DESIGN 133

6.2.1 Solar Collector Field ... *133*
6.2.2 Storage ... *134*
6.2.3 Coupling to the Existing Heat Supply and Regulation ... *134*
6.2.4 Solar Thermal Systems and Cogeneration ... *135*

7 APPLICATION POTENTIAL 137

7.1 RESULTS OF THE POSHIP-STUDY 139

7.1.1 Quantitative Analysis of the Industrial Heat Demand and the Solar Process Heat Potential *139*
7.1.2 Qualitative Aspects ... *142*

7.2 BEER BREWING AND MALTING 145

7.2.1 Malt ... *145*
7.2.2 Beer ... *145*

7.3 FOOD INDUSTRY 146

7.3.1 Wine and Other Beverages ... *146*
7.3.2 Meat ... *146*
7.3.3 Canned Vegetables ... *146*
7.3.4 Canned Fish Production ... *146*
7.3.5 Children Nutrition Products ... *147*

7.4 MILK INDUSTRY 148

7.5 TEXTILE INDUSTRY 148

7.5.1 Finishing 148
7.5.2 Wool Production 148
7.6 PAPER INDUSTRY 149
7.6.1 Paper Pulp Production 149
7.6.2 Paper Production 149
7.7 CHEMICAL INDUSTRY 149
7.8 AUTOMOBILE INDUSTRY AND AUXILIARY INDUSTRIES 149
7.8.1 Tyre Production 149
7.8.2 Painting Section 149
7.9 TANNING SECTOR 150
7.10 CORK INDUSTRY 150
8 PUBLIC FUNDING FOR INDUSTRIAL SOLAR THERMAL SYSTEMS 152
8.1 PUBLIC FUNDING 153
8.1.1 European Community Funding Programmes 153
8.1.2 National Funding Programmes 153
8.1.3 Regional Funding Programmes 154
8.2 FINANCING OF INDUSTRIAL SOLAR THERMAL SYSTEMS 157
8.2.1 Spain: IDAE-ICO Financing Solution 158
8.2.2 The FITA SOLAR Programme in Catalonia 158
8.2.3 Andalucía: PROSOL Programme 158
8.2.4 Canary Islands: PROCASOL Programme 158
8.3 ADMINISTRATIVE MEASURES AND ENERGY POLICY (PORTUGAL) 160
8.4 PRESENT SITUATION AND FUTURE PROSPECTS 161
9 DISSEMINATION ACTIVITIES 162
9.1 INFORMATIVE DOSSIER FOR INDUSTRY 163
9.2 POSHIP - BROCHURE 163
9.3 WORKSHOPS AND CONFERENCES 163
9.3.1 Workshops and Conferences Organised by the POSHIP Partners 163
9.3.2 Presentations on Other Events 164
9.4 OTHER PUBLICATIONS 165
9.5 CONCLUSIONS FROM DISSEMINATION ACTIVITIES 165
10 CONCLUSIONS 166
10.1 LESSONS WE LEARNED FROM POSHIP ... 167
10.2 ... STILL OPEN QUESTIONS ... 168
10.3 ... AND WHERE WE SHOULD GO IN THE FUTURE 169

REFERENCES **170**
General References *171*
Industrial Heat Demand and Potential for Solar Process Heating *171*
Solar Process Heat Plants *172*

COMPLEMENTS **173**

1 INTRODUCTION

Industrial solar thermal systems as a renewable energy source can cover a significant fraction of the industrial heat and electricity demand. This industrial heat demand constitutes about 1/3 of the total final energy demand in Southern European countries. About 7% of the total final energy is consumed in form of industrial process heat at temperatures below 250 °C. Fulfilling the goal of installing 2 000 000 m^2 of solar thermal collectors for industrial process heat and solar cooling, as outlined in the "Campaign for Take-Off" of the European Commission would represent a primary energy saving of about 2 000 000 MWh/year. Therefore, solar thermal energy in industry can be an important contribution to a reliable, clean, safe and cost-effective energy supply based on renewable energy sources.

Solar collectors for hot water production at low temperatures are a well-known and well-extended standard technology. With recently developed high performance solar collectors, heat at temperatures up to 250 °C can be produced with an excellent efficiency. Heat at these temperatures is required in many industrial processes, such as steam generation, washing, drying, distillation, pasteurisation, etc.

At present, industrial solar thermal systems are operating in Europe with a total installed collector surface of about 10 000 m^2. Solar collector arrays can be integrated either into industrial roofs or installed on an available ground area.

The large scale of industrial installations leads to very low cost systems, so that solar systems for industrial process heat production can become economically competitive to fossil fuels on a very short term. Present investment costs for solar thermal systems range from 250 to 500 €/m^2 (corresponding to 250-1 000 €/kW of thermal power) leading to average energy costs in Southern Europe from 2 to 5 cent/kWh for very low temperature applications and from 5 to 15 cent/kWh for medium temperature systems.

The present cost per kWh of saved primary energy in industrial applications is less than in small / medium scale solar domestic hot water applications and can be further reduced. Cost reductions can be obtained by large-scale production, reducing operation and maintenance costs and improving collector efficiency and system design, especially for medium temperature solar collectors. Cost reductions of up to 50% on a medium term (by 2010) are expected.

The present report is a summary of the results of the POSHIP project, a study on the potential for solar heat in industrial processes, funded by the European Commission within the 5th Framework Programme.

In this project, a large number of industries in Spain and Portugal have been analysed. Case studies for solar systems in industries with favourable conditions have been carried out resulting in possible solar industrial plants of more than 25 000 m^2.

2 OVERVIEW OF THE POSHIP PROJECT

2.1 OBJECTIVES OF POSHIP

Several studies have been carried out on the industrial heat demand at different temperature levels for several countries. A general tendency is confirmed, that more than 50 % of the industrial heat demand is at temperatures in the low (<60 ^{o}C), medium (60 ^{o}C - 150 ^{o}C) and medium-high (150 ^{o}C - 250 ^{o}C) temperature range. Nevertheless, the potential for the same industrial sectors can vary substantially from one country to another.

Detailed and recent studies for the heat demand at medium temperature level were not available for Southern European countries, were the application potential of solar energy is best (nearly double of yearly energy savings per unit collector area than in Central Europe). The industrial structure in Southern Europe is different from that in Central and Northern Europe, so that data cannot be directly extrapolated. Consequently one basic objective of the present study is to *quantify the potential of solar heat at medium temperature level for the Iberian Peninsula (Spain and Portugal)*. By means of questionnaires, interviews and case studies data for the heat demand of industry in these countries was acquired. A *classification* into different temperature intervals, industrial sectors and applied processes was carried out.

For the technical and economical feasibility of solar thermal energy use in industry not only the overall heat demand at low and medium temperature is of importance. *Several additional - technical and – non-technical - aspects* have to be considered:

- The annual, weekly and daily variation of the heat demand for different processes and temperature levels is of great importance. A continuous demand with maximum in summer favours solar energy use.
- The possibilities of a connection with available conventional heat supply units have to be analysed. Systems may be designed for preheating or generation of low-pressure steam. The possible interfaces with the available heat distribution systems have to be studied. A direct connection to the general steam distribution may be difficult, if this works at pressures corresponding to too high temperatures. A coupling with existing cogeneration systems may be possible in some cases.
- In the existing systems, great fluid volumes may already be available (existing storage tanks, steam vessels, liquid baths etc.). In these cases no additional storage for the solar system is necessary, so that system cost can be reduced.
- The available (roof-) area may be a limiting factor, and the possibility of integration into the roof of industrial buildings is of great importance. An adequate orientation of the building and an adequate inclination of the roof contribute to an optimum output of the solar system.
- The cost of conventional energy sources is the decisive factor for the economical evaluation of the solar system. Energy costs may vary from company to company, depending on the energy consumption and on special contractual agreements.

A second basic objective of this project was, therefore, the identification and analysis of these factors. *Detailed case studies* were carried out at two levels:

- in a first step, the principal factors mentioned above were analysed for a sufficiently large number of industries. The data have been statistically analysed, so that a representative overview of the technical and economical potential in different industrial sectors is obtained.
- in a second step, a detailed analysis and system optimisation was carried for a small number of projects with favourable conditions. The objective of this step is a detailed proposal for several demonstration projects. Companies participating in this second step had already shown their interest in developing a demonstration project in their industry.

In addition to the individual case studies, *clear general guidelines for the evaluation of the technical and economical feasibility of solar process heat* have been elaborated, that can easily be applied by technicians from industrial companies. These guidelines are available to the interested public in form of a brochure (as a hard copy and for download on the POSHIP web-site).

2.2 INNOVATION AND MAIN RESULTS

The innovative character and the main results of this project can be resumed as follows:

Application Potential

Detailed data material on industrial heat demand at medium temperatures for the Iberian Peninsula was not available before this project. The new data confirm the tendency that can be seen in several studies for other countries, showing a large application potential at medium temperature, especially high in industrial sectors such as the food industry, pulp and paper industry, textile industry. The technical potential for solar process heat in the Iberian Peninsula is estimated to 5 804 MWh (20.9 TJ). This corresponds to 3.6 % of the industrial heat demand and to 0.7 % of the total national final energy demand.

Case Studies and Design Guidelines

A detailed techno-economical evaluation of individual cases gives new insight in (technical and non-technical) problems that have to be solved in order to reach a market introduction. The general guidelines for the evaluation of the technical and economical feasibility of solar process heat in specific cases are an important tool for system designers.

Demonstration Projects and Market Introduction

The potential for solar process heat in industry is immense, but up to now has not been exploited except in very few pilot plants. At present system costs, which may be competitive to conventional energy sources under favourable conditions, a systematic study of the technical and economical potential can change this situation substantially.

The idea of using solar heat in industry has already been discussed in the 80ies, and several pilot plants have been built (see chapter 3.5). The new situation we have nowadays is a substantially reduced cost and improved technology for high efficient solar collectors and in addition an improved system technology (regulation, pumps, etc.). Some of these advances are due to recent developments that have been carried out within the 4th and 5th Framework Programme of the European Commission (Programmes JOULE-THERMIE and ENERGIE).

Within the present project, proposals for demonstration plants in several industries have been elaborated. These projects can contribute in a decisive way to the dissemination and market introduction of a technology using these components of recent development.

The present situation of energy policy and public funding programmes has been analysed in chapter 8.

2.3 STRUCTURE OF THE WORK

The work on the present project was structured into the following three blocks:

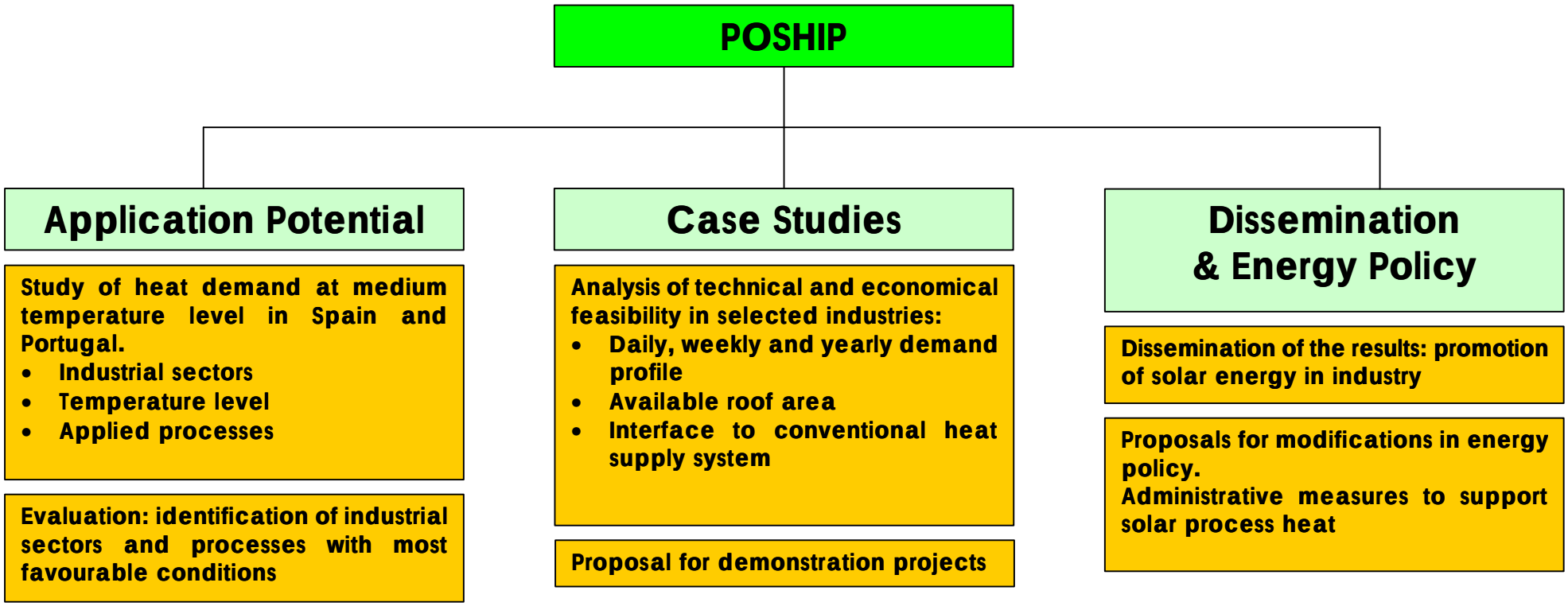
1. *Quantification of the potential* of solar heat at medium temperature level in the Iberian Peninsula, representative for the Southern European climate in general. *Classification* into different temperature levels, industrial sectors and applied processes. *Identification of the industrial sectors and processes* with most favourable conditions. Extensive data material for the industry in the Iberian Peninsula was collected by mailings and interviews. Together with a wide-spread mailing an informative dossier on the possibilities of solar process heat was distributed. (Chapter 9.1)

2. *Case studies, analysing the technical and economical feasibility* of solar process heat: annual, weekly and daily variation of the heat demand, connection with available conventional heat supply units and heat distribution system, available roof or ground area for collector installation. From the cases with best conditions, detailed *proposals for several demonstration projects* were elaborated. *Guidelines for evaluation* of the technical and economical feasibility were elaborated on the base of the collected data material and case studies (Chapters 4-6).

3. *Promotion* of the use of solar thermal energy in industry: edition of a brochure with extensive data material and additional material for dissemination; workshops for technicians of industry. *Analysis of present energy policy and administrative measures* with respect to solar process heat. Elaboration of adequate measures in order to include solar heat at medium temperatures into *public energy policy* programs. (Chapters 8 and 9)

The Potential for Solar Heat in Industrial Processes

Overview of the Work Programme



3 SOLAR THERMAL TECHNOLOGY

3.1 INTRODUCTION

Industrial processes usually require energy within a range of temperatures from ambient temperature to 250 °C. Active solar liquid or air heating systems can be used to deliver energy to these processes.

Depending on the temperature range needed, different solar collector technologies and different concepts for their integration into the industrial heating system can be considered.

In sections 3.2 and 3.3, a brief technical description of the available solar collector technologies and solar system concepts is given. Furthermore, an evaluation of the thermal and economical performance of active solar systems for industrial heat production is presented in section 3.4. Moreover, in section 3.5 an overview of some already existing projects can be seen.

The main component of a solar heating system is the *solar collector*. The simplest solar collector consists of a black surface with some fluid circulating in or around it, as means to extract the heat produced by the radiation absorbed from the sun for some practical application.

It is clear that the heat losses from such an absorber are large if nothing is done to reduce them, like placing it inside a box, with insulation behind it and with a transparent cover. This simple arrangement is known as a single cover flat plate collector

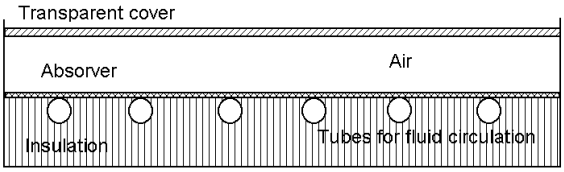


Figure 1. Cross section of a flat plate solar collector.

The selection of the appropriate collector type depends mainly on the desired working temperature and the climatic conditions.

Solar collector efficiency decreases as the fluid temperature increases or the available solar radiation decreases. A graphical representation of the instantaneous efficiency for different collector technologies is given in Figure 2.

For applications in which temperatures above 80 °C are required, standard flat plate collectors cannot be used since their efficiency is then lower than 40%.

Different collector technologies were developed in order to achieve a higher efficiency at higher temperatures. Two major types of solar collectors can be considered for industrial heat production:

Stationary collectors. These collectors do not use any mechanisms to track the sun. They can produce heat at low and medium temperatures up to 150 °C. Flat plate collectors, evacuated tube collectors and CPC type concentrators, belong to this group of collectors.

Parabolic trough collectors. These are one-axis sun tracking collectors used both in solar process heat plants and in large power plants for solar thermal electricity generation. Temperatures up to 300 °C can be obtained with good efficiency.

A description of the most important solar collector types is given in the following sections.

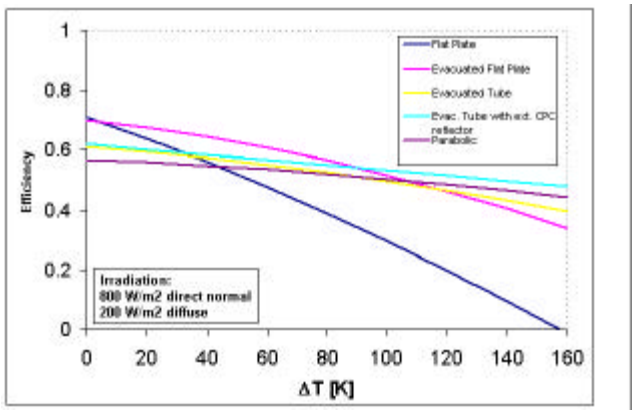


Figure 2. Instantaneous efficiency for different solar collector types.

Box 1. Solar collector efficiency parameters

The instantaneous efficiency (η) of a solar collector is defined by the ratio of the power delivered to the load (circulating fluid) to the incident solar irradiation on the aperture area of the collector. The efficiency is usually represented as a function of $\frac{\Delta T}{G_T}$ where:

ΔT (K) is the difference between the average fluid temperature (the temperature of the fluid used to extract the collected power) and the atmospheric temperature;

G_T (W/m^2) is the amount of incident solar radiation available to the collector.

η is thus written as:

$$\eta = c_0 - (c_1 + c_2 \Delta T) * \frac{\Delta T}{G_T}$$

Where:

c_0 is the optical efficiency (a function of the collectors' cover transmission, receiver absorption and reflectivity of mirrors in the case of concentrators)

c_1 , c_2 are the linear and quadratic heat loss coefficients; parameters that characterise the heat losses from the collector to the atmosphere (including convection, conduction and radiation heat losses mechanisms). c_1 (W/K m^2); c_2 (W/K^{2}m^2).

3.2 SOLAR COLLECTOR TYPES

3.2.1 Flat Plate Collectors

As already mentioned, the flat plate collector (FPC) is the simplest form to transform the energy from the sun into heat.

The fluid circulating in the absorber is mainly water (often with additives for freeze protection). However, other liquids (and even steam) can be used depending on the application, particularly depending on the operating temperature.

In an attempt to control heat losses, these collectors are built with the incorporation of different technologies.

Selective vs non-selective absorbers. Radiation losses are one of the three mechanisms of heat losses present in solar collectors. They can be controlled by the use of so-called selective coatings applied on the absorber. These coatings are designed to have the highest possible absorption in the visible and near infrared, and the lowest possible emissivity in the infrared corresponding to the collector operating temperatures. Collectors using these coated absorbers are called selective and all the others, with a simple black paint, are referred to as non-selective.

Single cover / double cover; convection barriers. Another heat loss mechanism is convection. One way to reduce the effect of convection is by using a double transparent cover, which is usually a transparent film placed behind the glass cover. The best material for this is Teflon, which has a high transmissivity and very good heat resistance. The use of transparent insulation materials is another possibility to build high efficient stationary flat plate collectors.

3.2.2 Evacuated (Tube and Flat Plate) Collectors

These devices eliminate the conduction and convection heat losses by removing the air surrounding the absorber: that is why they are called evacuated (see Figure 3).



Figure 3. Evacuated tube collector (ETC).

3.2.3 CPC Type Collectors (Stationary Concentrators)

Another way to reduce the heat losses of a solar collector consists in reducing the area of absorber with respect to the collecting area, since the heat losses are proportional to the absorber area and not to the collecting (aperture) area. This concentration can be obtained using reflectors that force the radiation incident within a certain angle into the collector aperture in direction to the absorber after one or more reflections.

The concentration of the solar radiation can be obtained by so-called non-imaging optics, where the relation between concentration and the above mentioned angle (called acceptance angle, θ) is the maximum allowed one by basic principles in physics and is, in a two dimensional geometry:

$$C_{max} = \frac{1}{\sin(\theta)}$$

For a fully stationary collector, θ must be large, i.e. the concentration must be low. It can be demonstrated that, for an ideal concentrator the acceptance angle should be θ = 30° and, in turn, the concentration would then be equal to 2.

These collectors are also called CPC (Compound Parabolic Concentrator) type concentrators (see Figure 4) since a combination of parabolas was the first configuration discovered to operate on the above-mentioned limit. Mirrors are produced with the proper shape and reflect the radiation on to the absorber.

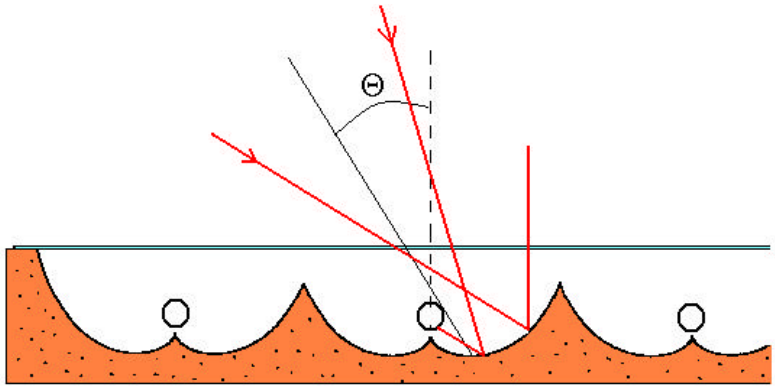


Figure 4. Layout of a CPC type collector with a tubular absorber.

The wide acceptance angle of these devices allows them to collect both diffuse and beam radiation just like a flat plate collector does. This is an interesting feature for this type of concentrators in comparison with tracking concentrators.

3.2.4 Parabolic Trough Collectors

Solar tracking concentrators are classified depending on the way they track the movement of the sun:

- *One-axis solar tracking and linear focus system*s can track the sun only along its angle of elevation over the horizon.

- In *two-axis tracking and point focus systems* (parabolic dishes, tower plants with heliostats and solar furnaces) the sunrays are always perpendicular to the collector surfaces. Point focus systems are normally used for applications over 400 °C only.

The most characteristic one axis-tracking collector is the so-called *parabolic trough collector* (PTC, see Figure 5). Parabolic trough collectors are the most mature concentrating solar technology to generate heat at temperatures up to 400 °C for solar thermal electricity generation or process heat applications. Reflectors with a parabolic shape concentrate the direct solar radiation onto the receptor located in the focal line of the parabola. The receptor consists of an absorber tube of an area usually 25 to 35 times smaller than the aperture. The fluid to be heated is circulated through the absorber piping. Water and thermal oil are typically used as working fluids.

Parabolic trough collectors have a very low thermal loss coefficient and are therefore well suited also for applications at higher temperatures. They do not use the diffuse part of the solar radiation. However, they make a better usage of the direct (beam) radiation than stationary collectors due to the sun tracking mechanism.



Figure 5. Parabolic trough collector with east-west oriented axis.

Only in the US several installations with collector areas between 500 m² and 2 500 m² have been erected in the 90‘s. They are reliably running in contrast to former systems. Several companies have started selling parabolic trough collectors for the temperature range between 50-300 °C in the last years. Two solar cooling projects with parabolic trough collectors in Barcelona (Spain) and Alanya (Turkey) will start operating in the year 2001.

3.2.5 Comparison of Market Available Solar Collectors

In Table 1 some market available solar collectors are listed. In order to obtain a fast comparison of different collector types, the efficiency for typical working conditions in solar process heat is calculated from the quadratic efficiency curve:

$$h = h_0 - (c_1 + c_2 \Delta T)\frac{\Delta T}{G_T}$$

The following parameters have been used:

- low temperature: ΔT = 40 K (T = 60 °C)
- medium temperature: ΔT = 80 K (T = 100 °C)
- beam radiation with normal incidence of G_T = 800 W/m^2

From these typical efficiency values an *effective collector area* has been calculated. The physical meaning of this effective area is as follows: the useful heat extracted from the solar collector is equal to the solar radiation incident to the effective area.

$$A_{effective} = hA_{absorber}$$

From the solar collector costs obtained from offers or catalogues from the installers the solar collector field costs are estimated supposing additional costs for supports, mounting and field piping of 80 €/m^2. From these data then the solar collector field costs per effective area are calculated and used for an approximate comparison (Table 1). A more exact comparison of different collector types for specific climatic conditions using dynamic system simulation is given below in section 3.4.

A graphical comparison between the collectors with best relation cost-efficiency in each sub-class is given in Figure 6. It can be seen that for medium temperature applications (100 °C) parabolic trough collectors are most cost effective, followed by high-performance stationary collectors (selective flat plate with convection barrier, non-evacuated CPC and evacuated flat plate collectors). For low temperature applications (60 °C) standard selective flat plate collectors are the most cost effective option, with little difference to other non-evacuated collectors and parabolic trough collectors.

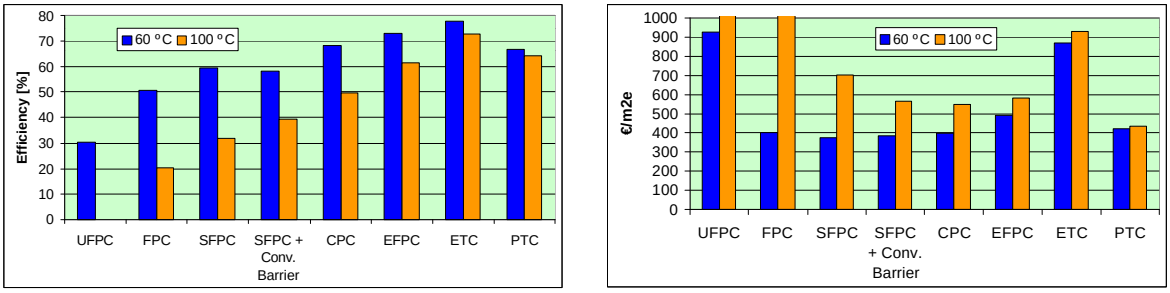


Figure 6. Comparison of different solar collector types. Left: mean collector efficiency at GT = 800 W/m^2, T_a = 20 °C. Right: solar collector field cost per effective area .

Table 1. Comparison of some market available solar collectors

	efficiency data					collector area(s)		collector cost (euro)			mean efficiency values η		solar collector field cost per effective area (installer)	
Collector model	η_0	c_1	c_2	b_0 (ASHRAE)	K(50°)	absorber	gross	end user (catalogue)	installer (500 m²)	cost per m² (installer)	low temp.	medium temp.	low temp.	medium temp.
	%	W/m2K	10^{-3} W/m²K²	-	-	m²	m²	€	€	€/m²	%	%	€/m²	€/m²
Unglazed selective collector														
Energie Solaire AS	93.0	12.00	14.0	0.09	*0.95*	1.93	2.13			200	30	0	*927*	*>1000*
Standard flat plate (black paint)														
Isofotón Garol I	84.4	8.30	0.0	*0.15*	*0.92*	1.88		379	*265*	141	43	1	*515*	*>1000*
MADE Unisolar 4000 E (theoretical)	81.0	6.08	0.0	*0.15*	*0.92*	2.13		373	*261*	122	51	20	*400*	*>1000*
FPC	**84.4**	**8.30**	**0.0**	**0.15**	***0.92***	**1.00**				**144**	**43**	**1**	***522***	***>1000***
Selective flat plate (black chrome and similar, e > 0.1)														
CHROMAGEN CR120	80.0	5.60	0.0	*0.09*	*0.95*	2.56		576	346	135	52	24	*414*	*896*
VIESSMANN CalorSol	82.0	3.37	23.0	*0.09*	*0.95*	1.70				*200*	61	30	*462*	*936*
UFE SOLAR Eurostar Sc	79.0	3.35	15.0	*0.09*	*0.95*	2.10	2.40	610	*366*	174	59	34	*429*	*759*
WAGNER Eurosolar C18	77.6	3.78	9.2	*0.09*	*0.95*	2.34	2.61	709	425	182	57	32	*461*	*808*
Highly selective flat plate (TINOX and similar, e < 0.1)														
ESTEC SK 6250 Prestige	84.5	4.50		0.09	*0.95*	*2.30*	2.50	743	*446*	194	62	40	*442*	*693*
KALKGRUBER Solarfocus F1 (tinox)	78.2	3.14	15.9	0.09	*0.95*	2.70	2.78	752	451	167	59	34	*417*	*726*
Paradigma Solar750	77.9	2.64	22.0	0.09	*0.95*	7.43	8.03	2606	*1564*	210	60	34	*482*	*857*
SOLVIS F75 TINox	*84.0*	*3.50*	*15.0*	0.09	*0.95*	7.40	8.20	2562	*1537*	208	64	37	*453*	*778*
SONNENKRAFT FK500	79.4	3.88	9.8	0.09	*0.95*	2.20	2.50	629	*377*	172	58	33	*433*	*768*
SONNENKRAFT GK6	79.8	3.28	18.7	0.12	*0.93*	5.62	6.31			145	60	32	*377*	*703*
UFE SOLAR Eurostar Tx	78.0	3.06	18.0	0.09	*0.95*	2.10	2.40	712	*427*	204	59	33	*480*	*859*
WAGNER Eurosolar C18-HT	80.8	3.50	12.2	0.09	*0.95*	2.34	2.61	780	*468*	200	61	36	*460*	*776*
SFPC	**79.4**	**3.88**	**9.8**	**0.09**	***0.95***	**1.00**				**168**	**58**	**33**	***427***	***757***
Selective flat plate with convection barrier (teflon foil, transparent insulation, double glazed collectors ...)														
ARCON HT	76.0	3.50	2.0			*12.50*	13.50			*142*	58	39	*382*	*563*
TINOx flat plate + 40 mm teflon TI	*80.0*	*2.50*	*5.0*			1.00		*300*	*210*	*210*	*67*	*51*	*436*	*569*
TINOx + CPC + 20 mm teflon TI	*75.0*	*1.50*	*5.0*			1.00		*300*	*210*	*210*	*67*	*56*	*436*	*518*
Non-evacuated CPC collectors														
AOSOL Sol 2002	60.0	3.50	14.0			1.97	2.23	338	*237*	120	40	14	*504*	*>1000*
AOSOL CPC 1.5 X	*70.0*	*3.00*	*10.0*			2.00		*450*	*315*	158	53	32	*448*	*742*
KALKGRUBER Solarfocus S1 (tinox)	74.1	3.30	12.0			2.70	2.78	959	*672*	249	55	32	*596*	*>1000*
SOLEL CPC 2000 C=1.2	82.8	2.50	10.0			2.03	2.23	557	*390*	193	68	50	*399*	*547*
SOLEL CPC 2000 C=1.75														
CPC	**82.8**	**2.50**	**10.0**	**0.20**	***0.89***	**1.00**				**184**	**68**	**50**	***387***	***530***
Evacuated flat plate collector														
THERMOSOLAR	81.0	1.26	8.6	0.24		*1.80*	2.00	893	*499*	*277*	73	62	*489*	*581*
Evacuated tube collector														
ESTEC VR12 CPC	82.5	0.91	0.6			1.50	2.20	1282	*897*	598	78	73	*872*	*931*
MICROTHERM SYDNEY SK-6	68.0	0.60	1.9			0.95	1.18	762	*533*	561	65	60	*992*	*>1000*
PARADIGMA CPC21	61.4	0.29	11.0			3.30	3.80	2251	*1576*	478	58	50	*965*	*>1000*
SOLEL VAC 2000 DS	79.1	0.38	2.3			0.90	1.64	*500*	*350*	389	*77*	*74*	*611*	*638*
Parabolic Trough Collector														
SOLEL 150	*77.0*	2.00	0.0			1.00				?	67	57	*?*	*?*
SOLEL VAC 300	*77.0*	1.00	0.0			1.00				?	72	67	*?*	*?*
IST	69.3	0.48	0.3			0.97	14.03			200	67	64	*419*	*435*
SOLITEM	*?*									?				
PTC	**69.3**	**0.48**	**0.3**			**1.00**				**200**	**67**	**64**	***419***	***435***

Standard conditions used for comparison	**DT** K	**G_T** W/m²
low temperature	40	800
medium temperature	80	800
Cost for supports, mounting, field piping	80	€/m2

Red numbers: estimated values
Green: best relation cost/efficiency within sub-class
Violet: standard collector types used in Case Studies

3.3 SOLAR SYSTEM CONCEPTS

3.3.1 Introduction

An industrial solar installation consists of a solar collector field through which water or water and glycol is circulated (primary circuit). A regulation system controls this circulation depending on the available solar radiation intensity. By means of a heat exchanger, solar energy can be used for the heating of liquids, air flows or for steam generation

The coupling of the solar system with the conventional heat supply system can be done in several points of the system: direct coupling to a specific process, pre-heating of water and steam generation in the central system.

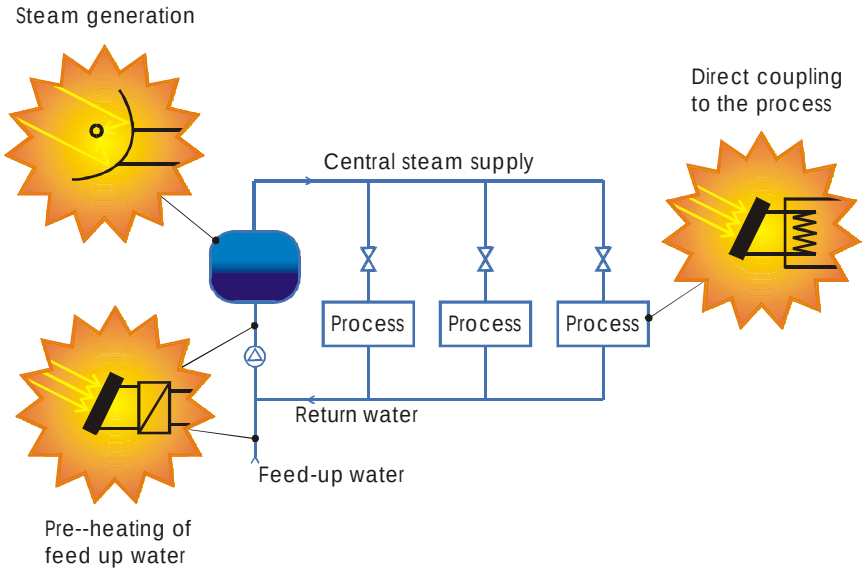


Figure 7. Possibilities for the coupling of the solar system with the conventional heat supply.

3.3.2 Industrial Solar Systems without Storage

In many industries the heat demand is so high that there is no need for storage of solar energy. This allows building very low cost solar systems by eliminating storage related costs.

The simplest case is an industrial solar system supplying heat for a process with a continuous operation and a load always (or at least during most operating hours) higher than the solar gains (process operating at least 12 hours per day during daytime).

In these cases, the solar system can be conceived without storage. The solar heat produced will be fed directly to the process or to the heat supply system. A scheme of such a system can be seen in Figure 8.

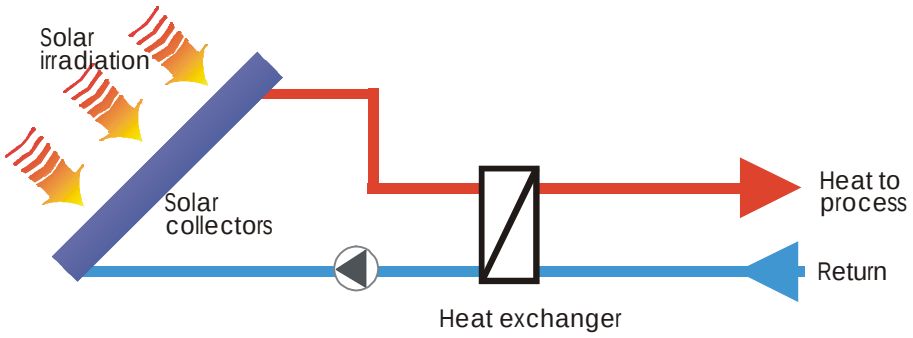


Figure 8. Solar system without storage.

The represented system is an indirect system, as the use of special fluids to protect the collector and its materials from freezing and corrosion, imposes the use of a heat exchanger to separate the collector circuit (primary circuit) from the load circuit.

3.3.3 Industrial Solar Systems with Heat Storage

If, as it is mostly common, the industrial process operates only 6 or 5 days a week and it is idle during the weekend, the system can be designed considering storage of the energy collected during these weekend-breaks. The collected energy will be used during the rest of the days of the week.

Storage may also be necessary if there are strong fluctuations of the process heat demand during the operational periods (demand peaks, short breaks of operation).

The principle of a solar thermal system with storage is shown in Figure 9.

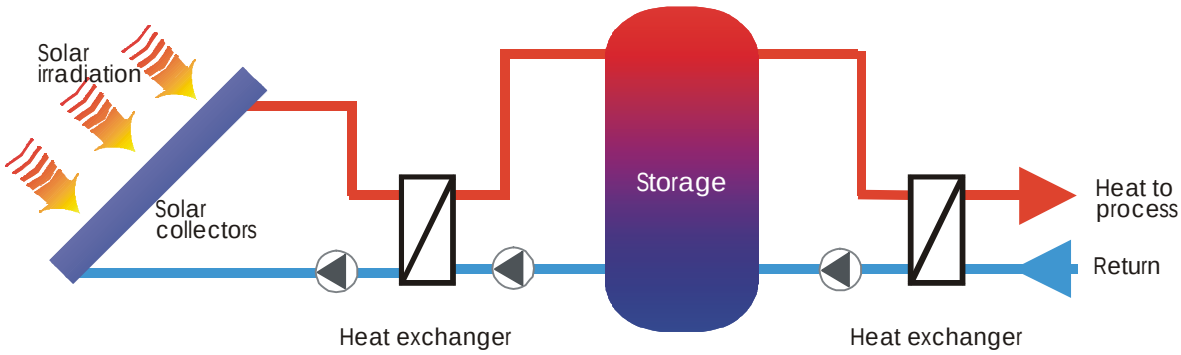


Figure 9. Solar system with heat storage.

3.4 SYSTEM THERMAL AND ECONOMICAL EVALUATION

3.4.1 System Efficiency

To estimate the solar energy gains, TRNSYS-calculations were carried out for 5 different sites: Bilbao, Barcelona, Madrid, Lisbon and Huelva (near Sevilla). Table 2 shows the global and the direct normal irradiation at these sites (data from METEONORM). Para un mapa de radiación solar de la Peninsula Ibérica ver sección 6.1.

Table 2. Irradiation at the 5 selected sites on the Iberian Peninsula.

Site	Annual global irradiation (horizontal) in kWh/m²a	Annual direct normal irradiation in kWh/m²a
Bilbao	1 294	1 092
Barcelona	1 445	1 312
Madrid	1 664	1 784
Lisbon	1 686	1 751
Huelva	1 872	2 092

For the calculations we used five different collectors. To cover the suitable and market available range of stationary collectors, 4 representative collector types were used:

- Flat-plate collector (FPC)
- Evacuated flat-plate collector (EFPC)
- Evacuated tube collector (ETC)
- Evacuated tube collector with external CPC-reflector

A parabolic trough collector was simulated as well (PTC). The collector parameters are given in Table 3. To allow comparability of the results, all parameters and output results are related to the collector gross area. The resulting efficiency curves are shown in Figure 11. They are related to a global irradiation of 1000 W/m2 (800 W/m² direct and 200 W/m² diffuse).

Table 3. Collector parameters for the five collectors applied in the simulation. R is the ratio between absorber area and collector gross area. h_0 is the optical efficiency and c_1 an c_2 are linear and quadratic heat loss coefficients. Efficiency parameters related to gross area.

Collector	R [-]	h_0 [-]	c_1 [W/m²K]	c_2 [W/m²K²]
flat-plate collector	0.89	0.71	3.52	0.0062
evacuated flat-plate collector	0.86	0.70	1,08	0.0074
evacuated tube collector	0.72	0.61	0.77	0.0036
CPC-collector	0.96	0.62*	0.87*	0
parabolic trough	0.071	0.69†	0.48†	0.0031†

(*) Only valid for normal incidence of the direct irradiation (G_d ³ 800 W/m²).
(†) For direct normal irradiation

For the estimation of the yearly energy supply to an arbitrary process, the following assumptions were made:

- The energy demand of the process is always bigger than the supply of the collector field.
- The collector field has a gross area of 1000 m² and consists of 20 m²-sections in 10 parallel rows. The non-tracking collectors are oriented towards south and are inclined with an angle, which is 90% of the local latitude (about 35°). Mutual shading of collectors is considered. The rows are fixed in a distance that exactly avoids shading at winter solstice noon. For parabolic trough collectors north-south orientation of the collector axis is regarded.
- Heat losses of the piping are considered by applying pipes in the collector field and by applying 50 m long pipes (indoor, 20 °C ambient temperature) between the collector field exit and the process. The diameters of the pipes in each section of the field are adapted to the collector type and to the process temperature. The following diameters were used:

diameter	DN [mm]	20	25	32	40	50	65	80	100	125	150	200
insulation	[mm]	40	40	50	50	60	80	80	80	80	80	80
heat losses	[W/K/m]	0.22	0.25	0.25	0.27	0.28	0.27	0.3	0.34	0.39	0.45	0.55

- The outlet temperature of the collector field is controlled by adapting the mass flow in a range between 15% and the maximum of the mass flow. Below an irradiation of 200 W/m² the mass flow set to zero. The heat removal of the process is considered in a way that temperature is reset to T_{set} - 10 K. The delivered solar heat only contributes to the yield if the temperature raise at the process interface is more than 8 K. Otherwise the collector field runs in short circuit.

For dynamical system simulation with the TRNSYS program a system without storage such as the one described in Figure 10 was considered. The system consists of a collector field (collector gross area of 1 000 m^2), field and connection piping, and the necessary control elements for the circulation of transfer fluid in the collectors. The calculations for the sites were carried out using METEONORM hourly climatic data.

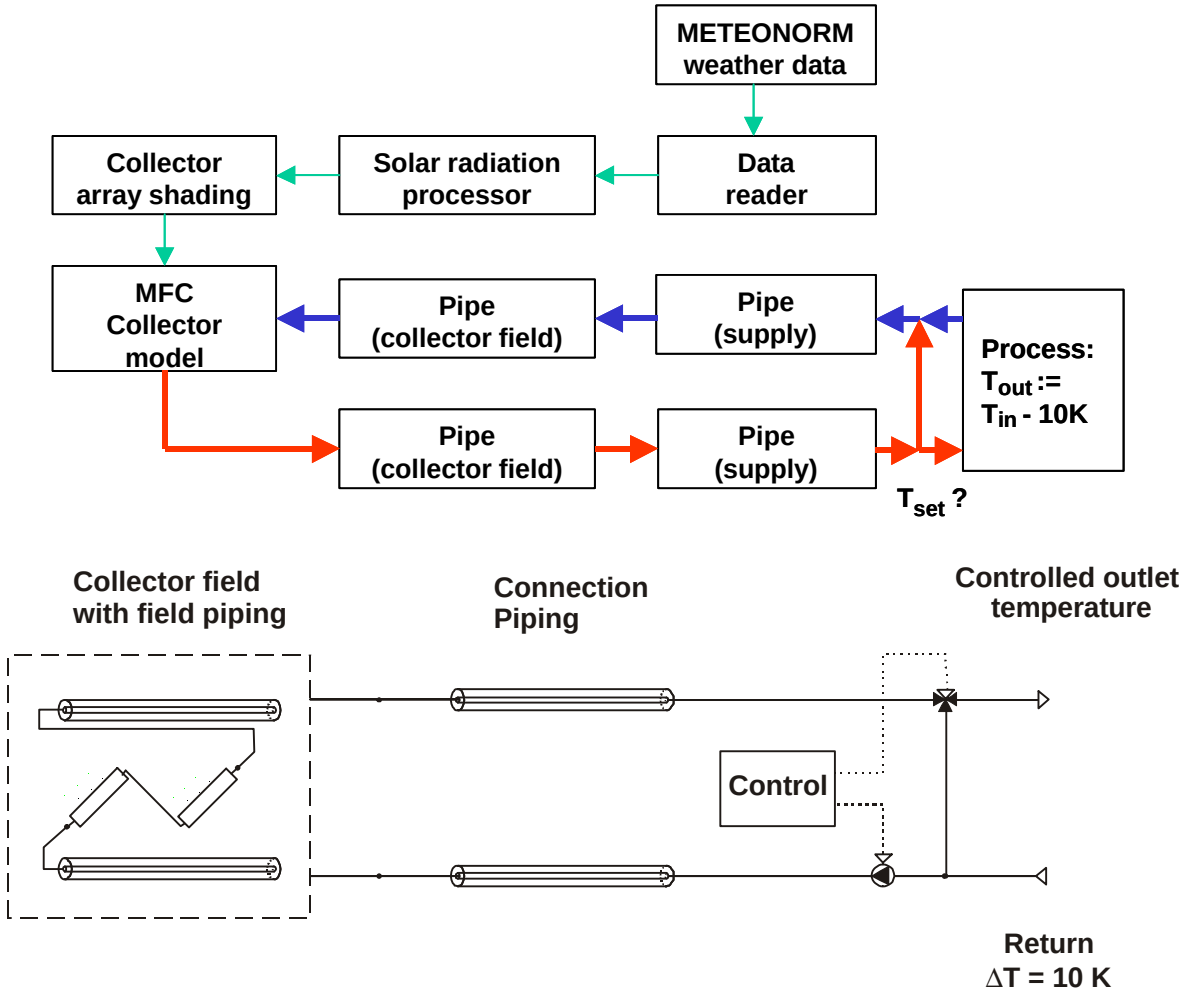


Figure 10. Structure of the TRNSYS simulation. a) block diagram b) scheme of the circuit

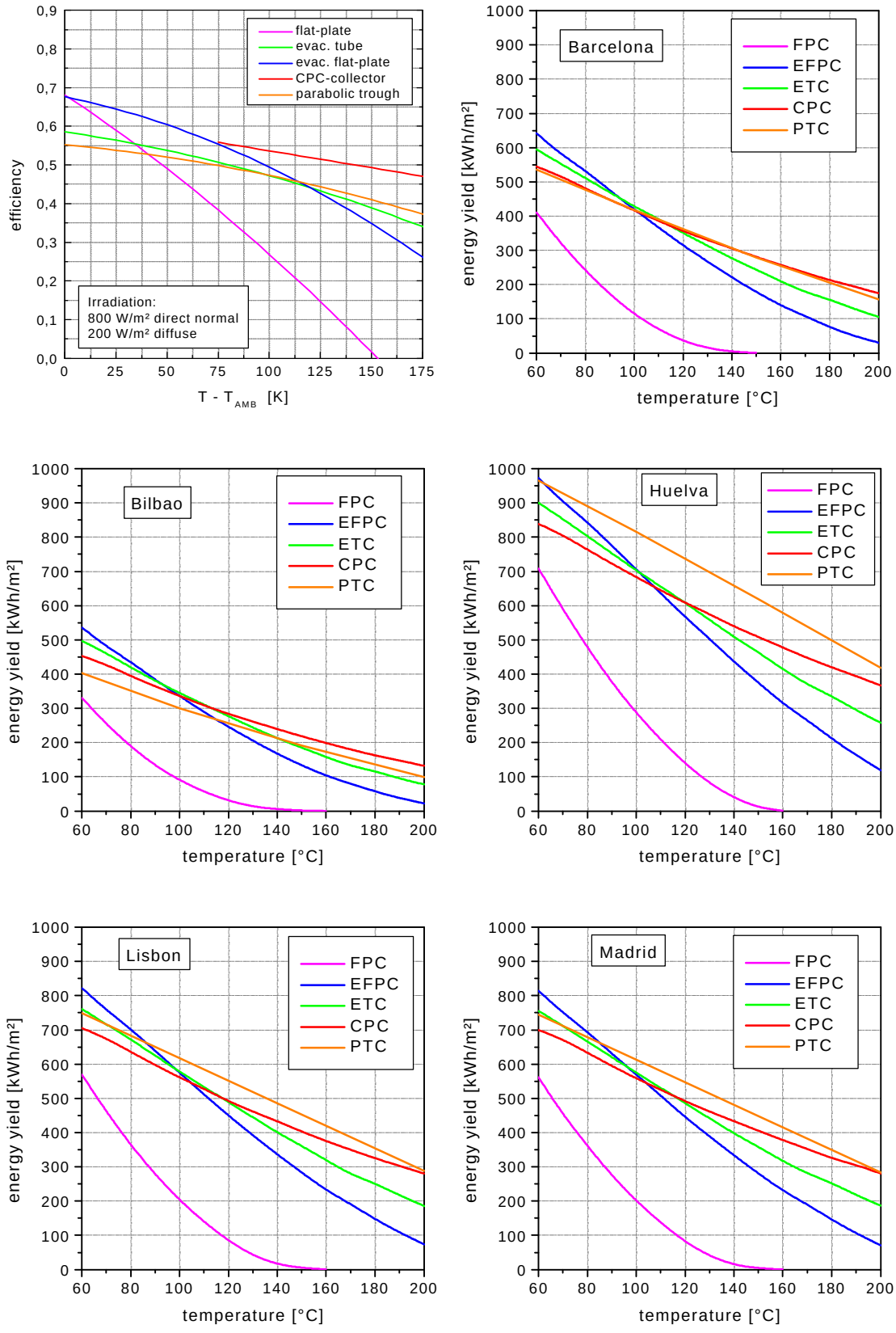


Figure 11. Efficiency of the five collectors and yearly energy yield delivered to a process for the 5 sites, depending on the process temperature. All values are related to collector gross area.

Figure 11 shows the yearly energy yield delivered to processes at the five sites. The energy gains are represented as a function of the process temperature, i.e. the temperature of the fluid at the outlet of the solar system (interface to the process). The calculations were carried out for process temperatures between 60 °C and 200 °C. The results can be summarized as follows:

- The yield strongly depends on the site (i.e. the irradiation). In Huelva the yield is twice as high as in Bilbao. At temperatures around 100 °C where all collectors perform about similar, the yield at different sites increases with the direct irradiation. At all sites, the annual efficiency is around 30% of the direct irradiation.

- Obviously the yield depends on the process temperature, due to thermal losses of the collector and the field piping. Even the most efficient collectors produce only half the amount of energy at 200 °C compared to the amount at 100 °C. Standard selective flat plate collectors (FPC) show a poor performance in all locations for temperatures above 60 °C. These collectors, however, are the most inexpensive choice for industrial applications at low working temperatures. For medium temperatures below 100 °C also non-evacuated CPC- and evacuated flat plate collectors (EFPC) can be used.

- Evacuated tube and evacuated flat plate collectors are more efficient at sites with lower irradiation (e.g. Bilbao) and at temperatures below 100 °C, compared to CPC and parabolic trough collectors, which perform better at temperatures above 100 °C and at sites with high direct irradiation (see Table 4).

It has to be noted that the obtained results are valid for solar systems with a 100% utilisation. This means that all of the produced heat can be used directly in the process without storage. The performance of real systems will be somewhat below these values, depending on the continuity of the process heat demand.

Table 4. Most efficient collectors

	Most efficient collectors	
	T< 100 °C	100 °C < T < 200 °C
Bilbao	ETC / EFPC	CPC
Barcelona	ETC / EFPC	CPC / PTC
Madrid	ETC / EFPC / PTC	CPC / PTC
Lisbon	ETC / EFPC / PTC	CPC / PTC
Huelva	PTC	PTC

3.4.2 Energy Costs

Based on the results for the solar useful heat gains an economical evaluation has been performed, considering the estimated system costs given in Table 5. The system costs have been estimated based on the prices of solar collectors quoted by the manufacturers. It is assumed that the collector field costs (including mounting, supports, foundations and field piping) amount 80% of the total costs. The additional 20% are for piping, heat exchangers, pumps, control devices and planning. The given costs are valid for large collector fields (1 000 m^2).

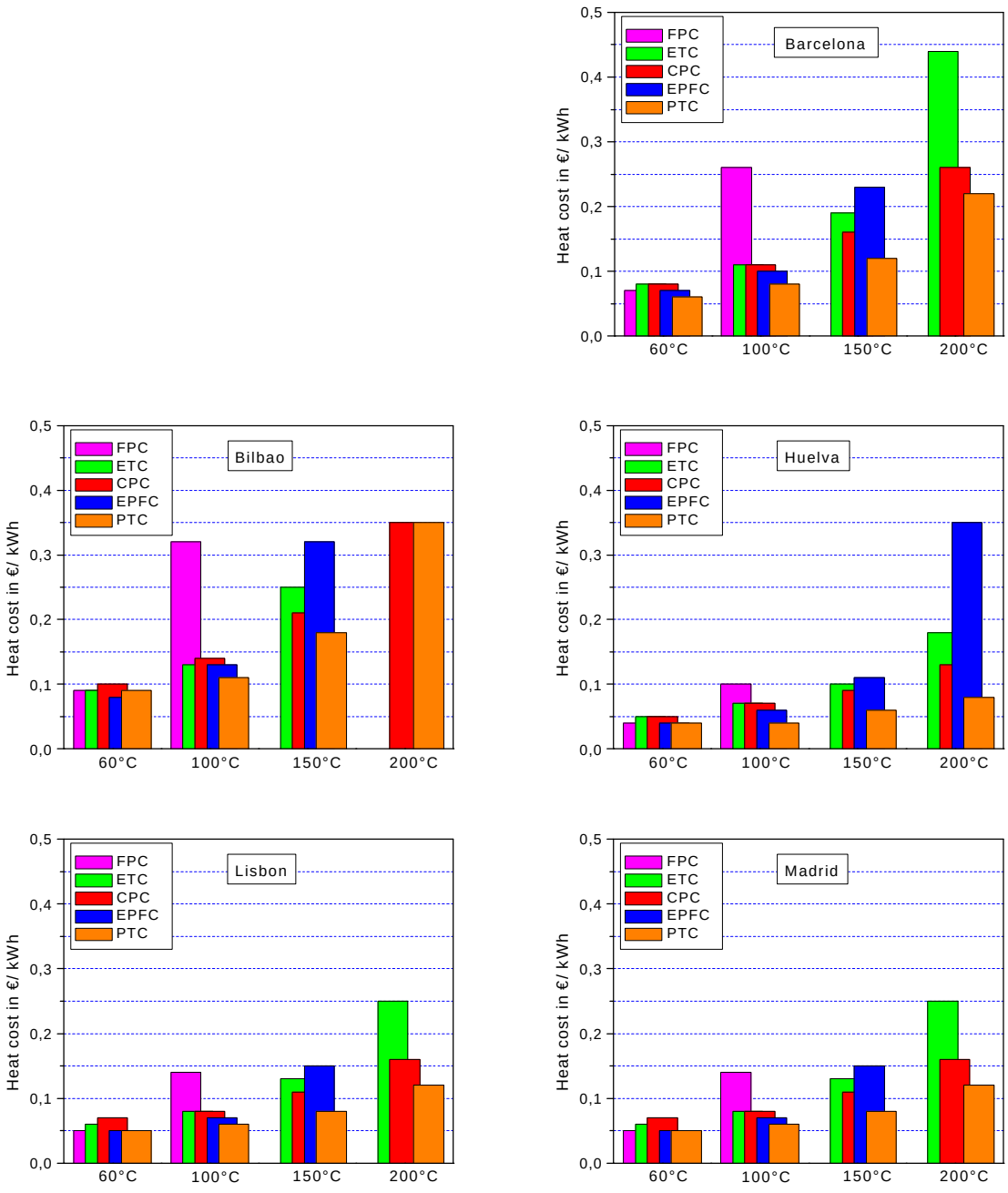


Figure 12. Heat costs for the 5 systems at different process temperatures. Considered are only heat costs below 0.5 €/kWh

Table 5. Investment costs for the solar collector field related to the gross collector and to the absorber area.

Collector type	Investment costs for collectors in €/m²	
	gross area	absorber area
Evacuated tube	≤ 350	≤ 500
Evac. tube with CPC	≤ 350	≤ 370
Evacuated flat-plate	≤ 320	≤ 370
Parabolic trough	240	-
Flat plate	≤ 220	≤ 250

Figure 12 shows the heat costs in €/kWh at process temperatures of 60 °C, 100 °C, 150 °C and 200 °C, for the same locations as in Figure 11. The heat costs are calculated including the investment costs for the collector field as given in Table 5. The annuity is assumed to be 10.5% (15 years lifetime, 6% interest). Maintenance costs are assumed to be 2.5 €/m^{2}year for stationary collectors and rise up to 5 €/m^{2}year for parabolic trough collectors.

The solar heat costs for the most economic solution for each temperature range vary from 0.04 €/kWh to 0.22 €/kWh depending mainly on the climate and the working (process) temperature. The climatic conditions should therefore be carefully regarded during planning.

Applications requiring temperatures below 150 °C can be supplied with solar heat at significantly lower costs then those operating at higher temperatures. In the Central and northern Mediterranean climates of the Iberian Peninsula (e.g. Barcelona, Lisbon or Madrid) heat costs can be below 0.08 €/kWh for a supply temperature of 100 °C. In the southern Portuguese and Spanish climates solar heat at this temperature can even be delivered at costs down to 0.04 €/kWh.

3.5 EXISTING SOLAR PROCESS HEAT PLANTS

Since the 1980's, several solar thermal systems for industrial applications have been developed and are currently operating. A list of existing projects is given in Table 6 and Table 7. A view of two existing solar thermal systems for industrial applications is given in Figure 13.

Table 6. Industrial solar thermal systems in Spain and Portugal

	General information					*information on the process*			*information on the solar system*		
Short name	**Company (user of the plant)**	**Companies (Design and construction)**	**Site**	**Year of start of operation**	**Actual state**	**Process**	**Temperature of use**	**Type of collectors (1)**	**Details solar collectors**	**Collector area**	**Temperature (output of collector field)**
							°C			m^2	°C
SPAIN											
LACTARIA CASTELLANA	Lactaria Española		Alcorcón (Madrid)	1981	dismantled (since 1987 out of use)	Processing of steam for pre-sterilisation		PTC (Casa-Auxini)		600	180 / 220
CARCESA	Carnes y Conservas Españolas S.A.		Merida (Badajoz)	1982 definitively 1985	dismantled (operating 1984-1988)	Sterilisation of meat products (steam for back-up)	207 (1)	PTC	selective tube absorber with concentric glass tube $F_R\eta_0$: 55 % F_RU_L 6.8 (100 °C) 9.5 (150 °C)	1024	180 (2)
ENUSA	Empresa Nacional de Uranio S.A.	IER-CIEMAT ENDESA / GESA	Juzbado (Salamanca)	1985	shutdown (operating 1983-1988)	Cold generation with absorption machine	20-300	PTC	selective tube absorber with concentric glass tube FRh0: 68 % U_L*C = 1.92 + 0.069 ΔT	1080	180
BENIDORM	Hotel		Benidrom	1992		water-heating, cooling, heating		VTC		-450	90
ARINAGA			Gran Canaria		shutdown	Desalination of water				360	120
ACUINOVA	Acuinova Andalucia S.A.		Huelva (Spain)	1996		Fish growing	23-26	?		1316	
CARTE	Autoclavados Carte S.A.		Huelva (Spain)	1994		Washing of cisterns, cars etc.	?	Preheating of water		138	
TE-PE	TE-PE S.A.		Sevilla (Spain)	1997		Olives; preheating of water	?	Preheating of water		260	
PORTUGAL											
UCAL, AGUAS DE MOURA	UCAL	TECNIVEST, SA	Águas de Moura (Portugal)	1985	out of service	Dairy	188	PTC	Helioman 480 Global reflection surface: 16x(6x6x2.2) concentration ratio=40 absorver pipe coating=black chromium (α/ε=0.95/0.15) mirror reflectivity=94% prototype optical rate=0.68(Salgado Prata et al.) prototype concentrator loss factor=0.30 W/m^2°C(S.P.et al) Evaporator type "kettle"	1120 *1280	280 *prototype test:140-280 (Salgado Prata et al.)
VIALONGA	Sociedade Central de cervejas	TECSO, Técnica Solar Lda. (Valado de Frades Nazaré, Pt.)	Vialonga (Portugal)	1985	out of service	Brewery	63	Non evacuated 1.5 x CPC	80x2.41 m^2 Roof mounted Incident solar radiation on site = 1008 W/m2(23/03/86)/n.a. Cylindrical storage, 15 m^3. Heat exchanger of 48 m^2 inside the storage tank. Problems: L(coll-tank) =300m(designed 150m) Tilt angle:45º (d.39°) azimut angl.-15º (d.0°)	192.8	65
KNORR	Knorr Best Foods S.A.	Pretec	Quinta do Mendanha, Carregado (Portugal)	1987	operating	Dairy; hot water for washing of work tools	40-45	Non selective flat plate	top roof mounte demand profile = 50 m^3 / day several tanks (steel), 5x2000 l used for machinery cleaning Problems: dirty glasses	440	

Table 7. Industrial solar thermal systems in other countries (Rest of Europe and USA)

	General information					*information on the process*		*information on the solar system*			
Short name	**Company (user of the plant)**	**Companies (Design and construction)**	**Site**	**Year of start of operation**	**Actual state**	**Process**	**Temperature of use**	**Type of collectors (1)**	**Details solar collectors**	**Collector area**	**Temperature (output of collector field)**
REST OF EUROPE											
PISTICCI			Pisticci (Italy)			Chemical		PTC (2 axis)		1728	280
SWISS: HATTWILL			Hattwill (Swiss)	1988		food industrie: farinaceous products factory (Drying)		VTC		400	90
SWISS: HALLAU	Vinejard		Swiss: Hallau	1983		food industrie: Pasteurization	80-120	VTC		500	140
TARGASSONNE			Targassonne (France)			Thermal		PTC		770	280
ACHAIA CLAUSS	Achaia Clauss, S.A.		Patras (Greece)	1993		Wine producer: Bottle washer	70 - 85	?		308	
ALPINO	Alpino S.A.		Thessaloniki (Greece)	2000		Dairy; Preheating of water for steam boiler	?	?		576	
KASTRINO-GIANNIS	Kastrinogiannis S.A.		Heraklion (Greece)	1993		Textile Dyeing and Finishing; preheating of water for steam boiler	?	?		180	
KOZANI	Kozani Greenhouses S.A.		Kozani (Greece)	1994		Greenhouse; Space heating	40-45	?		80	
MANDREKAS	Mandrekas S.A.		Korinth (Greece)	1993		Dairy; yoghurt production	40	?		170	
MEVGAL	Mevgal S.A.		Thessaloniki (Greece)	2000		Dairy; preheating of water for steam boiler; washing machine	40	?		727	
SARANTIS	Sarantis S.A.		Oinofita (Greece)	1998		Cosmetics stock warehouse; adsorption cooling	?	?		2700	
TRIPOU-KATSOURI	Tripou-Katsouri S.A.		Athens (Greece)	1993		Tannery; preheating of water for the steam boiler	?	?		308	
DRESDEN	Stadtreinigung Dresden GmbH		Dresden (Germany)	1998		Refuse Collection Department	?	?		151	
U.S.A.											
ACDF	Adams County Detention Facility		Brighton (Colorado, USA)					PTC		725	
FAIRFAX			Alabama			Drying		PTC		900	
MACON			Georgia		operating	Textile		PTC		10000	
PASADENA			California	1980	operating	Laundry		PTC		1000	
SAN ANTONIO			Texas		operating	Malt		PTC		1150	
CHANDLER			Arizona	dic-83		process-water	95	PTC		5620	260
TEHACHAPI	California Correctional Institution	IST	Tehachapi (California, USA)				105/55	PTC		2676	150



Figure 13. Examples of solar industrial process heat plants in operation: (upper foto) Knorr factory, Portugal. (lower foto) Production of hot water with parabolic trough collectors. California, USA.

In *Spain* there have been realised some solar process heat plants with parabolic trough collectors in the 1980's that at present are all dismantled (Lactaria Castellana, CARCESA, ENUSA). One plant with flat plate collectors has been working in Catalonia (Industrias Beltrán, Igualada, Tanning industry). There are a very few recently realised installations, all of them for hot water production at low temperatures (Acuinova, Carte, Te-Pe) (PROCESOL 2000).

In *Portugal* during the 80's three large solar demonstration systems were installed in industry, in the sequence of direct involvement of Portuguese Government, or taking profit of a governmental program, sponsoring renewables on industry:

- In UCAL (milk products factory) designed for Helioman linear parabolic concentrators. This installation was financed in equal parts by the Portuguese and German Governments in 1985, but it is not in operation now by lack of spare parts and lack of interest of the actual owners (PARMALAT) of the factory.
- In Central de Cervejas of Vialonga (beer industry) with low concentration CPC type collectors for preheating of water.
- At KNORR factory (in Carregado) with flat plate solar collectors for water heating.

From these 3 projects at present only one installation is in operation.

The main reason for the very low number of industrial solar systems in Portugal relies on the absence of a national energy policy for the promotion of solar energy. The absence of such policy did not allow the development of the market with the consequent correction of the natural mistakes that each new technology always carries with it in the beginning. The production of some of these products did even stop and after some time spare parts were not available, preventing a continuous maintenance program of those systems. All these aspects had a cumulative impact to the present negative image that solar energy has in the Portuguese industry.

Favourable conditions for solar energy in industrial processes were figured out by several studies in the mid 70's in the *USA* (Spongberg 1987, Szego and Fraser 1978). In the following years many efforts were made to open this market for solar energy (e.g. the SERI-project). For process temperatures above 100 °C mainly evacuated tube collector and concentrating systems were applied. The results remained below the expectations. The main reasons were (Kreider 1979, Schreitmüller 1987):

- System costs were too high (mainly collector costs).
- Operating costs were too high (electrical energy for pumps, fans, controllers, etc.).
- Degradation of collectors due to environmental influences (dust, humidity, salt, etc.).
- Problems with the cleaning of optical components (mirrors, lenses).
- Control problems (tuning of hysteresis, positioning of sensors, etc.).
- Excessive heat losses of system components (piping, heat store).
- Insufficient adaptation of the solar system to the consumer.

In Europe some encouraging studies on solar process heat were made in the 80's (Hurdes 1981, Ammansberger 1982, Blank and Joeschke 1985). A great heat demand in the industry exists as well and the problems reported in the SERI-project are no matter of principle.

In the last years several systems have been installed in Greece and one plant is reported in Germany (PROCESOL 2000).

4 CASE STUDIES

4.1 OVERVIEW

A great amount of work within the POSHIP project was dedicated to contacts to industry and the elaboration of case studies for companies from several industrial sectors in Spain and Portugal.

Contacts to industry were established by both a wide spread mailing and direct contacts.

Case studies using a standardised procedure have been carried out for 34 companies. Several companies have been visited in order to obtain detailed information.

If after these first feasibility studies there was further interest of the company of realising a solar plant, as a second step a more detailed case study has been elaborated.

Although beyond the scope of the POSHIP work-plan, during the time of execution of the project requests for public funding for several demonstration plants have been elaborated.

A systematic analysis of the results from all the case studies led to guidelines for evaluation and system design (chapter 6) and to an estimate for the application potential for solar thermal process heat (chapter 7).

For an overview of the work related with the case studies in industry see the flowchart in Figure 14.

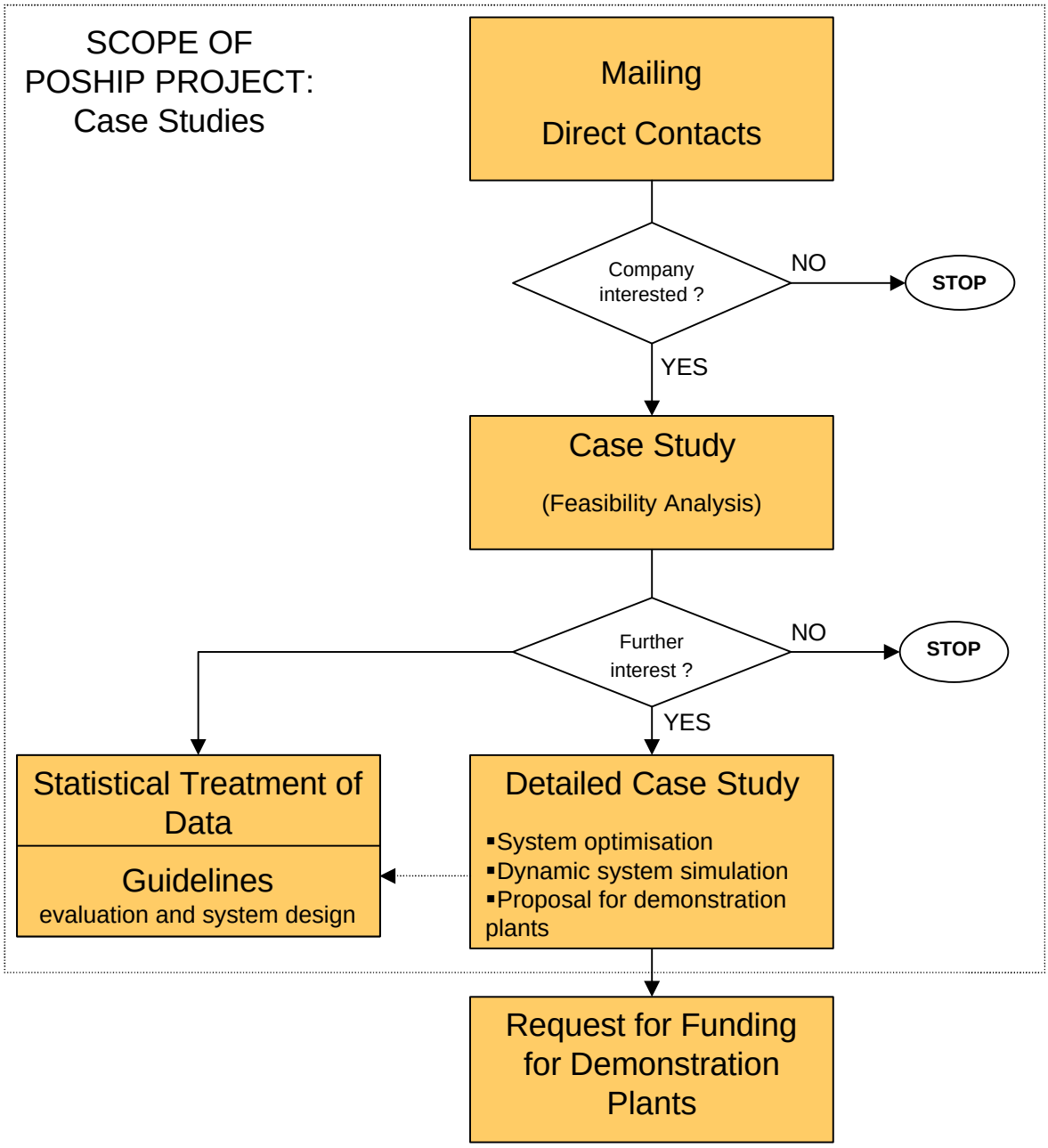


Figure 14. Flow chart for the work related with case studies in industry

4.2 METHODOLOGY

4.2.1 Data Acquisition - Questionnaire

For the purpose of data acquisition, a questionnaire has been elaborated that can be used for the analysis of industrial companies (heat demand, feasibility of solar system; see below).

This questionnaire has been used both in a wide spread mailing to industry and in individual contacts and visits (see section 4.3).

An initially elaborated long (about 10 page) version of the questionnaire has demonstrated to be too complex. Such detailed data are not available in most industries and time required for filling in the questionnaire is too long.

Therefore, for nearly all the work within POSHIP, both the mailing and direct contacts, a short questionnaire of 2 pages has been used.



The Potential of Solar Heat for Industrial Processes

Page 1: General Data and Solar System

General information

		notes
name of the company		*legal name of the company*
Town / city		*place where production is located*
branch		*industrial branch where the company is lined in*
name of contact person		
address		
Telephone No		
Fax No		
E-mail		

Statistical data

number of employees of the company			
annual turnover			
Is the company independent?	yes ☐	n ☐	*no, if more than 25% of the company are affiliated to another company*

Principal motivation for the use of solar energy

Possibility of saving fuel cost	yes ☐	no ☐
Contribution to a more ecologic energy supply	yes ☐	no ☐
Using solar energy helps for a better marketing of others:	yes ☐	no ☐

Solar System

		roof mounting	ground mounting	notes
Availabe roof and ground area	m²			*only areas with more than 200 m². Please give a short description, especially if there are different roofs*
Inclination of the roof or ground area	Inclination			*Please give a short description, especially if there are different roofs; Give the deviation from south orientation in degrees (SE or SW)*
	Orientation with respect to the south			
shading problems				*shading by other buildings, trees. Please give a short description or sketch*
Distance between the roof or ground area(s) and the process	m			*estimate the length of the piping from the edge of the roof or ground area to the process*
static load capacity of the roof(s)	kg/m²			*the additional load of a collector field is 25-30 kg/m²*

Fuel consumption

	Heavy fuel oil	Natural gas	Gas Oil	LPG	OTHER:	
	kg	Nm^3	kg	kg	kg	
Used in equipment no.:						*If available, give percentage used in the different equipment*
Electricity cosumption	**Contracted power**	**Installed power**	**Consumption**	**Sales to grid (co-generation)**	**Tariff class**	
	kW	kW	kWh	kWh		
Percentage of fuel and electricity cost on overall production cost	%	**Electricity**		**Fuels:**		

Process type		*Process 1*	*Process 2*	*Process 3*	*Process 4*	*please give a short description of the process*
process medium (water, oil, air, lye ...)						*the medium which is in direct contact with the treated product, e.g. air for drying, lye or water for washing, etc.*
typical heat (or cold) demand	kW					*during operation*
typical temperature of the **process** medium during operation	°C					*Please distinguish between the temperature of the process and that of the heat supply (see below)*
flow rate of the process medium	m³/h					*only if the process medium is flowing*
Quantity of process medium	m³					*If the process medium is stored, e.g. in a tank*
pressure in the process	bar					
hours of operation per day	hrs/day					
days of operation per year	days / year					
Data of existing Heat (or Cold-) Supply						give a flow chart of the heat supply if possible
medium (water, steam, air)						*medium in the heat distribution net*
temperature of the heat supply	°C					*close to the process*
pressure	bar					*system pressure in the heat distribution net*
flow rate	m³/h					*flow rate in the heat distribution net close to the process*
annual production of useful heat	e.g. MWh					*only for the process! Please secify the unit*
Heat recovery						
Heat from heat recovery available for the process ?	(yes/no)					*If yes: please give a short description of the heat supply from the recovery system to the process*
temperature of the heat recovery	°C					
Storage						
Heat storage system available ?	(yes/no)					*If yes: please give a short description of the heat storage. Is there a possibility to use the medium in the process as storage ?*
Volume of the storage	m³					
maximum temperature of the storage	°C					
Equipment for heat (or cold-) generation		*Eq. 1*	*Eq. 2*	*Eq. 3*	*Eq. 4*	*please give a short description of the equipment (boilers, heaters, ...)*
Manufacturer						
Year of manufacturing						
Model						
No. of units						
Fuel						
Nominal Power	kW					*during operation or stand by*
Fuel consumption (nominal)						
process medium						*e.g. air for drying processes*
nominal production	m³/h					
(specify units)	kg/h					
inlet temperature	°C					*during operation*
outlet temperature	°C					*during operation*
pressure	bar					*working pressure*
Mean overall conversion efficiency	%					
hours of operation per day	hrs/day					
days of operation per year	days / year					

4.2.2 Case Studies

The case studies have been carried out based on the data delivered in the questionnaire. Some of the factories have been visited or contacted by phone in order to obtain more detailed information than that submitted on the questionnaires. Based on these data a feasibility study has been carried out including the following topics:

- Analysis of the heat demand in the factory. Distribution by fuels, processes and temperature ranges.
- Description of the proposed solar system
- TRNSYS calculations for (a) optimised system dimensioning and (b) evaluation of system performance of the proposed system
- Cost estimation and economical analysis
- Proposals for complementary measures for improving energy efficiency (possibilities of heat recovery, etc.)

During the execution of the project, and in order to be able to give response to the large number of companies interested in those studies, a standardised procedure has been elaborated. The main features and objectives of this standard procedure are:

- Standardised criteria for the analysis of the heat demand, system dimensioning, evaluation of system costs, etc. (comparability of the results)
- Procedure for estimation of missing data (from the experience very few companies are able to give complete information as required in the questionnaire. Missing data have to be estimated on reasonable assumptions)
- Software-tools for fast analysis (EXCEL-sheet for semi-automatic analysis of data delivered in the short questionnaire and standardised TRNSYS-file for dynamical system simulation).

This standard procedure has been fully applied for the case studies no. 17 – 25 in Spain, as it has not yet been available for the earlier studies.

4.2.2.1 Analysis of Heat and Cold Demand

For the analysis of the heat demand the following definitions were used:

- *Useful process heat (UPH)*: heat delivered to a process (measured at the entrance of the process heat exchanger).
- *Useful supply heat (USH)*: heat generated in the heat supply system (boilers)
- *Final energy consumption (FEC)*: LCV of the fuel consumption

For most industries the fuel consumption (FEC) is known, whereas USH and UPH had to be estimated. If no data for the conversion efficiencies of the equipment were available, the following standard values were used for estimation:

- Boiler efficiency (USH/FEC): 85 %.
- Overall efficiency of heat generation and distribution (UPH/FEC): 70 %.

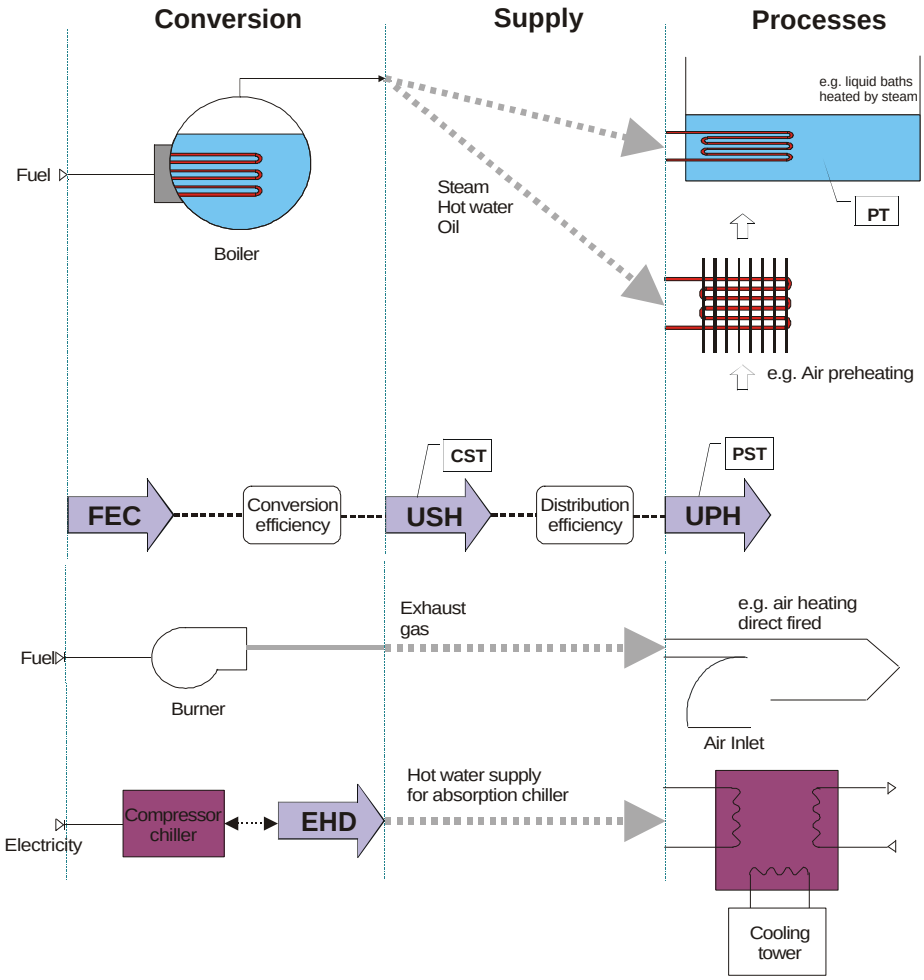


Figure 15. Definition of the energy flows in an industrial heat supply.

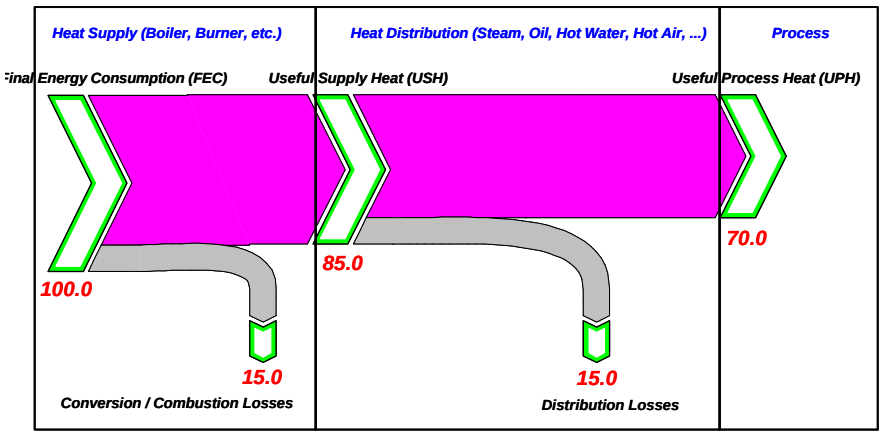


Figure 16. Sankey diagram for standard conversion efficiencies

Cold consumption has been added to the existing consumption of UPH assuming that cold could be produced by thermal chillers. Based on a supposed chiller efficiency the *Equivalent Heat Demand (EHD)* was calculated. The following values were used for conversion:

- Overall efficiency of an absorption cooling system: 70 %
- Mean temperature of the heat supply to the generator: 85 °C.

Pre-heating of supply water (PSW) for steam boilers is a possibility for solar energy utilisation even in cases where the heat supply temperature is too high for a solar system.

The total potential for solar energy use is not the sum of UPH (or USH) and PSW, as a reduction in UPH (USH) due to solar energy use also reduces PSW. Nevertheless, as generally low solar fractions are used in industry, and PSW is a small fraction of UPH (USH) – the sum of UPH (USH) and PSW gives a good estimate for the overall potential for solar heat. With a little effort in algebra a more exact calculation of the overall potential for solar heat could be carried out.

The *temperature levels* used in the analysis are the following:

- *Process temperature (PT)*: mean temperature of the fluid in a process. For cases where an open cycle of the process medium is used, the temperature level for the heat required for preheating is supposed to be distributed homogeneously over the temperature intervals from inlet temperature (or return temperature from heat recovery) and process temperature. The PSW demand is assumed to be distributed over the temperature range from the supply water temperature to the maximum temperature that can reasonably be covered by solar preheating, assumed to 120 °C. Recovery of condensates has to be taken in to account.

- *(Process-) Supply temperature (PST)*: temperature of the heat transport medium used for heating of the process (f. ex. Steam temperature at the entrance of the process heat exchanger).

- *Central supply temperature (CST)*: temperature of the heat transport medium at the outlet of the central heat supply (boiler).

The heat demand then was classified into different temperature intervals. The UPH was classified by intervals for the process temperature (PT), whereas USH was classified by the process supply temperature (PST).

The standard temperature intervals used for analysis are subdivided as given in Table 8.

Table 8. Standard temperature intervals used in the analysis

Temperature range (detail level 1)	Temperature range (detail level 2)	Temperature range (detail level 3)	Temperature interval	Recommended collector technology
Low temperature	Very low temperature	Very low temperature	<= 40 °C	Unglazed or non-selective standard flat plate
	Low temperature	Low temperature	>40 ... 60 °C	Selective standard flat plate
Medium and medium-high temperature	Medium temperature	Medium temperature A1	>60 .. 80 °C	High efficient stationary
		Medium temperature B1	>80 .. 100 °C	
		Medium temperature B2	>100 ... 120 °C	
		Medium temperature C1	>120 ... 140 °C	Parabolic trough
		Medium temperature C2	>140 ... 160 °C	
	Medium – High temperature	Medium – High temperature	>160 ... 240 °C	
High temperature	High temperature	High temperature	> 240 °C	

Both for the analysis and for the dynamic simulation a simple standard model for an industrial process has been used, that is able to describe nearly all of the industrial processes that have been analysed.

Most processes require both heating of a fluid stream (e.g. hot air streams, hot water, renovation of water in baths, ...) and heating of some reservoir (ovens, liquid baths). The latter can be subdivided into pre-heating before the start of operation and into maintenance of temperature (compensation of thermal losses during operation).

The process model used in the analysis is given in Figure 17.

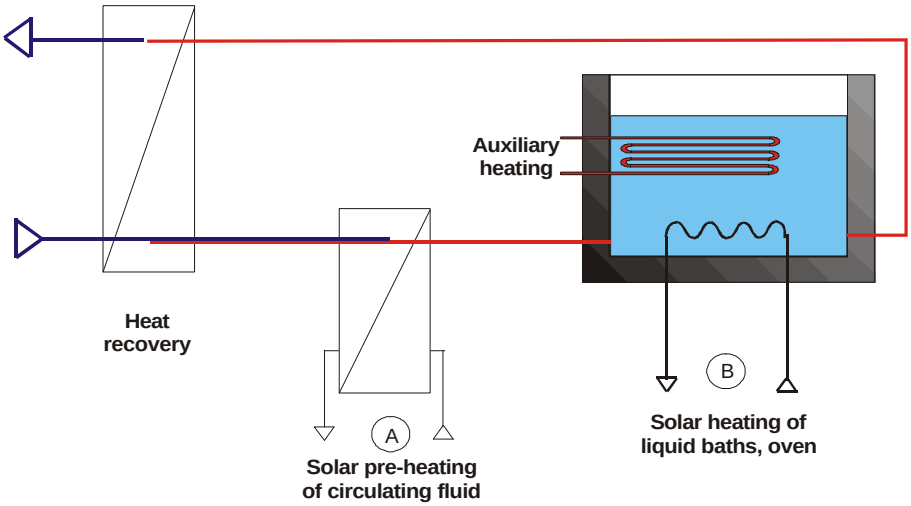


Figure 17. Model for an industrial process used in the analysis

4.2.2.2 The Potential for Solar Process Heat – Technical and Economical Potential

The potential for solar process heat is a function of the climate, the process temperatures and the demand profile. Solar energy costs can be estimated as a function of the desired solar fraction.

The *technical potential* may be defined by the maximum sized solar system that still avoids overheating in summer. For processes with a constant demand the technical potential has been defined by a solar fraction of 60 %. On the other hand, the technical potential is limited by the available roof or ground area. In most case studies actually the roof area was the limiting factor.

Applying economic criteria the maximum solar potential is given by the maximum solar fraction for a given upper limit of energy cost. The following scenarios have been used in the analysis:

- *Scenario 1 – pilot plants*: solar plants competitive with fossil fuels at present solar system costs, with a level of 50 % of public funding. A maximum energy cost for the end user of 30 €/MWh is allowed (equivalent energy cost without funding: 60 €/MWh).

- *Scenario 2 – market introduction*: solar plants that can become competitive with fossil fuels in a near future (up to 2010). The following assumptions are made: future system costs can be reduced to 50 % of present costs; public funding will be maintained but its level will be reduced to 25 %; energy costs will not raise significantly so that still a maximum energy cost for the end user of 30 €/MWh is assumed (equivalent energy cost with actual system costs and without funding: 80 €/MWh).

In order to carry out these evaluations the following tools are necessary:

- Rules for the estimation of system (installation and maintenance) costs
- Tool for the prediction of system efficiency (annual energy savings) as a function of system size (standard TRNSYS file for solar process heat)
- Economic analysis based on standard parameters (annuity).

These tools are described in the following sections

4.2.2.3 Economic Parameters Used in the Analysis

The economic parameters used for analysis are given in Table 9. The data are slightly different as those used in the preliminary analysis (Chapter 3.4). The reasons for this are as follows:

- The objective of the case studies was not only a theoretical one, but the case studies have been used at the same time for promoting solar thermal systems to the industries. Therefore the most cost effective solutions available on the market have been selected for every specific case. The expensive evacuated (tube and flat plate) collectors have not been included in this analysis.
- For the collector types used in the analysis, specific offers from manufacturers active in the Spanish and Portuguese market have been obtained. The numbers for highly

selective standard flat plate collectors are about 10 % lower than that used in an early stage of the project for the calculations in chapter 3.4. System costs used in the case studies include a short term storage of 25 litres / m^2 of collector area.

Table 9 Parameters for economic analysis. System costs for a system size of 1000 m^2.

Parameter	Case Studies	Analysis Chapter 3
System cost (based on *absorber* area; aperture area for parabolic trough and CPC)		
Non-selective flat plate (FPC)	250	
(Selective) Flat plate (SFPC)	270	309
CPC or similar	300	
Parabolic trough (PTC)	300	300
Evacuatied Flat Plate (EFPC)		465
Evacuated Tube (ETC)		608
ETC with CPC		456
Maintenance cost [€/m^2a]		
Parabolic trough	5	5
Stationary	2.5	2.8
Economic parameters		
Lifetime [a]	15	
Annuity [%]	10.5	
Interest rate [%]	6.0	
Yearly cost = Installation cost x annuity + maintenance [€/m^2a]	29 ... 37	34 ... 67

In order to take into account the variations of system costs in function of the system size and additional long-term (weekend-) storage volume, the data in Table 10 and Table 11 have been used in the case studies.

Table 10. System costs as a function of collector type and (effective) surface area (including short term storage (25 l/m^2).

Lower limit for system size	FPC	SFPC	CPC	PTC
0	350	380	400	not available
100	300	330	350	500
300	280	310	330	350
1000	250	270	300	300
3000	220	250	270	250
10000	200	200	250	200

Table 11. Storage costs as a function of storage size.

Lower limit for storage volume [m3]	€/m3
0	500
30	350
100	200
300	150
1000	100

4.2.2.4 Standard TRNSYS System

The standard TRNSYS system used for dynamical system simulations in the case studies (Figure 18) is similar to that described in chapter 3.4.

A solar storage tank has been added and 4 industrial processes can be simulated simultaneously.

For simplicity, the control of the solar (primary) circuit has been simplified with respect to the system of chapter 3.4 using constant flow rate (high-flow, 50 l/m^{2}h of water) and the standard TRNSYS TYPE1 solar collector model.

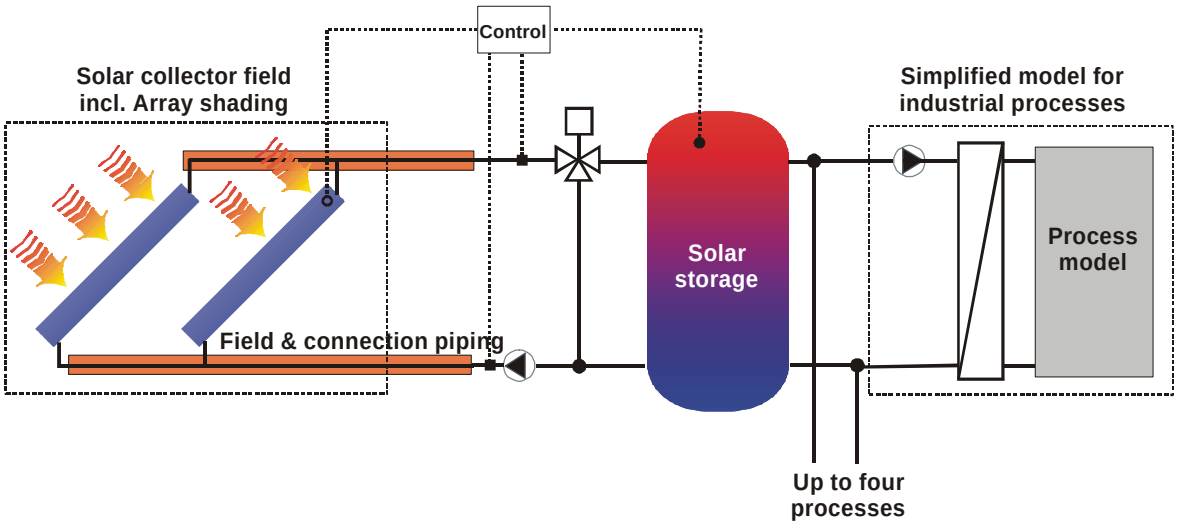


Figure 18. Standard TRNSYS system used in the case studies.

4.2.2.5 Main Outputs of a Standard Case Study

In the following the main output data produced by a standard case study as described above are plotted. The full case studies (in the respective national languages) are given in electronic format (PDF) in the annex as CD-ROM.

In Step 1 the final energy consumption is calculated from the data on fuel and electricity consumption. The distribution of the FEC on the differen fuel types is analysed.

FINAL ENERGY CONSUMPTION, USEFUL SUPPLY HEAT AND USEFUL PROCESS HEAT

			Heavy fuel oil	Natural gas	Gas Oil	LPG	OTHER:	Electricity	TOTAL FUELS	TOTAL FEC
1	fuel type									
	unit		kg	Nm3	kg	kg	kg	MWh		kg
2	yearly consumption	units/year	0	1 800 000	0	0	0			0
3	Standard conversion	kWh/unit	11	9,94	11	12,56	10			
4	**FEC**	**MWh/year**	**0**	**17 900**	**0**	**0**	**0**	**1 440**	**17 900**	**19 340**
5	Boiler efficiency	%	85	85	85	85	85			
6	USH (rough estimate)	MWh/year	0	15 215	0	0	0		15 215	15 215
7	Overall efficiency generation / distribution	%	70	70	70	70	70			
8	UPH (rough estimate)	MWh/year	0	12 530	0	0	0		12 530	12 530

Fig. III.1. Final energy consumption by fuels

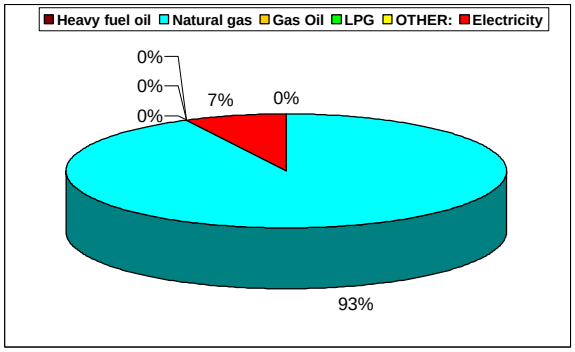


Figure 19. Standard case study. Step 1: analysis of final energy consumption.

In Step 2 the useful supply heat produced by each of the existing heat supply equipment is analysed. Numbers obtained from equipment data (nominal power, hours of operation) are cross-checked with data obtained from the fuel consumption.

SUPPLY SYSTEM

Estimation of USH from data on equipment for heat supply		1	2	3	4
Cooling yes/no		no	no	no	yes
Nomial power (burner)	kW	6978	1163	580	0
Days of operation per year	d	300	300	300	0
Hours of operation per day	h	24.0	24.0	24.0	0.0
Yearly hours of operation	h	7 200	7 200	7 200	0
Conversion efficiency	%	85	85	85	0
Percentage of mean power vs. nominal power	%	29	28	29	0
USH (EHD)	MWh/year	12171	2021	1019	0

Estimation of USH from data on fuel consumption		1	2	3	4	other eq.
Fuel type		NG	NG	NG	0	
Percentage of total consumption of one fuel type		80	13	7	0	
Heavy fuel oil	%	0	0	0	0	100
Natural gas	%	80	13	7	0	0
Gas Oil	%	0	0	0	0	100
LPG	%	0	0	0	0	100
OTHER:	%	0	0	0	0	100
Electricity	%	0	0	0	0	100
FEC	MWh/year	14 320	2 381	1 199	0	
USH	MWh/year	12 172	2 024	1 019	0	

Cross check USH - data		1	2	3	4
USH from equipment data	MWh/year	12171	2021	1019	0
USH from data on fuel consumption	MWh/year	12172	2024	1019	0
Error	%	0.01	0.11	0.07	#DIV/0!
Make one of the following changes in order to adjust the data					
1. Set percentage of mean power to:	%	28.5	28.4	28.7	#DIV/0!
2. Set percentage of fuel consumption to:	%	80.0	13.3	6.7	#DIV/0!

Preheating of boiler feed-up water		1	2	3	4	TOTAL
Inlet temperature of feed-up water	°C	20	20	20	0	0
Maximum temperature of preheating	°C	120	120	120	120	0
Steam flow rate	t/year	0	0	0	0	0
PSW	**MWh/year**	**0**	**0**	**0**	**0**	**0**
Ratio PSW/USH	%	0.0	0.0	0.0	#DIV/0!	0.0

Figure 20. Standard case study. Step 2: analysis of heat supply system

In Step 3 the useful process heat consumption is analysed for every process. If data are available, this consumption is directly calculated from process parameters, such as fluid circulation, inlet and process temperature, hours of circulation, parameters for thermal losses of baths, ovens, etc.. These result then is cross checkt with the data from the heat supply system (Step 2).

ANALISYS OF HEAT DEMAND - PREHEATING, MAINTENANCE

General data on the process		1	2	3	4
Cooling yes/no (cooling not supported in V1.0)		no	no	no	no
Process temperature	°C	150	0	0	0
Days of operation per year	d	300	0	0	0
Hours of operation per day	h	24.0	0.0	0.0	0.0
Hours of operation per year	h	7 200	0	0	0
Total process heat demand (from process data)	MWh/a	**13695**	**0**	**0**	**0**

Preheating of circulating fluid or fluid renovation		1	2	3	4
Hours of circulation per day	h	23.9	10.0	10.0	9.3
Circulation flow rate	m3/h	43500.00	0.00	0.00	0.00
Circulating volume (daily total)	m3	1040955.00	0.00	0.00	0.00
Heat recovery	yes/no	yes	no	no	no
Mean inlet temperature of preheating	°C	20.0	15.0	15.0	15.0
Working fluid		air	water	water	water
Fluid heat capacity	kJ/kgK	1.01	4.19	4.19	4.19
Fluid density	kg/m3	1.20	1000.00	1000.00	1000.00
Energy circulation	MWh/a	13 694.80	0.00	0.00	0.00
Percentage of preheating	%	100.0	#DIV/0!	#DIV/0!	#DIV/0!

Power requirements for maintenance		**1**	**2**	**3**	**4**
Temperature drop during reference time intervall	K	5.00	0.00	0.00	0.00
Duration of process break or cooling down (ref.)	h	13.05	12.00	12.00	12.00
Fractional temperature drop	-	0.04	0.00	0.00	0.00
Time constant	h	332.73	1200000.00	1200000.00	1200000.00
Liquid volume	m3	0.00	0.00	0.00	0.00
Thermal mass	kWh/K	0.00	0.00	0.00	0.00
Thermal loss coefficient	kW/K	0.00	0.00	0.00	0.00
Reference for conistency check. Approximate heat loss coefficient for ...					
well insulated storage (0.5 W/m2K)	kW/K	0.00	0.00	0.00	0.00
non-insulated closed tank (10 W/m2K)	kW/K	0.00	0.00	0.00	0.00
Heat demand for maintenance	MWh/year	0.00	0.00	0.00	0.00
Reference breaks every ... days (Fill in number)	-	1.00	1.00	1.00	1.00
Number of reference breaks per year		300.00	0.00	0.00	0.00
Lower temperature after cool-down	°C	145.00	0.00	0.00	0.00
Heat demand for start-up after breaks	MWh/year	0.00	0.00	0.00	0.00

Estimation of UPH from data on heat supply		**1**	**2**	**3**	**4**	**other**
Percentage of USH used in process no.						
Equipment 1	%	100.00	0.00	0.00	0.00	0.00
Equipment 2	%	100.00	0.00	0.00	0.00	0.00
Equipment 3	%	100.00	0.00	0.00	0.00	0.00
Equipment 4	%	0.00	0.00	0.00	0.00	100.00
Distribution efficiency	%	90.00	90.00	90.00	90.00	
UPH	MWh/year	13693.50	0.00	0.00	0.00	

Cross-Check estimates for UPH		**1**	**2**	**3**	**4**	**TOTAL**
Estimate from process data						
circulation / renovation	MWh/year	13694.80	0.00	0.00	0.00	
maintenance	MWh/year	0.00	0.00	0.00	0.00	
preheating at start-up	MWh/year	0.00	0.00	0.00	0.00	
TOTAL	**MWh/year**	**13694.80**	**0.00**	**0.00**	**0.00**	**13694.80**
Data from questionnaire	MWh/year	0.00	0.00	0.00	0.00	0.00
Estimate from USH-data	MWh/year	13693.50	0.00	0.00	0.00	13693.50

Figure 21. Standard case study. Step 3: analysis of process heat demand

In the following steps the resulting process heat demand is analysed and classified by the different processes (Step 4) and temperature levels (Step 5). Both the cumulative UPH-demand as a function of the process temperature PT (Figure 23) and the cumulative USH-demand as a function of the process supply temperature (PST) are plotted.

Table I.1. UPH demand by processes

Process	Heat demand	
°C	MWh	%
Procés 1	13694.80	100.0
-	0.00	0.0
-	0.00	0.0
-	0.00	0.0
TOTAL	**13694.80**	**100.0**

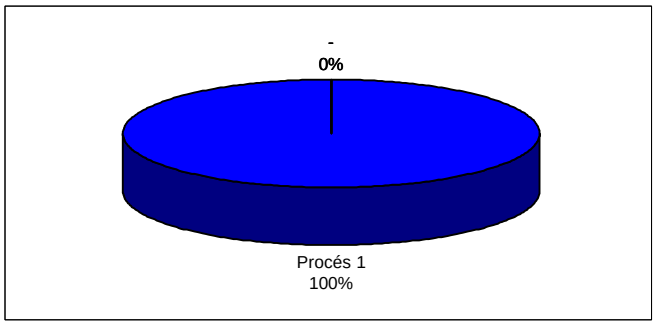


Figure 22. Standard case study. Step 4: analysis of heat demand by processes

UPH demand and temperature levels		1	2	3	4	PSW	TOTAL
Estimate from process data							
circulation / renovation	MWh/year	13694.80	0.00	0.00	0.00	0.00	
maintenance	MWh/year	0.00	0.00	0.00	0.00		
preheating at start-up	MWh/year	0.00	0.00	0.00	0.00		
TOTAL	**MWh/year**	**13694.80**	**0.00**	**0.00**	**0.00**	**0.00**	**13694.80**
Temperature levels							
circulation / renovation	°C	20.00	15.00	15.00	15.00	0.00	
start-up	°C	145.00	0.00	0.00	0.00		145.00
maintenance	°C	150.00	0.00	0.00	0.00	0.00	
Upper limit of temperature range	Cumulative heat demand						
°C							
40		2106.89	0.00	0.00	0.00	0.00	**2106.89**
60		4213.79	0.00	0.00	0.00	0.00	**4213.79**
80		6320.68	0.00	0.00	0.00	0.00	**6320.68**
100		8427.57	0.00	0.00	0.00	0.00	**8427.57**
120	MWh/year	10534.46	0.00	0.00	0.00	0.00	**10534.46**
140		12641.36	0.00	0.00	0.00	0.00	**12641.36**
160		13694.80	0.00	0.00	0.00	0.00	**13694.80**
240		13694.80	0.00	0.00	0.00	0.00	**13694.80**
10000		**13694.80**	**0.00**	**0.00**	**0.00**	**0.00**	**13694.80**

Table I.1. Cumulative heat demand (UPH + PSW) by process temperature

Temperature level	Heat demand (cumulative)	Heat demand by temp. Interval
°C	MWh	MWh
< 40 °C	2106.89	2106.89
41 - 60 °C	4213.79	2106.89
61 - 80 °C	6320.68	2106.89
81 - 100 °C	8427.57	2106.89
101 - 120 °C	10534.46	2106.89
121 - 140 °C	12641.36	2106.89
141 - 160 °C	13694.80	1053.45
161 - 240 °C	13694.80	0.00
> 240 °C	13694.80	0.00

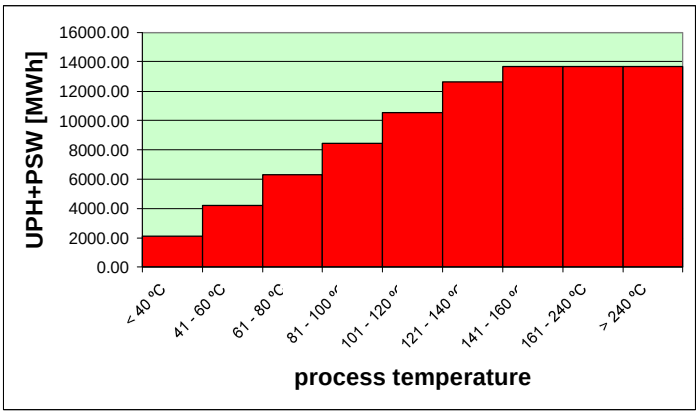


Figure 23. Standard case study. Step 5: analysis of heat demand by temperatures: process temperature

Once the analysis of the process heat demand is available, the processes suitable for coupling of solar energy are selected, following the criteria as outlined below in chapter 6.

Depending on the temperature level of the selected processes an appropriate solar collector technology is chosen.

The input parameters for the standard TRNSYS system are obtained automatically from the EXCEL – sheet for data analysis (Step 6) specifying the parameters of the solar system and the characteristic parameters for the process heat demand of each process.

Then a parametric study is carried out varying the solar system size (within the constraints given by the specific case: available roof area and upper limit given by 60 % solar fraction (technical potential). In an iterative way the system size is determined that corresponds to the limits for the technical potential, and for the economic potential (scenario 1 and 2) – (Step 7). The results of this analysis are represented in a summary Table (Step 8).

From all these options, an adequate solution has been chosen in order to be presented to the company. This has been either a system given by the maximum available roof or ground area, or by proposing a system – usually smaller than given by scenario 1 – in order to obtain energy costs low enough to make a solar system attractive to the industry.

In a short (about 10 – 15 page) report this system then has been proposed to the companies, together with a summary sheet (Figure 27). The reports included a description of the proposed systems, an analysis of the monthly energy gains and an economic analysis.

TRNSYS INPUT DATA

Climatic data		
Weather data file	TORDERA.DAT	
Supply water temperature file	not used in version 1.0	
Latitude	º	

Collector parameters	Type:	SFPC	FPC	SFPC	CPC	PTC	OTH
c0	%	79.4	84.4	79.4	82.8	not supported in V1.0	82.8
c1	W/m2K	3.88	8.3	3.88	2.5		2.5
c2	W/m2K2	0.0098	0	0.0098	0.01		0.01
b0	-	0.09	0.15	0.09	0.2		0.2
Mnom	kg/h	50					

Collector field parameters	TRNSYS Par. Name	
Maximum area to be considered	m2	6 667
Recommended area (first estimate)	m2	5 869
Collector area:	AREA	optimise by TRNSYS simulations
Collector inclination	SLOPE	30
Collector azimuth	AZIMUT	90
Use default values for all parameters not specified explicitly		

Storage and control parameters	TRNSYS Par. Name	
Storage volume per collector area	VOLPA	0.025
select manually value in between		
short term		0.025
weekend		0.250
Use default values for all parameters not specified explicitly		

Load profile (Parameters for TRNSYS-SHIP Version 1.0)						
Process No.	TRNSYS Par. Name	1	2	3	4	BFW
Days of operation						
Days per week	NWEEKx	6.0	6.0	6.0	6.0	6.0
Holidays Summer NSUHOL	NSHx	7	7	7	7	7
Holidays Spring (=Autumn=Winter)	NOHx	2	2	2	2	2
Days of operation per year (TRNSYS)	-	300	300	300	300	300
Cross check with total days of operation per year (questionnaire)	-	300	0	0	0	300
(a) fluid properties						
Fluid heat capacity	CPFx	1.01	4.19	4.19	4.19	4.19
(b) maintenance and preheating						
Hours of operation per day	HPDAYx	24.00	0.00	0.00	0.00	
Set temperature of the process	TSETx	155.0	5.0	5.0	5.0	
Return temperature	TRETx	150.0	0.0	0.0	0.0	
Dayly load	DLOADx	0	#DIV/0!	#DIV/0!	#DIV/0!	
Temperature drop over heat exchanger		5	5	5	5	
Heat exchanger effectiveness	HXEffx	0.50	0.50	0.50	0.50	
(c) circulation						
Hours of circulation	HPDAYx	23.93	10.00	9.98	9.28	24.00
Set temperature of the process	TSETx	150.0	0.0	0.0	0.0	0.0
Mean inlet temperature of preheating	TRETx	20.0	15.0	15.0	15.0	0.0
Daily circulation	DLOADx	1 249 146	0	0	0	#DIV/0!
Temperature drop over heat exchanger		10	5	5	5	5
Heat exchanger effectiveness	HXEffx	0.93	1.50	1.50	1.50	#DIV/0!

Figure 24. Standard case study. Step 6: input data for TRNSYS simulations

POTENTIAL OF SOLAR PROCESS HEAT

1	Maximum available roof and ground surface	m2	10000
2	Maximum effective area of parabolic trough arrays	m2	3333
3	Maximum effective area of stationary collectors	m2	6667
4	Azimuth of roof (negative = east)	°	90
	Check manually if there are static problems, shading problems etc.		

						auxiliary TRNSYS runs in order to obtain results for interpolation					
4	Solar Energy Potential		Technical potential	Economic potential (scenario 1)	Economic potential (scenario 2)	1	2	3	4	5	6
5	Collector type (FPC,SFPC,CPC,PTC or OTH=user defined)		SFPC								
6	Collector surface	m2	6667	6667	6667	6 667	5 869	5100	4000	3000	2000
7	Solar energy gains (UPH)	MWh	3465	3465	3465	3465	3218	2951	2521	2062	1515
8	***fill in from TRNSYS - results***	kWh/m2	520	520	520	520	548	579	630	687	758
9	Annual solar fraction	%	25	25	25	25	23	22	18	15	11
	Mean working temperature (not supported in V1.0)	°C									
10	System cost	€	1800090	1800090	1800090	1800000	1584684.461	1377000	1080000	810000	540000
11		€/m2	270	270	270	270	270	270	270	270	270
12	Maintenance cost	€	16667.5	16667.5	16667.5	16666.66667	14673.00426	12750	10000	7500	5000
13		€/m2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
14	Energy cost (useful heat)	€/MWh	4.8	4.8	4.8	4.8	4.6	4.3	4.0	3.6	3.3

Figure 25. Standard case study. Step 7: Results of TRNSYS simulations

POSHIP: Data analysis from short questionnaire (summary)

	General information on the company		
1	Company short name		
2	Industrial sector		
3	Country		
4	Region		
5	Number of employees		28
6	Annual turnover	€	1 500 000

	Heat demand (UPH)		
7	Total	MWh UPH	13695
8	Low temperature (<60 °C)		4214
9	Low and medium temperature (<160 °C)		13695
10	Percentage of low and medium temperature	%	100

	Solar system		
11	Solar collector type		SFPC
12	Mean working temperature (scenario2)		0
	Technical potential		
13	Collector area	m2	6667
14	Useful heat gain	MWh	3465
15	Heat cost	€/MWh	5
16	Solar fraction	%	25
	Economical potential (scenario 2)		
17	Collector area	m2	6667
18	Useful heat gain	MWh	3465
19	Heat cost	€/MWh	5
20	Solar fraction	%	25

	Additional information
21	

Figure 26. Standard case study. Step 8: summary of results

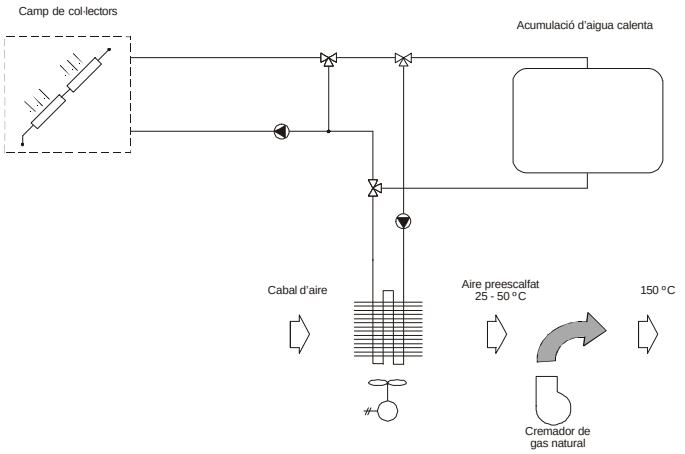
Fitxa tècnica

POSHIP
THE POTENTIAL OF SOLAR HEAT FOR INDUSTRIAL PROCESSES

SISTEMA DE CALOR SOLAR INDUSTRIAL

PROMIC, S. A.

ESQUEMA DE LA INSTAL·LACIÓ



DADES TÈCNIQUES I ECONÒMIQUES DE LA INSTAL·LACIÓ

Empresa	**Promic, S. A.**
Ubicació	**Les Masies de Voltrega (Barcelona)**
Sector de producció	**Pinsos**
Procés	**Assecat amb aire**
Temperatura de treball	**20 - 150 ° C**
Superfície col·lectors solars	**2 000 m^2**
Tipus de col·lectors solars	**Col·lector pla selectiu**
Producció anual de calor útil	**1 515 MWh**
Fracció solar	**11.2 %**
COST TOTAL INSTAL·LACIÓ	**106 500 000 ptes.**
TOTAL CONTRIBUCIÓ PRÒPIA	**42 600 000 ptes.**
Estalvi anual	**6 329 400 ptes.**

Figure 27. Standard case study. Step 9: summary sheet of the proposed system

4.2.3 Detailed Case Studies (Proposals for Demonstration Plants)

For the companies interested in continuing after that the first numbers from the case studies have been presented to them, a detailed pre-planning of a solar system has been carried out. This includes:

- optimisation of the system: comparison of different collector types, optimisation of system size and storage volume
- dimensioning of all the main components of the system (solar collector field, storage, heat exchangers, main piping, pumps, control ...)
- dynamical system simulations of the finally adopted system configuration
- cost estimation and economical analysis based on offers for the specific project
- scheme of the solar system, plans.

The elaborated documentation is sufficiently detailed in order to be used for a request to national or European funding programs.

4.3 RESPONSE TO THE MAILING AND DIRECT INDUSTRY CONTACTS

The mailing to industry of an informative dossier (see section 9: dissemination activities), together with the (short version) of the questionnaire and a letter of presentation of the project, has been sent out during the month of September 2000. A second mailing to additional industrial sectors has been carried out in Catalonia in February 2001.

One thousand six hundred fifty two companies in Spain and Portugal have been contacted by mailing and about 30 companies by direct contacts. The total number of data sets obtained from the response to the mailing and other direct contacts is 59 (Table 12) – only slightly more than the expected value of at least 50 responses to the mailing.

Table 12. Total number of responses (data of short questionnaire) to the mailing and other direct contacts.

Country	Number of companies contacted (mailing and direct contacts)	Number of responses
Spain	1 519	49
Portugal	133	10
Total	**1 652**	**59**

A summary of the contacts and the obtained response for each of the partners are summarized in the following sections.

4.3.1 Mailing IDAE (Spain)

The mailing from IDAE has been sent out to 924 in several industrial sectors all over Spain (except Catalonia). See Table 13.

The following databases have been reviewed in order to establish the mailing list:

- Fomento de la Producción, S. L.: “ESPAÑA 30.000”: detailed information on 30,000 companies in 64 sectors
- Grupo ASNEF-EQUIFAX: “DICODI: Anuario de Sociedades, Consejeros y Directivos” (Companies and Directors Yearbook): up-to-date information on 50,000 companies
- Other databases from other sources: Cinco Días, Chamber of Commerce, Spaindustry, etc.: all with a large number of companies, but only available in look-up mode, not accessible for mailings

For its ease of access and flexibility, we decided to use the “España 30.000” database. Additionally, the companies held on this database had appropriate levels of turnover (greater than or equal to 250 million pta/year).

924 companies throughout Spain (excluding Catalonia) were selected belonging to the sectors identified previously during the detailed study of industrial sectors and processes (See WP1-Report).

It was decided to use the short (2 page) questionnaire for the large-scale mail shot. Despite its size the questionnaire contains a considerable number of questions, many of

which are very specific or complex (almost an energy audit) and require exhaustive information from the company concerned. In many cases the company either does not have this information or does not have time to obtain it.

The questionnaires were sent out to the selected companies in the first half of September. The mail shot included:
• letter presenting the project, from the IDAE's promotions director
• brochure giving information about the POSHIP project (4 pages)
• questionnaire (2 pages)
• a reply envelope.

All 924 companies receiving the questionnaire were contacted by the IDAE by telephone. This involved a total of over 3 300 telephone calls and faxes.

Table 13. Mailing IDAE by sectors.

Industrial sector	Nº companies
Beer and malt	12
Wine	238
Fermented beverages	5
Non-distilled beverages	4
Mineral water and non-alcoholic beverages	93
Fish products	147
Meat	179
Fowl	52
Milk products	79
Child's food	2
Textile finishing	33
Manufacturing of carpets	11
Preparación, teñido y curtido de pieles	2
Elaboration of soaps, detergents ...	56
Manufacturing of tyres	2
Elaboration of paper pulp	9
TOTAL	**924**

In spite of an intense follow-up by telephone responses of only 20 companies could be obtained (2.2 %). See Table 14.

Table 14. Response to the mailing from IDAE

Industrial sector	Nº companies
Wine and other beverages	6
Meat	3
Olive	1
Food and food conserves	3
Textile	5
Paper	1
Chemistry	1
TOTAL	**20**

4.3.2 Mailing ICAEN (Catalonia)

In September 2000, ICAEN sent a first mailing presenting the POSHIP project to 439 industries of the tanning, tint, grease and oils, wines and champagne, plastics, glass, beverage, chemical, paper, textile and food sectors.

As the response to the mailing was not so successful as expected (8 answers), a second mailing was performed by ICAEN in February 2001. The aim was to address to the food, milk and animal feed sectors due to their intermediate but intensive heat demand. If the heat demand is not too high and constant, it enables us to offer a higher solar contribution and a solar field not so large that the industries can afford its expenses more easily.

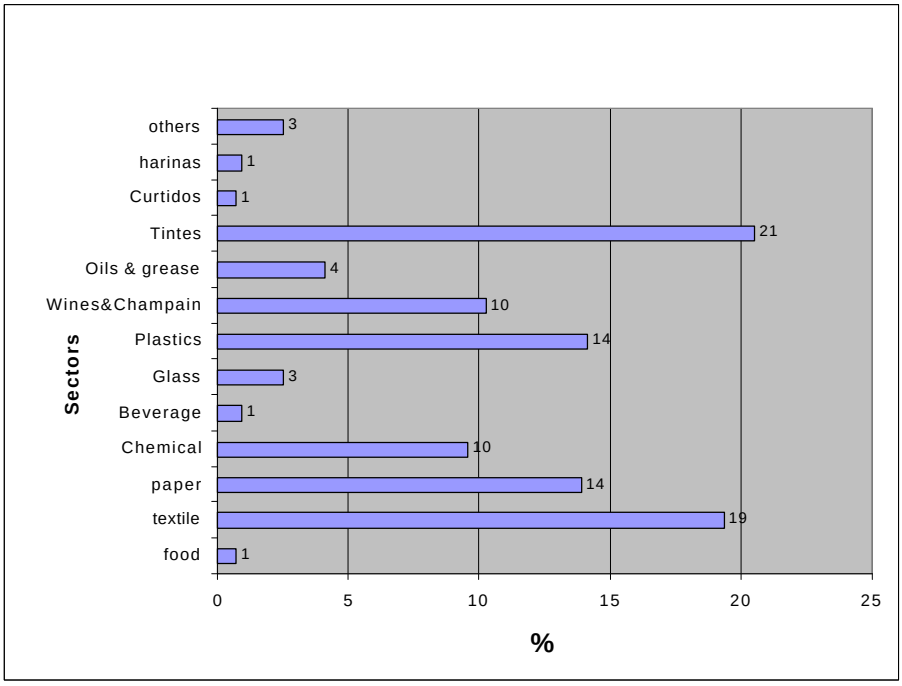


Figure 28. Distribution of the first mailing of ICAEN on industrial sectors

The second mailing was sent to 126 industries and up to now there have been 23 positive answers. ICAEN is still performing the follow up of the mailing. Most of the answers come from the cooking of foodstuff sector and some from the animal feedstock.

4.3.3 Mailing SPES (Portugal)

The Portuguese versions of the informative dossier and of the short questionnaire were mailed in September/October of 2000 to a wide range of industrial factories, located in different zones of Portugal, pertaining and distributed by the following industrial sectors (Table 15).

Table 15. Mailing Portugal. Distribution by regions and by sectors

Industrial sector	Lisboa	Porto	Norte	Centro	Sul	Açores	Madeira	*Total*
Dairies	3	2	4	1	2	2	1	**15**
Leather				16				**16**
Paper	14		1	3	1			**19**
Textiles		16	31					**47**
Wollen Textile		1	1	30	1			**33**
Wood Fiberboard		1		2				**3**
TOTAL	**17**	**20**	**37**	**52**	**4**	**2**	**1**	**133**

The distribution, in percentage, by zone and by sector is shown in the two following graphs.

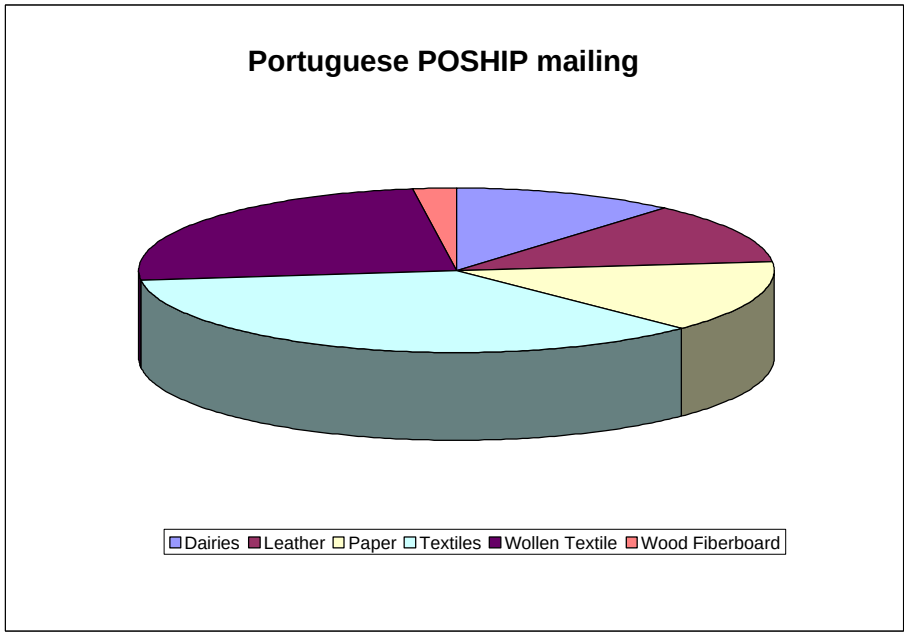


Figure 29. Mailing Portugal. Distribution by industrial sectors

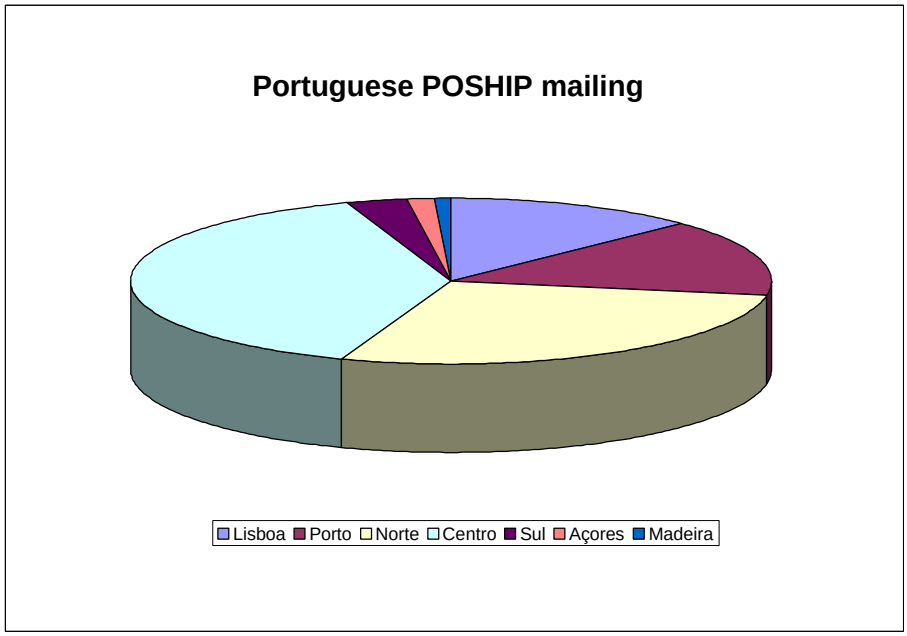


Figure 30. Mailing Portugal. Distribution by regions

The mailing action was accompanied by a set of parallel measures, which included the raising of awareness of the appropriate industrial associations and direct calling of the target factories.

The result of this mailing was very poor, because only 5 factories answered to it. In consequence all entities in the list were contacted again by phone (two times) and for some of them, new mailing was made. Even with this extra effort, there was no visible result. If we add to these answers the ones resulting from filling of the long questionnaire given at the time of the direct contacts in the frame of the technical visits, we have a total of 10 answers. The following table summarizes the data that covers common items of the received answers:

Table 16. Mailing Portugal. Response obtained.

Sector	Location	Roof (m^2)	Field (m^2)	Fossil Energy	Consumption (ton/month)
textil	interior	3 000	500	Thick fuel	58
textil	interior	No inform.	No inform.	Thick fuel	14
paper	interior	4 000	30 000	Thick fuel	540
paper	littoral	39 500	No av.area	Thick fuel	2217
paper	littoral	6 000	5 000	Thick fuel	43
textil	interior	10 000	No av.area	Thick fuel	83
textil	interior	Small area	No av.area	Thick fuel	32
leather	interior	600	5 000	Thick fuel	5.2
leather	interior	1000	No av.area	Thick fuel	5.6
food	littoral	No av.area	10 000	Thick fuel	160

Some conclusions can be drawn based on the previous table:

- It is not usual to have large outdoors area, available for collectors installation;
- The thick fuel is the most common fossil energy;
- Great variety on the factories dimension;
- Major part of the answers are coming from the interior;
- Those who answered, show interest in solar energy.

In Portugal technical visits should be reinforced as a way to get interest in solar energy and for getting directly some data. Proposals should be drawn at the end of the project, to the appropriate statistical institutions as a way to get the data that the present inquiry did not obtain.

The direct contacts and the technical visits that we realised showed that this is the right way to continue working if we want to improve the usage of solar thermal energy in industry, at least at the present in Portugal. We feel that this step cannot be overlapped because there is a number of (bad) pre-formed thoughts about solar energy, that only the correct technical information and confidence on experimented independent technicians can destroy. The inquiry itself does not give such approach and introduces a new factor of dispersion in some industries where there is a lack of compiled information about energy consumptions, of engineers or technical experts able to fill it easily. In the case of Portugal we also feel that in some cases the industrials does not like do give such information thinking that it can be used for different purposes.

4.3.4 Direct Contacts by AIGUASOL (Spain)

Apart from the mailing, direct contacts to industry have been established also in Spain. In an early phase of the project first industry contacts had been carried out (March-July 2000). Several more contacts have been carried out throughout the resting period of execution of the project (Table 17).

From the direct contacts data for a total of 16 companies (questionnaire + visit reports) could be obtained, 12 in Catalonia and 4 in Southern Spain.

4.3.5 Analysis of the Response

The quality of the data given in the short questionnaire varies strongly. The return of information from direct contacts was in most cases rather complete and useful. The quality of the response to mailing varied in a wide range. In most cases some additional data had to be obtained by phone, or to be estimated.

Table 17. Summary of direct industry contacts in Spain.

Contacts with positive feed back

Sector	Company	City Region	First contact Info-Pack sent	Return of (short) questionnaire	Visit	case study	detailed case study	Further interest ? NO = black	project & execution	Actual state	Reasons for rejection
Brewery and Malt	Cruzcampo	Sevilla						yes		Feasibility study. See visits report	
Brewery and Malt	Moravia	Lleida								Pay back too long	Excess heat of cogeneration
Brewery and Malt	INTERMALTA	Albacete								Interested. Factory in Portugal contacted by INETI	
Wine	Torres	Barcelona								Funding conceeded. Sytem to be built	
Wine	Bodegas Osborne	Cadiz						yes		Company interested. Delay due to changes in the company	
Paper	Guarro Casas	Barcelona								Feasibility study concluded	too much investment funding is not assured long pay-back period
Milk	La Fageda	Girona						yes		Case study to be realised	
Textile	FIBRACOLOR	Girona								Feasibility study - cost estimation. See visits report	
Automobile	NISSAN	Barcelona		long						Interest. Maybe to be considered further on	Long pay-back

Contacts without success

Sector	Company	City Region	First contact Info-Pack sent	Return of (short) questionnaire	Visit	case study	detailed case study	Further interest ? NO = black	project & execution	Actual state	Reasons for rejection
Brewery and Malt	Aguila	Madrid									Other priorities due to re-structuring of the company
	Cruzcampo	Valencia								depending on decision of the direction	
	S. Miguel	Lleida								Waiting for data in questionnaire	
Paper	Miquel Costas & Miquel	Barcelona, Tarragona, Valencia									Barcelona: excess heat of cogeneration; others: too large size of solar system
	ENSO	Barcelona								Not yet contacted with the responsible person	
	MB	Girona									Return of investment too low; bad location of the factory (deep valley)
Milk	Granjas Castelló	Lleida								Not yet contacted with the responsible person	
	Letona	Barcelona								Not yet contacted with the responsible person	
	Lacteas Sta. Eugenia	Girona									Energy is no priority for the company
	Puleva	Lleida									pay-back too long
Juice	MOLEVA	Lleida									Energy is no priority for the company
	Indulerida	Lleida									Excess heat of cogeneration
	NUFRI	Lleida									Fear of mounting a new technology
	SAFYC	Lleida								waiting for return of questionnaire	
Textile	TYBOR	Girona									Excess heat of cogeneration
	TINTS ORIENT	Girona								studying possibility in a new building	Excess heat of cogeneration
	Acabados Tintoreto	(Cataluña)								First contact by ICAEN	
Meat	PATEL	Barcelona									No time. Never thought about it.
	COPAGA	Girona									Excess heat of cogeneration
Aromas	Dallant	Barcelona								Interested. Depening on further contact.	
Glass	Cristaleria Española	Tarragona									Excess heat of cogeneration
Petroquimistry	BAYER	Tarragona								Waiting for response	
Tanning	COLOMER MUNMANY	Barcelona									not specified

4.4 CASE STUDIES

Within the POSHIP project, case studies have been carried out for 34 companies in Spain and Portugal that showed some interest in applying solar thermal energy in their factories.

Based on a detailed analysis of the heat (and cold) demand of the industries, an appropriate solar system has been proposed.

A prediction of the annual energy gains of these systems based on dynamic system simulations (TRNSYS) and economic analyses have been performed.

4.4.1 Spain

A total of 25 case studies have been carried out for companies in Andalucía (3), Valencia and Central Spain (6) and Catalonia (16).

The full text of the case studies is joined to this report in electronic format (PDF-files) in order to avoid excessive paper volume. Table 18 shows the most relevant parameters of the studied systems.

Table 18. Case studies: Overview – data on heat demand, technical and economical potential for solar process heat.

Global analysis WP5		1	2	3	4	5	6	7	8	9	10	11	12	13
General information on the company														
Company short name		Fibracolor	Cruzcampo	Guarro Casas	Nissan	Moravia	Torres	Mas Martinet	Osborne	Carbomas	Kimberly Clark	Unfasa	Sanchís	CREVISA
Industrial sector		Textile	Malt	Paper	Automobile	Malt	Wine and Beverage	Wine and Beverage	Wine and Beverage	Wine and Beverage	Paper	Wine and Beverage	Textile	Textile
Country		Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain
Region		Catalonia	Andalucía	Catalonia	Catalonia	Catalonia	Catalonia	Catalonia	Andalucía	Catalonia	Valencia and Central Spain	Valencia and Central Spain	Valencia and Central Spain	Valencia and Central Spain
Heat demand (UPH)														
Fuel type(s)		NG	HFO	HFO	NG	NG	LPG	GO	GO	GO	NG	GO	NG	HFO
Cost of useful heat from conventional fuels	€/MWh UPH	23.92	23.20	25.78	24.04	21.22	40.09	-	32.33	48.08	26.14	30.05	23.92	33.42
Total	MWh UPH	202 000	81 826	28 000	6 011	54 970	131	45	71	402	75 264	349	34 949	6 727
Low temperature (<60 °C)	MWh UPH	36 000	66 150	5 600	4 208	48 558	82	21	59	138	0	25	0	1 244
Low and medium temperature (<160 °C)	MWh UPH	144 000	81 826	28 000	6 011	54 970	49	23	12	402	5 464	349	16 000	6 727
Percentage of low and medium temperature	%	71.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	7.3	100.0	45.8	100.0
Solar system														
Solar collector type		CPC	UFPC	PTC	EFPC	UFPC	CPC	CPC	CPC	CPC	PTC	CPC	CPC	FPC
Proposed system size														
Collector area	m2	10 000	5 000	8 000	3 000	1 500	60	60	60	200	1 000	200	2 500	500
Useful heat gain	MWh	5 584	4 770	3 343	879	695	40	21	48	65	502	58	1 725	470
Total investment	€	2 788 700	1 322 200	1 929 250	994 075	763 300	30 830	54 100	23 600	75 096	307 540	72 950	763 300	137 700
Heat cost	€/MWh	56.9	31.7	66.6	127.3	120.7	84.0	277.6	54.4	128.4	69.3	141.7	50.1	33.4
Solar fraction	%	2.8	5.8	11.9	14.6	1.3	30.8	47.2	67.9	16.2	0.7	16.5	4.9	7.0
Technical potential														
Collector area	m2	20 000	10 000	14 000	3 000	1 500	180	60	50	900	20 000	1 000	10 000	500
Useful heat gain	MWh	8 349	7 760	5 600	879	695	83	21	43	235	7 500	145	5 584	470
Total investment		5 577 400	2 644 500	3 376 000	994 075	763 300	65 150	54 100	20 740	304 150	5 535 700	346 500	2 788 700	137 700
Heat cost	€/MWh	76.1	39.0	69.6	127.3	120.7	87.4	277.6	53.6	145.5	84.2	268.2	56.9	33.4
Solar fraction	%	4.1	9.5	20.0	14.6	1.3	63.7	47.2	60.4	58.5	10.0	41.5	16.0	7.0
Available roof area as limiting factor ?	yes/no	yes	yes	yes	yes	yes	no	yes	no	no	yes	yes	yes	yes
Economical potential (scenario 2)														
Collector area	m2	20 000	10 000	14 000	3 000	1 500	100	60	150	0	17 000	0	10 000	500
Useful heat gain	MWh	8 349	7 760	5 600	879	695	59	21	66	0	6 600	0	5 584	470
Total investment		5 577 400	2 644 500	3 376 000	994 075	763 300	42 300	54 100	46 875	0	4 704 900	0	2 788 700	137 700
Heat cost	€/MWh	76.1	39.0	69.6	127.3	120.7	79.8	277.6	80.3	-	81.3	-	56.9	33.4
Solar fraction	%	4.1	9.5	20.0	14.6	1.3	44.9	47.2	92.7	0.0	8.8	0.0	16.0	7.0
Solar radiation level														
Global radiation on horizontal	kWh/m^{2}a	1 492	1 768	1 445	1 445	1 421	1 445	1 544	1 872	1 445	1 664	1 608	1 608	1 755
Direct normal radiation	kWh/m^{2}a	1 080	1 924	1 312	1 312	1 415	1 312	1 162	2 092	1 312	1 784			
Annual mean ambient temperature	°C	15.2	18.0	15.9	15.9	15.0	15.9	15.4	18.0	15.9	14.7			

Table 18. Case studies: Overview – data on heat demand, technical and economical potential for solar process heat.

Global analysis WP5		14	15	16	17	18	19	20	21	22	23	24	25
General information on the company													
Company short name		LAVASOR	Viena	Matadero	Solès-Pagès	Sagra	Promic	Pinsos Grau	Frimancha	Nanta	Pinsos Baucells	Cárdeno	Augstin Barral
Industrial sector		Textile	Food	Food	Food	Food	Food	Food	Food	Food	Food	Food	Paper
Country		Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain
Region		Andalucía	Catalonia	Catalonia	Catalonia	Catalonia	Catalonia	Catalonia	Valencia and Central Spain	Catalonia	Catalonia	Andalucía	Catalonia
Heat demand (UPH)													
Fuel type(s)		NG	NG	HFO	LPG	GO	NG	GO	HFO	NG	HFO	OTH	HFO
Cost of useful heat from conventional fuels	€/MWh UPH	26.14	26.14	28.31	42.43	32.33	26.14	45.86	26.68	30.77	32.70		28.00
Total	MWh UPH	838	203	896	32	1 047	13 475	647	21 206	527	8 929	576	25 595
Low temperature (<60 °C)	MWh UPH	838	203	896	10	1 009	4 214	559	4 660	217	1 639	51	9 958
Low and medium temperature (<160 °C)	MWh UPH	838	203	896	32	1 047	13 475	647	4 660	527	8 929	51	15 637
Percentage of low and medium temperature	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	22.0	100.0	100.0	8.8	61.1
Solar system													
Solar collector type		FPC	FPC	FPC	CPC	CPC	SFPC	SFPC	SFPC	SFPC	SFPC	SFPC	PTC
Proposed system size													
Collector area	m2	200	150	300	30	500	2 000	500	1 000	300	500	60	2 000
Useful heat gain	MWh	255	100	240	14	391	1 515	237	923	171	299	44	1 086
Total investment	€	58 900	46 850	94 400	10 870	175 200	640 000	163 085	282 500	109 000	181 600	26 670	574 405
Heat cost	€/MWh	26.2	53.2	44.4	88.8	50.2	47.7	77.5	34.8	71.4	67.9	66.4	60.1
Solar fraction	%	30.4	49.0	26.8	42.7	37.4	11.2	36.6	4.4	32.4	3.4	7.7	4.2
Technical potential													
Collector area	m2	400	195	800	60	950	6 667	1 050	5 350	1 150	2 670	60	2 000
Useful heat gain	MWh	510	125	520	19	623	3 465	388	2 992	300	600	44	1 086
Total investment		115 000	60 900	240 000	24 000	314 160	1 800 000	283 500	1 411 063	310 500	720 090	26 670	574 405
Heat cost	€/MWh	25.7	55.1	52.3	138.3	56.8	59.4	83.4	54.0	118.3	137.1	66.4	60.1
Solar fraction	%	60.8	61.6	58.0	60.1	59.5	25.7	60.0	14.1	56.9	6.7	7.7	4.2
Available roof area as limiting factor ?	yes/no	yes	no	no	no	no	yes	no	yes	yes	yes	no	yes
Economical potential (scenario 2)													
Collector area	m2	400	350	1 500	15	2 000	6 667	1 000	11 651	500	1 200	110	2 000
Useful heat gain	MWh	510	190	670	8	841	3 465	375	3 774	222	460	57	1 086
Total investment		115 000	104 000	448 400	6 000	600 000	1 800 000	270 000	2 417 583	155 000	324 000	41 800	574 405
Heat cost	€/MWh	25.7	62.1	75.9	79.7	80.9	59.4	82.3	75.0	78.9	80.5	81.8	60.1
Solar fraction	%	60.8	93.6	74.8	26.1	80.3	25.7	57.9	17.8	42.2	5.2	9.9	4.2
Solar radiation level													
Global radiation on horizontal	kWh/m^{2}a	1 759	1 445	1 421	1 446	1 421	1 492	1 489	1 664	1 544	1 489	1 726	1 641
Direct normal radiation	kWh/m^{2}a		1 312	1 415	1 459	1 415	1 080	1 526	1 784	1 162	1 526	1 909	
Annual mean ambient temperature	°C		15.9	15.0	15.3	15.0	15.2	12.5	14.7	15.4	12.5	16.4	

Table 19. List of case studies (Spain): proposed systems

Summary case studies POSHIP		1	2	3	4	5	6	7	8	9	10	11	12	13
COMPANY NAME		FIBRACOLOR	CRUZCAMPO	GUARRO CASAS	NISSAN	MORAVIA	TORRES	MAS MARTINET	OSBORNE	CARBOMAS	KIMBERLY	UNFASA	SANCHÍS	CREVISA
Industry														
Industrial sector		textile	malt	paper	automobile	malt	wine	wine	wine	wine	paper	beverage	textile	textile
Process		preheating of liquid baths	preheating of air for malt drying	low pressure steam for drying drums	superheated water for several processes	preheating of air for malt drying, absorption cooling	preheating of water for bottle washer	absorption cooling / space heating	preheating of water for bottle washer	heating of water for bottle washer	low pressure steam for humidity balance of paper	heating of water for bottle washer	preheating of baths circulating water	preheating of liquid baths
Location		Girona	Sevilla	Barcelona	Barcelona	Lleida	Barcelona	Tarragona	Cádiz	Barcelona	Salamanca	Valencia	Valencia	Alicante
Characteristic data of the proposed system														
Collector model [*type*]		CPC	UFPC	PTC	EFPC	UFPC	CPC	CPC	CPC	CPC	PTC	CPC	CPC	FPC
Collector area	m^2	10 000	5 000	8 000	3 000	1 500	60	60	60	200	1 000	200	2 500	500
Volume of heat storage	m3	0	1500	0	0	500	5	1.5 (heat) + 3 (cold)	5	10	0	10	313	25
Working temperature (min. / max.)	°C	40	20	135	120	20	50	50	10	85	125	85	60	10
		80	80	135	120	80	90	85	85	85	125	85	90	40
Additional notes						system including absorption cooling	system including waste heat recovery	system including absorption cooling						
Estimation of system performance														
Production of useful heat	MWh	5 580	4 770	3 343	880	695	25	21	48	59	502	65	1 377	470
Useful heat per unit area	kWh/m^2	558	954	418	293	463	422	348	805	296	502	327	551	940
Solar fraction	%	13	7	12	15	11	39	49	68	15	9	19	9	38
Installation cost	k€	2795	1325	1934	996	645	35	54	24	75	308	73	754	138
Company's contribution	k€	928	410	536	377	271	22	36	11	30	123	29	302	55
Annual savings	k€	91.0	104.8	76.5	16.3	66.3	3.5	3.0	1.3	2.2	10.2	1.1	38.1	15.7
Simple pay-back	a	10	4	7	23	4	6	12	8	13	12	26	8	4
Energy costs (without funding)	€/MWh	57	32	73	127	103	151	280	55	142	74	125	62	33
Climatic data and system efficiency														
Yearly global radiation	kWh/m^2	1 492	1 754	1 470	1 470	1 421	1 470	1 544	1 872	1 470	1 626	1 608	1 608	1 755
Mean working temperature	°C	45	24	135	120	27	66	67	61	85	125	85	63	21
Mean annual system efficiency	%	37	54	28	20	33	29	23	43	20	31	20	34	54
Characteristics of load perfile														
Continuous: C; 5 days: W; Seasonal: S; 5 days with weekend storage: W-L.		C	C	C	W	S	W-L	S	W-L	W	C	W	W-L	W

Table 19. List of case studies (Spain) (-continued-)

Summary case studies POSHIP		14	15	16	17	18	19	20	21	22	23	24	25	
COMPANY NAME		S.C.A. LAVASOR	VIENA	MATADERO DE LLEIDA	SOLÈS-PAGÈS	SAGRA	PROMIC	PINSOS GRAU	FRIMANCHA	NANTA	PINSOS BAUCELLS	CÁRDENO	AGUSTÍN BARRAL	TOTAL
Industry														
Industrial sector		textile (laundry)	food	meat	meat	meat	animal food	animal food	meat	animal food	animal food	meat	paper	
Process		preheating of water for clothes washing	preheating of water for machine washing	heating of water	preheating of circulating water and baths heating	baths heating, preheating of water supply and PSW	preheating of drying air	preheating of circulating water and cleaning water	preheating of network water supply for processes and boiler	preheating of network water supply for processes and boiler	preheating of network water supply for processes and boiler	preheating of network water supply for processes and boiler	preheating of drying air	
Location		Jaén	Barcelona	Lleida	Girona	Lleida	Girona	Barcelona	Madrid	Girona	Barcelona	Badajoz	Barcelona	
Characteristic data of the proposed system														
Collector model [*type*]		FPC	FPC	FPC	CPC	CPC	SFPC	SFPC	SFPC	SFPC	SFPC	SFPC	PTC	
Collector area	m^2	200	150	300	30	500	2 000	500	1 000	300	500	60	2 000	**39 620**
Volume of heat storage	m3	10	5	15	1	125	500	13	125	38	63	8	250	
Working temperature (min. / max.)	°C	10	10	10	35	15	20	46	15	15	15	15	80	
		60	75	55	85	45	150	58	70	120	100	70	135	
Additional notes														
Estimation of system performance														
Production of useful heat	MWh	255	100	240	14	391	1 515	237	923	171	299	44	865	**22 889**
Useful heat per unit area	kWh/m^2	1 274	664	800	457	782	758	474	923	570	598	733	433	
Solar fraction	%	30	49	27	43	37	11	37	19	37	62	60	7	
Installation cost	k€	59	47	95	11	175	640	163	283	109	182	27	59	**11 005**
Company's contribution	k€	23	19	38	4	70	256	65	113	44	73	11	23	**3 869**
Annual savings	k€	6.0	2.3	6.0	0.5	11.4	38.0	9.7	22.3	4.5	8.6	2.2	6.0	**548**
Simple pay-back	a	4	8	6	9	6	7	7	5	10	8	5	4	
Energy costs (without funding)	€/MWh	26	53	45	89	53	48	78	35	71	72	67	13	
Climatic data and system efficiency														
Yearly global radiation	kWh/m^2	1 759	1 470	1 421	1 446	1 421	1 492	1 489	1 664	1 544	1 489	1 726	1 641	
Mean working temperature	°C	25	42	22	56	26	35	50	25	54	68	48	84	
Mean annual system efficiency	%	72	45	56	32	55	51	32	55	37	40	42	26	
Characteristics of load perfile														
Continuous: C; 5 days: W; Seasonal: S; 5 days with weekend storage: W-L.		C	W	C	C	W-L	C	C	W-L	W-L	W-L	C	W-L	

In the following Tables the distribution of the 25 companies studied is analysed.

The geographic distribution and the distribution on industrial sectors is analysed in Table 20. 62 % of the cases studied are in Catalonia, due to the large number of direct contacts that could be made in this region during the first project phase and due to the feedback to the second mailing from ICAEN. Studies in the rest of Spain have been focused to industries in regions with favourable climatic conditions (Central and Southern Spain).

Table 20. Case studies (Spain) by industrial sectors and regions

Industrial Sector	Andalucía	Valencia and Central Spain	Catalonia	Total
Food	1	1	8	**10**
Wine and Beverage	1	1	3	**5**
Paper		1	2	**3**
Textile	1	2	1	**4**
Malt	1		1	**2**
Automobile			1	**1**
TOTAL	**4**	**5**	**16**	**25**

Table 21 shows the distribution on working temperature ranges. The studied systems are well distributed over the whole temperature range up to 140 °C. Studies for industries with processes requiring higher temperatures have not been carried out, as the economic outcome of these systems becomes very poor.

System sizes of the proposed solar systems vary from 60 m^2 up to 10 000 m^2. Most of the systems were for water pre-heating or direct heating of water baths or circuits. Four systems for air preheating and two systems for low-pressure steam generation have been proposed.

Table 21. Proposed solar systems (Spain) by mean temperature level of operation of the solar system

Temperature range	Temperature interval	Andalucía	Valencia and Central Spain	Catalonia	Total
Very low temperature	<= 40 °C	2	2	4	**8**
Low temperature	>40 ... 60 °C	1		5	**6**
Medium temperature A	>60 .. 80 °C	1	1	3	**5**
Medium temperature B	>80 .. 100 °C		1	3	**3**
Medium temperature C	>120 ... 140 °C		1	1	**2**
TOTAL		**4**	**5**	**16**	**25**

Table 22. Proposed solar systems by solar system size

Solar collector area		Andalucía	Valencia and Central Spain	Catalonia	Total
Small	< 100 m^2	2		3	**5**
Medium	>=100 m^2 ... 1000 m^2	1	3	7	**11**
Large	>= 1000 m^2	1	2	6	**9**
TOTAL		**4**	**5**	**16**	**25**

Table 23. Proposed solar systems by system size and system type

Solar collector area		Air preheating	Water preheating	Direct bath or fluid heating	Steam generation
Small	< 100 m^2		4	1	
Medium	>=100 m^2 … 1000 m^2		8	3	
Large	>= 1000 m^2	4	2	1	**2**
TOTAL		**4**	**14**	**5**	**2**

Figure 31 shows the relative annual useful heat gain of the solar systems (with respect to global solar radiation on horizontal) for the different systems and working temperatures. System efficiency decreases as expected with increasing working temperature.

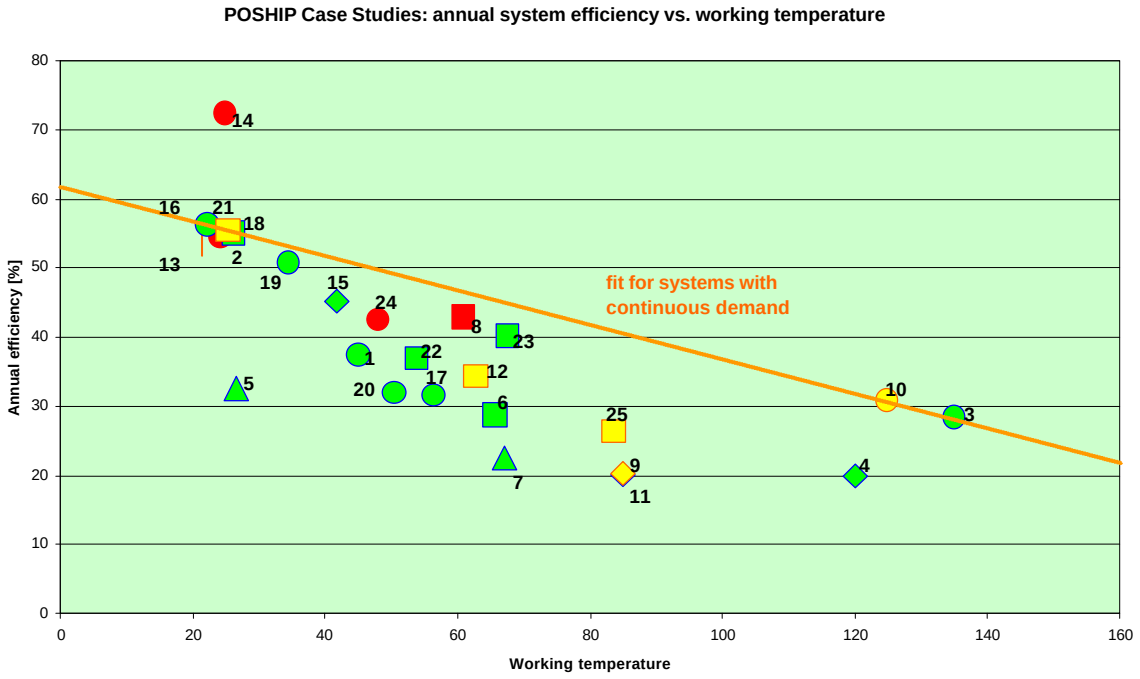


Figure 31. Relative annual useful heat gain of solar systems (with respect to solar radiation on horizontal) as a function of the working temperature.

Colours: Andalucía (red), Valencia and Central Spain (yellow), Catalonia (green).

Symbols: ● Systems with continuous demand; ◆ Systems with continuous demand during the week and breaks at weekend; Systems with continuous demand during the week and breaks at weekend, with long-term storage;▲ Systems with only seasonal operation.

For systems with a high temperature drop (e.g. pre-heating of water or air streams) the mean annual working temperature has been estimated by the following formula, as a function of the solar fraction:

$$T_m = T_{inlet} + 0.5\, f_{solar} \left(T_{process} - T_{inlet} \right)$$

A rough first estimate for the efficiency of the systems with a continuous operation throughout the year can be obtained from a simple straight line given by the expression

$$h = \frac{\overline{Q}_u}{\overline{H}} = (0.62 - 0.0025K^{-1} \cdot T_m)$$

Systems with breaks of operation on the weekends show efficiencies well below this line and poorest efficiencies are obtained for systems that are only seasonally operating (Systems 5 and 7). In cases with weekend – breaks system efficiency can be increased by long term storage. Efficiency for these systems lies close to that of systems with continuous demand

The economical outcome of the system has been analysed based on the economic parameters given in section 4.2.2.3. Best economic performance (26 – 35 €/MWh) has been obtained for a group of four projects working at very low temperature and located in Southern or Central Spain (water or air pre-heating, Projects 2, 13, 14 and 21).

For a group of five low temperature projects (1, 15, 16, 18 and 19) and one medium temperature project (8) energy costs between 40 and 60 €/MWh are possible. Large-scale systems for generation of low-pressure steam (Projects 3 and 10) yield energy costs of close to 70 €/MWh. A group of low and medium temperature projects yields (12, 20, 22-24) energy costs between 60 and 80 €/MWh. Systems of this type may become economically feasible in a near future.

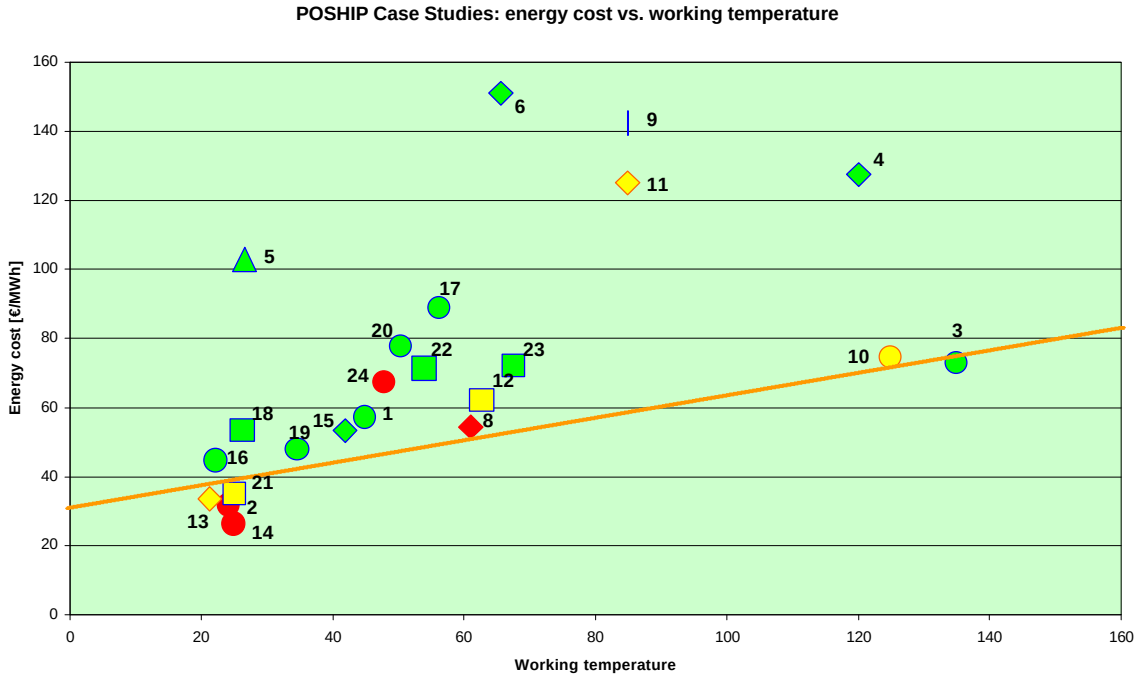


Figure 32. Costs of useful energy (without funding) for the different systems as a function of the mean annual working temperature (with respect to solar radiation on horizontal) as a function of the working temperature. Colours and symbols: see text of Figure 31.

Energy costs for systems 4, 5, 6, 9, 11 and 17 are too high for being considered as candidates for demonstration projects. Reasons for the bad performance of these systems are the combination of two adverse factors: (a) non-continuous operation of the plants (b)

elevated working temperatures (medium temperature) (c) non-favourable climatic conditions (except project 11).

4.4.2 Portugal

The companies visited and studied in Portugal are:

MALTIBÉRICA – Sociedade Produtora de Malte S.A.
Rua Alberto Valente
2965-309 Poceirão
Phone: 265 995 320
Fax: 265 995 386
e-mail: carlos.maltiberica@mail.telepac.pt
Contact persons: João Jacques de Sousa – Director Industrial
Carlos Pragana – Chefe dos Serviços de Produção

M. R. A. NABEIRO LDA
Av. Calouste Gulbenkian
7370 Campo Maior
Telf: 268 699 200
Fax: 268 688 960
e-mail: abarrocas@delta-cafes.pt
Contact person: Eng° Barrocas Guerra

SOTAVE – Sociedade Textil dos Ameeiros Verdes, S.A.
6260-951 Manteigas
Tel: 275 982 460
Fax: 275 982 464
e-mail: Sotave@mail.telepac.pt
Contact persons:Drª Patrícia Madeira
Eng° Jorge Mota Veiga

DANONE PORTUGAL S.A.
Zona Industrial, Apartado 1093
6001-997 Castelo Branco
Tel: 272 339 000
Fax: 272 339 090
Contact person: Sr. Rogério Sacramento

MONTEIRO RIBAS IND S.A.
Moitas
Alcanena
Tel: 249 881 614
Fax: 249 891 480
Contact person: Dra. Cristina Ribas
Sr. Armando Gomes

Beiralã – Lanifícios, S.A.
Av.1° de Maio
Apartado 217
6270-909 Seia
Tel: 238 310 265
Fax: 238 310 269
Contact person: Sr. Rui Dias Cardoso

CURTUMES FABRICIO, LDA
Vila Verde
6270 Seia
Tel: 238 979 010
Fax: 238 979 019
Contact person: Eng° António José Santos

FAPULME LDA
Casal das Figueiras
Ulme-Parreira
2140 Chamusca
Tel: 249 770 236
21 941 9681
Contact person: Eng° José de Sá Fragono
Dr. José Gonçalves

CORTICEIRA AMORIM ALGARVE LDA.
Vale de Lama, Apartado 27
8300-999 Silves
Tel: 282 442 336
Fax: 282 442 236
Contact person: Eng° Alves Lírio

ITEXCORK, Industria Transfor Exportação Cortiça, Lda.
Estrada de Lavre, Apartado 7
7084-909 Vendas Novas
Tel: 265 809 220
Fax:265 809 221
Contact person: Eng° Lopes Infante

Not all of these factories showed favourable conditions for implementation of solar energy and some of them did not deliver the necessary data in order to perform the pre-feasibility study.

The summary sheets of the case studies performed are given in the annex in electronic format.

4.4.3 *Parabolic Trough Technology*

The application of parabolic trough technology in industrial solar plant has been analysed in some of the case studies in Spain (case studies no. 3, 10 and 25).

Apart from these studies, a specific analysis for the application of solar thermal systems with parabolic trough technology for sludge drying has been carried out by DLR.

4.4.3.1 Introduction

Sludge drying consumes great amounts of heat for evaporating water. The company Lindauer-Dornier (Lindau, Germany) and the Solare Energietechnik at the research centre DLR (Deutsches Zentrum für Luft- and Raumfahrt) are investigating the application of parabolic trough collectors to find an economically and ecologically satisfying solution.

As Lindauer-Dornier is interested in using solar energy in southern Germany (Munich, Stuttgart) and Barcelona (Spain), these places have been investigated in this preliminary study. Various concepts are possible for the implementation of solar heat into the sludge drying process. Temperatures in the solar field have to be between 100 °C and 160 °C depending on the process. At this temperature level parabolic trough collectors are assumed to be the economically most viable solution for a solar contribution. Preferably these should be positioned on the roof area.

4.4.3.2 Model of the Solar Energy System

On the basis of the drying schemes and the efficiency parameters of the collector, the energy output of the collector has been calculated with the weather data of the TRY (Test Reference Year) Würzburg, representing the climates of Munich and Stuttgart and with the weather data for Barcelona from the program Meteonorm. The Direct Normal Irradiation (DNI) of Würzburg is 1066 kWh/m²a, for Barcelona it is 1312 kWh/m²a. The simulation program TRNSYS was used for modelling the solar field.

The solar field size is designed for a 100% supply at full irradiation. As the drying process continues all year, the available solar energy is assumed to be always fully consumed. A fossil heat source supplies the remaining energy.

4.4.3.3 Alternative 1: Low Temperature Drying

The scheme of the first alternative is presented in Figure 33.

The sludge drying system runs at 150 °C inlet and at 100 °C outlet temperature, which are also the corresponding solar field outlet and inlet temperatures. A power consumption of 900 kW is assumed for drying 1740 kg/h with 25% sludge fraction to a content of 90% sludge. A field area of 1800 m² is necessary for a nominal output of about 900 kW.

For installations in the area of southern Germany the solar system delivers 319 kWh/m² annually. This amounts to 573480 kWh for the whole field and a solar share of 7.2% of the annual total consumption.

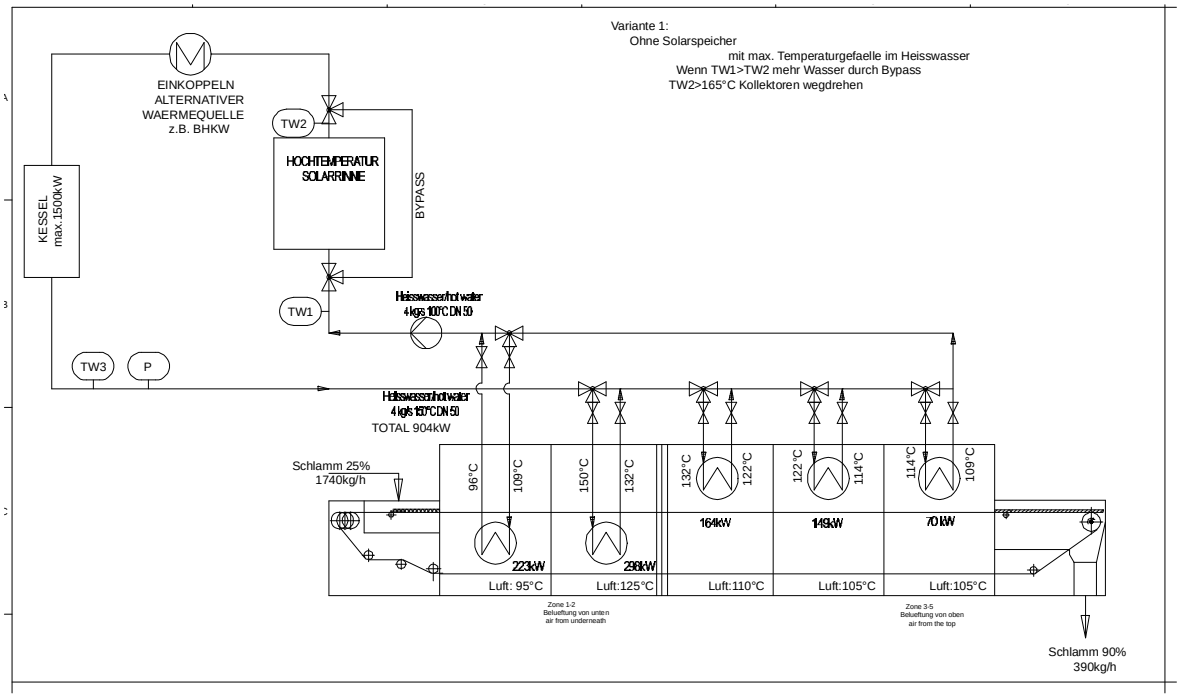


Figure 33. Scheme 1 of Sludge Drying with Solar Contribution

In the climate of Barcelona 383 kWh/m² contribute with a solar share of 8.7% to the energy supply of the drying process. Figure 34 shows the distribution of the energy flow in the solar field over the year for this simulation.

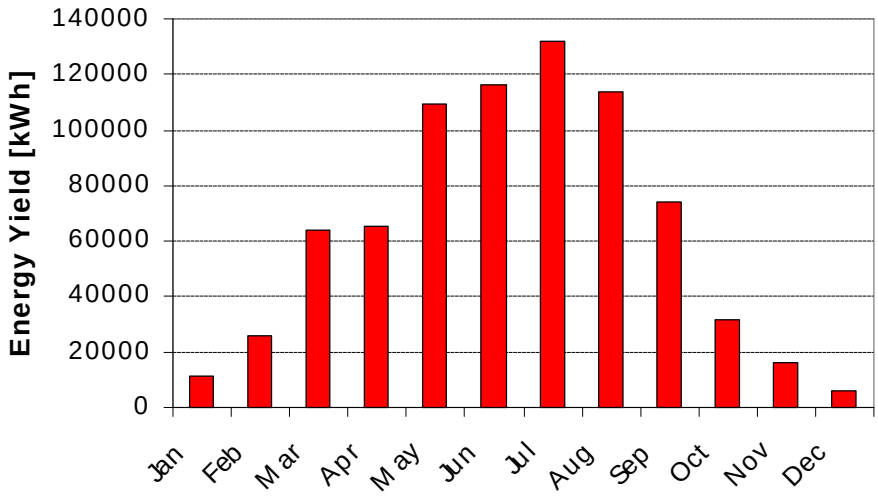


Figure 34. Monthly distribution of solar supply in Barcelona

The power supply per square meter of collector aperture area and the direct normal irradiation (DNI) is illustrated in a profile of a sunny day in Figure 35.

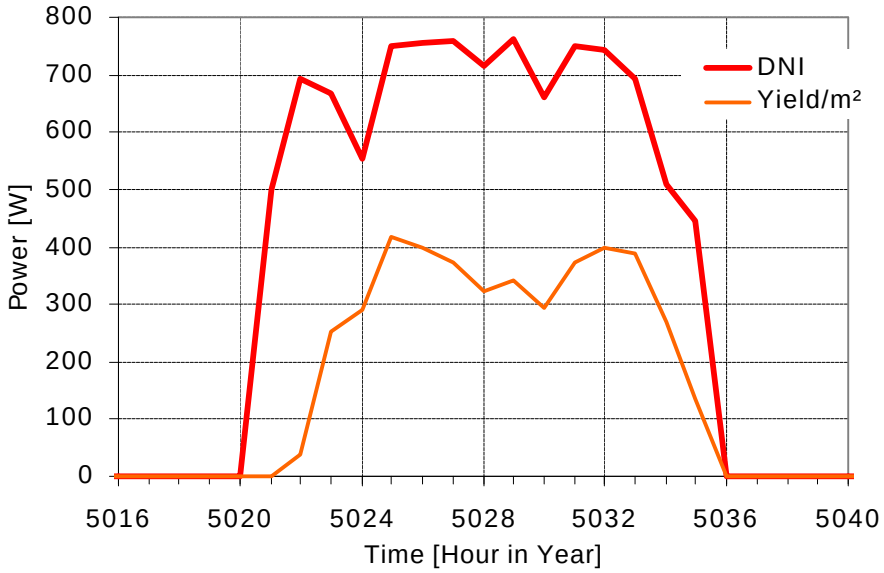


Figure 35. Day Profile of Irradiation and Energy Yield

4.4.3.4 Alternative 2: High Temperature Drying

For a higher efficiency of the dryer, resulting in an output rate of 500 kg/h of sludge, elevated drying temperatures of 160 °C at inlet and 145 °C at outlet are necessary (Figure 36). To reach the power rate of 1200 kW at nominal conditions, a field area of 2400 m² is considered.

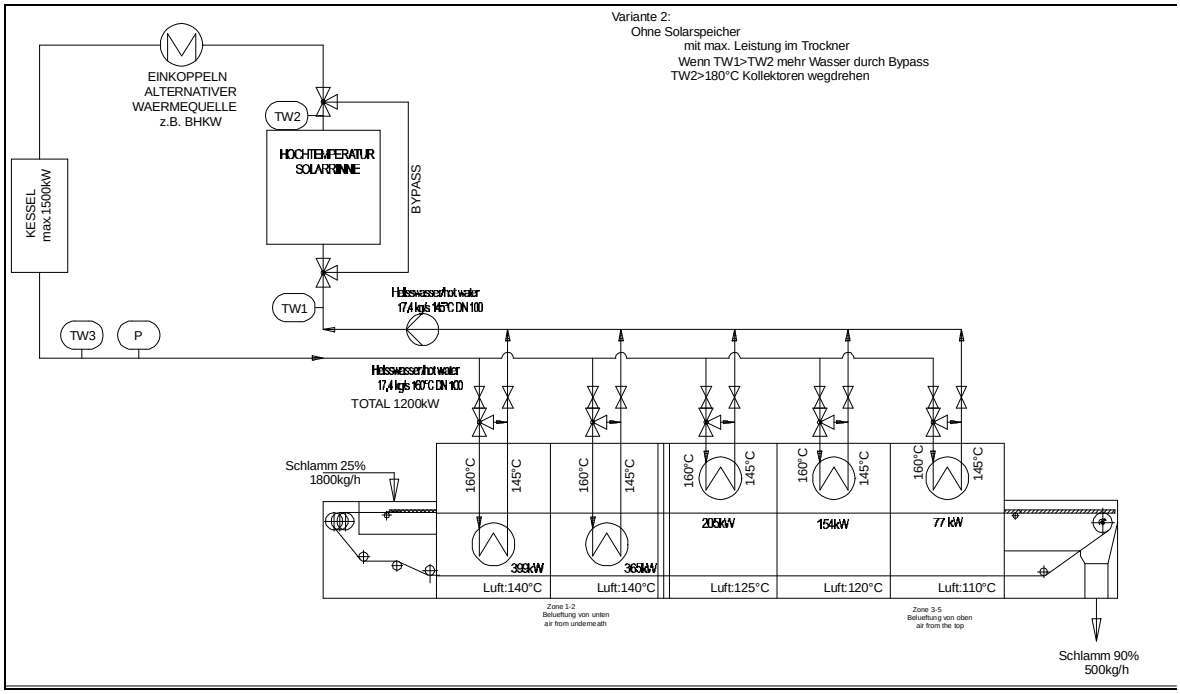


Figure 36. Scheme 2 of Sludge Drying with Solar contribution

The solar field temperatures are therefore several degrees higher compared to the first alternative leading to lower solar field efficiency. For the climate of southern Germany the annual output amounts to 264 kWh/m² resulting in a solar share of 6.0%. For Barcelona 317 kWh/m²*a are reached meaning a solar share of 7.2%.

4.4.3.5 Comparison of the Alternatives

All results discussed are gathered in Table 24.

Table 24. Gathered Energy Data from Simulations

		Alternative 1 low temperature		Alternative 2 high temperature	
		Würzburg	Barcelona	Würzburg	Barcelona
DNI		1 066	1 312	1 066	1 312
Field Size	m²	1 800	1 800	2 400	2 400
Annual Yield/m²	kWh/m²a	319	383	264	317
Annual Yield Field	kWh	573 480	688 500	632 880	760 320
Consumption	kW	904	904	1 200	1 200
Consumption per Year	kWh/a	7 919 040	7 919 040	10 512 000	10 512 000
Solar Share	%	7.2	8.7	6.0	7.2

As expected the solar fields performance is best at lower temperatures. The efficiency of the drying system is lower though, thus making less use of the solar energy, as well as from the conventional energy. Therefore the amount of sludge dried by solar energy has been calculated (Table 25) assuming 1740 kg/h to be dried in both processes. Overall it is slightly, by 3% more efficient to run the drying process as designed in alternative 2, as the high efficiency in drying more than compensates thermal losses in the solar field.

Table 25. Overall efficiency of solar heat

		Alternative 1 low temperature		Alternative 2 high temperature	
		Barcelona	Würzburg	Barcelona	Würzburg
Solar Share	%	7.2	8.7	6.0	7.2
Sludge Drying/h	kg/h	390	390	483	483
Sludge Drying/a	kg/a	3 416 400	3 416 400	4 234 000	4 234 000
Dried Solar	kg/a	247408	297 030	254 910	306 240
Ratio Alt 2 / Alt 1	-			1.03	1.03

4.4.3.6 Economic Discussion

For the investment costs of the collector field 240 €/m² are assumed. Figure 37 lists solar heat costs, which include annual operation and maintenance costs of 2 €/m²*a, for an annuity of 11%.

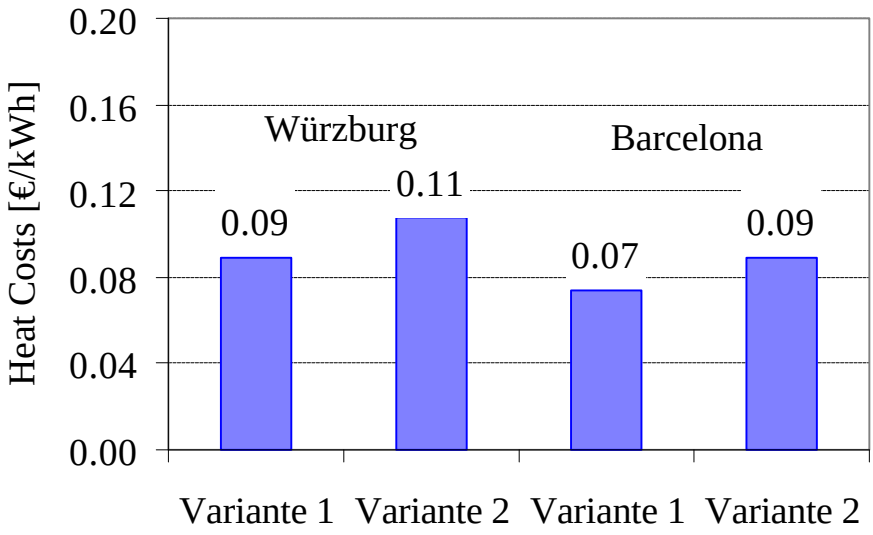


Figure 37. Heat Costs for Solar Energy

As found in the discussion about the efficiency of the solar energy compared to the output of the drying system, it is of advantage to operate dryer and solar field at higher temperatures. Therefore solar heat costs for Munich and Stuttgart amount to 11€cents/kWh and for Barcelona to 9 €cents/kWh.

4.4.3.7 Conclusion

In this first attempt to estimate the energy yield from a parabolic trough collector field and the associated costs a simple integration of the solar field has been chosen. By storage solar heat can also be supplied at night. This approach would lead to even higher heat costs though. Under the low fuel prices and the low radiation at the investigated sites the solar heat costs are not competitive yet. Further development in the efficiency of parabolic trough collectors, sites with higher radiation and also financial governmental support in first process heat projects could reduce the solar heat costs to an attractive level.

4.4.4 Response from Industry

In several industries a big interest in solar systems could be found. Nevertheless, in nearly all cases the analysis of the economical performance of the systems is decisive, although most industrials are aware also of environmental aspects and the possibilities of “green” marketing. Investments with pay back times of more than 5 years will hardly be accepted.

Current costs (spring 2000 - summer 2001) for useful heat in the visited industries are in the range from 1.5 – 7 Ptas / kWh (1 – 4.5 cents of €/kWh), the lower limit referring to heat from co-generation, and the upper limit corresponding to small consumers and fuels such as GLP or HFO. Present costs for large consumers for steam produced by natural gas fired steam boilers are about 2.5 – 3 cents/kWh.

At actual system costs the expectations on the return of investment can only be fulfilled if a very high percentage of funding and/or third party financing is obtained.

The uncertainty about the availability of funding is a great barrier in order to convince industrials to develop a demonstration project.

5 PROPOSALS FOR DEMONSTRATION PROJECTS

Some of the companies after knowing the results of the case studies showed an interest to possibly develop demonstration projects, if a sufficient level of funding can be obtained.

In Spain two companies have been selected to be studied with further detail:

- a malting factory in Southern Spain (Heineken España, S.A., Sevilla) with very good conditions (expected pay-back of less than 5 years).
- a wine cellar (Bodegas Mas Martinet, Tarragona) in Catalonia. This project has been selected due to the technical interest (demonstration plant for solar industrial cooling), although the economic performance is poor because of the small system size.

Among the case studies performed in Portugal proposals for demonstration projects have been elaborated for the the two following cases:

- Beiralã – Lanifícios, S.A.
- Maltibérica – Sociedade Produtora de Malte S.A.

These two factories showed a set of favourable characteristics, which encouraged us very much to continue the work with them:

- Available area for collectors installation
- The dimension of the solar system
- Importance of the industrial group that owns the factory
- Importance of the activity on the corresponding sector
- Economic interest on solar energy
- Environmental interest
- Quality management strategy

The two cases are also very attractive from the technical point of view and will permit the design of rather different solutions: i) water/air process fluid heating, ii) with/without storage, iii) multi pass/single pass design conceptions, iv) roof/field collectors installation, v) interior/littoral zone locations, vi) old/new factories solar system integration.

A short description of the systems selected for demonstration plants is given in the following sections. For an overview see Table 26. The geographical location of the proposed demonstration plants is shown in Figure 38.



Figure 38. Geographical location of the proposed demonstration plants.

Table 26. List of the most relevant parameters of the demonstration projects proposals described in the following sections.

Company / Sector / Country	Process	Working Temperature Range	Collector Type (**)	Projected Collector Area	Estimated Cost
				m^2	€
Malte Ibérica Malting factory Poceirao, Portugal	Air preheating for malt drying	Low temperature (20 – 60 °C)	FPC or CPC	3 500	624 000
Heineken España S.A. Malting factory Sevilla, Spain	Air preheating for malt drying	Low temperature (10 – 80 °C)	SFPC	3 046	930 000
Beirala Lanificios Textile factory Seia, Portugal	Water preheating in dying process	Low temperature (20 – 80 °C)	FPC or CPC	1 750	340 000
Bodegas Mas Martinet Wine cellar Tarragona, Spain	Cooling of wine stores and space heating	Medium temperature (50 – 85 °C)	CPC	60	55 000 (*)

(*) cost for solar system and absorption cooling system.
(**) FPC: flat plate collector; CPC: compound parabolic concentrator;

5.1 MALTING FACTORY: HEINEKEN ESPAÑA S.A., SEVILLA (SPAIN)

The malting factory of Heineken España S.A. is located in the province of Sevilla, in the South of Spain. The malt produced is used for the beer production in the same factory.

About 80% of the heat and cold consumption in the malting factory is used for air heating for the drying of malt (hot air at about 60 °C). Most of the remaining 20% is required for air-cooling in the germination process.

The profile of heat demand in this factory is ideal for the implementation of a solar system:

- The heat demand is high and continuous during 7 days a week and 24 hours a day, so that nearly all of the collected solar energy can be used directly in the process without need of large storage volumes.
- The required temperatures are very low. Air is preheated by the solar system only few degrees above ambient temperature.
- The factory is located in a region with a high solar radiation (1 770 kWh/m^{2}a).
- Energy costs are a significant cost factor in the malt production process, so that a reduction of energy consumption can help improving competitiveness.

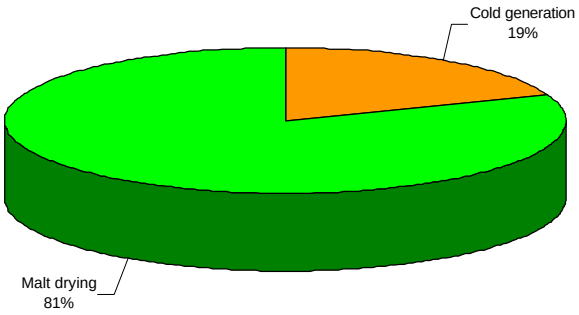


Figure 39. Heat demand by processes in the malting factory

5.1.1 Description of the Proposed Solar System

A solar system is proposed for the preheating of air for the malt drying process. An additional hot water-air heat exchanger will be installed in front of the existing heat exchanger using steam from the conventional heat supply system.

The solar system consists of two solar collector fields of a total surface of 3 046 m^2, and a storage tank of 500 m^3. The large-module selective flat plate solar collectors will be integrated in the saw-tooth shaped roof structure forming a rain-tight “solar roof”.

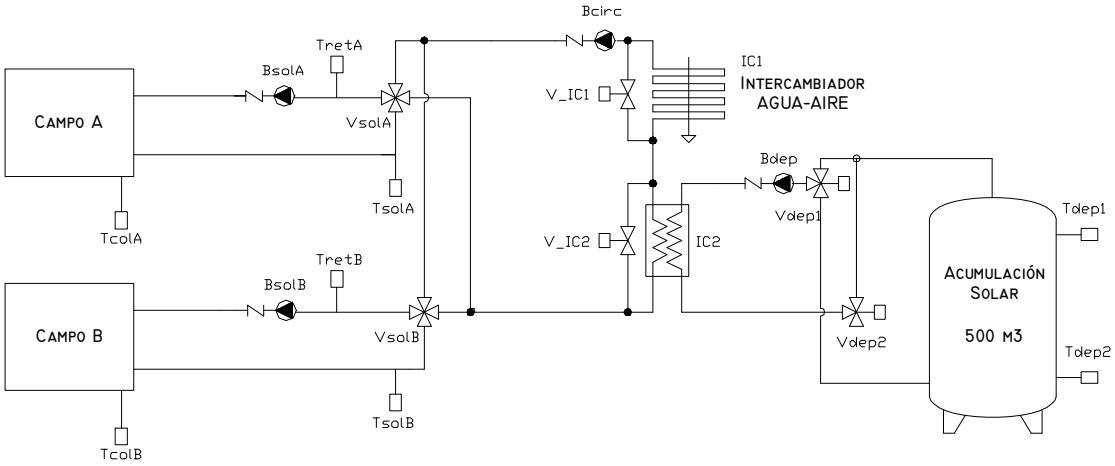


Figure 40. Scheme of the proposed solar system

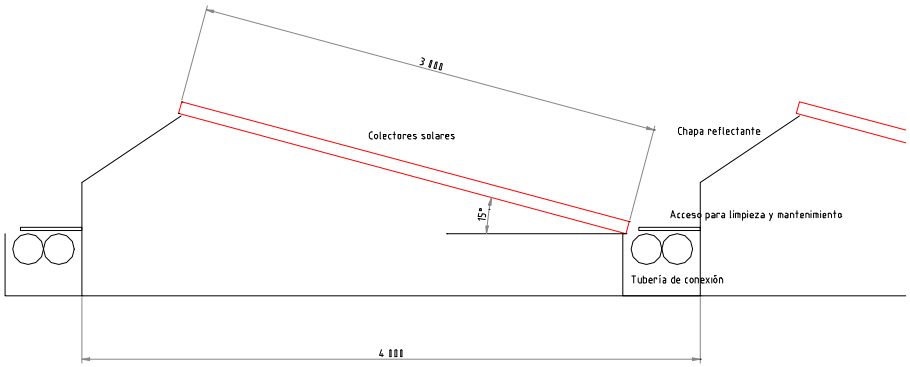


Figure 41. Integration of solar collectors into a sawtooth roof structure

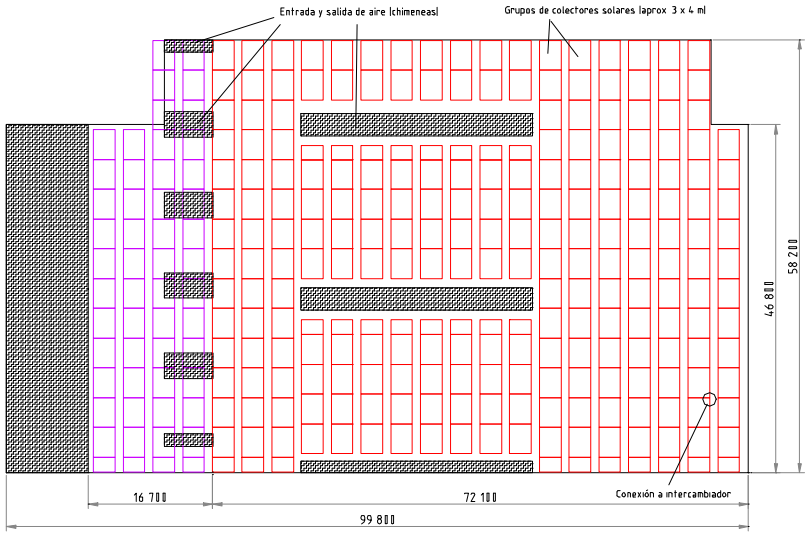
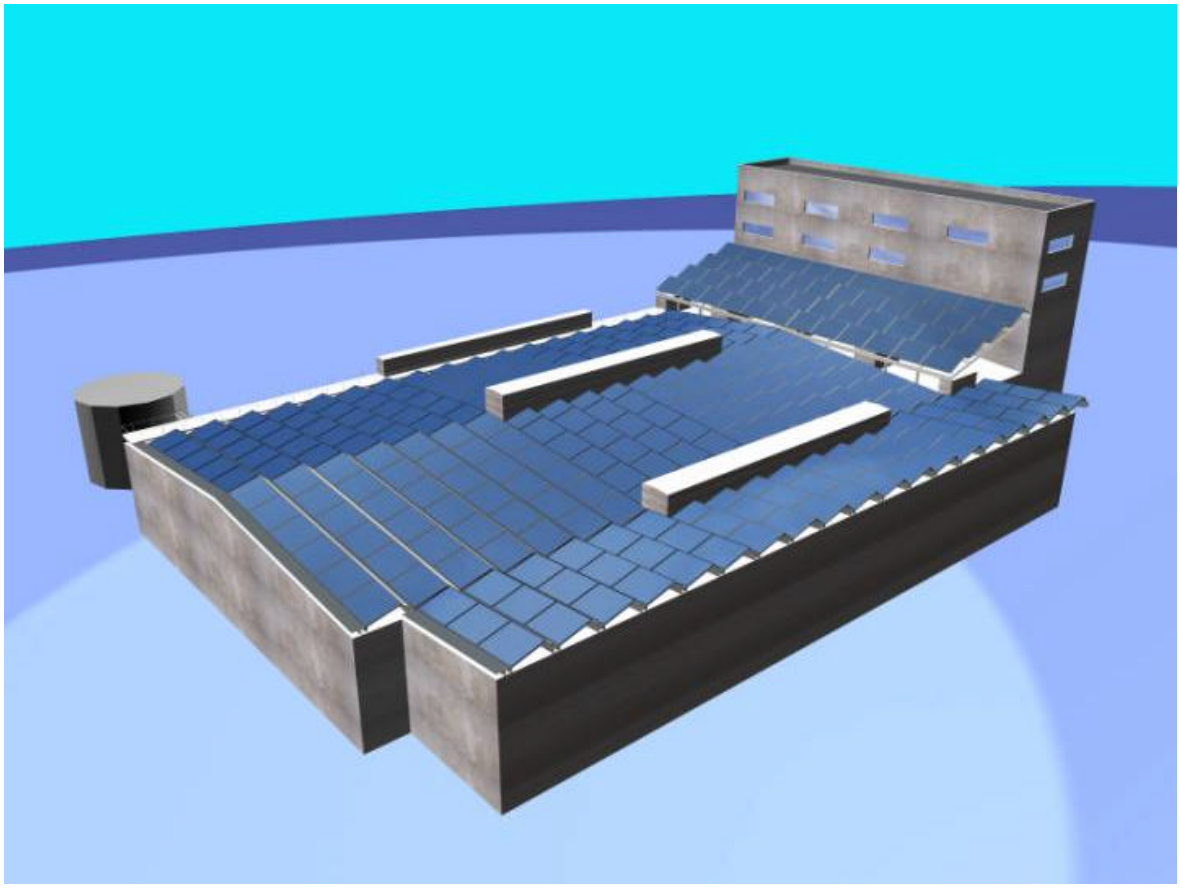


Figure 42. Distribution of Collector Rows



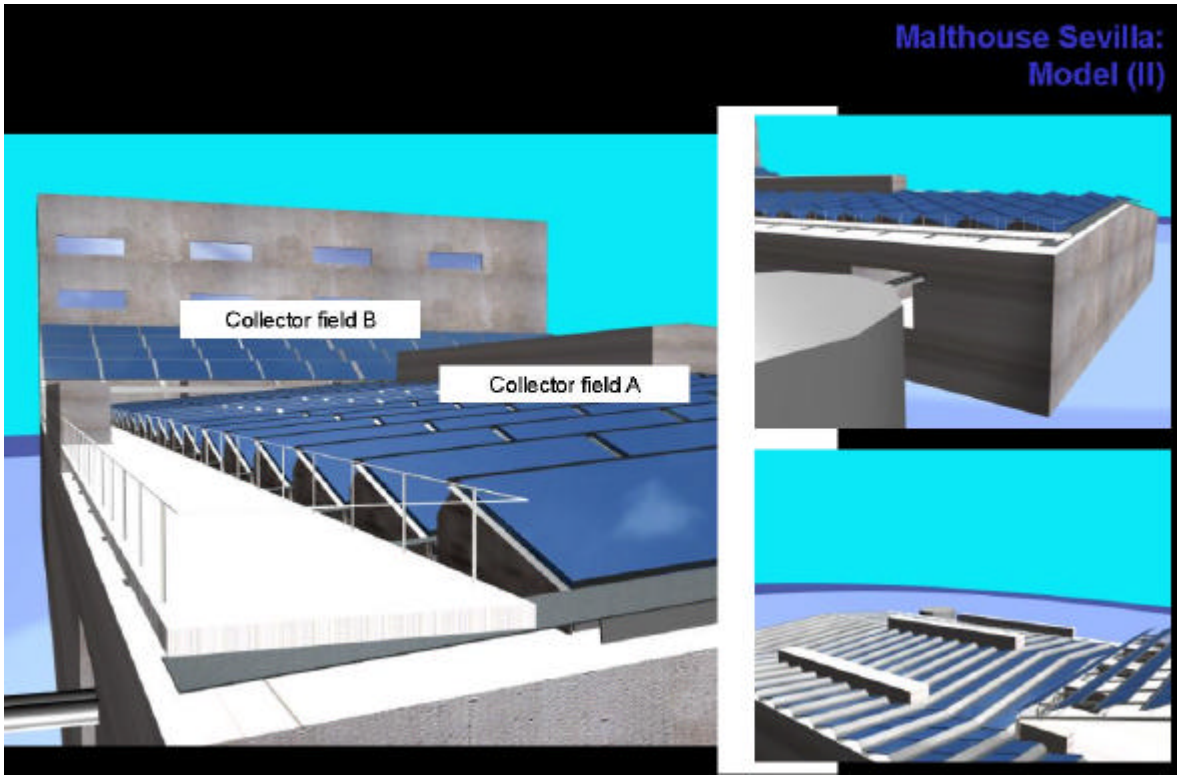


Figure 43. Model views of the proposed solar plant



Figure 44. View of the large module solar collectors for the proposed solar plant.

The heat demand and the solar contribution for the proposed system is given in Figure 45.

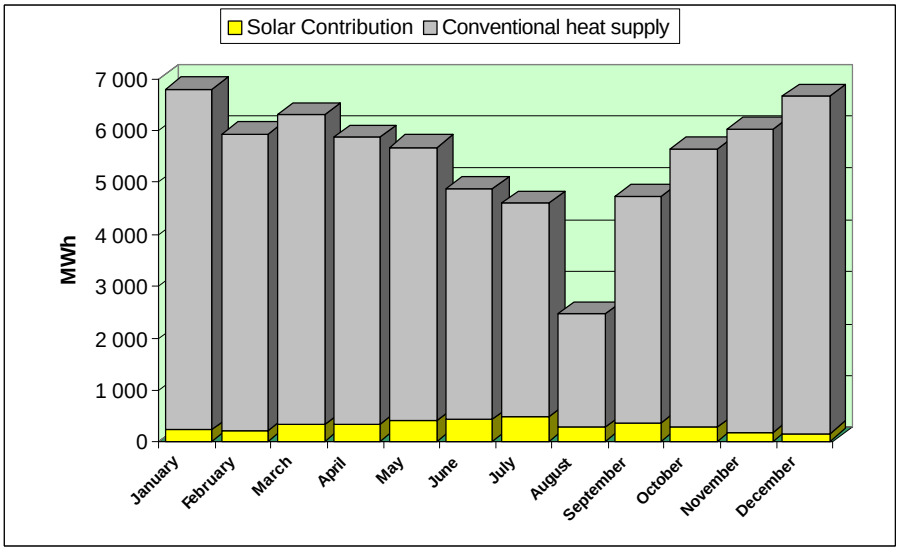


Figure 45. Useful heat demand and solar contribution for malt drying in Heineken Sevilla.

The annual solar energy gains (useful heat) are 3 570 MWh (1 172 kWh/m^2). This is a very good efficiency due to the high solar radiation in Sevilla and to the very low working temperatures.

An economic analysis of the proposed system is given in the following tables. A total solar system cost of 926 000 € and a pay-back period of 4.9 years (supposing 50 % public funding) is obtained.

Table 27. Characteristic data of the proposed solar system. (a) System costs; (b) Fuel savings and pay-back.

(a)

Description	PTA	Euro
Solar system incl. Support structure field B	160 409 000	964 078
Project planning	7 500 000	45 076
Roof structure (estimated)	16 200 000	97 364
TOTAL INVESTMENT	**184 109 000**	**1 106 517**
Add. cost solar system (*)	**154 109 000**	**926 214**

(*) Reference: new roof stucture without solar system. Estimated cost: 30 MPta.

(b)

INVESTMENT COST	PTA	Euro
Total investment (*)	154 109 000	926 214
Own contribution (50 % funding)	**77 000 000**	**462 779**
ENERGY SAVINGS		
Annual energy savings (**)	16 900 000	101 571
Annual maintenance cost	1 300 000	7 813
Net annual savings	**15 600 000**	**93 758**
PAY-BACK PERIOD		
Pay-back without funding	9.8 years	
Pay-back with 50 % funding	**4.9 years**	

(*) not including roof structure, estimated to 30 Mptas (180 000 €).
(**) calculated based on a cost for useful heat of 4.5 Ptas/kWh (2.7 cents/kWh)

5.1.2 Optimisation of the System - Step I: Comparison of Solar Collector Types and Parametric Study.

For this project a very careful optimisation of the system design has been carried out. In the early phase of project planning a comparison of different design options and a parametric study on the most important system parameters has been carried out by ZAE.

5.1.2.1 Load Profile

Solar heated air is used for the drying process of the malt. The assumed load profile in the simulation shows

Table 28. One process cycle is about 28 hours. In the first phase of the process the required temperature is low and the air mass flow is high. During the process cycle the temperature increases and the mass flow decreases. After 24 hours a break of 4 hours is necessary.

Table 28: load profil cruz campo

	time	temperature [°C]	massflow [m³/h]	duration [h]
Phase I	0:00 - 8:30	55	640000	8,5
Phase II	8:30 - 16:00	60	640000	7,5
Phase III	16:00 - 20:00	70	520000	4
Phase IV	20:00 - 24:00	80	390000	4
break	24:00 - 28:00	-	-	4

The heat demand for drying is constant during the year. Breaks for e. g. maintenance are not taken into account. The yearly heat demand is about 66 400 MWh.

5.1.2.2 Solar System and Dimension

Solar system

The drying process needs temperatures between 55-80 °C. Until now ambient air is sucked in, heated up to the necessary temperature and supplied to the malt, which has to be dried. A heat recovery does not exist.

The integration of the solar system into the conventional existing system is very simple. Solar heat produced by flat plate collectors is supplied to the sucked in ambient air by a heat exchanger. The solar system preheats the incoming air. Figure 46 shows the system.

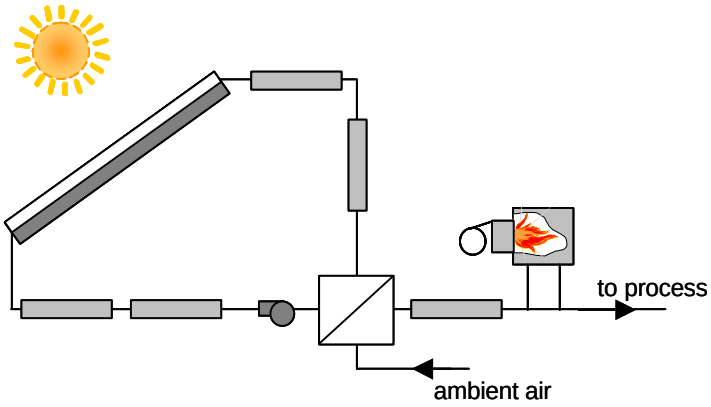


Figure 46: Solar system without storage

By use of air collectors a heat exchanger is not necessary. The process air is the collector fluid.

To use the solar heat during the breaks a system with buffer storage is modelled, too. The storage is integrated into the collector loop. Figure 47 shows the system.

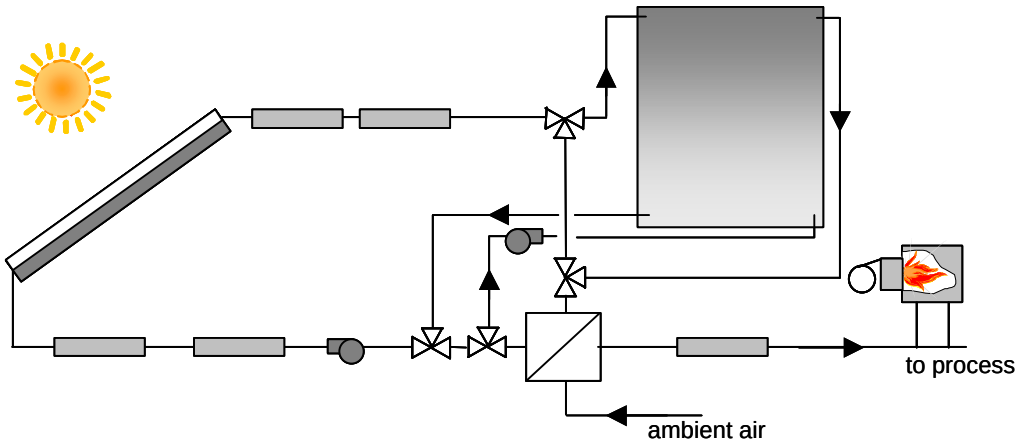


Figure 47: Solar system with storage

Collector data

Four different collectors from different manufacturer have been calculated, two flat-plate solar collectors, one air heating collector and one absorber collector. The parameters of the used collectors are shown in Table 29. A wind loss coefficient is used, this coefficient is calculated from the difference between the measured linear loss coefficient with and without wind divided by 3 m/s, which is the wind velocity during the test. The test data for Sonnenkraft and Energie Solaire are from [3], the other ones are from the manufacturer themselves. The wind loss coefficient for Isofoton is calculated from a similar collector from [3]. The Isofoton collector is a single glazed collector with non selective black paint. The Sonnenkraft collector is a single glazed collector with selective coating. The Energie Solaire collector is an unglazed collector with selective coating (cushion - absorber) and the Grammer air heating collector single glazed with selective coating.

The collector fluid is water, because frost protection is not necessary.

Table 29: Used collector coefficients

		Flat plat collector		Absorber collector	Air heating collector
		Isofoton, Garol - I	Sonnenkraft, SK 500 N sunselect	Energie Solaire Solardach AS	Grammer
η_0		0,844	0,758	0,938	0,843
u_linear	W/m²K	8,3	3,282	10,98	4,938
u_quadr.	W/m²K²	0	0,0098	0	0
u_wind	Ws/m³K	0,42	0,14	1,96	0,46
r_iam (Ambrosetti)		0,31	0,25	0,25	0,25
Height collector (brutto)	m	2,078	2,078	2,317	2,5
Height collector (incl. drainage)	m	2,378	2,378	2,671	2,8
Height collector (apertur)	m	1,997	1,997	2,317	2,5
Volumen	l/m²	0,61	0,61	2,35	50
massflow	kg/m²h	50	50	40	50

Collector area

The collector area is limited by the available roof area. Different arrangements are possible.

- 24 rows with a average row length of 51 m
- horizontal collector with the inclination of the roof (10°)

The distance between the rows is fixed by the construction of the roof. It is 4 m. The height of the collector is variable.

In the simulation model collector array shading is considered. The orientation of the roof is 32° western related to the south.

Two variations have been calculated - "normal" collector height (see Table 29) and height of 3 m. This is e.g. possible by lying three collectors on top of another. With respect to the collector geometry following collector areas are possible (Table 30).

Table 30: Dimension collector area

	Collector Isofoton	Collector Sonnenkraft	Collector Energie Solaire	Collector Grammer
24 rows, normal height	2446 m²	2446 m²	2817 m²	3062 m²
24 rows, height = 3m	3121 m²	3121 m²	3121 m²	3121 m²
horizontal, 10°	-	-	5157 m²	-

Piping losses

For calculation of the outside pipe losses within the collector area following assumptions were done: The collector area is divided into five fields parallel to the north-south course of the building. The length of one field is about 95 m respectively 73 m. Additionally a collecting pipe of 58 m (=latitude of building) is taking into account. The pipe length (simple way) is calculated to:

4 x 94,6 m + 1 x 73,4 m + 58 m = 510 m

The diameters of the pipes are calculated depending on the mass flow and the velocity of the fluid (assumption 0,5 m/s). The thickness of insulation is equal to the calculated diameter.

For calculating the inside pipe losses of the collector field a simple pipe length of 50 m was assumed.

Additional in the process circuit a pipe of 40 m after the heat exchanger is modelled.

Heat-exchanger

For flat plate collectors the power of the heat exchanger is assumed to 50 W/K per m² collector area, for the Energie solaire absorber collector it is 100 W/m²K. The heat exchanger model is counter flow.

Control strategy

The chosen standard control strategy for the collector area is very simple. For the system without storage the collector loop pump starts and stops if the total solar radiation on the collector surface is higher respectively lower than 200 W/m². The pump does not stop if there is no load during process breaks.

The mass flow in the collector loop is always constant. There is no matched flow.

For the system with storage the control strategy is similar. The storage is loaded only during process breaks if the insulation is high enough. Solar heat from storage supplies the process if there is no usable insulation and the temperature difference between top of the storage and ambient temperature is higher than 4 K.

5.1.2.3 Results

The criterions of assessment for the different collector types and systems are the solar fraction and the collector loop efficiency. The solar fraction is defined as the yearly solar energy, which is delivered to the drying process, related to the yearly energy demand for the process. The collector loop efficiency is the yearly solar energy gain related to the yearly solar radiation on the collector surface.

Solar Fraction and collector loop efficiency are shown in Figure 48 and Figure 49 for collector areas shown in Table 30 for system without storage.

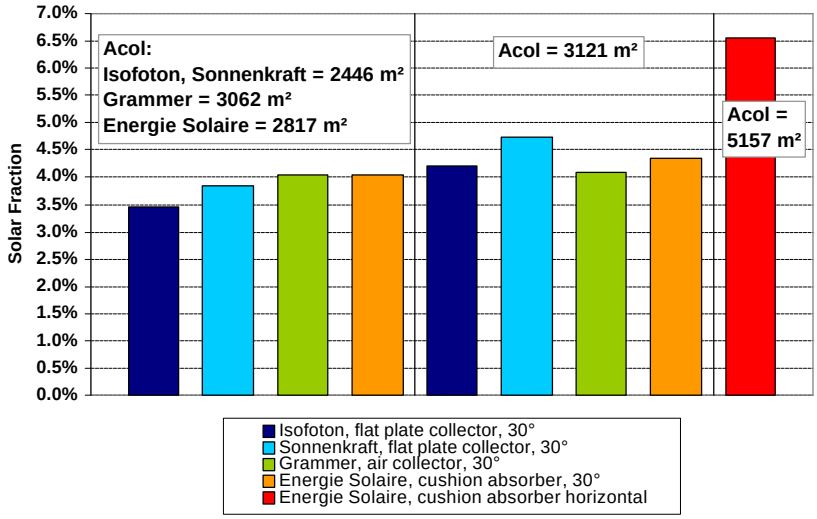


Figure 48: Solar Fraction

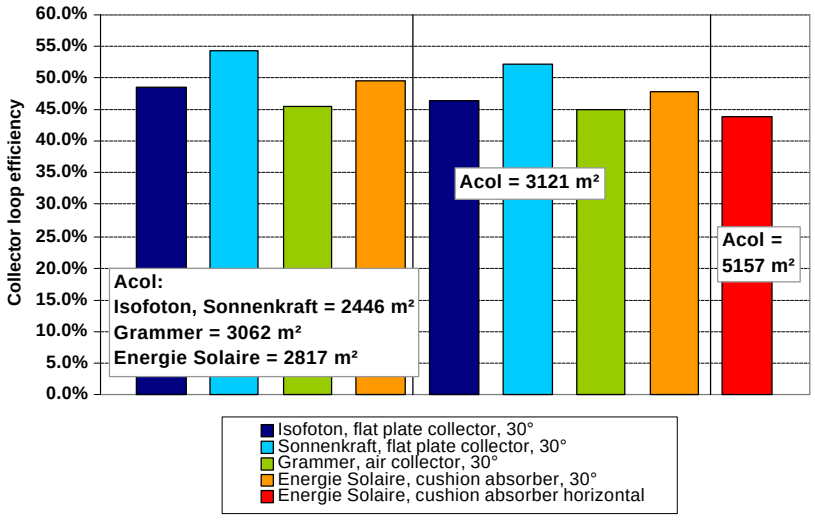


Figure 49: Collector loop efficiency

5.1.2.4 Parameter Variation

Several parameter variations were done to study the their influence on solar fraction.

Power of heat exchanger

In the simulation model the power of the heat exchanger depends on the collector area. Figure 50 shows the difference in solar fraction related to design power of 50 W/m²K as a function of power of heat exchanger. The calculations were done for the "normal" flat plate

collector of Sonnenkraft and for the cushion absorber of Energie Solaire. The used heat exchanger model is counter flow.

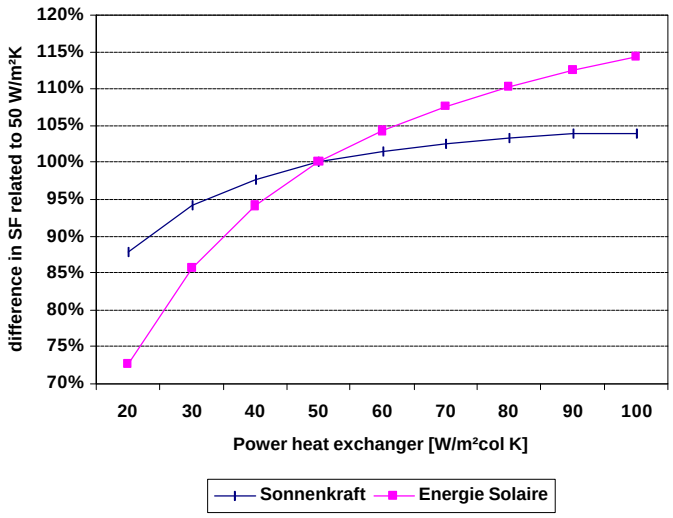


Figure 50: Solar fraction as a function of power of heat exchanger

The influence is significant for the cushion absorber but not for the normal flat plate collector. The reason for this is, that the cushion absorber works with a very good efficiency for low temperature differences between collector and ambient. For higher differences the efficiency decreases strongly because of the high thermal loss coefficient and the high wind dependence. The decrease of efficiency for normal flat plate collectors in the same temperature range is significantly less.

A heat exchanger with a high specific power in combination with cushion absorber chills the collector fluid stronger and the inlet temperature of the collector is colder. In consequence the efficiency and the solar gain is better.

Collector inclination

There is an optimum inclination for the highest solar gain. Figure 51 shows the solar fraction as a function of the inclination. The results are related to collector area of 3121 m², which is the corresponding area for the collector height of 3 m. The power of the heat exchanger is 50 W/m²K respectively 100 W/m²K for the cushion absorber.

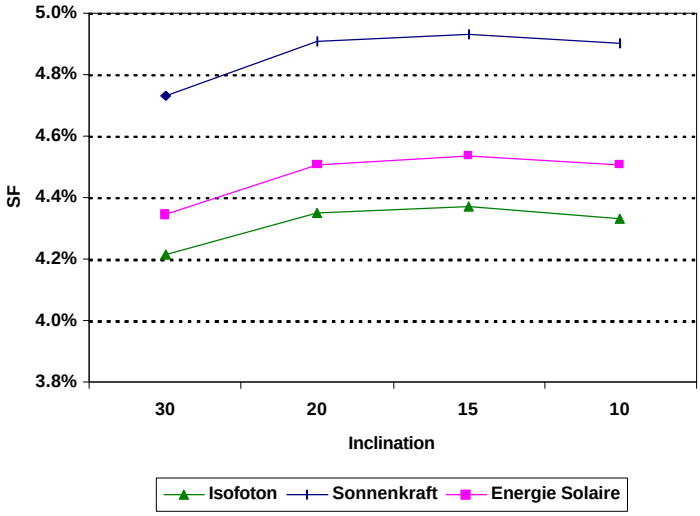


Figure 51: Solar fraction as a function of inclination of collector

The results are independent of the type of collector. The optimum of solar gain is obtained with an inclination of 15°. The solar fraction increases about 4% in comparison to an inclination of 30°.

Collector Mass Flow

The mass flow of the collector has an influence of the solar gain depending on the type of collector. Figure 52 shows the increase of solar gain related to the design mass flow of 40 kg/m²h.

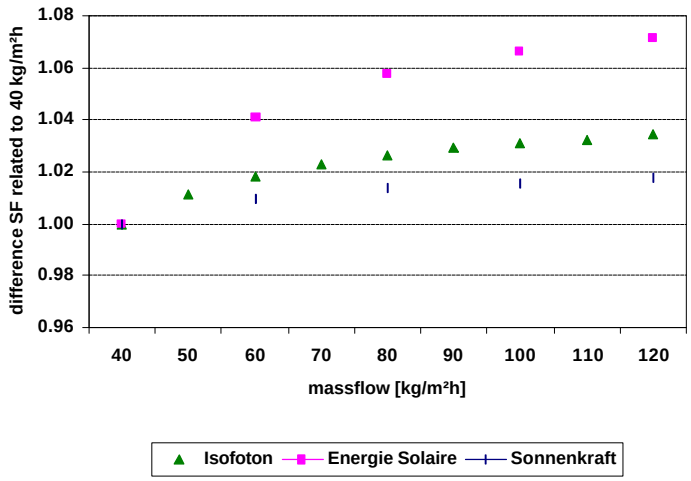


Figure 52: Solar fraction as a function of mass flow of collector

The influence is significantly stronger for the cushion absorber than for the normal flat plate collector. In principle the best solar gain is obtained with a high mass flow. But considering that increasing mass flow leads to bigger pipe diameters and connected to this higher investment cost respectively pump power and energy it is not recommended to choose the highest mass flow. The useful mass flow for cushion absorber is about 70 - 80 kh/m²h, for normal flat plate collector about 50 - 60 kg/m²h.

Control Strategy of the Collector Loop

Table 31 shows different control strategies. The criterion of assessment is the difference in SF in percent related to the strategy 1b.

Table 31: Comparison control strategy (calculated for cushion absorber)

		Difference in SF related to Basis 1b
Basis 1a	Pump ON/OFF, if IT >200 W/m² Pump ON, if no load	+2,6%
Basis 1b	Pump ON/OFF, if IT >250 W/m² Pump ON, if no load	-
Basis 1c	Pump ON/OFF, if IT >250 W/m² Pump OFF, if no load	-3,6%
Strategy 2a	Pump ON, if IT >250 W/m² and dT > 6 K Pump OFF, if dT < 4 K Pump OFF, if no load	-3,2%
Strategy 2b	Pump ON, if IT >250 W/m² and dT > 6 K Pump OFF, if dT < 4 K Pump ON, if no load	0%
Strategy 3	Pump ON, if IT >250 W/m² Pump OFF, if dT < 4 K Pump ON, if no load	+2,9%

The simplest strategy is to control the pump depending on insulation on collector surface. A decrease of the criterion of switch from 250 W/m² to 200 W/m² increases the solar fraction about 2.6%.

There is a significant difference if the pump is switched off during the process break or still runs. Switching off the pump causes a decrease in solar fraction about 3.6%.

Additional improvements in solar gain are possible if the remaining energy in the field after sunset is used by a ΔT-controller. The pump runs until the temperature difference between collector outlet and ambient is lower than 4 °C. The increase is about 2.9%.

Influence of the Buffer Storage

To check the influence of a buffer storage the system model was extended by a buffer storage (see Figure 47). The increase in solar gain depends on the collector type (see Figure 53). The increase of the system with the absorber of energy solaire is significantly bigger than the increase of the system with normal flat plate collector. The reason for this is, that the efficiency of the absorber system in this low temperature range is much better than the efficiency of the normal collector system.

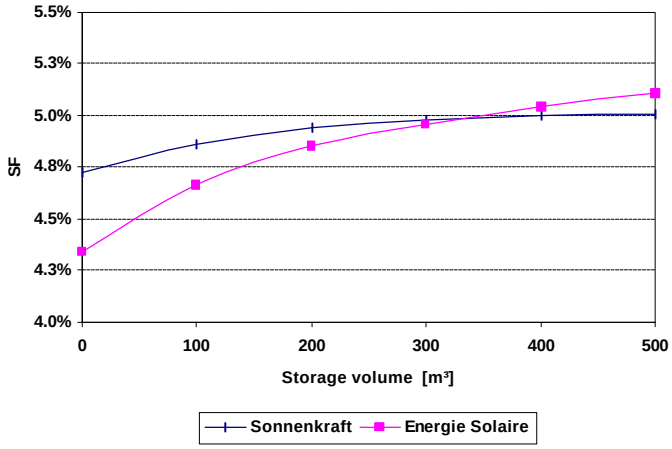


Figure 53: Solar fraction as a function of buffer storage

5.1.2.5 Economic Analysis

An economic analysis has been done. Table 32 shows the boundary conditions. Table 33 the results for the systems without storage. The system with mounted energie solaire absorber is the system with the most reasonable solar heat cost (33.4 €/MWh). The costs for the systems with normal absorber are about 40 €/MWh, the air system is about 46.3 €/MWh.

Table 32: Data for the economic analysis

interest rate		6%
use		15 years
Annuität		0,103
investment cost		
collector	isofoton	116 €/m²
	sonnenkraft	159 €/m²
	energie solaire	104 €/m²
	grammer	168 €/m²
miscellanneous	fondation, assembly pipes, etc..	150 €/m²
heatexchanger		10 €/m²
planning		15% of investment
maintenance		
		2,5 €/m²
operation costs		
electrical power		0,042 €/m²

Table 33: Solar heat cost for systems without storage (Acol=3121m², b=15°)

System (without storage)	Solar heat cost [€/MWh]	Investment costs (incl. planning) [€/m²]	Solar fraction [%]
isofoton	40,0	317,4	4,4
sonnenkraft	40,3	366,9	4,9
energie solaire (3121 m²)	33,4	269,1	4,5
energie solaire (5157 m²)	37,4	269,1	6,6
grammer	46,3	365,7	4,3

The solar heat cost for systems with storage are significantly dependent on the investment cost for the storage. The solar heat costs are equal or less in comparison to systems without storage, if the investment for the storage is less than 200 € per m^3 storage volume. The storage solution can only be recommended if a cheap storage is available.

5.1.2.6 Summary and recommendation

A preplanning for the brewery Cruzcampo in Sevilla was done. Dependent on the collector type the available roof area for collector mounting (maximum 3121 m²) is between 4.4% and 5.0% with collector loop efficiency between 45% and 52%. Several parameter variations were done. Table 34 shows the solar fraction for the optimum solution for the flat plate collector systems with out storage (Akol = 3121 m², β = 15°, collector loop control strategy 3, heat exchanger cross flow).

Table 34: Results for optimum configuration without storage

System	mkol	Heatexchanger	Solar fraction
isofoton	60 l/m²h	50 W/m²K	4,4%
sonnenkraft	60 l/m²h	50 W/m²K	5,0%
energie solaire	80 l/m²h	100 W/m²K	4,5%

5.1.3 Optimisation of the System. Step II: Comparison of Design Alternatives

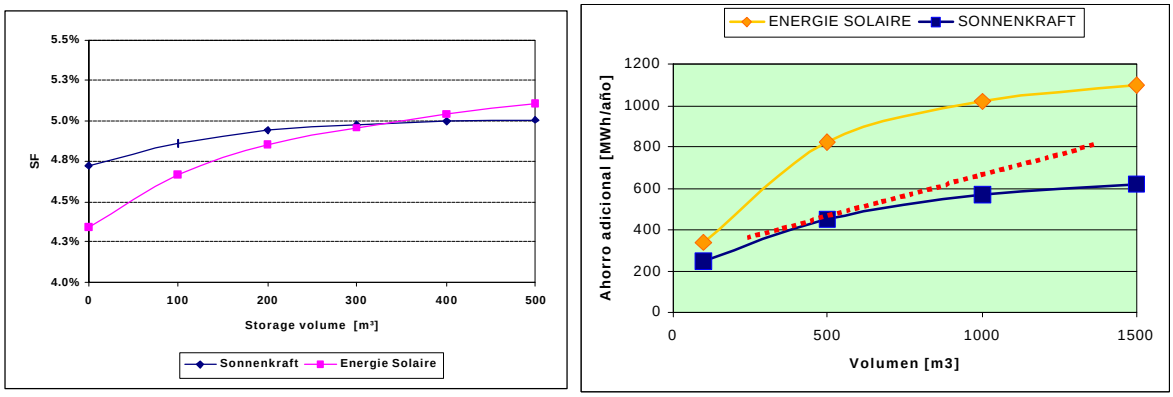
A second step of optimisation has been necessary in a later phase of project planning:

- The influence of heat storage has been studied in more detail
- The exact collector surface has been calculated on base of the real roof geometry
- Collector costs have been revised on the base of offers from manufacturers for the main system components for the specific project

5.1.3.1 Influence of Heat Storage

In Figure 54 the solar heat gain as a function of the storage volume is plotted. It has been shown that the additional heat gain that can be obtained by a storage depends strongly on the control strategy. The solar system may either be coupled directly to the process, and charge the storage only during process breaks (left figure, priority to direct coupling), or may be coupled always to the storage, whereas heat for the process is extracted from the heat storage (right figure, priority to storage). The latter control strategy gives better results and has therefore been adapted for the present project.

System simulations had therefore to be repeated using this control strategy.



Priority: direct coupling
Savings 500 m3 storage:
ES + 19 %
SK + 4 %

Priority: coupling to storage
Savings 500 m3 storage:
ES + 27 %
SK + 15 %

Figure 54. Influence of storage volume on the solar system output. Left figure: solar fraction as a function of the storage volume (from section 5.1.2). Right figure: addtional heat gains with respect to a system without storage.

5.1.3.2 Economic Analysis

With the finally adapted system concept and collector surface, 4 options have been compared (Table 35). Options 1 – 3 include a new roof construction in form of a south oriented saw-tooth. As a comparison, option 4 has been included: unglazed selective solar collectors integrated into the existing E-W oriented roof. This option has a higher collector surface (5 000 m^2).

Table 35. Characteristic parameters of the studied options. Total surface: 3 046 m^2 (except option 4: 5 000 m^2).

	Collector Field A (2 484 m^2)	Collector Field B (562 m^2)	Integration into roof (Field A)	Storage Volume [m^3]	Heat Transfer Coefficient Heat Exchanger [kW/K]
Option 1	unglazed selective flat plate	highly-selective flat plate	YES	1000	300
Option 2	highly-selective flat plate		YES	500	150
Opción 3	colector plano no selectivo		NO	1000	150
Option 4	*unglazed selective flat plate – 5000 m^2 integrated into existing E-W oriented roof*			*1000*	*300*

The energy savings and the resulting solar heat costs are listed in Table 36. Energy savings from 1 160 – 1 230 kWh/m^2 can be obtained with an adequate heat storage and control strategy, due to the high solar radiation and the very low working temperatures. The differences between the different options are very small, both regarding the useful energy gains and regarding the energy costs.

Table 36. Solar gains and energy costs for the four options

Energy savings					
Conversion efficiency conventional heat supply	%	70			
Opción no.	**Useful solar heat**	Electricity cons.	Primary energy savings	**Cost for useful heat**	**Cost for saved primary energy**
	MWh	MWh	MWh	**€/MWh**	**PTA/MWh**
unglazed UFPC	**3 749**	15	4 861	**27**	21
selective SFPC	**3 570**	10	4 770	**29**	22
standard FPC	**3 540**	10	4 727	**31**	24
UFPC, E-W oriented, 5000m2	**5 035**	25	6 380	**28**	22

The solution with highly-selective flat plate collectors has been adopted finally, as this solution is less sensitive to a rise in the working temperatures due to an integration of the solar thermal system with heat recovery (see the next section).

5.1.4 Integration of Solar Thermal System and Heat Recovery

Even if it was not in the original scope of this project, in order to propose an energetically and economically optimized system to the company, a preliminary study was carried out on the possibilities of integrating the solar plant into an global concept for energy efficiency.

The main potential for energy savings in the malt drying process is the heat recovery from the warm and humid exhaust air. The technologies proposed are:

- air-to-air heat exchanger (glass tubes) between inlet and exhaust air
- heat pump for preheating of the inlet air flow (both thermally and electrically driven heat pumps have been considered)
- contribution by the heat pumps to the cold water supply in the factory
- heat exchanger for latent heat recovery from the exhaust air cooled by the evaporator of the heat pumps

The configuration of the proposed system is plotted in Figure 55.

A feasibility analysis has been carried out estimating the energy saving potential in a system integrating these components.

The TRNSYS simulations for the solar system have been repeated with a higher air inlet temperature (40 °C). In this case the solar gains (useful heat) are reduced from 3 570 MWh (system without heat recovery) to 2 660 MWh (75%). Nevertheless, much higher overall primary energy savings and reduced pay back times can be obtained, as can be seen from Table 37.

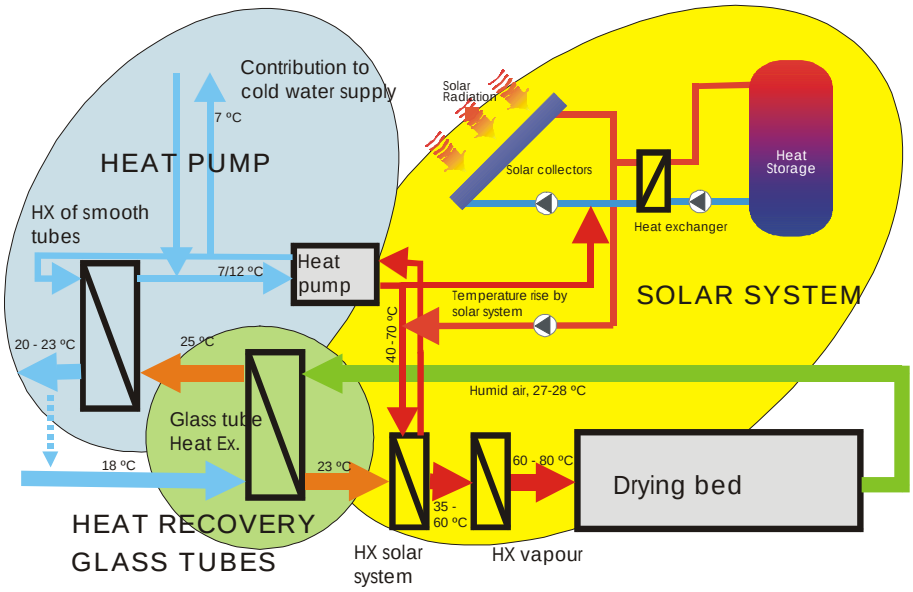


Figure 55. Scheme of the proposed system for the drying process integrating solar system and heat recovery

Table 37. Energetic and economic analysis of different heat recovery systems in combination with a solar system.

Subsystems in the different options	Reference: Steam Boiler	Solar System only	Solar + LiBr-H20 Heat Pump	Solar + Compression Heat Pump	Solar + H20-NH3 Heat Pump
Solar system	no	yes	yes	yes	yes
Glass tube heat exchanger	no	no	yes	yes	yes
Air Preheating by the Heat Pump	no	no	yes	yes	yes
Contribution of heat pump to cold supply	no	no	yes	yes	yes
Latent heat recovery by heat pump stainless steel heat exchanger	no	no	no	yes	yes

		Reference: Steam Boiler	Solar System only	Solar + LiBr-H20 Heat Pump	Solar + Compression Heat Pump	Solar + H20-NH3 Heat Pump
Heat Pump Data						
Heating Power	MW	0	0	2.5	8.3	8.3
Cooling Power	MW	0	0	1.0	6.2	3.1
Utilisation of cold	--	--	--	contribution to cold water net	contribution to cold water net and latent heat recovery	
Maximum Possible Contribution to the Total Heat and Cold Demand						
Solar heat	GWh	0	3.75	3.0	3.0	3.0
Heat recovery by glass tubes	GWh	0	0	7.0	7.0	7.0
Heating by heat pump	GWh	0	0	8.0	33.3	33.3
Cooling by heat pump	GWh	0	0	3.3	25.0	13.7
Fuel and Electricity Consumption						
Consumo total combustibles	GWh	77.6	73.2	62.0	26.7	52.0
Consumo total eléctrico	GWh	3.1	3.1	2.0	8.3	0.0
Consumo energía primaria	GWh	87.0	82.6	68.1	51.7	52.0
Primary Energy Savings	**%**	**--**	**5%**	**22%**	**41%**	**40%**

		Reference: Steam Boiler	Solar System only	Solar + LiBr-H20 Heat Pump	Solar + Compression Heat Pump	Solar + H20-NH3 Heat Pump
Energy Costs (*)						
Cost for heat production	k€	1 867	1 761	1 491	641	1 251
Electricity cost	k€	132	132	86	351	0
Total energy costs	k€	1 998	1 892	1 576	992	1 251
Savings Energy Costs	**%**	**--**	**5%**	**21%**	**50%**	**37%**
Investment Cost						
Solar system (own contribution)	k€	0	463	463	463	463
Glass tube heat exchanger	k€	0	0	240	240	240
Heat Pump	k€	0	0	186	635	1 584
Heat exchanger for latent heat rec.	k€	0	0	0	120	120
Additional air-water heat exchanger	k€	0	0	0	72	72
Total investment	**k€**	**0**	**463**	**889**	**1 530**	**2 479**
PAY-BACK	**years**	**--**	**4.4**	**2.1**	**1.5**	**3.3**

5.2 MALTIBÉRICA – SOCIEDADE PRODUTORA DE MALTE S.A. (PORTUGAL)

5.2.1 Identification and Location

MALTIBERICA – Sociedade Produtora de Malte S.A.
Rua Alberto Valente
2965-309 Poceirão (Palmela)
Phone:265 995 320
Fax: 265 995 286
Contact Persons: Engº Lereno Machado (Lereno_Machado@unicer.pt)
Engº Carlos Pragana (Carlos.Maltiberica@mail.telepac.pt)

MALTIBERICA is a Portuguese-Spanish factory, with 14 employees, producing malt for breweries pertaining to UNICER Group in Portugal and exporting also the malt to Spain.

Although it is located not far from a very industrialized zone of Portugal, Setúbal Peninsula and around 50 km far from Lisbon, nearby this factory there is no other factories, making difficult to extend until there the natural gas network. As a result it is very expensive to change from the actual usage of thick fuel in great quantities, to a more clean than conventional energy source.

Like other factories, the objective to be certified by ISO 14000 series, becomes more difficult which opens space and facilitates the introduction of solar energy, at least as a complementary energy source on process heat.

To help on this *desiderato*, the factory is located in a very sunny part of Portugal, as can be seen on Figure 56, which shows its location in the sunshine hours and radiation maps of Portugal.

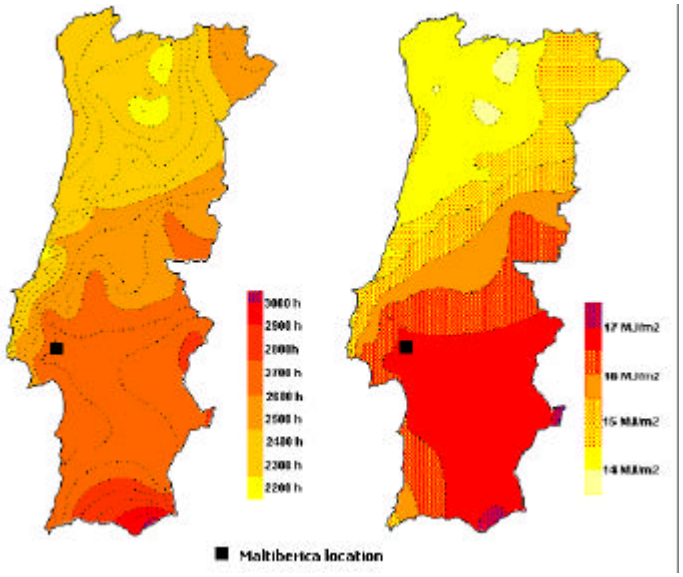


Figure 56. Sunshine hours and radiation maps (daily global horizontal) of Portugal [1].

The factory layout can be seen in Figure 57, which also shows the possible location on the ground where solar collectors field can be installed, depending on its final dimension.

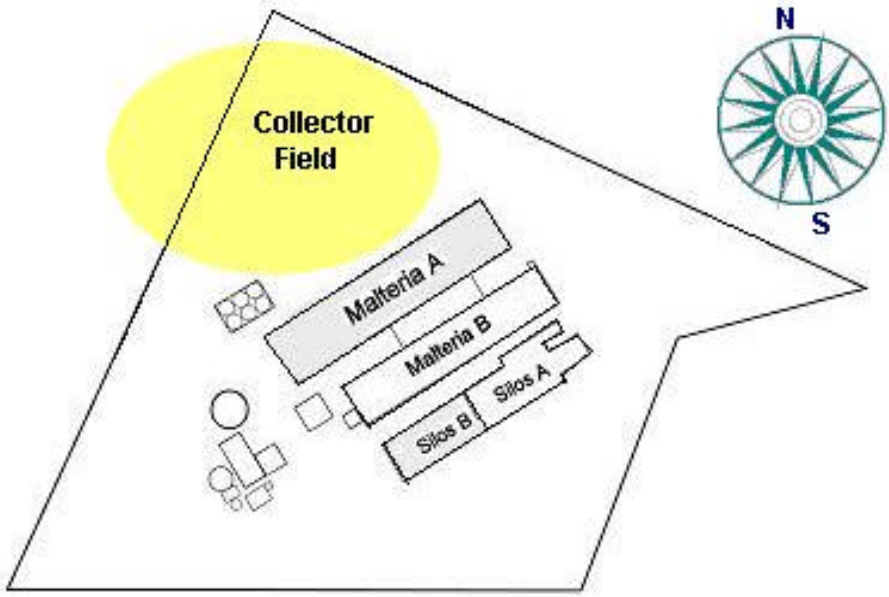


Figure 57. Maltiberica ground layout.

5.2.1.1 Process Heat Distribution

The factory is in operation all year around (24 hours/day, 7 days/week, 52 weeks/year), producing malt, which performs 3 steps until the end of the process:

1st step : Wetting of barley
2nd step: Germination of green malt
3rd step: Drying of malt

The major part of energy consumption is on overheated water production (180 °C, 14 bar), which is dissipated on the water-air heat exchangers that promote drying of the malt. A small part is consumed on keeping the appropriate temperature of thick fuel in its storage. The factory is a quite new factory (less than 10 years) and it incorporates on its design heat recovery measures that even makes more important to go directly to solar, when thinking in new energy savings actions.

Figure 58 shows a scheme of process heat distribution through the main components of existing system

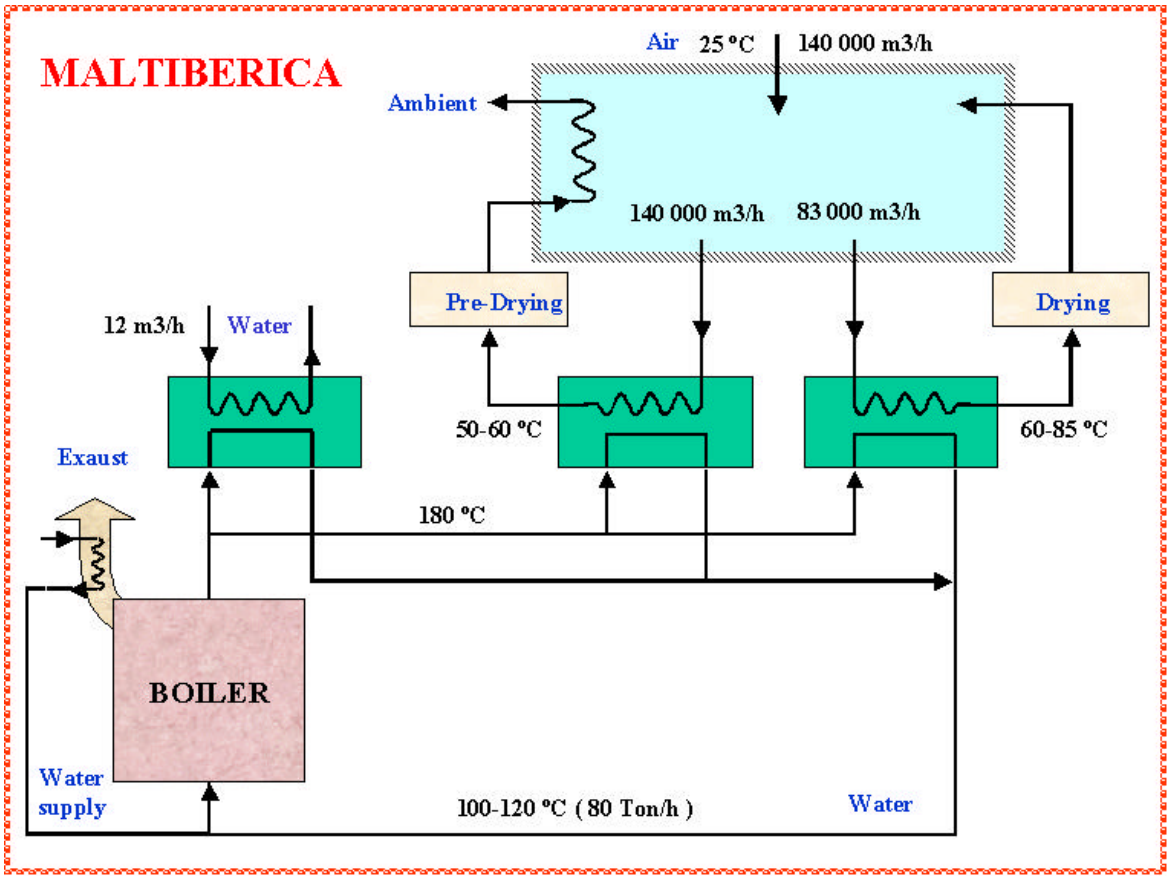


Figure 58. Process heat distribution scheme.

5.2.2 Solar Energy Integration

There are two possible ways to integrate solar energy, in the malting process:

- production of overheated water using parabolic troughs;
- production of hot water with common flat plate or CPC type collectors to pre-heat the 140000m3/h of outside air for drying malt.

The last option has been chosen because it maximizes solar energy fraction and overall system performance, given the lower temperatures operation of solar system and also because it uses solar collectors technology with lower cost.
The large amount of energy consumption of the malt factory, its constant and continuous load profile also led us to the following design decisions:

- solar process heat will be available all the time that there is favorable meteorological conditions; then system control will switch to solar leading to the consumption of solar energy at the time it is being produced.

- In consequence there is no need to introduce solar heat storage and by this way it is possible to lower costs and to improve overall performance. The solar heat storage can be justified in the future after a decision was taken to increase the size of solar system, making then available solar energy for using at night. In the

present case it means that solar storage will only be useful for getting solar energy fractions higher than 50% in summer months.

- The other important item of this installation will be an additional heat exchanger, an water-air heat exchanger, that will deliver collected solar thermal energy to the fresh air flow, that is continuously admitted (140 000 m^3/h) to the drying process.

- Solar input can be controlled by a simple temperature differential controller, which will compare temperatures at solar collector exit and at solar water-air heat exchanger exit; the temperature difference values for switching on and off the solar pump(s), will be a result of the design of that heat exchanger.

- The solar system will pre-heat the air before it passes through the heat exchangers where conventional energy is delivered, reducing by that way the contribution of the last one to process heat demand.

- The result of this design (Figure 59) is that solar system remains totally independent of existing conventional system, which will keep its actual configuration without any modifications.

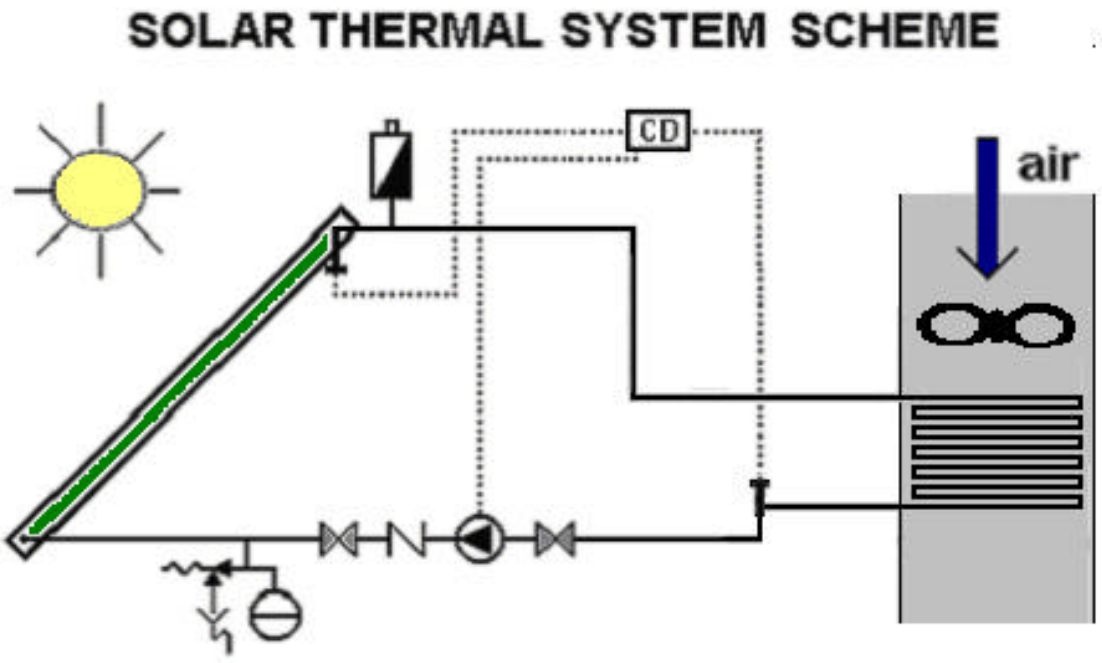


Figure 59. Schematic representation of solar system

5.2.3 Solar System Design

The size of the solar system, its energy delivery and the corresponding solar fraction will be calculated according to SOLTERM [2] software which has been developed at INETI and permits to model the regular solar thermal systems, using average monthly data of temperature and solar radiation, which can be obtained using P_CLIMA [3] software, which is also a code developed at INETI, for a wide range of latitude locations.

5.2.3.1 Inputs for Simulations

Table 38. Meteorological data (Lat.=38.9°N; Long.= 8.3°E; Altit.= 40m):

Month	Daily Global Horiz. Radiation (MJ/m2)	Temperature (°C)
Jan	7.5	10.4
Feb	10.4	11.3
Mar	13.9	12.8
Apr	19.0	14.7
May	23.3	17.5
Jun	26.2	19.9
Jul	27.6	22.9
Aug	25.1	23.1
Sep	18.1	21.5
Oct	12.7	18.1
Nov	8.8	13.4
Dec	7.1	10.6
Annual	**16.6**	**16.4**

Table 39. Operation System Parameters

Operating Parameters	Values
Solar Heat Exchanger Efficiency (SHE)	65%
Drying air temperature	80 °C
Volume air flow	140000 m3/h
Collector fluid inlet temperature	30 °C / 40 °C
Collector fluid flowrate	60 Kg/(h.m2)
Collectors azimuth	0°
Collectors inclination	30°

Table 40. Solar Collector Performance and Cost

Collector	F'η_0 [%]	F'U_L [W/(m2.K)]	Cost [€/m2]
Unglazed	93	16.9	150
Non-Selective Flat Plate	71	8.4	250
Selective Flat Plate	70	5.2	275
Non-Evacuated Selective CPC Type	72	4.5	275

Table 41. Financial Parameters

Financial Parameters		Values
Substituted energy		Fuel
Calorific power		43 MJ/Kg
Overall heat conversion efficiency		65%
Cost of substituted energy	(48 Esc/Kg)	0.24 €/Kg
Energy inflation rate		5%
General inflation rate		3 %
Interest rate		5%
Amortization tax	(4 years period)	25%
Collector system lifetime		15 years
Final value		10%
Substitution year		10th
Substitution value		10%
Annual maintenance		1%

5.2.3.2 Output Results

Delivered Energy

Table 42. Average daily monthly energy by square meter [*MJ/(m2 .day)*], delivered by the different collectors at 30 °C and 40 °C collector fluid inlet temperature.

Month	Unglazed		Non-Selective Flat Plate		Selective Flat Plate		Non-Evacuated Selective CPC Type	
Temp	30 °C	40 °C	30 °C	40 °C	30 °C	40 °C	30 °C	40 °C
Jan	4.11	2.52	4.65	3.33	6.17	4,99	6.83	5.70
Feb	5.10	3.04	5.65	4.07	7.31	5.98	8.03	6.78
Mar	6.09	3.64	6.52	4.74	8.21	6.78	8.95	7.62
Apr	7.62	4.26	7.98	5.73	9.79	8.11	10.58	9.06
May	9.64	5.75	9.44	6.97	11.08	9.31	11.85	10.26
Jun	11.42	7.11	10.67	8.03	12.13	10.28	12.88	11.23
Jul	14.24	9.37	12.64	9.78	13.85	11.91	14.57	12.85
Aug	14.88	9.90	13.15	10.24	14.36	12.40	15.09	13.36
Sep	11.69	7.10	10.72	7.96	12.03	10.13	12.73	11.04
Oct	8.73	5.40	8.47	6.27	9.93	8.29	10.62	9.13
Nov	5.61	3.37	5.99	4.32	7.56	6.18	8.25	6.97
Dec	4.37	2.64	4.92	3.53	6.49	5.26	7.17	6.00
Annual	8.63	5.34	8.40	6.25	9.91	8.3	10.63	9.17
(*)A_{nodump}	3200	4000	3700	4300	3500	3800	3400	3600

(*) $A_{no\text{-}dump}$ is the collector field area above which some of the energy will be lost by dumping.

The first output of system simulation is the average daily monthly energy delivered by square meter of each collector type hereon considered, operating in this system according to the parameters above referred. Table 42 shows those results for two inlet collector fluid temperature values: 30 °C and 40 °C. The results are also illustrated in the following graphs (Figure 60):

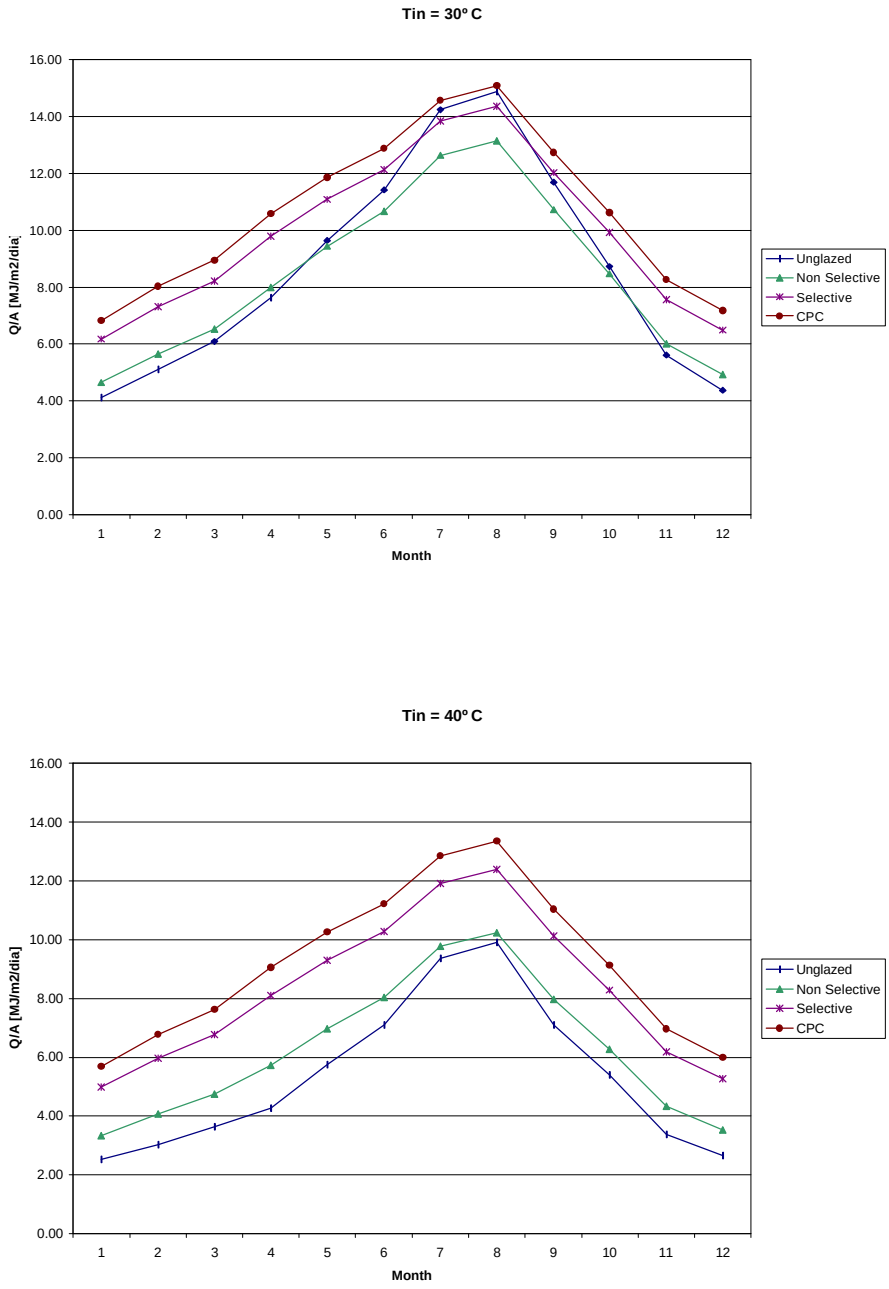


Figure 60. Representation of the average daily monthly energy by square meter [*MJ/(m2.day)*], delivered by the four collector types .

Economic Study

Considering Table 41 financial parameters and energy results of Table 42, it was performed an economic study for each collector type indicated in Table 40. The results of the economic study are summarized in Table 43, which gives, for each collector, the optimized collector area, the corresponding investment, the amortization period, IRT (TIR) and NAV (VAL). The graph of Figure 61 represents the evolution of NAV as a function of collector field area.

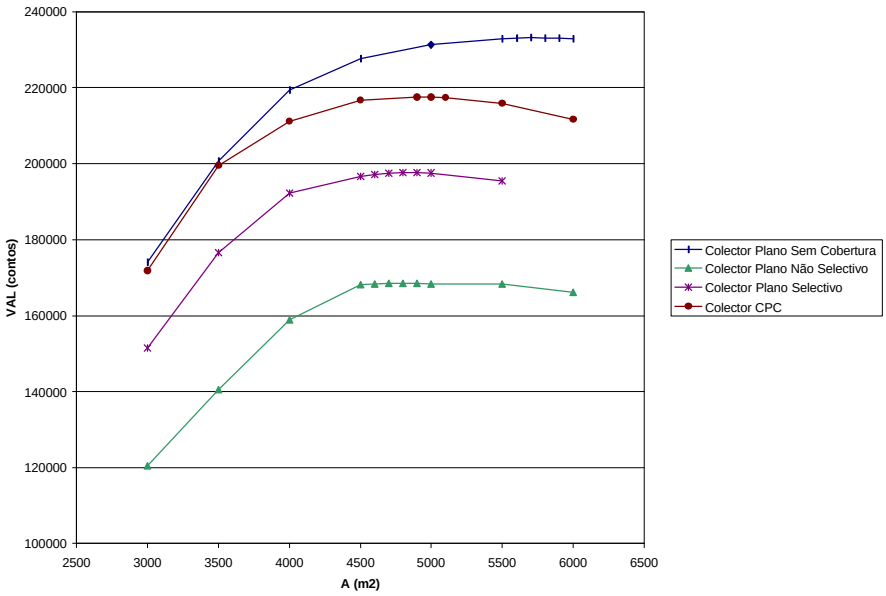


Figure 61. NAV as a function of collector field area for the collectors of Table 40 and for 30 °C (fluid inlet temperature).

Table 43. Results of economic study considering energy delivered at 30 °C.

		Unglazed	Non-Selective Flat Plate	Selective Flat Plate	Non-Evacuated Selective CPC Type
Area	(m2)	5700	4900	4800	5000
Investment	(k€)	554	794	856	892
Subside	(35%)	194	278	300	312
Amortization	(Years)	4	7	6	6
IRT	(%)	24.8	16.0	18.8	17.5
NAV	(k€)	1163	840	1175	1085

The results of this table show that:

- For the mentioned inlet temperature – 30 °C – the unglazed solar collector appears as being the most interesting solution which results from the much lower costs (almost one half of the other solutions) and also from the important delivered energy which is significant for this low temperature operation of the system.

- Anyway the unglazed collector, even for this low temperature delivers less energy in the annual base, than others, as it is the case of the CPC collector. This implies that the contribution to CO_2 emissions mitigation is also affected, but this fact is not taken into account in the current economic studies, like the previous one. And it is sure that this will introduce modifications in those economic studies. The importance of this aspect grows with increased temperature when the differences between the different solutions become clearer, as it is shown in Figure 60.

- The unglazed solar collector can take a significant advantage if is to be installed on roof, because of its light weight and consequently it implies less expensive installation costs, but in this case the collector field will installed in the ground where a special structure will be mounted anyway independently of the collector type and with overall comparable mounting costs.

- These types of considerations will be important at the time of choosing the collector type that finally will be installed. It is also possible to happen modifications on market conditions and available collectors, which can introduce variations in the economic study and final choice. Only at that time that choice can be done, also when the final detailed project is drawn and of course after owners final decision.

5.2.4 Solar Energy Project Impact

To the general motivation for solar energy usage, like:

– Environment problems created by fossil fuel consumption and leading to maritime, ground and aero pollution, greenhouse effects of CO_2, etc.;
– Finite nature of fossil fuels and insecurity provision caused by market troubleshoot;
– Macroeconomic reasons related with energy bill reduction needs;
– Credibility of the technology given by the diffusion of “Guarantee Results Schemes”;

We have to add the particular reasons that can help the justification of this investment:

– Factory energy bill reduction;
– Reasonable amortization period for the investment;
– EU and Portuguese financial incentives, reducing the initial investment;
– Favorable conditions given by solar energy to the ISO 14000 series certification process and marketing needs, which ask more and more the factories to present an environmental benign image.

Some of these aspects can be quantified as we do in the following points.

5.2.4.1 Substituted Energy

Conventional fossil fuel energy that is going to be substituted is directly related with the final design of the solar thermal system. Assuming that a field of 3 500 m^2 CPC type collectors will be installed, then the substituted energy can be calculated as follows:

Solar process heat	3 500[m2] * 10.63[MJ/(m2.day)] *365 [days] = 13 580GJ/year
Fossil fuel substituted	13.58 [GJ/year] / 65 [%] / 43 [MJ/Kg] = 486 ton of fuel
Cost of substituted energy	486*10^3 [Kg] * 0.24 [€/Kg] = 116 640 €/year

5.2.4.2 Environmental Impact

It is regularly accepted the following relationship between 1 MJoule production by a non fossil fuel source, as it is the case of solar energy, and the following values of aero pollutants that are avoided:

CO_2 : 0.22 Kg
SO_x : 0.89 g
NO_x : 1.21 g

This direct relation it is not totally correct because it doesn't incorporate the environmental problems created by transportation and managing of fossil fuels. The corresponding depollution costs are also not quantified.

5.2.4.3 Social Impact

The correlation between investment in solar energy systems and new job creation is not yet established, but it is sure that a positive relation with employment exists, at the production, mounting and maintenance of those systems. An indirect relation also exists because of the parallel effects on other industries that provide materials and equipments used in solar systems.

It should also be stressed the distributed characteristics of solar energy source, as well as its major intensity at the interior of the country; these two aspects also play a favorable role on the creation of employment in the interior of Portugal.

5.2.5 Conclusions and Recommendations

It was studied the usage of solar energy in the malting process of MALTIBERICA, which showed the competitiveness of the already existing solar collectors technology to this application. In the present case solar heat will be coupled to the process, pre-heating the new air that is permanently introduced to dry the malt. By this way it is possible to use unglazed, glazed flat plate or low concentration CPC type collectors because the needed fluid temperature will be well below 100 °C. As seen previously the final choice, between unglazed and CPC type collectors, is still not clear because the final design and precise market conditions are needed to be known before such decision.

The very big size of the proposed solar system presents special constraints, related mainly with hydraulic equilibrium, which will certainly require a detailed analysis, within the project that should be drawn after final decision about investment. The other aspect to take into account it will be the design of the solar water-air heat exchanger that will transfer heat from the liquid collector fluid to outside new air that is permanently admitted at 14 000 m^3/h flow-rate. The other equipment is regular solar system equipment and everything should be acquired as a whole and an overall guarantee should be asked to the mounting company.

In the same way we strongly recommend that the following aspects should be considered during the process acquisition of the solar thermal system:

- To draw a pre-project before the contest, defining technical conditions
- Mounting of solar system according to security standards

- To ask for a “Guarantee of Results” to the solar system provider
- To include monitoring equipment to follow system operation along its lifetime
- To ask for the manual of the installation and to ensure regular maintenance operations, using the owner technical capabilities or contracted ones.

REFERENCES

[1] - Metorological Institute of Lisbon.

[2] – P_CLIMA, INETI, Lisboa.

[3] – SOLTERM, INETI, Lisboa.

5.3 BEIRALÃ – *LANIFÍCIOS S.A.* (PORTUGAL)

5.3.1 Identification and Location

BEIRALÃ – Lanifícios, S.A.
Avenida 1° de Maio,
Apartado 217
6270-909 SEIA
Phone:238 310 260
Fax: 238 310 269
Contact Person: Rui Cardoso (Presidente)
e-mail: *ruicardoso@beirala.com*

BEIRALÃ is a Portuguese textile factory, with 224 employees, producing woolen garments and woolen cloth, specialized in very good quality products to the national and mainly to the international market.

It is located in the center of Portugal, at NW side and at the foot of the highest Portuguese mountain - Serra da Estrela, close to the capital of textile industry in Portugal – Covilhã. This zone is relatively industrialized but it is not expected for soon the access of these factories to the national natural gas network. Because of this situation, the change from heavy fuel, that this factory is actually consuming, to a cleaner fossil fuel, like propane gas is very expensive due to the transport costs.

Beiralã is an old factory that is being remodeled in its production flowchart, is resizing its production installations and the owners are intending to adopt energy conservation measures on its industrial processes as well, recovering heat from ongoing industrial processes and changing to cleaner sources of energy.

This strategy has been adopted by Beiralã to become possible its certification by ISO 14000 series, which is an important goal for the near future of this factory, also because of marketing necessities related with the destination market for its products.

With this scenario it is easy to understand the interest of the owners of the factory on studying the possibility of solar heat introduction in their industrial processes, lowering the heavy bill that they are expecting to pay after changing from heavy fuel to propane gas. Solar energy is there on the place just waiting to be collected, contrarily to the natural gas network that will take time (years) to come…

Its location in the center of the country and near the mountain, is not the best one regarding solar energy availability, but we can say that it is exposed to the average Portuguese solar radiation conditions, as can be seen on Figure 62, which shows its location in the sunshine hours and radiation maps of Portugal.

5.3.1.1 Space Availability for Solar Field Mounting

The factory has not available space on the ground to mount the solar collectors, but it has very large areas on the roof of its industrial installations, with good orientation, too much in excess of possible area needed for installation of solar collector field.

A structure to support the collectors will however be necessary to adapt to those roofs, which will certainly increase a little bit the final costs. This additional cost has been estimated in 10% of the solar system cost.

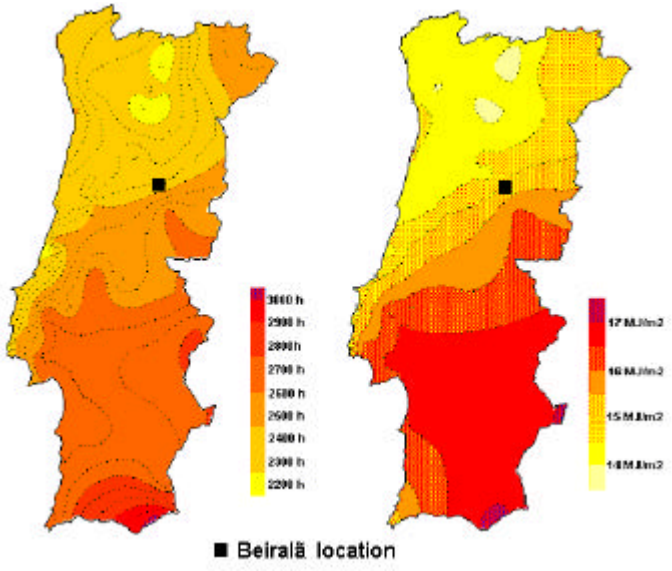


Figure 62. Sunshine hours and radiation maps (daily global horizontal) of Portugal [1].

5.3.1.2 Process Heat Distribution

The factory is in operation during working days of all year around, closing for holidays for 20 days per year. The type of factory imposes a great consumption in electricity, which is related with textile machines operation and air conditioning of the very big halls.

The most part of process heat (water at 180 °C, 14bar) is produced in a conventional boiler that uses thick-fuel as primary energy, to heat the water that is needed in great quantity for dying and cleaning processes.

The different dying processes consume different volume of water at different temperatures levels, up to 120 °C. Fortunately at this higher temperature level, only 1/5 of the volume of water is consumed, being 80 °C the more important temperature level regarding water consumption in dying process and 60 °C the one regarding washing process.

Actually heat is being recovered from the dying effluent to the mains water; this pre-heated water is then stored in an already existing concrete tank, from which the water is distributed to the different processes.

5.3.2 Solar Energy Integration

The schematic representation of solar system presented in Figure 63 shows the way how it was idealized solar energy integration in the dying processes. This integration is based on pre-heating the fresh water before conventional heating system and after the heat recovery from waste water that is already in operation.

The system will take profit of a big concrete tank that already exists, where the solar system will deliver collected energy through an external heat exchanger. The water needed for the process is pumped from this open tank.

By this way and because there is not a continuous process during working days, solar system will operate in separate from the process needs, accumulating thermal energy from the sun in the big solar tank solar. The same strategy also applies for weekends during which there are no process to deliver the energy.

With this configuration, solar system installation will not conflict with conventional system, because only small minor adaptations will be needed: those related with flowing of water between the tank and solar heat exchanger.

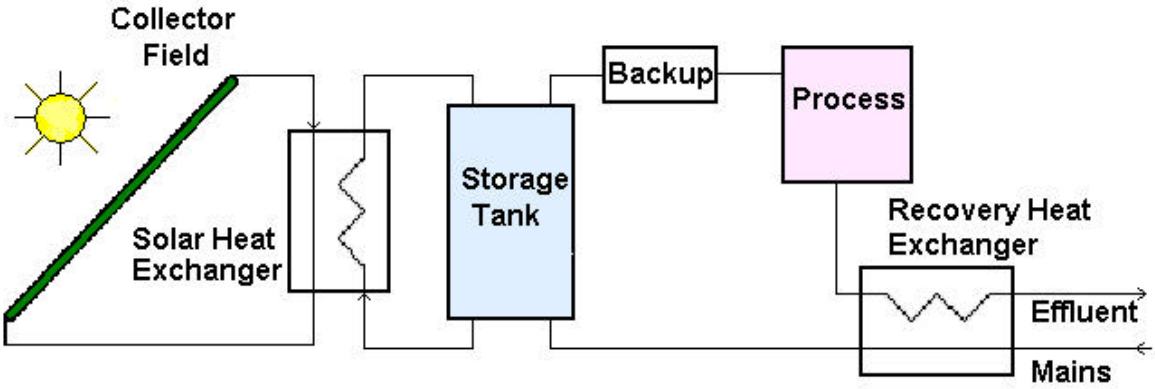


Figure 63. Schematic representation of solar system

5.3.3 Solar System Design

The size of the solar system, its energy delivery and the corresponding solar fraction will be calculated according to SOLTERM [2] software which has been developed at INETI and permits to model the regular solar thermal systems, using average monthly data of temperature and solar radiation, which can be obtained using P_CLIMA [3] software, which is also a code developed at INETI, for a wide range of latitude locations.

5.3.3.1 Inputs for Simulations

Table 44. Meteorological data (Lat.=40.4°N; Long.= 7.7°E; Alt.=500m):

Month	Daily Global Horiz. Radiation (MJ/m^2))	Temperature (Tamb °C)
1	6.6	3.7
2	9.4	3.9
3	12.8	5.6
4	17.6	7.6
5	21.4	11.1
6	24.3	14.8
7	26.6	18.3
8	23.8	18.1
9	16.9	15.7
10	11.5	11.1
11	7.7	6.5
12	6.1	4.3
Year	**15.4**	**10.1**

Table 45. Operation System Parameters

Operating Parameters	Values
Solar Heat Exchanger Efficiency (SHE)	65%
Collector fluid inlet temperature	Tamb + 5 °C (*)
Collector fluid flow rate	60 Kg/(h.m^2)
Collectors azimuth	0°
Collectors inclination	30°

(*) – This approach is related with heat recovery from dying effluent.

Table 46. Solar Collector Performance and Cost

Collector	F'η_0 [%]	F'U_L [W/(m^2.C)]	Cost [€/m^2]
Unglazed	85	15	150
Non-Selective Flat Plate	79	7.7	250
Selective Flat Plate	75	5.0	275
Non-Evacuated Selective CPC Type	72	4.5	275

Table 47. Financial Parameters

Financial Parameters	Values
Substituted energy	Propane
Calorific power	50 MJ/Kg
Overall heat conversion efficiency	75%
Cost of substituted energy (130 Esc/Kg)	0.65 €/Kg
Energy inflation rate	5%
General inflation rate	3 %
Interest rate	5%
Amortization tax (4 years period)	25%
Collector system lifetime	15 years
Final value	10%
Substitution year	10th
Substitution value	10%
Annual maintenance	1%

5.3.3.2 Output Results

Delivered Energy

The first output of system simulation is the average daily monthly energy delivered by square meter of each collector type hereon considered, operating in this system according to the parameters above referred.

Table 48. Average daily energy delivered by 1 750 m^2 collector surface [*GJ/day*]

Month	Unglazed	Non-Selective Flat Plate	Selective Flat Plate	Non-Evacuated Selective CPC Type
Jan	4.4	4.4	5.2	5.9
Feb	5.0	4.9	5.8	6.5
Mar	5.5	5.3	6.3	6.9
Apr	5.8	5.6	6.7	7.3
May	6.4	6.2	7.3	7.9
Jun	6.5	6.3	7.5	8.1
Jul	7.0	6.9	8.3	9.0
Aug	7.2	7.2	8.6	9.4
Sep	6.7	6.6	7.8	8.5
Oct	6.0	5.8	6.9	7.6
Nov	5.2	5.1	5.9	6.6
Dec	4.6	4.5	5.3	6.1
Annual	5.9	5.7	6.8	7.5

These results are also illustrated in Figure 64:

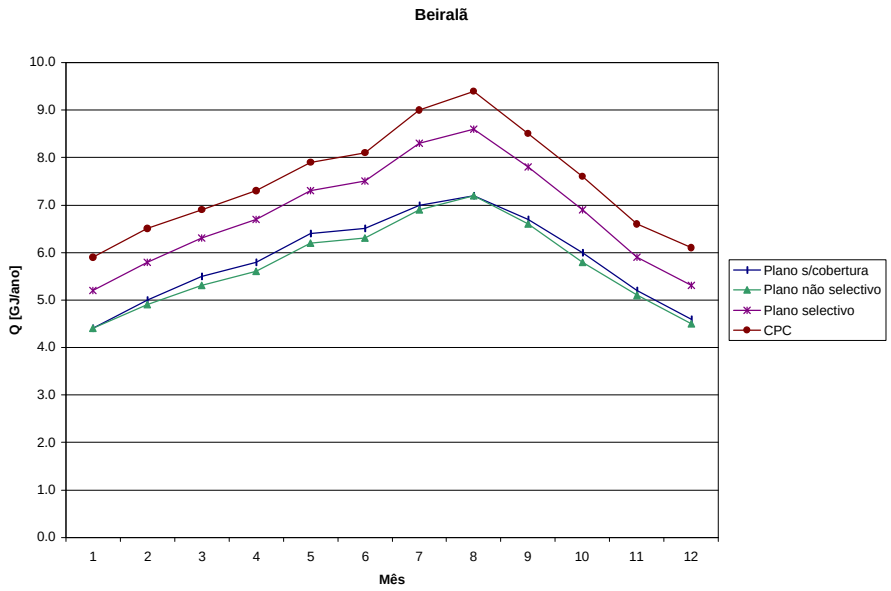


Figure 64. Graphical representation of daily energy (GJ/day) delivered by 1 750 m^2 of the four collector types

Economic Study

Considering Table 47 financial parameters and energy results of Table 48, it was performed an economic study for each collector type indicated in Table 46. The results of the economic study are summarized in Table 49, which gives, for each collector, the optimized collector area, the corresponding investment, the amortization period, IRT (TIR) and NAV (VAL).

Table 49. Results of economic study

		Unglazed	Non-Selective Flat Plate	Selective Flat Plate	Non-Evacuated Selective CPC Type
Area	(m^2)	1750	1750	1750	1750
Investment	(kEuro)	262	437	480	480
Subside(35%)	(kEuro)	92	153	168	168
Amortization	(Years)	2	4	4	3
IRT	(%)	43.3	25.1	27.4	30.3
NAV	(Euro)	777	606	755	872

The results of this table show that:

- As expected, with the most efficient collectors the amount of energy delivered along the year is greater. But the differential in energy delivered is not enough to compensate for the low price of the less efficient collectors.
- This can be seen when comparing the economic indicators of the two extreme cases: the unglazed and the CPC type collectors. In these cases however, the Net Added Value, is better for the last ones.

On the other side

- The maximization of solar contribution, it is connected with the usage of a more efficient collector because the processes in Beiralã need temperatures above 60 °C.

This set of considerations led us to choose, in a first attempt, a solar system based on CPC type collectors. However modification on market conditions and available collectors can introduce variations in this choice, which only can be definitely taken after a final detailed project is drawn and of course after owners' final decision.

5.3.4 Solar Energy Project Impact

To the general motivation for solar energy usage, like:

– Environment problems created by fossil fuel consumption and leading to maritime, ground and aero pollution, greenhouse effects of CO_2, etc.;
– Finite nature of fossil fuels and insecurity provision caused by market troubleshoot;

– Macroeconomic reasons related with energy bill reduction needs;
– Credibility of the technology given by the diffusion of “Guarantee Results Schemes”;

We have to add the particular reasons that can help the justification of this investment:

– Factory energy bill reduction;
– Reasonable amortization period for the investment;
– EU and Portuguese financial incentives, reducing the initial investment;
– Favorable conditions given by solar energy to the ISO 1400 series certification process and marketing needs, which ask more and more the factories to present an environmental benign image.

Some of these aspects can be quantified as we do in the following points.

5.3.4.1 Substituted Energy

Conventional fossil fuel energy that is going to be substituted is directly related with the final design of the solar thermal system. Based on the assumption that the choice will fall on the design previously recommended – solar system with 3 500 m2 of CPC type collectors – then the substituted energy can be calculated as follows:

Solar process heat	7.5 [GJ/day] * 365 [days] = 2738 GJ/year
Fossil fuel substituted	2738 [GJ/year] / 65 [%] / 50 [MJ/Kg] = 84 246 Kg/year
Cost of substituted energy	84 246 [Kg] * 0.65 [€/Kg] = 54 760 €/year

5.3.4.2 Environmental Impact

It is regularly accepted the following relationship between 1 MJoule production by a non fossil fuel source, as it is the case of solar energy, and the following values of aero pollutants that are avoided:

CO_2 : 0.22 Kg
SO_x : 0.89 g
NO_x : 1.21 g

This direct relation it is not totally correct because it doesn’t incorporate the environmental problems created by transportation and managing of fossil fuels. The corresponding depollution costs are also not quantified.

5.3.4.3 Social Impact

The correlation between investment in solar energy systems and new job creation is not yet established, but it is sure that a positive relation with employment exists, at the production, mounting and maintenance of those systems. An indirect relation also exists because of the parallel effects on other industries that provide materials and equipments used in solar systems.

It should also be stressed the distributed characteristics of solar energy source, as well as its major intensity at the interior of the country; these two aspects also play a favorable role on the creation of employment in the interior of Portugal.

5.3.5 Conclusions and Recommendations

It was studied the usage of solar energy in the washing and dying processes of BEIRALÃ factory, which showed the competitiveness of the already existing solar collectors technology to this application. In the present case solar heat will be coupled to the process, pre-heating the fresh water and storing thermal solar energy in an already existing tank.

Although there are different temperature needs, the major part is between 60 °C and 100 °C which permits the usage of flat plate collectors or low concentration CPC type collectors. The usage of unglazed solar collector has been also studied because the low temperature value of the fresh water that is being consumed and the economic study shows that in a more fine study, this alternative has to be considered. Anyway and being in mind maximization of conventional energy substitution, the CPC or a high performance flat plate collector, should be considered for this application.

In the same way we strongly recommend that the following aspects should be considered during the process acquisition of the solar thermal system:

- To draw a pre-project before the contest, defining technical conditions
- Mounting of solar system according to security standards
- To ask for a “Guarantee of Results” to the solar system provider
- To include monitoring equipment to follow system operation along its lifetime
- To ask for the manual of the installation and to ensure regular maintenance operations, using the owner technical capabilities or contracted ones.

REFERENCES

[1] - Metorological Institute of Lisbon.

[2] – P_CLIMA, INETI, Lisboa.

[3] – SOLTERM, INETI, Lisboa.

5.4 BODEGAS MAS MARTINET, TARRAGONA (SPAIN)

The Bodegas Mas Martinet wine cellar is located in the Priorat region, in the South of Catalonia. The company produces a high quality wine for national consumption and for exportation.

The cellar has no connection to the electricity grid, so that the company tries to cover most of the energy demand by solar energy (thermal and photovoltaic).

Most of the heat and cold consumption in the wine cellar arises for the cooling of the cellar during the summer months, and for the heating of an office building and a residential building during the winter season. A small fraction of the heat demand is used for domestic hot water production.

The electricity generation by the installed diesel generator is expensive, so that favourable conditions are encountered for an alternative thermal cooling system that substitutes the electricity consumption of the compression chillers.

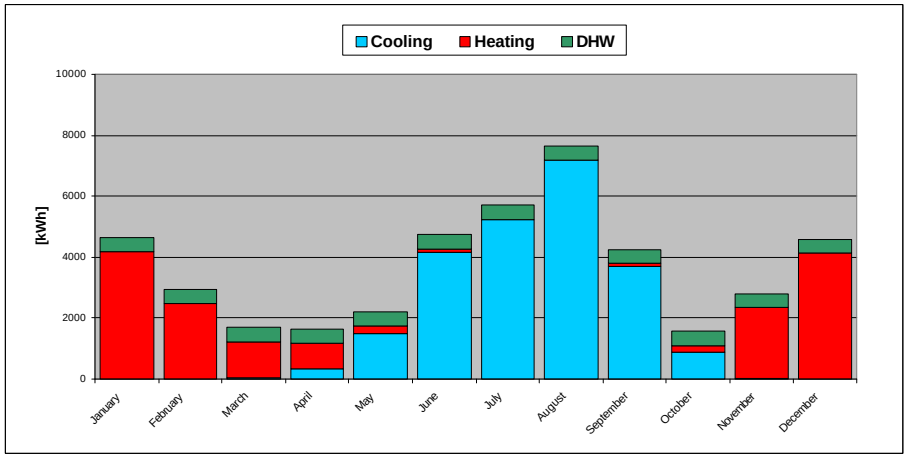


Figure 65. Heat (red), cold (blue) and domestic hot water (green) demand of the installations of Bodegas Mas Martinet.

A solar system is proposed for the air conditioning of the wine cellars and the office building using a Yazaki absorption cooling machine. The excess heat from the solar collectors during the winter months is used for space heating and domestic hot water production.

In the proposed system, fan-coils are used for the distribution of heat and cold to the wine cellar and the connected office building, and a floor heating system for a nearby residential building.

The solar system consists of a solar collector field of 60 m^2 of CPC collectors producing hot water at 80-90 °C and a hot water storage of 1 500 l. The absorption chiller has a nominal cooling power of 35 kW, and is buffered by a 3 000 l cold storage.

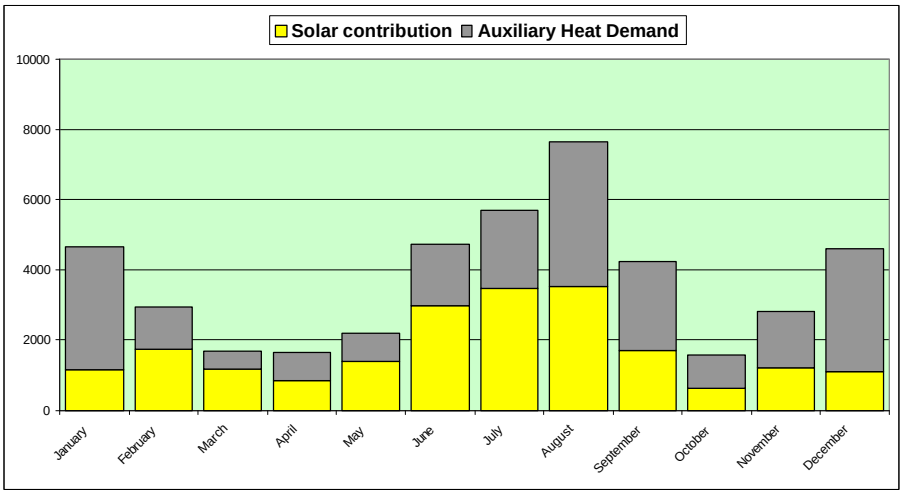


Figure 66. Total heat demand and solar contribution throughout the year.

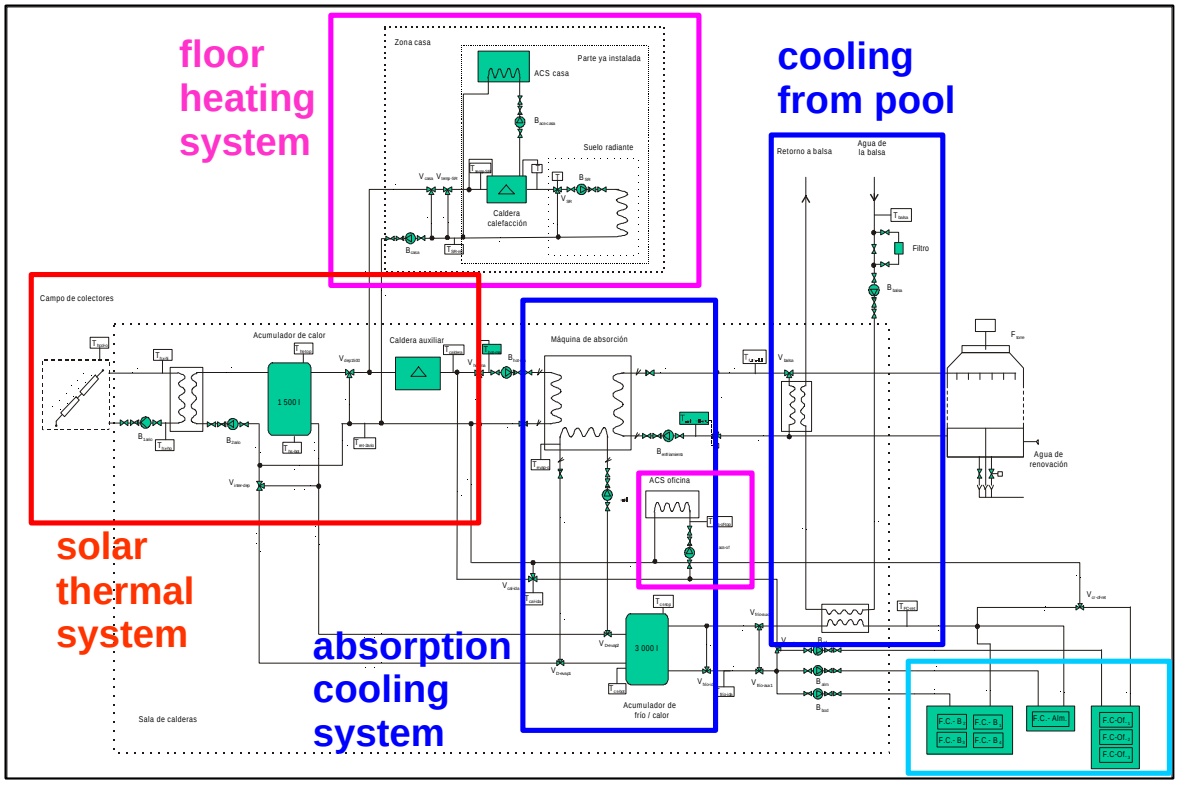


Figure 67. Scheme of the proposed solar system

Table 50. Characteristic data of the proposed solar system

Company	Bodegas Mas Martinet
Location	Tarragona, Spain
Ind. sector	Wine cellar
Process	Space cooling and heating
Working temperature	50 - 85 °C
Solar collector area	60 m^2
Solar collector type	CPC collectors
Solar storage	1500 l (hot) + 3000 l (cold/hot)
Annual solar gains (useful heat)	21 MWh
Solar fraction	58 % (cooling) 35 % (heating)
Total investment	55 000 €
Total own contribution	35 000 €
Yearly net savings	3 000 €
Pay back	11 years

6 GUIDELINES FOR EVALUATION AND SYSTEM DESIGN

In the following sections some general guidelines for the feasibility evaluation and the design of solar industrial process systems are outlined. A summary of the evaluation criteria is given in Table Table 52.

6.1 FEASIBILITY ANALYSIS – EVALUATION CRITERIA

In this section the most important aspects to be taken into account for the feasibility evaluation of solar industrial process heat plants are discussed.

6.1.1 Selection of Appropriate Interfaces for the Coupling of a Solar System

As a first step in the feasibility study, the most appropriate interfaces (processes) of coupling a solar system to the existing heat supply have to be selected.

The selection criteria are the following:

- *Low temperature level*. Solar heat at temperatures above 150 °C is technically feasible but not economically reasonable at present system costs. Applications at low temperature (< 60 °C) are best.
- *Continuous demand* (otherwise storage is needed)
- *Technical possibility* of introducing a heat exchanger for the solar system in the existing equipment or heat supply circuit.

Whenever possible, a *direct coupling* of the solar systems to one or several processes is preferred, as the working temperatures in this case are lowest (see section 3.3).

Direct coupling to a process can mainly be done in the following two ways:

(Pre-)heating of a circulating fluid (e.g. feed-up water, return of closed circuits, air pre-heating …). This possibility exists if fluid circulation is either continuous or periodic (e.g. periodic renovation of water in baths). If circulation is discontinuous, a storage tank has to be introduced.

Heating of liquid baths or hot (drying …) chambers. The energy demand in this case can be divided into the demand for heating-up at the operational start-up - either concentrated in the early morning hours or periodic after each renovation of the fluid content - and the demand to maintain the temperature throughout the operation, which is generally a nearly constant load during the operating hours.

The existing heat exchangers for bath heating generally use steam at temperatures too high for a solar system. The introduction of additional heat exchangers into existing baths is not always possible, due to the lack of space or other technical restrictions. In some cases an external heat exchanger in combination with a circulation pump can be used.

If process baths are well insulated, they can be used as solar storage. E.g. maintaining the temperature of the solar system during a weekend without operation can reduce the heat demand for start-up on Monday morning.

In almost all industries, the *coupling of the solar system to the central heat supply system* is possible. This can be done either by the preheating of the feed-up water for the steam boilers (the temperature level in this case increases with increasing condensate recovery)

or by a solar steam generator. The latter is only recommended in industries where a low-pressure steam (2-3 bar) is used and in climates with a high level of solar radiation. Conventional steam lines (7-8 bar) are working at temperatures too high for an economic operation of solar systems.

6.1.2 Influence of the Working Temperature

The influence of the working temperature on the useful solar energy gains has been shown in chapter 3.4. The upper limit for the working temperature depends on the climate.

As a rule of thumb, it can be stated that solar systems for temperatures above 100 °C are only recommendable in regions with high radiation (Southern and Central regions of the Iberian Peninsula). In the Northern regions only low temperature systems should be considered.

It has to be taken into account that the working temperature in the solar system is always somewhat higher than the required process temperatures, due to losses in the piping and the temperature drop in heat exchangers. In well-designed systems this temperature difference can, nevertheless, be less than 10 K.

In the case of fluid- or bath preheating, the mean working temperature of the solar system is lower than the required final process temperature. The smaller the solar fraction (percentage of the heat demand covered by the solar system), the lower is the mean working temperature. In very low solar fractions the mean working temperature is close to the fluid inlet (or return-) temperature.

6.1.3 Continuity of the Load and Storage

In order to obtain a reasonable economic performance, solar systems should be designed close to the ideal of 100% utilisation. This means, that the heat demand should always be higher than the maximum possible output of the solar system.

Otherwise, and if no storage is used, the useful heat drawn from the solar system is reduced.

Short term mismatches of consumption and demand (daily demand profile) can be buffered by a small short-term storage (up to 25 litres per m^2 of solar collector) that does not significantly increase the overall system costs (Figure 68).

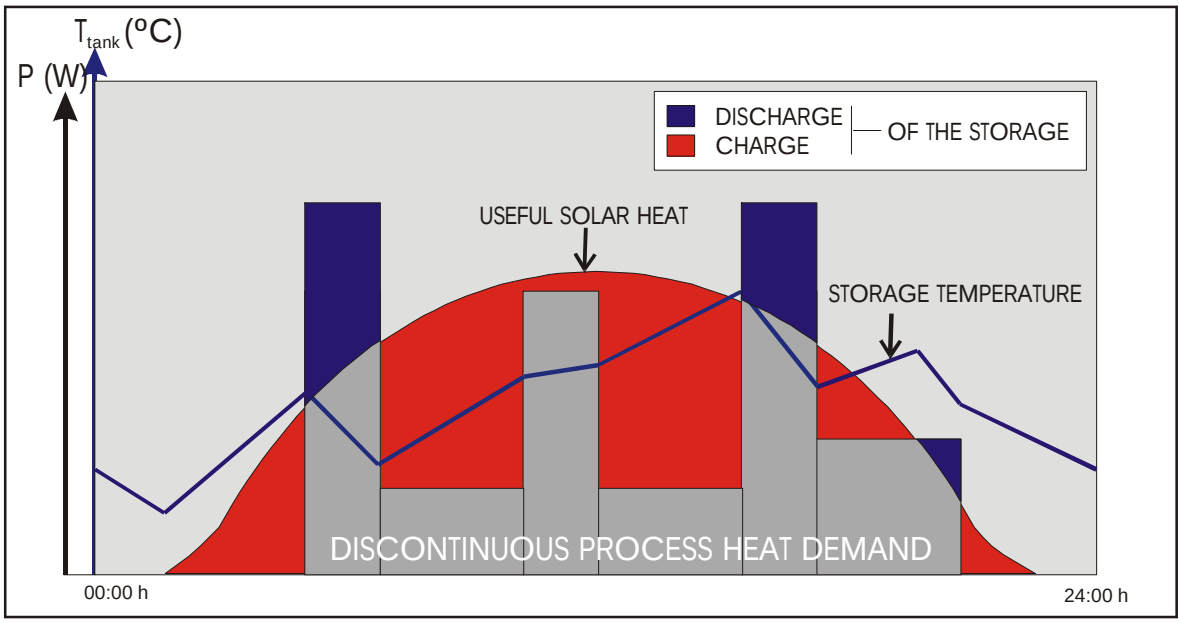


Figure 68. Short-term mismatch between heat demand and available solar heat.

Heat storage for breaks of one or several days (weekends, holidays) is more cost intensive. For a two day weekend storage, about 250 litres per m^2 of collector are necessary. Weekend storage is generally not recommended for small systems.

As a rough estimation, the annual solar gains of a real system without long-term (weekend-) storage can be calculated as

$$Q_{real} = Q_{ideal} * n_{days} / 365$$

Where Q_{ideal} are the solar energy gains of an ideal system with 100% utilisation and n_{days} are the days of operation per year.

Nevertheless, if holidays are concentrated during summer – the period with maximum potential solar production – the reduction of solar gains during these breaks is underestimated by this simple equation.

Systems with only seasonal utilisation (less than 6 months of operation a year) are in general not economic.

6.1.4 Climatic Zones in the Iberian Peninsula

The distribution of the global solar radiation on a horizontal surface throughout the Iberian Peninsula is shown in Figure 69.

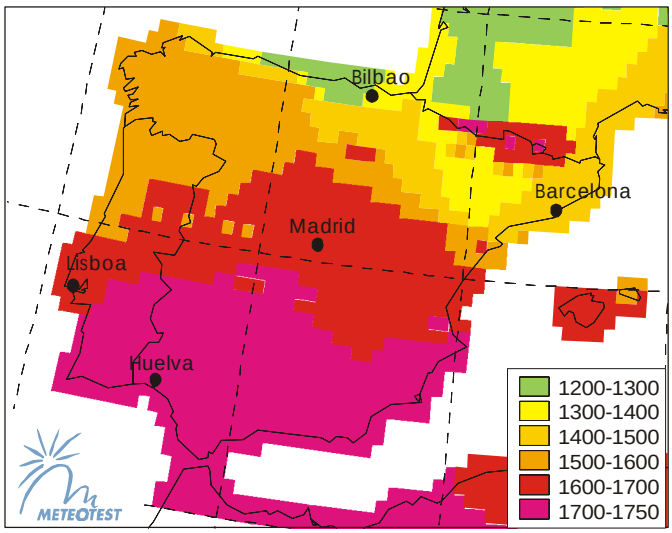


Figure 69. Global solar radiation on a horizontal surface (H) on the Iberian Peninsula. Data in kWh/m^{2}a. Source: Meteotest.

The geographic regions with very good meteorological conditions (H > 1 600 kWh/m^{2}a) are: South of Portugal, Andalucía, Murcia, Valencia, Central Spain. Medium levels of radiation (1 400 … 1 600 kWh/m^{2}a) are obtained in Catalonia, Galicia and in the North of Portugal. A relatively low level of radiation (H < 1 400 kWh/m^{2}a), comparable to Central European climates, dominates in the Northern coast of Spain.

Regarding the Spanish and Portuguese Islands, a very high level of radiation exists on the Canary Islands, a medium level (about 1 600 kWh/m^{2}a) on Madeira and a low radiation on the Azore Islands.

The strong influence of the climatic conditions on the annual solar gains can be seen from the results presented in chapter 3.4.

6.1.5 *Summary of Evaluation Criteria*

The influence of the combination of the determining factors: working temperature level, demand continuity and solar radiation level are shown in Figure 32. The costs of useful solar heat for several industries are plotted as a function of these factors.

In low temperature systems (<60 °C) reasonable energy costs (20-60 €/MWh, without funding; scenario 1 criterion) can be obtained even in non-optimum conditions cases (medium level of solar radiation or discontinuous demand).

Medium temperature systems with working temperatures above 100 °C at present system costs are only recommended if all other conditions are favourable (high solar radiation and continuous demand zones).

An important factor to be considered in addition is the system's size. System costs for small systems (< 100 m^2) can be more than 50% higher than that of large solar systems (> 1 000 m^2), with a corresponding increase in heat costs.

6.2 GUIDELINES FOR SYSTEM DESIGN

6.2.1 Solar Collector Field

The selection of an appropriate solar collector basically depends on the operating temperatures. Other aspects such as the possibility of roof integration or system size have to be considered as well. Table 51 gives an orientation for the selection of appropriate solar collectors.

The necessary collector field size can be estimated from the results presented in chapter 3.4. The maximum annual energy gain that can be obtained from a solar thermal system varies from 350 to 1 100 kWh/m^2, depending on the site and on the working temperature. For an accurate design and sizing of the systems, dynamical system simulations should be carried out taking into account the specific demand profile. The peak thermal power of solar collectors is about 500 W/m^2 for medium temperature and 1 000 W/m^2 for low temperature systems.

Optimum annual heat gains per unit collector area in the Iberian Peninsula are obtained at collector inclinations of 30° and a row separation of at least 1.5 times the gross collector (row-) height. The fraction of gross collector area to roof area in this case is less than 2/3. If a limited roof area is available and maximum total solar heat gains are desired the collector inclination can be set down to 10° approximately. Nevertheless, in glazed collectors a lower limit of 20° for the collector's inclination is recommended due to rain tightness and self-cleaning. A deviation from south orientation of up to 45° can be tolerated, leading to about 10% reduction in the system's output.

Table 51. Selection of solar collector types according to working temperatures

Temperature range	Process
< 40 °C	Unglazed selective collectors or low cost standard flat plate collectors
40 – 70 °C	Highly selective flat plate collectors or CPC collectors
70 – 100 °C	CPC collectors, evac. tubes or other high efficient stationary collectors Concentrating collectors for medium and large systems
> 100 °C	Concentrating collectors, evac. tubes with CPC

By an adequate design of flow rates, pipe diameters and pipe insulation, the electricity consumption for fluid circulation can be below 1% of the overall heat gains. Thermal losses in the piping and storage should not be above 5% of the overall heat gains for medium and large size systems.

Solar gains are highest if the load and solar supply flow rates are matched. An adequate regulation of the flow in the collector field (e.g. variable flow rate) should be foreseen.

A bypass for the preheating of the primary circuit during the morning hours and the extraction of the residual heat after sundown by appropriate regulation can improve solar gains by up to 20%.

6.2.2 Storage

An introduction to solar systems with heat storage has been given in chapter 3.3.3.

Short-term heat storage is recommended whenever a mismatch between available solar radiation and heat demand occurs. For short-term storage (several hours) in industrial systems storage volumes of about 25 litres/m^2 are recommended.

Short-term storage may even be recommended for continuously operating processes, in order to lower the mean working temperature of the solar system and thereby improving its efficiency, especially if low cost solar collectors with high thermal loss coefficients are used.

The larger the system's size the more effective the heat storage over longer periods (e.g. weekends) is. Weekend storage becomes economic from about 500 m^2 on. Weekend storage volumes should be about 125 - 250 litres/m^2. In this case, storage costs can range from 10-20% of the total system costs. Storage for longer periods (seasonal storage) can only be considered for very large systems (> 5 000 m^2).

6.2.3 Coupling to the Existing Heat Supply and Regulation

The coupling to the existing heat supply should always be attempted at the lowest possible temperature. Nevertheless, for fluid and air pre-heating, solar heat should be introduced after a first preheating by waste heat recovery systems, and not as an alternative to these systems. Even if waste heat recovery raises the working temperature in the solar system, the combination of both systems yields better results than a solar system at lower temperature without heat recovery.

If solar energy is being fed to several processes, a regulation strategy should be chosen in order to reach an optimum overall energy saving. In most cases feeding solar energy to the process with the lowest temperature might be the best choice, but in some other cases, giving preference to heat production at higher temperatures during the hours around noon with high radiation results in a better overall performance.

The regulation strategy should be optimised for the specific cases using dynamic system simulation techniques.

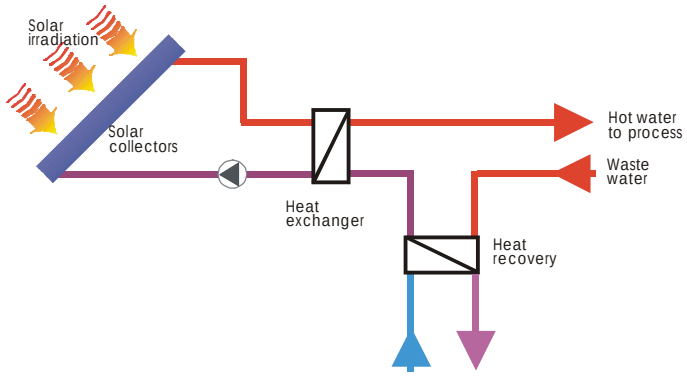


Figure 70. Combination of solar thermal system and waste heat recovery.

6.2.4 Solar Thermal Systems and Cogeneration

As a general rule, it is possible to state that solar thermal systems should be designed as a complementary system to cogeneration plants covering the remaining heat demand.

Only in few cases solar thermal energy can be considered as an alternative heat supply system. Shutting down an existing cogeneration plant during periods when solar heat is available in excess would imply a higher importation of electricity from the grid during this period. In Figure 71 the primary energy saved by producing 1 000 MWh of process heat by a solar thermal systems or by cogeneration, instead of a conventional steam boiler, is compared. The primary energy savings for the produced electricity is taken into account using as a reference the mean efficiency of the present electricity supply (about 35%). In addition, the possibility of simultaneous heat and electricity production from solar thermal systems is considered assuming a conversion efficiency of 30% from heat to electricity.

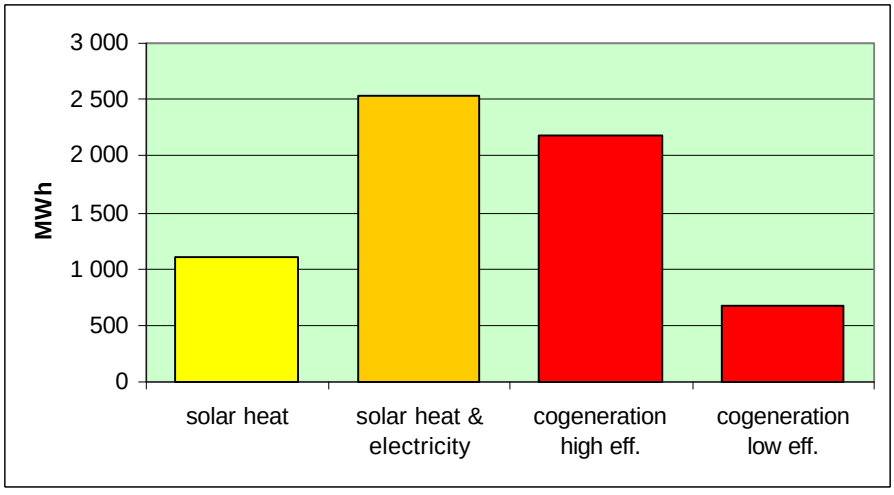


Figure 71. Primary energy saving with respect to a conventional steam boiler, for 1 000 MWh of industrial process heat produced either by solar thermal systems or cogeneration. Conversion efficiency (electrical) for (a) high efficient (combined cycle) cogeneration plants: 50%; (b) low efficient cogeneration plants: 25%

It can be seen, that solar heat does only save primary energy compared to cogeneration plants if either the electrical efficiency of the installed cogeneration plant is lower than the mean efficiency of the grid, or if the solar system itself produces both heat and electricity.

Table 52. Evaluation criteria for solar industrial process heat systems

Criterion	Influence on system performance
Working temperature	Working temperatures not higher than 150 °C, best performance below 100 °C
Climate	Very good conditions in the southern and central regions of the Iberian Peninsula. In regions with medium or low levels of solar radiation (H < 1600 kWh/m^2) systems should only be considered, if all other conditions are favourable (low temperature, continuous demand).
Continuity of the demand Annual variation Daily variation	 Breaks in summer reduce system performance. Losses in solar gains are more than proportional to the time interval of the break. Continuous demand or demand with peaks at daytime are favourable. Short interruptions (several hours) can be buffered by low volume storage with little increase in system cost
System size	The economic performance of solar thermal systems depends strongly on the system size. Resulting solar energy costs are up to 50 % lower for large systems (> 1000 m^2, thermal peak power > 0.5 MW) than for small systems (< 100 m^2, thermal peak power < 50 kW).
Annual solar gains	Annual solar gains of a solar system should be at least 500 kWh/m^2 for economical profitability.
Solar fraction	Systems should be designed for solar fractions not higher than about 60 % (for continuous demand)
Available roof or ground area	Sufficient roof or ground area should be available in order to obtain solar fractions from 5 to 60 %. Orientation to the south with inclination of about 30° is the optimum. Small deviations from these values are tolerable (±45° from south orientation, ±15° from optimum inclination). Long piping should be avoided.
Static aspects of the roof	The need for reinforcement of roof structures increases system cost and therefore reduces economic performance. The additional static load of solar collectors is 25 – 30 kg/m^2 for standard collectors.
Waste heat recovery and cogeneration	First all means of improving energy efficiency by waste heat recovery and by co-generation should be exploited. Solar systems should be designed to cover (part of) the remaining heat demand.

7 APPLICATION POTENTIAL

The industrial uses of solar energy may become an important contribution to meet the target of supplying a 12% of the energy demand with renewable energy sources by the year 2010. The total potential for industrial process heat at medium temperature (below 150 ^{o}C) for the 12 countries that formed the EU in 1994 was estimated to 202.8 TWh (millions of MWh) (Laue and Reichert 1994). The present energy demand in the EU for medium and medium-high temperatures processes (below 250 °C) can be estimated to about 300 TWh, a 7% of the total final energy demand.

Favourable conditions for the application of solar energy are found in processes with a continuous heat demand during sunlight hours and all throughout the year.

These processes may be, for instance, the heating of liquid baths for washing, drying processes and chemical treatments, air heating for drying and low-pressure steam generation for several uses.

Another wide range of application of solar systems may be encountered in the generation of cold by means of absorption machines or other thermal chillers, being one of their advantages the match between the peak of demand and maximum sunlight rate.

Several studies have been carried out on the industrial heat demand at different temperature levels for the countries U.S.A.(Huerdes and Lachal 1986, Laue and Reichert 1994), Switzerland (Huerdes and Lachal 1986, Hurdes 1981), Sweden (Laue and Reichert 1994), Germany (Laue and Reichert 1994, Schreitmüller 1987), the U.K. (Lewis 1980), the Netherlands (TNO 1995), Japan (Laue and Reichert 1994), Spain (Schreitmüller 1986) and Portugal (Blank and Jöschke 1985). Theses studies give a representative overview of the typical process heat demand up to 250 °C. In spite of particular differences among these countries some general conclusions were drawn out of the analysis:

- In all recent studies a general tendency is confirmed: about 50% of the industrial heat demand is located at temperatures in the low (< 60 ^{o}C), medium (60-150 ^{o}C) and medium-high (150-250 ^{o}C) temperature range.

    - A very high percentage of the heat demand in the medium and medium-high range is found in food, paper, textile and chemical industries. These industries require more than 50% of their total process heat in the temperature range up to 200 °C.

    - The biggest heat demand is located in the paper and food industries. A considerable heat demand is also found in the textile and chemical industries.

    - In the range from 100 to 200 °C most of the process heat is used in food, textile and chemical industry for such diverse applications as drying, cooking, cleaning, extraction and many others.

In the following sections a summary of the most important data on heat demand by relevant sectors and industrial processes in Spain and Portugal is presented. It is actually on these countries, which the present study is focused at.

In Section 6.1 the available data from the case studies carried out in POSHIP are analysed and extrapolated in order to obtain the solar process heat potential for industrial sectors in Spain and Portugal.

In the following sections the information obtained from both the literature review and from the case studies carried out within POSHIP is summarised for the different industrial

sectors.

7.1 RESULTS OF THE POSHIP-STUDY

Within the POSHIP project an analysis of the heat demand for a large number of industries in Spain and Portugal has been carried out.

The focus of the analysis has been laid on the evaluation of the heat demand by the temperature levels of the processes. Based on the results of this analysis, the implementation potential of solar thermal systems has been studied. A detailed review of the studies carried out has already been given in chapter 4.

Table 53 gives an overview of the industries analysed in the POSHIP project. Even if the number of companies for which the available data is too scarce to draw exact quantitative conclusions by extrapolating them to entire industrial sectors, the obtained figures can be considered as a rough estimate of the potential of solar thermal energy in industry.

Table 53. Overview of the case studies carried out in POSHIP.

Industrial Sector	Andalucía	Valencia and Central Spain	Catalonia	Portugal	Total
Food	1	1	8	2	**12**
Wine and Beverage	1	1	3		**5**
Paper	0	1	2	1	**4**
Textile	1	2	1	2	**6**
Leather	0	0	0	2	**2**
Malt	1	0	1	1	**3**
Cork	0	0	0	1	**1**
Automobile	0	0	1		**1**
TOTAL	**4**	**5**	**16**	**9**	**34**

7.1.1 Quantitative Analysis of the Industrial Heat Demand and the Solar Process Heat Potential

Figure 72 shows the heat demand in the analysed industries – grouped by industrial sectors – and the fractions of the heat demand at low and medium temperature. In all the studied sectors (except for paper industry), more than 60% of the heat demand is at temperatures below 160 °C, and in several sectors nearly all heat is consumed at temperatures below 60 °C.

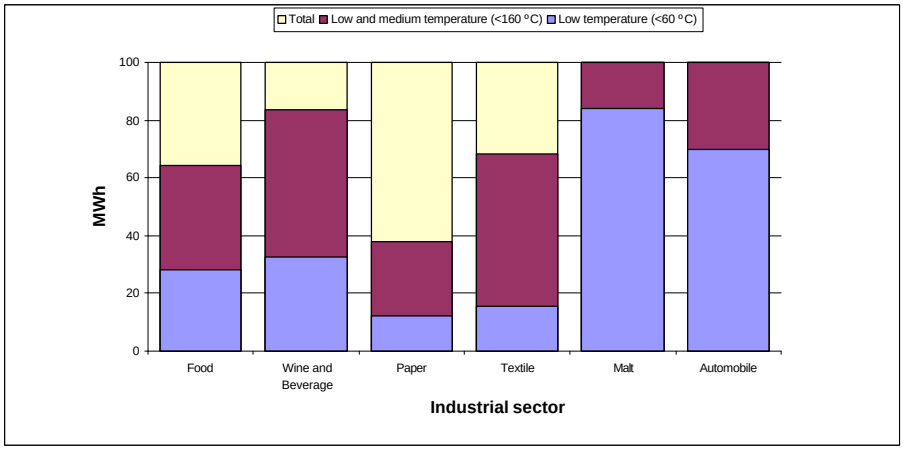


Figure 72. Distribution of the heat demand by temperatures. Industries studied in POSHIP, grouped by industrial sectors.

For all the industries the application potential of solar thermal systems has been analysed.

In Figure 73 both the technical application potential for solar thermal energy (given by the maximum available roof area and by a maximum solar contribution of 60%) and the economic potential (economic competitiveness with fossil fuels, considering a cost reduction potential of 50% for solar systems on a short term and 25% public funding) are shown. In many industries, the limiting factor is the available roof or ground area, so that there is no difference between technical and economical potential.

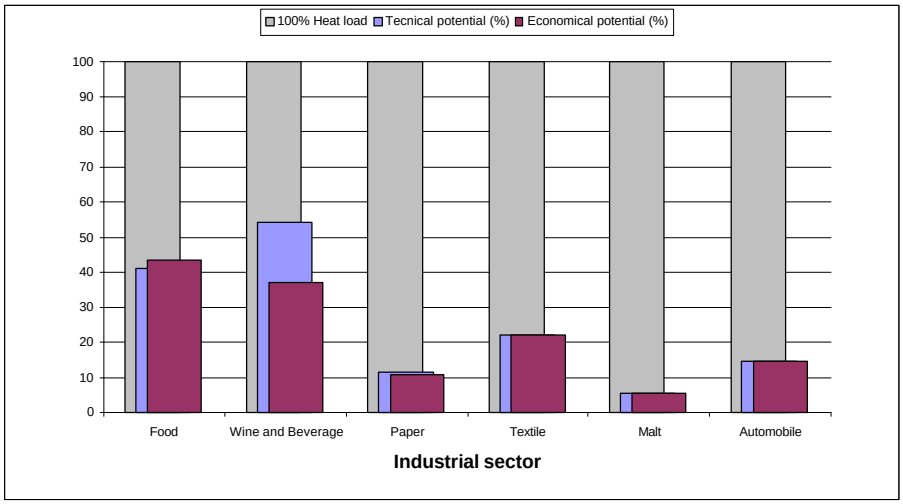


Figure 73. Technical and economical potential of solar industrial process heat (percentage of total heat demand). Companies studied in POSHIP grouped by sectors.

The absolute numbers of heat demand and solar potential for the different industrial sectors studied within POSHIP are given in Table 54.

Table 54. Summary of the data on heat demand and solar potential of the industrial sectors studied within POSHIP. Case studies for Spain (section 4.4.1). Data in MWh.

Industrial Sector	Process Heat Demand		Potential for solar thermal	
	Total	Low and medium temp.	Technical	Economic
Food	47 537	30 467	9 077	10 063
Wine and Beverage	998	835	527	146
Paper	128 859	49 101	14 186	13 286
Textile	244 514	167 565	14 913	14 913
Malt	136 796	136 796	8 455	8 455
Automobile	6 011	6 011	879	879
TOTAL	564 715	390 775	48 037	47 741

Using data on the overall process heat demand in the Spanish and Portuguese industry (Table 55) from the data for the case studies realised within POSHIP on the distribution of the heat demand by temperatures (Figure 72) and from the fraction of the technical and economical solar process heat potential on the overall heat demand (Figure 73) the order of magnitude of the overall solar potential can be estimated by simple proportional extrapolation to the whole industry (Table 55 and Table 56). The total technical application potential for solar industrial process heat in Spain and Portugal can be roughly estimated to 5.8 TWh or 3.6% of the total industrial heat demand.

The relative importance of each of the sectors can be seen in Figure 74. The category “other sectors” contains all the industries that consume heat mainly at high temperatures (metallurgy, ceramics, extractive industry).

Table 55. Heat demand and solar process heat potential for different industrial sectors in Spain. Data in TWh.

Industrial Sector	Process Heat Demand		Potential for solar thermal	
	Total	Low and medium temp.	Technical	Economic
Food, Beverage & Tobacco	14.0	12.7	1.4	1.4
Textile, Leather & Shoes	6.2	4.3	0.4	0.4
Pasta, Paper & Print	14.1	5.4	1.6	1.5
Transport equipment	4.2	4.2	0.6	0.6
Chemistry (*)	20.2	*4.0*	*0.8*	*0.8*
Other sectors (*)	78.1	*0.0*	*0.0*	*0.0*
TOTAL	**136.9**	**30.6**	**4.7**	**4.7**
Percentage of total	**100**	**22.3**	**3.4**	**3.4**

(*) estimated. No case studies available.

Table 56. Potential for solar industrial process heat in the Spanish and Portuguese industry.

	Spain	Portugal	Iberian Peninsula
Final Energy Consumption	855 119	209 340	1 064 459
Total Heat in Industry *(% of final energy consumption) (*)*	136 860	25 121	161 981
	20%	*16%*	*20%*
Low and medium temp. *(% of total heat in industry)*	30 580	7 016	37 596
	22%	*28%*	*23%*
Potential for solar thermal	**4 721**	**1 083**	**5 804**

(*) mean conversion efficiency final energy to useful heat: 75 % assumed

Data in GWh.

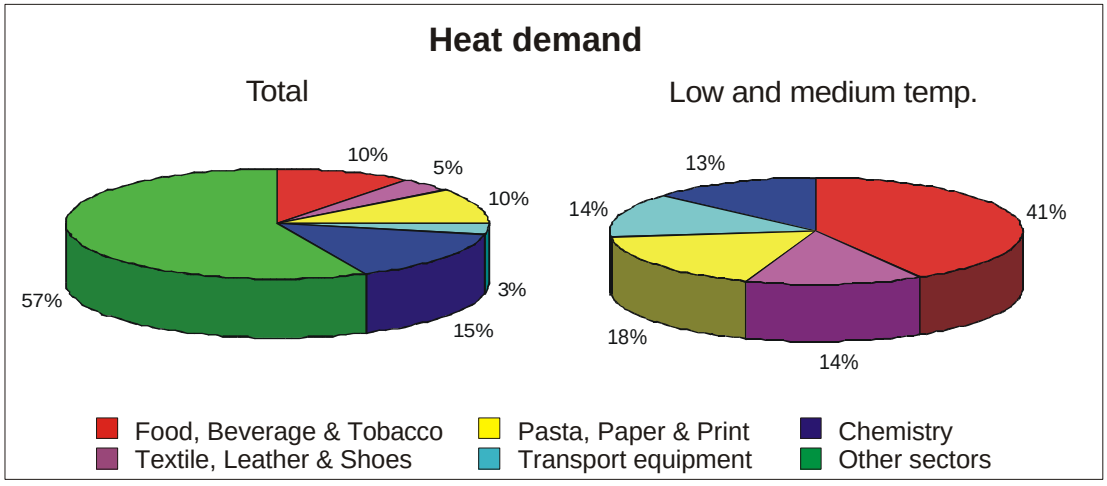


Figure 74. Distribution of the heat demand in the industry according to different industrial sectors. Data for Spain (1999). Source: MINER ,IDAE. Low and medium temperature heat demand estimated from own data.

7.1.2 Qualitative Aspects

7.1.2.1 Description of Typical Demand Profiles

Most industries work 5 or 5 ½ days a week. Breaks of operation due to collective holidays are usually concentrated in summer (2 – 3 weeks), the rest being distributed throughout the year.

7 days of operation a week are usual in the paper industry, in some textile industries and in the malt drying process.

In the following, the characteristics of the demand profiles in the industries studied in detail within POSHIP are analysed.

Continuous Demand

In many industries a continuous demand exists during 7 days a week and 24 hours a year. Examples studied in POSHIP are:

- drying in paper production (steam at 135 °C)
- malt drying (hot air at 60 °C)

Bath Heating

Heating of liquid baths is required in processes such as:

- dyeing, bleaching etc. in textile industry
- bottle washers in beverages sector

The heat demand in these cases is given by:

a) Maintenance of temperature during operation

The heat demand for maintenance can be assumed constant during the working hours, as the environment temperature usually is the indoor temperature of the factory, close to 20 °C.

The heat demand for maintenance strongly depends on the thermal insulation of the baths. Both very well insulated baths could be found and baths with a very high continuous heat demand (e.g. a textile industry using open baths with continuous evaporation of fluid).

b) Preheating of the baths at start-up

Baths have to be preheated at start-up of operation. This is usually in the early morning hours throughout the week, and with a peak demand on Monday morning, due to the cool-down over the weekend.

c) Renovation of fluid

In many processes using liquid baths the liquid is renovated only few times a year, so that the corresponding heat demand can be neglected.

In other industries (e.g. textile industry) frequent periodic renovations of the baths take place, so that periodic peaks in the heat demand occur throughout the working day.

If the periods are short (few hours in the most cases), the peaks can be smoothed by a short-term storage, so that the corresponding heat demand can be considered homogeneously distributed throughout the day.

Preparation of Hot Water for Diverse Uses

In several industries hot water is used for several different processes. Only daily quantities are given for the hot water draw and no distribution of the daily demand is given, so that the most reasonable approximation is assuming a homogeneous distribution throughout the day.

Seasonal Demand - Cooling

Seasonal demand occurred in the cases, where solar systems for cooling purposes were analysed. The cases studied were:

- Space cooling (wine cellar)
- Air cooling for malt germination

In both cases, the cold demand is mainly a function of the difference between outdoor temperature and a given constant process temperature (about 15 °C in both cases). The cooling demand is concentrated in the 5 - 6 summer months (May-October).

7.1.2.2 Available Roof or Ground Area

In nearly all cases studied the limiting factor for the technical solar process heat potential is the available roof area. The heat demand at low and medium temperature in 90 % of the studied cases is higher than the maximum possible solar output.

Only few companies, usually situated in rural areas, had free ground area available.

7.2 BEER BREWING AND MALTING

The total consumption of final energy in beer and malt brewing in Spain yields 1 867 GWh, from which 1 522 GWh are used for heat generation (81%). The required thermal energy is usually generated in saturated steam boilers fired by fuel or natural gas. At present, the malting and beer brewing processes can be integrated or separated. 80% of the malt brew is produced in independent facilities.

7.2.1 Malt

The most important share of heat in the malting process is used for the *drying* of the germinated malt, in order to reduce its moisture content. Therefore, air at 35 to 80 °C preheated by means of an auxiliary fluid (low pressure saturated steam or superheated water) is used.

The heat consumption at low temperatures in the malting process is very high. The obtainable solar contribution in the studied cases is limited by the available roof or ground area to 7% and 20% respectively. Due to the low temperatures and its continuous operation, the malting process is ideal for solar energy utilisation.

About 14% of the total fuel consumption is used in cogeneration systems, which in turn generate around 41% of the required electrical energy.

Besides the above-mentioned heat consumption for the drying of the malt, there is also a demand of cold for the *germination*, where the temperature is to be kept at 14-15 °C. This demand can yield up to 20% of the total heat and cold consumption in malt breweries in the southern part of the Iberian Peninsula.

7.2.2 Beer

In the brewing process, thermal energy represents a share of 77%. Table 57 shows the distribution of the heat demand for beer brewing.

Table 57. Heat demand by processes in breweries.

Process	Percentage of total heat demand
Must preparation	40 - 50 %
Local heating	< 5 %
Bottling	25 - 35 %
Utilities	15 - 20 %

The energy demands for the brewing of beer are the following:

- Successive heating up to boiling temperature of the beer liquor for the *must production*, using low pressure saturated steam and sometimes superheated water or even direct combustion.

- *Refrigeration* of the must, preheating the feed-up water using conventional chillers.

Therefore, it is possible to use solar thermal energy in this industrial sector for the production of steam (at 104-110 °C) and cold using absorption chillers.

7.3 FOOD INDUSTRY

In the food industry, the following fuels are used, most of all for steam generation or direct application: fuel oil (most extended), natural gas, gas-oil (C), propane and biomass. In the recent years, fuel oil has been partially substituted by natural gas.

Besides the heat consumption, in many sub-sectors there is the possibility of covering part of the cold demand by solar cooling.

7.3.1 Wine and Other Beverages

The most important heat consumption in this sector with a good potential for solar energy use is the production of hot water for *cleaning and disinfecting of bottles*. The required hot water temperatures range from 70 to 90 °C. In many industries of the beverages sector, the production volume increases during summer, so that a positive correlation between the heat demand and the solar radiation availability exists.

In the wine production, the *cooling of wine cellars*, being these sometimes in remote locations without connection to the electricity grid, is another potential application (see the project described in section 5.4).

7.3.2 Meat

The most important heat consumption in the production of meat products is hot water for *washing, boiling and cleaning*. Required hot water temperature ranges from 60 °C to 100 °C.

In the production of canned meat, the largest heat consumption is found in the *sterilisation* process, which is carried out with autoclaves using steam as heat supply. This operation is performed controlling the time vs. temperature curve.

7.3.3 Canned Vegetables

Two main processes may be distinguished in this sector: the scalding and sterilising.

Dry steam is usually used for the *scalding* of some products. Immersion in boiling water during a variable time may also be used, depending on the product. This process is characteristic due to its high fuel consumption.

The *sterilising* is carried out using direct pressurised steam in autoclaves for a few minutes, reaching a temperature between 110 and 125 °C.

In the production of deep frozen vegetables, the scalding process is performed by immersion of the product in a hot water bath at a temperature range of 95 and 100 °C during 2 to 6 minutes. This process consumes the main part of the required thermal energy.

7.3.4 Canned Fish Production

There is a large variety of processes in the canned fish production sector, requiring water or steam, either for the cleaning or cooking of products as well as for treating the cans in which the product is conserved.

In the *scaling and cleaning* process, the skins and scales of the fishes are removed by applying steam and water showers.

For the *pre-cooking* of the product, direct steam is applied during an appropriate period of time.

The *can sealing* process is carried out under vacuum conditions, usually supported by a stream of flash steam.

For the *cleaning of the cans*, these are introduced in a pressurised hot water washing machine, in order to eliminate the dirt and oil traces.

The *sterilisation*, in turn, is performed in horizontal discontinuous autoclaves, which use steam for the heating of the products up to the sterilisation temperature. This is the process consuming most of the required thermal energy.

During the *cooking* process in the production of fish flour and oil, the chopped product is placed in a steamer-dryer where the fish or sub-product is heated at high temperatures (95 to 110 °C) by means of steam during 3 to 20 minutes so that the moisture is eliminated.

7.3.5 Children Nutrition Products

The cooking and sterilising processes are the most interesting ones in this sector.

The *cooking* is one of the most significant energy consuming processes. It is usually carried out in discontinuous steamers using water heated to 70-98 °C by means of saturated steam.

The *sterilising* is the most important heat consuming process in the production of these kinds of products. Once the jars have been vacuum-sealed and placed in so-called cages, they are introduced in rotary discontinuous sterilisers, where they undergo a heating-cooling process according to the adequate curve for the product and the size of the jars. Water and steam are used in this process. Steam is used in order to reach temperatures between 110 and 125 °C.

7.4 MILK INDUSTRY

The dairy products industries are of great interest for solar energy, as they are operating seven days a week.

Particularly interesting are the *dehydration* processes (powdered milk production) due to their high and constant heat demand. In the production, both milk and whey are pulverised in large towers by means of air, which is heated from 60 °C (from the heat recovery) up to 180 °C. These processes operate up to 8 000 hours/year.

Pasteurisation and sterilisation processes are other interesting ones in this sector.

In the *pasteurising* process, it is possible to differentiate between LTLT (low temperature, long time) in which the product is heated to 62-65 °C during 30 minutes and is cooled down to 4 °C, and HTST (high temperature, short time), which operates at temperatures between 72 and 85 °C and is also cooled down to 4 °C.

Besides, the UHT (ultra high temperature) *sterilisation* requires temperatures between 130 to 150 °C to be applied during 2 to 3 seconds. This is attained by means of direct steam injection or, indirectly, in a heat exchanger.

7.5 TEXTILE INDUSTRY

7.5.1 Finishing

Among the textile producing operations, the *finishing* process is the most energy consuming one. Most of the thermal demand is located in the preparation and colour-dying operations. The most representative ones are *washing, scrouding, bleaching, mercerising and dying*.

The heat is used for the heating of liquid baths up to temperatures from 70 to 90 °C, and for drying the textiles by means of hot air and steam heated drying drums.

The most widely used system for the heating of the baths is using steam, either by direct injection in the fluid or indirectly circulating the steam through a pipe submerged inside the bath.

The production in many of these industries is continuous and the heat demand is very high. Very good conditions exist for solar energy use for bath heating.

Natural gas has taken a predominant position among the combustibles used in the finishing of textile products.

7.5.2 Wool Production

In the *storage, pumping and pulverisation* of the fleece, temperatures between 40 and 130 °C are required. Different techniques are used for waste heat recovery within this sector.

7.6 PAPER INDUSTRY

7.6.1 Paper Pulp Production

The paper industry (paper pulp, paper and printing) is one of the largest energy consuming industrial sectors.

The fundamental part in all the chemical pulp production processes is the *cooking process*. In the production of bleached sulphate paper pulp the chips are bleached at a temperature of 170-180 °C and 8 to 10 bar pressure during the lixiviation process.

The most widely used fuels are sulphite spent liquors, fuel oil, fuel-oil-chips, chips and natural gas.

Cogeneration systems with back pressure steam turbines are frequently used.

7.6.2 Paper Production

More than 90% of the heat demand for paper production is used in the *drying processes* using both hot air streams and drying drums heated by steam at about 135 °C. The heat demand in this industry is continuous, 24 hours a day and nearly 365 days a year. The relatively high temperatures required in the drying drums can be obtained by means of parabolic trough solar collectors. The two paper industries included in the POSHIP analysis showed a very large heat demand of 28 000 and 75 000 MWh.

7.7 CHEMICAL INDUSTRY

There are many different processes consuming large amounts of heat in the chemical industry (e.g. distillation columns, drying processes, fusion and transformation of plastics, etc.).

7.8 AUTOMOBILE INDUSTRY AND AUXILIARY INDUSTRIES

7.8.1 Tyre Production

It is possible to estimate the following energy consumption distribution in this sector: electricity 38 to 45%, fuels (mostly natural gas) 62 to 55%.

The heat consumption is mainly for steam production. Steam is used in characteristic *rubber treatment* processes (85 to 90%) and the rest of heat consumption is used for the *air conditioning* of the buildings (10-15%).

7.8.2 Painting Section

In the painting section of the automobile industry, liquid baths at very low temperature (35 to 55 °C) are used for *cleaning and degreasing*.

7.9 TANNING SECTOR

The energy in this sector represents between 4 and 5% of the productive costs. On the total cost, the electric power represents 60 to 65% and thermal energy 40 to 35%.

The total consumption of energy amounts some 700 GWh/year, distributed in the following way: thermal energy: 550 GWh; electric power: 153 GWh/year.

The most widely used combustible is fuel-oil (80% in 1994), followed by natural gas (18%), gas-oil, propane, forest residuals and others.

Heat consuming processes are *humid processes* (hot water at temperatures between 30 and 60 °C) and *drying processes* (heating of air).

7.10 CORK INDUSTRY

In the *storage processes and pumping of the fuel*, the level of temperature used for heating is, respectively, of 40-45 °C and 60-70 °C. For the *pulverisation of fuel*, this is heated to temperatures of 100-130 °C, either inside of or outside of the burner.

The cork is boiled at a temperature of 100 °C, in order to *extract the tannic acid*, to increase its flexibility and to expand it.

The full *elimination of moisture* of the cork for stoppers, in order to prevent the development of micro-organisms, is carried out heating the air to 40-55 °C, either directly or indirectly. The same procedure is applied for the production of damping elements and compound processing. In this case, the air temperature reaches up to 150 °C.

However, the highest temperature is attained in the *cork filling production*, in which the steam is heated up to 300-370 °C at the inlet of the autoclave using a burner operated by powdered cork.

Table 58. Industrial sectors and processes with favourable conditions for the application of solar process heat

Sector	Processes	Temperature level (°C)
Brewing and Malting	Wort boiling Bottle washing Cooling Drying	100 60 90 60
Milk industry	Pasteurisation Sterilisation Drying	62 – 85 130 – 150 n. a.
Food preservation	Sterilisation Pasteurisation Cooking Scalding Bleaching	110 – 125 < 80 70 – 98 95 – 100 < 90
Meat	Washing, sterilization, cleaning Cooking	< 90 90 – 100
Wine and beverage	Bottle washing Cooling	60 – 90 85 (*)
Textile industry (incl. wool industry)	Washing, bleaching and dying Cooking	< 90 140 – 200
Automobile industry	Paint drying Degreasing	160 – 220 35 - 55
Auxiliary industry for the automobile sector	Spinning and weaving Finishing Mats and others	
Paper industry	Paper pulp: cooking Boiler feed water Bleaching Drying	170 – 180 < 90 130 – 150 130 – 160
Tanning	Water heating for damp processes Drying	steam at 165 – 180
Cork industry	Drying, cork-baking, others	40 – 155

(*) single effect absorption cooling

8 PUBLIC FUNDING FOR INDUSTRIAL SOLAR THERMAL SYSTEMS

8.1 PUBLIC FUNDING

Some of the challenges subscribed by the European Union, among other countries, in the Kyoto World Conference in December 1997 are to achieve a reduction of European greenhouse gas emissions of 8%, compared to 1990 levels, and to cover 12% of the European primary energy demand from renewable energies by the year 2010. In order to reinforce political measures to respond to these challenges, there are some funding programs to promote renewable energy and energy efficient projects on an European, national, regional and municipal basis.

8.1.1 European Community Funding Programmes

Their main strategic goal is the development of sustainable energy systems and services for Europe, contributing to a more sustainable world wide development, leading to an increased security and diversity of supply, the provision of high-quality, low-cost energy services, improved industrial competitiveness and reduced environmental impact.

Fifth Framework Programme. Aims to promote renewable energy demonstration projects to be developed in Europe. The proposed energy systems must achieve a degree of innovation and sustainability, taking into account the social aspects and its demonstrative potential in all economical sectors. Maximum funding: 35% of expenses. In Spain, the IDAE annually calls for funds for the preparation of proposals for this programme.

ALTENER and SAVE Programmes. These programmes are oriented to the policies centred in non-technological measures to exploit the best economical potential in innovative practices in the energy market. Maximum fund: 50% of expenses

*Other programmes for promotion of Renewable Energies in third countries. The INCO p*rogramme.

8.1.2 National Funding Programmes

Most of the European countries have developed funding programmes to reinforce and support the sustainable and renewable initiatives. The present situation in Spain and Portugal is as follows:

- *Portugal*

In the framework of the 3rd "Quadro Comunitario de Apoio" the so-called POE – Operational Economy Programme, for the collective institutions, was created. It includes a sub-programme called MAPE, which focuses on Energy. In MAPE, solar thermal systems are eligible for a subsidy of 20% (with a limit value of 300 000 €) and an additional 20% of tax free loan for private entities, and all the 40% as funding for public entities.

Companies investing in solar equipment can pay-off the related investment over a period of four years as part of their corporate annual income tax. This is a very important measure as it allows the paying-off *of solar systems in four years*, independently of the incentive.

The specific equipment for solar systems (mainly solar collectors) is charged with a reduced VAT of 5%.

The new energy plan for Portugal: "*E4 - Energy Efficiency and Endogenous Energy*" has been approved by the Portuguese Government on September, 17th 2001. This Program considers a set of measures that are directed to the modernisation of the national energy system, having in mind security on energy supply, improvement of competitiveness of the Portuguese economy and promotion of environment quality, creating the necessary conditions to achieve the 39% target of electricity production by renewables in the year 2010. The contribution of all renewable energy sources will be improved and for that in the next months several regulatory documents will published. Information about this Program can be obtained in the SPES web site (www.spes.pt)"

- *Spain*

National Energy Programme (PROFIT): the Ministry for Science and Technology regulates the concession of funds for industrial research projects, technical feasibility studies and technology demonstrations projects. These funds cover 35% of the investment costs for demonstration projects when granted to small and medium companies and 25% when large companies are involved. Among others, the programme aims to develop technologies for a reliable, efficient, save, clean and economic energy service, the integration of renewable energies, besides thoroughly evaluate the environmental and social economics of energy. These funds are presented in the form of advanced payment and, exceptionally, subsidies.

In the framework of the Renewable Energies Promotion Plan, the IDAE calls for funding for the promotion of projects investing in solar thermal energy at low temperatures, in any sector with such energy demand. For the selection of quality offers to collaborate in the procedure, broadcasting and application of these funds, the collaborating companies and institutions must be authorised. Funding may cover, generally speaking, a maximum amount of 35 000 ptas. (210€) per square metre of usable surface. The IDAE allocates yearly a budget of around 1 000 million ptas. (6 M€) for this programme.

8.1.3 Regional Funding Programmes

- *Catalonia*

Every year there is a new call for subsidies to renewable and energy efficient projects. Maximum fund: 210 euro per square meter of solar thermal collector being installed.

- *Andalucía*

The PROSOL programme is a system for promotion and financing renewable energy systems, created by the Junta de Andalucía (regional government) and managed by SODEAN (Andalucían Energy Agency). The programme supports solar thermal systems for hot water production, independently of the type of use (domestic, industrial, etc.). The maximum amount of funding for these installations is 41 500 ptas. (250 €) per square meter.

PROSOL defines a "recognized energy cost" (CER), which determines the amount of funding and financing that corresponds to a given installation. The VAT, together with the difference between the real investment cost and the CER are on charge of the user.

- *Canary Islands*

The PROCASOL programme is a system for the promotion and financing of hot water producing solar thermal energy plants, promoted by the Council for Industry and Commerce and the Government of the Canary Islands and administrated by the Technological Institute of the Canaries. The programme allows the acquisition of a solar thermal system for hot water generation, as long as the usable energy surface is 50 square metres or above.

There is a range of subsidies for forced circulation solar systems between 20 000 and 30 000 ptas. (120-180 €) per square meter.

- *Other Spanish Autonomous Communities*

There are also subsidies to renewable energy sources available in other Spanish communities. In Asturias, for instance, there are subsidies for active solar thermal systems up to 50 000 ptas. per square metre, with a maximum amount of 5 000 000 ptas. (30 000 €). There is also a range of subsides for solar thermal projects in Castilla and León, within the Solar Plan of Castilla and León, line I – Solar Thermal Energy. In the case of Navarra, non-returnable funds are available for either solar thermal, photovoltaic, hydroelectric and wind energy plants, for the promotion of renewable energy investments.

- *Madeira Island*

The regional Government of Madeira is preparing a legislation to promote solar thermal systems (domestic and public services), which will be connected with the energy production of the system all throughout their lifetime. The values of the incentives are not yet known.

- *Local and Municipality Incentives*

There are several different incentives for solar thermal systems available from town councils, municipalities and local councils. The “Ordinance on the incorporation of solar thermal systems in buildings” of the Council of Barcelona should be pointed out. This ordinance states that the energy contribution of the solar installation has to be a minimum 60% of the yearly hot water demand in the industries.

Table 59. Overview of funding programmes for solar industrial process heat plants. Status: July 2001

Deadline	Call / Organism	Maximum amount of funding	General description of the program	Contact information
1. European Programmes				
V Framework Programme European Comission / Energy Programme	Deadline: 14th of December, 2001	Maximum funding of 35% of total cost in technology demontration projects; maximum 50% in RTD projects	Cooperation among companies (at least three companies of different member states)	Organism: DG TREN y DG Research www.cordis.lu/eesd
2. National and Regional Programmes				
Spain				
(PROFIT) National Energy Programme / Ministerio de Ciencia y Tecnología	Call: 3rd of April 2001; Deadline: 7th of May 2001 (except programmes EUREKA and IBEROEKA: 1st of September 2001) / Calls for 2002 to be published	Technology demonstration projects: maximum funding of 35% to small and medium companies; maximum of 25% to large companies / advanced payment and, exceptionally, subsidies	Strategic action: development of technology for design and manufacturing of evacuated meditum temperature collectors.	Organism: Ministerio de Ciencia y Tecnología Contact: Dirección General de Política Tecnológica tel.: +34 91 349 51 61 www.mcyt.es/profit
Renewable Energies Promotion Plan - Sector: Solar Thermal Energy / IDAE	Call: July 2001; Deadline: 15th of September 2001	Maximum funding: 35 000 ptas (210 euros) per square meter of installed useful collector area for new installations	Promotion of the investment in low temperature solar thermal installations. Process hot water in industries is considered, too. Eligible technologies: glazed standard flat plate collectors and evacuated tubes.	Organism: IDAE Contact: Dpto de Gestión Programas Públicos tel.: +34 91 456 50 16 www.idae.es
Portugal				
2001-2006	POE / MAPE	20 % + 20 % tax free loan Max. 300 000 €	Solar thermal systems	Organism: Gestor do POE-MAPE www.poe.min-economia.pt
	Tax reductions	Amortisation of investment in solar thermal equipment over a period of four years as part of the corporate annual income tax. Reduced VAT (5%) for equipment specific for solar systems	Solar thermal systems	Organism: Direcção Geral de Energia www.dge.pt
3. Regional Programmes				
Spain				
Catalonia		Maximum fund: 210 euro per square meter of solar thermal collector installed	Subsidies to renewable and energy efficiency projects	Organism: Institut Català d'Energía tel.: +34 93 622 05 00 www.icaen.es
Andalucía: PROSOL programme	Calls for presentation of projects once a year (last call: max. 15th of October 2006)	Maximum amount of funding: 41 500 ptas (250 euro) per square meter	Solar thermal systems	Organism: Sociedad para el Desarrollo Energético de Andalucía (SODEAN) tel.: +34 95 446 09 66 www.sodean.es
Canary Islands: PROCASOL programme	Deadline 2000: 31st of May 2001 (yearly calls until 2006)	Forced circulation solar systems: between 20 000 and 30 000 ptas (120 to 180 euro) per square meter	Solar thermal system for domestic hot water production, minimum useful area: 50 m^2	Organism: Gobierno de Canarias Contact: Dirección General de Industria y Energía www.gobiernodecanarias.org
Castilla y León: Solar energy plan of Castilla y León, Area I: Solar thermal	Deadline: 31st of August 2001	Solar thermal energy projects: maximum amount of funding 100 000 € during three years	Solar energy plan of Castilla y León, Area I: Solar thermal	Organism: Junta de Castilla y León Contact: Consejería de Industria, Comercio y Turismo
Other regions				Direct to the corresponding authorities

8.2 FINANCING OF INDUSTRIAL SOLAR THERMAL SYSTEMS

Third party finance (also known as contracting) is a financing model in which, depending on the scope of the project regarded in the contract, a third party, other than the energy user, develops, finances and operates the energy system during an agreed fixed time. This third party is also known as ESCO (Energy Service COmpany). The energy user in turn has to make periodical payments to the third party, which are either linked to the energy consumption or are fixed by the contract. This contract is usually designed so that the pay-back period covers the investment and the variable costs of the third party financier, plus a profit margin. Depending on the size of the project and the security for cash flows the repayment mode is either:

- Payment by instalments
- Hire purchase
- Any other leasing agreement

Usually the energy system becomes the property of the energy user at the end of the contract, although in smaller projects it is sometimes the user's property from the beginning. Third party finance is based on contracts. These contracts have to ensure that the project's risks assumed by the financing party are covered if energy production or consumption does not meet the expected target.

In an optimally designed project, the energy user will save money compared to alternative energy supply systems and the financier makes a profit.

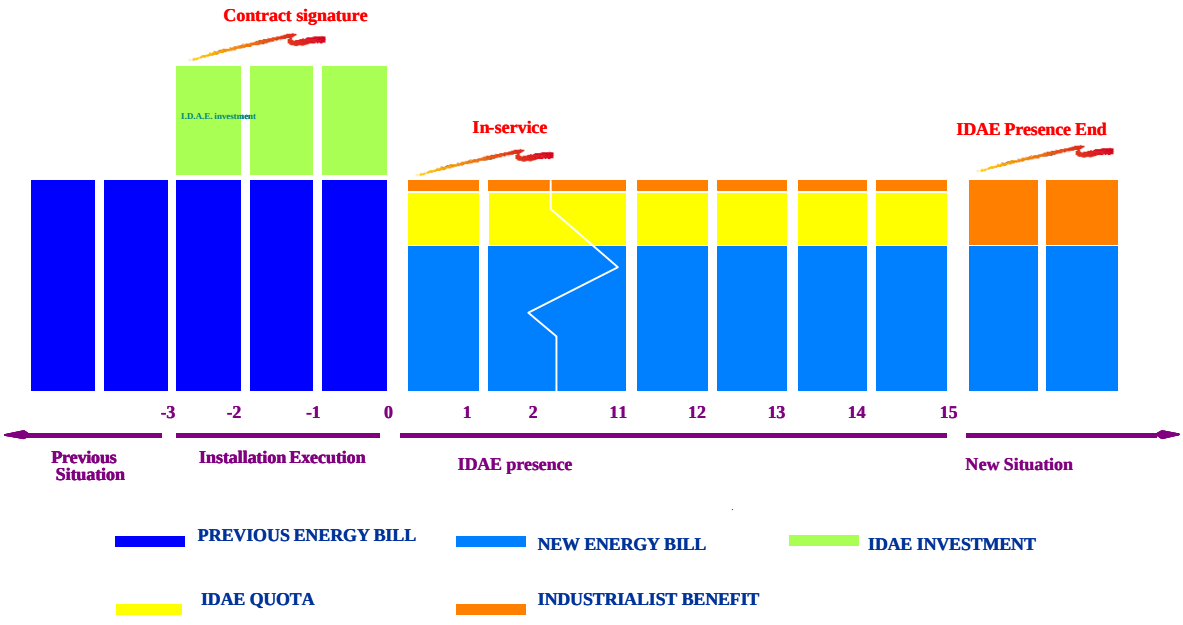


Figure 75. Third party-financing model applied by IDAE (Spain).

8.2.1 Spain: IDAE-ICO Financing Solution

The Institute of Official Credit (ICO) and IDAE have signed, for the second consecutive year, a collaboration agreement by which the ICO will arrange financing of investment projects on renewable energy and energy efficient systems, therefore allocating 20 000 million ptas. (120 million euros). Among the eligible thematic areas for 2001, only the photovoltaic and solar thermal electricity are included, but the solar thermal energy for heat production has not been considered.

8.2.2 The FITA SOLAR Programme in Catalonia

The FITA SOLAR financing product is a technical, financial and administrative scheme to cover the entire investment of a solar thermal facility or a photovoltaic installation. Its objective is to finance the solar facility by ensuring an optimal performance and a cost effective solution. The system will be monitored according to the terms of the guarantee of results.

I. A three-sided agreement among the final user, the installer and ICAEN in order to ensure the intention of all parties in developing the project will be signed, authorising ICAEN to supervise and to accede to the gathered data through the telemonitoring equipment.

II. A turnkey contract solar installation for solar hot water generation will be executed. It will be built with high quality materials, hot water consumption counter, warranty of results and a service of maintenance.

III. The financing of the solar installation will be at a long period (maximum 10 years) and with instalments around the substituted energy savings produced. The guarantee of the credit will be the installation itself and the interest rate of the loan is one point above the EURIBOR.

The distribution of financing amounts is the following:

- 30% to be paid by the client at the moment of commissioning
- 70% credit from the Institut Català de Finances (Catalan Finance Institute (ICF)).
- regional subsidies (estimated value) will be used to reduce the loan.

Granting of this aid will be conditioned on the compliance with certain technical requirements under the terms of the guarantee of results.

8.2.3 Andalucía: PROSOL Programme

The PROSOL programme (see 5.1.3) allows for acquiring an installation that uses renewable energy for the production of hot water. One of the aids for the user is the subsidy on the interest from the loan dedicated to fund the CER financed amount.

8.2.4 Canary Islands: PROCASOL Programme

The PROCASOL programme (see 5.1.3) contemplates a subsidy type adapted to the interest, that allows the applicants to pay part of their installation, referred to as financing cost, by means of a loan subscribed with any of the collaborating entities from the

program for three years. The PROCASOL programme assumes the interests and expenses of the loan opening. In order to calculate the interests to subsidy, a maximum loan of 70 000 ptas. (420 €) per square meter will be considered.

There is also the chance of financing the installation by simultaneously using the subsidy to the square meter and to the type of interest.

8.3 ADMINISTRATIVE MEASURES AND ENERGY POLICY (PORTUGAL)

The set of policy measures that are being proposed resulted from the actions undertaken during POSHIP duration and also from our participation in the discussions and workshop promoted by INETI among others to know from public institutions, public in general, solar industry and users from industry what are their expectations in relation to ER promotion and what are the main constraints that should be eliminated to promote solar energy.

There exist a positive expectation on the acceptance of these measures by the Government, which will modify radically the RE policy of Portugal. Three types of measures have been already proposed:

1 - Measures without direct costs:

The attitude
A *positive attitude from the government towards RE, is asked*

Regulations

- *New buildings should have pre-installation of insulated ducts for solar thermal system like it happens now for gas, electricity and telephone installations.*
- *- Equipment and installers certification*
- *Obligation for public and social buildings and later for all construction.*

Reduction of bureaucracy on incentive programs

2 - Revision of Actual Incentive Schemes:

POE – MAPE, Measure 2.5: 40*% incentives for all solar thermal systems*

VAT: *all solar system components with 5% VAT*

IRC: amortization *rate: 50% - 2years - or even 100% - 1 year.*

Bank tax*: bank tax reductions for financed projects.*

3 - Other Measures:

Publicitary campaign for Solar Thermal promotion *(quality aspects, environmental, economic, and security benefits, type of incentives)*

New Incentives *(prizes and new fiscal reductions related with buildings like "sisa", local tax)*

Training: *special training courses and school manuals*

Research: *new materials, architectural integration, acclimatization, higher temperatures, etc.*

Solar Observer: *with INETI, AGEEN and other institutions to monitor the results of planned strategy for solar/RE*.

8.4 PRESENT SITUATION AND FUTURE PROSPECTS

It has been outlined above, that for industrial solar thermal systems the availability of public funding is necessary.

In order to evaluate the future market possibilities for these systems the technical potential for solar industrial process heat is correlated with present situation on the market of solar thermal in general, the available budget for public funding and low-interest financing at present and the prospects of national energy programmes (Table 60).

Table 60. Present situation and future prospects for solar thermal systems in Europe.

Present reality (End 2000)		**Spain**	**Catalonia**	**Portugal**	**Total Iberian P.**	**Total EU**
Solar thermal systems in operation	x 1000 m2	400	39	260	660	7800
Industrial systems [m2]		<3		<1		10
New solar thermal systems installed in 2000		44.6	5.5	6.0	50.6	
National / regional energy plans until 2010		**Spain**	**Catalonia (v)**	**Portugal**	**Total Iberian P.**	**Total EU**
Solar thermal systems (total) installed in 2010	x 1000 m2	**4841**	**110**	**1760**	**6601**	**15000**
Industrial systems installed in 2010			?	440		2 000 (**)
Technical potential solar industrial process heat		8 800	*2200 (vi)*	2 200	11 000	*30 000 (***)*
Systems to be constructed (total) 2001-2010		**4 441**	**71**	**1 500**	**5941**	**7 200**
Necessary annual growth rate		**28%**	**11%**	**21%**	**26%**	**7%**
Yearly investment necessary in 2001	M€	34	1	16	51	158
Reality of funding / financing programs (2000/2001)		**Spain**	**Catalonia**	**Portugal**	**Total Iberian P.**	**Total EU**
Public funding conceeded 2000	M€	8.2 (iv)		n.a.		?
Low-interest financing conceeded 2000				n.a.		?
Total budget available for public funding 2001	M€	6 (iv)	0.5	n.a.		?
Total budget for low-interest financing 2001			6.0	n.a.		?

(*) assuming a total investment cost of 300 €/m2 and linear increase of installed area
(**) goal of Campaign for take-off for 2003 (!!!), including solar cooling.
(***) rough estimate from the data for Spain and Portugal, extrapolating to Greece, Southern France, Italy and (in minor degree) the rest of EU
(iv) only "Plan de Fomento", other programs to be added.
(v) Green book of RES - goal for 2005: 55 - extrapolated to 2010 by factor 2
(vi) estimated from overall potential for Spain

9 DISSEMINATION ACTIVITIES

Beyond the technical work, one of the objectives of the POSHIP – project was the dissemination of the results to the interested public.

The following activities have been realised:

- Elaboration of an informative dossier for industry
- Elaboration of a brochure (summary of the results)
- Workshops and conferences
- Other publications

9.1 INFORMATIVE DOSSIER FOR INDUSTRY

A 4 page informative dossier has been elaborated in an early stage of the project (see Appendix). This dossier has been sent together with the mailing to industry to more than 1500 industrial companies in Spain and Portugal, and furthermore distributed at workshops, conferences, trade fairs and direct contacts with customers.

9.2 POSHIP - BROCHURE

A brochure summarising the main results of the POSHIP study has been printed in four languages.

The brochure has (or will be) distributed as follows:

- Mailing to all the industries that have collaborated within the POSHIP – study
- Presentation of the brochure in Spain on a workshop on solar industrial process heat in Sevilla, October, 10th, 2001.
- Mailing of the English version of the brochure to the interested public in other European countries.

9.3 WORKSHOPS AND CONFERENCES

9.3.1 Workshops and Conferences Organised by the POSHIP Partners

Solar Energy Workshop Portugal
This workshop was organised in collaboration with INETI, with a special focus on POSHIP project objectives and results. To this workshop assisted the most important partners in solar energy business in Portugal, involving industry (fabricants and users), the governmental related institutions of the sector, the public in general and including an important coverage by mass media. The present situation will be analysed, listening the different partners and new energy policy measures were proposed that can encourage the usage of solar thermal energy. June, 2000.

Workshop "Integration of Renewable Energies in the Industry"
Workshop organised by ICAEN, with a presentation of POSHIP by AIGUASOL.
Barcelona, October, 25th, 2000.

Workshop "Dissemination of the Use of Solar Thermal Energy in the Tanning Industry"
Workshop organised by SPES in the framework of a previous project. Centro Tecnológico das Indústrias dos Curtumes, Alcanena (Portugal), December, 4th, 2000.

Workshop "Dissemination of the Use of Solar Thermal Energy in Industry. Application to rice drying"
Workshop organised by SPES in the framework of a previous project. Estação Agronómica Nacional, Oeiras (Portugal), December, 6th, 2000.

Conference for the commemoration of 20 years of the Portuguese Solar Energy Society (SPES)
A special presentation of POSHIP Project was done during this conference. Lisbon, December,18th, 2000.

"FORUM ENERGIAS RENOVÁVEIS EM PORTUGAL",
Workshop Energia Solar Térmica,
INETI, 12 de Julho de 2001
Solar térmico – As aplicações na indústria.
Eng° João Farinha Mendes – INETI

Workshop "Solar thermal energy for industrial processes"
This workshop, organised by IDAE will present the results of the present project together with the ALTENER – Project PROCESOL. Sevilla, October, 10th, 2001.

9.3.2 Presentations on Other Events

Biennial Conference of the European Solar Energy Society (EuroSun 2000).
A paper on first results of POSHIP has been presented to this Conference. Copenhagen, Denmark, June 2000.

Mexican National Co-ordination for Renewable Energies (COFER).
A presentation of the POSHIP project has been given on the regular meeting of this forum joining professionals from industry and research institutes. Mexico – City, November, 9th, 2000.

Biennial Spanish Trade fairs for Heating and Air-Conditioning (CLIMATIZACIÓN) and Cogeneration (GENERA). A conference on the project POSHIP has been held at the work shops accompanying these fairs in Madrid (IFEMA). Madrid, March, 1st, 2001.

Conference on Renewable Energies, Sabadell (Barcelona), Spain.
A presentation of the POSHIP project has been given by AIGUASOL, May, 2001.

Meeting of IEA-SolarPACES in Cologne,Germany.
A short presentation of the results from POSHIP has been presented by DLR. June, 2001.

SunDay'2001 - Dia do SOL, Palmela (Portugal) - 22/Junho 2001 - Solstício de Verão
ENERGIAS RENOVÁVEIS PARA UM DESENVOLVIMENTO SUSTENTÁVEL..
Projecto POSHIP - Energia Solar em Processos Industriais
Eng. Farinha Mendes, SPES

Local Agenda 21 Meeting at Sta. Perpetua de la Moguda (Barcelona), Spain.
A presentation at this meeting with representants from local industry was given by AIGUASOL. June, 2001.

Seminário – Eficiência Energética e Energias Renováveis (29 Junho 2001)
APEMETA – Associação Portuguesa de Empresas de Tecnologias Ambientais
Energia Solar em Portugal. Aplicações Industriais - Projecto POSHIP
João A. Farinha Mendes
Investigador do DER/INETI e Presidente da SPES

Workshop on Renewable Energies, Olot (Girona), Spain
A presentation of POSHIP will be given by AIGUASOL. October, 19th, 2001.

Presentations at Several Solar Energy Related Events in Portugal
The intervention of SPES Board of Directors as well as researchers of INETI in a variety of solar energy related events, occurred during the project period in Portugal, has been also an opportunity to present the POSHIP project and to ask for the interest of participants coming from industry.

9.4 OTHER PUBLICATIONS

www.aiguasol.com/poship.htm
On this site on the web of AIGUASOL all the public information from the POSHIP project is available for download in PDF-format.

www.spes.pt
At the moment the web site of SPES (www.spes.pt) is being reformulated and it will address to POSHIP project objectives and results, giving to it a special projection in the framework of the current SPES activities.

9.5 CONCLUSIONS FROM DISSEMINATION ACTIVITIES

A growing interest between industrial partners for the usage of solar energy has been noted. This interest results from the economic analysis of that investment but also from the environmental concerns and quality management strategy that some enterprises are undertaking to have their factories certified by ISO 14000 Standards. Solar thermal energy application, combining those different aspects, in some cases appears like a very promising alternative. Specific local conditions, like e.g. in the interior of Portugal, where the natural gas is not available and will not be introduced so soon, are favourable to the use of solar energy.

10 CONCLUSIONS

10.1 LESSONS WE LEARNED FROM POSHIP ...

Very Large Application Potential

The application potential of 11 millions of square meters of solar collectors is larger than the production capacity of solar industry and the available budget of funding programmes. Very few systems are realised at present (about 10 000 square meters all over the EU). In POSHIP not only data on the application potential have been collected, but also a methodology has been developed for standardised feasibility studies, that allows for giving a fast response to industries that might be interested in solar thermal.

Energy Costs from 2.5 to 8 cents/kWh

The energy costs for feasible systems are in the range from 2.5 to 8 cents/kWh. This is up to 50% lower than costs that can be obtained in solar domestic hot water systems. The cost per kWh of primary energy saved by solar thermal systems is the lowest in industrial systems.

50% Funding Necessary for Pilot Plants

The really best systems (like the two malting factory projects selected as demonstration plants) have pay back times without funding of 10 years. Normal “good” systems are closer to 15 years at present system and energy costs.

Although many industries have been found very interested in solar thermal, the finally decisive criteria are the expectations in industry on pay back of investment for energy efficiency of 5 years or less. Therefore, systems can either be realised by a high level of public funding (about 50%) in order to fulfil these expectations, or by other financing models that make solar thermal systems sufficiently attractive for industry from an economic point of view.

Possible cost reductions and the development of fossil fuel prices may change this situation in the next 5 to 10 years.

10.2 ... STILL OPEN QUESTIONS ...

¿ Are solar systems really the best way to save energy ?

Although in many cases together with a solar system the possibility of waste heat recovery and other means of improving energy efficiency has been proposed to the industries, it has not been possible to carry out a systematic and comparative study of these – sometimes – competing technologies. In order to answer this question, integrated studies would be required considering solar thermal, waste heat recovery, cogeneration and possible improvements in the process itself. Within POSHIP such an integral concept has been analysed for industrial drying processes (malting factories).

Where is the future: low or medium temperature ... ?

Pay back times for medium temperature systems (> 80 °C) are nearly twice as high than for good low temperature systems, mainly due to the lower energy output.

On the other hand: the best and cheapest way for energy savings at low temperatures (<60 °C) is (nearly) always to use *waste heat recovery* (from residual water, exhaust air etc.) by heat exchangers or heat pumps (see the example of the Heineken malting factory). Therefore in most cases the really interesting potential for solar process heat is for covering the heat demand after waste heat recovery, at temperatures above 60 °C.

For these applications solar collectors are necessary which should not cost more than present highly-selective standard flat plate collectors, but with improved efficiency.

Solar Thermal Systems and Cogeneration

High efficient industrial cogeneration plants with conversion efficiencies well above the present mean efficiency in the electricity supply save more primary energy than solar at lower cost (see section 6.2.4). Therefore solar systems should be designed as a complementary system to cogeneration plants covering the remaining heat demand.

10.3 ... AND WHERE WE SHOULD GO IN THE FUTURE

Need for Demonstration Plants

The realisation of some large-scale industrial solar demonstration plants with the help of public funding or other incentives could stimulate the development of the local solar industry. This could help to create a virtuous circle: large systems ➔ stimulation of demand ➔ reduction of system (component and installation) cost and improvement of quality (industrial-scale production, qualification of installers, etc).

Without an important public support for demonstration plants it will not be possible to obtain the goal marked in the “Campaign for Take Off” to install two millions of square meters of solar collectors for solar process heat and solar cooling, not even until the year 2010.

Care should be taken in such a strategy for take-off in order to realise “best praxis” – design systems, taking into account the guidelines elaborated within this project, and especially caring for integral solutions: solar thermal – waste heat recovery - cogeneration

Need for Component and System Development

Market introduction of solar thermal systems requires for further component and system development oriented at cost reduction for medium and large sized solar systems producing heat above 60 °C. Some developments have taken place in the last years (e.g. high efficient non-evacuated stationary collectors – CPC, transparent insulation, convection barriers - and roof mountable concentrating collectors) but have not yet reached a sufficient market penetration.

Tasks for further Research

The compatibility – and even possible synergy effects – between industrial (and other large-scale) solar thermal systems and cogeneration could not be investigated in a systematic way within this project. Nevertheless, answering this question is decisive in order to develop concepts that do not only rise the contribution of renewable energies, but that really minimise overall primary energy consumption. Integrating concentrating solar thermal technologies into cogeneration plants on an industrial scale may be one way to reach this goal.

REFERENCES

General References

Brown H. Hewett R., Walker A., Gee R., May K., (1997) *Performance Contracting for Parabolic Trough Solar Thermal Systems* Energy Engineering, 94, No. 6, pp. 33-44

Collares-Pereira, Manuel (1998) *Energias Renováveis, a Opção Inadiável.* Soc. Portuguesa de Energía Solar, Lisboa 1998.

Geyer, Michael A., (1995) *"A prospective Technology Strategy for the Mediterranean Region";*

K. Hennecke, W. Meinecke, D. Krüger, (2000) *Integration of solar energy into industrial process heat and cogeneration systems,* Proc. 9th International Symposium on solar thermal concentrating technologies, Font-Romeu, France, June 2000

LTS - Catalogue 1.4 of Laboratory SPF, Solartechnik Prüfung Forschung, Rapperswil, Switzerland, 2000

Mangold, D. (1996) *Kostenanalyse der Herstellung von Solarkollektoren und mögliche Kostenreduktion durch Massenfertigung.* Sechstes Symposium Thermische Solarenergie. OTTI, Staffelstein, Germany, 1996.

METEONORM. Global meteorological database for solar energy and applied climatology, Meteotest, CH-3012 Bern, Switzerland.

Schweiger, H., Farinha Mendes, J., Benz, N., Hennecke, K., Prieto, G., Cusí, M., Gonçalves, H. (2000) *The Potential of Solar Heat for Industrial Processes*. Proc. EuroSun 2000 Congress, Copenhagen (Denmark).

TRNSYS. Software for Dynamical System Simulation. Solar Energy Laboratory. Madison (Wisconsin), USA.. Version 14.2 (1997) and 15.0 (2000).

Industrial Heat Demand and Potential for Solar Process Heating

Amannsberger K., Schildhauer J., (1991) *Solare Prozeßwärmeerzeugung* Brennstoff Wärme Kraft, Band 43, Nr. 10 S. 476 - 480

Ammansberger, K. (1982) *Wirtschaftlichkeit solarer Prozeßwärme im Temperaturbereich 100 °C bis 300°C. in ISES-BSE Fachtagung: Bewertung der Wirtschaftlichkeit Regenerativer Energien.*

Blank, H. , Joeschke, M., (1985) *Studie zur Strukturanalyse der industriellen und gewerblichen Dampferzeugung im Temperaturbereich bis 300°C unter Berücksichtigung der Möglichkeiten der Substitution fossiler Brennstoffe durch Solarenergie in Portugal* Forschungsstelle für Energiewirtschaft: München.

Brunner, D. und J. Mellitzer, (1998) *Sunrise über Österreichs Betrieben.* Europäische Hochschulschriften. Vol. 2353. 1998, Frankfurt(Main): Peter Lang.

Demeter, c.p. *Market Potential for Solar Thermal Energy Supply Systems in the US Industrial and Commercial Sectors: 1990-2030.* EA Engineering, Science and Technology, Arlington, Virginia.

Direcção-Geral de Energia, (1996) *"Informação Energia n.° 21"* Edited by Direcção-Geral de Energia, 1996.

Garg, H.P., (1987) *Advances in Solar Energy Technology.* Vol. 2. 1987, Dordrecht, Holland: Reidel Publishing Company.

Huerdes J.V. , Lachal B. (1986) *Calor Solar Industrial.* Spanish Edition, Delta Energy Ltd., Rafz, Switzerland, 1986.

ICAEN (unpublished) *Estudi del Potencial d'Aplicació de la Tecnología d´Absorció en els Sectors Industrial i Serveis.* Institut Català d'Energía: Generalitat de Catalunya, Direcció General d´Energía.

ICAEN - A. Mitjá i Sarvisé (Ed.) (1993) *Tecnologíes Avançades en Estalvi i Eficiència Energètica, No. 10: Les Instal.lacions frigorífiques de la Indústria Agroalimentària.* Institut Català d'Energía, Generalitat de Catalunya, Direcció General d´Energía, 1993.

Kreider, J.F (1979) *Medium and High Temperature Solar Processes.* 1979, New York: Academic Press.

Laue H.J. ,Reichert J. (1994) *Potential for Medium and Large Sized Industrial Heat Pumps in Europe.* European Commission, Directorate General for Energy (DGXII), Contract No. XVII/7001/90-8. Final report, 1994.

Lewis, C.W. , (1980) *The Prospects for Solar Energy Use in Industry within the United Kingdom.* Solar Energy, 1980. **24**: p. 47-53.

Melsheimer, M., (1997) *Andere Anwendungen der Solarenergie* http://rotor.fb12tu-berlin.de/michael/vortrag/vortrag.html

Mitjá i Sarvisé, Albert (Ed.) (1995) *Els Costos Energètics en la Indústria Catalana.* Institut Catalá d'Energía, Estudis Monográfics No. 2, Barcelona, 1995.

Monjo J. (1986) *"Aplicación de los colectores concentradores en la industria"* 'Era Solar', 31-32 Mai/August 1988.

NIFES/TECNINVESTE/PROFABRIL/PROTERMIA/STAFF (1986) *Vol 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21.* Editor: Direcção Geral da Energia (Portugal), 1986.

Nitsch, J. und J. Luther, (1990) *Energieversorgung der Zukunft.* 1990, Berlin: Springer-Verlag.

Sequeira J. (1986) *"Lanifícios – Manual Conservação de Energia"* , edited by: Ministério da indústria e Energia, prepared by: NIFES, Consórcio TECNINVEST, PROFABRIL, PROTERMIA, STAFF, 1986.

Spongberg, R.C., (1987) *A US Government Appraisal of the Potential of Solar Energy for Industry.* Solar Energy for Industry. 1987, London: UK-ISES.

Steinborn, P., (1996) *Bedeutung des rationellen Enegieeinsatzes für die Industrie* Schlierseetagung '96 "Wettbewerbsfähig durch effizienten Energieeinsatz"

Szego, G.C. and M.D.Fraser, (1978) *Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat in the United States.* Solar Energy for Industry. 1978, London: UK-ISES.

TNO Bouw (1995) *Potentieelstudie Hoogrendement-zonnecollectoren en Nederland.* Report 94-BBI-R 1368, TNO, Delft, Netherlands, 1995.

Wagner, U., (1996) *Entwicklung und Struktur des industriellen Energieverbrauchs* Schlierseetagung '96 "Wettbewerbsfähig durch effizienten Energieeinsatz"

Wagner, U., (1998) *Energieanalyse und Facility-Management: Perspektiven zur Entwicklung des Energieverbrauchs in Deutschland* Forschungsstelle für Energiewirtschaft: Tagungsband zum Fachseminar am 29/39 April 1998 im Kurzentrum Schliersee

Williams, T. A., Hale, M. J., (1993) *Economic Status and Prospects of Solar Thermal Industrial Heat* ASME/ASES Joint Solar Energy Conference, Washington, D.C.

Winter, C.-J., (1997) *Sonnenenergie nutzen. Technik, Wirtschaft, Umwelt, Klima.* 1997, Berlin: VDE-Verlag GmbH.

Solar Process Heat Plants

Barker G. , Hale M.J. (1996) *Performance Data Network for Solar Process Heat Systems.* In J.H. Davidson, J. Chavez (eds): Solar Engineering 1996. Proc. Int. Solar Energy Conf., 1996, San Antonio, Texas, pp. 179-186.

Benz, N., Gut, M., Beikircher,Th., Ruß, W. (1999) *Solar Process Heat with Non-Concentrating Collectors for Food Industrie* ISES 1999 Solar World Congress, Jerusalem, submitted to Solar Energy

Blanco, J., Sixto, M., Vincent, M. (1999) *Compound Parabolic Concentrator Technology Development to Commercial Solar Detoxification Applications* ISES 1999, Solar World Congress, Jerusalem, Israel

Brunold, S., Frey R., Frei U. (1994) *A comparision of three different collectors for process heat applications* SPF-ITR Solartechnik Prüfung Forschung Solarenergie Prüf- und Forschungsstelle Ingenieurschule ITR

Cañada Ribera, Javier (1987) *"Algunas consideraciones sobre la aplicación de la Energía Solar Fototérmica en procesos industriales"; ;* in the journal 'energía', May/June 1987.

Duff, W.S., Hodgson, D. (1999) *Evacuated Tubular Collector Solar Water Pasteurization System* ISES 1999, Solar World Congress, Jerusalem, Israel

Editorial Alción (1999) *"Solar Termoeléctrica"* November/December 1999 issue of the journal 'energía' (published by "editorial alción")

ENDESA (1994) *"Pre-Feasibility Study on Solar Thermal Trough Power Plants for Spain";* ENDESA, 1994 (FLACHGLAS SOLARTECHNIK GMBH / PILKINGTON).

Hafner, B., Schwarzer, K. (1999) *A System for Solar Process Heat for Decentralized Applications in Developing Countries* ISES 1999, Solar World Congress, Jerusalem, Israel

Hale, M.J., Williams,T., Barker, G. (1993) *Current Performance and Potential Improvements in Solar Thermal Industrial Heat* ASME/ASES Joint Solar Energy Conference, Washington, D.C.

Hewett, R.l, Gee,R., May, K. (1992) *Solar Process Heat Technology in Action: The Process Hot Water System at the California Correctional Institution at Tehachapi* ASME/ASES Joint Solar Energy Conference, Washington, D.C.

Krüger D., Hoffschmidt B., Hennecke K., Pitz-Paal R. Rietbrock P. and Fend Th. (2000) *Results from Parabolic Trough Collectors for Process Heat at the DLR Cologne* Proceedings of the 10th International Symposium on Solar Thermal Concentrating Technologies, 8-10 March, 2000, Sydney, Kreetz, H., Lovegrove, K., Meike, W.(ed.), pp. 113-120

Kumar, M., Vipradas, M. (1999) *Solar Thermal Industrial Process Heating for CO2 Abatement: A Case Study* ISES 1999, Solar World Congress, Jerusalem, Israel

Müller, M., Hennecke, K. (1993/1994) *Solare Farmkraftwerke und Direktverdampfung in Parabolrinnenkollektoren* Forschungsverbund Sonnenenrgie: "Themen 93/94"

Nitsch, J., Klaiß, H., Meinecke , W., Staiß, F. (1993/1994) *Thermische Solarkraftwerke und solare Prozeßwärme im Mittelmeerraum* Forschungsverbund Sonnenenrgie: "Themen 93/94"

Norton, B. (1999) *Solar Process Heat: Distillation, Drying, Agricultural and Industrial Uses* ISES 1999, Solar World Congress, Jerusalem, Israel

Pitz-Paal, Krüger D., Hennecke K. *Prozesswärme mittels Solarthermie* Brennstoff Wärme Kraft, Band 52, Nr. 6, in press

PROCESOL (2000) *Energía Solar Térmica en Procesos Industriales*. SODEAN (Ed.). Brochure edited within the EU-ALTENER Project PROCESOL No. XVII /4.1030/Z/98-205.

Schreitmüller, K. (1987) *Stand und Perspektiven der solaren Prozeßwärmebereitung unter besondrere Berücksichtigung der Aspekte von Entwicklungsländern,* 1987, DFVLR, Institut für technische Thermodynamik.

Schreitmüller, K.R. (1986) *Erfahrungen mit solaren Prozeßwärmeanlagen* Solar Thermische Prozeßwärme, Klaus Scharmer, Gesellschaft für Entwicklungstechnologie mbH: Aldenhoven.

COMPLEMENTS

The following complements to the present report are available either as hard copy or for download from the POSHIP web site (www.aiguasol.com/poship.htm):

- Short informative dossier
- Questionnaire for industries in EXCEL-format.
- Brochure on the results of POSHIP
- Summary sheets of case-studies (national languages)

Where not otherwise mentioned, the documents are available in English, Spanish, Portuguese and Catalan language.

Acknowledgements

The present study has been funded by the European Commission - Directorate General for Energy and Transport. Programme ENERGIE (5th Framework Programme for Energy, Environment and Sustainable Development), Project No. NNE5-1999-0308.

We want to thank all the industries and other entities that have collaborated in the present study.

company	city/province	country
Acabados Tintoretto, S.A.	Barcelona	Spain
Agencia Local de la Energía	Jaén	Spain
Agencia Local de la Energía	Sevilla	Spain
Agustin Barral, S.A.	Barcelona	Spain
Argal, S.A.	Lleida	Spain
Balenzategui, S.A.	Guipúzcoa	Spain
Beirala Lanificios, S.A.	Seia	Portugal
Bodegas Carbomás, S.A.	Barcelona	Spain
Bodegas Osborne, S.A.	Càdiz	Spain
Bodegas Torres	Barcelona	Spain
Calsonic	Barcelona	Spain
Cárdeno, S.A.	Badajoz	Spain
Cárnicas Ciezanas, S.A.	Murcia	Spain
CAVISA	Viladecavalls	Spain
Cervezas DAMM	Barcelona	Spain
Colortex 1967, S.L.	Valencia	Spain
Coop. Ganaderos Valle de los Reproches	Andalucía	Spain
Corporació Alimentària Guisona, S.A.	Lleida	Spain
Crevillente Industrial, S.A.	Alicante	Spain
Cortumes Fabricio, LDA	Seia	Portugal
Danone Portugal, S.A.	Castelo Branco	Portugal
Dallant, S.A	Barcelona	Spain
Denso Barcelona, S.A.	Barcelona	Spain
Doménech Hermanos, S.A.	Valencia	Spain
Escorxador Gremial de Catalunya, S.A.	Girona	Spain
Establiments Viena, S.A.	Sabadell	Spain
Estampados Sanchís, S.A.	Valencia	Spain
Fapulme LDA	Chamusca	Portugal
Fibracolor, S.A.	Barcelona	Spain
Frigoríficos del Nordeste, S.A.	Girona	Spain
Frigoríficos Andaluces de Conservas de Carne, S.A.	Málaga	Spain
Frimancha Industrias Cárnicas, S.A.	Ciudad Real	Spain
Grupo Cruzcampo, S.A.	Valencia	Spain
Guarro Casas, S.A.	Gélida	Spain
Heineken España, S.A.	Sevilla	Spain

company	city/province	country
Intermalta, S.A.	Albacete	Spain
Itexcork, LDA	Vendas Novas	Portugal
Kimberley Clark, S.L.	Salamanca	Spain
La Fageda	La Garrotxa	Spain
La Moravia, S.A.	Lleida	Spain
MB Papeles Especiales	Girona	Spain
Miquel Costas & Miquel	Barcelona	Spain
M. R. A. Nabeiro LDA	Campo Maior	Portugal
Maltibérica, S.A.	Poceirão	Portugal
Monteiro Ribas Ind. S.A.	Alcanena	Portugal
Nanta, S.A.	Reus	Spain
Nissan Motor Ibérica, S.A.	Barcelona	Spain
Panrico, S.A.	Barcelona	Spain
Persan, S.A.	Sevilla	Spain
Pinsos Baucells, S.A.	Tona	Spain
Pinsos Grau, S.A.	Barcelona	Spain
PROMIC, S.A.	Barcelona	Spain
Puleva	Granada	Spain
Refrescos del Atlántico, S.L.	Pontevedra	Spain
S.A. De Orujo Gallego	Orense	Spain
S.C.A. Lavasor	Jaén	Spain
Safyc	Lleida	Spain
Sagra, S.A.	Lleida	Spain
San Miguel	Lleida	Spain
Soc. Coop. "Ntra. Sra. de la Soledad"	Badajoz	Spain
Soc. Coop. Ntra. Sra. del Espino	Ciudad Real	Spain
SODEAN	Sevilla	Spain
Solès-Pagès, S.A.	Girona	Spain
Sotave, S.A.	Manteigas	Portugal
Subproductos Industriales, S.L.	Córdoba	Spain
Textil Navazo, S.A.	Salamanca	Spain
Tintes Orient S.A.	Girona	Spain
Unión de Fabricantes de Gaseosas, S.L.	Valencia	Spain
Univ. de Córdoba (Prof. Antonio López Pinto)	Córdoba	Spain
Viñas del Bierzo, Soc. Coop.	León	Spain