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Use and applications of solar heat in the malting and brewing industry – A review

In this review paper an overview of the studies and projects is given for the malting industry and selected projects for the brewery industry in connection to the use of solar heat. Even during the historical times green malt was dried with the sun and open fire, just since 40 years solar heat is investigated in the industrial malt production of with solar collectors. In order to keep pace with this emerging and fast growing sector for renewable energy applications, it is necessary to get in depth knowledge about the overall potential in the brewing and malting industry and where solar process heat is currently in use. Energy savings of up to 100 % in malt kilning have been achieved in the various studies, leading to a significant reduction in CO_2 emissions with the use of solar collectors. But the breakthrough and acceptance in the industry have not yet been achieved.

Descriptors: solar, heat, kiln, malting, brewing, review

1 Introduction

The heat source which is conventionally used for the kiln is primary energy from natural gas, mineral coal, light or heavy oil which are fired indirectly on-site or converted by a local boiler into steam or hot water.

Sometimes biomass is used as a heating source for the boilers, as in Germany, with wooden chips or in India with rice husks, but the possibility of the use of renewable energy is relatively unexplored even though there is a solid potential in energy saving.

The use of solar energy had been studied only at some projects in a few maltings in South West Europe (subtropical areas) with older technology. In others areas worldwide this type of energy conservation has still not yet been considered [12].

Therefore, in the following paragraphs, this issue will be discussed and the studies and installations will be examined. It can be concluded that the high costs for a malting can only be diminished significantly by reducing the investment and/or the energy costs.

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Already in 1979 – 1980 there had been trials in the U.S.A. [32; 33] but in a comparatively too early stage when the solar thermic development was not advanced yet. This consequently did not lead to any large industrial scale use or any further trials.

The following existing systems of energy saving can be looked at beside the possibilities of the use of solar heat [23]. These systems are not competing systems but complementary.

- Glass tube heat recovery of the humid outgoing air;
- Double deck kilning system;
- Cogeneration of electricity and heat;
- Heat pump;
- Biomass.

Solar collectors are an excellent alternative for heating because of the following characteristics:

- The Subtropical areas are convenient area because of the continuous radiation intensity throughout the year;
- The sourced energy can be directly used for the process;
- It is a clean energy and does not contribute the greenhouse effect;
- Low investment costs;
- Short payback time and attractive amortisation;
- Little additional electrical energy necessary for pump operations;
- Easy to install and to integrate to an existing heating system for a heat pool.

An additional system with a backup of a 100 % conventional heating source should be available in any case.

2 Solar Thermal Energy

Solar radiation – also called solar irradiation – is a general term for the electro-magnetic radiation emitted by the sun. Solar radiation

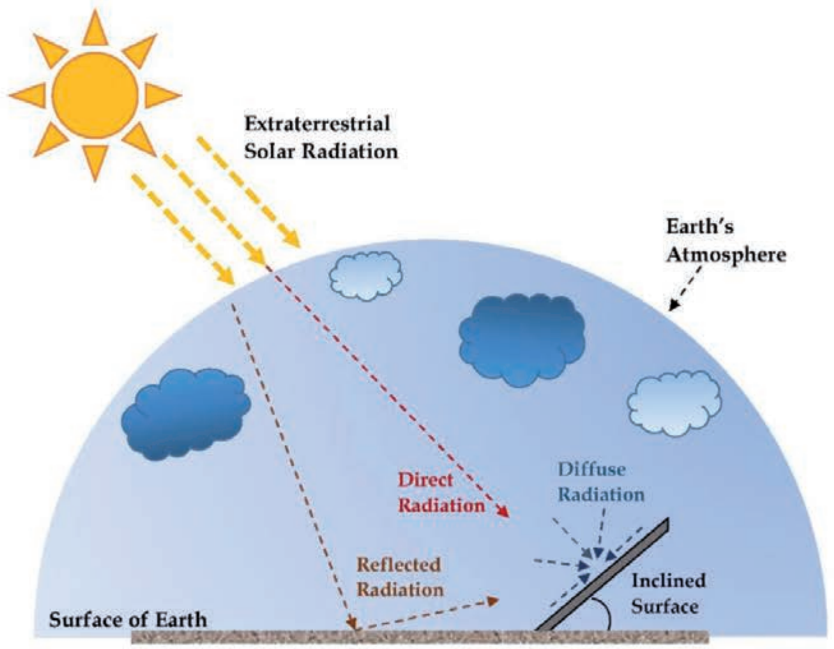

Fig. 1 Diagram of Solar Radiation [16]

can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economical operation of these technologies at a specific location depends on the solar radiation available.

As sunlight passes through the atmosphere, some of it is absorbed, scattered and reflected. This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct solar radiation. Atmospheric conditions can reduce direct radiation by 10 % on clear, dry days and by 100 % during thick, cloudy days. [36].

In figure 1 the different Solar Radiation is shown [16]. Direct Normal Irradiance (DNI) [kWh/m^2] is the amount of solar radiation received per unit area by a surface that is always held perpendicular or normal to the rays that come in a straight line from the direction of the sun at its current position in the sky.

Diffuse Horizontal Irradiance (DHI) [kWh/m^2] is the amount of radiation received per unit area by a surface, not subject to any shade or shadow, which does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

Global Horizontal Irradiance (GHI) [kWh/m^2] is the total amount of shortwave radiation received from above by a surface horizontal to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

Different solar power technologies are able to use different components of the total Irradiance. While solar photovoltaics panels are able to convert both direct irradiance and diffuse irradiance to electricity, concentrated thermal solar power is only able to operate efficiently with direct Irradiance, thus making these systems suitable only in locations with relatively low cloud cover.

3 Solar Collector Types for Process Heat Applications

The malt kilns have operating temperatures for withering between 55 °C to 65 °C and for curing of between 65 °C to 85 °C for Pilsner Malt [23]. The solar collectors either are required to supply the heat with the full capacity for these temperatures or alternatively their generated heat could only be used as a pre-heating stage to support a primary energy source.

3.1 Suitable Solar Energy Systems

The kind of heating medium from the solar energy needed to heat up the kiln should be considered or whether there is possibly no need, as the air heated by the sun can be used right away for kilning.

However, water as the heating medium offers some advantages, as the heat produced by the sun can be temporarily stored and used when it is needed as there are also dead times without sun, as with rain and nightfall.

Water can be easily handled and is readily available in sufficient quantities. Furthermore, water has a good thermal coefficient with 4.1851 kJ·kg-1·K-1 at 20 °C.

3.1.1 Description and Selection of a Solar Collector

Solar collectors are the important and central part of the solar thermal system and are a special kind of heat exchangers that transform solar radiant energy into heat [11].

In the literature concerning solar technology and its potential for use the temperature ranges are categorized in low < 60 °C, medium 60 – 150 °C and medium-high 150 – 250 °C temperature industrial applications. [12].

As there are several collector types in the market, an initial overview is advisable in order to select the appropriate type. For the specific application for an industrial malting process there can be considered the following five types of solar collectors:

Flat Panel (FPC), Vacuum Tube (ETC), Vacuum Tube Collectors (CPC), Parabolic Trough Collectors (PTC) and Linear Fresenel Reflectors (LFR).

Stationary collectors are mainly used for fluid heating for small, middle and large section regions and they are also good in power generation but are less efficient if used for power generation. The concentrating collectors are collectors with high efficiency and high temperature rate. They are more suitable for solar thermal power plants as the collectors increase the intensity of sunlight and, due to this, the heating of fluid is fast and generation of electricity is fast.

In general a differentiation can be made between Stationary

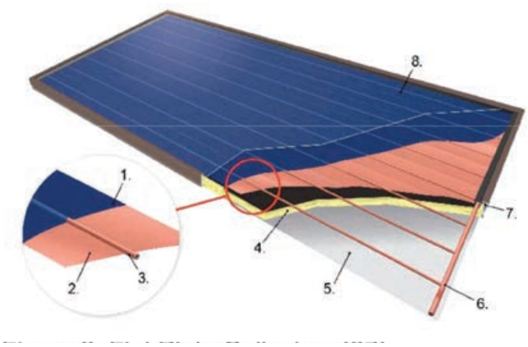

Fig. 2 **Flat Plate Collectors [37]**

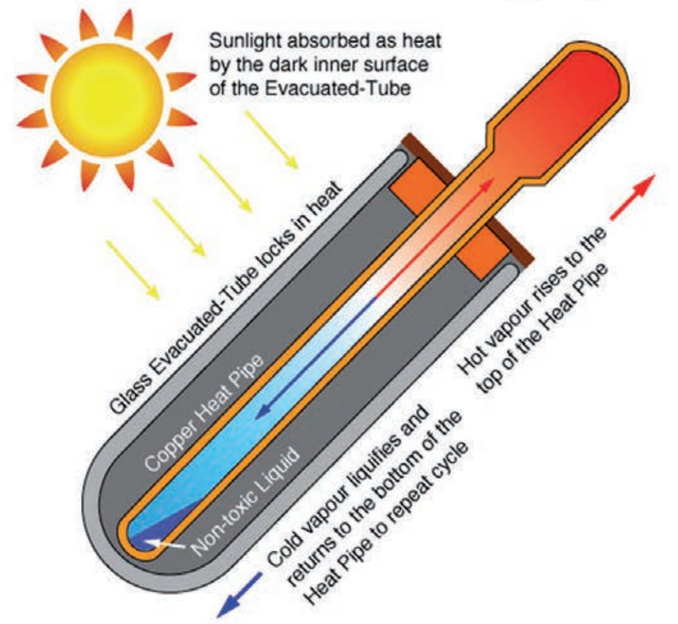

Fig. 3 **Section Tube of Evacuated Tube Solar Collector [35]**

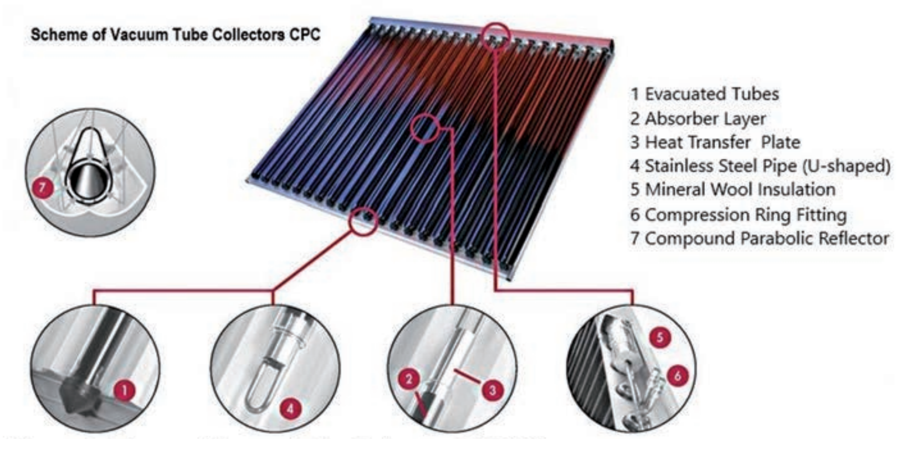

Fig. 4 **Scheme of Vacuum Tube Collectors CPC [19]**

Collectors (non-concentrating) with Flat Plate Collectors (FPC), Evacuated Tube Collectors (ETC), Compound Parabolic Collectors (CPC), Compound Parabolic Vacuum Tube Collectors (CPVTC) and Concentrating Collectors with Parabolic Trough Collectors (PTC), Linear Fresenel Reflectors (LFR). Other collector types are currently not for discussion in the brewing and malting industry.

3.1.2 Flat Plate Collectors (FPC)

The most commonly used collector is the Flat Plate Collector (FPC). It can be used for low temperatures up to 80 °C (for simple FPC) as well for higher temperatures (for advanced FPC) up to 120 °C [37]. Flat-plate collectors have been built in a wide variety of designs and from many different materials. The flat-plate collector consists mainly of the collector box, the absorber, the heat insulation and transparent cover. Solar radiation enters the collector through the transparent cover and reaches the absorber. Here, the absorbed radiation is converted to thermal energy.

The absorber plate is usually made of copper, aluminium or stainless steel, which is connected to flow tubes and the manifolds. The transparent cover is used for reducing convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation it receives by the sun.

3.1.3 Evacuated Tube Collectors (ETC)

The evacuated tube solar thermal system is one of the most popular solar thermal systems in operation. An evacuated solar heat system is the most efficient and a common means of solar thermal energy generation with an efficiency rate of 70 percent. Evacuated (or vacuum) tubes are solar panel built to reduce convective and heat conduction loss (vacuum is a heat insulator). It consists of a heat pipe inside a vacuum sealed tube as shown in figure 3.

Evacuated tube collectors have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate). Protruding from the top of the tube is a metal tip attached to the sealed pipe (condenser).

The system is an efficient and durable system with the vacuum inside the collector tubes having been proven to last for over twenty years. The reflective coating on the inside of the tube will also not degrade unless the vacuum is lost. Because no evaporation or condensation above the phase change temperature is possible, the heat pipe offers inherent protection from freezing and overheating. This self-limiting temperature control is a unique feature of the evacuated heat pipe collector.

3.1.4 Compound Parabolic Collectors (CPC)

Compound Parabolic Collectors (CPC) are collectors with benefits of parabolic trough and flat plate collector. By making use of both principles the CPC can function without continuous tracking and still achieve some concentration. The necessity of moving the concentrator to accommodate the constantly moving solar orientation can be reduced by using a trough with two sections of a parabola facing each other. Compound Parabolic Collectors can accept incoming radiation over a relatively wide range of angles.

3.1.4.1 Compound Parabolic Vacuum Tube Collectors (CPVTC)

Relatively new on the market from various suppliers are the Compound Parabolic Vacuum Tube Collectors (CPVTC). They concentrate the sun energy and are pipe-type collectors which consist of Compound Parabolic Concentrators which are non-tracing concentrated and vacuum hot-tube collectors (see Fig. 4). These collectors also have features of non-imaging and low concentration. On the basis of the edge-radiation principle they can collect incident radiation within the specified scope by ideal concentration ratio to the receiver. The vacuum hot-tube collector converts the solar energy to heat energy and the medium transfers the heat energy to water.

Compared to Evacuated Tube Collectors (ETC) there is no water in the vacuum tubes which can avoid leakage upon tube breakage. Vacuum Tube Collectors are made of evacuated glass tubes with two copper tubes inside. The evacuated solar heat system is the most efficient and a common means of the solar thermal energy generation with an efficiency rate of 70 percent. Evacuated (or vacuum) tubes are built as solar panels to reduce convective and heat conduction loss (vacuum = heat insulator). It consists of two copper heat pipes (supply and return) inside a vacuum sealed tube with the Tichelmann principle.

3.1.6 Concentrating Collectors

Concentrating collectors are the collectors with a sun tracking system or the collectors with more absorbing surface. With concentrating collectors, the solar energy is optically concentrated before being transferred into heat. Concentration can be obtained by reflection or refraction of solar radiation by the use of mirrors or lenses.

3.1.6.1 Parabolic Trough Collectors (PTC)

A Parabolic Trough Collector is curved as a parabola with a polished metal mirror and can effectively produce heat at temperatures between 50 °C and 400 °C for solar thermal electricity generation or process heat applications (see Fig. 5). Parabolic trough technology is the most advanced of the solar thermal technologies because it has been in use the longest, and considerable experience has thusly been gained using them.

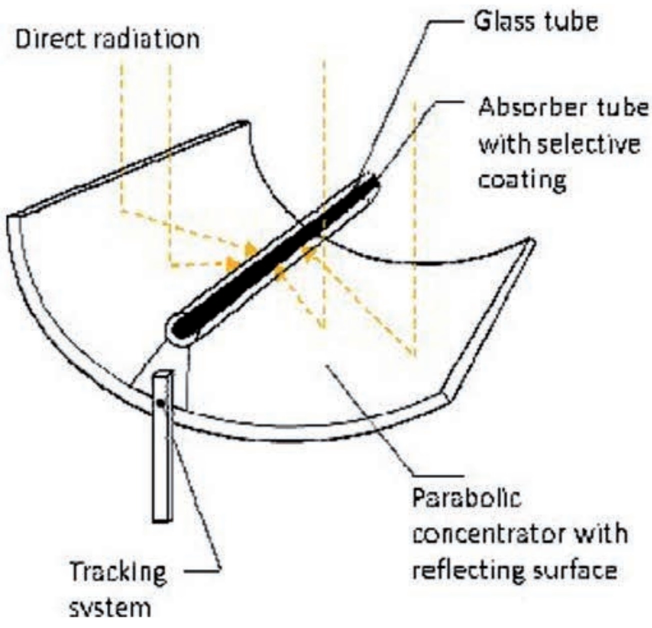

Fig. 5 3D-Scheme of Parabolic Trough Collectors [26]

3.1.6.2 Linear Fresenel Reflectors (LFR)

In Linear Fresenel Reflectors (see Fig. 6) long and thin segments of mirrors focus sunlight onto a fixed absorber located at a common focal point of the reflectors optimized for industrial applications. These mirrors are capable of concentrating the sun energy to approximately 30 times of its normal intensity. It can provide heat at up to 400 °C and operate with pressures of up to 120 bars. The greatest advantage of this collector type is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally they are mounted close to the ground, thus minimizing structural requirements.

One difficulty with the Linear Fresenel Reflector technology is that the avoidance of shading and blocking between adjacent reflectors leads to increased spacing between the reflectors which can be

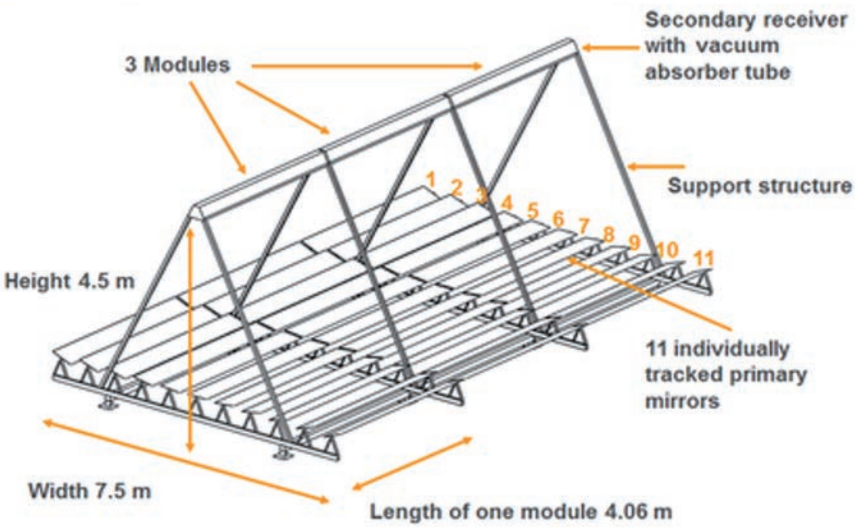

Fig. 6 3D-Schematic of a Fresenel Collector [8]

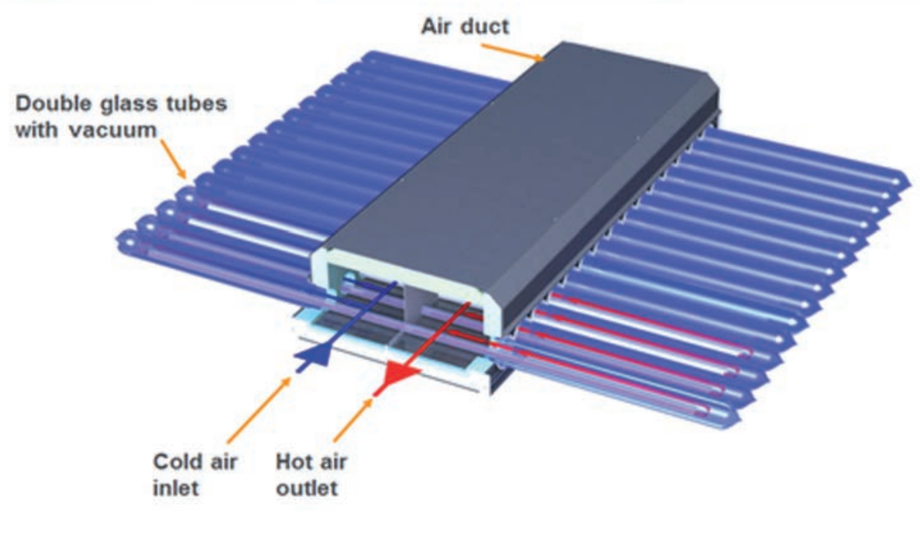

Fig. 7 3D-Schematic of an Air Collector [15]

Table 1 Advantages and Disadvantages of Air Collectors

Advantages	Disadvantages
No further heat exchanger needed for hot air applications	No energy storage is possible and the hot air produced has to be consumed right away or is lost
Inexpensive safety equipment as no pressures have to be treated	In case of rainy weather the conventional back up heating has to be switched on immediately
Easy integration in the existing air ducts	Flexibility with other water based heating systems for pooling like heat pump etc. is not possible.
High efficient vacuum tube	Air has a much lower thermal coefficient than water. Thus the heat transfer is less efficient than with water.

reduced by increasing the height of the absorber towers, but with increasing costs. Additionally, water thermal oil or high-temperature glycol can also generate steam directly. Due to its modular design, the system can be scaled up from a few hundred kW to several MW.

3.1.7 Air Collectors

Instead of using solar water heating systems with the heating medium of water or other liquids solar heat for air heating can also be generated with air collectors. For the malting kiln process this would mean that the kiln air could be generally heated directly via air collectors.

The Air Collectors are highly efficient vacuum tube solar air collectors and optimized for hot air applications. Due to the vacuum tubes and the thermal insulation, heat losses are minimized and high air temperatures can be generated and especially suitable for drying applications [15].

The air collectors have the following advantages and disadvantages (see Table 1) over the solar water heating collectors:

Thus, with the given comparison and evaluation of the advantages and disadvantages it must be stated that the air collectors are less suitable for a malting process than collectors with water even though they are an interesting application.

3.1.8 Selection of the suitable Solar Collector

The above introduction of solar collectors gives a good overview of the applicable technologies. The selection of the suitable solar system should follow the criteria on maximum temperature (> process temperature for the kiln during curing), high thermal efficiency, expenditures, space or size required for the installation, level of maintenance and of course the approximate solar radiation range and the climatic condition.

Many researchers [6] have studied the Flat Plate Collectors (FPC) and the Evacuated Tube Collectors (ETC) for their performance and efficiency and found that the Flat Plate is less efficient than the Evacuated Tube Collector. If, however, these two technologies are used in solar water heating systems, then the Flat Plate provides less costs and better results. In comparison to FPC, Vacuum Tubes result in higher costs, but with good performance and thermal efficiency. The standard Flat Plate Collectors would have a maximum temperature of 80 °C only, but the advanced Flat Plate Collectors can go up to 120 °C. Accordingly, the FPC can be considered in the advanced version with better materials and temperatures of up to 120 °C.

Ultimately for practical application, environmental conditions like

Table 2 Overview of the available solar energy systems for thermal heating

Solar Collector type	Gross heat output at 50°C	Gross heat output above 100°C	Max. Operating temp.	Costs
STATIONARY				
Flat Plate Collectors (FPC)	●	○	80 °C	▼
Evacuated Tube Collectors (ETC)	●	●	250 °C	▲
Vacuum Tube Collector (CPC)	●	●	250 °C	▶
CONCENTRATING				
Parabolic trough collector (PTC)	●	●	400 °C	▲
Fresnel collector (LFR)	●	●	400 °C	▲

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climate, available area for solar collectors, plant conditions and the actual situation will have a tremendous influence on the decision regarding the most suitable system. [6].

The Compound Parabolic Vacuum Tube Collectors described under 3.1.4.1 are possibly quite suitable for the development of the heating system of a solar kiln up to 120 °C. They are able to generate water temperatures to the maximum possible air temperature with the given energy and maximum aeration capacity [29] at reasonable investment costs.

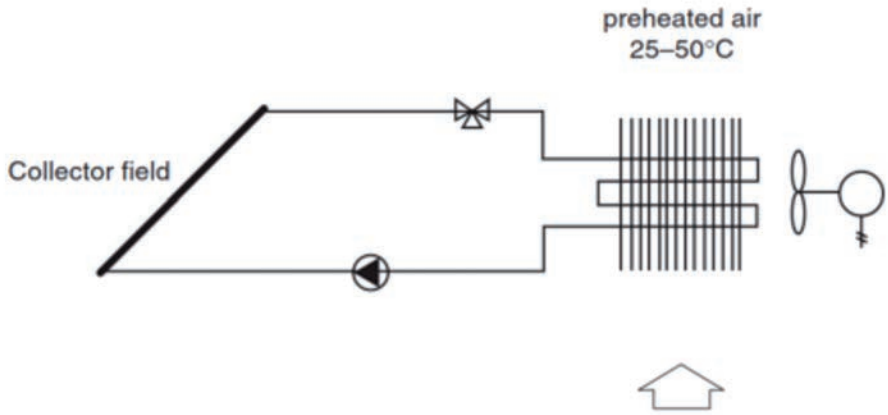


Fig. 8 Layout of the Proposed Solar System for the Malt Factory at Poceirão, Portugal [30]

A simplified comparison in table 2 helps to provide a comparison. As per evaluation of [9] the following solar collectors shall be compared regarding suitable materials, operating temperature, thermal efficiency, costs and long-time experience.

Depending, however, on the environmental conditions like available area for solar collectors, plant conditions and other circumstances the Fresnel collectors (LFR) could also be also an interesting economic option on the basis of water heating.

Considering the need of the required heat of up to 20,000 kW for a batch size of barley as green malt, with heating capacity being quite significant, the chosen solar heat system has to fulfil this requirement and the necessary area and for the generation of energy, the solar heat has to be available.

In conclusion for the selection of the suitable solar collector, it must be stated that all the factors must be taken into consideration for the suitable collector type which can vary from case to case.

4 Methodological Approach

There are a few studies which treat the recent projects in the malting and brewing industry for the use of solar heat and the potential in the industry.

Starting with *Smith C.C.* from the US.A, end of the 1970ies where the idea was discussed academically for the first time [32; 33].

But the use of solar heat for malt kilning was in a comparatively too early stage when the solar thermic development was not advanced yet. This consequently did not lead to any large industrial scale use or any further trials.

Almost 20 years later in 1998 the study of *Benz*, *Gut*, *Ruß* [2] for the pre-heating of the processes in diaries, breweries and one malting in 1998 explored the possibility of the use of solar heat for a malting in South Germany. For the design calculations, solar heat is supplied to the hot water circuit between the heating and power stations and the peak load heating boiler, where the temperature level is 77 °C [3]. It was foreseen to use the solar heat for pre-heating the kiln air. Unfortunately this project was not carried out and followed up.

In year 2000 solar heat for maltings and breweries had been mentioned as potential process in the general study of "The Potential of Solar Heat in Industrial Processes" by *Schweiger* et al. in year 2000 (POSHIP 2000) [29] – supported by the European Commission – and in year 2001 (POSHIP 2001) [30] two maltings in Portugal and Spain (Seville) were looked at and identified the brewing and malting industry as one of the targeted and most potential industries for the use of solar heat.

It is mentioned that if the funding is sufficient there was good possibly to develop these demonstration projects. It was planned to use the solar heat from flat plate collectors (FPC) or compound parabolic collectors (CPC) for pre-heating the kiln air.

It was calculated that at low temperatures up to max. 80 °C the saving potential can be generated to over 20 %. The solar system has been proposed for the pre-heating of air for the malt drying process. An additional hot water to air heat exchanger was installed in series before existing heat exchanger using steam from the conventional heat supply system. A hot water storage wasn't foreseen.

The Set Ups described above for the solar assisted kiln could have been an appropriate start for the malting industry and the data would deem it valuable to continue the development for these studies in particular.

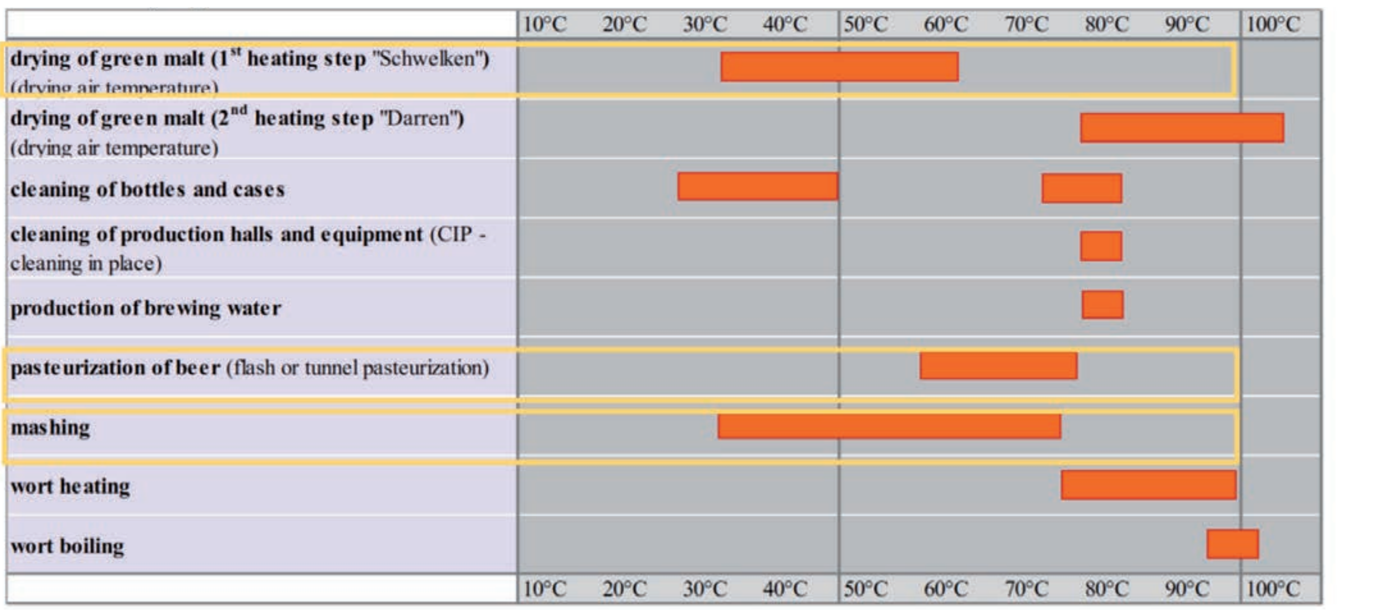
Under the umbrella of the project "FP7 project Solarbrew" [5] a new start was made in 2012 with three projects of a larger brewery group and installations had been planned at Brewery Göß, (Austria), a Brewery Valencia (Spain) and Malting Plant Vialonga (Portugal) for using the solar heat for pre-heating the processes.

Beside the brewery group an Austrian Solar Engineering institute, a larger German brewery engineering company and a Danish solar collector supplier formed a project consortium.

Their studies can be found from *Mauthner*, *Hubmann*, *Brunner*, *Fink* [20] and *Michel* and *Scheller* [21] and [25]. The "FP7 project Solarbrew" was also financially supported by the European Commission.

The studies treated the pre-heating of green malt withering in the

Table 3 Thermal processes and associated process temperatures in malting plants and breweries [20]



malting and heating the mashing process and the pasteurisers. The table 3 about the thermal process in maltings and breweries shows a good overview of the used processes and the incorporated temperatures [25].

For the malting project at Vialonga the collector panels are engineered by a Danish supplier [1] with the simple Flat Plate Collector type (FPC) which is not suitable for higher temperatures above 80 °C.

The schematic diagram shown in figure 9 explains the solar assisted pre-heating stage in front of the main steam operated heating coil and after a CHP heating coil.

It also needs to be considered that the heating, respectively preheating with a total of 3 heating stages (step II, step III, step IV), also creates a high air pressure loss which leads to higher electrical consumption.

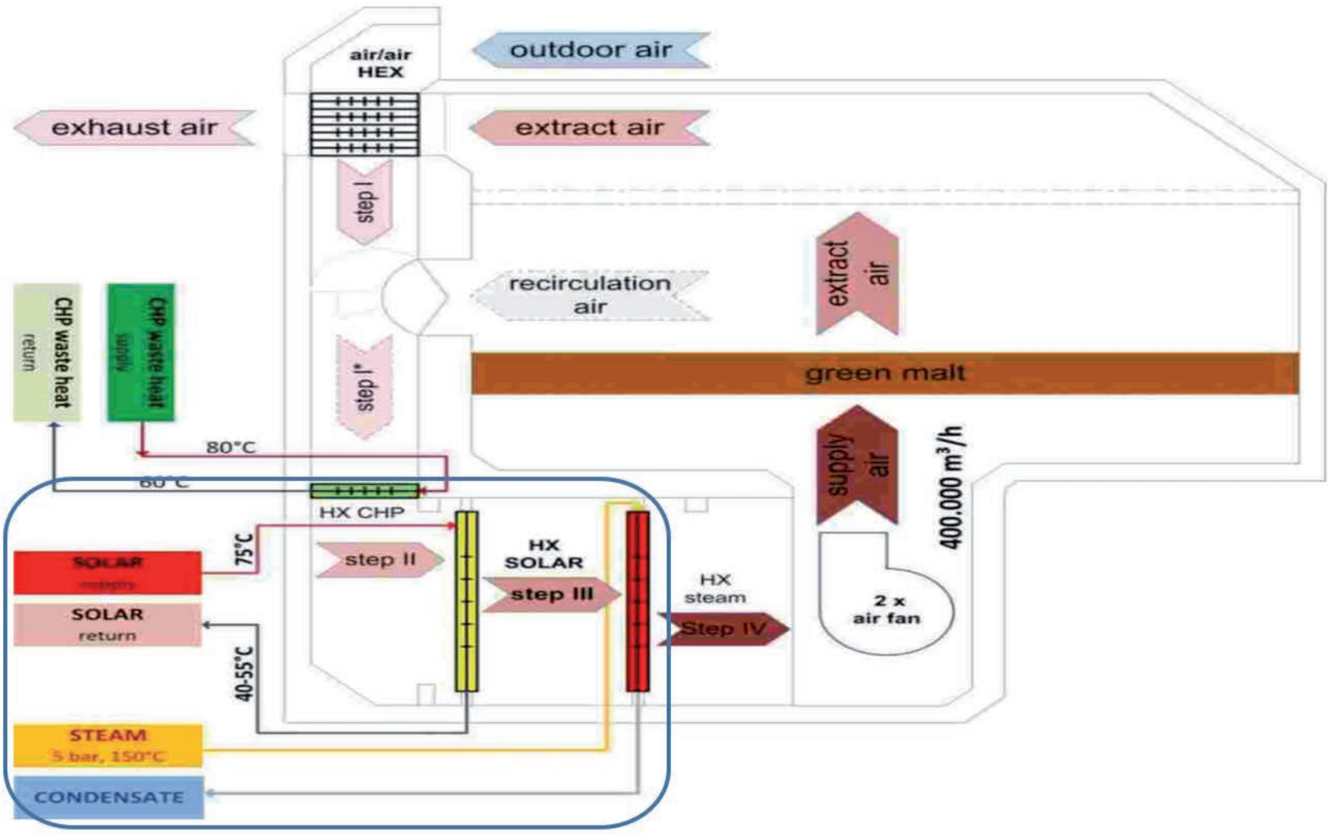


Fig. 9 Schematic diagram of the cascade energy supply for a solar pre-heated kiln at low temperatures [20]

The collector panels are used from a Danish supplier [1] with the Flat Plate Collector type (FPC) which is not suitable for higher temperatures above 80 °C.

The schematic diagram shown in figure 9 explains the solar assisted pre-heating stage in front of the main steam operated heating coil and after a CHP heating coil.

It also needs to be considered that the heating, respectively pre-heating with a total of 3 heating stages, also creates a high air pressure loss which leads to higher electrical consumption.

So far, only the project at Gößß (Austria) hat been realised. The other two were stopped during the project phase with a design freeze.

Another two studies from *Schmitt* and *Lauterbach* [17; 18; 27; 28] from the University of Kassel (Germany) which are part of the project SOPREN (Solare Prozesswärme und Energieeffizienz) and supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU - Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) treat a branch concept for solar thermal process heat [27].

Among other sectors two brewery projects had been scientifically monitored for solar heat feasibility: Hofmühl Brauerei at Eichstädt (Bavaria, Germany) with a system utilization ratio of about 20 % [37].

Lauterbach [18] monitored the Hütt Brauerei (Hessen, Germany). By incorporating the measured ambient temperature, irradiance, process load profiles and system operation data in a TRNSYS simulation, the authors found a very good correlation between the measured and simulated performance of the flat-plate SPH system applied.

Schmitt published a guideline for planners for brewery planners as well [28]. Based on this work, generalized technical solar heat integration concepts were developed. Lauterbach developed a preliminary design methodology for systems of solar thermal process heat [18].

The award winning brewery for Energy Efficiency Karmeliten Brauerei at Straubing (Bavaria, Germany) aims to obtain the total primary energy of the Karmeliten Brauerei almost completely from renewable energy sources [7].

For this purpose, various actions and measures shall be implemented for example, a biogas-driven micro gas turbine shall be installed for the electricity and heat generation. In addition, it is planned to use the solar-generated process heat for process steps with high heating temperatures.

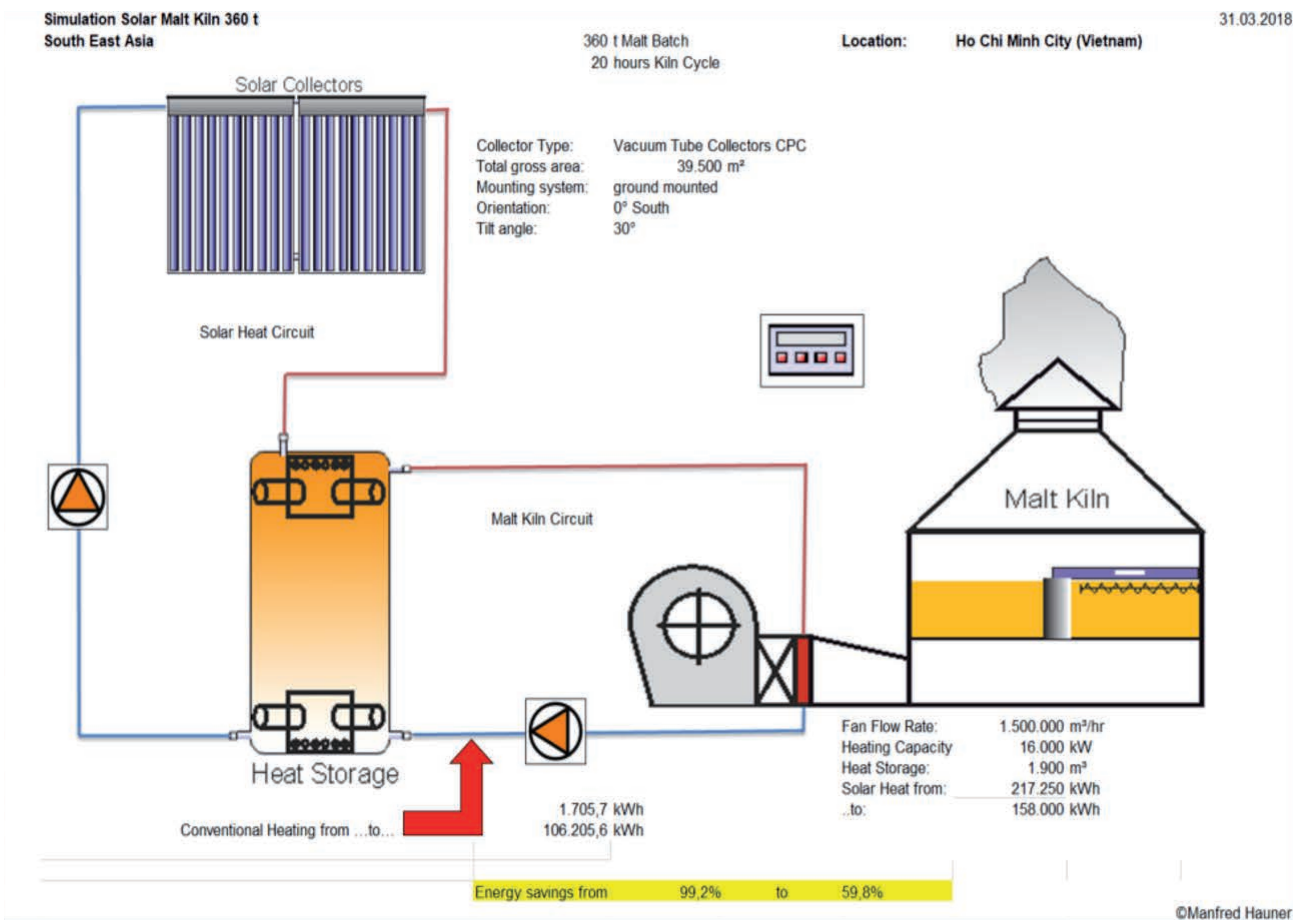


Fig. 10 Output Display of a simulation of a 360 t industrial solar malt kiln and conventional supplementary heating for the rainy season [13]

The solar heat is foreseen for process steps with high heating temperatures. This is where Linear Fresnel Reflectors (LFR) [14] come in, with which significantly higher temperatures can be reached than with conventional solar collectors (see 3.1.8). With an absorption cooling system, the process heat obtained from solar thermal heat shall be converted into process cooling.

In another area of the world, in South Vietnam which is part of the subtropical belt the latest investigation had been processed with a pilot solar malt kiln by *Hauner*, *Eichhorn* et al. [13].

A solar assisted malt kiln with the maximum usage of solar energy has been investigated and the investment costs for a large scale installation were validated. Trials have been executed successfully and the first solar malt, kilned with thermal energy solely from the sun were produced in small scale. The savings compared with the usage of fossil energy was conducted in a computer based model calculation. These savings can be generated between 99.2 % and 59.8 % for the representational case for an industrial batch of 360 tonnes of barley in Vietnam.

The CO_2 footprint savings were calculated as annual average of 137.63 kg CO_2 per tonne of finished malt for savings of natural gas and 150.14 kg CO_2 for savings of fuel oil. The representational case calculation with the investment in solar heat in South Vietnam gives an amortisation period of 4.6 years for natural gas savings and 6.7 years for fuel oil savings.

5 Current Solar Heat Installations in Malting and selected Installations in Breweries

Since the 1980's, several solar thermal systems for industrial applications have been developed and are currently operating. [30]. A few are in the brewery and malting business.

An overview had been composed (see Table 4) with the current solar installation in the malting and brewery business. This overview is not exhaustive but gives a good impression of which projects had been realised and are operating and which projects could be realised. Furthermore the potential of using solar heat will be visible.

In figure 11 it is shown that out of 28 projects in the beverage industry worldwide 12 projects are from breweries/maltings. The others are from other beverage manufacturer. The information can be found at the platform http://www.ship-plants.info whereas SHIP means Solar Heat Industrial Process.

Starting with various applications like with direct heating of the kiln air with air heaters, pre-heating of the kiln air end of 1970ies/early 1980ies, for breweries pre-heating the process water circuits or other processes, followed by using more advanced technology like Flat Plate Collectors (FPC) to Vacuum tube Collectors CPC to Fresnel and possibly to large scale Parabolic Trough Collectors (PTC) the industry took some development in using solar energy.

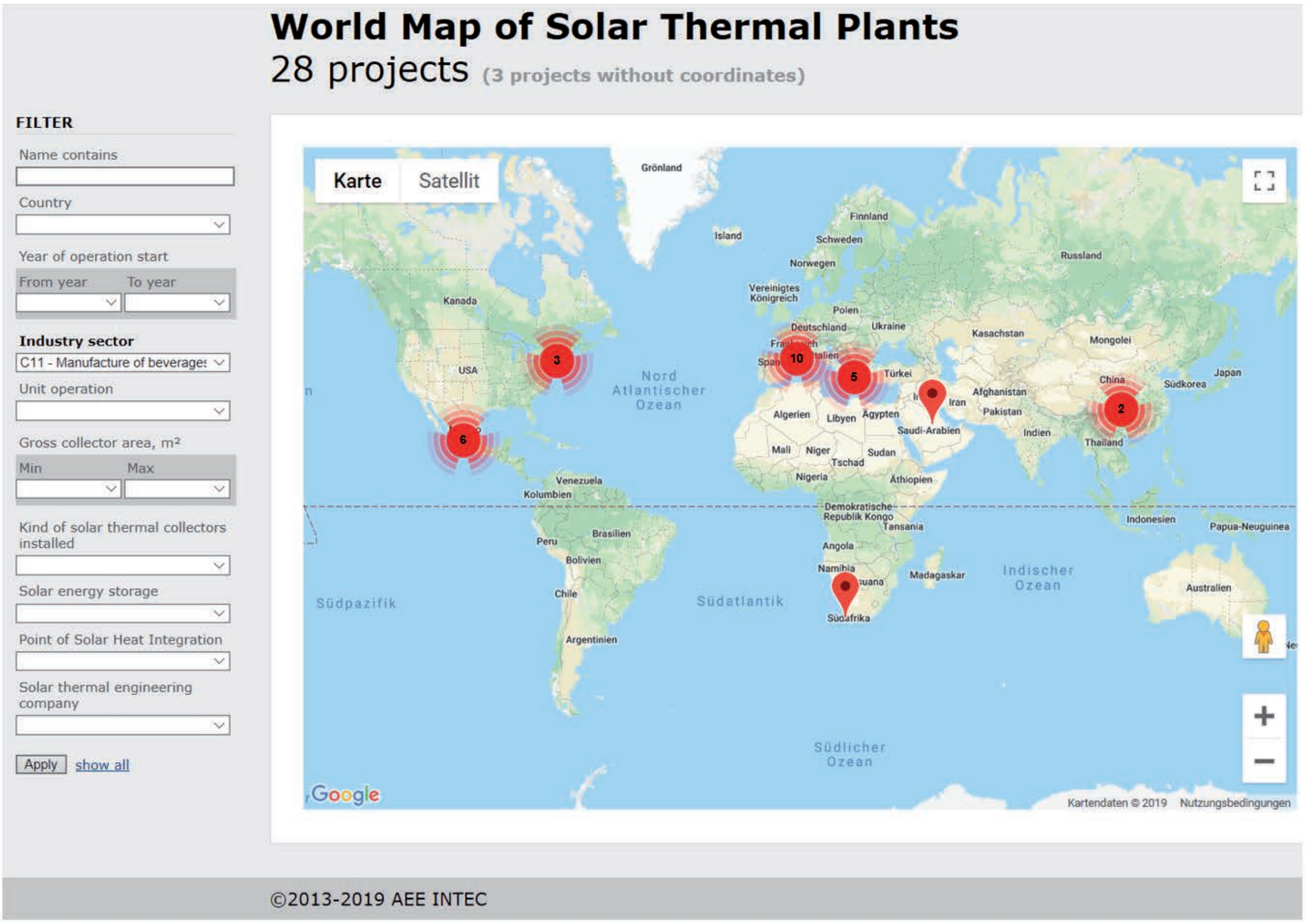


Fig. 11 **World Map of SHIP Plants (Solar Heat Industrial Process) in the beverage industry [31]**

Table 4 Order of the existing installations of Solar Heat in Maltings/Breweries

#	Year	Project name	Owner	Location	Operation	Collector Type	Tempera-ture	in operation
1	1979/80	Solar energy for kilning malt	Smith C.C.	Fort Collins, Colorado, U.S.A.	Pre-Heating for a pilot solar malt kiln	Air Collectors	50 C° to 65 °C	n/a, only pilot
2	1980	Air collectors	Neumarkter Lamsbräu	Neumarkt i.d.Opf., Germany	Pre-Heating the air for malt kiln	Air Collectors	60°C	out of service
3	1985	Vialonga Brewery	Sociedade Central de cervejas	Vialonga, Portugal	Pre-heating of water for the brewery	Non-Evacuated CPC	65 °C	out of service
4	1998/99	Solar Process Heat in Breweries and Diaries	Malzfabrik Bamberg	Bamberg, Germany	Pre-heating of the hot water circuit for the kiln			n/a
5	2000?	San Antonio	San Antonio	San Antonio, Texas, U.S.A.	Pre-heating of kiln air	PTC	?	?
6	2000	Renewal of air collectors	Neumarkter Lamsbräu	Neumarkt i.d.Opf., Germany	Pre-Heating the air for malt kiln	Air Collectors	60 °C	in operation
7	2013	SolarBrew	Heineken-BrauUnion	Göß, Austria	Heating of Mashing in the Brewhouse	FPC	80 °C	in operation
8	2015	SolarBrew	Heineken	Valencia, Spain	Pre-heating of Pasteur hot water circuit	FPC	80 °C	n/a
9	2015	SolarBrew	Heineken	Vialonga, Portugal	Pre-heating of the air with a hot water circuit for the kiln	FPC	80 °C	n/a
10	2010	Brauerei Hütt	Brauerei Hütt	Baunatal, Germany	Pre-heating of the water circuits	FPC	80 °C	in operation
11	2011	Solar Heat for the brewing process	Hofmühl Brewery Solarbayer	Eichstätt, Germany	Pre-heating the water circuits for brewing/domestic water & bottle washer	Vacuum tube Collectors CPC	110 °C	in operation
12	2018/19	Solar Malt Kiln	Hauner; Eichhorn	Ho Chi Minh City, Vietnam	Up to 100% solar heat for a pilot solar malt kiln	Vacuum tube Collectors CPC	110 °C	n/a, only pilot
13	2019	Fresnel Collectors	Karmeliten Brewery	Straubing, Germany	Pre-heating of all hot water circuits of the brewery	LFR	180 °C	in operation
14	2019	Solar Energy Supply to a Malting	Boortmalt -NewHeat-Kyotherm	Issoudun, France	Pre-heating of the air with a hot water circuit for the kiln	Concentrated	< 70 °C	under construction

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The pilot solar kiln plant from C.C.Smith in 1979 and the results in 1981 [33] give a good starting point and the Neumarkter Lammsbräu was one of the pioneers in Germany for using solar technology in the malting business who started also with organic beer (Bio-Bier) as well.

About the malt production in San Antonio (Texas) [30] couldn't gathered sufficient information, which is using Parabolic Trough Collectors. But considering there area and the possibilities there the use of this technology make very much sense.

The projects of Brauerei Hütt, Brauerei Hofmühl and Karmetlitten Brauerei are not only demonstration projects for breweries, they are also a good step for the malting industry that it can be proved that the use of solar heat is feasible in use.

The studies from South East Asia in Vietnam [13] give a strengthening of the view that the use of solar heat for up to 100 % of the necessary energy is possible.

Another bright spot is the new project of a large French malting [4] to use the solar heat produced by a contracted supplier and investor by reducing the CO_2 foot print by 2,200 tonnes per year.

6 Conclusions

Since at least year 2000 maltsters and brewers have the opportunity to equip their heating with solar heat equipment. The support from engineers, the governments and European Union is there. The expertise including project execution and amortisation calculation were done by the experts.

But only a few projects had been realised by the maltsters and brewers pioneers so far, and in Europe only pre-heating of the kiln air in the withering state and pre-heating of water circuits for the brewing process have been executed.

There is a good potential in the countries closer to or in the subtropical areas where the full supply can be used up to 100 % for the process. This would reduce the use of fossil resources very much and make a contribution against global warming.

But with the pioneering spirit and the expertise of the experts the market of the Solar Heat Industrial Processes (SHIP) including the brewery and malting industry will be gaining a foothold in the future. There is only required a long-term commitment to the environment.

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