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Model calculation of a solar assisted system for a malt kiln

The kilning of green malt requires large amounts of thermal energy which is nowadays mainly based on fossil fuels. In a standard state-of-the-art malting plant in South-East Asia, 800 kWh is needed for one tonne of malt. At such a high level of energy usage, it is obvious that more sustainable energy sources must be investigated. The purpose of these studies is, therefore, to investigate a solar assisted malt kiln with the maximum usage of solar energy and to validate its performance by a model calculation. With a pilot plant in Vietnam, trials have been executed successfully and the first solar malt, kilned with thermal energy solely from the sun were produced. Furthermore, trials were carried out with conventional and solar heat for maximum energy conservation. The finished malt from all trials was then tested in the industrial malt laboratory and qualified as brewing malt. Starting from the design of the malt kiln, the energy demand and air flow, the dimensioning of the solar circuit for the solar malt kiln, the savings compared with the usage of fossil energy was conducted in a computer based model calculation. The savings from solar heat investigated as the representational case for 360 tonnes of barley in Vietnam can be generated at between 99.2 % and 59.8 %. Thus a larger impact can be identified with the rainy season in South-East Asia. Due to changing the solar contribution and heat demand over the seasons, for the industrial scale it will be always essential to have 100 % backing with a conventional heating. 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 results generated from the model calculation in these studies demonstrate huge potential for the malting industry.

Descriptors: model calculation simulation solar malt kiln

1 Introduction

As maltings are rarely based in Subtropical Areas like South-East Asia the usage of solar energy has never been considered in practice and subsequently never proved economically. With the given climate conditions, the economical operation and a suitable system has been investigated after the development of a completely assisted solar system for a malt kiln heating.

1.1 The Malt Business worldwide and in South-East Asia

The worldwide annual malt production amounts in 2018 thus far to approximately 23 million tonnes of malt [12] which is mainly found in the brewery industry for 2 billion hectolitres of beer, for whisky production and as food ingredients.

In South-East Asia only two maltings can be found in Vietnam with a total capacity of 140,000 tonnes per year. The malt demand for an approximated 100 million hectolitre beer production in South-East Asia is covered by imports of approximately 1.5 million tonnes of malt from Australia, Europe, Canada and China [20].

1.2 Resources for Malt Production

For the three process stages of the malt production there are different types of resources and energy necessary:

- Water
- Electrical energy for drives and motors, i.e. aeration
- Cooling, generated from electricity
- Heating, generated from primary energy

The energy requirement for kilning of 100,000 tonnes of malt is 80 GWh heating capacity and 9 GWh electricity in one year. The requirement for the steeping and the germination process comes on top with an additional 65 kWh per tonne of malt whereas the main portion is the refrigeration plant [24].

For a 360 t batch which is equivalent to a 100,000 t annual malt production at 340 days with an output of 292 t of finished malt

https://doi.org/10.23763/BrSc18-15hauner

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on the demand of kiln air is up to 1,700,000 m^3/h that need to be heated [24].

1.2.1 Energy Demand for Kilning

It has to be highlighted that the energy consumption of the kiln process is considerable. For a 24 h kiln the heating capacity is approximately 20,000 kW for a batch size of 360 tonnes of barley as green malt and the aeration capacity is 1,700,000 m^3/hr at 1,850 Pa total air pressure [24].

This capacity mentioned with a daily turnover of 360 t as barley in the form of green malt yields approximately 292 tonnes of finished malt. This gives an annual capacity of approximately 100,000 tonnes of malt production. This is equivalent to a beer production of approximately 6 million hectolitres, provided the beer is produced with 100 % pure malt without adjuncts.

In a hot climate country the production of 1 tonne of malt requires approximately 800 kWh as heat and approximately 90 kWh as electrical energy just for the kilning. Due to the higher absolute air humidity because of the higher ambient temperature the air volume for the kilning process as well the heat demand is higher compared to European countries.

1.2.2 Conventional heat sources

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 at place or converted by a local boiler into steam or hot water.

1.2.3 Alternative heat sources

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.

Solar energy is used only in a few maltings in South West Europe (subtropical areas) with older technology. In other areas worldwide this type of energy conservation has still not yet been considered [14].

Therefore, in the following paragraphs, this issue will be discussed and a few practical examples will also be examined.

1.3 Purpose of the Studies for a Solar Assisted System Model for a Malt Kiln

Even maltings are to date rarely based in subtropical areas, the given climate conditions make the economical operation with solar energy interesting.

The suitable system shall be investigated in these studies after the completed development of a solar system for a malt kiln heating.

Through the development of a calculation model for malt drying, the basis for the feasibility for greater use of solar energy shall be investigated and validated.

In order to do so, the first solely kilned malt powered by the sun will then be produced with the maximum use of solar energy and consequently the accuracy shall be confirmed though model calculation.

By applying the model to a real case pilot malt kiln, the system model can offer the malting industry a better understanding and help the industry reduce the energy costs.

With this investigation and the development an industrial set up for a malt kiln with solar thermal heating can be realised and operated under economically sound conditions.

1.4 Investigation of the Usage of Solar Energy in Maltings

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. Already in 1979 – 1980 there had been trials in the U.S.A. [40 and 41] 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.

1.4.1 Energy Saving Possibilities with Solar

In order to discuss the possibilities of energy saving and use of renewable energies the following existing systems beside solar collectors can be looked at:

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

These existing systems are not competing systems but complementary. The malting investor can decide on the suitable system for their specific application.

Solar collectors have been chosen for the South-East Asia Region because of the following reasons:

- Convenient region 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
- Little additional electrical energy necessary
- 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

1.4.2 Water as heating medium

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.

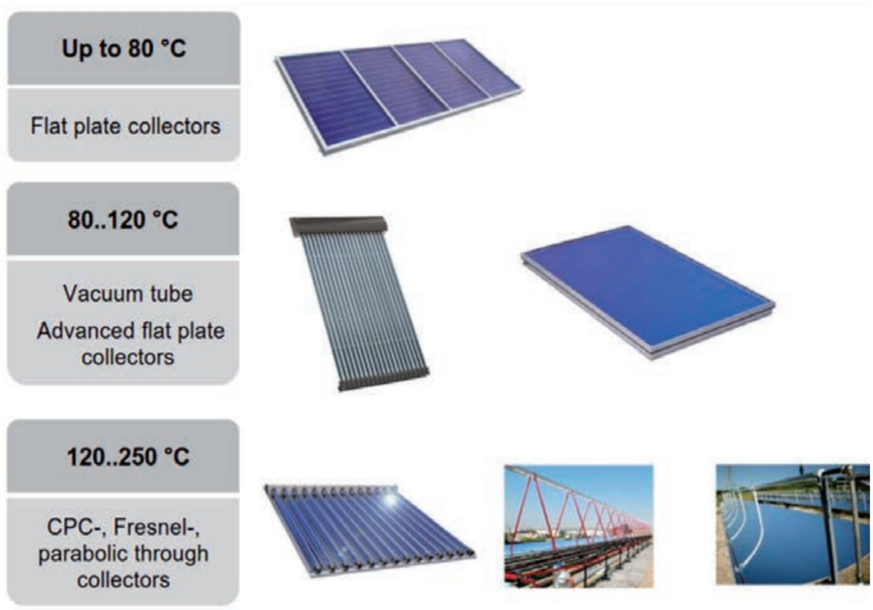

Fig. 1 Overview Collectors for Process Heat Applications with temperature ranges [23]

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 $kJ \cdot kg^{-1} \cdot K^{-1}$ at 20 °C. In South-East Asia, the problem of frozen water pipes is non-existent.

1.4.3 Current Developments in Solar Maltings.

In another area of the world, for example, one of the global brewery groups set up a research program in 2012 for a solar-based brewery in Austria and a basic solar-based malting kiln as implementation of a malting in Portugal [39] for pre-heating. The basis figures and results are a good background, but the process of implementation is different to those done in these studies.

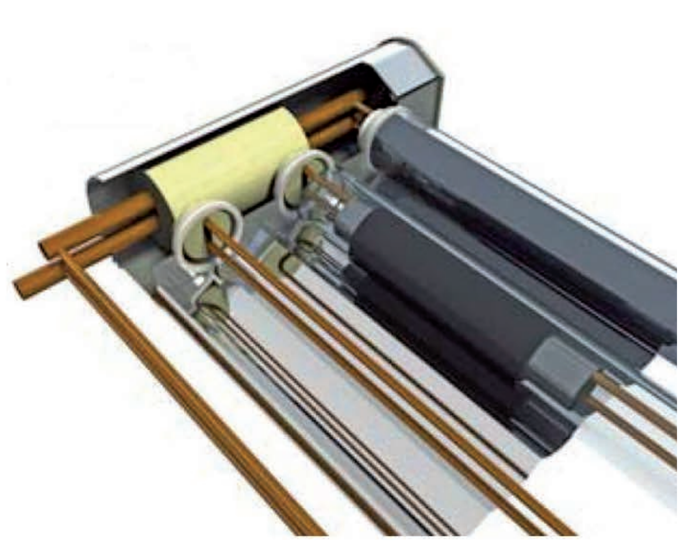

Fig. 2 Vacuum Solar Panels – 3D view [42]

Furthermore another studies [25] are also engaged with the financial support of the European Commission under 'FP7 project Solarbrew' for the same project of the larger global brewery group [6].

The focus therewith is more concentrated on the brewery process and at lower temperatures below 80 °C for the pre-heating stages with a further preheating phase from a cogeneration plant (Combined Heat and Power, CHP) of the withering process and utility water for bottle filling.

The collector panels are used with the Flat Plate Collector type (FPC) which is not suitable for higher temperatures above 80 °C.

Furthermore two older malting projects in Spain (Sevilla) and Portugal (Poceirão) have already started operation in 2007 [14] at low temperatures up to max. 80 °C and the saving potential has been generated to over 20 %.

The solar system has also 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.

The set ups described above for the solar assisted kiln is a very good start for the malting industry and the data would deem it valuable to continue the development for these studies in particular.

Just recently some more maltsters in subtropical areas are starting to think about the possibility of using solar energy as an alternative source.

2 Materials and methods

2.1 Suitable Solar Energy Systems

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. The solar collectors treated in this paper were required to supply the heat with the full capacity for these temperatures or alternatively their generated heat could only be used as a preheating stage to support a primary energy source as the system described above.

2.1.1 Description and Selection of a Solar Collector

A solar collector is a special kind of heat exchanger that transforms solar radiant energy into heat [13].

As there are several collector types in the market, an initial overview was advisable in order to select the appropriate type.

In general a differentiation can be made between *Stationary*

Collectors (non-concentrating) with Flat Plate Collectors (FPC), Evacuated Tube Collectors (ETC), Vacuum Tube Collectors CPC (Compound Parabolic Concentrator) and *Concentrating Collectors* with Parabolic Trough Collectors (PTC), Linear Fresenel Reflectors (LFR), Parabolic Dish Reflectors (PDR) and Heliostatic Field Collectors (HFC).

For the specific application for an industrial malting process in South-East Asia for these studies there can be considered the following five types of solar collectors:

Vacuum Tube (ETC), Flat Panel (FPC), 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 have less efficiency.

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.

Above these, selection criteria of maximum temperature, high thermal efficiency, sheet metal structural formula, maintenance-free, high cost performance, a comparison of all the selected types should be executed.

At the end in the practical application, environmental conditions like climate, available area for solar collectors, plant conditions and the actual situation, the decision will also have tremendous influence [6].

The Vacuum Tube Collectors CPC are possibly quite suitable for the development of the heating system of the solar kiln.

They are able to generate water temperatures to the maximum possible air temperature with the given energy and maximum aeration capacity [42] at reasonable investment costs.

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 360 t of barley, 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 figure 1 the comparison of the collectors with different temperature ranges can be found.

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.

The selected 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 is a heat insulator). It consists of two copper heat pipes (supply and return) inside a vacuum sealed tube with the Tichelmann principle as shown in figure 2.

Collectors using non-imaging concentrators are also called CPC (Compound Parabolic Concentrator) type collectors (see Fig. 3) since a combination of parabolas was the first configuration discovered to operate within the above-mentioned limit [50]. Mirrors are produced with the proper shape and reflect the radiation onto the absorber.

The Compound Parabolic Vacuum Tube Collectors are concentrating and pipe type collectors which consist of Compound Parabolic Concentrators which are non-tracing concentrated and vacuum hot-tube collectors. 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.

The concentration of solar radiation can be obtained by so-called non-imaging optics, where maximum concentration of radiation

Fig. 3 Scheme of Vacuum Tube Collectors CPC [43]

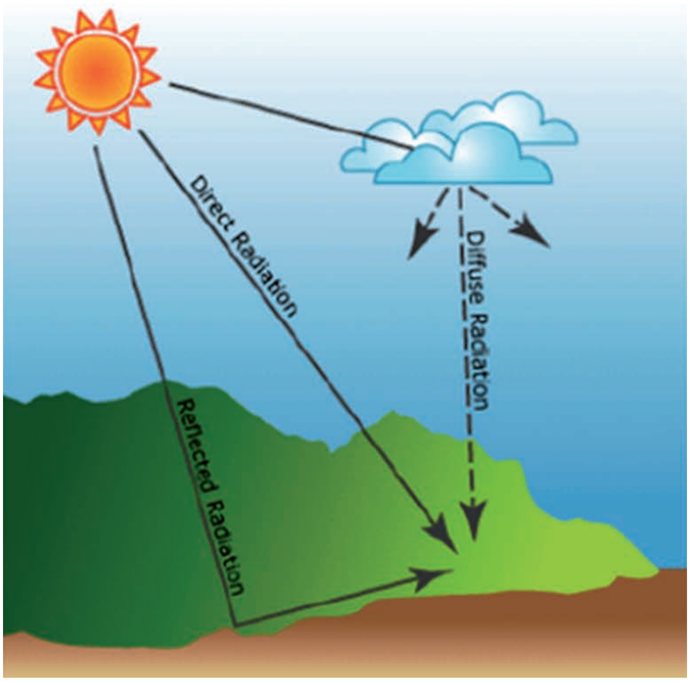

Fig. 4 Diagram of Solar Radiation [47]

within the acceptance angle allowed for a two dimensional geometry is given [50] by:

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

where θ is half the acceptance angle and Cmax the maximum concentration of radiation.

2.2 Solar Radiation

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. [46].

In figure 4 the different Solar Radiation is shown [47].

Direct Normal Irradiance (DNI) [kWh/m²] 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/m²] is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that 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/m²] 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):

Global Horizontal (GHI) =

Direct Normal (DNI) X cos(θ) + Diffuse Horizontal (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 solar power (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.

2.3 Description of the Solar Assisted Model for the Malt Drying

The simulation assisted model was developed and introduced with all the necessary parameters and results from the malt process, the local climate, the energy demand, the solar data and the dimensioning of percentage of the solar supply and the energy savings (see Fig. 5).

The Solar Assisted System Model for a Malt Kiln is developed in a way that first the energy demand of the conventional kiln process is calculated via an Excel Calculation Sheet.

After the determination of the energy consumption the parameters of the solar heating plant are to be calculated. The model calculation shall also allow different types of solar collectors to be investigated.

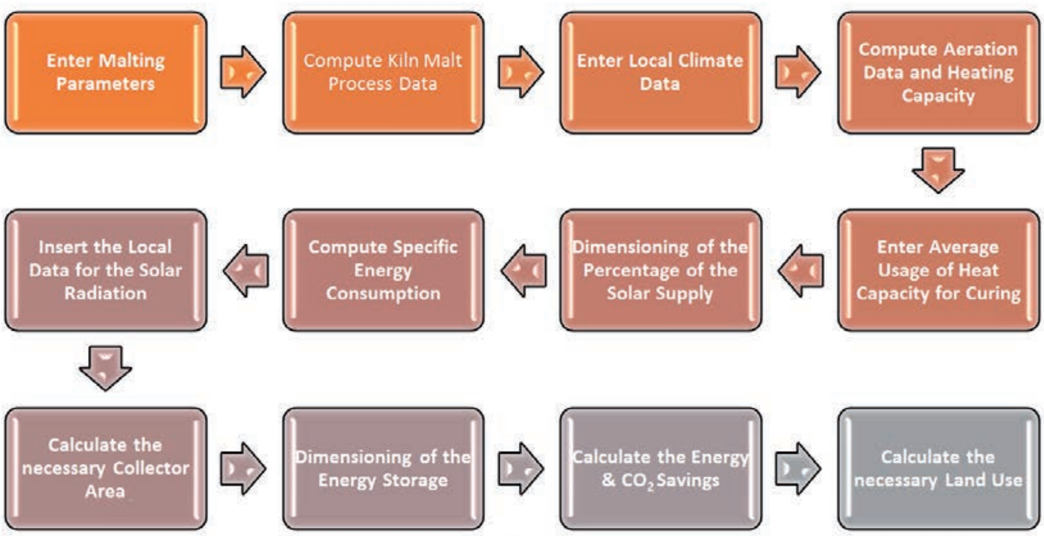

Fig. 5 Flow Chart of Solar Assisted Model for a Malt Kiln

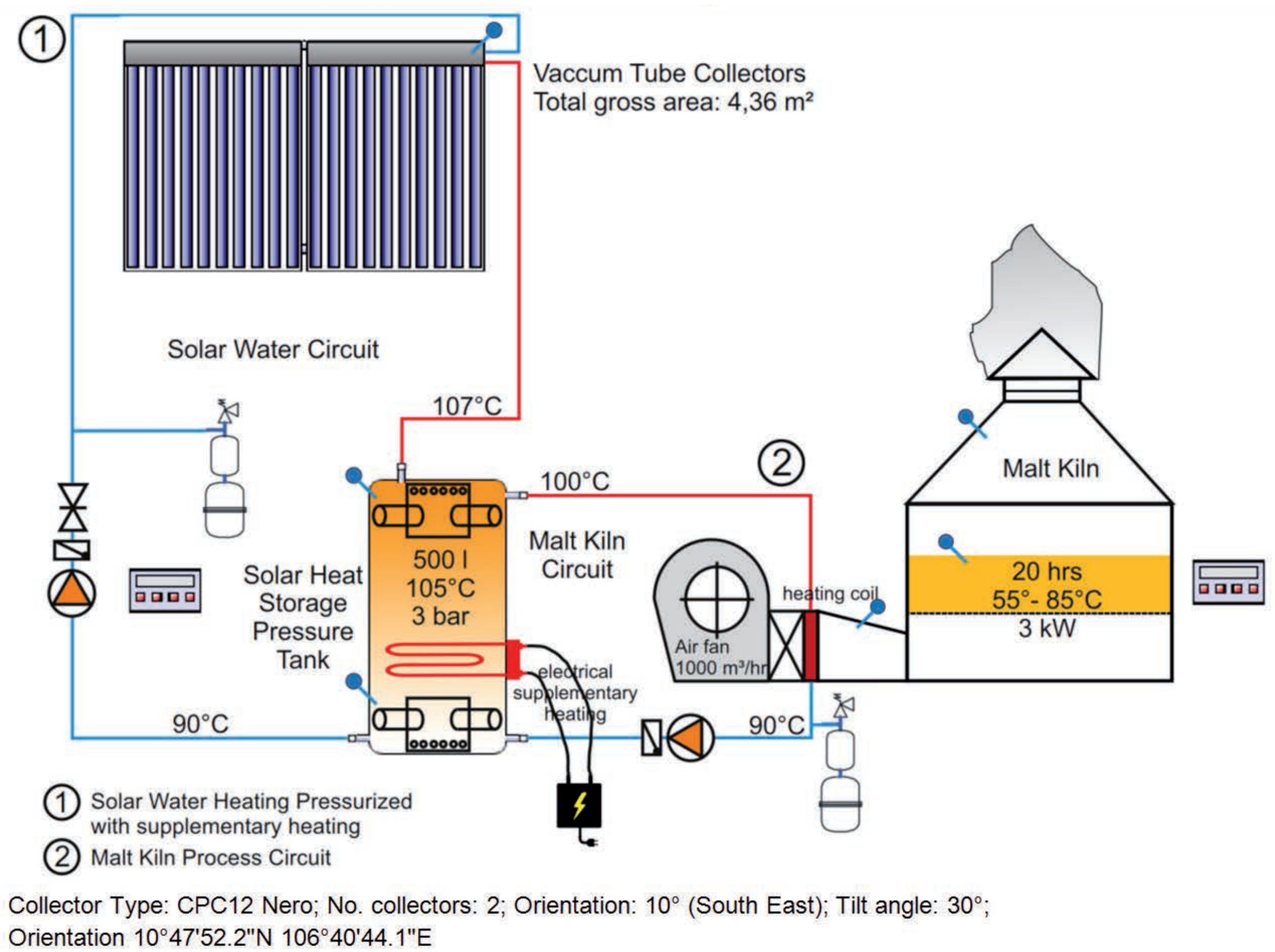

Fig. 6 Experimental Set Up for a Solar Assisted Malt Kiln with Economical Usage of Solar Collectors for a Malt Kiln and Electrical Supplementary Heating

The single steps are described herewith:

- Enter Malting Parameters

Enter initial data such as batch size [t barley as green malt] and moisture content start [%], moisture content end [%], yield [% barley-malt], withering time [hrs], cycle time [hrs], sea level [m], finally heat recovery efficiency [%].

- Compute Kiln Malt Process Data

Compute technological data such as dry matter [kg], weight of finished malt [kg], weight of green malt [kg], total water evaporation [kg], specific water evaporation [kg/h], and Atmospheric pressure [mbar].

- Enter Local Climate Data

Enter climate data such as ambient air temperature [°C], rel. humidity [%], temperature withering air [°C], for summer (dry season) / winter (rainy season) / averages.

- Compute Aeration Data and Heating Capacity

Compute water evaporation capacity of air [g/kg], temperature above kiln malt bed, kiln air mass flow [kg/h], kiln air volume [m³/h] and required heating capacity [kW] and chose the air volume [m³/h] and heating capacity [kW].

- Enter Average Usage of Heat Capacity for Curing

As the heating requirement for curing is lower than it is for withering, the average usage for curing in [%].

- Dimensioning of the percentage of the solar supply

Sizing of the solar heating with 100 % supply, 80 % supply, 50 % supply and 30 % supply capacities [kW].

- Compute Specific Energy Consumption

With the calculated heat capacity [kWh] and the calculated finished malt [t] the specific energy consumption [kWh/t] is computed.

- Insert the Data for the Solar Radiation

Enter daily solar radiation - Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI) [kWh/m²/day] and daily solar radiation [hrs].

Table 1 Malt Analyses

		BATCH 18112 (Barley Andreia)		BATCH 18115 (Barley Andreia)	
			Test No. 12		Test No. 13
Parameter	Unit	INDUST.	KILN TRIAL partly Solar	INDUST.	KILN TRIAL 100% Solar
Smell		Normal	Normal	Normal	Normal
Insect		No	No	No	No
Ergot		No	No	No	No
Odour of the Mash		Normal	Normal	Normal	Normal
Flavour and aroma		Normal	Normal	Normal	Normal
Moisture before transfer to kiln	%	43.9	44.3		
Moisture content	%	4.2	6.4	4.3	7.1
Extract-fine DM	%	80.8	81.0	81.0	81.3
Extract-coarse DM	%	80.1	79.9	80.2	80.0
Extract diff DM	%	0.8	1.1	0.8	1.3
Total Protein DM	%	10.8	11.0	10.8	10.8
Soluble Protein	g/100g	4.5	4.6	4.8	4.8
Soluble N	%	0.73	0.74	0.8	0.8
Kolbach index	%	42.0	42.0	44.0	44.0
Viscosity CW (8.6%)	mPas	1.56	1.55	1.52	1.58
Final attenuation	%	80.6		83.1	
pH- Wort		6.17	6.25	6.10	6.20
FAN	mg/l	153.0	157.0	164.0	176.0
Wort Colour	EBC	3.2	2.9	3.3	2.7
Boiled Wort Colour	EBC	5.3	4.9	5.4	4.3
Friability	%	92.0	83.2	91.2	84.8
Partly unmodified grains	%	1.8	1.8	1.0	1.6
Glassy grains	%	1.8	1.0	0.8	1.0
Grading >2.8 mm	%	89.4	88.5	88.5	89.5
Grading >2.5 mm	%	98.0	98.9	97.9	98.7
Grading 2.2-2.5 mm	%	1.4	1.0	1.4	1.2
Grading <2.2 mm	%	0.5	0.1	0.6	0.1
Foreign material	%	0.1	0.0	0.1	0.0
Saccharification time	min	8	8	9	9
Filtration time CW-fine	min	126	126	100.0	110.0
Beta-Glucan CW	mg/l	147	156	154.0	191.0
Diastatic Power DM	°WK	277	318	284.0	361.0
Hectolitre weight	kg/hl	54.7		54.3	
Clarity of wort	EBC	4.3	3.4	4.8	4.8

- Calculate the necessary Collector Area

Depending on the percentage of the solar supply [%] calculate the necessary collector area and chose the collector area [m²], calculate the heat supply [kWh].

- Dimensioning of the Energy Storage

Calculate the necessary size of the energy storage [m³] from the radiation data and the solar heat capacity.

- Calculate the Energy & CO_2 Savings

Depending on the percentage of the solar supply [%] and the conventional heat supply [kWh] the savings with the solar heat system are calculated.

- Calculate the possible CO_2 Savings [kg] on the substitution of Natural Gas and Fuel Oil.

- Calculate the necessary land use

Calculate the necessary land use [m²] for the installation of the solar collectors with the calculated energy supply.

It was decided to test the model with a pilot solar malt kiln as an experimental setup and then upscale the results to the industrial size. The idea was to produce the hot water exclusively from a solar collector circulation and use it for the pilot kiln in the tests. Back up heat can be integrated in the circuit with a centralized Energy Storage Tank.

In figure 7 the design and in figure 6 the complete experimental setup are shown with the solar malt kiln and the chosen solar heat system. The batch size is designed for up to 50 kg barley as green malt. This state of the art pilot malt kiln was designed of stainless steel construction metal sheeting with an insulated vessel including a perforated floor, a heating coil, kiln fan with an electrical motor and variable frequency drive and aeration piping. There are two circuits of hot water (solar circuit and malt circuit) which have a solar heat pressure tank in common.

The trials were executed initially without back-up heating source. In the second stage of the trials, an additional electrical heater for

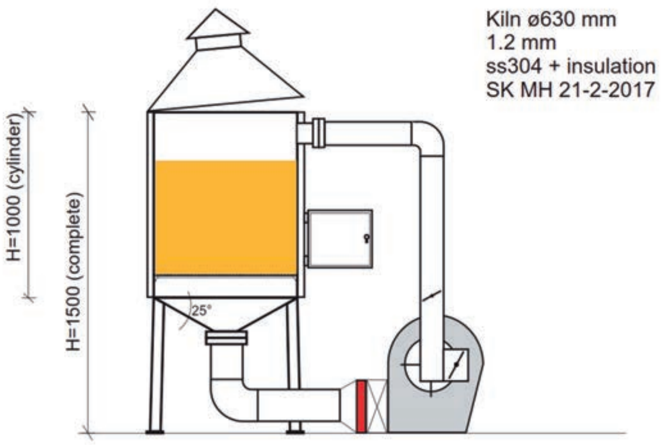

Fig. 7 Design and set up of the pilot kiln

Fig. 8 **Picture with 2 CPC Solar Heat panels mounted at the building roof**

Fig. 9 **Picture with Pilot kiln with kiln fan, heating coil and air piping**

Fig. 10 **Picture with Kilned Malt inside the Solar Kiln during the test**

Fig. 11 **Picture with pilot kiln connected to the solar circulation, ready for operation incl. insulation**

the solar heat pressure tank was used.

In table 1 exemplary malt analyses are shown from the trials. The brewing quality characteristics show normal values.

The malt analysis of Test No. 12 and No. 13 are found in the left and right block. These analyses are executed by the industrial malting where the green malt was supplied from. The right column has the analysis data from the pilot trial and the left column contains the data from the industrial malting for comparison. Even though the malt moisture content was significantly higher at the trial than in the comparison, the brewing quality characteristics show normal values. The reason for higher malt moisture content and the liaised lower friability is that in particular for the Test No. 12 and 13 the heat energy was limited during curing. It shows the tendency for the ability to produce quality malt.

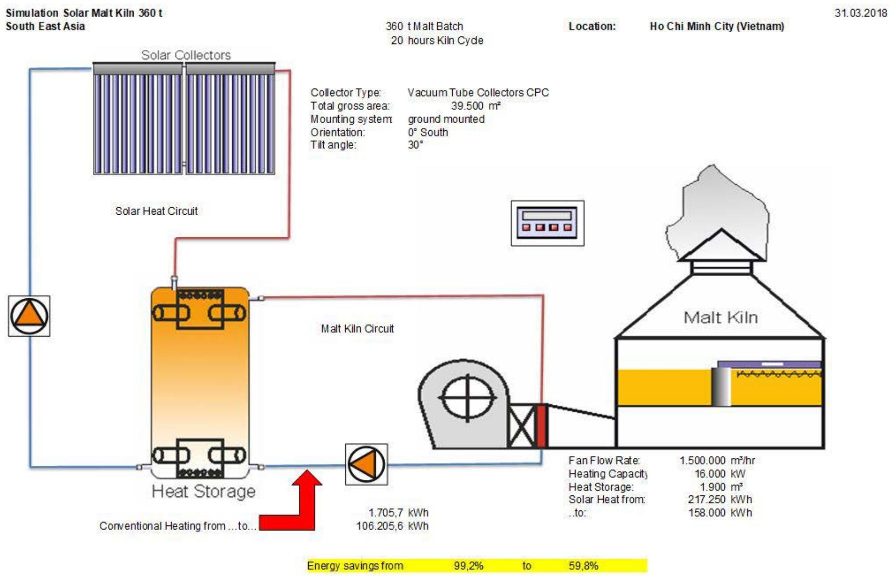

Fig. 12 **<Screenshot> Output Display of the model calculation of a 360 t industrial solar malt kiln**

In particular, the Kolbach Index, which is the value for the soluble nitrogen ratio, was over 42 %, which gave an indication of very highly modified malt. The viscosity at 1.58 mPa gave an indication about the wort during lautering and beer filtration.

Table 2 Simplified Calculation Spread Sheet of the Solar Malt Kiln with 360 t batch

Model Calculation Solar Malt Kiln 360 t					
Location	**Ho Chi Minh City (Vietnam)**				
Malting Parameters					
Batch size (BaGM)	[t]	360			
Green malt water content	[%]	42			
Water content after withering	[%]	12			
Finished malt water content	[%]	5			
Kilning Cycle	[h]	20			
Withering time	[h]	12			
Climate Data			Dry Season	Average	Rainy Season
Ambient air temperature	[°C]		35	28	24
Rel. humidity of ambient air	[%]		55	60	80
Withering temperature	[°C]	55			
Water evaporation capacity of air	[g/kg]		8.9	10.3	10.1
Temperature above bed	[°C]		31.3	28.5	29.0
Kiln air volume	[m³/h]		1,465,556	1,265,556	1,293,981
Capacity of heat recovery	[kW]		0	0	0
Temperature above bed	[°C]		33.1	30.5	31.0
Required heating capacity	[kW]		13,190.1	14,.047.7	15,916.0
Heat Capacity for the kiln process	[kWh]		218,955,.7	233,191.8	264,205.6
Specific Energy Consumption	[kWh/t]		750.9	799.7	906.1
Daily Solar Radiation - Global Horizontal Irradiance (GHI)	[kWh/m²/day]		4.8	4.2	3.6
Daily Solar Radiation - Direct Normal Irradiation (DNI)	[kWh/m²/day]		5.5	4.8	4.0
Averaged Daylight Hours	[hrs]		9.0	8.0	7.0
Necessary Collector Area [100%]	[m²]		39,810	48,581	66,051
Heat Supply from Solar	[kWh]		217.250	189.600	158.000
Heat Storage	[m³]		3,910	3,028	2,696
Heat Storage Temperature initially	[°C]		35	35	30
Heat Storage Temperature end	[°C]		100	95	90
Storage Energy	[kWh]		144,083	133,000	133,000
Remaining conventional heating	[kWh]		1,705	43,591	106,205
Energy Savings	[%]		99.2%	81.3%	59.8%
CO_2 savings Natural Gas CO_2 output	[kg]	0.22 kg CO_2/kWh	47,795	41,712	34,760
CO_2 savings Fuel Oil CO_2 output	[kg]	0.24 kg CO_2/kWh	52,140	45,504	37,920
Necessary land use (land used per m² of collector)	[m²]	3.5		138,250	

The EBC wort colour was quite low, at 2.7 for light malt. Friability is also an indication of lautering. Wort clarification and beer filtration with above 83 % which is good. The Diastatic Power is the value of the enzyme activity for mainly β-amylase for the conversion of starch into sugar. The beta-glucan value is also an indicator used in beer filtration. These two values were higher than the industrial malt which can be considered positive. The differences in general can be attributed to the lower curing temperature in the pilot trial.

For the brewer, it is always important to know which values correspond to a good malt or whether there is concern with the malt analysis according to the EBC or MEBAK [23].

In general, the experiments with solar malt have shown that green malt can be fired with 100 % or partial solar heat. However, there is still much room for optimization in order to meet all malt specifications for the global brewers, particular the malt moisture.

With such a malt, it is always possible to put into operation an ideal mashing procedure and consequently produce good quality of the beer.

In order to compare and confirm the experimental results with the simulation assisted model the data obtained from the trials were inserted in a calculation spread sheet. In general the calculated data correlated directly with the data of the experimental setup and the trials. The required heat energy for the kiln malt process

Table 3 The main special formulas used for the calculations in these studies

Description	Formula
Dry matter DM	$DM[\text{kg}] = \frac{(100\% - MC_{fm}[\%]) \cdot m_{fm}[kg]}{100\%}$
Kiln air mass flow to Kiln Air volume	$\dot{V}_{air}[\text{m}^3/\text{h}] = \frac{mf_{air}[kg/h]}{1.08\ kg/m^3}$
Specific Energy Consumption	$P_s\left[\frac{\text{kWh}}{\text{t}}\right] = \frac{HC_K[kWh]}{m_{fm}\ [kg]} \cdot 1{,}000\ \text{kg/t}$
Collector Area	$A_C[\text{m}^2] = \frac{HC_K[kWh]}{DNI\ [\frac{kWh}{m^2}/day]}$
Storage Energy	$E_S[kWh] = \frac{V_S[m^3] \cdot 10^3\ \frac{kg}{m^3} \cdot (T_{HS.end} - T_{HS.ini})[K] \cdot 4.2\ \frac{kJ}{kg\ K}}{3600\ \frac{kJ}{Wh}}$
Energy Savings	$\eta\,[\%] = \frac{HS_{solar}[kWh]}{HC_K[kWh]} \cdot 100\%$
CO_2 savings	$\eta_{CO2}[\text{kg}] = q_{CO2}[\frac{kg}{kWh}] \cdot HS_{solar}[kWh]$

Table 4 Formula Caption

DM	[kg]	Dry matter
MC_{fm}	[%]	Moisture Content finished malt
m_{fm}	[kg]	Mass finished malt
$\dot{V}_{air}$	[m³/h]	Kiln air mass flow to Kiln Air volume
mf_{air}	[kg/h]	Kiln air mass flow
P_s	[kWh/t]	Specific Energy Consumption
HC_K	[kWh]	Heat Capacity for the kiln process
A_C	[m³]	Solar Collector Area
DNI	[kWh/m²/day]	Direct Normal Irradiance
E_S	[kWh]	Storage Energy
V_S	[m³]	Storage Energy Volume
$T_{HS.end}$	[°C]	End Temperature Heat Storage
$T_{HS.ini}$	[°C]	Initial Temperature Heat Storage
c_w	4.2 kJ/kgK	Specific storage capacity water
η	[%]	Energy Savings
HS_{solar}	[kWh]	Heat Supply from Solar
η_{CO2}	[kg]	CO_2 Savings
q_{CO2}	[kg/kWh]	Specific CO_2 Emission

is 34.9 kWh in average. The measured total heat energy of the exemplary test was 35.4 kWh.

The performance of a solar assisted malt kiln is characterized by the drying rate, specific moisture extraction rate and thermal efficiency. The data shown prove that the developed solar assisted model works.

heating coil, heat storage and solar collector area.

These data are the basis for the investment decision. Heating capacity and fan flow rate are attributable to the malt kiln process. These calculated data are dependent on the climate data. With an integrated h-x diagram according to Mollier, for air conditions and relative humidity the air flow rate and the heating capacity can be determinated.

3 Results and discussions

The results of the simulation for a solar assisted model were applied to a real case solar kiln for a batch size of 360 t barley as green malt in Vietnam. The cycle time is 20 hrs and the fan flow rate is 1,300,000 m³/h with a heating capacity of 16,000 kW.

With a collector area of 39,500 m² and an orientation of 0° South with type Vacuum Tube Collectors CPC and a heat storage capacity of 1,900 m³ saving can be generated from 99.2 % (dry season) and 59.8 % (rainy season). This provides a solar heat contribution from 217,250 kWh to 158,000 kWh with an average throughout the year of 189,600 kWh (81.3 %) per batch.

In order to show all the results of the malt kiln design and the solar circuit including the possible saving with the use of solar energy, the two circuits (kiln heating and solar heating) are displayed with all the devices, like kiln fan,

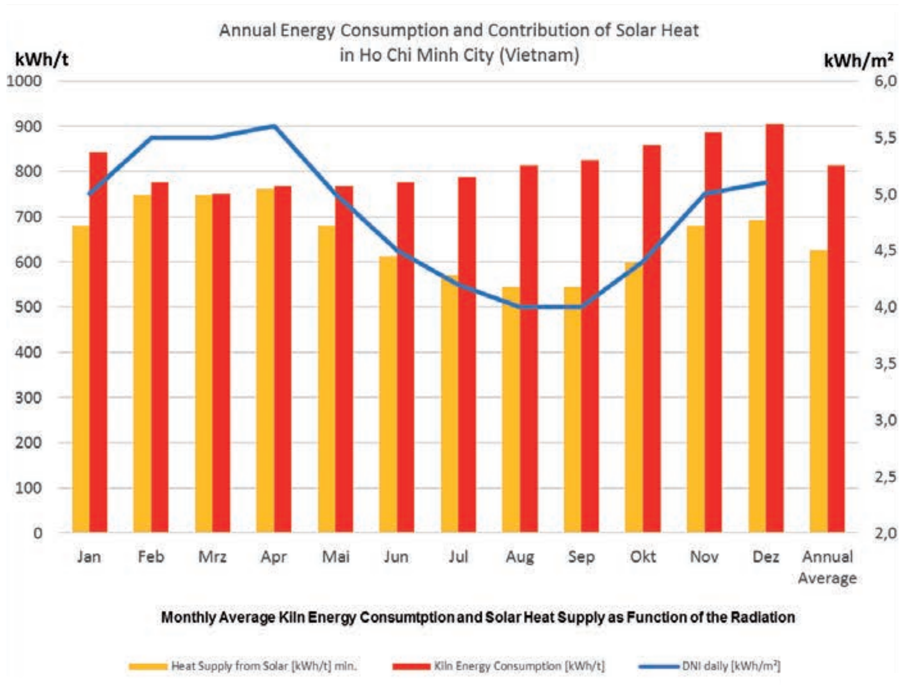

Fig. 13 Specific Annual Solar Energy Consumption of Solar Heat per tonne of Malt

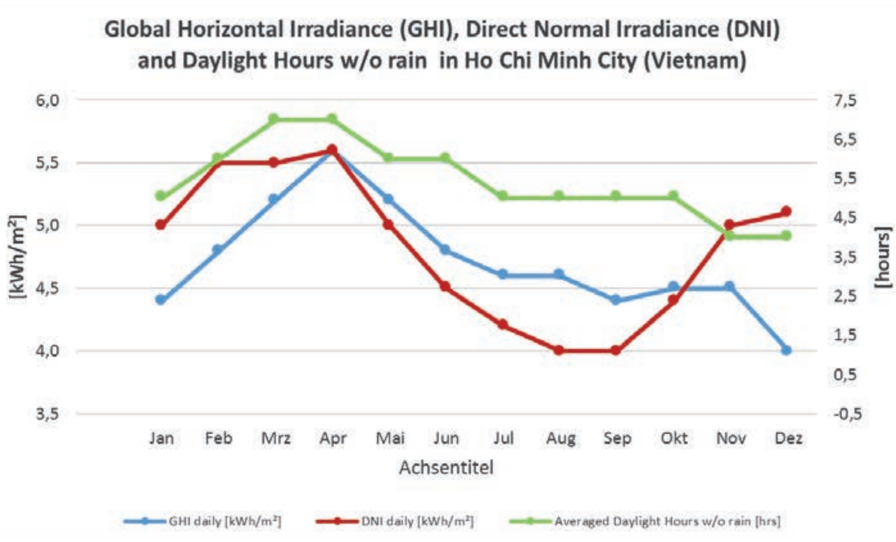

Fig. 14 **Global Horizontal Irradiance (GHI), Daily Normal Irradiance (DNI) and Daylight hours without rain**

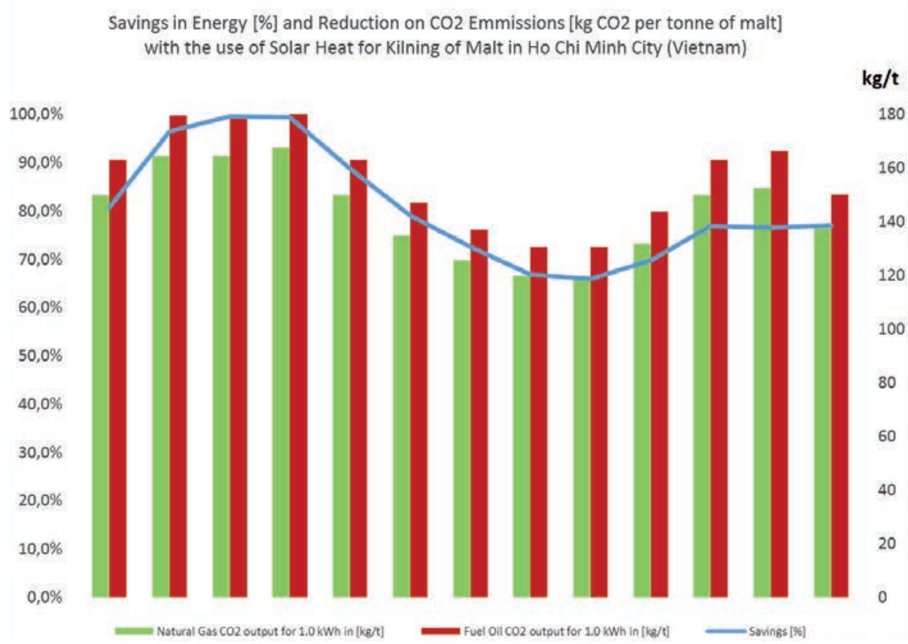

Fig. 15 **Savings in Energy [%] and Reduction of CO_2 Emissions [kg CO_2 per tonne of malt] with the use of Solar Heat for Kilning of Malt**

The Direct Normal Irradiance (DNI) of Ho Chi Minh City (Vietnam) was determined as 4.2 kWh/m² for daily average total.

The calculations and formula in table 3 have been used for the simulation calculation in the Excel spread sheet.

With the Malt Solar Model Calculation, the specific results per malt tonne have been investigated as well. The figure 12 contains all the local data with radiation and the specific values, such as specific kiln energy consumption per month. This results in the percentage of use of the solar heat supply per malt tonne and the specific solar collector area and heat storage per malt tonne.

The monthly kiln energy demand of kilning per tonne of malt average monthly solar radiation is shown with the result that during the dry season 99.2 % of the heat demand could be supplied by the solar heat and during the rainy season only 59.8 %. In regards to dimensioning, the month with the maximum heat supply needs to be taken as the limit.

In figure 14 the Daily Normal Irradiance (DNI) and the Global Horizontal Irradiance (GHI) are shown with the daylight hours without rain and clouds. This offers an overview about the available solar heat at Ho Chi Minh City (Vietnam).

Together with the specific savings of energy the reduction of CO_2 emissions are shown on a monthly basis in figure 15. 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 basis of these exemplary calculations are the specific values for gas as 0.22 kg CO_2/kWh and for oil 0.24 kg CO_2/kWh.

3.1 Future Optimisation of the Solar Kiln Design

The execution and studies with the solar assisted model give a guideline of the design of a solar heat equipped malt kiln. In addition to the considered areas of the solar equipment also the other areas need to be mentioned such as cost of land (in case there is a ground mounted installation of the solar collectors) and extended transmission piping, control system etc. Heat losses are undoubtedly existing in this kind if system which have to be taken into account during the planning phase and realisation of such a project.

4 Conclusions

A Solar Assisted Model for a Malt Kiln and trials with a solar malt pilot kiln were successfully executed and the feasibility of a large scale real case project could be demonstrated.

The dimensioning of the solar circuit and savings of fossil energy was constructed in a simulation. A considerable contribution from the solar heat with 360 tonnes of barley in Vietnam could be generated.

Starting from the design calculation of the malt kiln, the energy demand and air flow, the dimensioning of the solar circuit for the solar malt kiln, the percentage contribution and the savings compared with the usage of fossil energy was constructed in the simulation. The contribution (savings) from the investigated solar heat with the representational case of 360 tonnes of barley in Vietnam could be generated at between 99.2 % (dry season) and 59.8 % (rainy season) in monthly average.

Thus, a larger impact can be identified with the rainy season. Due to changing solar contribution and heat demand over the seasons, it will be always essential to have 100 % back-up heating.

Hence, there is the fact that the contribution of solar energy on some days is well below the monthly average of 59.8 %, in particular in the rainy season. Therefore, great attention must be paid to the design of the plant and the plant construction in order to achieve good and economic results.

Also CO_2 footprint savings were calculated per tonne of finished malt. With the display of the specific solar heat per tonne of malt as a function of the local radiation, the potential of solar heat can be allocated.

In summary, these studies show a considerable savings potential for the operation of malting plants in subtropical areas.

5 Conflict of Interest

The authors declare no financial or commercial conflict of interest.

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Received 10 September 2018, accepted 15 February 2019