WEENTECH Proceedings in Energy

ICEEE 2016

16th -18th August 2016
Heriot-Watt University, Edinburgh
United Kingdom

Volume 3: International Conference on Energy, Environment and Economics, September 2016

ISSN: 2059-2353
ISBN: 978-9932795-2-2
www.weentech.co.uk

Edited by:
Dr. Renu Singh, IARI, New Delhi, India
Dr. Anil Kumar, PSU, Thailand
Published by World Energy and Environment Technology Ltd.

Performance of a Low Profile, Concentrating Solar Thermal Collector for Industrial Process Heating Applications

Yoann Guinard[1,2], Qiyuan Li[2], Gonzalo Diarce[2,3] , Robert A Taylor[2]

[1]*National Institute of Applied Sciences, Lyon, France*

[2]*School of Mechanical and Manufacturing Engineering, University of New South Wales, Kensington, New South Wales, 2052, Australia*

[3]*ENEDI Research Group, University of the Basque Country UPV/EHU*

[*]*Corresponding author's mail: yoann.guinard@insa-lyon.fr*

Abstract

Recent studies have demonstrated that solar heat has a critical role to play in providing heat for industrial processes. In the present work, the thermal performance of a novel low profile concentrating solar thermal collector as a means to replace gas usage by mounting it on the rooftop of factories is investigated. The proposed collector incorporates an internal linear tracking system that concentrates beam radiation during a large part of a sunny day without external or rotational motion. The configuration presented here is suitable for an industrial metal process heating (drying and cleaning) application. In this paper, the annual behavior of the collector has been simulated for this application with TRNSYS (Transient System Simulation Tool) software in order to study its performance and economic feasibility. The annual solar fraction and economic metrics were used as selection criteria among design options (e.g. varying the solar array, storage tank sizes, and control methods). Assuming a constant thermal load of 260 kW_h per day, the optimal total area of the collectors was calculated to be 200 m² for this application. *Overall, the results show that, for the meteorological data of Sydney, the proposed concentrating collector can reach a solar fraction of 53%, while achieving positive economic returns.* A preliminary economic analysis of this system indicates that a government subsidy of 50% of the capital equipment will reduce the payback period to 11 years. Due to the fact that solar-derived industrial heat production is an emerging market, further research and economies of scale could potentially be expected to drastically improve the economic viability of these types of systems going forward.

Keywords: Solar thermal; Concentrating collector; Industrial Process

1. Introduction

Industrial process heat represents a large piece of the global energy pie and the global economy is largely on the goods and services these heat inputs enable. Industrial operations around the world account for more than 11 million GW_{th} hours each year (excluding power generation) [1,2]. In Europe, at the industrial scale, two third of the final energy consumption is spent for heating applications [3]. A large part of this heat is provided through consumption of gas, coal, and other non-renewable fuels. Therefore, finding and developing sustainable ways of providing heat for industry is necessary if we truly hope to decarbonize our economy [4,5].

Solar energy is the largest energy resource on earth. In two hours, the energy received by the land and the oceans is greater than the energy consumed by the world in one year [6]. Given the available large collection area of a typical factory, this resource is critically under-developed – particularly for providing process heat energy.

According to a 2014 IEA report, only 132 plants (~100 MW) are installed around the world to provide heat for industrial processes [7]. At intermediate and high temperatures (more than 100 °C), most of the installed solar systems are based on parabolic troughs, which are not suitable for rooftop installation. Therefore, the authors believe that market is primed for the development of new rooftop solar thermal collector technology that can provide heat between 100 °C and 400 °C. As a result, this work studies the behavior of a novel concentrating collector design (developed at UNSW [8,9,10,11]) – a design which is suitable for rooftop use and which can achieve these temperatures. To this end, a parametric optimization of the collector and the system was undertaken, and the resulting system was evaluated in terms of its economic performance.

2. Collector design

The collector used in this study is a low-profile concentrating solar thermal collector, with a height of 13 cm (Figure 1). It is designed to deliver heat energy in the range of 100-250 °C, which is useful for many industrial heating processes [8].

The collector consists of three Fresnel lens segments, each of which are 1.5 meters long and 0.15 meters wide. These lens segments then focus light down into compound parabolic secondary concentrators (CPC) and onto the absorbers (black chrome-coated copper tube, shown in Fig. 1)[10,11]. To track the sun throughout the day, the collector has an internal mechanism to move the CPC/absorber assembly horizontally to keep them in the focal zone of the lens. The tracking system is effective as long as the incidence angle of the sunlight on the collector is between 0 and 45° – i.e. ± 3 hours from solar noon. Outside of these incidence angles, the optical efficiency begins to drops off rapidly. In order to operate at >100°C, vacuum insulation is employed around the absorbers. The vacuum minimizes the conductive and convective heat loss from the tube absorbers.

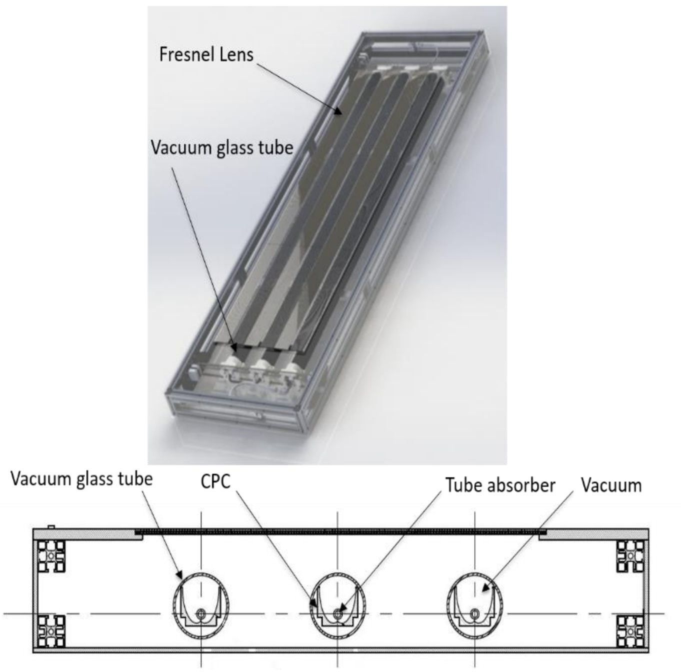

Fig. 1 Collector design [Top: 3D view of the collector; Bottom: Cross-sectional view of the collector]

3. Properties of the collector

While the behaviour of the collector has been tested and modelled previously at the component level [8], the aim of this paper is to provide the first study of its long term performance in a characteristic industrial process heating application. The behaviour of the collector was studied by means of numerical simulations performed with the TRNSYS software. For this purpose, the 'type 1245' component from the TESS Library [12,13] was used, which represents a generic concentrating collector. To accurately represent the collector described above, the experimentally determined collector performance parameters were input into this 'type'. As such, all of the following parameters have been taken into account for the simulation: concentration ratio (aperture area: receiver surface area); collector efficiency as a function of the mean receiver temperature, and the incident angle modifier (which represents the change in the optical efficiency when the incident angle of the sunlight on the collector increases) [14].

3.1. Thermal Efficiency

The non-linear efficiency equation of the collector is given as Eq. 1. The optical efficiency obtained through experimental tests was 0.80. The first order and second order loss coefficient were found to be 0.64 and 0.004, respectively. The experimental results obtained during the tests are shown in Figure 3.

$$\eta = 0.80 - 0.64\frac{Tm - Ta}{Gb} - 0.004\frac{(Tm - Ta)^2}{Gb} \qquad (1)$$

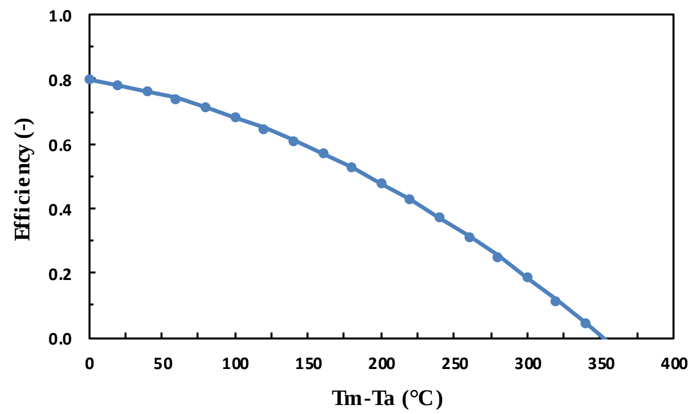

Fig. 3 Efficiency of the collector (Gb = 900 W/m²)

3.2. Optical Performance

Another important parameter – particularly for annual simulations – is the IAM (Incident Angle Modifier). It can be considered as a de-rating factor to the first term (0.8) in equation 1. This can be represented, simply, by Eq. 2:

$$IAM(\theta) = \frac{optical\_efficiency(\theta)}{optical\_efficiency(0)} \qquad (2)$$

Eq. 2, θ can be broken into two orthogonal angles: the transverse and the longitudinal IAM. For angles greater than 45°, it was found (experimentally) that both IAMs approach zero for this collector design involved (e.g. no heat production), as shown in Figure 4.

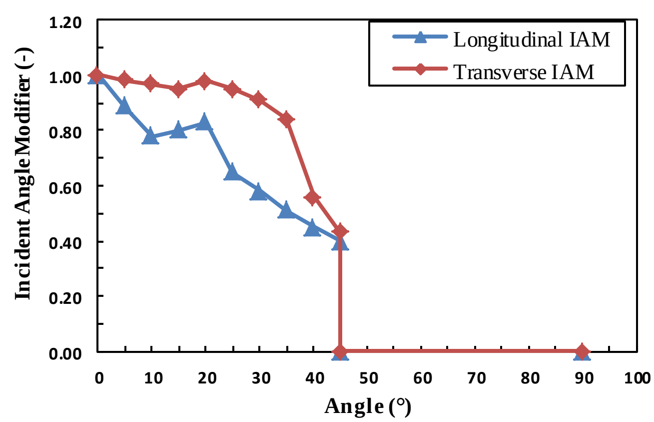

Fig. 4 Transverse and Longitudinal IAM

3.3. Modelling of the collector on TRNSYS

In 'type 1245', the full performance of the collector can be represented by Eq. 3:

$$\eta = a_0 * IAM_t(\theta_t) * IAM_l(\theta_l) - \frac{a_1}{Cr}\frac{T - Ta}{G} - \frac{a_2}{G}\frac{(T - Ta)^2}{G} \quad (3)$$

The parameters of equation 3 were calculated to fit the equation 1. The calculated values for the parameters are shown in Table 1. A file containing all the values of the IAM was created and provided to the TRNSYS type as an external file.

Table 1 Parameters of the collector

Concentration Ratio	4.5	-
Fluid Specific Heat	2.63	kJ/kg.K
Collector Test Mode	2	
Tested Intercept Efficiency a_0	0.80	-
Coefficient a_1	2.88	W/m².K
Coefficient a_2	0.018	W/m².K²

4. Description of the industrial process

The IEA's Task 49 provides a database for industrial process heating around the world [15]. Data from a metal processing company was used from this database as a case study for implementing the low profile solar thermal collector [16]. The process consists mainly of a washing and drying tunnel for finished metal pieces, both of which are essentially continuous (24/7) thermal loads (neglecting maintenance down time): a bath which remains at a constant temperature of 50 °C and a dryer that stays at 160 °C.

A schematic overview of the modeled process is depicted in Figure 5. The two actual loads were gathered into a total thermal load of 260 kWh_{th} per day. The solar loop circulates thermal oil between the collector and a hot tank, then the fluid is delivered to the process via a shell and tube heat exchanger. The working fluid is a synthetic thermal oil (Pirobloc, HTF-Basic [17]), which can operate between -50°C to 330 °C in a closed system. For the simulation, this fluid always provides a controlled 180 ºC to the process. After delivering its heat, the HTF exits the process at 20 °C, at which point the fluid is returned to the cold tank.

Since the solar resource is intermittent, this 180 °C output is modulated by other components in the system. If the temperature at the outlet of the hot tank is greater than 180 °C, a diverter sends a fraction of the fluid at 20 °C through a tee valve to cool the output to an average temperature of 180 °C. If the temperature at the outlet of the hot tank is less than 180 °C, an auxiliary burner provides heat to reach the desired temperature of 180 °C.

In the solar loop, an on/off controller regulates the flow rate in the collector. If the difference of temperature between the bottom of the tank and the outlet of the collector is greater than 10 °C, then the pump delivers its nominal flow rate.

It is important to note that the solar loop and the process loop use two different flow rates. Since the process requires a constant heat input at a constant temperature, the process loop has a constant flow rate of 100 kg/hr. The flow rate in the solar loop is variable and turns on/off with the solar resource.

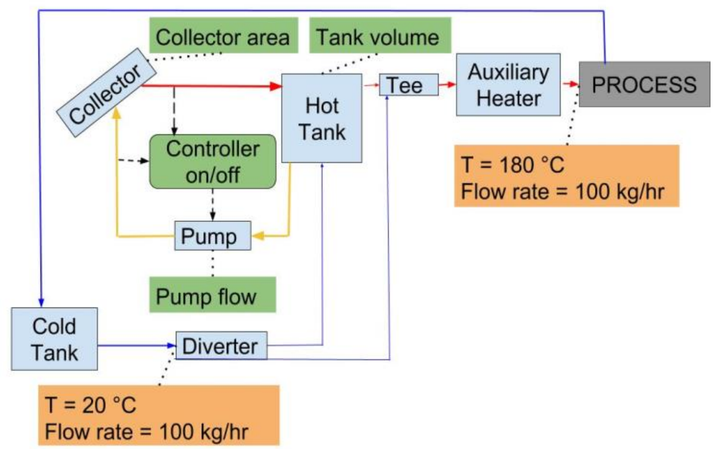

Fig. 5 Schematic of the solar system. [Blue boxes = system components; Black box = Load, represented by data from [16]; Orange boxes = fixed conditions; Green boxes = variable parameters investigated here]

5. Results and discussions

First off, a parametric study was carried out using meteorological data for Sydney. Using the optimal design from this study, the influence of the climate was studied through simulations performed under Alice Springs, Sydney and Paris. Finally, an economical assessment was performed for this application in each of these locations.

The non-dimensional parameter, solar fraction, was the main parameter used to evaluate the performance of the system. It is defined as the ratio between the energy provided by the solar system on the total energy required for the load (Eq. 4).

$$SF = \frac{Qcoll - Qloss}{Qcoll - Qloss + Qaux} \quad (4)$$

The energy supplied by the solar system is defined as the energy provided by the collector minus the energy losses in the solar loop.

5.1. Optimization of the operation parameters of the system.

Simulations were initially carried out to determine the optimum collector area for this application. For the Sydney climate, the collector was tilted to the equivalent latitude,

~33°. As a first step, we determine the amount of solar collector area needed, shown in Figure 6.

For a collector area of 200 m², the solar fraction is 53 %. This data point corresponds to the best operation of the collector, achieving the best solar fraction before that the curve flattens. This result will be taken as a reference for the following comparisons.

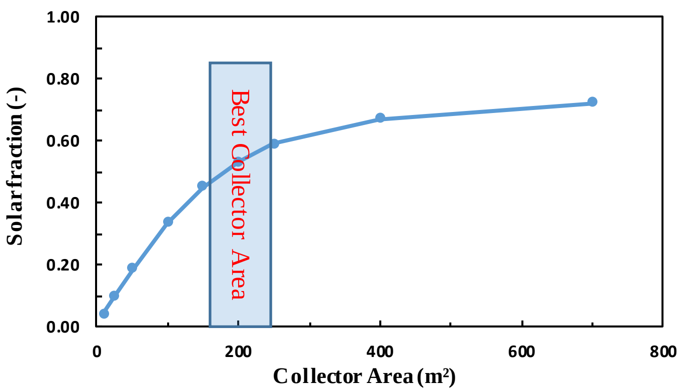

Fig. 6 Effect of collector area on the solar fraction (tank volume = 4 m^3; collector flow rate = 500 kg/hr)

The performance of the system depends also on the size of the tank and the flow rate circulating in the collector. In Figure 7, the size of the tank is fixed at 4 m^3, the collector area is fixed at 200 m², and the effect of the flow rate delivered by the pump is investigated.

The flow rate that maximizes the solar fraction is 500 kg/hr in these conditions. When the flow rate is lower than that value, the temperature of the fluid often becomes very high, reducing the efficiency of the collector and the storage of energy for the night. Conversely, for flow rates higher than 500 kg/hr, the temperature rise in the collector is small, indicating that auxiliary heater provides a large fraction of the annual energy, leading to a decrease of the solar fraction. The pumping power of the system has been neglected so far – therefore the value of 500 kg/hr corresponds to the best thermal efficiency but not to the actual design choice, which should be smaller to reduce the pumping power consumed.

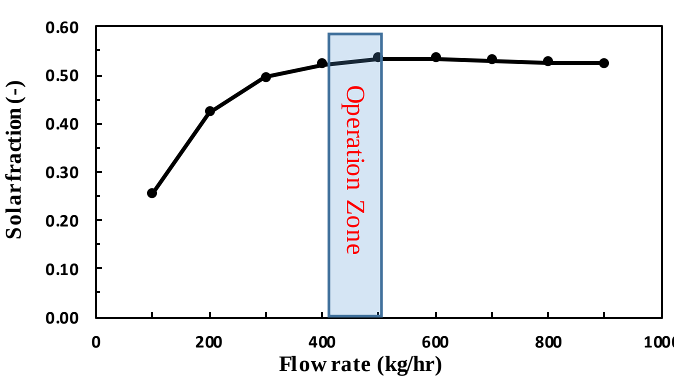

Fig. 7 Effect of flow rate in the collector on the solar fraction (tank volume = 4 m^3; collector area = 200 m²)

The effect of the volume of the tank was also investigated. Based on the results above, the flow rate was fixed at 500 kg/hr and collector area of 200 m² was assumed to determine a good storage tank volume. The results of this sizing are shown in Figure 8.

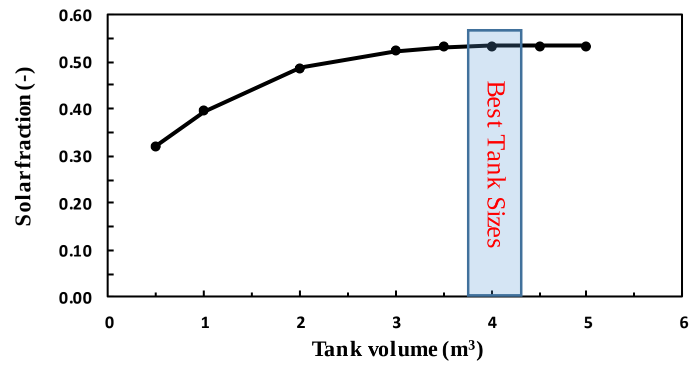

Fig. 8 Effect of tank size on the solar fraction (collector flow rate = 500 kg/hr; collector area = 200 m²)

The volume that maximizes the solar fraction is 4 m^3. For smaller volumes, the tank is not able to store the total energy available. On the other hand, for larger volumes, the energy losses increase, so that the solar fraction is not improved further. For these reasons, 4m^3 was chosen to guarantee a high level of storage while keeping the tank loss low. However, the actual design choice might be smaller to reduce the capital cost of the tank.

In the simulations presented so far, an On/Off controller that delivers a nominal flow rate to the collector was employed. The behaviour of the system when an iterative feedback controller ('Type 22') is applied was also studied [18]. This kind of controller activates a variable speed pump in order to obtain a fixed collector outlet temperature of 180°C, by changing the flow rate depending on the irradiation. The results obtained are shown in Figure 9.

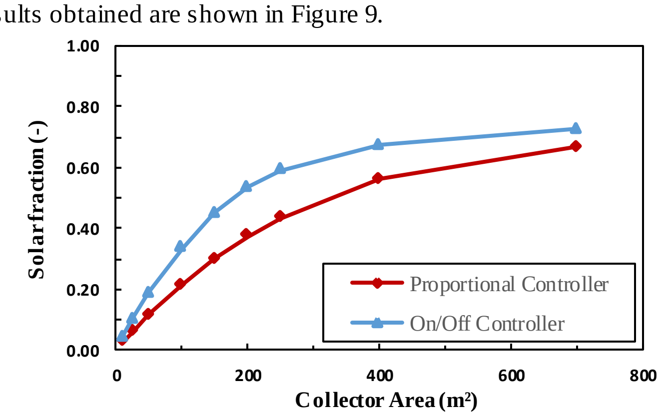

Fig. 9 Effect of collector area on the solar fraction (tank volume = 4m^3)

The solar fraction values attained with the iterative feedback controller were lower than those reached by means of the On/Off controller. This occurred for every value of collector area simulated. This happened because the feedback control method does not harvest any solar energy when the collector temperature is lower than 180°C. On the other hand, by using an on/off controller, a flow rate is circulated in the collector even when the collector temperature is slightly higher than the fluid in the tank. So, the collector contributes to the increase of temperature of the working fluid even when it is unable to reach 180 °C. As indicated by Fig. 9, an On/Off controller represents the better solution and, thus, is our choice for this system.

5.2. Influence of climate on annual system performance

The performance of the collector design – using the decisions from the previous sections – was investigated for two additional cities: Alice Springs and Paris. Alice Springs is located in the Australian desert, a location with very high direct normal irradiation. Paris, conversely, does not have excellent resources, but does have a considerable industrial heating demand. The results are presented in Figure 10.

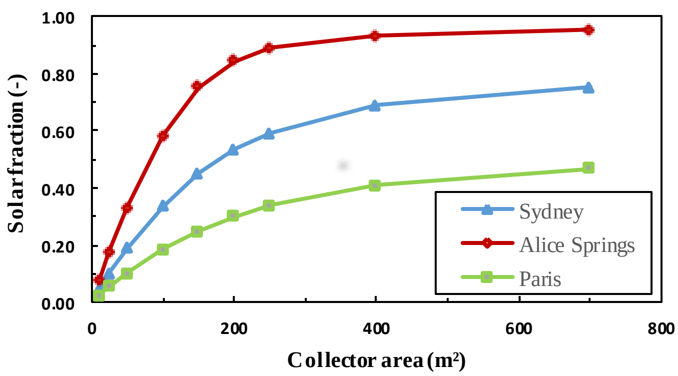

Fig. 10 Effect of collector area on the solar fraction (tank volume = 4m^3; collector flow rate = 500 kg/hr) for three different cities: Sydney (slope of the collector 33°, facing north), Alice Springs (27°, facing north) and Paris (42°, facing south)

The performance of the collector is significantly affected by the beam radiation, which is highly variable by location/climate. The beam radiation in Paris is lower than Sydney and much lower than Alice Springs, yielding the lowest energy harvesting potential.

6. Economic and environmental analysis

Solar systems (generally) have high capital and installation costs, but low operating costs [19, 20]. This high investment is the main barrier for the development of solar technologies.

To determine if any of these systems are economically feasible, a simple economic analysis was performed for the reference case involved (collector area 200 m², solar fraction 53 %) over an estimated lifespan of 20 years. The capital cost of the collector comes from various manufacturer quotations. A discount rate was applied to the cash flow each year. Government subsidies were also applied to reduce the capital cost and therefore the payback period of the installation. A carbon tax was also applied to take into account the environmental benefit of the solar system. A projection of the price of the gas was used to get a more accurate economic analysis. The specific values applied are summarized in the Table 2.

Table 2 Data used for the economic analysis of the system design

Parameter	Value	Unit
Collector Area	200	m²
Cost of collector	800	AUD/m²
	160,000	AUD
Installation cost	32,000	AUD
Subsidies	0-50	%
Price of gas in Sydney	0.042	AUD/MJ
Price of gas in Paris	0.049	AUD/MJ
Carbon Tax	25	AUD/ton CO2
Discount Rate	5	%
Life span of the system	20	years

The results of the full economic analysis are given in the Table 3. The payback period is defined as the length of time required to recover the initial investment costs. The net present value is the sum of all the cash flows, with the discount rate applied on them. The internal rate of return is the discount rate that makes the net present value equal to zero.

Although recent trends are different, historical trends indicate that gas prices tend to increase over time. Thus, we chose to use a rate increase in the gas price of 2%, 5%, and 10% annually.

Table 3 Economic feasibility results

			Sydney	Alice Springs	Paris
Price of gas constant	Without subsidies	Payback Time (years)	99	21	/
	With subsidies of 50 %	Payback Time (years)	16	8	30
		Net Present Value (AUD)	14, 100	85, 788	-18, 858

		Internal Rate of Return (%)	7%	16	2
Price of gas +2 % annually	Without subsidies	Payback Time (years)	36	16	82
	With subsidies of 50 %	Payback Time (years)	13	8	22
		Net Present Value (AUD)	32, 700	116, 491	-5, 746
		Internal Rate of Return (%)	9	18	4
Price of gas +5 % annually	Without subsidies	Payback Time (years)	23	14	33
	With subsidies of 50 %	Payback Time (years)	11	7	16
		Net Present Value (AUD)	69, 641	177, 559	20, 336
		Internal Rate of Return (%)	12	21	7
Price of gas +10 % annually	Without subsidies	Payback Time (years)	16	11	16
	With subsidies of 50 %	Payback Time (years)	9,5	6	12,5
		Net Present Value (AUD)	168, 053	340, 088	89, 748
		Internal Rate of Return (%)	17	27	12

A discount rate of 5% is also a reasonable assumption, given today's bank loan rates. For these scenarios, the high capital costs make economic viability questionable without subsidies. Even in the best location, Alice Springs, a payback time of 11-21 years is estimated, depending on the gas price.

However, in case of 50% government subsidies, the payback time is reduced noticeably and the system achieve satisfactory economic returns.

For the reasonable estimation of a gas price augmentation of 5 % annually, the payback time in the three cities are all achieved during the life span of the collector (7 years for Alice Springs, 11 years for Sydney, 16 years for Paris), leading to a substantial net present value.

7. Conclusions

The behaviour of a rooftop low profile (< 15cm) concentrating solar thermal collector for an industrial process heating application was investigated. The application is a metal washing and drying process which requires 180 °C. The daily thermal load is 260 kWh, and the process is assumed to be continuous (day and night). Our simulations indicated that for a collector area of 200m², a solar fraction of 53% can be realised in Sydney. With government subsidies of 50% of the capital outlay, and with a reasonable estimation of the gas price escalation (+5% annually), the system yields a payback period of 11 years and a net present value of $69,641 for a system with a 20 years life. Due to the fact that solar-derived industrial heating is still in its infancy, further research and development could drastically reduce the capital cost and improve the efficiency of this kind of system, leading to much more attractive payback time and net present value.

Abbreviations

η	Efficiency of the collector (-)
Tm	Average temperature in the collector (°C)
Ta	Ambient temperature (°C)
Gb	Beam radiation (W/m²)
Gd	Diffuse radiation (W/m²)
ϑ	Incidence angle of the sunlight on the collector (°)
ϑ_t	Transverse incidence angle (°)
ϑ_l	Longitudinal incidence angle (°)
IAM	Incident Angle Modifier (-)
IAM_t	Transverse Incident Angle Modifier (-)
IAM_l	Longitudinal Incident Angle Modifier (-)
Cr	Concentration ratio (-)
a_0	Intercept efficiency (-)
a_1	1st Order Loss Coefficient (W/m².K)
a_2	2nd Order Loss Coefficient (W/m².K²)
SF	Solar Fraction (-)
Qcoll	Energy transferred from the collector to the fluid (kJ)
Qloss	Energy loss via the tank (kJ)
Qaux	Energy transferred from the heater to the fluid (kJ)

References

[1] R. Taylor, Q. Li, G. Rosengarten, Optical Design & Engineering Bright ideas for the future of industrial heating.

[2] F. Mauthner, W. Weiss, M. Sprk-Dr, Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2013, tech.

[3] D. Pietruschka, R. Fedrizzi., F. Orioli, R. Söll, & R. Stauss (2012). Demonstration of three large scale solar process heat applications with different solar thermal collector technologies.

[4] S. Kalogirou. (2003). The potential of solar industrial process heat applications. *Applied Energy*, *76*(4), 337–361.

[5] H. Schweiger, JF. Mendes, N. Benz, K Hennecke, G. Prieto, C. M. (2000). The potential of solar heat in industrial processes. An estate of the art review for Spain and Portugal. *Eurosun 2000*, (January), 19–22.

[6] MA. Maehlum, M. (2015). *What is the Potential of Solar Energy? - Energy Informative*. [online] Energy Informative. Available at: http://energyinformative.org/potential-of-solar-energy/ [Accessed 10 May 2016].

[7] C. Brunner. Solar Heat for Industrial Production Processes - Latest Research and Large Scale Installations [online] Available at: 3. http://task49.iea-shc.org/data/sites/1/publications/SHC-2014--Brunner--Solar-

[8] Q. Li, C. Zheng, X. Gu, A. Woffenden, G. Rosengarten, E. Hawkes, M. Yang, R.A. Taylor, Design and analysis of a low-profile, concentrating solar thermal collector, in: Proceedings of the 15th International Heat Transfer Conference, Kyoto, Japan, 2014.

[9] Q. Li, C. Zheng, S. Mesgari, Y. L. Hewakuruppu, N. Hjerrild, F. Crisostomo, K. Morrison, A. Woffenden, G. Rosengarten, J. A. Scott, R. A. Taylor, Experimental investigation of a nanofluid absorber employed in a low-profile, concentrated solar thermal collector in: Proc. SPIE 9668, Micro+Nano Materials, Devices, and Systems, 96683P (December 22, 2015); doi:10.1117/12.2202513.

[10] C. Zheng, Q. Li, G. Rosengarten, E. Hawkes, R.A. Taylor, A new optical concentrator design and analysis for rooftop solar applications, in: SPIE

Optical Engineering+ Applications, International Society for Optics and Photonics, 2015
[11] C. Zheng, Q. Li, G. Rosengarten, E. Hawkes, R.A. Taylor, Design and Analysis of Compact Optical Concentrators for Roof-Integrated Solar Thermal Applications, in: Optics for Solar Energy, Optical Society of America, 2014.
[12] TRNSYS 17: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA. [online] Available at: http://www.trnsys.com/ [Accessed 27 May 2016]
[13] TRNSYS TESS Library, Volume 7: Solar Library Mathematical Reference. [online] Available at: http://www.trnsys.com/tess-libraries/TESSLibs17_General_Descriptions.pdf [Accessed 27 May 2016]
[14] Sultana, T., Morrison, G. L., Taylor, R., & Rosengarten, G. (2015). TRNSYS Modeling of a Linear Fresnel Concentrating Collector for Solar Cooling and Hot Water Applications. *Journal of Solar Energy Engineering*, *137*(April), 1–9. http://doi.org/10.1115/1.4028868
[15] Ship-plants.info. (2016). *Solar Thermal Plants Database | Solar Heat for Industrial Processes (SHIP) Plants Database*. [online] Available at: http://ship-plants.info/solar-thermal-plants [Accessed 12 May 2016].
[16] Ship-plants.info. (2016). *SILAMPOS, S. A. | Solar Heat for Industrial Processes (SHIP) Plants Database*. [online] Available at: http://ship-plants.info/solar-thermal-plants/170-silampos-s-a-portugal?name=silampos [Accessed 27 May 2016].
[17] Fluidotermico, Pirobloc HTF Baisc [online] Available at: http://www.fluidotermico.com/downloads/pdf/en/Technical-datasheet-Pirobloc-HTF-BASIC.pdf [Accessed 27 May 2016].
[18] TRNSYS documentation, Volume 4: Mathematical Reference [online] Available at: http://web.mit.edu/parmstr/Public/Documentation/05-MathematicalReference.pdf [Accessed 27 May 2016]
[19] A. Shirazi, R.A Taylor, S.D. White, & G.L. Morrison. (2016). Transient simulation and parametric study of solar-assisted heating and cooling absorption systems: An energetic, economic and environmental (3E) assessment. *Renewable Energy*, *86*, 955–971
[20] A. Shirazi, R.A Taylor, S.D. White, & G.L. Morrison. (2016). A systematic parametric study and feasibility assessment of solar-assisted single-effect, double-effect, and triple-effect absorption chillers for heating and cooling applications. *Energy Conversion and Management*, *114*, 258–277. http://doi.org/10.1016/j.enconman.2016.01.070

Acknowledgement

I would like to thank Professor Robert Taylor and the University of New South Wales for offering me an internship that corresponds to my interest in the field of solar engineering.

Appendix

Table 1 List of the TRNSYS types used in the simulation deck.

Component	Type	Comment
Controller	Type 2b	On/off with hysteresis
Auxiliary Heater	Type 6	TRNSYS 17 Library
Diverter	Type 11b	TRNSYS 17 Library
Tee	Type 11h	TRNSYS 17 Library
Tank	Type 60c	Stratified fluid storage tank
Solar collector	Type 1245	TESS Library
Pump	Type 110	Variable speed pump
Weather data generator	Type 109	Data format: tm2
Pipe	Type 31	TRNSYS 17 Library

Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:

Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.

Dr. Kumar is visiting faculty at Prince of Songkla University, Thailand. He have 16 years of research and teaching experience in the field of solar energy, drying and energy efficiency.

WEENTECH Proceedings in Energy- International Conference on Energy, Environment and Economics, September 2016
Edited by:
Dr. Renu Singh, IARI, New Delhi, India
Dr. Anil Kumar, PSU, Thailand
Publisher: World Energy and Environment Technology Ltd., Coventry, United Kingdom
Publication date: 12 September 2016
ISSN: 2059-2353
ISBN: 978-9932795-2-2
To purchase e-book online visit www.weentech.co.uk or email conference@weentech.co.uk