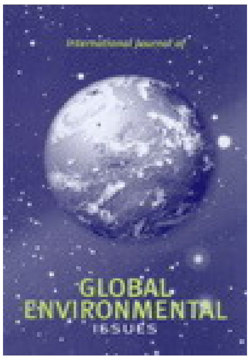

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Rasaq Adekunle Olabomi, A. Bakar Jaafar

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The techno-economics of growing high-value temperate crops under controlled soil temperature on tropical climate lowland

Rasaq Adekunle Olabomi*

Science, Technology and Innovation Department,
Directorate of Research,
National Institute for Policy and Strategic Studies,
PMB 2024, Bukuru, Plateau State, Nigeria
Email: rasaqolabomi@gmail.com
*Corresponding author

A. Bakar Jaafar

Perdana Centre,
Razak Faculty of Technology and Informatics,
Universiti Teknologi Malaysia,
Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
Email: Bakar.jaafar@utm.my

Abstract: Demand for high-value temperate fruits and vegetables such as lettuce, cabbage, and berries have increased with population growth despite decrease in available space for cultivation due to urbanisation. These crops particularly grow well under low soil temperature, hence their cultivation pose huge challenge in the hot tropics except on a few cool highlands and via greenhouse farming. Outputs from these methods are always complemented with importation to meet the demand. Studies have however shown that low soil temperature gives the right conditions for microbes that promote development of these crops. This study presents application of solar thermal chilled water for agricultural soil cooling, and the economic analysis of the cooling process. The analytical and experimental models show the cooling process is technically feasible. However, to ascertain its financial viability, additional scenarios with 1 kW, 5 kW and 10 kW cooling capacities were analysed together with the experimental size of the developed system of cooling. This shows that the viability of the system improves from 5 kW cooling capacity. In addition to all other widely cultivated crops, implementation of the proposed system would promote local production of temperate crops hence diminish heavy reliance on importation of these crops in tropical climate countries and enhance food security.

Keywords: soil cooling load; low-grade heat; temperate crops; financial viability; greenhouse gas emission reduction.

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Biographical notes: Rasaq Adekunle Olabomi is a Senior Fellow in the Science Technology and Innovation Studies Department under the Directorate of Research National Institute for Policy and Strategic Studies. National Institute is the highest Think Tank for Research, Reflection and Dialogue where professionals, academics and policy actors meet to find solutions to issues of national interest. He had his PhD in the area of solar energy application for chilled water production and utilisation for growing of temperate crop in the hot and humid tropical region via soil cooling system. He is also into solid waste management research.

A. Bakar Jaafar is a Professor at Perdana Centre, Razak Faculty of Technology and Informatics. He is the Founding Director and Research Fellow of UTM Ocean Thermal Energy Centre. He is a Mechanical Engineer by profession, an Environmental Scientist by specialisation, and a maritime expert by current pre-occupation. He has served in the professional civil service for 22 years where he turned around a privatised company on environmental quality monitoring and data management; commercialised an industrial patent, pioneered the incubation of dehydration technology for tropical fruits and produce; provided consultancy services and advice on matters relating to waste management.

1 Introduction

Temperate crops are high-value agricultural crops with higher returns per hectare of land than other commonly cultivated crops, having the potentials to increase farmer's income. The quest for growing temperate fruits and vegetables is triggered by the understanding of their rich in essential nutrients required for human health (He, 2017). High-value crops such as cabbage, berry fruits, broccoli, and lettuce grow well with low soil and air temperature (16°C–22°C) that is mostly obtainable in the temperate region. Therefore, cultivating them in the hot tropical climate countries is usually a big challenge (Yara, 2015) due to high cooling load imposed on the soil by solar radiation. This is worsened with gradual increase in global temperature occasioned by the climate change. Tropical climate soils are particularly characterised with high temperature (Mongkon et al., 2014), making it practically difficult to grow temperate crops except with the aid of cool greenhouse or on cool high altitude such as Jos Plateau in Nigeria and Cameron Highland in Malaysia. The demand for these crops is substantially complemented by importation since the few cool highlands and greenhouse farms cannot meet the ever increasing demands for the crops. Greenhouse farming for this purpose involves cooling the whole volume of the planting zone to create temperate-like thermal condition for the planted crops; this is usually energy intensive while highland farming in some cases leads to gully erosion (Prokop and Poreba, 2012).

Alternatively, soil cooling system offers more economic and precise method of providing the right temperature for the roots of temperate crops, therefore it is found suitable for thermal conditioning of tropical climate soil (Olabomi et al., 2016). Furthermore, radiant floor cooling with chilled water has been found to be more effective and economical in building indoor thermal comfort than air-cooling due to better thermal capacity and less pumping power requirement of water than air (Zarrella et al., 2014; Zhou et al., 2019). This becomes relevant in agriculture as most of the physiological processes of planted crops are controlled by soil temperature (Kim and Joo, 2020), excess of which results to alteration of the roots and functionalities of the crops (Ogbodo et al., 2010; Labeke et al., 1993).

In addition to the foregoing, a number of studies have been conducted around the application of chilled water for agricultural soil cooling, and aimed at cultivation of high-value temperate crops in the tropics with some experimental set-ups to support the studies (Sabri et al., 2018). Experimental soil cooling was conducted by Sabri et al. (2018) to lower soil temperature using chilled water, to a range of 14.6℃ and 20.1℃ in order to create conducive growth condition for temperate crops under the tropical climate. To assess the effects of soil temperature on planted crops (Labeke et al., 1993) conducted experimental soil cooling on selected cultivars using chilled water to attain soil temperature between 13℃ and 15℃, plus supplemental lighting.

Solar thermal chilled water has been given preference in this direction of studies (Kwong et al., 2017). However, the economic analysis of studies on the application of solar thermal chilled water for agricultural soil cooling has not been properly explored to ascertain its financial viability and to propose a number of viable options. Techno-economics of a system of solar thermal chilled water production and application for agricultural soil cooling is hereby presented in this paper. This consists of a dimensioned size of soil bed whose cooling load has been determined, with equivalent capacity solar-powered absorption chiller to provide the chilled water for the soil cooling through a network of chilled water pipe. The study is further conducted on the technical and economic analyses of the system, taking into consideration the costs of the system, the comparative costs savings and emission reduction potentials, and revenue generation scenario over the projected life of the project. Objectives of the study therefore include; to determine the soil cooling load and equivalent chiller's capacity to overcome the load, to evaluate the efficiency of the cooling system, and to assess the financial viability of the cooling system over its projected life span.

The economic analysis of the system is carried out using RETScreen® tool that has been found suitable for analysis of technical and economic studies of renewable energy technology (RET) projects prior to full-scale implementation of such projects in order to ascertain its viability (Moya et al., 2018; Pan et al., 2017).

Nomenclatures

R_n	Net solar radiation	$e_a(t)$	Water vapor pressure at reference height
Q_{inc}	I $\bar{Q}_h$ ncident solar radiation on the soil	R	Ideal gas constant
$\propto$	Soil surface albedo	M_w	Molar mass of water
σ	Boltzmann constant	A_s	Surface area of the soil bed
ε_s & ε_a	soil and air emissivity	h_c	Convective heat transfer coefficient
T_s & T_a	Temperatures at soil surface and air	l	Length of chilled water tube
$\bar{Q}_h$	Sensible heat flux	r_t	Inner radius of the chilled water tube
$\bar{Q}_L$	Latent heat due to vaporisation	t_p	Tube thickness,
ρ_a	Density of air above the soil	k_w	Thermal conductivity of water
C_{pa}	Specific heat of air	N_u	Nusselt number.
r_a	Boundary layer resistance	U	Component heat transfer coefficient

Nomenclatures (continued)

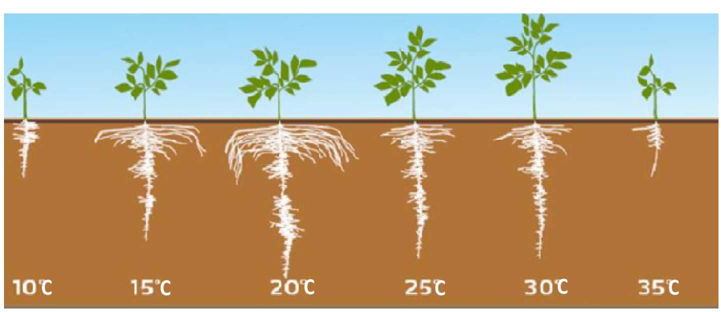
Z_r	Reference height	ΔT_{lm}	Log temperature difference between inlet and outlet fluid
U_r	Wind speed	γ	Factor of safety
K	Van Karman constant.	$Q_{load}(t)$	Cooling load imposed on the soil over the measurement period.
ρ_{v_0}	Soil surface vapour density	T_p	Undisturbed soil temperature along the chilled water tube
ρ_{v_a}	Water vapour density at reference height	T_s^t	Soil surface temperature at time t

2 Materials and methods

2.1 *Effects of soil temperature on planted crops*

Soil temperature plays an important role in the physiological balance of any planted crops (Figure 1). Studies have shown that high soil temperature or its wide variation negatively affects the activities of soil micro bacteria (Nik et al., 1986; Dai et al., 2020), with resultant effects on the development of roots and shoots of the planted crops (Nabi, 2008; Jewel et al., 2014; Sihag et al., 2020). Effects of soil cooling and supplemental lighting on five selected cultivars were investigated by Labeke et al., (1993) in which soil cooling contributed to increase in flower production of the tested cultivars and extended the flowering production beyond winter to summer periods. Soil and air temperatures were reported to have significant effects on growth and quality of vegetables in their home garden experimental study (Jewel et al., 2014).

Figure 1 Effects of soil temperature on development of planted crop (see online version for colours)

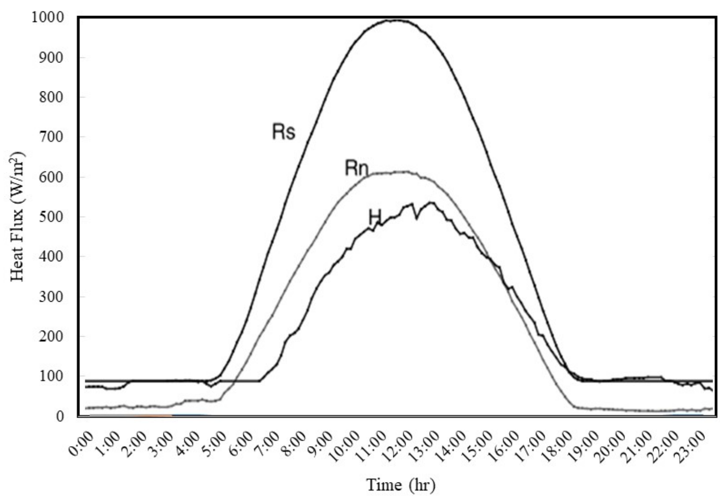


Temperate crops are mostly regarded as cold season crops and are more adaptable to soil temperature ranging from 14°C to 22°C for optimum development of the roots and shoot (Sabri et al., 2018). Growing these crops on tropical climate lowland soil with hot and humid characteristics results in heat-induced crop damage, and delayed heading (Fazilah et al., 2017). This is due to solar radiation induced cooling load. Meanwhile, according to Krarti and Kreider (1996), and experimentally demonstrated by Qin et al. (2002), as shown in Figure 2, at any given (z) depth below the ground surface, the resultant effects of solar heat flux on the undisturbed soil temperature (T_s^u) follows a periodical/harmonic variation with time.

$$T_s^u(z,t) = T_m + T_{am} R_e \left(e^{iwt}\right)$$

where T_s^u is the undisturbed soil temperature, T_m & T_{am} are mean and amplitude of the ground surface temperature variations, w is the angular frequency of the periodic variation ($w = 2\pi/day$)

Figure 2 Effects of solar heat on soil temperature profile



Source: Qin et al. (2002)

In tropical Singapore, temperate and sub-temperate vegetables have been grown in the recent past by cooling the root zone, leaving the shoot exposed to the ambient air (He, 2017).

2.2 Soil cooling load

The concept of cooling load is specifically used in heating, ventilation and air-conditioning (HVAC) system where HVAC equipment is used to offset the cooling load from the HVAC facility. The radiation heat absorbed by the soil constitutes the soil cooling load; that is the amount of heat needed to be removed from the soil for it to be cooled to the desired temperature. In estimating this load, it is a common practice to consider uncertainties that may arise from service conditions due to load variations (Moser and Folkman, 2008; Liu et al., 2014). This is usually taken care of by 'factor of safety', that is used either to allow future growth in loads so that the equipment can operate within the safe range (Ahmedullah, 2006; Gang et al., 2015, 2016) or to reduce the possibility of oversizing or under-sizing of HVAC equipment (Parameshwaran et al., 2012). The cooling load is therefore the product of the net heat flux on the soil and a safety factor, given as:

$$\bar{Q}_{load} = \bar{Q}_s \times \gamma$$

where γ is the factor of safety and $\bar{Q}_s$ is the net heat flux on the soil, $\bar{Q}_{load}$ is the soil cooling load

2.3 Solar resource in the tropics

As a region lying between latitudes 23.5 N and 23.5 S (Figure 3), the tropical climate is mostly found to be torrid, having hot and humid weather (Mekhilef et al., 2012; Parameshwaran et al., 2012; Chang et al., 2009), hence presenting both cooling load challenge and solar energy application opportunities. As a decentralised energy source, solar energy has been given a lot of research prominence in the recent times especially in the tropical regions where its potential is relatively higher (Chua and Oh, 2012; Agyenim et al., 2010). To make the better use of the tropical climate solar characteristics, a number of theoretical and experimental studies have been conducted towards the utilisation of the ample solar energy resources in the region (Yin et al., 2013), most especially with solar sorption cooling system (Fong et al., 2010). However, a major constraint in this area is the diffuse nature of the energy source (Hlbauer, 1986), hence solar collector is required to capture it in technologically useful quantity. The collector must therefore be properly sized to avoid unnecessarily increased cost (Bajpai, 2012).

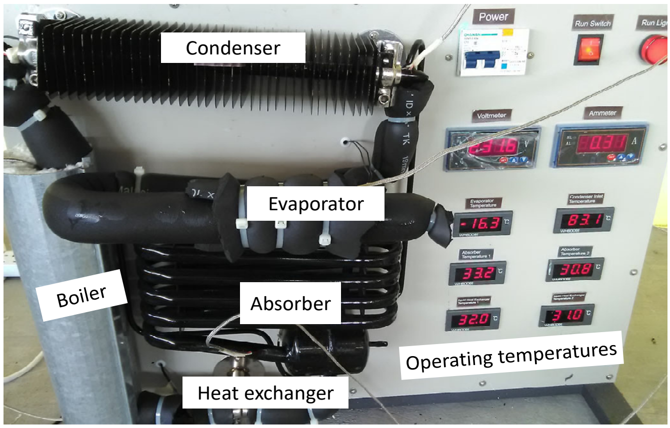
Figure 3 Global latitudes of regions (see online version for colours)

Solar thermal collector is used majorly to capture solar heat and supply it through thermal fluid for the activation of sorption cooling systems (Duan et al., 2012; Tsoutsos et al., 2009). The coefficient of performance (COP) of solar collector is however between 0.7 and 2.0 (Fong et al., 2010; Mokhtar et al., 2010), depending the type of the collector.

2.4 Chilled water production

An ammonia based vapour absorption refrigeration (VAR) system is considered in this study for chilled water production. The system is designed to operate on low-grade heat such as solar energy, using evacuated tube solar collector. The study is conducted on a laboratory size absorption cooling unit (shown in Figure 4), taking its operational parameters at steady state to determine its performance characteristics. The chiller is a thermally activated system, manufactured by Shandong XINGKE Intelligent Technology Company Limited.

Figure 4 Experimental absorption refrigeration system (see online version for colours)



The size of each of the components of the chiller is expressed in terms of its components heat transfer area (A_{ht}), given as:

$$A_{ht} = \frac{\bar{Q}}{U.\Delta T_{lm}} = \frac{\dot{m}(h_2 - h_1)}{U.\Delta T_{lm}}$$

Energy balances across each of the components is used to determine the total energy required to activate the chiller as well as the solar collectors size to capture the equivalent solar energy (Khan et al., 2017; Yeh et al., 2002; Bajpai, 2012).

$$Q_u = \frac{Q_b}{k_c}$$

$$A_c = \frac{Q_u}{Q_{inc}}$$

where $\bar{Q}_u$, $\bar{Q}_b$, A_c, k_c, are the energy received by collector, heat to vaporise working fluid, collector effective area, and collector thermal efficiency, respectively.

2.5 Chilled water flow rate

To control the soil temperature, a relation developed earlier by Olabomi et al. (2022) is used to determine soil temperatures corresponding to the optimised chilled water flow rate.

$$T_s^t = \frac{d_z}{k_s A_s} \tau \{Q_{load}(t) - \dot{m}_w C_{pq} \Delta T\} + T_p$$

where $\dot{m}_w$ is chilled water flow rate, T_s^t is soil surface temperature at time t, d_z is the depth of chilled water pipe, k_s is soil thermal conductivity, $Q_{load}(t)$ is cooling load imposed on the soil over the measurement period, C_{pw} is heat capacity of water, ΔT is temperature difference, and T_p is undisturbed soil temperature along the chilled water pipe.

2.6 Experimental set-up

The experimental soil cooling was conducted at the back of the Ocean Thermal Energy Centre (OTEC) of the Universiti Teknologi Malaysia. Chilled water from the chiller was channelled through the high density polyethylene (HDPE) pipe to the soil bed for the soil cooling process. The properties of the experimental soil cooling system are presented in Table 1.

Table 1 Soil bed and chilled water pipe specifications

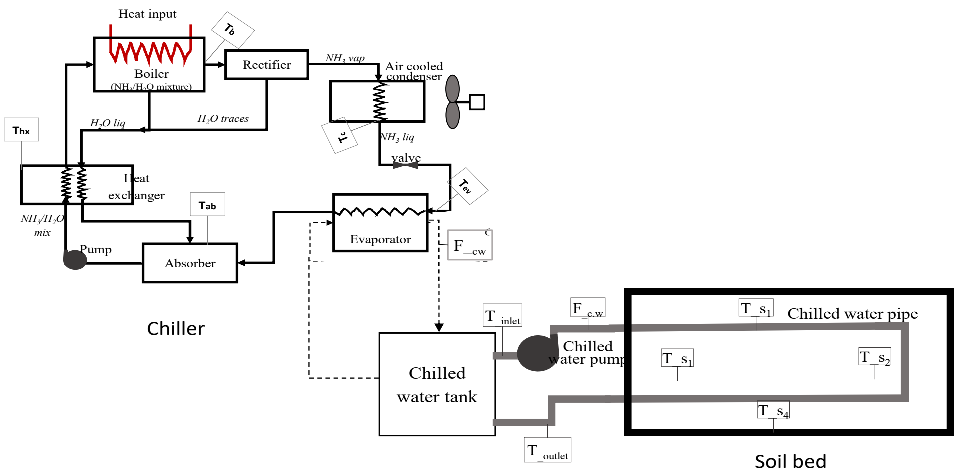
Soil bed container		*Soil*			*Chilled water pipe*				
Material	*Top surface area*	*Type*	*Thermal cond.*	*pH*	*Material*	*Length*	*OD*	*Thickness*	*Thermal cond.*
Polystyrene box	0.25 m^2	Loamy	1.5 W/m-K	4.85–5.0	HDPE	1.0 m	0.02 m	0.0025 m	0.42 W/m-K

The data collected for the soil cooling process were chilled water temperatures and flow rates, and soil temperatures (cooled soil and control soil). The data was collected and logged directly to the computer hard disk through the National Instrument data logger (Figure 5).

Figure 5 NI and LabVIEW installation for data logging (see online version for colours)

The experimental rig (Figure 6) has 15 data collection points comprising of; 2 flow sensors for measuring chilled water flow rates, 13 T-Type thermocouples for temperature measurements on chiller, chilled water, cooled soil, control soil, and ambient air. The experimental trials of four different flow rates were repeated each for seven days and data obtained were averaged. Since Malaysia has a fairly constant year-round weather, the period of the experiment represents the average daily weather throughout the year.

Figure 6 Schematic diagram of the experimental rig (see online version for colours)



2.7 Economic analysis

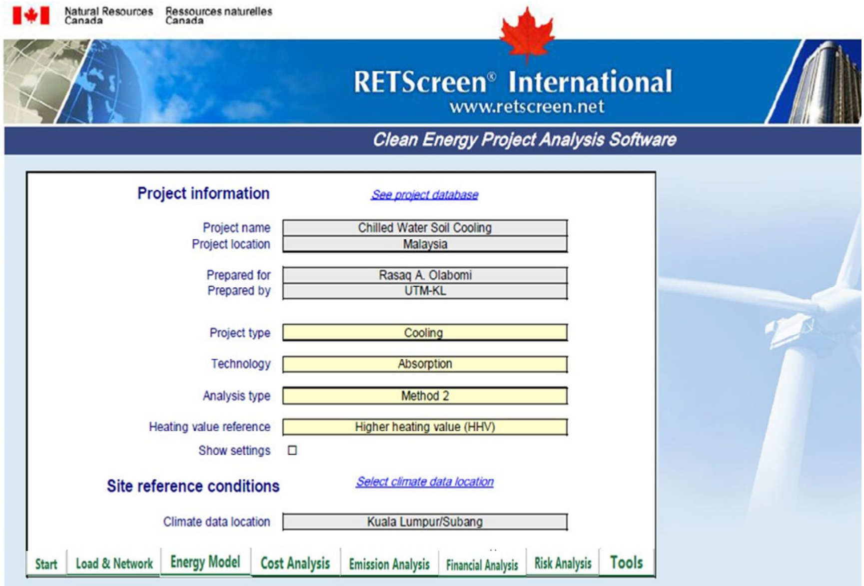
Decision making on RETs remains critical to implementation of clean energy projects because, the prove that a similar technology is cost-effective and reliable in some locations may not be enough to establish same in other locations (Kofi, 2005). With RETScreen® (Figure 7), the feasibility of a proposed project (Sy et al., 2020), performance analysis of an ongoing project and benchmarking of alternative projects (Sangroya et al., 2020) can be carried out for informed decision making on such project. Economic analysis of renewable energy like solar is carried out to access the pre-feasibility and feasibility studies of RETs projects at the initial stage with consideration to project location information as well as prevailing economic parameters. Analysis is done on the present study in comparison with a base case of the same capacity, using conventional cooling system.

The cost contents of the project economic analysis (shown in Table 2) include the initial costs and annual costs. Initial cost comprises of the costs associated with; project feasibility study, project development, engineering design, procurement of components and spare parts, and miscellaneous expenses. On the other hand, the annual cost (annual operating cost) refers to the cost incurred during the service life of the project, expressed as:

$$C_{op} = C_{fc} + C_m$$

where C_{op} is the annual operating cost, C_{fc} is the annual fuel cost and C_m is the annual maintenance cost of the project.

Figure 7 RETScreen® workspaces (see online version for colours)



However, since the developed project is an experimental scale, the results of the analyses may not be significant enough to conclude on its economic performance. As such, three additional scenarios (1 kW, 5 kW, and 10 kW) were analysed under the same operating conditions so as to observe the developed project in a near practicable sense. Additionally, the study was conducted at Universiti Teknologi Malaysia, hence Malaysian Ringgit (MYR) is used as the currency in the economic analysis as presented in this study.

Table 2 Project cost and income summary

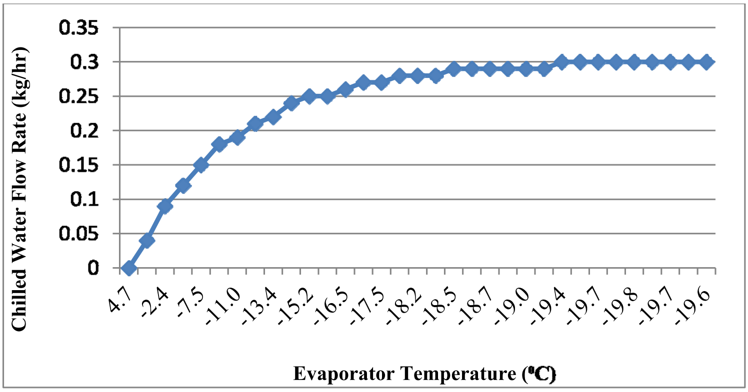
System capacity	*0.05 kW*	*1 kW*	*5 kW*	*10 kW*
Total initial costs (MYR)	11,500	32,288	44,756	74,550
Annual cost (MYR)	45	158	263	735
Annual savings and income (MYR)	233	2,260	8,963	17,726

3 Results and discussions

3.1 Chiller's performance

Chilled water production was achieved from the chiller's evaporator (Figure 4) which cooling rates were used to determine the chilled water production rates. As shown in Figure 8, an average flow rate of 0.03kg/hr of chilled water was achieved from the experimental chiller with the inlet and exit chilled water temperature of the chiller at an average of 5°C and 10°C, respectively.

Figure 8 Experimental chilled water flow rate at 5°C (see online version for colours)



3.2 Soil cooling performance

The chilled water inlet temperature to the soil was at maximum of 10°C, with a range of flow rates from 0.24kg/min to 0.6kg/min. The effect of the peak load during the middle of the day was observed on the soil cooling process, nevertheless, with set of temperatures and flow rates, soil cooling load was substantially offset and the temperature was kept within the suitable range for the temperate crops as shown in Figure 9 to Figure 12.

Figure 9 Chilled water flow rate at 0.24 kg/min (see online version for colours)

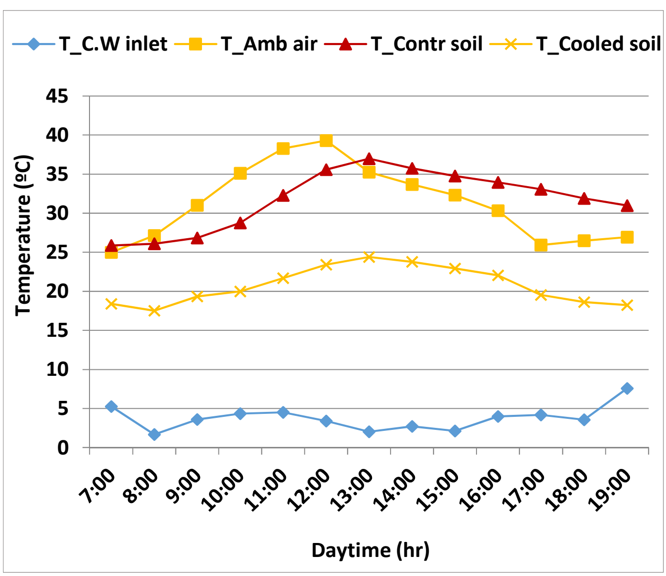


Figure 10 Chilled water flow rate at 0.36 kg/min (see online version for colours)

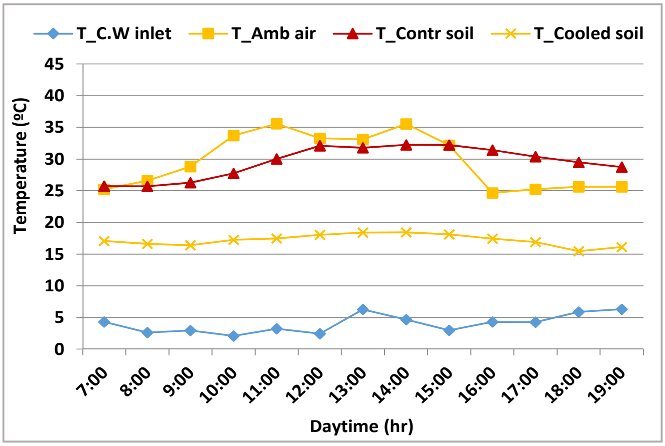


Figure 11 Chilled water flow rate at 0.42 kg/min (see online version for colours)

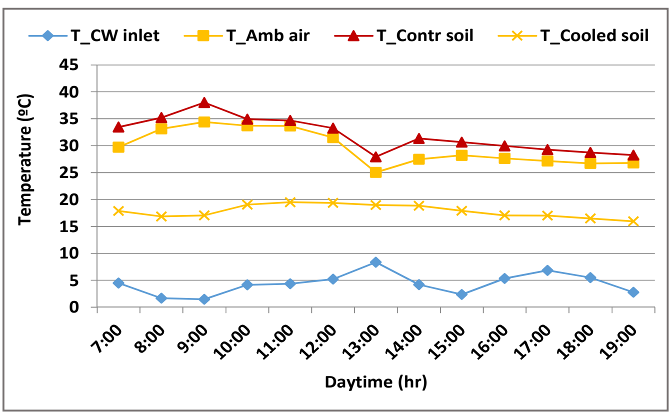
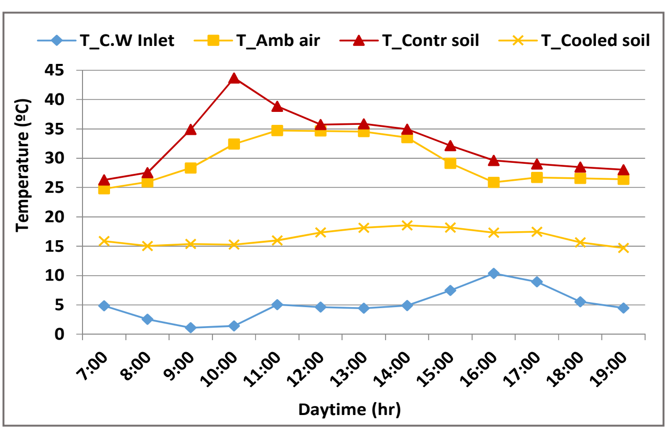


Figure 12 Chilled water flow rate at 0.6 kg/min (see online version for colours)



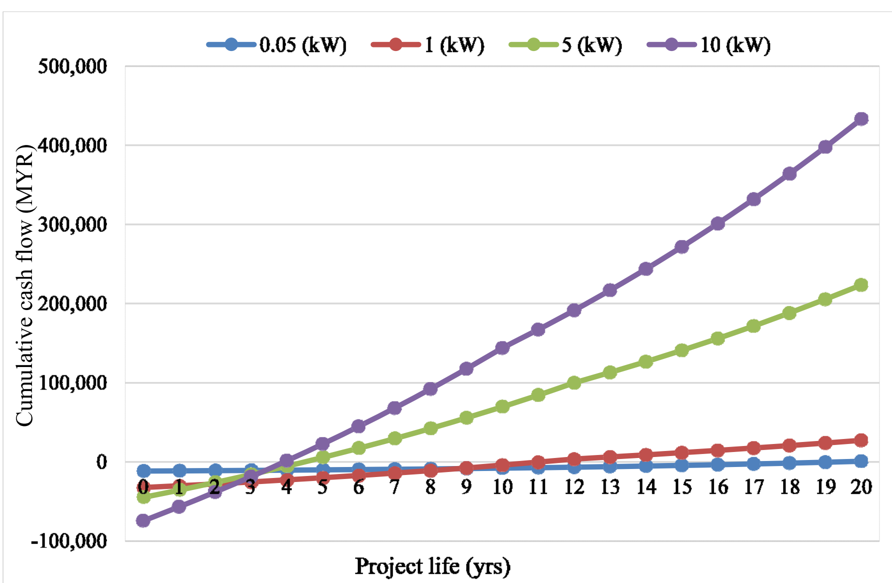
As shown in Figures 9 to 12, soil temperatures (T_s) in the four experimental trials are at lower range after 6pm on each of the trials. This is due to lack of additional soil cooling load for chilled water to offset. Therefore, to save energy cost, chilled water pumping may not be required beyond this period until the next day when solar radiation imposes soil cooling load again.

3.3 The economic analysis

Economic analysis is carried out not only to assess the financial viability for ascertaining commercialisation potentials of renewable energy project (Lee et al., 2021), but also to analyse its environmental impact with respect to its emission reduction in comparison with a base case of the same capacity but using different energy source (Wu et al., 2014). This study compares the chilled water production and application for the soil cooling process via solar powered vapour absorption chiller with a conventional (electricity powered) chiller of the same capacity, as a base case. Furthermore, the feasibility of most energy related projects may not be sufficient enough for its implementation (Olabomi et al., 2017), hence the analysis of its financial viability. This helps in planning and decision making on project prioritisation (Pölling et al., 2016) as well as evaluation of the social impacts on the larger society.

As presented in Figure 13, with respect to annual cash flow of the various capacities analysed, the projects shows increase viability with increase in capacity. However, 5 kW capacity system appears to be more relatively impressive even than 10 kW capacity. This is not unconnected with the different discount and depreciation rates applicable to the two cases based on their sizes as (shown in Appendix).

Figure 13 Projected annual cash flow (see online version for colours)



As presented in Table 3, the proposed system's financial viability improves with increase in cooling capacity. Besides the experimental size which is, of course not expected to be financially impressive, 1 kW capacity is also smaller in size than being viable. Both of the experimental size and 1 kW capacity give deficit NPV of MYR –7,494 and MYR –8,105 respectively throughout the 20 years of operating the project. However, irrespective of the difference in financial parameters affecting the annual cash flow, 10 kW capacity presents overall a better viability with respect to the net present value (NPV), annual life cycle saving cost, and cost-to-benefit (B-C) ratio that indicates the positive social impacts of the proposed system against the conventional (base case) system of the same capacity.

Table 3 Project financial viability

System capacity	*0.05 kW*	*1 kW*	*5 kW*	*10 kW*
Simple payback (yr)	49.6	15.4	5.1	4.4
Equity payback (yr)	19.4	11.1	4.5	3.9
Net present value (MYR)	–7,494	–8,105	82,064	225.803
Annual life cycle saving cost (MYR/yr)	–880	–952	8,050	18.119
Benefit-Cost (B-C) ratio	0.35	0.75	2.83	4.03

Part of the techno-economic analysis of energy related project is the environmental impacts of the energy production and its application. Specifically, greenhouse gas reduction potential is a major target in RET application (Lee et al., 2021; Sy et al., 2020). As presented in Table 4, despite the economic performances of the proposed systems with capacities less than 5 kW, each of the proposed capacities presents greenhouse gas emission reduction potentials that are quantified in terms of barrels of crude oil not burnt, implying the environmental friendliness of the proposed system in addition to its comparative cost saving benefits.

Table 4 Greenhouse gas emission summary

System capacity (kW)	*Net Annual GHG emission reduction (tCO_2)*	*Barrels of crude oil equivalence*
0.05	0.2	0.5
1	4.6	10.7
5	23.1	53.7
10	46.2	107

4 Conclusions

The growing demand for high-value fruits and vegetables, and the challenge of cultivating them in the tropical climate region result to heavy importation of the crops. The difficulty in cultivation of these crops is caused by heavy cooling load imposed on the soil due solar potential in the tropical climate countries. This though inhibits the cultivation of high-value crops, but the solar energy could equally be harnessed via vapour absorption refrigeration system to overcome the soil cooling load, to lower the soil temperature thereby making it suitable for the high-value temperate crops. The soil cooling load and equivalent absorption chiller's capacity had been analytically determined with experimental setup conducted to verify the model. The technical feasibility of the proposed cooling system has been demonstrated by both the analytical and experimental studies.

Since the technical feasibility may not be enough to make an informed decision on the project, its economic analysis had been carried out. This shows the overall viability of the project with increased capacity size. It is obvious from the study that capacities ranging from experimental sizes to 1kW may not suitable to decide on the viability of the project; these are basically for the proof of concept. However, 5 kW and 10 kW capacity present better financial viabilities, with the 5 kW capacity showing better annual cash flow than 10 kW in relation to their capacity sizes and selected financial parameters. Meanwhile, other indicators, such as NPV, B-C ratio, and annual life cycle savings indicated that bigger capacities generally give better financial viabilities of the proposed system of cooling. Furthermore, irrespective of the size, this system also shows the potentials for greenhouse gas emission reduction, hence environmentally benign. This may influence its application and adaptation to a wide variety of temperate crops and in any of the tropical climate regions.

The output of this study presents an excellent opportunity for tropical climate countries to overcome heavy reliance on importation to meet high-value crops demand, bearing in mind the availability of relative high solar energy potential. Further research may however be focused on crop-specific and location-specific performance analyses of this system.

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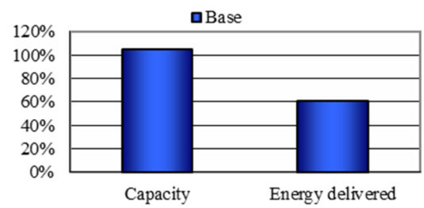
Appendix

0.05 kW capacity

Proposed case system characteristics		
Cooling		
Base load cooling system		
Technology	Absorption	
Fuel type	User-defined fuel	
Capacity	0.05 kW	104.7%
Cooling delivered	0 MWh	60.5%



Project costs and savings/income summary		
Initial costs		*MYR*
Development	39.0%	4,500
Cooling system	43.3%	5,000
Balance of system & misc.	17.7%	2,050
Total initial costs	*100.0%*	*11,550*
Annual costs and debt payments		
O&M		0
Fuel cost – proposed case		0
Total annual costs		*0*
Annual savings and income		*MYR*
Fuel cost – base case		69
Customer premium income (rebate)		14
Other income (cost) – 20 yrs		150
Total annual savings and income		*233*

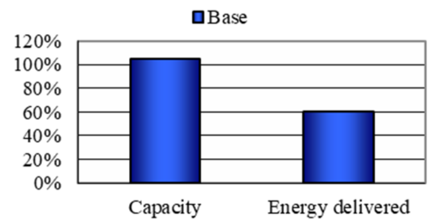
Financial parameters		
General		
Fuel cost escalation rate		5.0%
Inflation rate		10.0%
Discount rate		10.0%
Project life		20 yrs
Financial viability		
Pre-tax IRR – equity		0.5%
Pre-tax IRR – assets		0.5%
After-tax IRR – equity		0.5%
After-tax IRR – assets		0.5%
Simple payback		49.6 yr
Equity payback		19.4 yr
Net present value (NPV)	MYR	–7,494
Annual life cycle savings	MYR/yr	–880
Benefit-cost (B-C) ratio		0.35
GHG reduction cost	MYR/tCO_2	3,814

Yearly cash flows			
Year	*Pre–tax*	*After–tax*	*Cumulative*
#	*MYR*	*MYR*	*MYR*
0	–11,550	–11,550	–11,550
1	252	252	–11,298
2	273	273	–11,025
3	296	296	–10,729
4	321	321	–10,409
5	348	348	–10,061
6	377	377	–9,684
7	409	409	–9,275
8	444	444	–8,831
9	482	482	–8,348
10	524	524	–7,824
11	570	570	–7,254
12	620	620	–6,634
13	674	674	–5,960
14	734	734	–5,226
15	799	799	–4,427
16	870	870	–3,556
17	948	948	–2,608
18	1,034	1,034	–1,574
19	1,127	1,127	–447
20	1,229	1,229	782

GHG emission reduction summary					
Cooling project	Years of occurrence	Base case GHG emission	Proposed case GHG emission	Gross annual GHG emission reduction	Net annual GHG emission reduction
	yr	tCO_2	tCO_2	tCO_2	tCO_2
	1–20	0.2	0.0	0.2	0.2
Net annual GHG emission reduction			0.2 tCO_2	Equivalent to 0.5 barrels of crude oil not consumed	

1 kW capacity

Proposed case system characteristics			
Cooling			
Base load cooling system			
Technology	Absorption		
Fuel type	User-defined fuel		
Capacity	1 kW	104.7%	
Cooling delivered	9 MWh	60.5%	



Project costs and savings/income summary		
Initial costs		*MYR*
Development	13.9%	4,500
Cooling system	67.4%	21,750
Balance of system & misc.	18.7%	6,038
Total initial costs	*100.0%*	*32,288*
Annual costs and debt payments		
O&M		158
Fuel cost - proposed case		0
Total annual costs		*158*
Annual savings and income		*MYR*
Fuel cost – base case		1,383
Customer premium income (rebate)		277
Other income (cost) – 12 yrs		600
Total annual savings and income		*2,260*
Financial parameters		
Fuel cost escalation rate		5.0%
Inflation rate		10.0%
Discount rate		10.0%
Project life		20 yrs

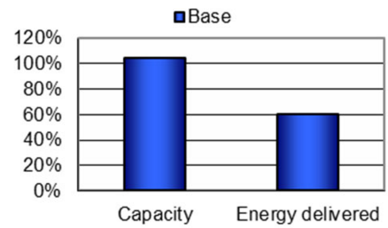
Financial viability		
Pre-tax IRR – equity		6.3%
Pre-tax IRR – assets		6.3%
After-tax IRR – equity		6.3%
After-tax IRR – assets		6.3%
Simple payback		15.4 yr
Equity payback		11.1 yr
Net present value (NPV)	MYR	–8,105
Annual life cycle savings	MYR/yr	–952
Benefit-Cost (B-C) ratio		0.75
GHG reduction cost	MYR/tCO_2	206

Yearly cash flows			
Year	*Pre-tax*	*After-tax*	*Cumulative*
#	*MYR*	*MYR*	*MYR*
0	–32,288	–32,288	–32,288
1	2,215	2,215	–30,073
2	2,333	2,333	–27,740
3	2,457	2,457	–25,282
4	2,589	2,589	–22,694
5	2,726	2,726	–19,967
6	2,872	2,872	–17,096
7	3,024	3,024	–14,071
8	3,185	3,185	–10,886
9	3,354	3,354	–7,532
10	3,532	3,532	–3,999
11	3,719	3,719	–280
12	3,916	3,916	3,636
13	2,587	2,587	6,222
14	2,689	2,689	8,911
15	2,793	2,793	11,705
16	2,900	2,900	14,605
17	3,009	3,009	17,613
18	3,119	3,119	20,733
19	3,232	3,232	23,965
20	3,345	3,345	27,310

GHG emission reduction summary					
Cooling project	*Years of occurrence*	*Base case GHG emission*	*Proposed case GHG emission*	*Gross annual GHG emission reduction*	*Net annual GHG emission reduction*
	1 to 10 and beyond	*4.6 tCO_2*	*0.0 tCO_2*	*4.6 tCO_2*	*4.6 tCO_2*
Net annual GHG emission reduction			4.6 tCO_2	Equivalent to 10.7 barrels of crude oil not consumed	

5kW capacity

Proposed case system characteristics			
Cooling			
Base load cooling system			
Technology	Absorption		
Fuel type	User-defined fuel		
Capacity	5 kW	104.7%	
Cooling delivered	44 MWh	60.5%	



Proposed case system summary	*Fuel type*	*Fuel consumption*	*Capacity*	*Energy delivered*
Cooling base load	User-defined fuel	242,405,425 kJ	5 kW	44MWh

Project costs and savings/income summary		
Initial costs		*MYR*
Development	10.1%	4,500
Cooling system	72.9%	32,625
Balance of system & misc.	17.1%	7,631
Total initial costs	*100.0%*	*44,756*
Annual costs and debt payments		
O&M		263
Fuel cost - proposed case		0
Total annual costs		263
Annual savings and income		*MYR*
Fuel cost – base case		6,917
Customer premium income (rebate)		346
Other income (cost) – 12 yrs		1,700
Total annual savings and income		*8,963*
Financial parameters		
Fuel cost escalation rate		5.0%
Inflation rate		7.5%
Discount rate		7.5%
Project life		20 yr

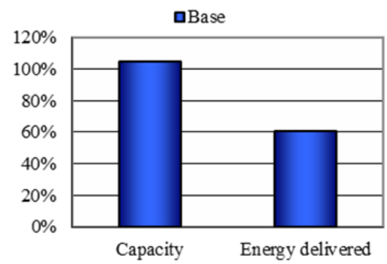
Financial viability		
Pre-tax IRR – equity		24.2%
Pre-tax IRR – assets		24.2%
After-tax IRR – equity		24.2%
After-tax IRR – assets		24.2%
Simple payback		5.1 yr
Equity payback		4.5 yr
Net present value (NPV)	MYR	82,064
Annual life cycle savings	MYR/yr	8,050
Benefit-Cost (B-C) ratio		2.83
GHG reduction cost	MYR/tCO_2	(369)

Yearly cash flows			
Year	*Pre-tax*	*After-tax*	*Cumulative*
#	*MYR*	*MYR*	*MYR*
0	–44,756	–44,756	–44,756
1	9,129	9,129	–35,627
2	9,578	9,578	–26,049
3	10,050	10,050	–16,000
4	10,544	10,544	–5,456
5	11,062	11,062	5,606
6	11,606	11,606	17,212
7	12,176	12,176	29,389
8	12,774	12,774	42,163
9	13,401	13,401	55,564
10	14,059	14,059	69,622
11	14,748	14,748	84,370
12	15,471	15,471	99,841
13	13,023	13,023	112,864
14	13,657	13,657	126,521
15	14,322	14,322	140,844
16	15,019	15,019	155,863
17	15,749	15,749	171,612
18	16,514	16,514	188,126
19	17,316	17,316	205,441
20	18,155	18,155	223,597

GHG emission reduction summary					
Cooling project	*Years of occurrence*	*Base case GHG emission*	*Proposed case GHG emission*	*Gross annual GHG emission reduction*	*Net annual GHG emission reduction*
	yr	tCO_2	tCO_2	tCO_2	tCO_2
	1 to 9	23.1	0.0	23.1	23.1
	10 and beyond	20.8	0.0	20.8	20.8
Net annual GHG emission reduction		23.1 tCO_2	Equivalent to 53.7 barrels of crude oil not consumed		

10 kW capacity

Proposed case system characteristics			
Cooling			
Base load cooling system			
Technology	Absorption		
Fuel type	User-defined fuel		
Capacity	10 kW	104.7%	
Cooling delivered	88 MWh	60.5%	



Proposed case system summary	*Fuel type*	*Fuel consumption*	*Capacity*	*Energy delivered*
Cooling base load	User-defined fuel	484,810,851 kJ	10 kW	88 MWh

Project costs and savings/income summary		
Initial costs		MYR
Development	6.7%	5,000
Cooling system	80.5%	60,000
Balance of system & misc.	12.8%	9,550
Total initial costs	*100.0%*	*74,550*
O&M		735
Fuel cost – proposed case		0
Total annual costs		*735*
Annual savings and income		*MYR*
Fuel cost – base case		13,834
Customer premium income (rebate)		692
Other income (cost) – 10 yrs		3,200
Total annual savings and income		*17,726*

Financial parameters		
Fuel cost escalation rate		5.0%
Inflation rate		7.5%
Discount rate		5.0%
Project life		20 yr
Financial viability		
Pre-tax IRR – equity		27.5%
Pre-tax IRR – assets		27.5%
After-tax IRR – equity		27.5%
After-tax IRR – assets		27.5%
Simple payback		4.4 yr
Equity payback		3.9 yr
Net present value (NPV)	MYR	225,803
Annual life cycle savings	MYR/yr	18,119
Benefit-Cost (B-C) ratio		4.03
GHG reduction cost	MYR/tCO_2	(415)

	Yearly cash flows		
Year	*Pre-tax*	*After-tax*	*Cumulative*
#	*MYR*	*MYR*	*MYR*
0	–74,550	–74,550	–74,550
1	17,758	17,758	–56,792
2	18,560	18,560	–38,232
3	19,399	19,399	–18,833
4	20,276	20,276	1,443
5	21,193	21,193	22,636
6	22,152	22,152	44,789
7	23,155	23,155	67,944
8	24,204	24,204	92,148
9	25,300	25,300	117,448
10	26,447	26,447	143,895
11	23,215	23,215	167,110
12	24,335	24,335	191,446
13	25,509	25,509	216,954
14	26,737	26,737	243,691
15	28,023	28,023	271,714
16	29,370	29,370	301,084
17	30,780	30,780	331,864
18	32,256	32,256	364,121
19	33,801	33,801	397,922
20	35,419	35,419	433,341

GHG emission reduction summary					
Cooling project	*Years of occurrence*	*Base case GHG emission*	*Proposed case GHG emission*	*Gross annual GHG emission reduction*	*Net annual GHG emission reduction*
	yr	*tCO_2*	*tCO_2*	*tCO_2*	*tCO_2*
	1 to 9	46.2	0.0	46.2	46.2
	10 and beyond	41.5	0.0	41.5	41.5
Net annual GHG emission reduction		46.2 tCO_2	Equivalent to 107 barrels of crude oil not consumed		