Increasing energy efficiency and assessing an alternate energy option for Australian Protected Cropping

Joshua Jarvis
NSW Department of Primary Industries

Project Number: VG09124

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This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetables industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of:
Solar Dryers
the vegetables industry

ISBN 0 7341 3351 0

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

Horticulture Australia

NSW Department of Primary Industries

Final report

VG09124 'Increasing energy efficiency and assessing an alternate energy option for Australian protected cropping'

Author: Joshua Jarvis, Ourimbah
Research provider: NSW Department of primary Industries
Description: Final report
Date: 8/6/2014

Project leader VG09124:

Joshua Jarvis
Industry & Investment NSW
Central Coast Primary Industries Centre
Locked Bag 26, Gosford NSW 2250
Tel 02 4348 1900 Fax 02 4348 1910
Email joshua.jarvis@dpi.nsw.gov.au

Project personnel:

Jeremy Badgery-Parker, David Sargent

Collaborators:

David Hunt EHR consultants, formerly QDAFF (QDPI)

DR D.Alterman *et al.*
University of Newcastle.
Faculty of Engineering and Built Environment.

Solar Dryers Australia Pty ltd
34 Coronation Street
Bellingen NSW 2454
sales@solardry.com.au
Phone: 61 2 6655 2100
Fax: 61 2 6655 2017

The purpose of this project was to conduct an investigation into alternate energy sources for the heating of protected cropping structures, and provide a cost benefit analysis of some of the identified alternate energy sources.

June 2014

ACKNOWLEDGMENT

The project team wish to express their appreciation to the contribution provided by QDAFF (QDPI), Solar Dryers, the University of Newcastle, and all the other members of the technical team who provided inputs during the project.
Our appreciation is also extended to the participating farmers who gave us access to their farms and especially those who adopted our energy saving measures and provided valuable feedback on the energy self audit survey tool.

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Glossary

Energy survey audit kit	a collection of audit sheets, factsheets and a audit guide manual to help growers identify areas for energy savings
Geothermal heat pump (GHP)	is a central heating and/or cooling system that transfers heat to or from the ground, as is also referred to as ground source heat pump (GSHP)
Heat load	the amount of heating required to keep a structure at a specified temperature, regardless of outside temperature.
Hydronic heating	Hydronics is the use of water as the heat-transfer medium in heating and cooling systems.
Phase change material (PCM)	is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units.
Thermal resistivity	is a heat property and a measurement of a temperature difference by which an object or material resists a heat flow (heat per time unit or thermal resistance). Thermal resistance is the reciprocal of thermal conductance.
U-value	a measure of the flow of heat through an insulating or building material: the lower the U-value, the better the insulating ability.
Walk through	that portion of the inspection where the inspector makes non-intrusive, visual observations of readily accessible areas of the subject property.

Media Summary

Energy has become an increasingly important factor in determining greenhouse enterprise profitability. As energy prices rise the economy will inevitably move towards full accounting for carbon dioxide emissions.

A two tiered approach was utilised in this project.

Firstly, the creation of a self-assessment energy audit kit will help growers identify, categorise and identify actions to achieve energy savings aimed at a reduction of energy demand through upgrading of systems.

Energy efficiency is more than simply turning equipment off. It involves using electricity or fuel more efficiently to get the most output from equipment at the least practical cost.

Undertaking the audit process has more benefits than simply estimating energy use. It helps growers to identify the major components of their energy bills and attribute an operating cost to each item. It also helps show where significant savings can be made through replacing inefficient pieces of equipment and/or identifying the costs of running equipment unnecessarily.

Secondly, through the comparison of alternate heating technology for greenhouses, analysis shows that compared with conventional heating systems, significant energy and cost savings can be achieved through investment with different heating options.

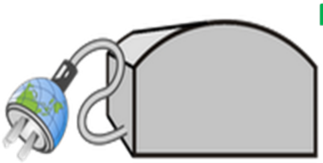
Over the next decade, the cost of electricity across Australia is projected to rise 2% per year while the gas price is expected to increase by 8.6% per annum.

Such an increase in LPG prices over the next decade will alter the economic balance to favour the use of “electricity driven” alternatives such as ground source heat pumps. Likewise, as energy prices rise, the return on investment in solar thermal technology noticeably improves.

A dollar investment in a ground source (surface water) heat pump heating system could return almost ‘two dollars’ at current energy price predictions while still showing a return on investment of around 30% if electricity costs rise considerably and LPG prices remain moderate.

To assist the industry in calculating estimated greenhouse heat loads and to provide a model for analysing the comparative energy costs, a series of Greenhouse energy (heating) estimator tools have been developed. Heating estimator requires Excel 2007 or better to run effectively, all other resources can be downloaded in pdf format. These are available on the website portal established for this project - https://sites.google.com/site/greenhouseenergyefficiency/home

NSW DPI Greenhouse Energy Heating Estimator and Resource Page.
QR code link:



NSW DPI Greenhouse Energy Heating Estimator

https://sites.google.com/site/greenhouseenergyefficiency/greenhouse-energy-heating-estimators

Quick Search Type: google sites energy estimator

Technical summary

Managing energy and environmental emissions on farms firstly requires an understanding of where the energy is being used. To this end, a self-assessment energy efficiency audit pack was developed to help growers identify and estimate the energy use efficiency of their greenhouse production facility. This energy audit pack provides a three-step process for identifying all energy-using equipment and systems onsite, calculating what they cost to run over a year, and includes information on the options for lower cost methods that may be used to improve energy efficiency.

To test the functionality of the audit method, eight greenhouse facilities that represent different crops, geographical locations, and the level of technology used by the industry were used for audit development. Over a six month period an energy efficiency assessment was conducted at each facility for the purposes of:

1. Testing the ease and accuracy of the self-assessment audit process and questionnaire
2. Obtaining feedback from growers on how conducting an energy efficiency survey can help to change how they identify energy use
3. Providing an understanding of where energy is being used within a greenhouse
4. Gathering data on the energy used by equipment and systems for calculations of energy costs

Although conducting a comprehensive energy assessment can be time consuming, the process can help to identify simple low-cost energy saving options as well as providing a method of prioritising equipment upgrades.

The audits conducted during this project have shown that undertaking the audit process has other benefits than simply estimating energy use; it has helped growers to look beyond a dollar value on an electricity bill and separate out the operating costs of specific equipment.

Furthermore, the audits have shown that greenhouse energy efficiency relates to more than simply reducing electricity costs or heating fuel, it needs to be a whole-of-farm approach where the principles of energy use efficiency are applied to all production equipment, areas and management practices to ensure the best energy saving strategies are implemented.

Analysis of the cost benefit of three potential alternate heating technologies for greenhouses show that compared with conventional heating systems, significant energy and cost savings can be achieved through investment in different heating options.

Preliminary technical and economic assessments indicated the proposed solar technology may not be viable at this time for this industry. This however does not preclude other solar options from being utilised as a supplemental heating source.

A trial site demonstrating two alternate energy sources was installed at the NSW DPI research station at Somersby, this provided data for testing and refining energy budget calculations. This site aided the project in establishing the energy balance for these types of applications, computing economic and environmental feasibility and developing suitable infrastructure requirements in a typical greenhouse, especially with regards to heat storage and greenhouse energy efficiency.

The demonstration site consisted of three comparative greenhouses. One was fitted with containerised phase change material (PCM) and one with a hydronic heating system linked to a geothermal heat pump and heat exchange loop. The final acted as the control structure with no system installed.

Records of temperature and humidity were collected over a period of two years, with ambient records provided by site specific weather station and a nearby DPI weather station. This data was used to calculate energy movements and heat load requirements.

Using this energy data and with the costs calculated over a 10 year investment period, assuming an annual interest rate of 5%, LPG costs $0.67/L and will increase 3% p.a., electricity costs $0.21/kWh and increases 5% p.a. and off-peak electricity (available for 7 hrs. per night) costs $0.08/kWh and will also increase at 5% p.a. Calculations where based on these figures in August of 2013.

On this basis, it has been calculated that the geothermal heat pump system is the most cost effective option, followed by natural gas (not available in many production areas), then LPG and finally direct heating with electricity which is used as a benchmark.

Further investigation in to the use of a thermal exchange box and/or a thermal battery technology utilising solar thermal and heat pump is recommended. Thermal battery capacity may be able to be increased by the use of phase change materials as the thermal load source.

Introduction

Executive Summary

Energy to heat the greenhouse and maintain optimal growing conditions is, for most growers, one of the most significant costs in a greenhouse vegetable business.

This project makes it easier for greenhouse growers to identify areas of inefficiency, reduce costs and carbon emissions and to make better energy (heating) investment decisions. This has been achieved by giving growers easy to use and reliable tools for finding ways to save energy and by evaluating and demonstrating the cost to benefit of alternate energy systems.

Management of energy and environmental emissions is a significant challenge and opportunity for all of horticulture, in particular the protected cropping sector. Energy is a significant input in controlled environment horticulture and an important source of environmental emissions. Energy underlies this sector's capacity to provide a consistent supply of fresh, quality, safe food in a changing global environment/climate and will become an increasingly important factor in determining enterprise profitability as energy prices continue to rise.

Alternate energy technologies and improved energy management are expected to be able to reduce energy demands of the greenhouse industry by 30 to 60%. This project is the critical step needed in moving the Australian greenhouse industry forward into adopting alternate, lower carbon energy options and improving energy efficiency.

With all assessments of likely future trends suggesting that the cost of energy will rise, this project sought to assist greenhouse growers to improve energy efficiency and to determine feasible alternate energy management options for Australian protected cropping.

The technical review, developed from a desk-top study, identified the major technology types used in the protected cropping industry and considered the critical components (in terms of energy use) of each of these technologies. (Appendix A)

A technology review (Appendix B) has been completed identifying techniques and technologies that can improve energy efficiency in greenhouses in conjunction with a walk-through energy review audit to assist growers to identify potential efficiency gains.

The structure for on-site energy surveys has been developed as a farm walk through. The audit provides producers with a tool to highlight areas of potential energy savings, and assist them with canvassing options for replacement or changing use patterns.

The draft design for the primary solar technology option being investigated in this project coupled with preliminary technical and economic assessments indicated that the proposed solar technology may not be viable at this time for this industry.

The assessment of existing energy uses and energy demands for a 'typical' protected cropping enterprise, has determined energy demands and associated costs. The analysis of the use of solar thermal technology as an alternate integrated energy system has been reported in Appendix C.

A review of the potential application of phase change materials to improving greenhouse energy management has also been completed. Modelling by the Priority Research Centre for Energy (University of Newcastle) indicates that phase change material can significantly reduce the fluctuation of the greenhouse air temperature in both winter and summer (Appendix D).

The project also sought to determine a potential alternate energy option to supplement or replace fossil fuels where possible. Detailed data collection and assessment of energy inputs and outputs have been undertaken for the 2012 and 2013 winter period to determine the performance, practicality and, importantly, economic feasibility of two exciting energy technology applications for temperature management in greenhouses.

Firstly geothermal heat pump technology is a system where heat is exchanged with the ground, that is, heat energy can be extracted from the ground or 'disposed of' into the ground by way of a water loop. This technology is already well proven and increasingly being used in residential and commercial buildings and offers a lot of potential for greenhouse temperature (and humidity) management. A second innovation assessed was the use of a phase change material to provide passive heating (and cooling) within a greenhouse. A phase change material is a substance that can absorb or lose a large amount of heat before it changes phase, that is, melts or freezes.

A demonstration site was installed at the NSW DPI Somersby field station to trial and display these two promising technologies – geothermal heat pumps and phase change materials. The energy balances for the different systems were monitored and across summer and during the winters of 2012 - 2013 to collect accurate energy data on the performance and costs of these technology options. A benefit cost analysis was undertaken that showed that while the investment in PCM is substantial, the absence of on-going operating costs suggests this technology could provide significant energy and cost savings. The use of a geothermal heat pump is also very favourable full report see Appendix E. The demonstration site successfully generated significant energy data which was used to measure and calculate both the infield performance and costs of these technology options.

The final component of the project was the delivery of self-assessment packages including a newly published energy efficiency guidebook, assessment workbook and an online "greenhouse heating estimator" all designed for growers to improve energy efficiency and evaluate their carbon footprint in the greenhouse and around the farm (Appendix F).

A large proportion of this project reporting requirements, details and analysis are contained within supplemental reports included in the appendices. The information contained in the body of this final report outlines and defines the parameters under which these standalone reports were generated.

The cost of energy will continue to rise and the outputs from this project will assist greenhouse growers to improve energy efficiency and to determine feasible alternate energy management options for Australian protected cropping.

Materials and Method

Technical Review

A thorough review of the scientific and industry journal literature was undertaken to identify existing techniques and technologies with respect to energy efficiency that are currently being employed in protected cropping. This report was used to inform the various energy efficiency activities conducted in the project and was updated and expanded to reflect developments in the project. (Appendix G)

The technology review identified the main energy use areas within protected cropping enterprises. The review collated existing information on purchase costs and energy use i.e. running costs (where available) from product specifications or derived from manufacturer/product information. This will allow producers to begin the process of identifying potential alternative technologies and provide a framework for making investment decisions prior to purchase and installation.

The findings from the desktop technology research suggested that small, affordable ‘quick-fix’ measures can be identifiable by following the walk through audit process.

A cost benefit analysis has been conducted on three energy use reduction options in a greenhouse production facility. Examples are given on the potential energy and cost savings related to upgrading an irrigation pumping system, replacing old inefficient appliances in a staff room and replacing the greenhouse covering material with a material of greater heat retention capacity.

These examples show that there is potential to increase energy efficiency in virtually all areas of a greenhouse production facility. The benefit to cost analysis of all three examples have proved a positive investment return with considerable energy and cost savings obtained well within the first 2 years of implementing the changes. The full report *‘An analysis of three energy use reduction options for a greenhouse vegetable production facility’* is attached Appendix B.

Energy self-audits

The walk through audit structure has been developed for on-site energy surveys. A group of growers where selected for the initial trial of the audit, their feedback was positive and their ongoing participation secured.

The audit provides producers with a tool to highlight areas of potential energy saving by targeting high energy-use equipment procedures and identifying options that will assist them to alter or fine-tune those procedures and/or replace aging equipment.

The walk-through audit booklet was trialled in 2010 for its effectiveness in capturing energy use at greenhouse facilities and grower feedback on the ease of its use was sought. Eight walk-through audits were initially conducted at varying levels of technology sophistication. This process provided valuable information pertaining to the re-formatting of the audit document and in the collection of energy use data. This highlighted areas deserving further refinement and assisted with the development of the “reference compendium” for growers.

The walk-through audit pack prepared enables growers to assess the energy use in their enterprise, identify potential areas of energy savings and assist their decision making to address the problem areas in a practical and affordable manner.

An accompanying reference compendium comprises part of this energy audit pack. This provides information that will assist growers in working through the audit and its results and will specifically allow them to identify smaller, practical issues. These are not necessarily large energy sinks but collectively will assist in saving energy (and money) across the broader enterprise.

To increase the rigour of the process, the walk-through audit pack was aligned with the Australian Standards (*Energy audits AS/NZS 3598:2000*). This ensures that the vegetable industry adheres to current national best practice. In the longer-term, linking to the Australian Standards will increase the effectiveness of the walk-through audit to identify energy use in all areas and processes of a protected cropping enterprise.

An internal project team review was conducted in 2010. This review suggested that to improve the effectiveness of these materials as grower resources, they should be integrated into a more appropriate and grower friendly information guide and complementary farm energy self-review. Using as a model the highly successful *Keep it Clean* hygiene manual (developed in close consultation with industry participants in a previous project VG07118), the project collaborators reworked the technically dense materials into a more informative format and design.

The resulting self-assessment audit pack for energy efficiency will help growers identify and estimate the energy use efficiency of their greenhouse production facility. This audit pack provides a three-step process for identifying all energy-using equipment and systems onsite, calculates running costs over a year, and includes information on the options or low cost methods that may be used to improve energy efficiency.

A series of Greenhouse energy (heating) estimator tools have also been developed to assist the industry in calculating estimated greenhouse heat loads, and to provide a model for analysing the comparative energy costs,. These tools are available on the website portal for this project - https://sites.google.com/site/greenhouseenergyefficiency/home

All resources are available to growers on request and are available online at the above project portal site.

Three factsheets (FS) and 2 mini reviews have been completed in support of the audit tool, these are –

1) *Greenhouse covering materials and accessories - a mini review*

2) *Traditional and alternative fuel comparison - a mini review*

3) *What is energy efficiency - FS1*

4) *Irrigation energy efficiency - FS2*

5) *Should I upgrade my greenhouse to be more energy efficient - FS3*

Alternate energy systems and demonstration site

This project involved identification of an appropriate system and its subsequent design to integrate alternate energy sources into existing greenhouse heating systems. This analysis also included the collation of existing energy use data and economic feasibility.

We aimed to determine a potential alternate energy option from amongst several options, develop a design for such a system and install and analyse the system prior to demonstration. The original scope for the project indicated that an integrated solar hot water system could be a valid option.

Our assessments of alternate energy sources in this project takes into account the current subsidies of some fuels and relies on the fairly significant subsidies and rebates available for solar technology. A disadvantage of this solar technology is the area required to house a sufficient number of solar collection panels. The site used for the assessment has adequate space; however this is not the case for many greenhouse enterprises and could pose development problems for some sites.

While the technical assessment and payback period indicates that a solar thermal option is technically and economically feasible (performs within our target of 10-15 year return on investment), the current cost benefit is marginal due to the space required for the installation of sufficient solar panels. As a result, the installation of a field demonstration of this technology, though it remains an option, did not proceed and other options were pursued. So, although, solar thermal was found to be technically suitable and it met a pre-set outer limit of economic feasibility, it was found to be impractical at this point in time and was not pursued further.

Following preliminary analyses of technical and economic factors, the solar thermal technology originally proposed may not be viable at this time for this industry. A key component of this project was to determine for industry the economic feasibility of alternate energy options and so a number of alternative levels of solar energy supplementation were considered to determine whether a suitable or potentially optimal target level could be identified. Included in this assessment is a more basic, non-integrated base heating solar hot water system. However, the draft design for the selected demonstration site suggested that a huge amount of solar technology was required to adequately deliver the energy demanded and the economics were tenuous. (Appendix C)

Two other technologies were identified during this project as holding reasonable potential as alternate and/or supplementary energy options – geothermal heat pumps and phase change materials.

Phase change materials offer innovative passive temperature management opportunities for greenhouse growers. A preliminary assessment of the use of phase change materials for greenhouse applications was conducted in collaboration with the University of Newcastle. This indicated it could theoretically achieve the required result. Specifically, this technology could in principle meet the technical needs of this industry, and that potential reductions in energy use may exceed 30%.
A more intensive laboratory analysis was then undertaken by the University of Newcastle and a proposed technology option for field testing was prepared in conjunction with a cost benefit analysis (Appendix D)

The second energy option that was identified as having potential for this industry is the use of geothermal heat pumps, as used in Europe as part of integrated farm development. This technology in its various forms is starting to attract interest in Australia and holds a lot of potential for greenhouse growers and even other vegetable growers and was also incorporated into the field trial and demonstration site.

Demonstration site Somersby

To establish performance data for phase change material and ground source heat pump technologies, a trial site with three greenhouses was established in 2011 at the NSW DPI research farm located at Somersby on the NSW Central Coast.

Three identical structures were constructed out of aluminium (grade 6063) frame with 6mm thick twin walled polycarbonate panels (Figure 1). Polycarbonate panels were secured to the frame in full-length 14mm-15mm channelled grooves and the structures mounted on a 150mm galvanised steel base. Gaps left from the levelling of the steel bases were filled with plastic wrapped 25mm Styrofoam.

Figure 1 Three comparative demonstration greenhouse structures, Somersby NSW

Greenhouse 1 was fitted out with containerised phase change material (Figure 2).

Figure 2 Containerised PCM in structure 1

The PCM used in this trial was butyl stearate,($C_{17}H_{35}COOC_4H_9$), a liquid that solidifies at approximately 19°C, mixes with vegetable oils and is soluble in alcohol and ethers but insoluble in water. It is used as a lubricant, in polishes, as a plasticizer, and as a dye solvent. This PCM was identified in the report in Appendix D as a suitable material.

The choice of container was dictated by the volume required and the space available. In order to achieve the required volume a container with a low thermal resistance was required. It was found that freezer blocks offered a good ratio of volume to surface area, had low thermal resistance and would stack well into the structure. Approximately 730 2.5 litre freezer blocks were used, each painted black to help in UV stabilisation and filled with butyl stearate. This provided about 2,000L of PCM material. Greenhouse 2 acted as the control with no heating system installed.

Greenhouse 3 had hydronic heating, connected to a geothermal heat pump with a ground source heat loop to extract low grade heat energy from an adjacent water body. The hydronic heating system consisted of approximately 370m of 19mm poly pipe fed from a 32mm poly ring main (Figure 3). Ring main circulation was maintained by a 'Grundfos' (UPS25-60) Hot Water Circulating Pump. The ground source heat exchange loops consisted of 200m of 19mm poly stacked in open loops (Figure 4).

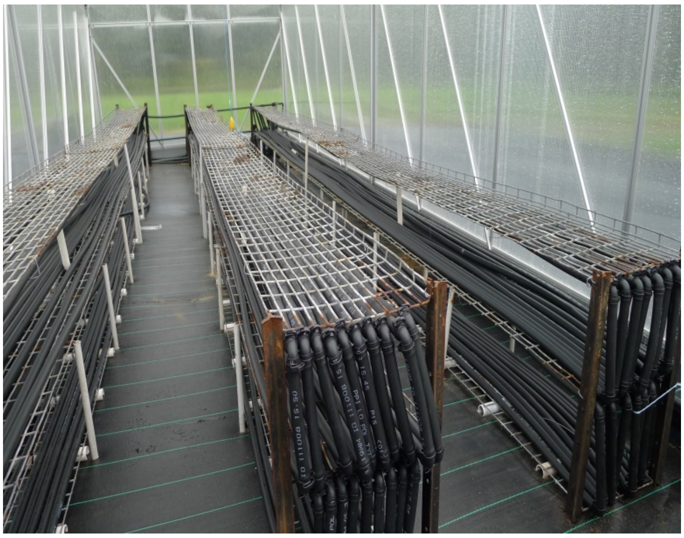


Figure 3 Hydronic heating system in demonstration greenhouse

Figure 4 Heat exchange loops prior to placement in dam

A 'Bosch FHP' (WW060-3CS-FXX) heat exchange pump was sized according to the structure and connected to 32mm poly ground loop line with a 25mm insulated flexible hose connection into the greenhouse to feed the hydronic heating system.

Internal and ambient conditions (including temperature, relative humidity, wind speed and insolation) were monitored hourly for over two years. Temperature and humidity loggers were placed at three heights in the centre of all houses, to record any thermal layering effects within the structures. All air temperature and humidity loggers were housed within Stevenson screens. Ambient temperature and humidity were measured by an external logger acting as a weather station as well as a 'Oregon' (WMR100) advanced weather station. This was installed in close proximity to the structures to provide wind speed and direction and conformational temperature and humidity data. Supporting data was provided by a Department of Primary Industries weather station situated on the same property but not directly proximal to the structures.

Dam water temperature was monitored by use of a ‘Hastings Tinytag Aquatic 2’ Logger submerged to the equivalent depth of the heat exchange coils. Temperature probes located in GHP shed also recorded the entry and exit temperature of the closed loop coils from the dam.

Power measurement was logged using a ‘Wattsup-proES’ meter with logging function. This enabled sophisticated data collection, a high level of resolution with an accuracy of +/- 1.5%.

Heat pump operation was controlled by a ‘Carel’(IR32V4L000 - 12-24VDC) controller with a temperature probe located in the centre level greenhouse 3. The set point of 18°C had a minimal band width of 2 degrees and was used as a trigger point for the water flow into the hydronic heating system. The geothermal heat pump only switched on when the returning water temperature fell below the hydronic heating system set point ~40deg C.

The entry and exit temperatures of the hydronic heating system were also logged to help in the determination of the heat loss into the structure. The delta T (temperature difference) from the entry to exit temperature was indicative of the heat moved into the structure to maintain the minimum set point of 18degC.

In order to accurately account for all energy movements into and out of the trial structures, an *in situ* measurement of the infiltration (leakage) rate of the structures was conducted by measuring the dissipation of carbon dioxide levels over time following artificially raising the internal concentrations of this gas (Figure 5). These tests were carried out using bottled CO_2 and an ICA 40 gas analyser.

Figure 5 Greenhouse leak testing utilising CO_2

Thermal load requirements were calculated to ensure thermal capacity of the heating systems could match expected heat load requirement figures for each structure. Preliminary calculations accounted for the thermal capacitance of materials and the deltaT requirements for heat replacement by each system. Heat loss through walls, floor and metal skirt were all calculated with the differential thermal exchange capacity’s (U values) to insure accuracy of infiltration heat loss figures.

Baseline data was gathered for the performance of each structure before installation of heating systems. This provided baseline data of thermal properties, uniformity and functional control conditions of the houses. All houses were consistent in performance prior to installation of heating systems. Small differences were explained by slight changes in sun position and shadowing effects in the morning and afternoon.

Basic thermal equations:

Heat load conduction: $\frac{U \times SA \times deltaT \times wind\ factor}{1000}$

Heat load leakage: $\frac{0.373 \times deltaT \times V \times leak\ factor \times wind\ factor}{1000}$

U= thermal resistivity ('overall heat transfer co-efficient')

SA= surface area

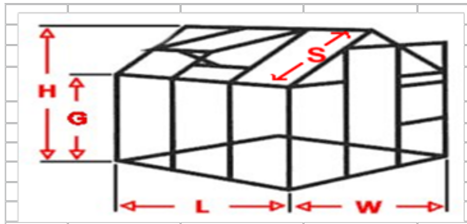
Delta T = the differential in temperature between inside and outside

Wind Factor = a constant applied to the increase in thermal loss due to air movement. A variable based on wind speed

Leak factor = the inherent leakiness of a structure

Figure 6 shows an example of heat load and energy replacement calculations required to develop the cost benefit analysis of the alternate energy options. The Figure 6 screen shot specificity applies to the Heat pump system with a Coefficient of Performance (COP) calculated from the measured returning dam water temperature of 4.44 (in red). Calculations of the enthalpy (amount of energy) incumbent in the air are highlighted in orange column header. Green and pink headers show electric power consumption for the GHP and its conversion to heating Kilowatts from the hydronic system. Purple headers are measurement and calculation of heat energy losses and replacement.

Example of heat load and energy replacement calculations



Whole structure		
S =	1.3	
W =	2.4	
L =	6.1	
H =	2.4	
G =	1.9	
span =	1	
Total surface area of walls =	50.56	m2 (wall)
Total floor area of structure =	14.64	m2 (floor)
Total volume of structure =	31.476	m3

Polycarb walls		
S =	1.3	
W =	2.4	
L =	6.1	
H =	2.4	
G =	1.9	
span =	1	
Total surface area of polycarb =	48.52	m2 (wall)

Steel base		
S =		
W =	2.4	
L =	6.1	
H =		
G =	0.12	
span =	1	
Total surface area of steel =	2.04	m2 (wall)

COP
4.44

Original values			GH SA	GH U Value	GH VOLUME
			50.56	3.4	31.476
			m2		M3
Volume of structure	SA of Polly walls	SA of Steel Base	SA of Floor	U value for Pollycarb	U value for Steel base	U value for Floor
31.476	48.52	2.04	14.64	2.9	6.249248888	0.380824373

		R-air(still)	R-air(12kmh)	R-air(24kmh)
U-value (polycarb walls)	low =	2.651162791	2.96566077	3.056300268
	high =	2.920353982	3.306613226	3.419689119
U-value (steel base)	low =	4.999519277	6.249248888	6.665812075
	high =	4.999519277	6.249248888	6.665812075
U-value (floor)	low =	0.118214269		
	high =	0.380824373		

Heating coil data

Heat transfer (U)		SA M2 pipe
26.65	w/m2.K	48.026

Date....Time

Start Time	Finish Time	Overnight	Solar	Enthalphy Start	TOTAL Energy IN Calc Watt Hours	In kW X COP	GH energy KW	AVE Delta T	Loss Polly wall to Ambient Kw	Loss GH Steel to Ambient Kw	Loss GH floor to soil Kw	Sum OF Loss All GH	leakage	GH energy KW	Loss + Enth Diff	Enth remain	Enth Diff	ACH	Wind Speed Km/Hr
28/05/2012 18:00	29/05/2012 6:00	28/05/2012		0.5302	8759.7	38.7310	39.2612	9.6	16.46	1.49	0.65	18.60	20.13	20.18	18.66	0.4722	0.0579	3.346256179	6
29/05/2012 18:00	30/05/2012 6:00	29/05/2012		0.6174	9090.2	40.1984	40.8158	11.8	20.28	1.84	0.80	22.92	17.28	17.40	23.04	0.4951	0.1223	2.588521486	4
30/05/2012 18:00	31/05/2012 6:00	30/05/2012		0.5154	10096.9	44.6682	45.1836	12.4	21.29	1.93	0.84	24.06	20.61	20.64	24.08	0.4895	0.0258	3.418295453	2
31/05/2012 18:00	1/06/2012 6:00	31/05/2012		0.5441	9756.4	43.1564	43.7005	13.3	22.77	2.06	0.90	25.73	17.42	17.44	25.75	0.5258	0.0183	2.714004183	5
1/06/2012 18:00	2/06/2012 6:00	1/06/2012		0.6042	7965.2	35.2034	35.8076	12.9	22.14	2.01	0.88	25.02	10.18	10.24	25.08	0.5459	0.0583	1.475259837	10
2/06/2012 18:00	3/06/2012 6:00	2/06/2012		0.5973	8134.4	35.9547	36.5520	9.4	16.09	1.46	0.64	18.19	17.77	17.84	18.26	0.5226	0.0747	2.643940825	7
3/06/2012 18:00	4/06/2012 6:00	3/06/2012		0.5954	8345.2	36.8906	37.4860	8.2	13.98	1.27	0.55	15.80	21.09	21.21	15.92	0.4781	0.1173	3.274120496	14
4/06/2012 18:00	5/06/2012 6:00	4/06/2012		0.5105	10298.2	45.5619	46.0725	8.1	13.80	1.25	0.55	15.60	29.96	30.06	15.71	0.4072	0.1034	5.441141007	13
5/06/2012 18:00	6/06/2012 6:00	5/06/2012		0.5190	10933.4	48.3822	48.9013	11.8	20.28	1.84	0.80	22.92	25.46	25.52	22.98	0.4631	0.0560	4.321045899	9
6/06/2012 18:00	7/06/2012 6:00	6/06/2012		0.5271	11407.5	50.4872	51.0143	12.5	21.41	1.94	0.85	24.20	26.29	26.37	24.28	0.4461	0.0810	4.501595042	4
7/06/2012 18:00	8/06/2012 6:00	7/06/2012		0.5099	12236.7	54.1689	54.6788	13.5	23.16	2.10	0.92	26.18	27.99	28.10	26.29	0.4032	0.1067	5.109256354	8
8/06/2012 18:00	9/06/2012 6:00	8/06/2012		0.4944	10737.6	47.5129	48.0073	12.4	21.18	1.92	0.84	23.94	23.57	23.66	24.03	0.4056	0.0888	4.364571477	10
9/06/2012 18:00	10/06/2012 6:00	9/06/2012		0.4972	10560.5	46.7266	47.2238	12.0	20.61	1.87	0.82	23.29	23.44	23.52	23.37	0.4155	0.0817	4.279558016	15
10/06/2012 18:00	11/06/2012 6:00	10/06/2012		0.5028	9863.9	43.6559	44.1586	12.8	21.99	1.99	0.87	24.85	18.81	18.83	24.87	0.4832	0.0196	3.178937704	8
11/06/2012 18:00	12/06/2012 6:00	11/06/2012		0.5001	9715	43.1346	43.6347	11.5	19.73	1.79	0.78	22.30	20.83	20.85	22.31	0.4875	0.0125	3.515774712	13
12/06/2012 18:00	13/06/2012 6:00	12/06/2012		0.5624	9276.5	41.1877	41.7500	9.8	16.76	1.52	0.66	18.94	22.25	22.38	19.06	0.4365	0.1259	3.712703652	15
13/06/2012 18:00	14/06/2012 6:00	13/06/2012		0.5651	1293.6	5.7436	6.3087	4.6	7.93	0.72	0.31	8.96	-3.22	-2.99	9.19	0.3403	0.2248	-0.592189115	2
14/06/2012 18:00	15/06/2012 6:00	14/06/2012		0.5242	1254.4	5.5695	6.0937	3.4	5.76	0.52	0.23	6.52	-0.95	-0.69	6.77	0.2721	0.2522	-0.197944541	4
15/06/2012 18:00	16/06/2012 6:00	15/06/2012		0.5008	1478	6.5623	7.0631	1.0	1.79	0.16	0.07	2.03	4.54	4.69	2.18	0.3437	0.1570	0.895448167	5
16/06/2012 18:00	17/06/2012 6:00	16/06/2012		0.5252	9253	41.0833	41.6086	10.4	17.86	1.62	0.71	20.18	20.90	20.98	20.26	0.4491	0.0761	3.575035751	8
17/06/2012 18:00	18/06/2012 6:00	17/06/2012		0.4908	9097.8	40.3942	40.8850	9.9	16.90	1.53	0.67	19.10	21.30	21.36	19.16	0.4304	0.0603	3.853048819	6
18/06/2012 18:00	19/06/2012 6:00	18/06/2012		0.4873	9819.7	43.5995	44.0867	11.2	19.15	1.73	0.76	21.64	21.96	22.03	21.71	0.4145	0.0728	4.058802257	7

Results and Discussion

Economic feasibility of alternate energy options

This project sought to identify and assess alternate energy options for the greenhouse industry with the aim of establishing a first step to improving energy management in this industry.

A cost benefit analysis was undertaken to determine baseline feasibility for the two technology options identified and assessed as the main potential opportunities for the greenhouse industry. A complete package of data regarding energy flows into and out of the trial structures was collected over a 42 month period with an emphasis on collecting data for two winter periods to provide a comprehensive understanding of the performance of these technologies. This information has better informed the economic aspects of alternate temperature management options and a cost benefit analysis was developed. (Full report Appendix E).Both of the technologies investigated indicated a significantly lower cost than that of an LPG powered hydronic heating system (a common industry standard).

The two primary forms of heat loss accounted for in this trial are losses via conduction (through the walls, roof and through the floor) and from infiltration (air leakage). The following graphs illustrate the estimated conductive (Figure 7) and infiltration heat losses (Figure 8) from the greenhouses respectively. They have been averaged on an hourly basis and plotted over a calendar year.

Data for these graphs is based on modal year weather data from a combination of DPI weather station and demonstration site weather data. Hourly weighted averages for ambient conditions were calculated to give an ambient temperature and humidity modal year data set.

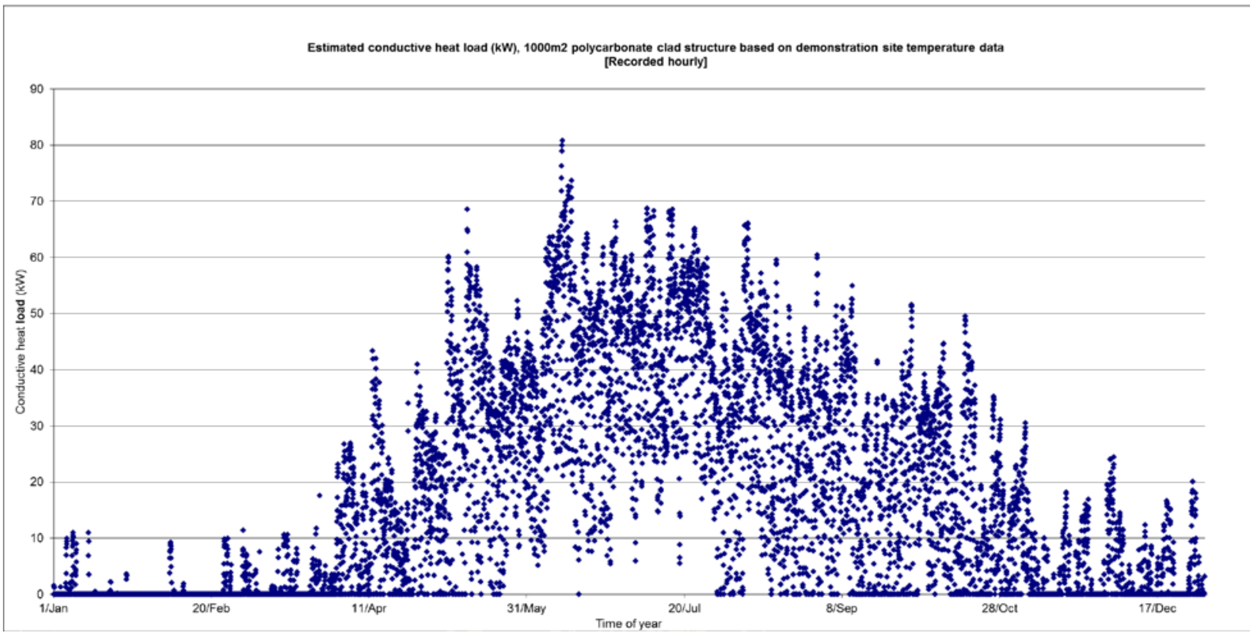


Figure 7 Conductive heat loss hourly averaged for a calendar year

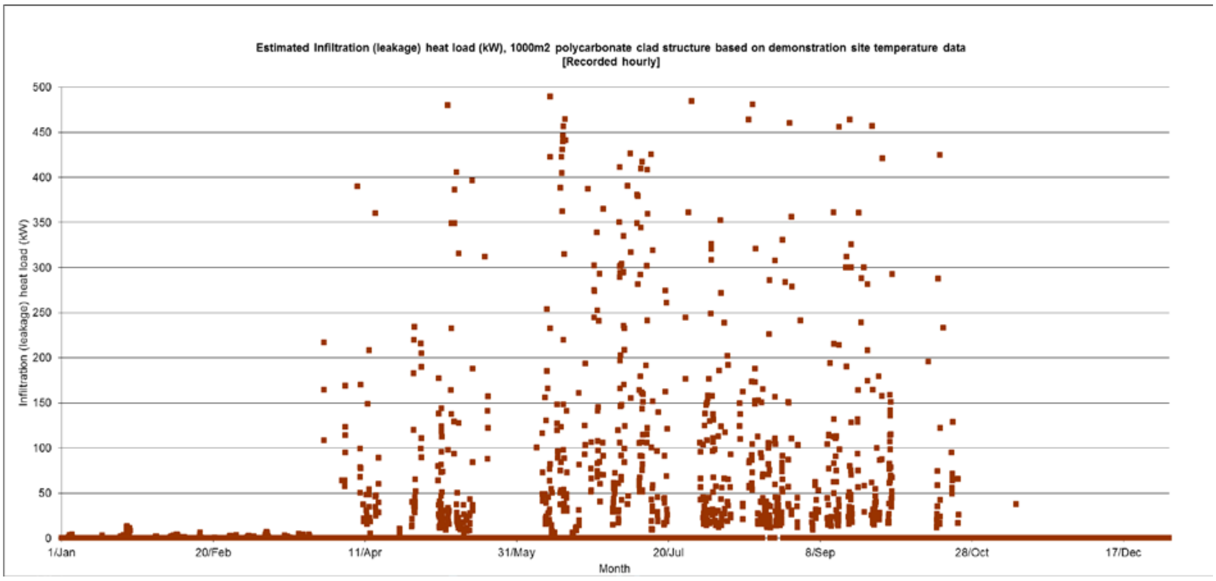


Figure 8 Infiltration heat loss hourly averaged over a calendar year

The thermal performance of the demonstration structures was based on heat load data calculations over two years, for these structures. These performance parameters where then calculated against the modal year weather data, giving a better fit of performance of the structures because it accounts for possible weather conditions beyond the two recorded years.

Figure 9 shows cumulative cost analysis over 10 years of alternate energy options. This used as a model a greenhouse located on the NSW Central Coast to calculate the estimated capital cost for equipment and installation (in light blue) and operating costs (in red), with each section equivalent to the annual operating cost). The greenhouse was modelled with a floor area of 1000m^2, a 4m gutter height and single polythene cladding and with a target minimum internal air temperature of 18°C and coldest expected ambient conditions. Comparisons are made against straight electric heating i.e. radiant style in order to provide a comparison for alternate energy sources. See Appendix E for further detail.

In Figure 9, costs have been calculated over a 10 year investment period, assuming an annual interest rate of 5%, LPG costs $0.67/L with a 3% p.a. increase, electricity costs $0.21/kWh and increases 5% p.a. and off-peak electricity (available for 7 hrs. per night) costs $0.08/kWh and will also increase at 5% p.a.

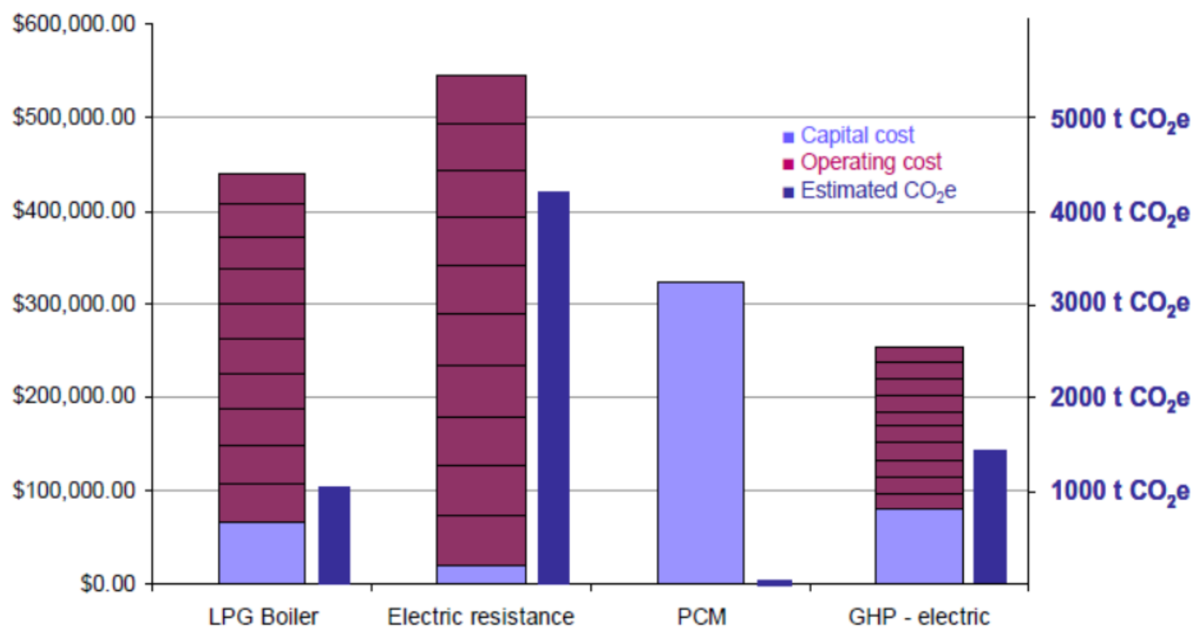


Figure 9 Cumulative cost analysis over 10 years of alternate energy options

While the investment in PCM is substantial, the absence of on-going operating costs suggests this technology could provide significant energy and cost savings. The use of a geothermal heat pump is also very favourable.

Carbon dioxide emissions

Basic emissions calculations have been made to provide a more complete picture of the energy character of this industry. Based on basic energy use figures, although electricity use is fundamentally higher in carbon dioxide emissions, the preliminary assessment is that carbon dioxide gas emissions could be lowered significantly using a geothermal heat pump resulting from a substantially smaller electricity demand. The use of LPG would still produce the lowest level of emissions; however the potential cost savings of the heat pump technology could enable increased investment in carbon offsets or other mitigation measures. Further advances in this area could be achieved with the use of gas powered heat pumps (adsorption heat pumps) though these appear to be significantly more expensive at this time (June 2014). The application of phase change materials, as well as eliminating operating costs also avoids carbon dioxide emissions. With a price on carbon dioxide, this may facilitate investment in this type of technology for greenhouse temperature management.

Demonstration of technologies

The two energy innovations were identified for further investigation in this project, geothermal heat pump systems and phase change materials, were established in a demonstration capacity at Somersby, NSW.

A) Geothermal heat pump systems (GHP)

Geothermal heat pump systems are clearly an important development opportunity for the greenhouse vegetable industry. The economic feasibility is clear long term and offers the opportunity to significantly reduce carbon emissions.

A net present value analysis has been generated for maintaining a minimum greenhouse air temperature of 18°C with the use of a geothermal heat pump system (on mains peak and off-peak power), natural and LP gas-fired hot water boiler and direct heating with mains (peak and off-peak) power. Real-time hourly field data was used as the basis for the greenhouse heat load figures and hourly temperature and humidity data provided a tight, accurate determination of the heat loads throughout the period of analysis. Costs have been calculated over a 10, 15 and 20 year investment period, assuming an annual interest rate of 5%, LPG costs \$0.0948/kWh and will increase 4.8% p.a., natural gas costs \$0.00684/kWh and will increase 4.8% p.a., electricity costs \$0.343/kWh and increases 3.5% p.a. and off-peak electricity (available 10pm to 7am) costs \$0.133/kWh and will also increase at 3.5% p.a.

In the comparison, calculations use a model greenhouse located on the NSW Central Coast with a floor area of 1000m^2, a 4m gutter height and polycarbonate cladding. The geothermal heat pump system uses a ground water loop in a dam as the heat source, for which a conservative performance coefficient of 4.0 is used. This essentially means that for every kilowatt of electricity used, 4 kilowatts of heat energy can be supplied to the greenhouse.

Costs of different heating options were assessed against meeting this heat demand – direct electric heating, using a geothermal heat pump system and using a hydronic boiler fired with either natural gas or LPG. Figures 10 and 11 below have been provided to illustrate the relative economics of these options.

From analysis of modal year weather data and the heat load calculations based on the demonstration site performance. It has been calculated that the geothermal heat pump system is the most cost effective option, followed by natural gas (not available in many production areas), then LPG and finally direct heating with electricity is provided as a benchmark.

The net present value (cost) over 10 years of the GHP is just over $354,000 while natural gas fired hydronic heating system is $370,000. By comparison; LPG would cost just under $500,000 over this period and direct electric heating would cost almost $1.3 million to heat the same greenhouse.

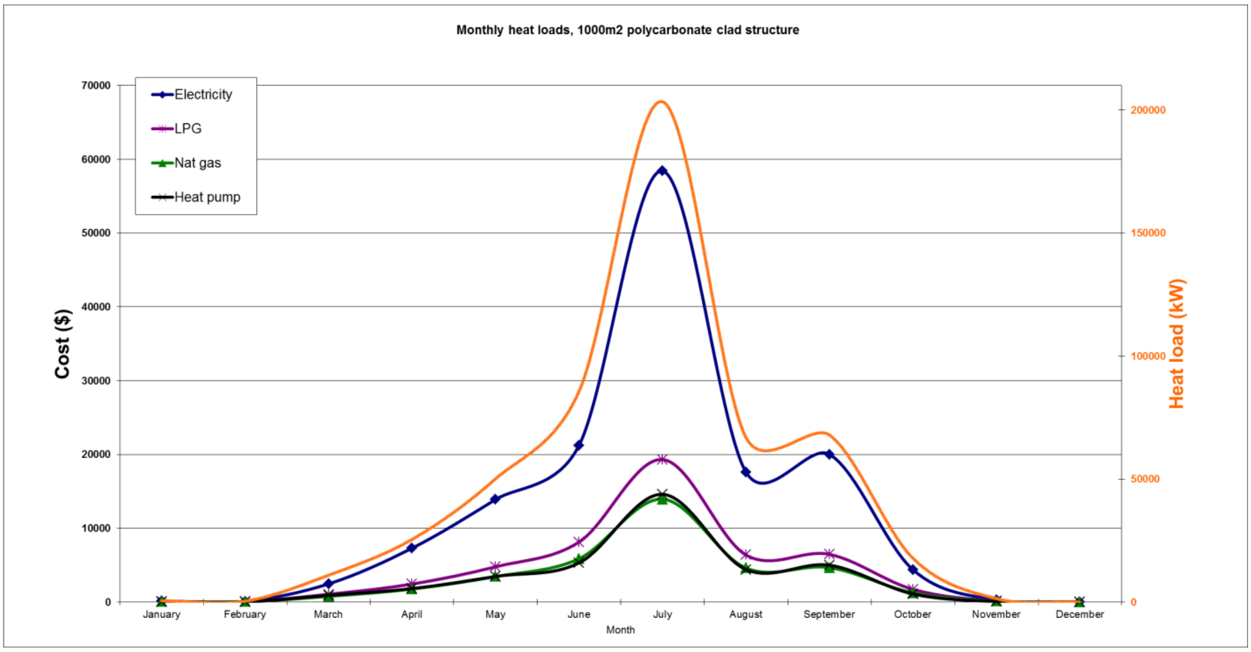


Figure 10 Monthly costs of meeting heat load demand for various energy sources

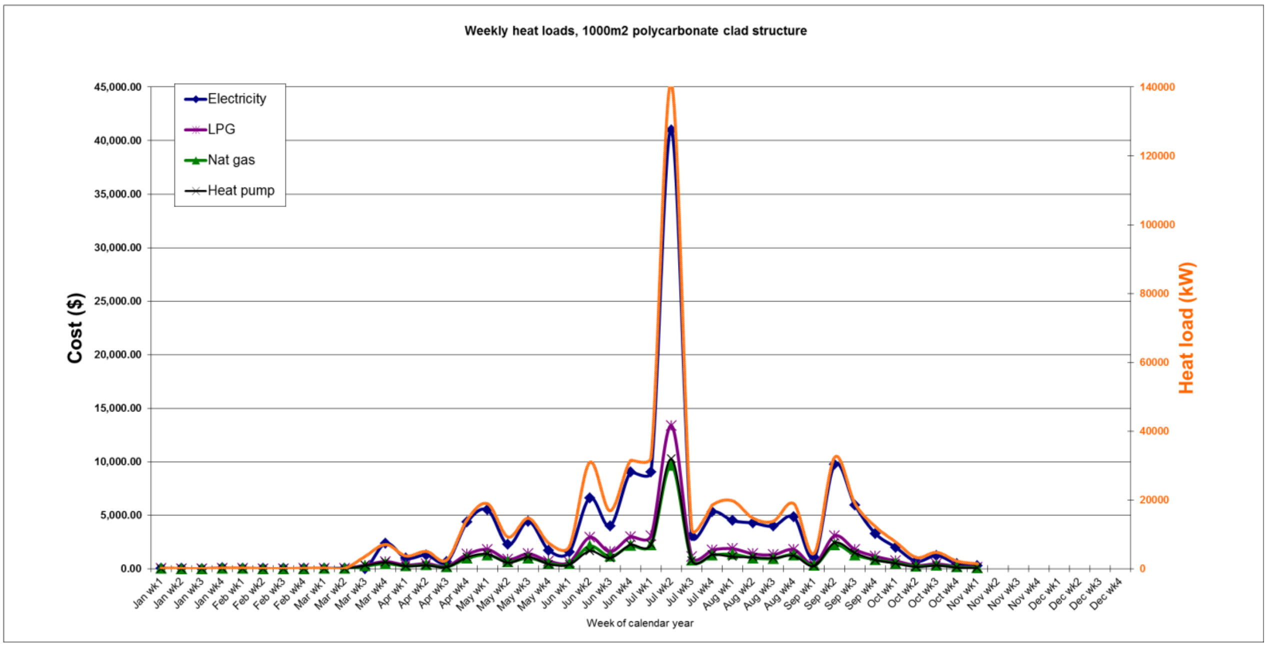


Figure 11 Weekly costs of meeting heat load demand for various energy sources

B) Phase change materials (PCM)

The field trial of the use of phase change materials as an energy buffer within the greenhouse produced some interesting results. This technology remains very promising but a different strategy for its use is proposed. The initial plan developed in conjunction with the University of Newcastle installed the PCM within the structure. The expectation was that the material would provide both a cooling and heating effect depending on the conditions and result in an even, passively maintained temperature. Expected issues revolved around aspects such as volume and surface area and configurations within the structure, and across the course of the trial this proved to be the case.

Results illustrate a daytime cooling effect resulting from the PCM absorbing heat and a night time heating effect as the PCM releases heat. Large quantities of PCM are required to supply 100% of the heat load of a greenhouse (in a moderate climate) and configuration within the structure presents a significant challenge.

There is most likely an economically optimal proportion of daily heat load that can be supplied. This will have to be determined for specific situations, though this approach will still require another heating system to supply the remainder of the heat load. The capital costs need to be carefully determined before implementation of this technology.

A modified approach to using phase change materials has been identified. The method is that the PCM is located outside of the greenhouse in a 'thermal' box. The material is heat loaded during the day (such as with direct solar radiation and, more likely, solar thermal heating, potentially also using a geothermal heat pump system to "ramp up" the energy). Air is then drawn from this thermal box into the greenhouse. In the reverse hot air from the greenhouse could be circulated though this 'thermal box' while PCM absorbs the excess heat, charging the PCM and removing the heat from the air before it is returned to the greenhouse.

The thermal exchange box ensures that the air within it is a consistent, standard temperature, such as 20°C and therefore if the greenhouse is cooler than this, heating is achieved and if the greenhouse is hotter than this, cooling can be achieved. The primary constraints with phase change materials are the large quantities of material required and the substantial upfront costs.

Cost Benefit analysis undertaken and reported for alternate energy option

A cost benefit report has been conducted on the benefits of alternative energy options. The use of heat pumps and geothermal sinks has shown to provide a positive outcome. However, the level of energy savings and the appropriate use of such energy options will vary depending on geographical location, climate and land area available. Therefore an independent assessment should be conducted for each greenhouse enterprise to determine the size of the installation required. This will provide a better understanding of the associated capital costs, potential energy savings and return on investment period. The full report is provided in the attached document (Appendix E) –

'An assessment of the benefits and costs of three potential energy options for greenhouses'

Technology Transfer

Communications and extension

Extension program events (6 locations - full day workshop/field day and seminar)

A total of six energy efficiency workshops and one field day were organised in six states. Each workshop was welcomed by local growers with varying numbers of attendees. Each workshop proved to heighten the interest in energy efficiency techniques with many questions being raised on energy efficient techniques.

Energy workshops

New South Wales, Kemps Creek on the 2nd of July, 2013. A successful grower's workshop was held with a variety of local growers attending. The workshop was well received with discussions of energy efficiency continuing after the completion of the workshop.

West Australia, Baldivis on the 13th of August, 2013. An energy workshop was held in collaboration with Vegetables WA.

Tasmania, Ulverstone on the 28th of August, 2013. This workshop was conducted in collaboration with the Tasmanian Association of Greenhouse Growers and combined a site visit to a producer that had installed a large wind turbine.

South Australia, Adelaide on the 26th September, 2013. A hands-on display and discussion field day and display was presented at the HORTEX trade day. Growers were encouraged to trial the energy efficiency resources and engage in discussions of alternative energy options.

Victoria, Werribee on the 16th of October, 2013. The Victorian workshop was arranged for a date in September but was delayed to co-inside with a Hydroponics Farmers Federation meeting to attract a larger number of growers.

Queensland, Cleveland on the 23rd of October, 2013. This workshop was originally organised for a date in September in North Queensland in conjunction with local QDAF researchers but due unforeseen circumstances was changed to Cleveland with the anticipation of attract a larger audience.

Project field day

New South Wales, Somersby on the 5th of September 2013. An Energy field day held was held at the NSW DPI facility at Somersby to showcase the alternative energy option trial.

Communications program events (conference presentation and electronic media development)

A conference presentation was given at the Protected Cropping Australia conference held Melbourne between the 28th and 31st of July 2013. The presentation was attended by a cross section of growers and encouraged follow up questions and discussions.

A website dedicated to the project and distributing the energy efficiency information has been created with all resources developed during the project uploaded for grower access. The website has also been used in the promotion of the workshops and a central source of energy efficient resources including links to other energy websites that can provides further information.

https://sites.google.com/site/greenhouseenergyefficiency/home

Media articles (on alternate energy option in greenhouse enterprises)

An article outlining and identifying the potential benefits of using geothermal heat sinks and energy efficient technology for heating a greenhouse has been published in issue 136 October 2013 of Practical Hydroponics and Greenhouses. *'Ground Heat Source as an option for greenhouses'*

A media article outlining the project and the development of the energy self-assessment audit tool kit with examples of energy reduction techniques has been published in issue 136 October 2013 of Practical Hydroponics and Greenhouses. *'New tool kit for better energy efficiency in the greenhouse - Practical Hydroponics article Oct2013'*

A summary article was provided for the Vegetable Industry Annual report.

Additionally, meetings have been held with two companies to discuss their relevant energy technologies. It is likely that the increased awareness in both the horticultural and energy industries of geothermal heat pump systems and their applicability to the greenhouse vegetable industry will engender new opportunities going forward for growers.

Recommendations

Data collection on case study enterprises re: implemented changes

All case study enterprises were contacted to discuss the results of their energy assessment. All growers commented on the potential benefits of conducting an energy assessment but only 2 of the 8 greenhouse facilities surveyed have acted upon suggestions provided in the post survey report. A summary of the energy breakdown for each greenhouse enterprise and growers/owners comments about the energy audit is provided in the attached document *'Grower comments on the effect of conducting an energy survey'* (Appendix Hi)

Overall, the heat pump with either a horizontal ground source loop or a surface water loop offers the best investment at all combinations of energy price assumptions. The vertical loop heat pump option has a higher capital cost and subsequently does not demonstrate as good a return on investment when gas and electricity prices inflate at the same rate.

A dollar invested in a ground source (surface water) heat pump heating system could return almost $1.90 at current energy price predictions while still showing a return on investment of around 30% if electricity costs rise considerably and LPG prices remain moderate.

Solar thermal would be a good investment provided gas prices rise above 2%, but if not, the potential savings are insufficient to offset the large capital investment required in a solar thermal system. Phase change materials are the most significant capital expense and even if gas prices rise at 8% per annum, there are insufficient savings over 10 years to cover the upfront cost of this type of system. It should be noted, however, that **over** a 15 year investment horizon, phase change materials do offer a positive return.

No single energy source is a "silver bullet" to reduce input costs. However through identification and management of energy use and supplementation with alternate energy options significant savings can be made.

Appendices

A) Energy alternatives for application to Australian greenhouses

Overview of options:

Energy alternatives for application to Australian greenhouses

B) An analysis of different options to reduce energy in a greenhouse vegetable production facility

An analysis of different options to reduce energy use in a greenhouse vegetable production facility.

C) Feasibility report – Greenhouse Solar Heating

Solar Dryers Australia Pty Ltd

34 Coronation Street Bellingen NSW 2454

Feasibility Report

Greenhouse Solar Heating

Revision Date:	26/07/2010
Revision Num:	1.0
File Name:	Greenhouse Solar Heating Feasibility Report.doc
Num of Pages:	21
Author:	Bruce Bishop

D) Phase Change Materials Greenhouse Study –UON

Priority Research Centre for Energy

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

www.newcastle.edu.au

PHASE CHANGE MATERIALS GREENHOUSE STUDY

(Study undertaken for NSW Department of Primary Industries, Central Coast Primary Industries Centre, Ourimbah as part of a national greenhouse industry project "Increasing energy efficiency and assessing an alternate energy option for Australian protected cropping" supported by Horticulture Australia Ltd.)

NSW GOVERNMENT | Primary Industries

Prepared by: Dr D. Alterman*, Dr C. Luo and Prof. B. Moghtaderi

Priority Research Centre for Energy
Chemical Engineering, School of Engineering
Faculty of Engineering & Built Environment
The University of Newcastle
Callaghan, NSW 2308
Australia

* Corresponding author's email: Dariusz.Alterman@newcastle.edu.au

Date: 15/10/2011

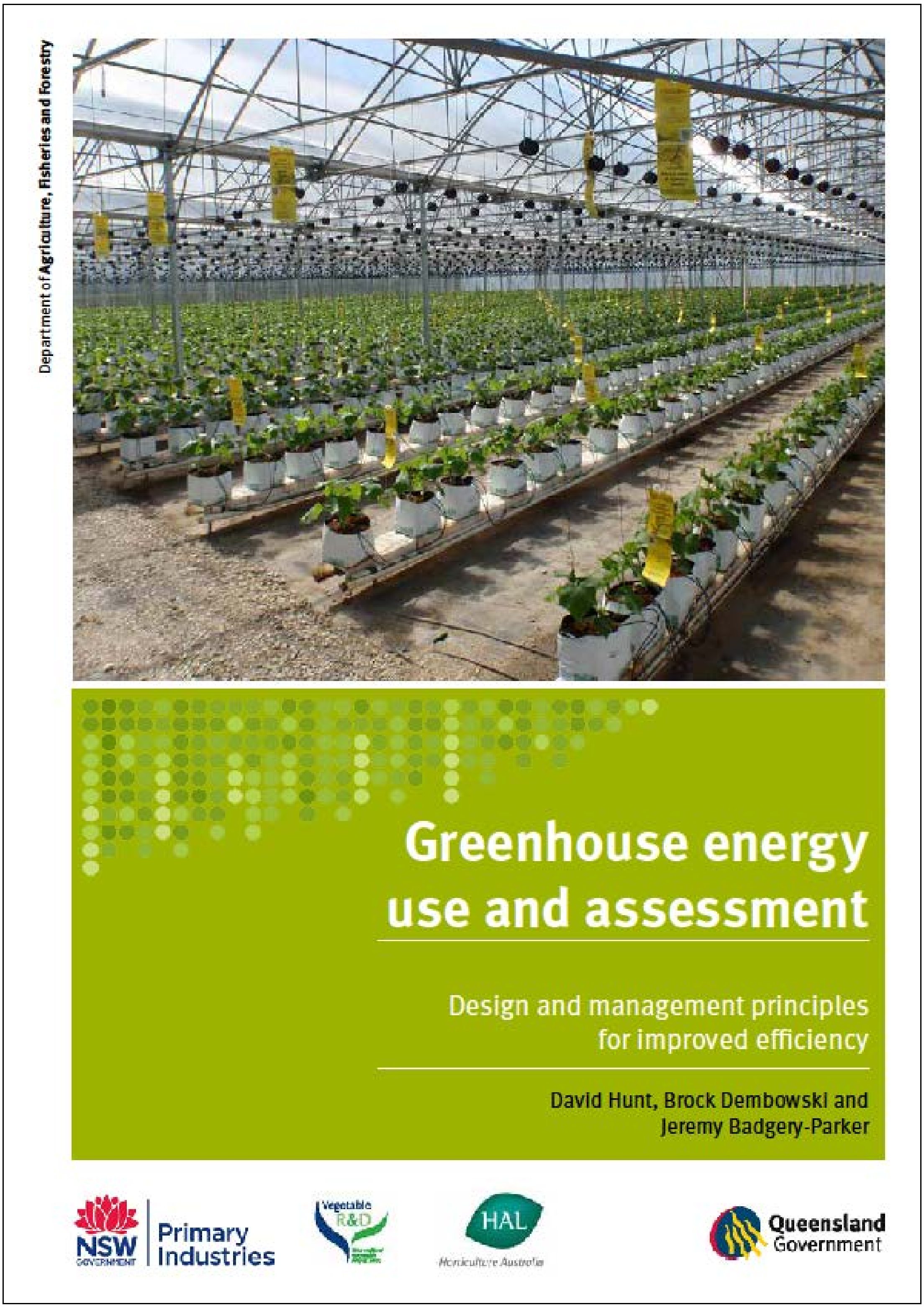
E) The benefits and costs of three potential energy options for heating greenhouses

An Assessment:

The Benefits and Costs of three potential energy options for greenhouse heating

F) Greenhouse energy use assessment audit

i) Design and management principles for improved efficiency



ii) Energy use questionnaire

Department of Agriculture, Fisheries and Forestry

Greenhouse energy use and assessment

Energy use questionnaire

David Hunt, Brock Dembowski and Jeremy Badgery-Parker

NSW Government | Primary Industries
Vegetable R&D
HAL Horticulture Australia
Queensland Government

G) Opportunities for the Australian protected cropping industry: An international study tour

Opportunities for the Australian protected cropping industry: An international study tour

David Hunt

Agri-Science Queensland

Department of Employment, Economic Development and Innovation

Queensland Government
Department of Employment, Economic Development and Innovation

1

H) Technology Transfer

i) Influence of conducting and energy walk through audit on greenhouse energy use and grower comments

The influence of conducting an energy walk-through survey on greenhouse energy use and growers comments

Introduction

Energy, particularly electricity, has been a relatively cheap and readily available resource in the past. However with a global push to reduce greenhouse gas emissions and the increasing costs of electricity and fuel, many growers have seen profit margins eroded by direct and indirect energy costs. Managing energy and environmental emissions in a greenhouse vegetable production facility firstly required an understanding of where the energy was being used. To this end, a self-assessment energy efficiency survey pack was developed to help growers identify and estimate the energy use efficiency of their greenhouse production facility. This energy survey pack provides a three-step process for identifying all energy-using equipment and systems used onsite, calculating what they cost to run over a year, and includes information on the options or low cost methods that may be used to improve energy efficiency.

To test the functionality of the survey method, eight greenhouse facilities that represent different crops, geographical locations, and the level of technology used by the industry were contacted. Over a six month period an energy efficiency assessment was conducted at each facility for the purpose of:

1. To test the ease and accuracy of the self-assessment survey process and questionnaire
2. Obtain feedback from growers on how conducting an energy efficiency survey can help to change how growers identify energy use
3. Provide an understanding of where energy is being used within a greenhouse
4. Gather energy use data of equipment and systems for calculations of energy costs

The energy efficiency surveys conducted proved to be very beneficial in developing the self-assessment survey questionnaire and information booklet, as well as identifying the energy use of each facility. The energy use data gathered surprised both researchers and facility owners, and highlighted several issues relating to obtaining the relevant equipment information for calculating energy costs. Although this process can be time consuming, it has proven to be a good method of engaging the grower in assessing energy use on farm. Feedback has been positive with some growers being encouraged to further evaluation of their property and explore upgrade options. This report provides an overview of energy use on each farm and growers comments on the influence of conducting an energy survey has had on farm energy use.

Energy assessment summary

These walk-through surveys have shown that the amount and cost of energy used on farm is influenced by many factors, and energy savings can be made in all areas of a greenhouse facility. The level and efficiency of the technology installed will have an influence on greenhouse energy usage. The type and design of the greenhouse structure itself has a large influence on energy use efficiency and a well-designed greenhouse can still be relatively efficient even with less efficient production systems or equipment. A modern greenhouse design and the use of energy saving materials will provide a more precise control of the growing environment which in turn influences other systems such as heating, ventilation, humidity control and even management practices. Installing highly

ii) Comparison of energy and costs of different fuel types

Comparison of energy and costs for different fuel types

Fuel Efficiency ($/GJ), Cleanliness ($CO_2$ emissions), and weight (kg/GJ)

Fuel type	Energy (GJ) per unit of measure	Average $/GJ	Kg CO_2/GJ	Kg/GJ
Gaseous Fuels				
Natural Gas	1	$2 - $15	50-60	0
Liquid Fuels				
Liquefied Natural Gas (LNG)	1	$8.07	50-60	18.66
Petrol	0.0342 GJ/L 45.6 GJ/T	$38.36 - $44.21	65-70	29.24
Diesel	0.0386 GJ/L 46 GJ/T	$33.98 - $36.58	65-70	25.91
Heating Oil	.0374 GJ/L 46 GJ/T	$15.75 - $21.54	70-75	26.74
LPG				
Propane	0.0255 GJ/L (25.5 MJ/L) 49.6 GJ/T	$18.50 - $19.50	50-60	20.07
Butane	0.0281 GJ/L (28.1 MJ/L) 49.1 GJ/T	$19 - $20.50	50-60	18.07
Mixture	0.0257 GJ/L (25.7 MJ/L) 49.6 GJ/T	$18.75 - $20	50-60	19.92
Solid Fuels				
Black Coal (Metallurgical)	29.5 GJ/T	$3.54 - $4.36	80-90	19.01- 32.58
Black Coal (Thermal)	24.1 GJ/T	$4.33 - $5.34		23.26 - 39.88
Black Coal (Electricity)	23.4 GJ/T	$4.46 - $5.49		23.96 - 41.07
Black Coal (Steel)	30 GJ/T	$3.48 - $4.29		18.69 - 32.04
Black Coal (Other)	23 GJ/T	$4.53 - $5.59		24.38 - 41.79
Brown coal (lignite)	12.5 GJ/T	~$4 - $6	90-100	44.85 - 76.89
Brown coal (Briquettes)	22.1 GJ/T	$8	90-100	25.39 - 43.49
Wood (Oven Dried)	0.018 – 0.020 GJ/kg	?+	10-60	
Wood Waste (sawdust with 40% moisture)	0.01 GJ/kg	$4		100
Wood pellets	0.01 – 0.020	?+		
Cereal Straw (15% MC)	25 GJ/T	$6-10		40
Macadamia Nut shells/ Olive Pits/ Peach Pits	0.019 GJ/kg	$10.50		52.63
Electricity				
Electricity	0.0036 GJ/KWh	$25 - $91	219.44	0
Alternative Energy Sources				
Solar power	0.0036 GJ/KWh	$122.22	8.5-60.5	Area required
Wind power	0.0036 GJ/KWh	$122.22	2.5 -11.5	Area required

*Average cost of kWh is a range of standard domestic and industry tariffs.
+ Real dollar values unavailable.
^ Energy value subject to change based on moisture content of wood.

Collated by EHRC September 2013

iii) Greenhouse covering materials and accessories - a mini review

Greenhouse covering materials and accessories – a mini review

David Hunt and Will Pearce
EHR Consultants

HAL Horticulture Australia | AUSVEG | NSW Government Department of Primary Industries | Primary Principles | EHR Consultants

iv) Traditional and alternative fuel comparison - a mini review

Greenhouse heating fuels – A brief explanation and comparison of traditional and alternative fuels

David Hunt
EHR Consultants
September 2013

v) What is energy efficiency - FS1

What is energy efficiency?

Energy efficiency is more than simply reducing the amount of electricity used on your farm. It is about the appropriate use of electricity or fuel to generate the most production for the least amount of energy and cost.

Energy efficiency should be a whole-of-farm approach and for businesses to remain competitive, sustainable and profitable, all possible methods to increase energy efficiency without increasing costs or sacrificing production need to be explored. This can be achieved in several ways, either by installing new highly efficient technologies during a re-build or retrofit, improving operating efficiency, reducing waste or by servicing and managing equipment, and refining processes to provide the most efficient use of energy. This factsheet briefly discusses five principles of energy efficiency and how these principles can affect energy use in a greenhouse.

Efficiently operating equipment

When selecting new equipment it is important to consider the efficiency rating as well as the cost and warranty of each available option. A product of higher quality may cost a little more but should have a longer life span than a cheaper product. Consider the purpose of the equipment and whether the function can be fulfilled more efficiently through better design or better systems. Ensure the equipment has the capacity to do the required job without straining. Consider the possibility of future expansion of your greenhouse. Seek advice about the most efficient location for the equipment and the level of control and integration that is available with the various options. Make sure your existing equipment is operating as efficiently as possible and make plans to upgrade any equipment that is not performing well. A two percent increase in equipment efficiency could save hundreds of dollars each year in electricity costs.

Reducing waste

Reducing waste can conserve energy. Simply changing your practices or equipment can limit the waste of resources. Common areas of waste include the loss of water and nutrients from excessive irrigation runoff, water leaks in the irrigation and heating systems, heat loss through damaged structures, poor insulation and incorrect programming of control systems.

Upgrade old worn equipment components, change irrigation scheduling to suit seasonal conditions and repair water leaks to provide an immediate reduction in pumping costs. Repairing damaged structures or cladding to reduce heat loss and heating requirements. Adjust control programs to suit the improved conditions and fit timers to non-essential equipment or use the built-in 'energy saving modes' to help reduce electricity waste and lower energy costs.

Providing optimal growing conditions

Maintaining optimal growing conditions in a greenhouse can use large quantities of energy. The level of control over the growing environment and the level of technology used for production will greatly influence the energy efficiency of the facility. A greenhouse with little or no technology may use very little energy

vi) Irrigation energy efficiency - FS2

The irrigation system and energy efficiency

All irrigation systems use energy. The design and maintenance of a system will determine how efficient it is at using that energy.

Correct design and installation and the regular servicing of an irrigation system can:

- reduce water use by 20 to 50%
- save thousands of dollars in water costs
- reduce plant death[i]
- reduce nutrient loss by avoiding over-irrigation
- reduce electricity use associated with pumping and water treatment
- maintain optimum performance, therefore influencing energy costs
- prolong the life of the components
- reduce maintenance costs.

This fact sheet looks at what makes a good irrigation system and the factors that can affect energy efficiency. It provides some simple principles to follow; however, to ensure your system is working at optimum performance, it is advisable to consult an irrigation specialist. The costs of a yearly service are usually returned within the year through reduced plant death.

Physical parameters

Does your application rate meet your crop irrigation requirements? If the application rate does not meet crop demand, both production and pump operation are affected. A poor or low application rate will not only create plant water stress but cause longer pump run times, using more energy. If the application rate is too high, excess water is used, wasting pump and water treatment energy, as well as leaching nutrients from growing media.

Does every plant get the same amount of water? An irrigation system with an incorrect operating pressure or flow rate will also affect plant yield and energy use. Incorrect pressures can alter flow rates, affecting the uniformity of application, which can cause water stress and crop growth variations as well as increase wear on the pumps and irrigation components. Increasing the stress and wear on pumps and irrigation components reduces system efficiency and increases energy use. The irrigation system performance should be adjusted to the operating requirements of the sprinklers or drip emitters being used.

Operating pressures and flow rates are also affected by pipe size. Systems that have been repaired, modified or extended in an ad-hoc manner with incorrect pipe sizes can cause operating pressures to fluctuate and increase friction, causing poor flow rates and damage to pipes or fittings.

How many leaks are there in the irrigation system? Leaking irrigation lines and faulty solenoid valves can significantly reduce the irrigation rate. Unfortunately, small leaks tend to go unnoticed until it is too late and the plants are showing signs of water stress.

vii) Should I upgrade my greenhouse to be more energy efficient - FS3

Should I upgrade my greenhouse to improve energy efficiency?

Upgrading or rebuilding a greenhouse facility is a large task and can be very expensive, it should not be undertaken lightly. If your greenhouses are old and showing signs of structural damage or you want to improve the land-use efficiency, then building new greenhouses with the latest energy efficient equipment is a good option. However replacing or rebuilding greenhouses may not be the most cost effective option to simply reduce energy costs. Upgrading or retrofitting key systems and components with new highly efficient technology could be more cost effective and provide better quicker energy savings.

An upgrade doesn't have to be a whole system, it could be as simple as installing a new thermostat, updating climate control software or repairing and servicing equipment. New technologies are constantly being improved and most modern equipment will be more energy efficient than older equipment. So upgrading a 20 year old piece of equipment could actually improve the whole-of-farm energy efficiency considerably. Choosing what systems or equipment to upgrade will determine the extent of energy savings and the payback period.

The first step is to look at where your energy is being used and asking what other equipment is directly or indirectly influencing the energy use. For example, a high heating fuel bill may not be due to an inefficient heating system, it may be the greenhouse covering has a high heat loss (high U-value), is torn and damaged or there are gaps around entry points allowing hot air to escape, refer table 1.

In this case there is little benefit of installing a new boiler for heating without addressing the air leaks in the system. A new boiler would simply be burning fuel more efficiently to compensate for the lost heat. It would be better to

- Replace the greenhouse covering with one that has a lower U-value (better insulation),
- Stop hot air losses by patching tears or holes in the covering and plug gaps by installing weather strips around vents, louvers, pipe entry points or doors,
- Repair any damage to the insulation on the hot water distribution pipes to stop heat loss during transport
- Replace old or damaged thermostats with a new electronic thermostat to provide more accurate readings
- Calibrate thermostats to ensure readings are accurate
- Check and adjust climate control parameters to stop or reduce clashes e.g. venting while heating.
- Service the burner and clean the heat exchangers in the old boiler to increase burning efficiency.

Addressing these points will increase heat retention within the greenhouse and increase the efficiency of your existing heating system by reducing the workload and fuel required to maintain greenhouse temperatures. These same principles apply to maintain the efficiency of an

I) Extension activities & materials

i) Workshop flyers

This FREE workshop is open to all protected cropping vegetable growers in Qld.

Based on the HAL project VG09124 'Increasing energy efficiency and assessing alternate energy options for Australian protected cropping. It explores how to estimate equipment energy use and discusses option to reduce energy costs.

Workshop overview

Project background and review of energy in greenhouse enterprises

Using Greenhouse energy use and assessment guide and workbook

- How to conduct an energy assessment
- Examples of quick low-cost energy saving methods

Alternate energy options – the benefit to cost

- Integrating alternative technologies
- Geothermal storage and heat pumps for climate control

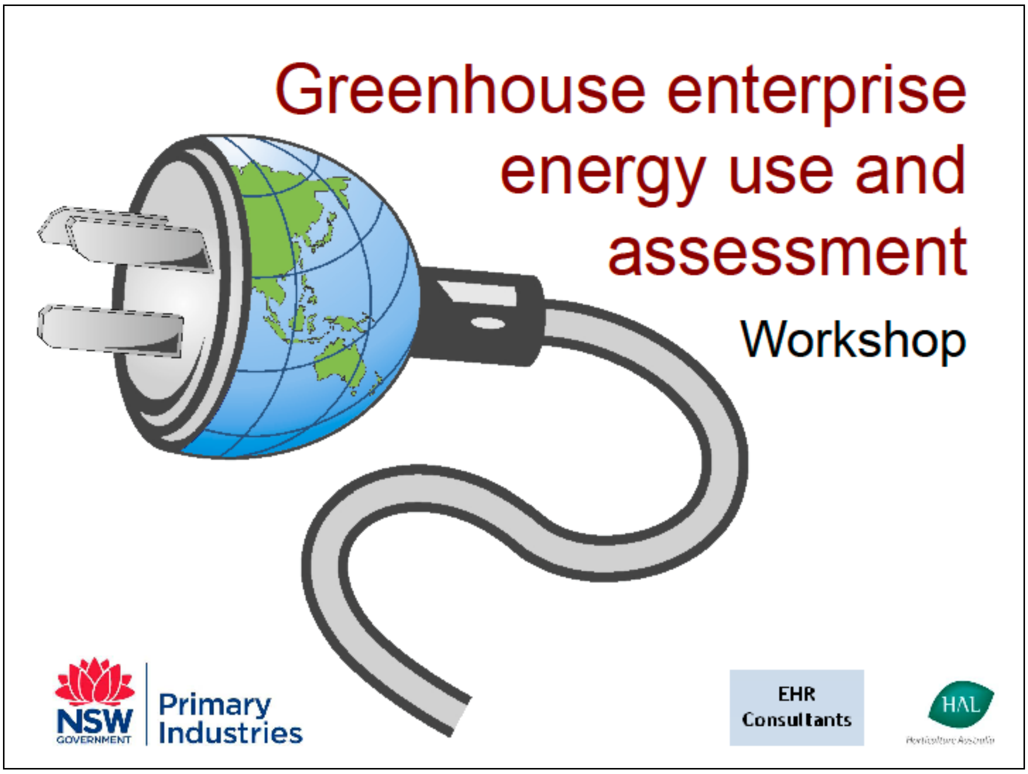
Using the Greenhouse energy estimator tool

- Using the estimator to make financial and carbon emission comparisons

Wednesday, 23rd October, 12 noon to 4pm
Queensland Department of Agriculture, Forestry and Fisheries
Redlands Research Station, 26 Delancey Street, Cleveland
Afternoon tea provided

Please RSVP by Monday 21st October, if you plan on attending:
Send your name (and number of people coming) to David Hunt
By Text (SMS) to 0408637644 or Email envirohortRC@gmail.com

NSW Department of Primary Industries | Primary Principles | FHR Consultants | HAL Horticulture Australia


Greenhouse enterprise
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ii) Energy estimator – screen shot