Energy saving potential
in the New Zealand agricultural sector
with emphasis on the vegetable greenhouse industry

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Anna Fay Wilson

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Abstract

In the last decade, the energy demand of New Zealand's horticultural and agricultural sub sectors has increased as a result of land use conversion, intensity of production, the use of irrigation and an increase in energy intensive horticulture, such as greenhouse vegetable production. This has highlighted the sector's reliance on fossil fuels leaving it susceptible to future shortages, higher prices and the forthcoming carbon charge. As part of a contract with the Energy Efficiency Conservation Authority, which aimed to compile, estimate and analyse information from a wide variety of sources on energy end uses and patterns of energy consumption within the agricultural sub-sectors, available literature on energy demand by fuel type and the various uses to which energy is put in the New Zealand primary production sub-sectors was collated in matrices. Through the compilation of these matrices it was evident that limited energy related research was available relating to the greenhouse sub sector.

The New Zealand greenhouse industry is a relatively energy intensive sub-sector of the primary production industry and relies heavily on the use of fossil fuels. The impending carbon charge may result in a cost which growers may be unable to pass on due to competition on the domestic and export markets from non-Kyoto countries. It follows that reducing energy consumption and consequently avoiding the emissions charge would be a means of increased viability for the industry. This part of the research was funded and conducted in conjunction with the New Zealand Vegetable and Potato Grower's Federation Inc. A walk-through energy audit was designed and conducted with 22 greenhouse vegetable growers. This provided an in-depth case study perspective in terms of what technologies and practices are currently used by the New Zealand's protected cropping industry. The findings from the energy audit show that location and the heating system type are significant factors in determining energy use. The main areas identified where potential energy saving could be made were minimising heat loss, through the cladding, the heat distribution system and the flue, and improving heating efficiency, through improved heater maintenance.

An energy saving model was designed using Microsoft Excel for the purpose of encouraging the user to think about potential energy savings that could be made within their individual greenhouse operation, and also the potential cost of the carbon charge

on to their business. Recommendations from the model were based on best practice and use of energy saving technologies identified through the energy audits, review of current literature and consultation with manufacturers.

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Abbreviations and SI Units

Units

kJ	kilojoule 1,000 joules
MJ	megajoule 1,000,000 joules
GJ	gigajoule 1,000,000,000 joules
TJ	terajoule 1,000,000,000,000 joules
PJ	petajoule 1,000,000,000,000,000 joules
kWh	kilowatt-hour = 3.6 MJ
W	watt = 1 joule per second
kW	kilowatt = 1,000 watts
ha	hectare 10,000 square metres
m	metres
kg	kilogram
t	tonne
l	litre

Abbreviations

CO_2	carbon dioxide
EECA	Energy Efficiency and Conservation Authority
MAF	Ministry of Agriculture and Forestry
Vegfed	New Zealand Vegetable and Potato Grower's Federation Inc.
NZCCO	New Zealand Climate Change Office
MED	Ministry of Economic Development

1.0 Introduction

The New Zealand primary production sector (agriculture, horticulture, fishing and forestry) account's for 4-5% of national consumer energy (Eastwood and Sims, 2003). While this is only a small fraction, the New Zealand economy is heavily dependent on primary product exports, including fisheries and forestry, which provide over 55% of all export earnings (Fig. 1).

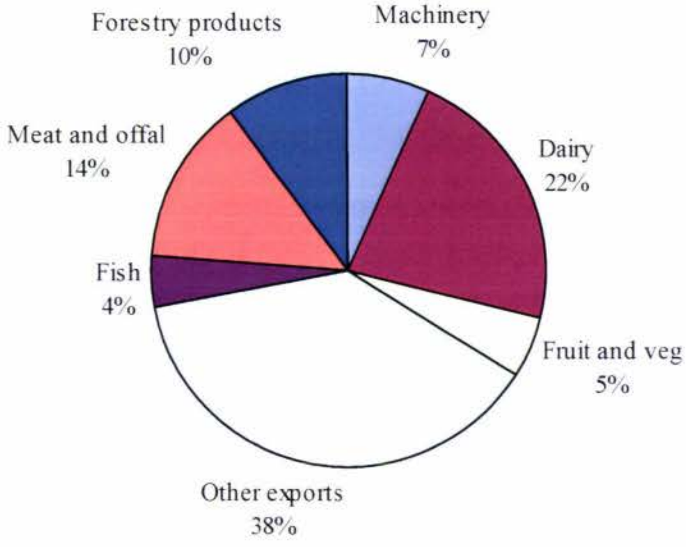

Figure 1. Major commodities exported by New Zealand.

(Source: Statistics NZ, 2004)

In the last decade, the energy demand of New Zealand's horticultural and agricultural sub sectors has increased as a result of land use conversion, intensity of production, the use of irrigation and an increase in energy intensive horticulture, such as greenhouse flower and vegetable production. This increase in energy demand has highlighted the sector's reliance on fossil fuels leaving it susceptible to future shortages and higher prices. The sustainability of farming systems and the ratio of energy input to output has drawn international attention as environmental sustainability is used increasingly as a marketing tool with the threat of a potential trade barrier for agricultural exports.

International concern at possible global warming effects from the release of greenhouse gases resulted in the 1997 *Kyoto Protocol*, being ratified in 2005. New Zealand has agreed to reduce its total greenhouse gas emissions back down to 1990 levels. A New Zealand inventory of greenhouse gases shows that primary production contributes 54% of New Zealand's total emissions mainly from ruminant methane (Keedwell, Robertson and Barnett, 2004).

To recognise the environmental impact of fossil fuel use the New Zealand Government has introduced a charge of \$15/tonne of CO_2 equivalent will be applied in April of 2007. The uncertainties of the proposed carbon charge, future security of oil supplies and possible cuts in electricity supply by line companies to many rural areas past 2013, under the Electricity Act (1993) meant that New Zealand farmers and growers must now operate within a climate of increasing economic instability and environmental awareness, both nationally and globally. Consequently there has recently developed a strong interest by the agricultural and horticultural sectors in the utilisation of energy saving and on-farm energy production technologies.

The New Zealand greenhouse industry is a relatively energy intensive sub-sector of the primary production industry. Energy use can be influenced by a number of factors including management, location, seasonal production, the design of greenhouse structure, greenhouse age, crop type and heating requirements (EECA, 2004). A report by Barber & Wharfe (2004) highlighted how dependent the greenhouse industry is on energy, particularly fossil fuel inputs with a total national annual consumer energy demand of 2.6-3.5 PJ/yr.

Many growers within the industry have significantly improved their production output in recent years in terms of units of product/m^2 of greenhouse. This has resulted in an improved return on investment for what is a high capital investment sector. The industry is now concerned about the forthcoming carbon charge. Barber & Parminter (2004) estimated a carbon charge of \$25/tonne CO_2 will increase the price of petrol by 6%, diesel by 12%, electricity by 16%, gas by 24% and coal by 44%. This will result in a cost which growers may be unable to pass on due to competition on the domestic and export markets from non-Kyoto countries. It follows that reducing energy consumption and consequently avoiding the emissions charge would be a means of increased viability for the industry.

A number of options have been suggested for reducing the impact of the carbon charge such as Negotiated Greenhouse Agreements and small-medium enterprise policy packages. The solution proposed by Pete Hodgson, when Minister of Energy, was to minimise the impact of the carbon charge by using energy more wisely. For some growers this solution may be a viable option whereas others are already utilizing energy efficient production methods, and would find it difficult to reduce further.

1.1 Problem statement

When compared with other sectors of the primary production industry in New Zealand, horticultural greenhouses are highly energy intensive. Barber & Wharfe (2004) clearly showed how dependent the industry is on energy inputs. The industry is now concerned with the forthcoming carbon charge for fossil fuels which threatens to reduce both the profitability and viability of greenhouse production and potentially encourage the industry to shift to Australia where no carbon charge is proposed at this stage.

1.2 Aim

This research aims to identify ways in which the New Zealand greenhouse vegetable production sector can implement energy saving technologies to reduce energy use and associated carbon emissions.

1.3 Objectives

1. To determine energy demand by fuel type and the various uses to which energy is put in the New Zealand primary production sub-sectors, with emphasis on New Zealand greenhouse vegetable production.

2. To review current and emerging energy efficient related technologies in greenhouse vegetable production.

3. To conduct an energy audit to determine the current energy efficient technologies used by the greenhouse production sub-sector.

4. To discuss the potential for the further and widespread application of energy saving technologies in the New Zealand greenhouse sub-sector.

5. To develop a computer model to determine the potential energy savings that could be made by growers as a decision making tool.

1.4 Limitations

This research was conducted in conjunction with the fulfilment of two contracts. A review of energy use in New Zealand agriculture for the Energy Efficiency and Conservation Authority (Chapters 2 and 3), and an on-site energy audit to determine potential opportunities for energy savings in the greenhouse industry for the New Zealand Vegetable and Potato Growers' Federation (Vegfed). The contract with Vegfed also included designing a model that growers could potentially enter their own data and use as a decision making tool to implement energy saving technologies and practices within their business. The fulfilment of these contracts influenced the approach taken to solving the problem and the choice of methodology.

A postal survey was originally proposed to Vegfed as the data collection method, however this was later changed to a walk-through, on site, energy audit because Vegfed had recently commissioned a national survey of New Zealand vegetable and flower greenhouse growers (Barber and Wharfe, 2004). Concerns were raised that a postal survey would repeat many of the questions used in this study. Restrictions were also placed on access to membership data bases, which meant that the survey participant selection was not truly representative of the New Zealand greenhouse production industry which would have biased the results. A walk-through energy audit was eventually chosen, with participants selected to cover a range of greenhouse sizes, locations, crop type and heating fuel types.

Due to the time involved in conducting the energy audits only a limited number of greenhouse operations were selected, whereas a greater number of participants would probably have strengthened the results and better represented the industry.

1.5 Research approach

Two different approaches to minimising energy consumption in greenhouses have been identified by previous studies; reducing energy consumption per m^2 of floor area and reducing energy consumption per unit of produce (Breuer, 1985; Barber and Wharfe, 2004). The latter addresses the more desirable end result for the industry and can be implemented through both greenhouse technology design and increasing crop production. Crop production techniques fall outside the scope of this research. Consequently the focus was on the development and utilisation of energy efficient greenhouse technologies and practices under New Zealand conditions.

A case study approach to data collection was taken in the form of an energy audit, conducted to determine what steps growers are currently taking to reduce their energy demand. Data collected from the energy audit was used along with existing data to develop a model that allows the user to input his/her own data. The model benchmarks the user against other growers and recommends specific energy savings measures for the user.

1.6 Thesis outline

The structure and content of each chapter is outlined together with a brief overview of the content of each chapter.

Chapter 2

Energy use in New Zealand's agricultural sector outlines the context for this study including the role of energy and energy research in New Zealand's agricultural and horticultural sector, it discusses climate change in relation to the New Zealand agricultural sector.

Chapter 3

Describes the different primary production sub-sectors, including their energy use, patterns of energy consumption and the outlook until 2012.

Chapter 4

Energy use in greenhouse production relates to energy conservation and energy efficient technologies in greenhouse production it focuses specifically on the areas of greenhouse design and heating.

Chapter 5

The methodology describes the development and design of the proposed postal survey and the energy audit. The rationale behind the hypotheses is explained and the statistical tests used to prove them are described. The content and structure of the energy saving model is also described.

Chapter 6

Results are presented from the analysis of the hypotheses.

Chapter 7

Describes the limitations of the study so the methodology and the results can be placed in the context of the literature. The focus of this chapter is on the steps growers are currently taking to reduce their energy demand for heating.

Chapter 8

Discusses the findings of this study in the context of the research aim and objectives. Areas for further research are identified.

2.0 Energy in New Zealand's agricultural and horticultural sector

Agriculture (and hereafter to include horticulture) is a high consumer of fossil fuels through the direct use of electricity, diesel and petrol fuels to power machinery and indirectly for the manufacture of fertilisers and agri-chemicals. Other forms of indirect energy include that embodied in machinery manufacture, building components, fences, irrigation systems etc. Some studies have endeavoured to include this embedded energy in the overall analysis e.g. Wells (2001).

Total indirect energy is around 60% (20 PJ/annum) of total agricultural energy inputs, half of which is for fertiliser (EECA, 1997). Direct energy inputs make up around 40%, of which diesel is 20%, petrol 12%, electricity 6% and other direct inputs such as oil 2% (EECA, 1997).

The breakdown of energy use on farms (Sims, Henderson, Martin, McChesney, Rennie and Studman, 1983) repeated in a more recent context by the Centre for Agricultural Engineering (1996), identified the major energy end uses in agriculture and areas where potential energy saving could be made. A more recent study reviewed energy related literature with a focus on dairy farming (EECA, 2004). Sims *et al.* (1983) identified the major energy end uses for liquid fuels as cultivation, non-specific tractor use and on-farm vehicle use. The main electrical energy end uses were identified as irrigation, water heating, refrigeration and cooling.

2.1 Trends affecting energy use of the New Zealand agricultural sector

While modern agricultural practices have grown to meet the needs of an expanding population and export market, it is generally agreed that current farming practices and their heavy reliance on fossil fuel inputs are not sustainable. Most production increases in agriculture are generally due to increased inputs of fossil fuels, either directly to replace human labour, or embodied in fertilisers and agri-chemicals (CAE, 1996). This increase in demand has come from a growing trend towards more intensive farming systems.

Pastoral farming dominates agricultural land use in New Zealand for grazing, fodder and fallow (including arable) making up 76% of the total production area. This land is primarily used for dairying, followed by sheep and beef farming. Horticulture makes up around 1% of the total production land area; the remaining 33% being used for other purposes mainly plantation forestry (Statistics New Zealand, 2005) .

Several land use trends may affect the agriculture sectors overall energy use. The improved profitability of dairying over other types of pastoral farming has led to strong growth in the dairy industry in the last ten years. This has provided incentive to convert sheep and beef farms to more intensive dairy farming systems (Table 1) with the national herd now close 4,000,000, up 1,000,000 since the early 1990's (Statistics NZ 2004). Consequently the overall energy demand of the sector is expected to continue to increase.

Table 1. Actual and forecasted change in pastoral land use (x1000 ha).

	2002	2003	2004*	2005*	2006*	2007*
Sheep	4,160	4,070	3,990	3,990	3,820	3,740
Beef	1,924	1,900	1,870	1,840	1,820	1,800
Dairy	2,018	2,050	2,050	2,060	2,070	2,080
Deer	370	380	390	402	413	423
Total	8,472	8,380	8,290	8,210	8,120	8,040

* Estimated

(Source: MAF, 2003)

Grazing and arable land use has decreased by 12% since 1994 to 12.0 million hectares in 2002 (Statistics NZ 2004), while land used for horticultural production increased, especially area planted in grapes. The horticulture sector has grown 6% since 1994 to 110,000 hectares in 2002 (Statistics NZ 2004), with a number of arable farms undergoing conversions to orchards and vineyards. CAE (1996) estimated orchard enterprises could be up to four times more energy demanding per hectare than arable crop farming. This is still likely to be the case some 10 years later. The conversion of marginal farmland, particularly pasture, to forestry is a noteworthy land use trend, with the area planted increasing by more than a quarter since 1994. Forestry falls outside the scope of this study and will not be considered further.

The effect of subdivision of rural areas into smaller units and lifestyle blocks on the overall energy use of the agricultural sector is not clearly understood. There are a number of factors that require consideration such as capital investment, the intensity of the farming system and choice of machinery (Williams 1993). Subdivision will not be considered further.

2.2 Previous research on energy use in the New Zealand agricultural sector

The two oil shocks in the 1970s resulted in the building of "think big" energy projects throughout New Zealand. The first shock in 1973 increased the awareness of the primary production sector's reliance on fossil fuels and instigated research into energy use. Between 1974 and 1984 a number of research projects were carried out by the Joint Centre for Environmental Sciences (JCES) funded by the New Zealand Energy Research and Development Committee. The Agricultural Economics Research Unit, Lincoln College, and the Agronomy and Agricultural Engineering Departments of Massey University provided other significant contributions to the literature of this period.

A review of energy analysis methodology (Pearson, 1976) formed the foundation for future research. The first study of aggregate energy use in New Zealand agriculture was carried out subsequently (Brown and Pearson, 1977). Using process analysis, direct and indirect inputs into farming were identified and estimated (Chudleigh and Greer, 1983). The JCES publications were divided into three categories: literature reviews, methodologies and farm energy surveys (Hendtlass, 1987). In 1976 a JCES study was the first to quantify energy inputs into agriculture (Pearson and Corbet, 1976), and in 1977 this study was updated to include indirect energy inputs of farming systems (Brown and Pearson, 1977). Process analysis was used to calculate total energy inputs including overseas energy inputs, transport to and within New Zealand and lists of farm inputs (Dawson, 1978). This report has been widely used by subsequent studies. An ecological approach was taken to energy analysis by summarising total energy use for different farming enterprises (Smith & McChesney, 1979).

McChesney *et al.* (1978) and McChesney (1979, 1982), reported on the energy use of different sub sectors of the agricultural industry, surveying sheep and beef and mixed cropping farms to provide more detailed information on the breakdown of energy inputs.

A detailed study of "On farm energy supply and conservation" for the NZ Energy Research and Development Committee was conducted in 1979, which emphasised energy saving opportunities within New Zealand agriculture (Sims, Henderson *et al.*, 1983).

Although the agricultural sector's reliance on liquid fuels had been highlighted by previous studies, this was reinforced by the second oil shock in 1979, which prompted a detailed study of fuel use in agriculture (McChesney, 1983).

Further research during the following decade was virtually non-existent as funding services declined once the crude oil prices dropped to lower levels. In the late 1990s and the beginning of the 21st century oil prices started to increase again, although not until recently was this near to the same extent as in 1979. However, this time, as well as rising energy costs there are new threats from climate change concerns and some overseas trading partners possibly using environmental compliance as a form of non-tariff trade barrier. The Centre for Advanced Engineering (CAE 1996) reviewed energy efficiency technologies across the New Zealand economy. Within this review the primary industry was a key sector (Sims *et al.* 1996). More recent legislative changes and energy shortages have renewed interest in the use of energy in agriculture, particularly within the dairying and greenhouse sectors. Recent significant research (Wells, 2001; Barber and Wharfe, 2004) gives insight into the consumption, energy type and end use of energy.

2.3 International outlook on climate change

In 1992 at the Rio "Earth Summit", the world community adopted the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is the global response to climate change and it has been ratified by almost all countries, including New Zealand.

The ultimate objective of the Framework Convention is to achieve: *Stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system* (NZCCO, 2002).

The Kyoto Protocol was the next development of this Convention. It aimed to introduce legally binding commitments for OECD countries and economies in transition to limit greenhouse gas emissions, as voluntary commitments agreed under the Framework Convention were not successfully implemented. New Zealand has ratified along with

150 other countries and it came into force on February 16th 2005. The U.S.A and Australia have both withdrawn, which will make the modest 5.2% reduction target bellow 1990 greenhouse gas levels harder to achieve.

Economic benefits of the Kyoto Protocol are likely to include technology and energy efficiency improvements (NZCCO, 2002). Limits on greenhouse gas emissions from all sources will create additional incentives for Protocol signatory countries to develop and adopt new energy technologies less reliant on fossil fuels. Energy efficiency incentives will also be enhanced, resulting in the double benefit of lower emissions and higher productivity per unit of energy.

2.4 National outlook on climate change

New Zealand is obligated under the Kyoto Protocol to ensure that the total greenhouse gas emissions for the first commitment period (the five years from 2008 to 2012) are no higher than New Zealand's 1990 level of emissions, and that responsibility has been taken for any emissions over this level through the emissions trading mechanisms and sinks provisions of the Protocol (NZCCO, 2002). In 1990, our total greenhouse gas emissions from all sources were equivalent to almost 62 million tonnes of carbon dioxide. The most recent data indicates that emissions have risen by about 21.6% since 1990 and projections indicate that we could be more than 24% above our target during 2008 to 2012 if we do nothing to reduce our emissions (Brown and Plume, 2002).

The Government's policy package to achieve the emissions target included a carbon charge levied on fossil fuels and industrial process emissions. This charge will be set at $15/tonne of carbon dioxide and will and will take effect in April 2007 (NZCCO, 2005).

New Zealand is unusual amongst developed nations that about half of it's total emissions are produced by agriculture (Table 2), predominantly methane from farm animals and nitrous oxide from animal waste and nitrogen. According to estimates in the National Inventory Report (Brown and Plume, 2002), these agricultural emissions were then 12% above 1990 levels.

Table 2. An overview of New Zealand's greenhouse gas emission profile in 2001.

	Total emissions (Mt CO_2 equivalent)	Proportions of GHG emissions %
Energy sector emissions	**32**	**43%**
Waste sector emissions	**2.4**	**3%**
Industrial processes & solvent emissions	**3.6**	**5%**
Agricultural sector emissions	**36.9**	**49%**
Agricultural soil emissions (N_2O)	12.6	34%
Sheep (CH_4 from enteric fermentation)	9.1	25%
Dairy cattle (CH_4 from enteric fermentation)	8.3	22%
Beef cattle (CH_4 from enteric fermentation)	5.4	15%
Other, including horticulture and greenhouse operations	1.4	4%
Total Agricultural Emissions	**74.9**	**100%**

(Source: Brown & Plume, 2002)

New Zealand's economy is heavily dependent on primary industry exports and policies that affect agricultural production will also affect New Zealand's economy. As an intermediary step the Government and agricultural groups have signed a partnership agreement on voluntary research into reducing agricultural greenhouse gas emissions. This approach recognises the circumstances of the agriculture sector and focuses on developing technical solutions for reducing non-carbon dioxide emissions over the medium term. It provides for sectoral engagement with the issue, and for the sector to take a leadership role in addressing emissions prior to and during the first commitment period (Barber and Parminter, 2004).

2.5 Industry involvement in this research

Due to the nature of this study it was necessary to remain in close liaison with the Energy Efficiency and Conservation Authority and Vegfed which provided funding and resources for this research. The functions of each organisation are briefly outlined.

2.5.1 The Energy Efficiency and Conservation Authority (EECA)

EECA is the principal body responsible for delivering the Government's National Energy Efficiency and Conservation Strategy (NEECS). The function of EECA is to encourage, promote and support energy efficiency and conservation and the use of renewable energy resources, through raising consumer awareness of energy efficiency issues and by providing businesses and individuals with the tools to make changes (EECA, 2005).

EECA (2001) developed the National Energy Efficiency and Conservation Strategy in conjunction with the Ministry for the Environment to address requirements under the Energy Efficiency and Conservation Act (2000) and contribute to Government's energy, environmental and social policy agendas.

2.5.2 The Vegetable and Potato Growers' Federation (Vegfed)

Vegfed is the New Zealand vegetable growers trade association and represents around 3000 growers including greenhouse vegetable, potato, onion and asparagus growers. Vegfed's main objectives are to promote the production, distribution and consumption of New Zealand grown vegetables and to foster the interests of the industry. This includes commenting on legislation that may impact on the industry, taking part in discussions and funding activities and selected research projects.

3.0 Sector overview

The overall energy intensity, patterns of energy consumption, energy types and energy end uses within each of the sheep and beef, arable farming, pig and poultry, protected crop (greenhouse) production, fruit production and dairy, sectors are briefly described, with a cross cutting section on irrigation. Possible future trends within these sectors and their possible impacts on energy demands are discussed.

3.1 Sheep and beef farming

Pastoral agriculture is practised widely throughout New Zealand mainly comprising beef cattle, dairying, and sheep with smaller areas for deer, goats, llamas and horses. Sheep and beef products accounted for 17% of merchandise exports which have been New Zealand's second largest export earner, though forest products and tourism have both challenged this standing in recent years.

The sheep population has declined, 39.7 million in 2003, the lowest number recorded since 1955 (Fig. 2). In 2002, there were about 10 sheep for every person in New Zealand compared with 20 sheep for every person in 1982 (Meat NZ, 2004). The Ministry of Agriculture (2003) predicted this trend will continue. Beef cattle population is showing a similar trend (Fig. 3) whereas deer numbers are steadily increasing to around 1.2 million (Meat and Wool Innovation, 2004).

The overall area used for sheep and beef farming in New Zealand has decreased due to land conversions to dairy and forestry. However productivity per hectare has tended to increase through advances in breeding technology, disease control and pasture management (Frazer, 2004). The continuing decline in stock units and land area will reduce the energy demand of this sector. However this will not be reflected in the overall energy demand of the agricultural sector.

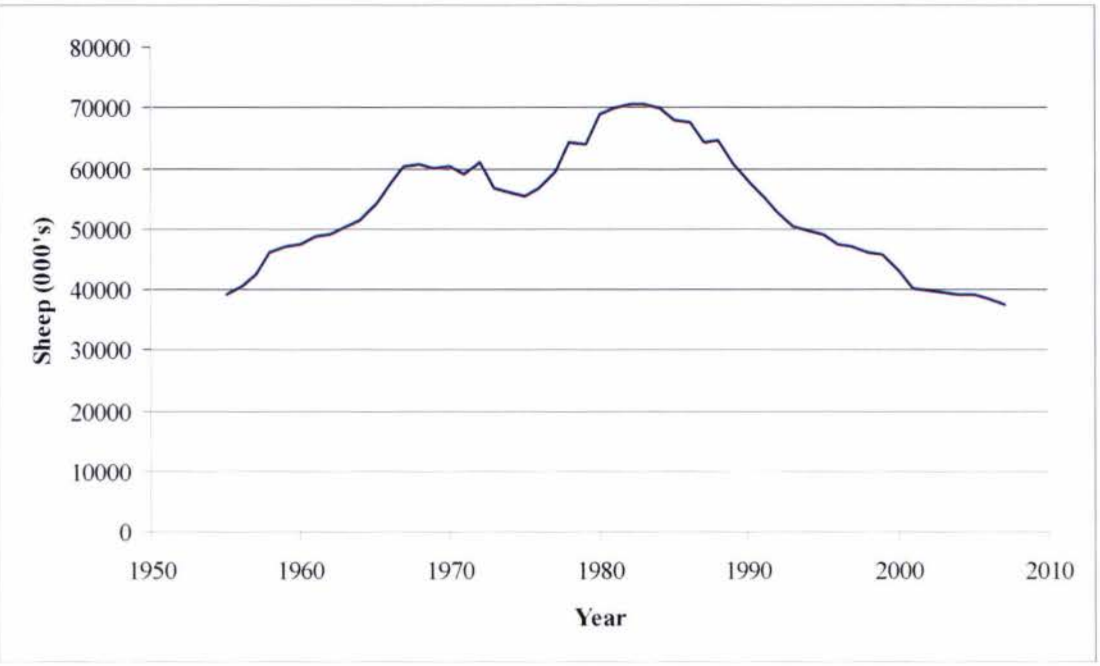

Figure 2. Sheep numbers per year in New Zealand during the past five decades.

(Source: Meat and Wool Innovation, 2004)

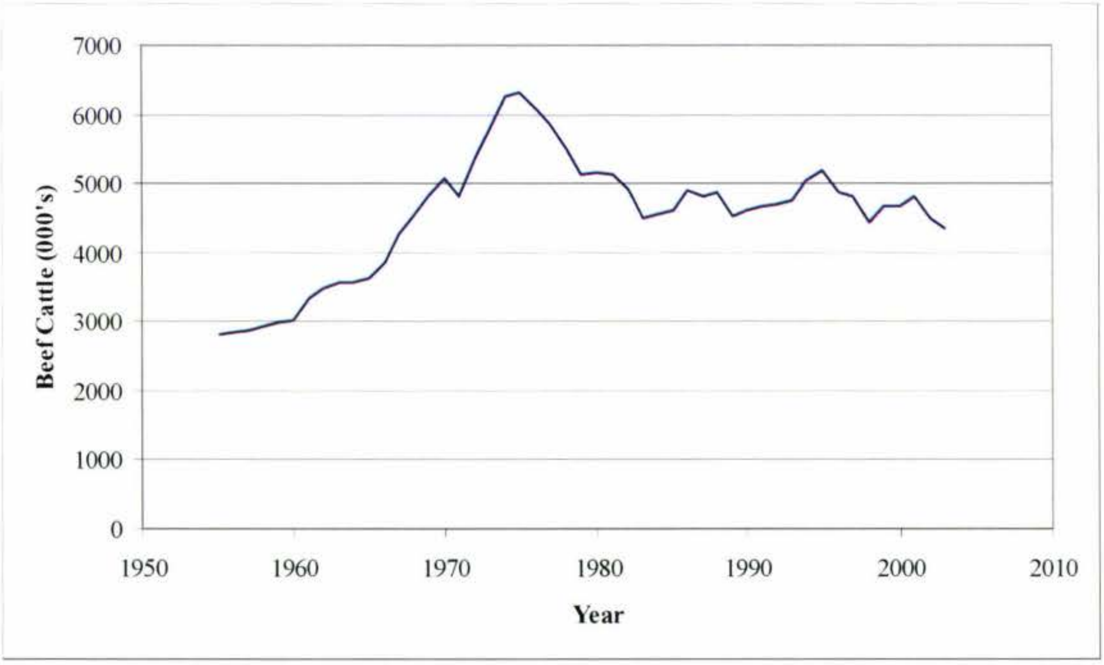

Figure 3. Beef cattle numbers per year in New Zealand during the past five decades.

(Source: Meat and Wool Innovation, 2004)

3.1.1 Energy intensity and patterns of energy consumption in the sheep and beef sector

Sheep and beef farming systems are generally not energy intensive due to the limited use of buildings and machinery compared with other farming systems such as dairying. Energy demanding activities may involve feedlots, feeding out, forage conservation, irrigation, pasture management and occasional cropping (Fig 4).

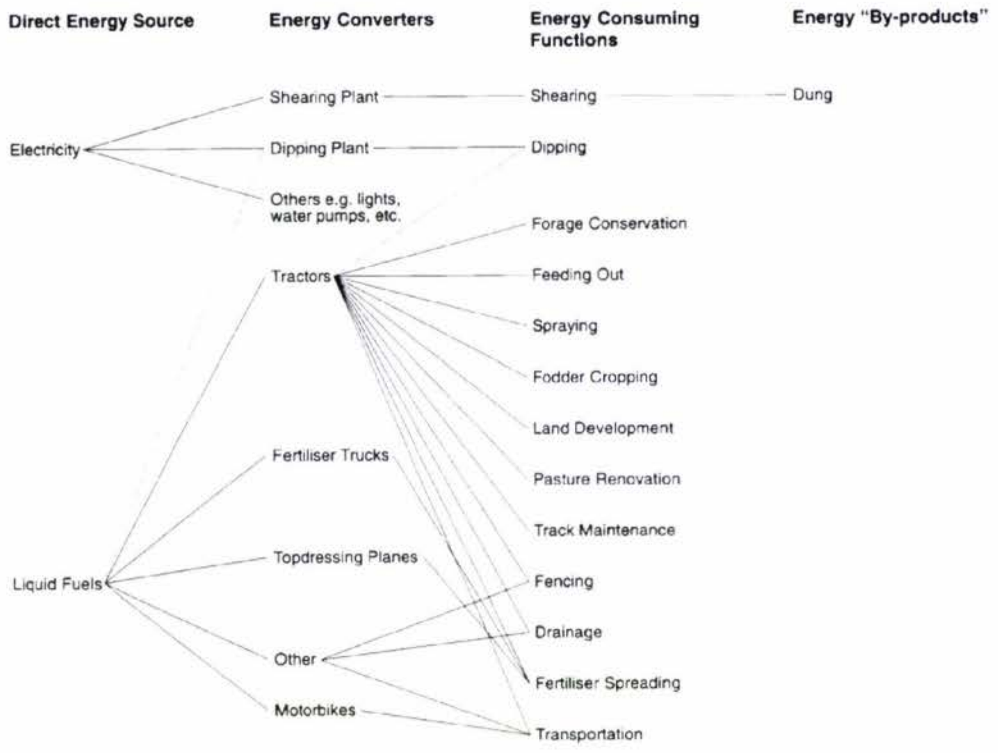

Figure 4. Direct energy flows of a sheep and beef enterprise.

(Source: CAE, 1996)

McChesney (1979) produced a report on energy use in the sheep and beef farming sector of New Zealand, which while dated, remains the best guide to energy use in this sector. The estimated overall energy intensity of sheep and beef farming was 1.1 GJ/ha per year of which 73% of the energy inputs were indirect with almost half being for the manufacture, transport and application of fertiliser (Table 3). It is unlikely these figures will have changed significantly over the years, although replacement of conventional fencing with electric fencing has reduced the capital input while improving pasture growth by better management and pasture rotation has reduced the need for supplement animal feed. For 2003, based on the total area of sheep and beef farms being 5,970,000ha the total direct energy demand was 1.75 PJ (EECA, 2004).

Table 3. Energy inputs and intensity of sheep and beef farming systems

Input	Energy intensity (GJ/ha/year)
Direct:	
Fuel	0.29
Electricity	0.01
Indirect:	
Fertiliser	0.36
Machinery	0.1
Water Supply	0.07
Contract Cartage	0.07
Fences	0.06
Buildings	0.04
Field Contractors	0.03
Chemicals	0.03
Shearing	0.02
Other	0.01
Total	1.09

(Source: McChesney, 1979)

The energy intensity of sheep and beef production systems is strongly correlated to the stocking rate. McChesney (1979) found that Canterbury hill country farms that had low stock unit (su) rates (3.6 su/ha) had low energy intensities (0.4 GJ/ha), whereas those farms with higher stocking rates (9-10 su/ha) had higher energy intensities (1.8-2.3 GJ/ha). A higher stocking rate increases the requirement for supplementary feed and consequently a much higher proportion of tractor fuel was used for cultivation of forage crops and hay making on those farms. This relationship is subject to the law of diminishing returns. Therefore, in terms of net livestock output, the energy requirement per unit of production at stocking rates of 9-10 su/ha was 40% higher than at a stocking rate of 3.6 su/ha (McChesney, 1979).

The total annual liquid fuel consumption of a sheep and beef enterprise was estimated at between 4000-14000 l/ha, or around 2 l/su (McChesney, 1979). Off site transportation was the main energy consuming activity using 50%, while on site transport used around 20% and the remaining 30% was for fertiliser application, cultivation, pasture renovation and forage conservation (CAE, 1996). Stationary plants used mainly for sheep dipping consumed just 5MJ/ha per annum.

Tractors, crawlers and other miscellaneous self propelled vehicles used around 40%, while the remaining 60% was used by transport vehicles. Since McChesney's study (1979) the use of farm bikes for stock management instead of tractors and other vehicles (which largely replaced the horse in the 1960s and 1970s) has reduced overall fuel consumption (Frazer, 2004).

Note that in all these studies it is difficult to separate out petrol and diesel consumed in vehicles for on-farm use from that consumed in cars and trucks off-farm since often the fuel is sourced from the same on-farm tank.

Electricity consumption by a typical sheep and beef farm is generally low ranging from 3000 to 7000 kWh/annum or around 1.0-1.5kWh/su (CAE, 1996). Pumps for stock water reticulation systems are the main electrical energy consumers with an energy intensity of about 12.5kWh/ha. Vehicle use to maintain the pumps consumes a small amount of fuel, bringing the total energy intensity to around 80MJ/ha (Eastwood and Sims, 2003). Williams (1993) estimated that 2GWh/year of electricity was used nationally during shearing equating to only 0.02kWh per sheep shorn (CAE, 1996).

The prime variable influencing fertiliser energy input is the quantity of fertiliser used rather than the methods used during transportation and application. The typical energy requirement for processing, transport and aerial distribution of super-phosphate was calculated to be 2.3GJ/tonne, with decreasing stock numbers reduce the overall energy use of this sector. Phosphate fertilisers were used extensively on New Zealand's predominantly grass/clover hill country pasture, nitrogen fertilisers used to a lesser degree (Statistics NZ, 2004) though this is increasing. If stock numbers continue to decrease, this will further reduce the overall fertilizer use of this sector.

Deer and Goat Farming Systems

Deer and goats are farmed on a similar pastoral system to sheep and beef. Obvious differences are the 2 metre high electric fencing needed and the level of supplement feed. The sector remains small and will not be considered further in this study.

Horse breeding and training

Breeding and training horses is a similar pastoral and low energy intensive farming system to a sheep and beef enterprise. Pasture production is similar but often with the addition of high protein feed. A trend may develop towards replacing labour with mechanised aids to reduce labour costs which will increase the overall energy intensity of the sector (CAE, 1996). This sector is also small and will not be considered further.

3.1.2 The outlook for the sheep and beef sector until 2012

New Zealand beef cattle and sheep numbers are projected to fall in the next 5 years because of continued land use conversions to more profitable dairy, deer and forestry (MAF 2003). The fall is expected to be proportionately greater for beef cattle than for sheep, as beef to lamb price ratios are projected to decline. The increasing use of nitrogenous fertilisers for year round pasture production has increased the indirect energy input of the sector and reduced the need for supplementary feed and feeding out system, with consequent reduction in direct energy consumption (Frazer 2004). The continuing decrease in size and production of the sheep and beef industry is expected to reflect a decline in the overall energy demand of the sheep and beef sector. Since it is not an energy intensive sector, major investment to seek improved energy efficiency is unlikely to be warranted.

Many extensive livestock farming systems are located in rural back country areas and may be a considerable distance from the national grid transmission system. CAE (1996) suggested that consideration of remote area power systems may be worthwhile either now or when the existing local distribution line is up for renewal.

3.2 Arable crop farming

Although pastoral farming remains the major land use in New Zealand, in recent years there have been significant increases in the area planted in horticulture and other crops. After a period of decline in the 1980s following deregulation of the industry, the area planted in traditional cereals, such as wheat, barley and maize stabilised. In the early 1990s a fall in commodity prices meant cheap wheat was imported from Australia (CAE, 1996). This reduced the area farmed for crops in New Zealand and hence the overall energy use of this sector.

In the last ten years however, the arable cropping industry has grown due to the expansion of seed production, oil crops, organic crops and an increase in irrigated arable land (Eastwood and Sims, 2003). There has also been an increase in plantings of pasture seeds and specialist crops to meet the demands of an increasing size dairy industry. The total area of grain and seed crops grown in New Zealand at present is estimated to be 186, 000 hectares (MAF, 2004).

3.2.1 Energy intensity & patterns of energy consumption in the arable cropping sector

Recent literature on energy use by the arable cropping industry is limited. Barber (2003) investigated the energy use of vegetable, irrigated arable and dry arable cropping systems and identified potential areas where energy savings could be made. McChesney (1978, 1982), while dated, offered the most comprehensive investigation into the breakdown of energy consuming activities on an arable cropping farm. Values will have remained relatively unchanged but the real cost of energy, particularly fuel, may have increased in proportion to total farm costs, since then.

The main direct energy inputs into an arable cropping system are liquid fuels, most of which are consumed during field operations, and electricity where irrigation is undertaken (see Fig. 5). Overall energy intensity can range anywhere from around 5 GJ/ha for dry arable farms growing cereals, to 20 GJ/ha if irrigated, and 22 GJ/ha for potato and onion production (Barber, 2003).

EECA (2004) estimated that 3.0PJ of direct energy per year is consumed behind the farm gate, assuming an average total energy demand of 15GJ/ha across all types of crop production and soil types and a total area of 195,000ha grown annually. It is not known how much post-harvest processing occurs behind the farm gate. This may affect the total energy demand of this sector.

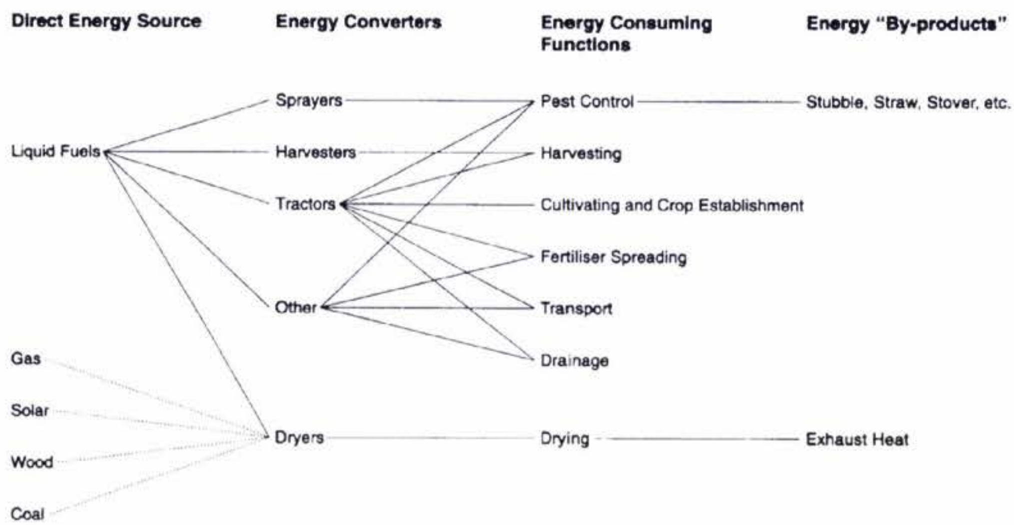

Figure 5. Direct energy flows of an arable cropping enterprise.

(Source: CAE, 1996)

Fuel use and type vary between irrigated arable, dry arable and vegetable production systems (Fig. 10). The direct energy embedded in fertilisers, agri-chemicals and buildings (capital) is also significant. Vegetable production in the field is more energy intensive per hectare then arable crops except for irrigation due to the larger land areas involved in the latter.

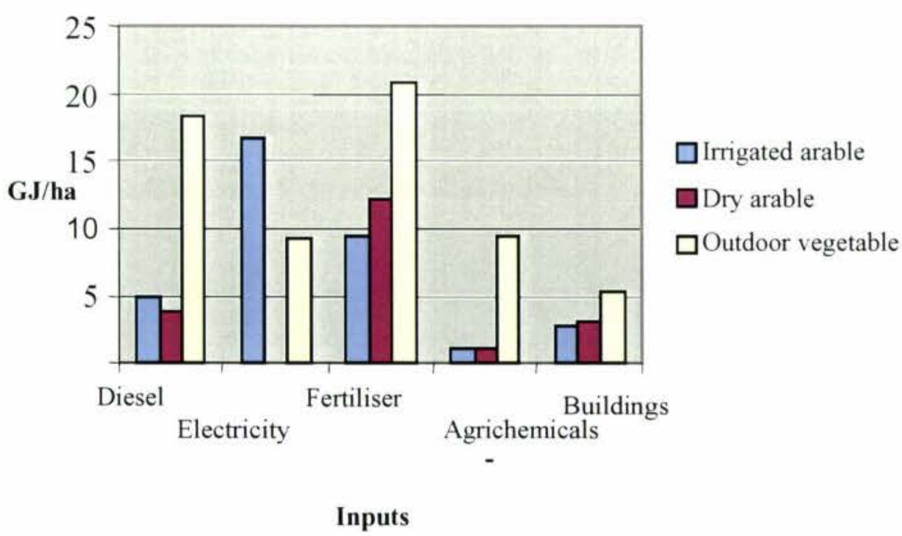

Figure 6. Direct and indirect inputs for arable and outdoor vegetable production.

(Source: Barber, 2004)

Around 70-80% of the diesel fuel used on an arable farm is for the tillage with conventional methods of ploughing and cultivation consuming over 50l/ha (McChesney, 1978). Ploughing alone accounts for around 40% of the total fuel used and can consume around 18l/ha (McChesney, 1983) varying with depth and soil type.

Conservation tillage was identified as a more fuel efficient crop establishment technique. There is a range of such methods from reduced cultivation to more fuel efficient direct drilling which consumes only 10l/ha of diesel (Table 4).

Land clearing should be viewed as a one off activity which can consume between 5-15 GJ/ha of liquid fuels in large crawler tractors, the consumption varying with the terrain and cover (McChesney, Bubb and Pearson, 1978). Very little clearing occurs today though some plantation forest in the central North Island is being reverted to pasture as a result of the present low return for forest products.

Table 4. Activities and fuel use associated with cultivation of an arable cropping farm.

Activity	Fuel Use
Ploughing	18l/ha
Cultivating	6 l/ha
Discing	12 l/ha
Rolling	4 l/ha
Power Harrowing	8 l/ha
Light Harrowing	4 l/ha
Conventional Drilling	5 l/ha
Direct Drilling	10 l/ha
Spraying	3 l/ha
Fertiliser Spreading	3 l/ha
Aerial Topdressing	7 l/ha
Aerial Spraying	0.035 l/ha
Road Cartage	0.079 l/tonne-km

(Source: McChesney *et. al.*, 1978 and CAE, 1996)

Tractor selection and design are important factors when trying to maximise fuel efficiency on a farm. Tractor selection is generally based on the heaviest activities, making tractor use inefficient for lighter tasks. Regular maintenance of both tractors and implements are essential for energy efficient operation. The "Tractor Facts" campaign of the early 1980s to help farmers reduce fuel consumption still stands today and could be recommended for revival.

The use of tractors for transport (33%), cultivation (27%), harvesting (6%), haymaking (8%) and running the stationary plant (3%) are the main fuel consuming activities on an arable farm (McChesney, Bubb *et al.*, 1978). Non-specific tractor use including travelling between farm blocks, farm track maintenance and on-farm vehicle transport are also main energy consuming activities at around 0.8 GJ/ha (McChesney, Bubb *et al.*, 1978) or 23% of liquid fuel energy demand.

Annual harvesting of cereal crops consumes over 5 million litres of liquid fuels annually assuming an energy demand of 40l/ha (CAE, 1996). Estimates range from 6l/t of grain (McChesney, 1983) to 12l/t (McChesney, Bubb *et al.*, 1978). Other than regular engine and harvester maintenance there is little opportunity for energy savings.

Cereal straw may be collected and used on farm as boiler fuel to provide space heating for homes and livestock sheds but in New Zealand it is typically burnt in the fields after the harvest a practice banned in Europe due to air pollution. If it were to be banned in New Zealand extra energy would be required to chop and incorporate the straw into the soil.

Hay making and silage production generally occur on a mixed cropping farming system where supplemented stock feed is required. McChesney *et. al.,* (1978) estimated that the whole hay making operation from field to barn consume around 14l/ha, while silage production consume around 38l/ha of liquid fuels (McChesney, 1983). Haymaking operations such as mowing (4l/ha), raking (3l/ha) and baling (5l/ha) consumed small amounts of energy, while forage harvesting consume up to 22 l/ha of liquid fuels (McChesney, Bubb *et al.*, 1978).

Tractor spraying consume around 270MJ/ha (McChesney, 1983) of liquid fuels, however this figure may be less on some cropping farms through the recent application of integrated pest management techniques. Integrated pest management aims to save time, reduce chemical and increase crop yields but also has the benefit of reducing energy consumption.

Fertiliser input into both irrigated and dry arable farming systems accounts for approximately 9.5 GJ/ha and 9.3 GJ/ha of indirect energy respectively whereas outdoor vegetable production has a considerably higher input of around 20.9 GJ/ha (Barber, 2004). Fertiliser application may involve tractors and light aircraft. Aerial distribution of fertilisers was estimated to consume around 428MJ/t in the form of liquid fuels (McChesney, 1983), while ground spreading consumed 64.5MJ/ha. Application of lime was not significantly different at 428MJ/t for aerial distribution and 54MJ/ha for ground-spread distribution. With introduction of more concentrated fertilisers and more efficient plane and vehicle engines these inputs may have since been reduced.

McChesney *et. al.* (1982) compared the energy input between arable farms in New Zealand and the United Kingdom, and found that the energy requirement for cereals per tonne of grain grown in New Zealand was half that of the United Kingdom. However, the opposite was true of potatoes for which total energy requirements were almost 60% higher in New Zealand. New Zealand's favourable climate and low use of nitrogen fertiliser due to the use of clover fixed soil nitrogen in the cereal rotation mix could explain the lower energy input for cereals. There was no obvious explanation why New Zealand's potato production used more energy, other than perhaps lower yields/ha.

Electricity consumption varies with the different arable farming types and farming systems. Negligible electricity is used for field operations, while a small input at times is required for conditioning and refrigeration of the crop. To preserve grain condition it must be stored at low moisture content. Using natural drying is the most cost and energy efficient method however adverse weather may result in crop losses. While most grain is transported to contract processing installations (generally run by natural gas, oil or coal) it is possible to dry grain on the farm in small scale dryers using LPG, oil, electricity, wood or coal. Drying generally requires 1000-2500 MJ heat input/tonne of grain when dropping the moisture content by 12-14% (CAE, 1996). A wide range of dryers is available including dehumidifiers, solar drying, storage (with a capacity of 15-20 kW/t), batch and continuous dryers (25-30 kW/t) (Farm Electric, 1989)

The application of water to crops and pastures during dry periods is increasing, with irrigated arable currently making up a quarter of all irrigated land (Eastwood and Sims, 2003). Irrigation normally involves pumping large volumes of water for use in high pressure sprinkler irrigation systems, but can also involve low pressure trickle systems, and flood irrigation systems (section 3.6). Irrigated arable systems can consume around 16.7 GJ/ha of electricity per year while more intensive outdoor vegetable production consume up to 9.3 GJ/ha.

3.2.2 The outlook for the arable cropping sector until 2012

The sector is forecast to hold its current output of crops from a decreasing area of crops grown in the next 5 years (MAF, 2003). The small seeds industry will continue to produce seeds for the New Zealand pastoral industry and for export markets. As a greater area of land is converted to intensive dairying, the demand for supplement animal feed from cereals will also continue to grow.

Significant opportunities for potential energy efficiency savings exist throughout the arable cropping production system. Barber (2004) confirmed the earlier "Tractor Facts" studies showing reduced tillage, increased driver education and matching of tractors and implements to specific tasks could reduce fuel consumption by up to 15% (around $7.25/ha for arable crops and $28.75/ha for vegetables).

Energy conservation measures for current grower practices are mainly related to tractor and implement use and design. The "Tractor Facts" campaign of the early 1980's provided guidelines on how to minimise fuel use. However farmers are unlikely to take up tractor operation methods or minimum tillage methods solely to save diesel. Other factors such as reduced soil erosion, extension of grazing period and increased crop yields will enter into the decision. Simple measures to conserve fuel, such as reducing the number of passes and cultivating at a shallower depth, may also provide the added benefits of saving time and reducing soil erosion.

3.3 Intensive pig and poultry production

While intensive pig and poultry production is a relatively high energy demanding farming system, it is only a small sub-sector so total energy demand is low. In the last 20 years the number of registered pig and poultry farms has declined, while farm size and production has increased (Fig. 7). Between 1995 and 2002 the number of pig farming enterprises fell by more than half to 360 farms with herds of 1000 and over now accounting for 72% of New Zealand's total pig population. This trend is similar for the poultry industry (Statistics NZ, 2004). Deregulation of the industry has lead to competition between owners, a closer eye on profit margins and overall increased energy efficiency of the industry (Eastwood and Sims, 2003).

Domestic pork production increased slightly in 1998 after declining since 1995 due to increasing pressures from the importation of competitively priced Canadian, Australian, American and Danish frozen pork and relatively high feed costs. Present production is slowly increasing (Statistics NZ, 2004).

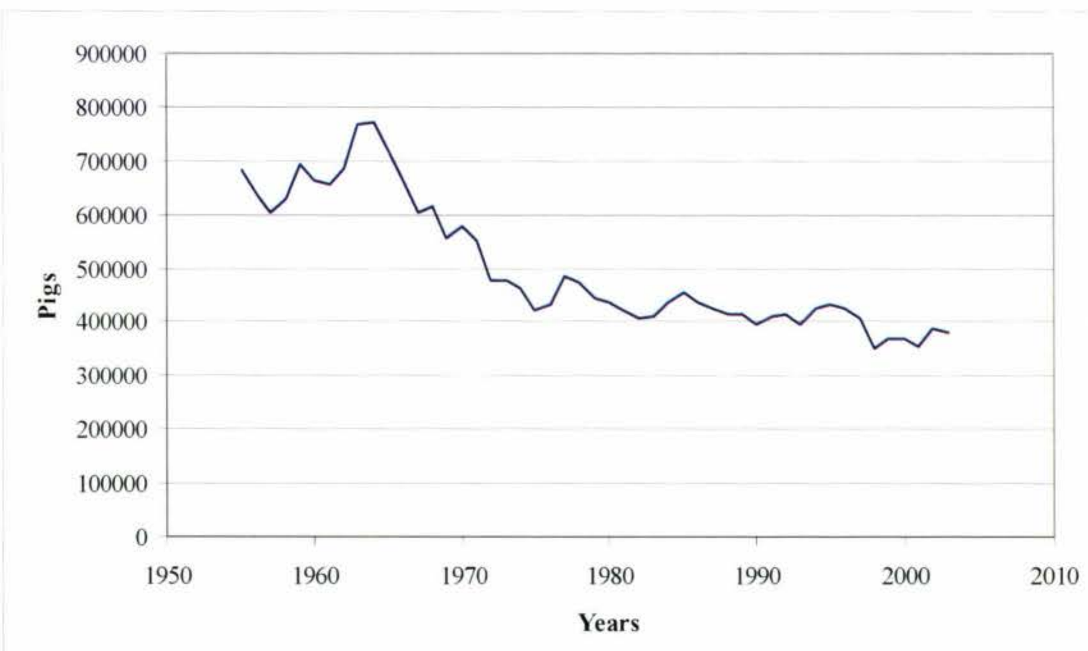

Figure 7. Pig numbers per year in New Zealand during the past five decades.

(Source: Meat and Wool Innovation, 2004)

The poultry industry is expanding rapidly and is now a major intensive livestock industry in this country. Since 1990, poultry production has grown by 7% on average per year. Driving this industry growth has been the rising per capita consumption of poultry meat and the competitive retail prices for chicken products. In 1998 New Zealand's estimated 2.2 million laying hens produced close to 756 million eggs (Statistics NZ, 2004). Total egg production remained relatively static for the past decade, with slight drops in per capita consumption – now around 200 eggs per person annually. Most eggs produced in New Zealand are from caged hens, with free range and barn egg production accounting for 5 % of the total (Statistics NZ, 2004).

3.3.1 Energy intensity and patterns of energy consumption in the pig and poultry sector

Data relating to energy use in the pig and poultry sector is limited. A significant study undertaken by McChesney (1982) remains the most comprehensive published data on pig production. Poultry production has only recently become a major intensive livestock industry for New Zealand and was probably not considered to the same extent during the oil shocks of the 1970s and 1980s. This may explain why there is very little data relating to energy use in the poultry farming sector.

The major energy demanding activities in this sector are maintaining environmentally controlled buildings through heating, lighting and ventilation and for the indirect production and transport of bought in animal feed (Fig. 8).

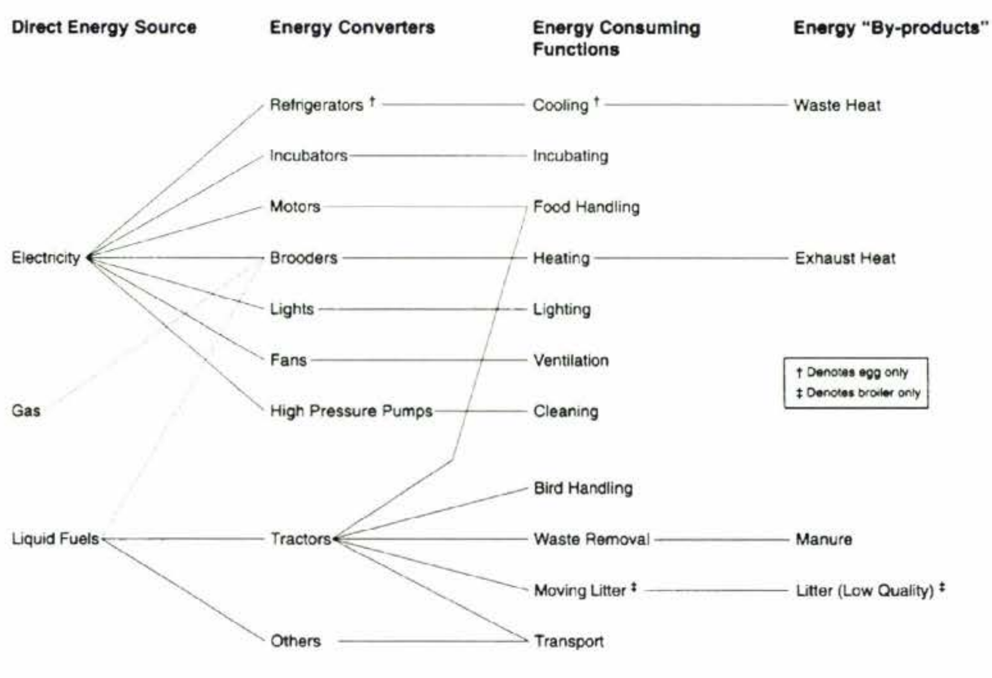

Figure 8. Energy inputs into a pig and poultry farm.

(Source: CAE, 1995)

Only 14%-16% (around 550 GJ/annum) of the total energy input into a pig and poultry farming system is from direct input (CAE, 1996). This figure, unlikely to have changed significantly over the last ten years, included electricity for lighting, ventilation and heating, and petrol for use in transport and motors.

The total electricity consumption for a pig and poultry farm is estimated to be 367 GJ/annum (McChesney, 1982). This consumption shows seasonal variation with peaks in summer due to the increased use of air conditioning fans for ventilation. The climate within a piggery or a poultry house can be affected by external temperatures, the heat released by the livestock, insulation, ventilation rates and the amount of excreta (McChesney, 1982).

Infra red lamps are typically used to heat young animals, as livestock mature the height of the lamps can be raised or the heat output reduced. Quartz linear lamps are favourable in large, open, and draughty situations. The alternate option is good under floor heating of a brooder house designed to deliver 300-400 W/m^2 (McChesney, 1982). Supplementary heating is generally provided for young piglets using electric pads at 0.15 kW consumed 92 GJ/annum, and is subject to seasonal variation (McChesney, 1982).

Effective building design can reduce the need for artificial lighting and temperature control by utilising natural sunlight and providing shelter from wind. Correct building orientation, window placement and insulation may reduce the need for energy consumption. Ventilation either natural or forced airflow is necessary to remove the body heat. Typically electrically powered axial fans are used to provide this forced ventilation (McChesney, 1982)

Water supplies often use an electric pump of around 0.5 to 1 kW where water is readily available. A high pressure water supply with greater capacity motor (around 2-3 kW) is necessary for animal housing wash down purposes (McChesney, 1982).

Animal waste removal is an important activity in maintaining a livestock production system and options for disposal or treatment include recycling by applying to crops as a fertiliser and anaerobic digestion to produce methane with recycling of the digested solid residue to the soil.

Maintaining optimal temperature control of the building ensures an efficient feed to meat conversion as less energy is needed to maintain body heat. Electricity is also used to power electric drives to automatically controlled feeding systems and for additional lighting to encourage egg production.

3.3.2 The outlook for the intensive pig and poultry sector until 2012

Pork production is expected to increase up till 2007. Increases in the size of the breeding herd and higher slaughter weights are expected to contribute to increased production (MAF, 2004). More industry consolidation is anticipated in both the pig farming and processing sector with fewer farms producing more pigs (Statistics NZ, 2004).

Poultry consumption continues to increase due to declining prices in real terms, changes in lifestyle and consumer perceptions (MAF, 2003). Consumption of white meat has increased from 14 kg/capita in 1990 to over 37 kg/capita in 2004. With the proportion of poultry meat consumed has increased from 15 % to 25 % of total meat consumption largely at the expense of sheep meat. Industry growth and domestic consumption of chicken is expected to increase with continued competitive pricing of chicken products, the increasing range of value added chicken products and the increase in supply to fast food contractors. MAF (2003) estimated production to increase by 6% a year or 1.9% per capita dressed weight over the next 3-4 years.

As the pig and poultry sectors continue to grow, so will their energy demand. The main energy input of pig and poultry farms is the indirect energy embodied in animal feed. There are few opportunities for energy efficiency savings to be made on farm concerning this input. Most energy efficiency gains can be made through effective building design, to reduce the direct energy required to maintain environmentally controlled buildings and potentially reduce feed intake per animal (EECA, 2004).

Concern over animal welfare has prompted a trend towards less intensive farming systems, though these are not necessarily less energy demanding than more intensive systems, particularly if poor equipment choices are made (Williams, 1993).

3.4 Fruit production

Significant changes within the pip-fruit, stone fruit, kiwifruit, citrus and viticulture sub-sectors have increased the land area and production of orchard operations, and consequently the energy use of this sector. Deregulation of the industry has resulted in competition between multiple exporters and the introduction of higher quality control on production. More than 70% of ENZA pipfruit is sold by offshore subsidiaries and joint ventures to retail operations and major wholesale distributors. By removing the middle person who acts as a distributor, ENZA ultimately improved returns to growers (Turners and Growers, 2004). While technological advances in controlled atmospheric storage allow year round supply of pip fruit for the domestic and export markets, this has increased the overall energy use of the sector.

Horticultural exports have grown from $200 million to almost $2.0 billion in the last 20 years, with kiwifruit, apples and wine the most valuable in 2002. Tremendous growth in the New Zealand wine industry has seen export earnings increase from $27 million in 1991 to $198 million in 2001 (Fig. 9) (HortResearch, 2003). There have been extensive plantings of wine grapes since 1994, with the area under wine grapes increasing from 7,200 hectares to 17,400 hectares in 2002. This trend continues with many traditional apple and stone fruit orchards undergoing conversion to grapes.

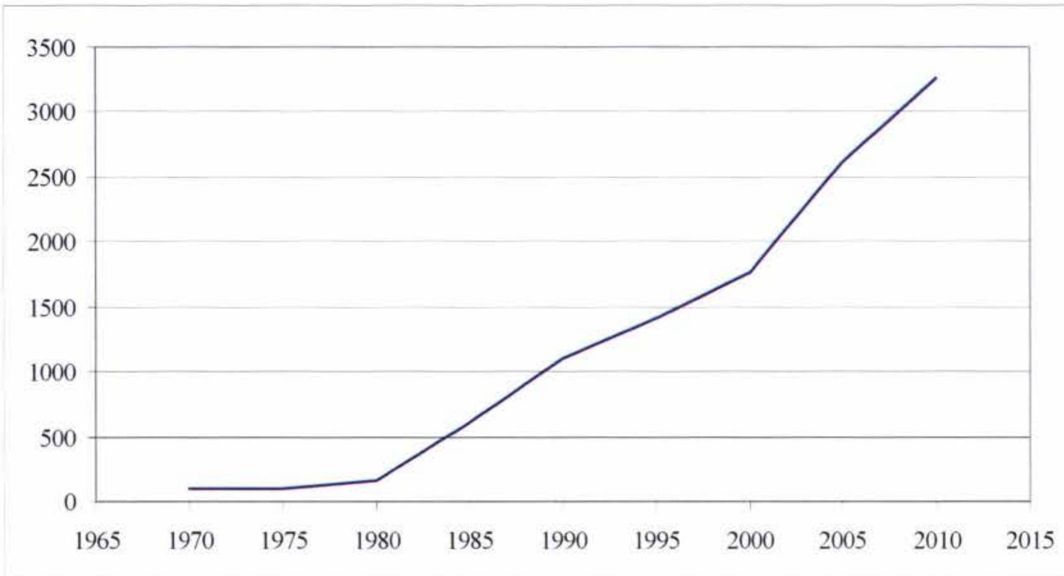

Figure 9. Horticulture (real and projected) exports 1970-2010 ($fob million).

(Source: HortResearch, 2003)

Pipfruit, kiwifruit and grapes are grouped together here in this "fruit production" section as their energy demands are similar and there is little information available specifically for vineyards.

3.4.1 Energy intensity and patterns of energy consumption in the fruit producing sector

The breakdown of energy using activities in the orchard sector (CAE, 1996), is unlikely to have changed much in the last 10 years. Energy inputs into the fruit producing farming systems can be up to four times higher than conventional arable cropping operations. Most energy inputs occur in the orchard as fuel for tractors, hydra ladders and forklifts (Fig. 10).

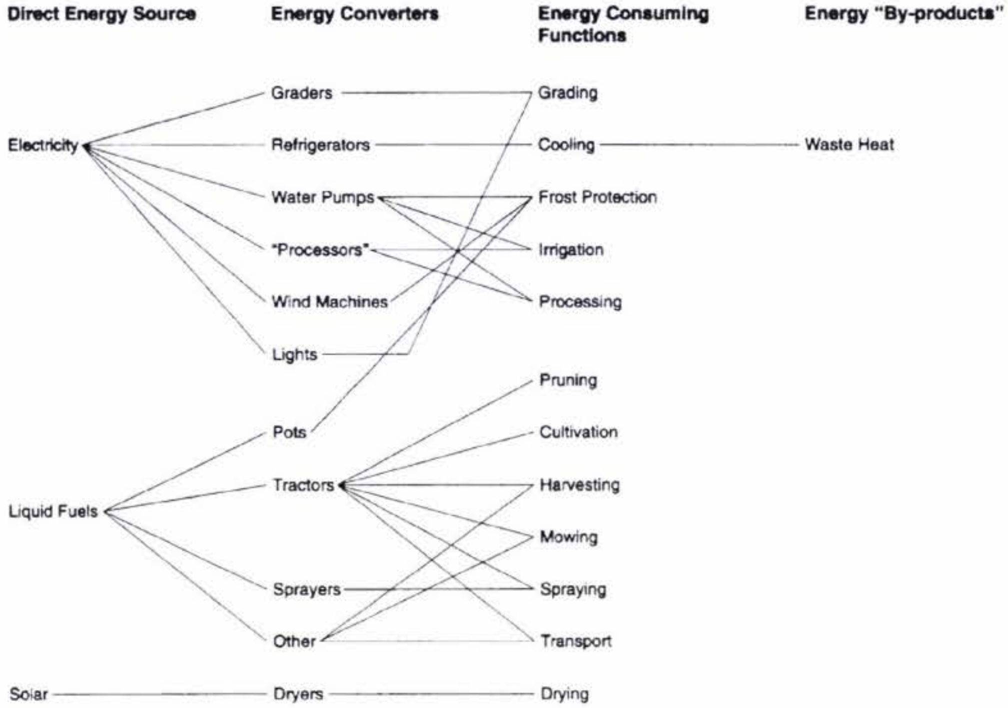

Figure 10. Direct energy flows of an orchard enterprise

(Source: CAE, 1996)

Orchards are relatively fuel intensive at around 850 l/ha (CAE, 1996), a quarter of which is consumed by spray application using air blast sprayers. This practice is well established in spite of its low efficiency with often only 20-30% of the chemical reaching the target.

Using more concentrated sprays may reduce energy demand due to lower application volume rates, as would reducing the number of applications per season. This would require the implementation of integrated pest management techniques that involve only spraying when required rather than at fixed intervals. Tank mixing of approved chemical and simultaneous application of more than one spray, where appropriate, would also reduce the number of passes. More complex sprayer designs tend to require greater energy and require increased maintenance; consequently they have not become popular.

Field operations are the major energy user for an orchard (Table 5), including trimming and pruning, mowing, top dressing, shelter belt maintenance, materials handling and harvesting. Hydra ladders are commonly used for pruning, thinning and picking fruit.

Table 5. Direct energy flows and activities in kiwifruit, grape and pip fruit enterprises.

Activity	Kiwifruit l/ha	Grapes l/ha	Pipfruit l/ha
Vine/tree spraying	120	35	225
Inter row cultivation	-	16	-
Mowing	80	-	60
Trimming and pruning	20	20	65
Weed spray	15	11	5
Topdressing	10	3	10
Shelter maintenance	35	2	10
Harvest	40	44	100
Materials handling	20	8	35
Product transport	60	18	130
On-farm transport	390	28	210
Total	790	220	850

(Source: CAE, 1996)

Frost protection is not a large energy user but may be a vital activity for some orchards. Sprinkler irrigation systems can be used in some instances to form a thin ice layer to protect delicate tissue. Compared with other alternatives this is a low energy input system but can result in water logged soils in some regions. Where the water is supplied by an electric pump, a suitably sited thermostat could be used for start up only when the temperature deviates from the desired range. Low water use trickle irrigation is normally installed. It is unlikely that growers will install overhead sprinklers purely for energy efficiency purposes unless the costs of other methods rise significantly. Wind machines have been installed in some orchards to mix the layers of air and avoid frost conditions developing which has met with limited success. The use of helicopters to force warmer air down is energy intensive using on average 160 l/hr (EBEX 21, 2004), but the cost is warranted if the crop can be saved from frost damage.

Crop cooling post-harvest can improve the quality for both domestic and export markets. Deregulation of the industry has seen a rise in on-farm cool stores and packing facilities which has increased overall electricity demand. Cool stores and refrigeration units can produce high peak load demands of up to 800 kW per facility and around 200 kW when the system is idle (Eastwood and Sims, 2003). Cooling methods include ambient cooling, refrigeration, ice banks, hydro cooling and vacuum cooling.

The total energy demand of the enclosed sector is not known. Based on Table 5, the average liquid fuel demand is around 6000l/ha, and electricity consumption around 1000 kWh/ha/yr. There are 70,000 ha of orchards and vineyards, EECA (2004) estimated the total consumer energy of the fruit production sector up to the farm gate to be around 1.93 PJ/yr.

3.4.2 The outlook for the orchard sector until 2012

The use of more productive species, such as Royal Gala, and better orchard management has increased total production of the pip fruit sector. The increase in production intensity is likely to continue, and will be reflected in the overall energy use of the sector. MAF (2004) forecasted a 22,000 ha increase in land planted in grapes by 2007, with production and area likely to increase in the long term. Horticultural exports in 2003 are projected to increase 10-15% by 2007, with wine exports increasing two and a half fold (MAF, 2003). While the organic and environmentally sustainable produce markets are growing it is unknown how this will affect the overall energy demand of the sector.

The main energy consuming activities are related to field operations, in particular, spray application. There are significant opportunities for energy savings, particularly through the implementation of integrated pest management techniques, which can reduce the volume of spray used and the energy required to apply it. Since deregulation of the industry, on site packing and cooling facilities have become popular. While this has increased on-farm electricity use, it is not a major concern for farmers and is outweighed by the benefit of improved quality of production. The use of co-operative facilities may reduce the overall energy use of the sector.

3.5 Dairy

The New Zealand dairy sector is the largest agricultural sub-sector, contributing over $5 billion annually to export earnings since it is relatively energy intensive compared with other primary sectors. Significant research (Barrie, 2005) has been conducted to identify where energy is being used and how steps can be taken by farmers to reduce energy demand. Further research by the Centre for Energy Research at Massey University funded by Dairy Insight is currently being undertaken.

The number of dairy herds has declined to around 13,500, but the average herd size has risen to over 280 cows plus followers. Of 3,741,000 milking cows in the 2002/2003 season, 26% were farmed in the South Island and 74% in the North Island, with 29% in the Waikato/South Auckland region. The number of herds has declined, with average farm size increasing on average from 93 ha to 111 ha, and predicted to increase (MAF, 2003). EECA (2004) attributes this to smaller less economic farms exiting the industry.

The past decade has seen an increase in the effective land area occupied by dairy farms, reaching 1.5 million ha by the 2002/2003 season, as a result of sheep farm conversions. An increase in land price has pushed dairying from traditional regions into new non-dairy areas such as Canterbury and Otago. This has further increased the energy demand, of this already energy intensive industry through the need for irrigation. Factors such as climate, soil and land-use capability play a role in the varying direct and indirect energy requirements of the different regions. Fertile soils and high rainfall are essential for good pasture production, although fertiliser and irrigation can increase the productivity of lower quality land.

3.5.1 Energy intensity and patterns of energy consumption in orchard enterprises

The main energy input into a dairy farming system is from the manipulation of fertiliser, followed by electricity. In a typical non-irrigated dairy farm electricity accounts for around 25% of the total energy inputs, whereas on an irrigated dairy farm this may reach 40% (Fig. 11).

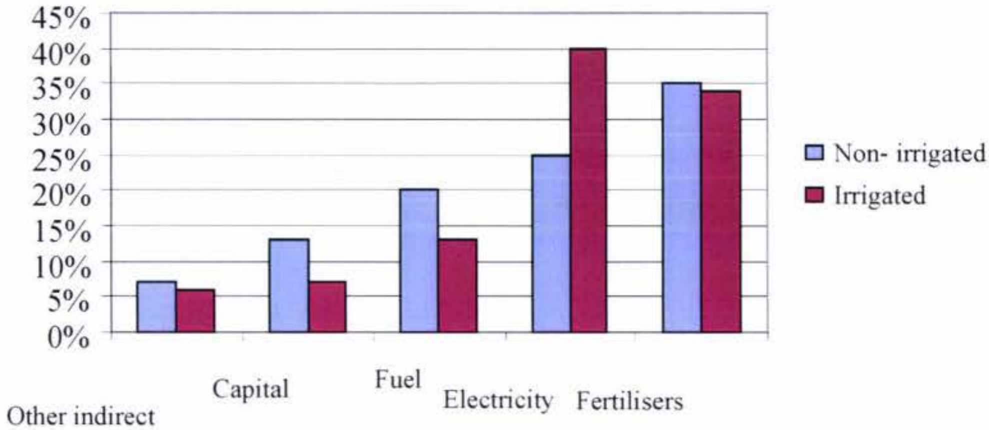

Figure 11. Comparison of total direct and indirect energy inputs on a typical non-irrigated and irrigated New Zealand dairy farm.

(Source: Wells, 2001)

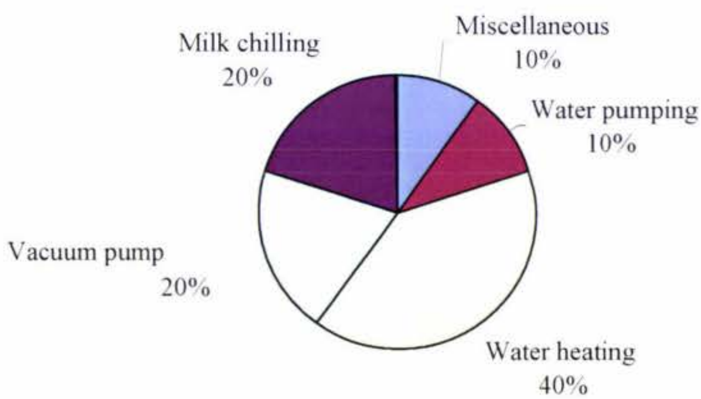

Figure 12. Breakdown of the typical electricity use of a dairy farm.

(Source: CAE, 1996)

Approximately 450 GWh/annum of electricity is consumed by dairy farms each year. A survey in the 1990s undertaken by ECNZ (CAE, 1996) showed over 3500 litres of milk were produced annually by each cow, which required 116 kWh of electricity for water heating (40%), milk chilling (20%), vacuum pump/milking system (20%) and to pump water (20%) (CAE, 1996), the remainder used for miscellaneous operations (Fig. 12).

3.5.2 The outlook for the dairy sector until 2012

Dairy cow numbers are forecast to increase by 1.8% per year and expected to reach 5.16 million by 2010, which will increase the energy demand of the sector as production intensifies (MAF, 2003). A 26,500 ha/yr increase in land used for dairy farming was also predicted until 2010 (MAF, 2003).

3.6 Irrigation

The role of irrigation in agriculture has changed from drought insurance to a means by which farmers, and therefore the economy, can diversify and meet market expectations for quality and quantity of produce. The net contribution of irrigation at the farm gate was estimated to be $920 million in 2002/03 over and above GDP that would have been produced at the farm gate without irrigation (MAF 2004).

Although irrigation provides significant production and economic benefits it is a high energy using activity, consuming up to 160 GWh/annum of electricity, or around 25% of on farm electricity demand for an arable cropping enterprise (CAE, 1996). Diesel engines are also used to operate irrigation pump systems, away from a power line.

On irrigated dairy farms electricity can account for 40% of total energy requirements, compared to 26% for non-irrigated farms (Wells 2001). Wells' (2001) survey of 150 dairy farms evaluated electrical energy intensities of 3400 kWh/ha/yr (12.2 GJ/ha/yr) for irrigated farms and 950 kWh/ha/yr (3.4 GJ/ha/yr) for non-irrigated respectively. Of 12 farms studied in more depth one fully irrigated farm had 93% of its total direct energy input from electricity (38.2 GJ/ha), 95% being for irrigation pumping.

The use of irrigation is increasing. MAF (2000) estimated the total area of irrigated land in New Zealand to be around 410,000 ha of which approximately 70,000 ha is horticultural, 110,000 ha arable, 90,000 ha dairy pasture and the remaining 140,000 ha used for a mixture of meat, fibre and crop production (Fig. 13). The latest estimate of irrigated land area has risen to around 475,700 ha (MAF, 2004). With an increase in dairy counteracted by a decrease in sheep and beef due to land conversions, this land use shift is expected to increase the overall energy consumption of the agricultural sector, irrigation being one of the underlying causes, along with increased use of nitrogenous fertilisers and greater intensification. Based on this data and assuming an average energy intensity of 10 GJ/ha/yr across all irrigated farm sectors, EECA (2004) estimated the total energy demand to be 4.8 PJ/yr and increasing.

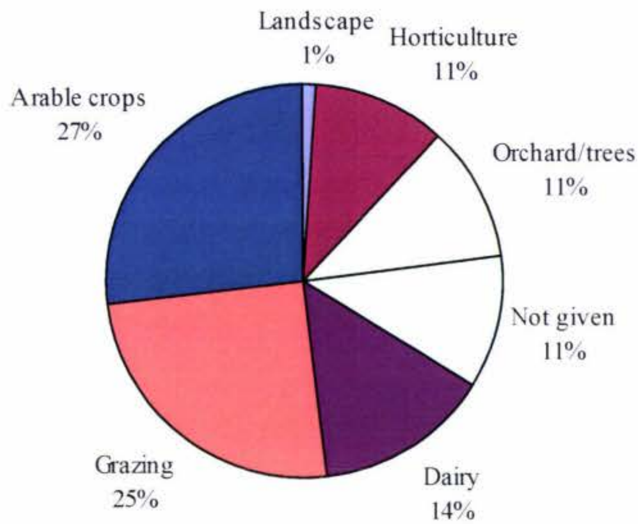

Figure 13. Irrigated land uses in New Zealand.

(Source: MAF, 2000)

Canterbury is the most heavily irrigated region in New Zealand, representing over 65% of the land irrigated nationally (Table 6) with dairy farms in the region spending three times more per year on electricity the to the rest of the country (EECA, 2004).

Table 6. Irrigated areas in New Zealand (000's ha).

Region	Area ha x 10^3	Total land %
Auckland/Waikato	6	1.5
Gisborne	6	1.5
Tasman	4	1
Marlborough	10	2.4
North Canterbury	30	7.3
Central Canterbury	79	19.3
Mid Canterbury	126	30.7
South Canterbury	45	11
North Otago	25	6.1
Central Otago	40	9.8
Northland	4	1
Hawke's Bay	16	3.9
Lower North Island	7	1.7
Rest of South Island	2	0.5
Total	**400**	**100**

(Source: MAF, 2000)

Irrigation typically involves pumping large volumes of water for use in high pressure sprinkler irrigation systems but can also involve the use of low pressure trickle and flood irrigation systems. Different systems vary considerably in the amount of energy they consume. Typically new irrigation systems installed on dairy and intensive vegetable and crop production farms use high pressure sprinkler irrigation requiring high electrical energy inputs but with a high potential for greater energy and water use efficiencies (Eastwood and Sims, 2003). MAF (2000) found in a survey of irrigated farms that travelling irrigators are the most frequently used irrigation application method (Fig. 14).

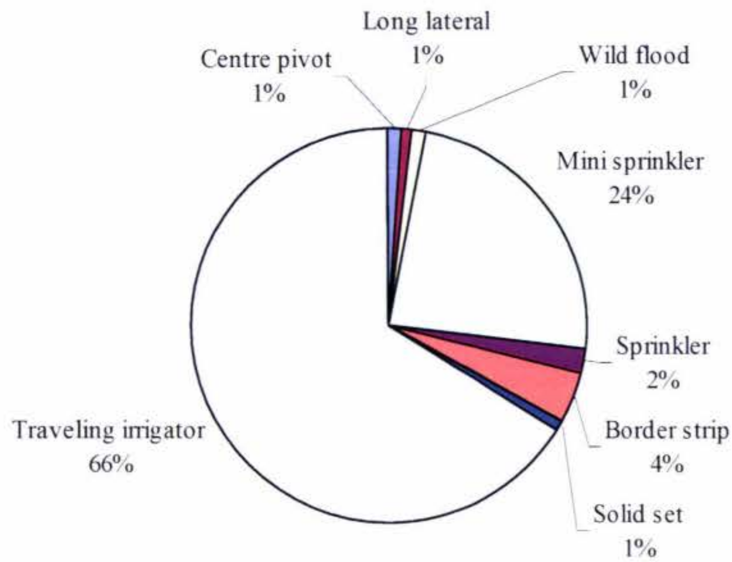

Figure 14. The use of different irrigation systems on New Zealand farms.

(Source: MAF, 2000)

3.6.1 The outlook for irrigated land use until 2012

While irrigation is a high energy consuming activity, farmer focus is typically on maximising irrigation effectiveness in terms of crop and pasture production rather than saving water and energy. Maintaining water supply can limit resource consents for taking water for irrigation, however there is potential for synergies between energy efficiency and reducing water wastage. To encourage more efficient use of water, MAF published *"Best Management Guidelines for Sustainable Irrigated Agriculture, 2000"*, which offers a range of initiatives to improve the efficiency of irrigation, such as optimum irrigation scheduling (MAF, 2000). Implementation of these guidelines will have the added benefit of reducing energy consumption. Saving water also saves energy.

Even with annual fluctuations in electricity demand due to climatic factors the demand trend for irrigation electricity is expected to rise. Considerable investment is currently underway in irrigation systems in Canterbury, both in upgrading old systems and expansion of irrigation capacity (Eastwood and Sims, 2003).

Soil moisture monitoring to control water use application only when required is a method of reducing demands for both water and energy. This is an area yet to be fully developed in New Zealand where traditionally water has been applied purely on a rotational basis leading to inefficiencies.

Irrigation has the potential to make a significant impact on New Zealand's economy through increased agricultural productivity. Estimating the economic value of irrigation in New Zealand could increase annual farm gate GDP by between $330-million and $660 million by the year 2013, with horticulture generating most of the value from new irrigation developments. MAF (2004) estimated an increase in irrigated land of between 201,000 ha and 470,000 ha by 2013, consisting of 84,000 ha of private development and between 117,000 and 386,000 ha of community scheme development.

Overall the increase in irrigated land is likely to significantly increase the energy use of the agricultural sector. However there are opportunities for energy efficiency gains to be made to partly offset this increase.

4.0 Energy use in greenhouse production

A recent survey of the New Zealand greenhouse industry estimated around 20% (2-4 PJ/annum) of the total national agricultural energy use was for greenhouse crop production, with the overall intensity of a greenhouse production ranging between 700 to 2,600 MJ/m^2 (Barber and Wharfe, 2004). The main energy inputs are direct energy inputs, such as coal and natural gas, for the purpose of maintaining the controlled heated environment, and indirect energy inputs in the form of fertilisers and agri chemicals (Fig. 15). Greenhouse production requires high capital and fuel investment compared to other forms of horticultural production.

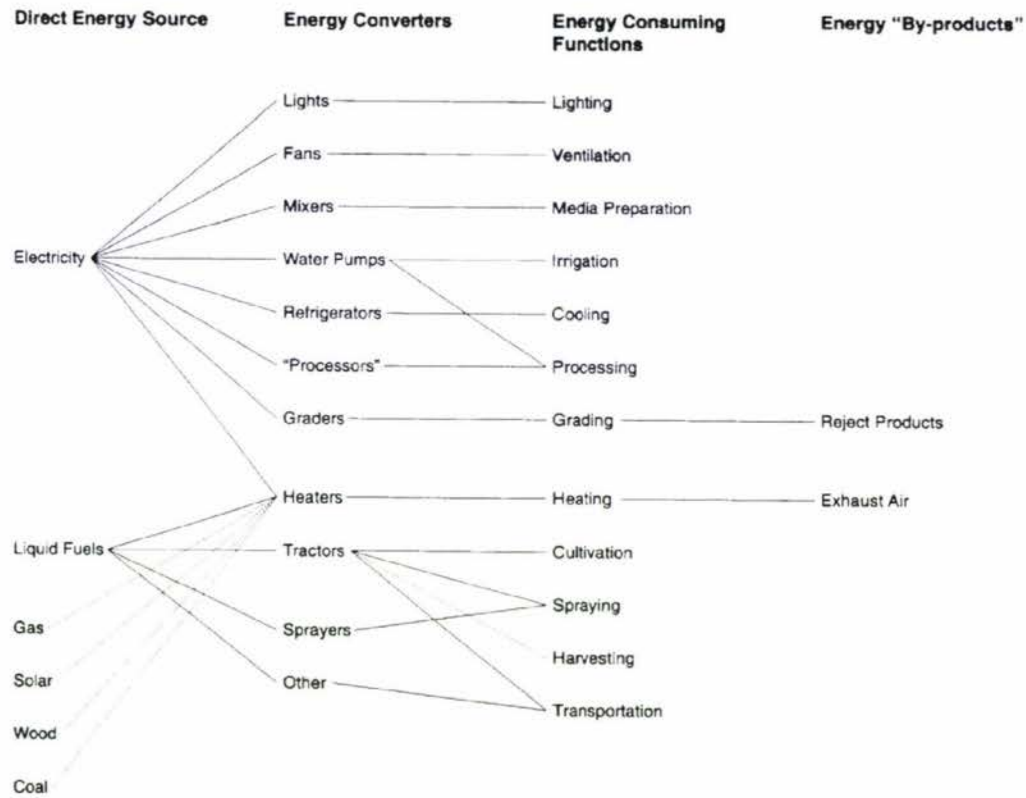

Figure 15. Direct energy flows for a greenhouse enterprise.

(Source: CAE, 1996)

The New Zealand indoor cropping industry has undergone significant growth in the last decade (HortResearch, 2003) (see Table 7). Barber & Wharfe (2004) estimated 83% of New Zealand's greenhouse area is heated with the average heated area per operation increasing to 6,150 m^2; this can be attributed to several large operations, a median area of 2,400 m^2 remains a better representation of most in the current industry.

Table 7. Change in indoor crop area, m^2 (000's).

	1992	2002
Tomatoes	92	166.5
Capsicum	8.2	43.4
Cucumber	6.8	55
Nursery Crops	47.7	91.3
Orchids	30.7	62
Other	63.7	269.5
Total	248.1	687.7

(Source: HortResearch, 2003)

Like other farming sub-sectors there is a trend towards higher production intensity farming systems. The survey by Barber & Wharfe (2004) found that the average tomato yields for the total surveyed area were 45 kg/m^2 and 95% of the operations now produce more than 28 kg/m^2 which 10 years ago was the industry average. This can be attributed to a number of factors including advancements in greenhouse climate technology and improvements in cultivar breeding. These factors have had a major impact on the energy intensity in terms of energy inputs per kg of product.

The impact of the proposed carbon charge on individual greenhouse operations will depend on their total energy use and type of fuel. The exact effect of the carbon charge on the greenhouse industry as a whole is not known. Although it is likely that South Island operations will be hit harder due to a combination of higher energy use and using coal as their main fuel source.

Reducing energy consumption is a means of increasing the viability of the industry, but this cannot be accomplished in isolation of other factors. Greenhouse management involves a complex interaction between heating systems characteristics, ventilation, greenhouse management strategies, solar radiation and structure characteristics. The focus of this section is the application of energy wise technologies and practices in the greenhouse industry without compromising crop yield.

4.1 Previous research into New Zealand's greenhouse industry

Studies in the 1970s focused predominantly on the major exports of that time, dairy, sheep and beef. However several significant studies since then have examined the role of energy in New Zealand greenhouse industry.

A workshop on 'Energy in New Zealand Greenhouses' was organised in 1985 under the New Zealand Energy Research and Development Committee. This report concluded that the New Zealand greenhouse industry was relatively inefficient in terms of its energy use. The study recommended a range of techniques for energy conservation, utilisation of alternative fuels and technology transfer and demonstration projects (Breuer, 1985).

Wells (1992) designed a complex computer model that described the expansion of the leaf surface area as a function of the environmental condition for a cucumber crop. He then determined crop productivity through combining environmental simulation, crop development, photosynthesis, respiration, and partitioning models, and simulated the whole growth season. The results of this process were compared to the measured yield figures for the crops to test the validity of the combined model (Wells, 1992).

A report commissioned under the Centre for Advanced Engineering (1996) reviewed the available literature on energy use in New Zealand's primary production industries, including protected horticultural production. A number of traditional methods for reducing energy loss were identified, are still relevant including boiler maintenance and the installation of thermal screens (sections 4.3.1.4 and 4.3.2.1).

A number of articles investigating energy use and aspects of environmental control in greenhouses by Nederhoff (2005) are available online at www.greenhouse.co.nz/bulletins/. These brief articles are targeted at growers and recommend methods and new technologies for increasing production and minimising energy use (Nederhoff, 2005).

The threat posed by the carbon charge to fossil fuel intensive industries prompted MAF's Sustainable Farming Fund, Vegfed, and the Northern Flower Grower's Federation to fund a detailed study into the energy profile of the New Zealand greenhouse industry (Barber and Wharfe, 2004). It estimated the size, production and energy use of the sector, along with the emissions units produced by the sector and identified that further analysis should include an improved understanding of both the industry profile and the statistical significance of the indicators along with analysis into the key variables of greenhouse type, fuel type and location to determine what energy efficiency measures are available and what their likely payback periods might be.

4.2 Energy saving model

One of the main objectives of this research and a requirement of Vegfed was the design and development of a user-friendly energy saving model to help determine the cost of the carbon charge to the user and identify areas of potential energy savings specific to their business. The following section reviews the use of models in greenhouse production, and also the use of interactive energy saving models not specific to the greenhouse sector.

4.2.1 Existing greenhouse models

A wide range of literature relating to the use of models in greenhouse production exists, therefore only models relating to energy consumption will be considered here. If further information is required, Wells (1992) provided a comprehensive description of the various model types and catalogued the available literature up to 1991. Energy saving models used by industry were also discussed. A number of models exist to investigate the energy consumption of greenhouses and to evaluate new greenhouse technologies such as thermal screens and heat pumps. Most of the available literature is from the 1970s and 1980s which is most likely attributed to the anticipated increase in energy prices, at the time.

Time series models have been used to determine the heating requirements of greenhouses (Schockert and Von Zeabeltitz, 1980; Strom and Amsen, 1981). Schockert & Von Zabeltitz (1980) related the energy usage to the prevailing wind speed for double and single structures while Strom & Amsen (1981) designed a model that related energy usage to the outside temperature. These models were both derived from site specific data and are not widely applicable to the greenhouse industry as a whole. Similarly an early model by Walker (1965) developed the energy balance of the greenhouse air and the heat fluxes contributing to the energy balance. Equations were used to relate the greenhouse air temperature to the input variables, solar radiation and outside air temperature (Walker, 1965).

Several studies have since expanded Walker's model to include various cladding materials (Rotz, Aldrich and White, 1979; Garzoli and Blackwell, 1981), and also to predict energy consumption based on continuous weather data (Wass and Barrie, 1984; White, 1984). Chandra & Albright (1980) developed a model used to test the effect of thermal screens and included extensive treatment of long wave radiation exchanges. Businger (1963) identified many of the energy fluxes within a greenhouse and formulated a model based on the energy balances at the soil surface and the greenhouse cover. This model provided a basis for many subsequent models (Businger, 1963). One of the most comprehensive models of the greenhouse environment was developed by Bot (1983) which considered all components of the greenhouse system to be dynamic (Bot, 1983).

A more recent study developed a model to test the effect of various energy conservation measures to arrive at a set of design features for an energy efficient greenhouse, whereby the gothic arch greenhouse design required 2.6% and 4.2% less heating as compared to gable and Quonset roof structure shapes respectively (Gupta and Chandra, 2002).

A number of energy saving models targeted at the consumer by industry are available, many designed by power companies to minimise electricity consumption in the home or business. The "Tokyo GHG Half Project" is one example of this type of model, which aims to provide potential energy savings and CO_2 emission reduction from architectural and facility improvements in residential and commercial buildings. This model consists of an estimate of thermal energy consumption, the effect of energy saving technologies such as insulating and efficient lighting system, electric power and gas requirement by various systems in buildings, and the CO_2 emission reduction possible by using the energy saving technologies (Favrat, Takahashi, Wallace and Kraines, 2005).

Massey University's Centre for Energy Research has recently developed an energy saving model for use by the dairy industry based on ECNZ data from the late 1980s. The basic objective of the model was to enable the user to benchmark the normalised electricity use of a specific dairy farm against that of a "typical" dairy farm and an "energy efficient" dairy farm, in respect of each major energy use subsystem (e.g. milking machine, milk chilling unit, cleaning in place hot water system etc.). This way users are able to identify the necessary gaps (in terms of energy efficiency) that exist in different subsystems within their own milking sheds (Jahamaya and Barrie, 2004).

4.3 The utilisation of energy-wise greenhouse technologies and practices

This section reviews the available literature on energy saving technologies and practices within the greenhouse sector and where appropriate it evaluates how they could be applied to the New Zealand greenhouse industry in new and existing houses.

4.3.1 Greenhouse structure and design

Several studies have investigated the effect of different greenhouse design features on both energy use (Gupta and Chandra, 2002; Evans, 2004) and light transmittance (Facchini, Marelli and Canzi, 1983). Some are well proven commercially while others are still in the research phase.

4.3.1.1 Greenhouse shape

A variety of greenhouse designs and shapes are commercially built, most derived from basic designs, the quonset (hoop) and the A-frame. The gothic arch or the cosecant curved rafter house incorporates aspects of both a quonset and an A-frame, to increase the strength of the standard arch by more effectively directing the load to the ground, and hence increases the unobstructed area within the greenhouse and improve light transmittance (Fig. 16) (Evans, 2004). The slight curvature of the roof offers advantages over the standard A-frame by shedding condensation quickly, which reduces heat loss and increases solar radiation, these characteristics have made gothic arch greenhouses the most popular plastic-clad greenhouse design sold in New Zealand (Williams, 2004).

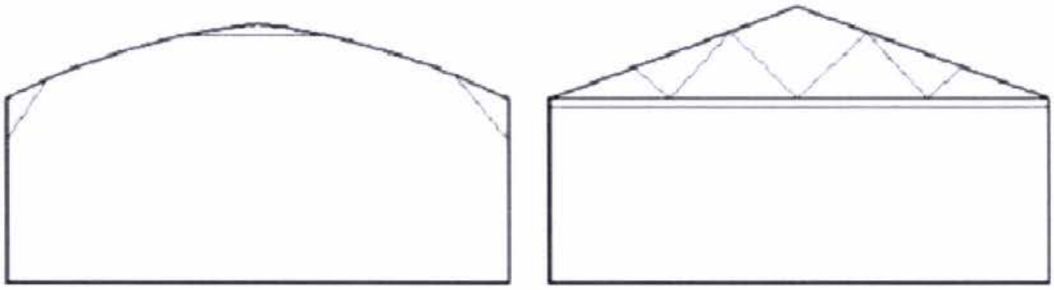

Figure 16. Cosecant curved roof (left) and standard gable roof (right) with alternative truss design of a greenhouse construction.

(Source: Redpath, 2005)

The angle of the roof has also been found to play an important role in energy efficient greenhouse design by enhancing light transmission and therefore improving quality and quantity of greenhouse production (Soriano, Montero, Sanchez-Guerrero, Medrano, Anton, Hernandez, Morales and Castilla, 2004). Soriano *et al.* (2004) found direct solar radiation transmission increased as slope of the roof increased, while Hanan (1998) suggested that the transparent cladding should be at right angles to the sun to maximise solar transmission.

Quonset and A-frame designs may be single structures or combined side-to-side with gutter-connections and with the interior walls usually absent. A variant which is very popular and dominates the European greenhouse industry is the Venlo design with higher walls, smaller gables; narrower individual greenhouse sections and reduced roof area compared to a standard gable structure (Fig. 17). This reduces the roof surface area (an area of major heat loss) and hence heating costs (Evans, 2004).

Figure 17. An open gutter-connected 'Venlo' glasshouse with boiler in South Auckland.

Many large commercial glasshouses now utilize some variation of the gutter-connected design because it allows for a large unobstructed interior which improves automated tasks such as irrigation and spraying (Hanan, 1998). By eliminating interior walls the cost of construction materials and heating costs are reduced.

Drawbacks exist for gutter-connected facilities since the entire production area is a single space. The ability to maintain different environmental conditions (such as would exist with numerous individual structures) is lost and uniformity and control of light, temperature, airflow and humidity can be reduced (Hanan, 1998). Evans (2004) suggested that drop-walls or curtains made of polyethylene film that can be raised or lowered between sections would overcome these limitations by allowing sections within the structure to be partially isolated so that different temperatures or relative humidity levels could be maintained, if only to a limited degree.

4.3.1.2 Building orientation

The effect of building orientation and positioning on greenhouse energy consumption is well recognised. An east-west oriented gothic arch required around 20% less heating as compared to a greenhouse of the same size oriented north-south (Chandra, 1976). Twenty years later Gupta & Chandra (2001) found that an east-west oriented greenhouse required only 2% less heating when compared to a north-south orientation which was attributed to an improvement in heat loss reduction technologies such as cladding and thermal screens. A similar study compared various greenhouse types and orientations and concluded that there was a consistent advantage in terms of light transmission and crop yield from orienting a multi-span structure east-west (Harnett, Sims and Bowman, 1979).

A study conducted under Mediterranean conditions tested the effect of building orientation on the greenhouse environment and found that north-south orientation contributed to a homogenous greenhouse climate more favourable to plant growth (Brun and Ville-o-de, 1974).

Gupta and Chandra (2001) stated that for a greenhouse with length greater than width, the building orientation could affect the amount of solar energy available. Similarly Facchini *et. al.* (1983) conducted experiments on solar greenhouses with low energy consumption and concluded that in north Italy greenhouses should have the longest side facing south. Therefore a greenhouse with length to width ratio greater than one, an east-west orientation can reduce the energy consumption (Facchini, Marelli *et al.*, 1983).

While many of these studies are site specific, they do highlight the effect of building orientation on the energy requirement. There is no available research into the effect of greenhouse orientation in New Zealand.

4.3.1.3 Cladding

The selection of the material not only affects the energy balance of a greenhouse, but also the amount and type of solar radiation received at the plant canopy which directly affects plant growth. In addition, the micro climatic factors such as air humidity or carbon dioxide concentration are indirectly affected by the cladding system.
The design of modern greenhouses is based on a compromise between a maximized transmission of solar radiation and a minimized heat loss within an economic context (Swinkels, Sonneveld and Bot, 2001). In this section the light transmittance and the heat loss aspects of the various covering materials will be examined. The selection of a specific covering is not an easy task as numerous alternatives have implications for the greenhouse structure and the enclosed crop production system. Light transmission under glass versus plastic is often a hotly debated subject within the industry. While several studies have attempted to produce a set of standards (Papadakis, Briassoulis, Scarascia Mugnozza, Vox, Feuilloley and Stoffers, 2000), there are no rigorous international standards which consumers may use to compare the various materials (Hanan, 1998).

The three major classifications of greenhouse cladding are glass, rigid plastic and film plastic (Barber and Wharfe, 2004). Glass allows maximum light transmission in greenhouse production however it requires a higher initial investment due to the added weight requiring stronger structural components. Modern plastics provided alternatives to traditional glass and range from thin films to multi-layer rigid thermoset plastic panels. Polyethylene film greenhouses have been developed that are reliable and usually have a lower initial cost than other greenhouse glazing systems. Rigid plastics will not be considered extensively in this section, Barber (2004) in his survey of the New Zealand greenhouse industry found that very few growers are currently using rigid plastic.

Several New Zealand studies have attempted to review the different properties of available covering materials (McNaughton, Jackson and Warrington, 1981; Breuer, 1985; Maurice, 1985; Wells, 1992). However with the advances in greenhouse technologies these studies are now dated.

Light transmittance and thermal properties

The two main factors in considering the various greenhouse covering materials are the light transmitting and thermal properties. A number of studies have investigated the effect of these properties on crop yield and energy demand.

Nijskens *et al.* (1989) tested the radiometric and thermal properties of polyvinyl, polyester and polyethylene. The materials performed similarly when measuring solar transmittance although polyethylene allowed significantly more far infra red transmittance (Nijskens, Deltour, Coutisse and Nisen, 1989).

Roberts (1998) tested the photosynthetic active radiation (PAR) transmission of different greenhouse coverings just below the glazing (Table 8) to represent the effect of the glazing material on the PAR and at the canopy level to include the influence of the structure.

Table 8. Overall PAR transmission for a range of greenhouse cladding types (%)

Type of Glazing	Single glass	Acrylic	Double glass	Double PE
Sensor location				
At glazing	0.60	0.58	0.58	0.67
At canopy	0.56	0.55	0.56	0.45

(Source: Roberts, 1998)

While single glass was expected to have the highest PAR transmission this was not the case due to obstruction from the structural materials supporting the glass. The double polyethylene glazing had a very low level of PAR at the canopy level due to obstruction by overhead heating and irrigation systems (Roberts, 1998). This highlighted the importance of considering the structure and other components required when selecting cladding materials. McNaughton *et al.* (1981) tested the PAR transmission of different covering materials under New Zealand conditions. Glass transmitted over 90% of the PAR, film plastics between 88-90% and rigid acrylic and fibre glass between 63-73%.

Van de Braak (1995) found that increasing the size of the window panes, reducing the width of the gutters, and increasing the spacing between the trusses could increase the total entry of diffuse light from 65% to 72% in Venlo designed greenhouses in the Netherlands.

A number of enhancements can be added to the cladding including ultra-violet radiation (UV) degradation inhibitors, infrared radiation (IR) absorbency, and anti-condensation drip surfaces, as well as unique radiation transmission properties (Hanan, 1998). To improve reflection of the light inside the houses, structural components such as gutters and pipes can be painted white (Evans, 2004).

Reducing heat loss

Minimising heat loss was identified as one of the least-expensive and effective energy saving measures that can be taken by growers (Bond, Gilroy, Thompson and Hasek, 2005). Heat loss occurs through the covering material, primarily through thermal radiation, conduction and infiltration.

Energy can be lost by conduction through the glazing, metal purlins, doors, and fans however the vast majority of both conductive and radiative heat loss is through the glazing (Bond, Gilroy *et al.*, 2005). The rate at which this heat loss occurs is affected primarily by the efficiency of the glazing material (National Greenhouse Manufacturers' Association, 1998). The 'U' factor provides a means of calculating the impact of different glazing materials on heat loss (Table 9.). Selection of a material with a low "U" factor will reduce the energy lost through conduction. In a single-walled or draughty greenhouse, thermal radiation losses are only a small part of the total heat loss. However in a well sealed, double skinned structure, thermal radiation can account for up to a third of the total heat loss (McNaughton, Jackson *et al.*, 1981).

Table 9. 'U' factor for glass and polyethylene.

Material	"U"
Glass, single	1.13
Glass, double glazing	0.7
Polyethylene, single	1.2
Polyethylene, double	0.7

(Source: National Greenhouse Manufacturers Association, 1998)

Swinkels *et al.*, (2001) suggested that light transmission can be maximised and heat loss minimised by the use of transparent double-layered zigzag plates as a covering material for Venlo designed greenhouses (Fig. 18). A computer model was developed to determine the effect on the light transmission of such cover. The addition of the plates had a gain in transmitted direct radiation of up to 5% in winter when compared with a single-glass cover and insulation was also increased by 16% (Swinkels, Sonneveld *et al.*, 2001). At the time of publication this design was still in a research and development stage and further developments are unknown.

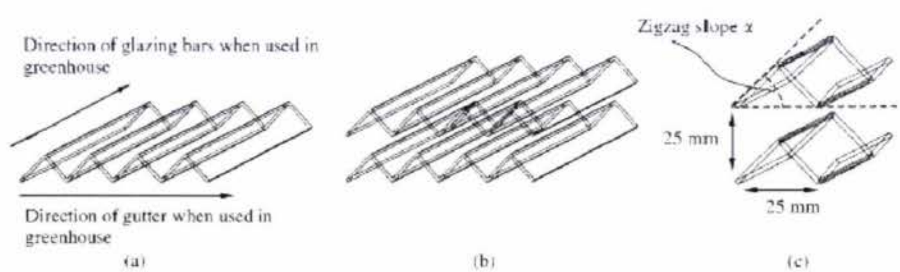

Fig. 3. Illustration of a single-zigzag plate (a), a double-zigzag plate (b), and dimensions and zigzag slope α (c)

Figure 18. Illustration of a double and single zig-zag plate, as a possible form of greenhouse cladding.

(Source: Swinkels *et. al.* 2001)

The principal cause of heat loss in New Zealand greenhouses is air leakage or infiltration (Breuer, 1985) which can occur through cracks between or around glass panels, doors, and fans by mass airflow. Evans (2004) suggested that even in a well-designed greenhouse, up to 10% of total heat loss may be through infiltration.

Breuer (1985) stated that lining the end and side walls with clear polyethylene may reduce fuel used for heating by at least 14%. It is not known whether this affects crop production and whether this approach would have less of an effect in multi-bay structures due to the relative wall area. Bond *et al.* (2005) listed some insulation methods suitable for the Californian greenhouses (Table 10). Based on similar climatic conditions (i.e. no snow loads, long day lighting hours), these recommendations may also be appropriate for New Zealand growers.

Table 10. Methods for reducing air infiltration of a greenhouse and the expected energy saving.

Method	Expected energy use reduction (%)
Polyethylene on roof	25
Polyethylene on walls	10
Polyethylene on roof and walls	35
Permanent poly sub roof	20-30
Thermal blankets	35-57
Double inflated polyethylene over glass	25-45
Double inflated polyethylene to replace FRP or single polyethylene	30-40
Single polyethylene over FRP or glass	25-35
Ridge vent insulation	5-10
Wall insulation	5-10
Seal glass laps	up to 10
Polyethylene tubes to close sides or vents	up to 20
Polyethylene tubes to cover evaporative pads	up to 20

(Source: Bond *et al.*, 2005)

The disadvantage of reduced air infiltration rates resulting from the continuous film cover have improved energy savings but contribute to high greenhouse air humidity conditions. Moisture condensation, especially on flattened arch-shaped roofs, promotes dripping on the crop below though this may be counteracted through a gothic-arch shaped roof (Williams, 2004). Fan ventilation is generally required for cooling and air circulation to prevent the formation of humidity related crop diseases.

Double glazing and twin skins

The effect of double glazing is well documented with energy savings between 25-40% observed (Breuer, 1985; Landgren, 1985; Christensen, 1986; Hanan, 1998). The use of air between two separated layers of polyethylene film increases the value as a greenhouse cover because of the reduced heat loss with low additional investment. The reduction in light transmission is generally viewed as a reasonable trade-off for the reduced fuel use for temperature control.

Cladding maintenance

Maintaining the covering material is essential to minimizing heat loss through infiltration and maximizing solar energy. The effect of weathering is well documented in the literature. Data reported by Giacomelli *et al.* (1989) compared the difference of daily transmission for new and four year old polyethylene film. New films transmitted significantly higher levels of PAR and consequently returned higher crop yields. Regular cleaning and replacing of part or all of the covering material is therefore necessary to maintain heating efficiency and crop yield, it is also identified as on of the most cost effective energy saving measures available to growers (Breuer, 1985; Van de Braak, 1995).

4.3.1.4 Thermal screens

Thermal screens are generally acknowledged as one of the most effective energy saving instruments applied in greenhouses (Breuer, 1985; Newman, 1991; Hanan, 1998). Traditionally screens were used for shading but in the late 1970s energy conservation became important motive for their use. As this study is primarily concerned with energy saving technologies only screens used for the purpose of energy conservation are considered here.

While thermal screens are used extensively overseas, in New Zealand it is estimated that only 10% of greenhouses have thermal screens installed (Williams, 2004). Although the number has doubled in the past 2 years this is still comparatively low when compared with other countries. Their limited use in New Zealand is because they are expensive to install and have a long payback period under ambient temperatures so the grower may not see it as an economic investment. Newman (1991) developed a mathematical model to ascertain the annual energy saving in heating expenditure achieved by different thermal screen materials in New Zealand. In terms of cost savings, black polyethylene, *infrane* and clear polyethylene recorded the highest internal rate of return. This model could be reviewed to include the additional cost of the carbon charge and the availability of new screen materials.

The Effects of Thermal Screens

Screen efficiency depends on a number of factors including the material, the outside weather conditions and the effectiveness of the seal (Breuer, 1985). High efficiency thermal screens reflect the infra red radiation emitted back into the greenhouse structure, plants and benches, to avoid heat loss to the outside.

The effects of thermal screens on the heating requirements are well documented with fuel saving estimates ranging from 20-70% (Chandra and Albright, 1980; Pirard, Dellour and Nijskens, 1994). The use of thermal screen in a standard double polyethylene house was reported to cause a reduction of 37% in the heat transfer coefficient (Zhang, Gauthier, de Halleux, Danserau and Gosselin, 1996). Recent research into thermal screens in New Zealand found that the energy required for heating a screened compartment was 42% less than the energy required to heat a non-screened compartment to the same temperature (Nederhoff, 2004).

Figure 19. A retracted screen used at night to reduce energy loss.

(Source: Nederhoff, 2004)

Thermal screens may cause a reduction in light levels from shading when retracted during the day which often means a reduction in crop production. Plasier (1992) estimated around 1-1.5% light is lost through a retracted thermal screen which is small and counteracted by the climate improvement due to the thermal screen (Fig. 19)ss.

Screen Material

Screen materials should be strong and have high resistance to wear and tear, resistant to aging from temperature, humidity, chemicals and ultra violet radiation. They are typically made of polyethylene, polyester film, aluminised polyester film strips, or polyester cloth. A recent study evaluated the effects of thermal screens made of clear polyethylene and polyester material on the microclimate and overall heat loss coefficient in plastic tunnel greenhouses and found that the use of a thermal screen reduced heating requirements by 16% and 19.8% for the polyethylene and polyester screens, respectively (Huseyin Ozturk and Bascetincelik, 2003). Polyester is superior to polyethylene as it blocks radiant heat better. Adding an aluminised surface will reflect radiant heat back to the plants (Nelson, 1998). Hanan (1998) suggested that the performance of thermal screens is improved by making them non porous with an aluminised layer in the upper surface, while acrylic fibres are the most resistant to aging (Bakker and van Holsteijn, 1995).

The final form of the screen is a result of different techniques used. For application in greenhouses four major groups can be distinguished: film, fabric, knitting and non-woven or a combination of these (Table 11).

Table 11. Light transmitting and energy saving properties of different films for thermal screens

Type	Materials	Transmission for diffuse light (%)	Energy savings (%)
Film	PE	82(dry) 62(wet)	35
Fabric/yarns	Polyester	55	35
Fabric/tapes	PE/aluminium/acrylic	70	35
Knitting/yarns+tapes	Polyester	68	40
	Polyester/aluminium	35-65	15-60

(Source: Bakker & van Holsteijn 1995)

Zhang *et. al.* (1996) found the energy saving effect of thermal screens in double anti-fog polyethylene houses was lower than the value given for single glasshouses and double standard polyethylene houses. These results suggest that a greenhouse with lower heat retention benefits the most from a thermal screen. The ageing effect of the materials and the effect of outside climate on heat consumption of the greenhouse were not affected when a thermal screen was deployed (Zhang, Gauthier *et al.*, 1996).

4.3.2 Greenhouse heating

Heating normally constitutes a major energy requirement for New Zealand vegetable greenhouses. The selection of heating equipment depends on the size and type of greenhouse operation, however most systems typically consists of a fuel burner, a heat exchanger, distribution and controls. This section examines energy saving technologies and practices for heating greenhouses, including central and local heating systems.

4.3.2.1 Central heating systems

A central heating system typically consists of one or more boilers that provide steam or hot water for circulation in pipes around the greenhouses. A central boiler is typically used in large operations with gutter connected greenhouses (Van de Braak, 1995) and uses water or steam as the transfer medium. Hot water is generally used in Europe and New Zealand, while steam is more popular in North America (Nelson, 1998).

Boiler Maintenance and retrofitting

Proper operation and maintenance are essential to the economic and energy efficient operation of boiler systems (Van de Braak, 1995; Ozdemir, 2004). Choosing an efficient new condensing boiler or retrofitting an existing boiler and practicing efficient boiler operation and maintenance can save up to 35% in heating fuel (Energy Star, 2004; Pacific Gas and Electric Company, 2004). The newest gas-fired condensing boiler technologies have efficiencies of over 92%, compared to efficiencies of 75 to 85% for older, standard boilers (Pacific Gas and Electric Company 2004).

Minimising heat loss from the boiler

Ozdemir (2004) stated that to improve boiler efficiency, the logical approach is to identify the losses, determine their relative magnitude and then concentrate on reducing the losses that have the greatest impact. The biggest energy losses in a conventional thermal boiler system occurs through the chimney (Van de Braak, 1995; Ozdemir, 2004). The amount of heat loss depends on both the temperature and volume of exhaust gas leaving the boiler. Reducing either of these will reduce heat and therefore total energy loss.

There are five basic strategies for minimising stack heat loss in a boiler system.

- Minimising excess air. A boiler should always be supplied with more combustion air than is theoretically needed in order to ensure complete combustion and safe operation. At the same time, boiler efficiency is very dependent on the excess air rate as it should be kept to a minimum to reduce the quantity of air that is heated and exhausted at stack temperature. The Pacific Gas and Electric Company (2004) suggest at least weekly monitoring of stack gas oxygen or carbon dioxide content for an indication of how much excess air is being used.
- Keeping heat transfer surfaces clean is particularly important in oil and coal-fired boilers where soot build up can act as an insulator against heat. Elevated stack temperatures may indicate excessive soot transfer and deposits should be removed on a regular basis. Scale build up on the water-side transfer surface (from minerals found in water, such as magnesium and silica) can also act as an effective insulator. Fuel wastage due to scale build-up may be up to 5% in some boilers (Energy Star, 2004).
- Energy savings of up to 15% can be obtained by means of flue gas condensers (Meijndert, 1982). Minimising flue gas heat loss, by additional heat recovery equipment of the flue gases of the boiler leads to improved efficiency. If no corrosive elements are present in the exhaust gases, which is the case when firing natural gas, the temperature can be brought down below the condensation point of the water vapour in the flue gases, thus considerably increasing the amount of extracted heat (Van de Braak, 1995).
- Minimising air infiltration of incorrectly adjusted boilers due to wear on linkages, pins etc. can often change the air/fuel ratio with a consequent loss of heat and drop in efficiency. Attaining the optimum excess air rate may be obtained by the use of correctly adjusted burner parts.
- Repairing or adding insulation to the boiler and associated piping will reduce heat loss though boiler walls. The addition of 2.5 cm of insulation can reduce heat loss by 80 to 90% (Pacific Gas and Electric Company, 2004).

Variable speed control systems

Adding a fan motor speed control is an easy option to some electronic controls to increase burner turndown without compromising efficiency. By adding a driver to control fan speed, electrical energy is saved and by restricting the air rate heat losses are minimised. Ozdemir (2004) measured the effect of installing a variable speed drive on a 30kW fan (see Table 12).

Table 12. Measured electrical values before and after variable speed drive (VSD) application.

Value	With VSD	Without VSD
Speed (rpm)	255	1460
Voltage (V)	31	380
Frequency	8.5	50
Current (A)	8	25
Power (W)	365	13500

(Source: Ozdemir, 2004)

Other energy saving devices

Several types of optional devices can be fitted to existing boilers to save energy.

Economisers - Boiler economisers recover the waste heat from the stack exhaust gas and transfer this to the boiler's feed-water. Consequently less energy is required to raise the temperature of the water which improves the efficiency of the boiler and therefore reduces overall energy requirements. It is estimated that boiler efficiency is raised by 1% for each 20°C reduction, which results in a 5-10% fuel reduction (Energy Star, 2004). Similarly air preheaters transfer heat from hot exhaust gas to incoming air that is to be mixed with fuel for combustion. This device saves energy by increasing the temperature of the mixture of fuel and air prior to combustion so more of the heat of combustion is available to heat water.

Turbulators – Twisted pieces of metal inserted in the tubes of fire-tube boilers, cause hot gases to travel more slowly and with more turbulence resulting in better heat transfer to the water. Turbulators can be a cost-effective way to reduce the stack temperature and increase the fuel to steam efficiency of single-pass horizontal return tubular (HRT) brick-set boilers and older two and three-pass oil and natural gas fuelled firetube boilers (Industrial Technologies Program, 2004; Pacific Gas and Electric Company, 2004). Turbulators are not recommended for four pass boilers or coal-fired units.

Oxygen trim controls - measure exhaust gas oxygen concentrations and automatically adjust the inlet air at the burner to give optimum efficiency (Pacific Gas and Electric Company, 2004).

Heat storage buffers

Heat storage buffers are popular in the Netherlands and are now becoming increasingly popular with larger greenhouse operations in New Zealand (Nederhoff, 2005). A buffer is an insulated tank filled with water that acts as a night store for residual heat produced during the day and as a by-product of CO_2 enrichment. Buffers are most useful on properties where natural gas is the heating fuel choice and the flue gases are used for CO_2 enrichment, especially in areas with low night temperatures.

Buffers used in New Zealand operate as part of a closed loop system with the boiler, transport ducts and heating spirals (Nederhoff, 2005). As fuel is burned and the CO_2 released into the greenhouse, the hot water is stored in the buffer tank and is used for heating during the night.

Load management

In a plant with several boilers, distributing the heat load from the most efficient boiler can improve conversion efficiency. Avoiding running boilers at very low capacities when possible gives the optimum efficiency since most boilers lie fairly close to their rated capacity.

4.3.2.2 Heat distribution systems

The heat distribution system exterior to and within the greenhouse is where a high degree of heat loss often occurs, reducing the overall efficiency of the heating system. The heat distribution method selected depends on heater type and location, the growing system used and the crop type.

Hot water pipe and hot air duct heating systems are quite common in many countries including New Zealand. Steel water pipes can also double as transport rails for this to maximise the production floor area by reducing wasted space. Pipe heating is an effective means of warming crops both by convectively heating the greenhouse air and by radiating heat directly to the crop leaves. Several ways to increase efficiency of this type of heating system are possible.

Pipe placement

During the last decade interest has grown in alternative pipe sizes and alternative locations such as near to the crop growing point or near to substrates for root zone heating. However, it is generally agreed that placing heating pipes nearest to the ground is the most efficient method of heating. Lowering overhead pipes to just above ground level can result in up to 20% energy savings (Heijna, 1985) because of more direct heating of the plants and less radiation loss through the transparent cladding (Bakker and van Holsteijn, 1995). Placing the pipes lower to the ground also stimulates air movement through the crop canopy due to the natural convection of warm air. Warm air rising through the canopy removes moisture and creates a uniform microclimate around the plants (Prenger and Ling, 2004).

The most successful radiative heating from pipes occurs when placed at the mid-height of the mature crop. The best position for pipes is between the mid-height and bottom of a crop, or pipes closer to the benches (if used) rather than between them (Teitel, Segal, Shklyar and Barak, 1999)

Tomato plant response to warm root-zone temperature has been well documented. To achieve optimum plant growth, root temperature is more critical than leaf temperature. When root-zone temperatures are at the optimum level, growers can lower air temperature around the plant canopy by a few degrees to reduce energy consumption without reducing plant growth and yield. A separate heating system of circulating hot water in pipes located under the growing bags to heat the growing medium is a way of increasing production (Hanan, 1998; Hanna and Henderson, 2002).

The disadvantages of lower pipe positions are that the pipes need to be resistant to horticultural chemicals (Hanna and Henderson, 2002), and they must not hinder cultivation or other operations. Some systems are now adjustable to allow growers to move pipes out of the way during cultivation. Lowering the pipe system does require careful attention so that crops are not scorched by any newly adjacent pipes (Prenger and Ling, 2004).

Pipe structure and materials

The application of fins on steel pipes provides a larger exchange surface with the air and may therefore transfer up to four times the amount of heat to the crop (Evans, 2004). However van de Braak (1995) found the temperature drop over the fins reduced the effect to a certain extent. The use of aluminium, which has conductivity four times that of steel, may counteract this effect. An aluminium tube with a diameter of 22mm and two fins of 24mm each can transfer as much heat as a steel pipe with a diameter of 51 mm under similar circumstances. Such a tube has a smaller water content causing it to respond quicker to temperature change than traditional steel pipes (Van de Braak, 1995).

Nijeboer and Van Holsteijn (1981) reported the heat transfer of various sizes of steel pipe and plastic tube (Table 13).

Table 13. Heat transfer in W/m length of pipe at various temperature differences between heating pipe and greenhouse air

Temperature difference	Steel pipe			Plastic tube
	diameter (mm)			diameter (mm)
° Celcius	51	33.2	26.4	25
10	15	10	8	6
20	34	23	18	14
30	55	38	31	24
40	77	53	44	35
50	101	71	58	46
60	128	90	73	*
70	156	108	90	*
80	185	129	107	*

* Not applied at this temperature.

(Source: Nijeboer & van Holsteijn, 1981)

Pipe lagging

Lagging or insulating the hot water pipes between the central heating system (boiler) and the greenhouse environment is well recognised as an effective energy saving measure. There is a gap in the literature comparing lagged and un-lagged pipes and the performance of different lagging materials.

Soil, floor and bench heating systems

Soil heating is usually comprised of buried pipes at a depth of 20-30 cm, depending on the supply water temperature, which extends from the central boiler to the greenhouse environment. Other forms based on a similar principle are electrically heated concrete floors, where heated pipes are embedded in the concrete attached to the bottom of a growing bench. Because of the small distance of the pipes to the surface and the often better conductivity of the concrete and bench material compared to soil, the temperature difference between pipes and surface will be smaller and the heat flux larger than in the case of soil heating.

The amount of heat transferred to the greenhouse is limited by the maximum temperature requirements of the roots of a crop. A significant disadvantage of these heating systems is the slow response to control actions due to the large thermal mass (Van de Braak, 1995).

The use of buried pipes for heat storage 1-2 metres below the surface is recognised as low energy way of maintaining greenhouse temperature (Santamouris, Mihalakakou, Balaras, Lewis, Vallindras and Argiriou, 1996). The use of the soil as a heat exchanger is acknowledged as a relatively efficient method of heating. Air from the greenhouse is circulated through underground plastic or aluminium pipes which act as an earth to air heat exchanger. This reduces the energy consumption for heating of greenhouses by increasing the air temperature and also improves indoor conditions by reducing temperature fluctuations during the day (Van de Braak, 1995). Santamouris *et al.* (1996) developed a model to calculate the thermal performance of buried pipes and found the average annual energy consumption of greenhouses with buried pipes to be 30-60% less than for a conventional greenhouse. This research was conducted in Athens, Greece where there are significant day/night temperature fluctuations. Few, if any, similar studies have been conducted in New Zealand.

Soil bed warming systems encourage propagation and can be more efficient than heating an entire greenhouse. Typically electrical cable or heating beds are buried in the soil. Power consumption is around 1-1.5 $kWh/m^2/day$ for soil beds, 1.3 to 2 $kWh/m^2/day$ for propagation beds and benches, and 1.7-2.5 $kWh/m^2/day$ for mist propagation beds (The Electricity Council, 1989). Energy consumption is relatively low for soil warming, so it is difficult to implement any energy saving measures.

Air distribution systems

This system typically involves heat delivered from a central boiler (either water or steam), a heat exchanger and a fan to propel the heat around the greenhouse. The heated air can be discharged freely into the greenhouse but it is preferable to distribute it evenly by a system of ducts to prevent undesirable temperature differences. Perforated polyethylene tubes are often used for this purpose as they are relatively cost effective (Hanan, 1998).

As with pipe and floor heating, air heating systems can be improved by lowering the heating ducts. Heat transfer by direct contact between the poly tubes and the growing bags is effective in heating the growing medium and plant roots. Placing the tubes directly contacting the grow bags saved 27.1% in fuel costs over the traditional overhead system (Hanna and Henderson, 2002). As warm air released from the poly tube orifices at the base of the growing bags heats both the growing medium and the roots. The same warm air also rises through the plant canopy thus heating the plant from the bottom up. Placing the poly tubes over the feeding pipes heats the fertilizer solution before it is released to the roots. The warm root environment further increases nutrient temperature that is absorbed by the roots and circulates the vegetative part of the plant, leading to more active plant growth. Moisture on the lower leaves evaporates faster, and dry leaves are less likely to be infected with disease. Moving the heating distribution system lower in the greenhouse improves heat transfer to the plants and helps prevent low canopy temperatures that lead to condensation problems. This results in a better climate around the plant canopy giving significant energy savings.

The main disadvantage of using heated air is the expense of running a fan to move the heated air, which can add 10% to energy costs (Bakker *et al.* 1995). Another problem is that air heating is a convective heat process, so the leaf temperatures cannot reach any higher than the air temperature.

Teitel *et al.* (1999) compared hot water steel pipe heating to hot air poly-tube heating, they discovered there was no significant difference between the two methods in the energy consumption required to obtain a given temperature level inside the greenhouse, as long as the pipes and ducts are positioned between the plant rows (Teitel, Segal *et al.*, 1999).

4.3.2.3 Local heating systems

The low initial investment for a unit heater system makes it a suitable system for smaller growers. Unit heaters typically consist of three functional parts:

- fuel is combusted in a firebox to provide heat which is initially contained in the exhaust, which rises through the inside of a set of thin-walled metal tubes on its way to the exhaust stack;
- the warm exhaust transfers heat to the cooler metal tubes and
- a fan in the back of the heater draws in air, passing it over the exterior side of the tubes and then out the front of the heater into the greenhouse environment again.

The advantage of a unit heating systems is the quick response to control actions and the possibility of applying a wide range of temperatures. Used in conjunction with natural gas it can offer the opportunity to boost CO_2 levels. However, when compared to a boiler system, Hanna and Henderson (2002) found that unit heaters when used with fan-jets and polyethylene tubes were 25% less efficient than a boiler and steel pipe system (Table 14).

Table 14. The efficiency of various greenhouse heating systems.

Heating system	Estimated heating system efficiency
Ideal heating system (theoretical)	100%
Boiler and hot water pipes, near floor	85%
Hot air: unit heaters, fan jets and tubes	60%

(Source: Hanna & Henderson, 2002)

Convection heaters are similar to unit heaters, only they have no internal heat exchanger, the heat is provided by convection from the exhaust travelling through pipes around the greenhouse (Evans, 2004).

Recent improvements in technology have increased the uptake of heat pumps. They can also double as dehumidifiers and be used for cooling in the summer months. However CAE (1996) estimated only 3% of greenhouse growers used heat pumps at that time. It is not known if this proportion has changed.

4.3.2.4 Infra red or radiant heaters

Nelson (1998) reported fuel savings between 30-50% from the use of low-energy infrared radiant heaters compared with a standard unit heater system and about 75% less electricity due to the only motor being needed for a small exhaust fan. Radiant heaters reduce fuel use by efficient combustion (around 90%) and a smaller temperature differential between the greenhouse environment and outside which reduces heat loss (Nelson, 1998). However Blom & Ingratta (1981) have showed significant variations of leaf temperatures depending on location. Thus infra red heating is particularly unsuited to crops with multi-layered canopies, such as cucumbers, where there is a potential for shading and condensation formation (Blom and Ingratta, 1981; Hanan, 1998). Infrared heating, at present, is not common in New Zealand. However the increasing costs associated with other methods of heating may increase the use of infrared heaters.

4.3.3 Environmental control

The use of computerised climate control systems in protected horticulture is well recognised as having a dual effect of increasing production by enabling the grower to exercise a higher degree of climate control and reducing energy consumption by controlling the heating systems in relation to greenhouse energy demand (Garzoli, 1988; Hanan, 1998; Sigrimis, Anastasiou and Rerras, 2000; Hectors, 2005). It has been questioned whether growers are actually making the best use of these systems in terms of energy savings. In response to this Hectors (2005) stated "the complex nature of the energy use in large greenhouses is partly to blame as the grower has lots of other issues to tackle with the crop so the energy management does sometimes not get the attention it deserves. As it is becoming more complicated I foresee that an energy specialist will come in to fine tune the heating aspect and work in conjunction with the grower to provide a suitable situation for the grower and the crop".

Accurate temperature control is an important aspect of energy conservation. By maintaining the greenhouse temperature as close as possible to the set point value energy costs can be minimised (Garzoli, 1988). While lowering temperature may ultimately lower production, the decision may be economically sound, even when some reduced rate of growth is taken into account. Temperature integration strategies have recently gained recognition in recent years. The basic principle is to increase temperature when energy is cheap (e.g. solar energy) and to decrease temperature when energy is expensive. This concept is applicable under the assumption that plants can integrate temperature and that the average temperature is more important than maintaining a constant temperature. This theory works on the principle of reducing cost rather than energy consumption.

Tantau (1998) experimented with varying set points in order to get the same temperature sum, and showed energy consumption was reduced up to 7% with no significant effect on yield. Korner & Challa (2003) improved plant temperature integration by introducing more dynamic constraints based on both a 24 hr and a one week period. Yearly greenhouse energy savings increased by 23% compared to standard commercial practice (Korner and Challa, 2003). Sigrimis *et. al.* (2000) developed a method (using the MACQU intelligent control system), to allow user defined time windows where the temperature set point can be user specified, model derived or floating within the constraints of energy savings. Energy savings of more than 20% were recorded (Sigrimis, Anastasiou *et al.*, 2000). Although only small savings can be made through temperature integration, it has the advantage of no additional cost, unlike other energy saving measures.

Approximately 30% of greenhouses use some form of automated ventilation and circulation systems to both increase yields and provide a more efficient use of energy through a more uniform environment reducing humidity related crop diseases. The main method of increasing ventilation and air circulation is to install fans with capacity of around 28-65 kW/ha for glasshouses and 5-46 kW/ha for plastic houses (CAE, 1996).

Few greenhouse crops are currently grown in soil, growers preferring to use replaceable mediums such as rock wool, sawdust, coco peat and hydroponic systems. This has eliminated the energy consuming task of soil sterilisation. Fertigation systems, essential to deliver a controlled flow of nutrients and water to the crop, typically comprise 2-6 pumps ranging between 1-3 kW capacities each. Warming the nutrient solution and accepting a lower ambient air temperature can reduce overall heating requirements.

4.3.4 Pumps and irrigation

There is very little data available on improving pump efficiency and reducing energy consumption, with most information available being in the form of manufacturers' reports and industry websites.

It is well recognised that the maximum energy savings can result from running a pump at its peak operating point (Aldrich and Bartok, 1994). It was estimated that energy savings may be as high as 20% if pumps are correctly sized, based on reasonable system heads and capacity requirements (The Hydraulic Institute, 2005). Wear is the main cause of decreased pump efficiency; therefore older pumps tend to be less efficient.

During peak demand periods two pumps can be operated simultaneously, with only one pump operating during lower demand periods. Energy savings result from running each pump at a more efficient operating point and avoiding the need to throttle a large pump during low demand (The Hydraulic Institute, 2005). Alternately a variable-speed pump could be used.

For growers planting directly into the soil, moisture content is an important variable for plant growth. There is a wide variety of trickle and drip systems which dispense water slowly and may or may not contain soluble fertilisers. Such greenhouse irrigation systems are a relatively low consumer of energy.

4.3.5 Lighting

In Central and Northern Europe light level is the factor restricting growth for about 3–4 months of the year. With the development of efficient high pressure sodium lamps the industry has been able to maintain a high standard of production year round (Autogrow Systems, 2005). Compared to Europe, New Zealand growers generally only use additional lighting for propagation, if at all, due to the negative cost/benefit investment. While lighting may constitute a major area of energy use in overseas greenhouses, its relevance to New Zealand growers is considered small and therefore the use of lighting for crop production will only be considered briefly.

Artificial lighting in greenhouses is typically used to supplement daylight to increase the irradiance level for photosynthesis for the purpose of improving production and increasing yield. Historically supplemented lighting has generally been regarded as uneconomic. Long life sodium lamps, however are now commonplace in many European greenhouses.

Poor lighting conditions can reduce plant growth, increase growth periods and waste heating fuel. Lighting using incandescent bulbs of 60-150 W each is generally preferred by growers because it produces a greater source of red light to which plants are sensitive. These lights could be replaced by nearly half the number of fluorescent or high pressure mercury 18 W lamps to achieve a similar lighting effect. While the fluorescent and mercury lamps are more expensive to install, they are more energy efficient and hence cost effective in the long run (CAE, 1996). Sodium low pressure lamps are an energy efficient alternative but not recommended as the sole lighting source, though coupled with cyclic (intermittent periods) of illumination can be an efficient alternative. Cyclic lighting enables different beds to be lit in succession using the same mobile light source but is only suitable for certain crops. Additional lighting is typically not used in New Zealand except possibly in the propagation shed.

For an overall evaluation of the use of artificial light in greenhouses, Meyer (1989) state that heat and electricity consumption, the greenhouse construction and light conditions have to be regarded simultaneously. Using a modular simulation program, control strategies for various artificial light systems were evaluated (Meyer, 1989). He stated that the energy consumption of artificial light systems is dependent on the insulation of the greenhouse. The artificial lighting acts like a heating system and reduces the amount of heating energy in the same magnitude as the installed electric power. The control strategy influences the possible running hours per year of the artificial light, especially if the heat demand of the greenhouse acts as an input parameter.

The high capital investment required in the application of European lighting technology in the New Zealand greenhouse industry is uneconomic at the present time (Nederhoff, 2005) attributed to the natural lighting conditions and market factors.

4.3.6 Alternative heating energy sources

Non-traditional heating sources, such as geothermal and biomass are currently being used in New Zealand. Interest in these alternative fuels for greenhouse heating is predicted to grow, as fossil fuel prices increase.

With some New Zealand greenhouse operations within close proximity of geothermal activity, geothermal heat is potentially a viable alternative heating source.

At the time of this research the use of biomass had been adopted by a Northland greenhouse operation. The proposed bio-energy plant, due to be completed in 2005, is a combustion and boiler system using sawdust shavings, waste wood and bark as fuel to generate heat that will be stored in large water tanks until required in the glasshouses. It was to replace a gas-fired boiler, providing cheaper, renewable energy (NZCCO, 2004).

Waste heat produced by industry may also be a viable alternative heating source. Warm waste water has very little usable heat and cannot economically be pumped very far. The greenhouse therefore must be located close to the heat source. A back up system able to handle the entire heating load may be required if the waste heat is not dependable (Bond, Gilroy *et al.*, 2005).

Cogeneration with additional heat storage measures was found to be the most economically feasible of four different environmentally friendly heating systems in seven European locations when compared with solar collectors and heat pumps (Garcia, De la Plaza, Navas, Benavente and Luna, 1998). In France, the utilization of landfill gas for heating and CO_2 enrichment for the production of greenhouse roses was conducted (Jaffrin, Bentounes, Joan and Makhlouf, 2003). Crop yields and quality of the rose crop were compared during 24 months. Higher crop productivity resulted from the CO_2 enrichment which contributed substantially more to the economics of the operation, being more important than the reduction of heating costs achieved by burning landfill methane.

The application of alternative fuels to the greenhouse industry is not an economically feasible option for many growers at the present time. Dr Christie (2005) commented that "as long as the industry is considered small or insignificant by the government there will be few incentives to assist with technology transfer to growers over and above what is already being done"(Christie, 2005).

4.4 Gaps in the literature

Most of the literature available on energy use in greenhouse energy coincides with the oil "shocks" of the late 1970s and early 1980s. Considering the rate at which greenhouse technology has improved this information is now becoming dated.

Many of the studies conducted on energy use in greenhouses focus on Central and Western Europe where growers face challenges such as high snow loads and limited natural light. In comparison New Zealand growers deal with a very different climate; snow is typically not a factor and in some case areas sunlight light levels are over and above the levels required for crop production. Therefore further research is required into the implementation of European designed technologies in New Zealand greenhouses.

At present there is no international standard for many greenhouse technologies such as the different types of covering materials and thermal screens that would allow comparison by consumers. While studies have investigated the optical and thermal properties of various screen material there is no up to date international classification of available cladding and screen materials (McNaughton, Jackson *et al.*, 1981).

5.0 Methodology

The following chapter details the steps taken in developing the data collection method, the subsequent data analysis and the energy saving model. Contractual requirements have partly influenced the approach taken and the method of data collection in order to match the specific objectives of the client Vegfed.

5.1 Conducting an overview of energy use and efficiency in New Zealand's agricultural sectors

As stated in the introduction, sections of this research also formed part of a research contract with ECCA which aimed to compile, estimate and analyse information from a wide variety of sources on energy end uses and patterns of energy consumption within the agricultural sub-sectors.

The objectives stated by EECA in conducting this study were to:

- estimate and analyse energy consumption and energy intensity in the primary agriculture sub-sectors, including energy use patterns and trends, relative shares of electricity and non-electricity fuels used and the major end uses to which energy is put; and
- identify key factors affecting energy use and energy intensities within the primary agricultural sub-sectors, including how they may be changing over time.

The method used to fulfil these objectives was to conduct a desk top study reviewing available literature from New Zealand and overseas. The energy end use data sourced from the literature for the various sub-sector including sheep and beef, arable cropping, fruit production, pig and poultry production and greenhouse production were organised in matrices using Microsoft Excel worksheets. Dairying was excluded as this covered by a different researcher working in collaboration on the EECA contract. The purpose of arranging energy end use values into matrices was to; allow gaps in the literature to be identified; give an indication of the age of the research; and allow for easy comparison between different sub-sectors.

Energy consuming activities specific to the various farming sub-sectors were listed down the left hand side of a Microsoft Excel worksheet (Table 15). The worksheet was divided by a lifecycle sequence (preparation, growth, harvest, storage and processing) listed along the top. This format was used for each sub-sector. As values for energy end uses were sourced from the literature they were entered into the spreadsheet according to the activity, where it featured in the lifecycle, the date of the research and a number correlating to the reference. This was later changed to the first three letters of the lead authors' name.

Table 15. An example of the matrix layout, showing reference 5 published in 1996.

Greenhouse crop production over 1 year					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Environmental Controls		3 kW (5/1996)			
Heating	18 W (5/1996)				
Heating Pumps			60-150 W (5/1996)		

When comparing the completed matrices for the various sub-sectors, the greenhouse or protected cropping sub-sector was identified as an area where relatively limited energy related research had been undertaken. It was conjectured that energy related research corresponds to high energy prices, most significantly during the late 1970s and early 1980s. The main focus of agricultural energy use research during this period was on pastoral farming, with only one significant study conducted focusing specifically on the greenhouse industry, which was conducted by Breuer in 1985 under the New Zealand Energy Research and Development Committee. The lack of topical energy-related research and the impending threat posed by the recent carbon charge has fuelled a strong interest in energy related research by the greenhouse industry. This has prompted Vegfed's interest in the second stage of this research.

5.2 Determining the energy saving potential in the New Zealand greenhouse sector

This section focuses on the development of the data collection method, including the choice of instrument and research participants.

Preliminary site visits

At an international level, the various aspects of greenhouse engineering, design and production have been widely researched. For the most part the literature available on greenhouse production is from northern hemisphere countries such as the Netherlands and, to a lesser extent, the U.S.A. Comparatively very little literature is available on New Zealand greenhouse production and the application of overseas technologies. Consequently it was necessary to undertake preliminary site visits to greenhouse enterprises to determine what technologies are currently used by New Zealand growers, and therefore what type of questions would eventually be used in the data collection instrument. The researcher accompanied Dr Elly Nederhoff from Technolutionz (www.technolutionz.co.nz) and Richard Hectors from RFT Climate Ltd (www.rftclimate.com) on a series of visits around South Island greenhouses in August, 2004. The objectives of these preliminary site visits were to:

- become familiar with the technology and systems currently utilised by New Zealand greenhouse growers;
- identify any differences between the technology used in New Zealand greenhouses and what is presented in the literature; and
- conduct informal discussions with growers to gauge their level of knowledge and interest in the use of energy and the potential effects of the proposed carbon charge on their business.

This site visit in conjunction with a review of available national and international literature was used to determine what technologies and methods of crop production were currently being used by growers and ultimately the content of the data collection instrument.

The data collection instrument

Following these preliminary site visits, a postal survey to be completed by greenhouse growers was proposed as the main method of data collection. The aim of the postal survey was to gain an overview of energy use and influencing factors in New Zealand greenhouses while providing a robust data set for analysis. It would also provide a means of identifying suitable participants for following site visits, which would allow greater insight into the technology and crop production methods used by a limited number of greenhouse operations.

The disadvantage of choosing this method of data collection was that the number and complexity of the questions proposed had to be restricted to ensure a reasonable response rate. This type of data collection would also not provide a representative sample of New Zealand greenhouse vegetable growers, as particular individuals may be more motivated to respond than others, and therefore be biased towards growers who already take an avid interest in energy use.

Many of the questions proposed in the draft postal survey largely repeated a similar study conducted for Vegfed the previous year as it was later pointed out. As a result the postal survey was not used. The alternative approach was to rework the postal survey objectives into a more comprehensive 'walk-through' energy audit. The term 'energy audit' can be used to describe a wide range of energy use studies ranging from a quick walk-through of the operation to identify major inefficiencies, to a comprehensive analysis of the implications of implementing energy efficiency measures complete with a detailed financial analysis. Due to financial and time constraints a 'walk through' energy audit was conducted of 22 growers. Growers were selected from a list of provided by Vegfed, these growers had been part of a previous energy related postal survey (Barber and Wharfe, 2004) and had indicated that they would be willing to participate in future energy related studies. Growers were selected on a nom-random basis to provide a reasonable spread over different variables such as crop type and location.

The energy audit relied on a single visit to the greenhouse operation and on the grower's knowledge about his or her operation. It involved informal discussions with the operator, a review of the energy accounts received over a 12 month period, and a walk-through of the operation to become familiar with the building structure and to identify obvious areas of energy waste or inefficiency. Many growers were able to provide extensive details of their energy consumption off the top of their head, while others had to review their account details. This level of detail was insufficient to reach a final decision on implementing energy saving measures for each operation. However it did provide a detailed and rigorous data set with which to carry out subsequent statistical analysis.

The objectives of conducting the energy audit were;

- to obtain detailed case study perspectives on what individual growers are currently doing to reduce their energy demand;
- to discuss growers' views on energy use and practical ways of reducing demand; and
- to provide a data set to be used for further analysis of energy.

The advantages of the energy audit were that it offered a comprehensive and rigorous method of data collection as the researcher was on site and physically collecting the data. It also resulted in a complete data set that provides a case study perspective of what was currently been achieved by growers. Collecting the data face to face offered an opportunity to talk to the participants about their thoughts and opinions on the energy subject matter which could give insights into areas previously not considered by the researcher. The main disadvantage of this type of data collection method was that it was not truly representative of the population. Also due to the time required to conduct each audit the data set is small in comparison to a postal survey.

5.3 Content and structure of data collection instrument

As mentioned previously the original method of data collection proposed was a postal survey (Appendix 2) later reworked into a more detailed energy audit (Appendix 4). The following section discusses the rationale behind the content and structure of both the postal survey and the energy audit.

The focus of the data collection method was to encompass the four main energy influencing variables in New Zealand greenhouses identified by Barber & Wharfe (2004); management, location, greenhouse type and greenhouse age. Factors that had a minor effect on energy use were originally excluded from the postal survey but later incorporated into the energy audit these included pumping, the fertigation (or nutrient) system and the packing shed.

Barber (2003) identified "location" as one of the main influencing variables in New Zealand greenhouse energy use. This was one of the most important pieces of data in terms of the analysis and was therefore placed at the beginning of the audit along with other grower details. The options listed for the postal survey were based on regional catchments. This question was removed from the energy audit but included as part of each grower's personal details.

The questions relating to crop production were outlined in a table format for the three main crop types (tomatoes, cucumbers and capsicums) and 'other' for unspecified crops such as herbs, lettuce and eggplants. This table format accounted for growers who may be growing more than one crop. By requesting yearly, summer and winter production data, a twelve month production profile of each grower by crop type could then be determined. This question was used in both the postal survey and the energy audit. Initially participants were asked for both the total greenhouse area and total heated area under cover, as it was assumed that not all greenhouses within one operation would be heated. This question also acted as a cross check for a later question about individual greenhouse floor area. Propagation sheds were initially included as a separate section due to the fact that they may have different energy requirements, but were eventually included as it became apparent that the structure could be used for both propagation and production.

Questions relating to the building structure and design were broken down for each greenhouse into floor area, the age of both the structure and the cladding, and whether any energy saving devices such as double cladding or thermal screens had been installed. This format kept the audit form visually uncluttered. It also sought specific details for each individual structure. Heating loss through poor cladding condition and insufficient lap seals can be significant (Bond, Gilroy *et al.*, 2005). Therefore a rating system for the cladding and the seals was devised. Rating scale questions were not included in the postal survey because the response to these questions would have been biased and subjective as each survey would have been completed by a different person. However as the energy audit was completed by the researcher this type of question was deemed to be valid.

Participants were asked for the number of heating systems currently in use, i.e. boilers and unit heaters, and then the specifics were sought about each, including age, capacity and fuel type. The method of heat distribution was not considered in depth in the postal survey in order to keep the survey brief and simple, however it was later included in the energy audit. In addition open ended questions where participants were asked questions regarding the maintenance of the heating system and whether any steps had been taken to improve energy efficiency were included. This allowed the opportunity to incorporate significant points of difference between the various operations.

While water pumping was not considered in the postal survey, a large section was included in the audit. This was difficult to devise as the pumping set up varies considerably between each operation and can be influenced by a number of variables including whether subsequent greenhouse structures have been built nearby, the heat distribution method and the fertigation system. The question was divided into main water pumps (defined as outside pumps providing more than one greenhouse structure) and secondary pumps (defined as pumps providing only one greenhouse structure often for the purpose of hot water distribution). This excluded secondary pumps used for nutrient circulation within the structure and at the fertigation stations.

Humidity control, ventilation and lighting generally make up only a very small portion of the total energy use (Barber, 2003 estimated around 4% of the total energy). However it was necessary to include these factors in the energy audit for a complete overview of energy use in greenhouse production. In addition, growers were asked if integrated plant management techniques were used and also whether CO_2 enrichment was used which can boost crop production and therefore reduce the seasonal energy inputs per unit of production.

Post harvest operations such as refrigeration, grading and shrink wrapping of product can potentially be high energy demanding activities. It was anticipated that many growers do not have packing operations on site and therefore this section would not apply.

Growers were asked whether a back-up power supply was present, and if so the fuel type and for how many hours in the last 12 months this power had been used.

The section on grower's opinions' were presented in a table format based on a 1-5 Likert scale. Growers were presented with statements regarding the potential for energy saving improvements and asked whether they agreed or disagreed. Several open ended questions were added, to give the grower an opportunity to express his or her ideas on energy savings within the operation.

Initially growers were asked for the yearly total of the energy use by fuel type. This was later changed to include energy use on a quarterly and yearly basis to account for seasonal variations. While this added significantly to the bulk of the audit, it also provided greater insight into the energy use of each operation.

5.3.1 Piloting the postal survey and the energy audit

The proposed postal survey was piloted with a capsicum grower and two tomato growers. While several format changes were made to make the survey easier to read and more user friendly, no major content changes were made.

The energy audit was piloted with 2 relatively small growers with less than 2000 m^2 of total greenhouse floor area. The most significant change made to the audit as a result was allowing for seasonal variations in energy use and crop production. In the section on crop production growers were asked for the average winter and summer harvest of the crop. The section on energy use was broken down to energy use for the months of January, April, July, October and the yearly total for each fuel type. This increased the size and the complexity of the audit considerably and it also required greater effort on the part of the participant. It had the advantage, however of providing greater insight into seasonal variations in energy use.

The question regarding whether artificial heating was used during the different seasons and day/night periods was shortened to whether artificial heating was used? Typically heating cuts in automatically at a set ambient temperature point irrespective of timing.

5.3.2 Participants and selection method

The participants for this research were New Zealand greenhouse vegetable growers only, mainly comprising of tomato, cucumber and capsicum growers. Barber & Wharfe (2004) determined in their survey of the New Zealand greenhouse industry, that flower growers (the other main greenhouse crop) are typically less energy intensive than vegetable growers. It was therefore assumed that recommendations drawn from this research for greenhouse vegetable growers would also apply to New Zealand flower growers, who were not part of the survey.

The initial method of identifying participants was a face to face short interview conducted with 130 growers at the Massey University Centre for Energy Research Stand at the 2004 Mystery Creek Fieldays. The theme of this Fieldays was 'Energy Efficiency' which heightened farmers' awareness of the research subject and increased their willingness to participate. The purpose of conducting this survey was to gauge farmers' opinions on energy use and the carbon charge. The survey was also used to identify potential candidates for the walk-through audit. This method however identified too few greenhouse growers and was not considered further.

A second approach was to request a list of greenhouse vegetable growers from Vegfed from which a random sample could be taken. The population includes all New Zealand greenhouse vegetable growers currently registered with Vegfed. A simple random sampling method was proposed with the following attributes (Table 16).

Table 16. Statistical attributes for the sample required for the postal survey

Population	800
Confidence level	95%
Sample size	260

However due to confidentiality reasons, permission to access Vegfed's database was not granted. Participants were eventually selected from a pre-approved list provided by Vegfed. The growers on this list had previously been involved in energy related research (Barber, 2003) and had given their consent to be approached again in the future. Hence growers were not able to be selected randomly, but were selected to obtain a reasonable spread over enterprise size, heating fuel type, crop type and location.

Due to the selection method and considering the growers had previously participated in an energy related survey, the results of the grower audit will be strongly biased towards growers who are aware of both the proposed carbon charge and its likely effects on their business.

The audit was conducted face-to-face with each of the 22 grower and took on average around 1-2 hours to complete depending on the size and complexity of the greenhouse enterprise and also how familiar the grower was with the minor technical aspects of their operation.

Growers were initially approached over the phone so the response rate was good. Out of the 41 growers approached, 5 were involved with the pilot of the postal survey and the energy audit, 22 participated in the energy audit, 2 were involved in piloting the audit, 6 were not interested in participating at all, 5 were no longer in business and 5 were interested in participating but could not arrange with the researcher an appropriate time to visit.

5.3.3 Research boundaries of energy use

The boundaries for this research were defined as the physical boundaries of the greenhouse operation. This included energy used in environmental control of the greenhouses, on site packing facilities, and on site transport. Energy used by any residential dwellings onsite and any energy used for offsite transport, were excluded.

Only direct energy, such as coal, electricity and liquid fuels was included. Greenhouse production also requires significant indirect energy inputs such as fertiliser inputs. Fertiliser use was monitored closely by the grower as it can have a significant impact on the health of the crop. It was therefore assumed that there are minimal energy savings that can be made in this area. Therefore indirect energy (in the form of agri-chemicals and fertilisers) was excluded from the analysis along with embedded energy in the building and machinery.

5.3.4 Ethical considerations

There was minimal risk to the physical and mental well being of the participants in conducting this research. A Low Risk Notification was prepared and submitted to the Massey University Human Ethics Committee (MUHEC). A cover sheet (Appendix 3) was prepared in accordance with the MUHEC guidelines and presented to growers. This was followed by a consent form requiring a signature from each grower for participation in the audit under the conditions set out in the cover sheet.

5.4 Secondary data

While the data collected from the energy audits showed what is currently being achieved by individual growers, a much larger data set was required to add strength and support the conclusions drawn.

A secondary data set provided by Vegfed was collected in 2003 by Barber (2004) through a postal survey sent to all New Zealand greenhouse flower and vegetable growers registered with Vegfed and the Northern Flower Growers Federation. It included all participants (229 growers) who were greenhouse vegetable and fruit growers and had agreed to be involved in further research.

On evaluating the appropriateness of the secondary data set, a number of factors were considered, including the sampling method, the variables and their values, and the time frame. Table 17 outlines the various factors taken into account.

Table 17. Attributes of the secondary data set produced by Barber (2004).

The sampling method	The data collected was through a postal survey therefore a number of values are missing from the data set. While not as rigorous as the data collected in this study, the secondary data set may better define the population due to the greater number of responses.
The variables and values	The variables, values and units of measurement of the postal survey were similar and in some cases identical to the energy audit. Comparison of the values and unit conversions can be easily made between the two sets of data.
Research boundaries	The research boundaries of secondary data were similar to the research conducted including direct on site energy inputs and excluding any off site inputs and indirect energy inputs such as fertiliser and agri-chemicals. Barber (2003) excluded electricity used for minor tasks, such as pumping from his analysis, for the purposes of this study electricity was included in the energy intensity in the energy audits.
Time scale	The secondary data set was collected in 2003 while this research was conducted in 2004. It is unlikely that significant changes in the industry were made in the year between.
Reliability	The reliability of the data set was compromised by analysing only a selected sample. It can no longer be assumed that the data set was representative of the population or that it followed a normal distribution.
Source bias	The secondary data set was collected through a postal survey. This resulted in a bias toward growers who were aware and informed of their energy use and the carbon charge.

5.5 Data Analysis

Microsoft Excel and Minitab 14 were used to compile and analyse the data. The data set comprised different data types including nominal, binary, ranked and continuous. Therefore different descriptive statistics were used where appropriate.

In order to carry out statistical analysis for such a small sample, it was assumed the sample represented a normal population. The Ryan-Joiner test was used to test the normality of each data set. If the P-value was larger than 0.1 then it was assumed that the data was from a normal population, smaller than from a non-normal population.

Statistical tests (such as a 2 sample T-Test) were used to assess whether variances were equal across groups or samples. The Levene's test was used to verify this assumption as an alternative to the Bartlett's test as it is less sensitive to departures from normality and is more robust when analysing smaller samples (Moore and McCabe, 1993).

5.5.1 Rationale and testing of the hypotheses

Table 18 outlines the hypotheses used to answer the research question, how they were derived from the literature and the statistical tests used to test these hypotheses.

Table 18. Hypotheses, rationale and statistical tests behind the data analysis.

	Hypothesis	Rationale	Tests Conducted
1.	*There is a significant difference between the energy intensity (MJ/m^2) of greenhouses in the North Island and the South Island.*	Barber (2003) clearly showed that location is one of the main influencing variables in determining the energy intensity (MJ/m^2) of a New Zealand greenhouse operation, presumably due to the associated climate. He found South Island energy use was 50% higher than the North Island.	A two sample t-test was used to determine whether there is a difference between energy intensity of greenhouses in the North Island and the South Island in both the sample collected and the secondary data. Box plots were used to display the difference between the mean energy intensity of North Island and the South Island operations.
2.	*Aspects of greenhouse structure and design have an effect on energy use.*	The effect of building design and structure on energy intensity is well documented. Breuer (1985) listed poor seals and cladding condition as one of the major sources of heat loss in New Zealand greenhouses. Giacomelli *et al.* (1989) found age and weathering had a significant effect on the heat retention and light transmitting properties of various cladding materials.	The average age of the greenhouse cladding for each operation was determined. A Pearson correlation was conducted between average cladding age and energy intensity. The average age of the cladding of each operation was then cross-tabulated with other aspects of greenhouse design and structure. Due to the difference in data values a 2 sample T-test was used to compare old (>10) and new (<10) claddings and the associated energy intensity.
3.	*Energy intensity is seasonal.*	Given that heating is the main energy consuming activity within a typical New Zealand greenhouse operation, the amount of energy required at any one time will be influenced by	Data was displayed on a time series graph. Peaks and slumps were then identified.

		climatic factors such as the outside temperature and the wind chill.	
4.	*Energy intensity is positively correlated with production.*	Barber and Wharfe (2004) found a weak positive correlation between energy intensity and yield. This was tested using the data collected and secondary data set.	A Pearson correlation was used to determine the strength of the relationship between tomato production yields and energy inputs for both the collected and secondary data.
5.	*Greenhouses with a central heating system are more efficient than those with a local heating system in each house and therefore are less energy intensive.*	This is a somewhat controversial topic and can be affected by a number of factors. However it is generally acknowledged in the literature that a central heating system is typically more efficient than a local heating system, particularly when operating multiple greenhouse structures.	A 2 sample T-test was conducted to determine whether there was a difference between the energy intensities for the various heating types. Box plots were used to display the difference between the means. The various heating types were then cross tabulated with the different methods of heat distribution.
6.	*Growers who use an automated climate control system will be less energy intensive than growers who do not.*	It is well documented that the use of an automated climate control system can improve crop production and minimise energy use, particularly heat loss. An automated climate control system can also aid in implementing temperature integration strategies.	A 2-sample T-test was conducted between growers who used automated climate control systems and growers who did not. This test conducted on the data collected and the secondary data set. For the secondary data set the test was also broken down into the North and South Island.
7.	*Growers have negative opinions about the energy efficiency of their greenhouses and the proposed carbon charge.*	The main purpose of this research was to determine ways in which greenhouse growers can reduce their energy use. It was therefore important to determine where growers saw potential for energy saving opportunities in their business and also whether they were aware of the carbon charge and the likely effects on their business.	Descriptive statistics, including quartiles, median and mode were used to give an indication of the likely response of the growers audited.

5.6 The energy saving model

The purpose of developing a computer model of energy use in greenhouses was to encourage the user to think about potential energy savings that could be made within their individual greenhouse operation, and also the potential cost of the carbon charge on to their business.

The objectives of the model were to:

- benchmark the user's energy use against other New Zealand growers, taking into account the crop type and location;
- determine the future cost of the carbon charge to the user;
- identify where energy savings could be made through the implementation of technologies and energy wise practices and
- provide growers with a method of quickly assessing which energy saving options available might best suit the specific situation.

Recommendations from the model were based on best practice and use of energy saving technologies identified through the energy audits, review of current literature and consultation with manufacturers.

5.6.1 Content and structure of the model

The first section of the model was focused on the potential cost of the carbon charge and also benchmarked each grower's energy use and production against other New Zealand growers. The second section concentrated on specific energy saving measures that can be applied to a grower's situation.

Section 1

Growers are asked to input basic data such as the location of their business (North or South Island), crop type, heating fuel type and total covered area, the price per tonne of CO_2 and the amount of fuel used, by type over a twelve month period. The model then calculates the additional cost of the carbon charge over a twelve month period and the overall energy intensity of the greenhouse operation. The model benchmarks the user against other growers in terms of production and energy use by location. Determining the actual cost in $ of the carbon charge was based on the following values (Table 19).

Table 19. Energy and carbon dioxide emission values used in developing the energy saving model.

Fuel Type	Units	Energy (MJ/unit)[a]	gCO_2/MJ[b]	gCO_2/unit
Natural gas	MJ/l	3.6	52.4	188
Diesel	MJ/l	35.4	69.5	2460
Coal	MJ/kg	21.1	91.2	1924
Waste oil	MJ/l	38.7	73.7	2852
Electricity	MJ/kWh	3.6	43.1	155
LPG	MJ/kg	26.5	60.4	1603
Wood (Wet)	MJ/kg	9.3		970
Wood (Dry)		20.6	104.2	2141
Petrol	MJ/l	34.7	66.2	2297

Data source:

[a] NZ Energy Data File (The Ministry for Economic Development, July 2004)

[b] National Inventory Report: Greenhouse Gas Inventory 1990-2004 (NZCCO, 2005)

Benchmarking was based on a secondary data set. This data set was tested for normality. It was assumed that this sample of growers was representative of the New Zealand greenhouse vegetable industry.

Section 2

The model user is asked short answer questions regarding the various aspects of their greenhouse operation including the building structure, heating system and climate control system. Depending on the response, recommendations are made based on the literature, case studies and the findings from the analysis of the energy audit. The potential fuel and carbon charge savings of implementing these measures are shown where appropriate.

6.0 Results

The results of the analyses of the energy audit and the secondary data are presented. The hypotheses are tested using the methods described in Section 5.4.1. A summary of the greenhouses audited along with a breakdown of the data structure including descriptive statistics are included as Appendix 5 and 6 respectively.

6.1 Checking assumptions

Due to the type of statistical tests used in the analysis it was necessary to test for equal variances. A Levene's test was conducted using the energy intensities of the data collected and the secondary data (Barber and Wharfe, 2004). The test statistic for the collected data was 0.19 and the P-value was 0.672. For the secondary data the test statistic was 0.53 and the P-value was 0.469. The P-values were greater than the chosen confidence level ($P<0.05$). Therefore this data did not provide enough evidence to claim that the two populations have unequal variances, and it was reasonable to assume equal variances when using a 2 sample T-procedure.

There was not enough evidence to assume that the data collected was sampled from a normal population. The normality tests for the energy intensities for both sets of data were plotted (Figs. 20 and 21). The collected data had a P-value of >0.100, which was not significant ($P<0.05$), while the secondary data had a P-value of <0.010, which was significant ($P<0.05$). Therefore there was not enough evidence to assume that the data collected was from a normal population. However we can assume that the secondary data was sampled from a normal population. This further highlights the importance of repeating the statistical analysis using the secondary data to strengthen conclusions drawn from the collected data.

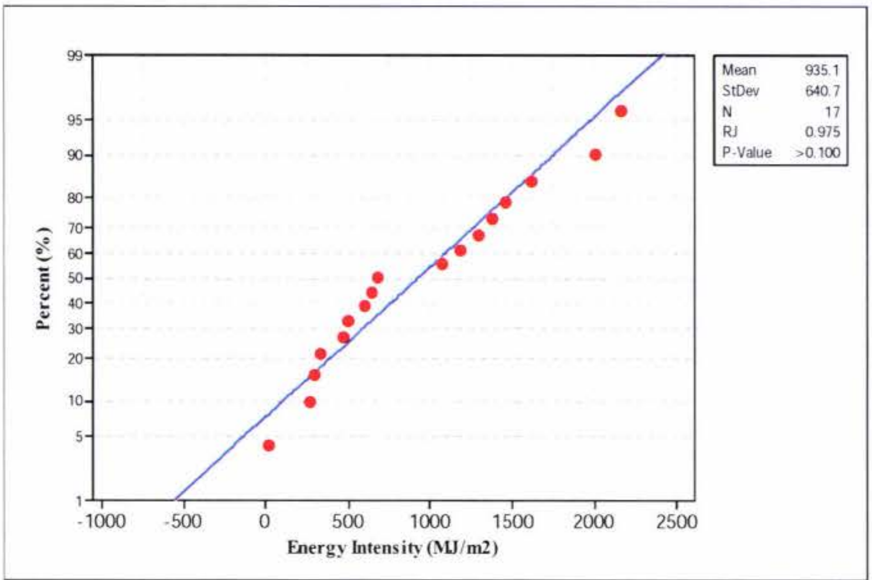

Figure 20. Normality test for energy intensity (MJ/m^2) for the data collected.

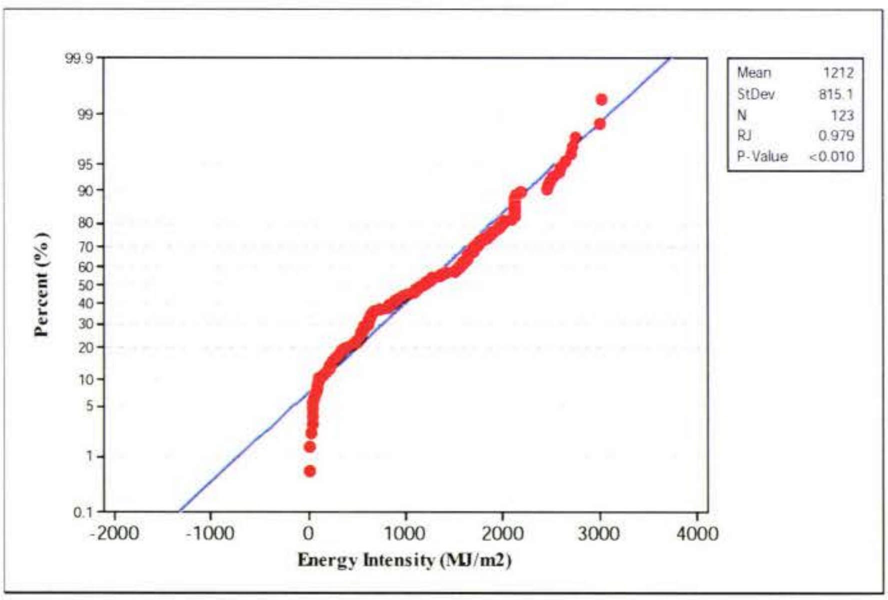

Figure 21. Normality test for energy intensity (MJ/m^2) for the secondary data.

6.2 Testing the hypotheses

The following section tests the hypotheses using the methods described in section 5.4.1. Tests wherever possible are repeated using the secondary data to increase the robustness of the conclusions drawn.

Hypothesis 1: ***There is a significant difference between the energy intensity (MJ/m^2) of greenhouses in the North Island and the South Island.***

A 2 sample T-test was used to determine whether location influenced energy use by analysing the energy intensities of greenhouse operations in the North Island and the South Island for both the data collected and the secondary data (Table 20). A box plot was used to show the difference between the two means (the connected circles) and medians (the central line) (Fig. 22). For the collected data the T-value was -4.20 and the P-Value of 0.001 was significant ($P<0.05$), based on this result greenhouse operations in the North Island were significantly less energy intensive than in the South Island. The North Island data showed two outliers (Fig. 22), which show considerably greater energy intensities than the median.

Table 20. The results of a 2 sample T-test comparing North Island and the South Island energy intensity(MJ/m^2) means for the data collected.

Location	N	Mean	StDev	SE Mean
North	11	598	447	135
South	6	1554	452	184

The test was repeated for the secondary data (Table 21 and Fig. 23), the T-value was -4.19 and the P-Value was 0.000 ($P<0.05$). This result supported the hypothesis and strengthened the conclusion drawn from the data collected.

Table 21. The results of a 2 sample T-test comparing the North Island and South Island energy intensity(MJ/m^2) means for the secondary data.

Location	N	Mean	StDev	SE Mean
North	74	977	784	81
South	49	1567	734	105

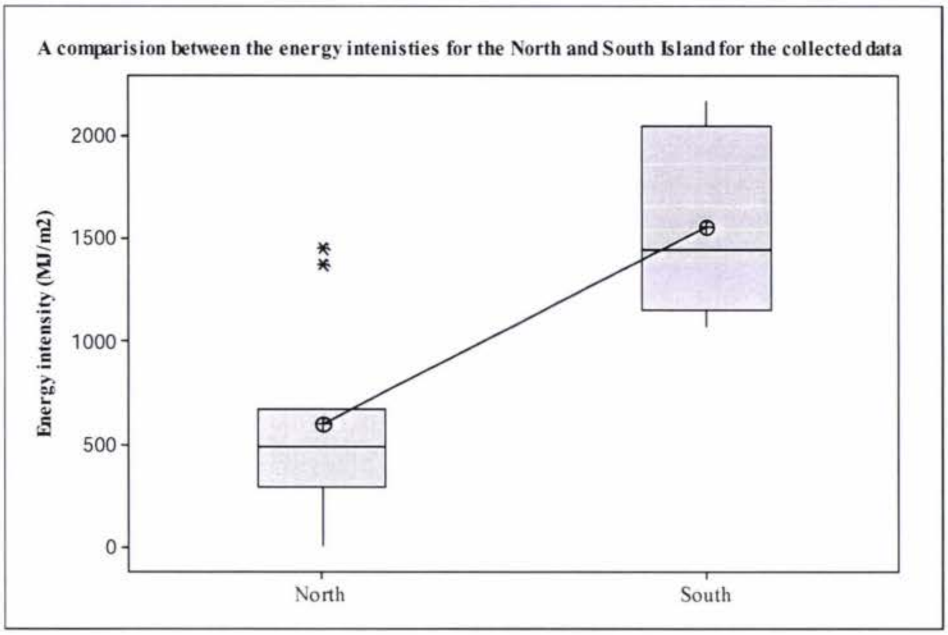

Figure 22. Box plot comparing the difference between the means of the North Island and South Island energy intensities for the collected data.

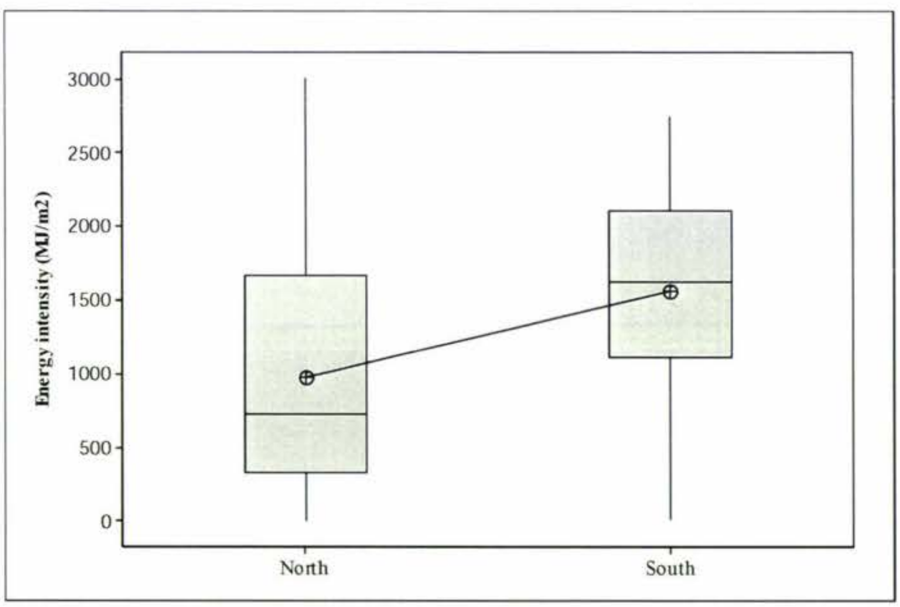

Figure 23. Box plot comparing the difference between the means of the North Island and South Island energy intensity (MJ/m^2) for the secondary data.

In summary energy intensity was significantly lower in the North Island compared to South Island greenhouse operations for the data collected. Analysis of the secondary data supported this conclusion.

Hypothesis 2: ***Aspects of greenhouse structure and design have an effect on energy use***

A correlation was conducted between the average age of the cladding for each greenhouse operation and the energy intensity of the operation. Due to the difference in the data values a 2 sample T-test was used to analyse this relationship using the secondary data. Other aspects of greenhouse structure and design were then cross tabulated with the average age of each greenhouse operation.

The Pearson correlation value for the energy intensity and the average age of the cladding was -0.156, while the P-value was 0.550 ($P<0.05$) (Fig 24). Therefore there was insufficient evidence to accept the hypothesis.

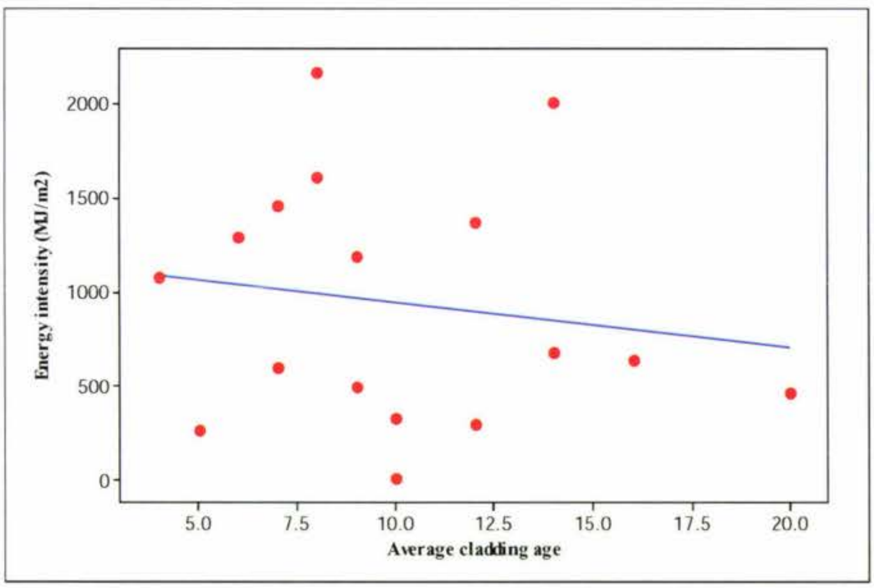

Figure 24. Scatter plot showing the correlation between the average age of the greenhouse cladding (years) and the energy intensity (MJ/m^2).

The T-value for the secondary data was 0.20 and the P-value was 0.841 ($P<0.05$). Therefore there is insufficient evidence to accept the hypothesis. The box plot shows very little difference between the two means (Table 22 and Fig. 26).

Table 22. The results of a 2 sample T-test comparing the means of the energy intensity (MJ/m^2) for newer (<10 years) and older (>10 years) greenhouses from the secondary data set.

	N	Mean	StDev	SE Mean
Newer(<10)	108	1333	817	79
Older (>10)	94	1310	794	82

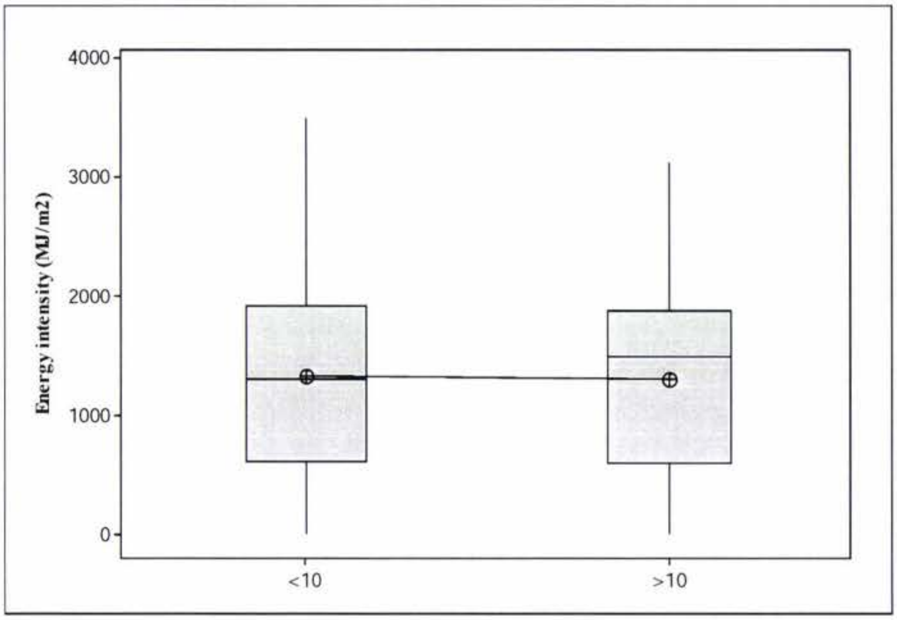

Figure 25. A box plot comparing the means of the energy intensity (MJ/m^2) for newer (<10 years) and older (>10 years) greenhouses from the secondary data set.

The following cross-tabulations assess the average cladding age of a greenhouse operation and the various aspects of greenhouse structure and design that are identified in the literature as potentially influencing energy use.

A cross tabulation of greenhouse structure material and cladding age showed that a greater proportion of older greenhouse structures (>10) were made of wood, whereas a greater proportion of newer greenhouse structures (<10) were made of steel (Table 23).

Table 23. A cross-tabulation of structure material and the cladding age.

	Structure material		
Age of the cladding material	Aluminium	Wood	Steel
<5	2%	4%	16%
<10	*	4%	29%
<15	*	18%	12%
<20	*	8%	4%
>20	*	4%	*

A cross tabulation of the cladding condition rating and the age of the cladding material showed a greater proportion of older greenhouses have a poor cladding condition rating while a greater proportion of newer greenhouses (<10) have a moderate-good cladding condition rating (see Table 24).

Table 24. A cross tabulation of the cladding condition rating and the age of the cladding material.

	Cladding condition rating		
Age of the cladding material	Good	Moderate	Poor
<5	12%	8%	2%
<10	16%	16%	2%
<15	8%	4%	18%
<20	2%	*	10%
>20	*	*	4%

A cross tabulation of the seal condition rating and the age of the cladding material shows a greater proportion of older greenhouses had a poor seal condition rating while a greater proportion of newer greenhouses (<10) had a good-moderate condition rating (Table 25).

Table 25. A cross tabulation of the seals condition rating and the age of the cladding material.

	Seals condition rating		
Age of the cladding material	Good	Moderate	Poor
<5	12%	8%	2%
<10	16%	16%	2%
<15	8%	4%	18%
<20	2%	*	10%
>20	*	*	4%

In summary the analysis of the relationship between cladding age and energy intensity was not significant. The cross tabulations of cladding age with the various aspects of greenhouse structure that influence energy intensity showed relationships between the structure material and the cladding and condition of the cladding and seals with greenhouse age.

Hypothesis 3: ***Energy intensity (MJ/m^2) is seasonal.***

Time series graphs were used to identify peaks and slumps in the overall energy use over a 12 month period. Two separate time series graphs displaying electrical energy intensity (Fig. 26) and heating energy intensity (Fig.27) are presented.

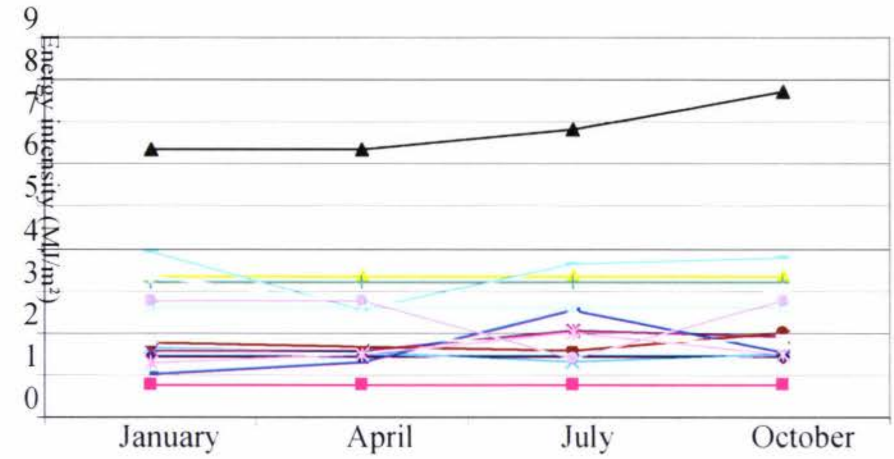

Figure 26. Seasonal electrical energy intensity.

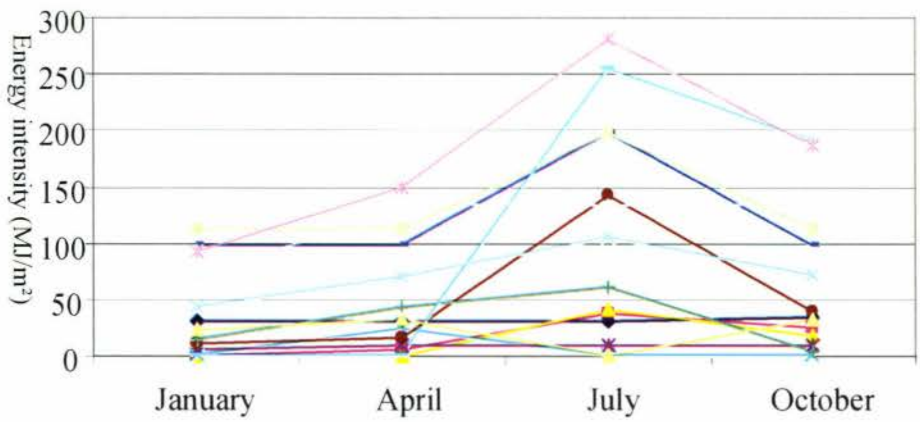

Figure 27. Seasonal energy intensity for heating only.

In summary the pattern of electrical energy consumption is relatively uniform over the twelve month period. For heating energy intensity quite a distinct pattern exists, with peak energy use in the winter quarter and low energy use in the summer quarter, as expected.

Hypothesis 4: ***Energy intensity is positively correlated with production.***

A Pearson correlation was used to determine the strength of the relationship between tomato production and energy intensity for the data collected and the secondary data. The Pearson correlation value for the collected data was 0.528, while the scatter plot showed a relatively strong positive correlation (Fig. 28) with a P-Value of 0.144. The result was not statistically significant (P>0.05) and therefore there was not enough evidence to accept the hypothesis.

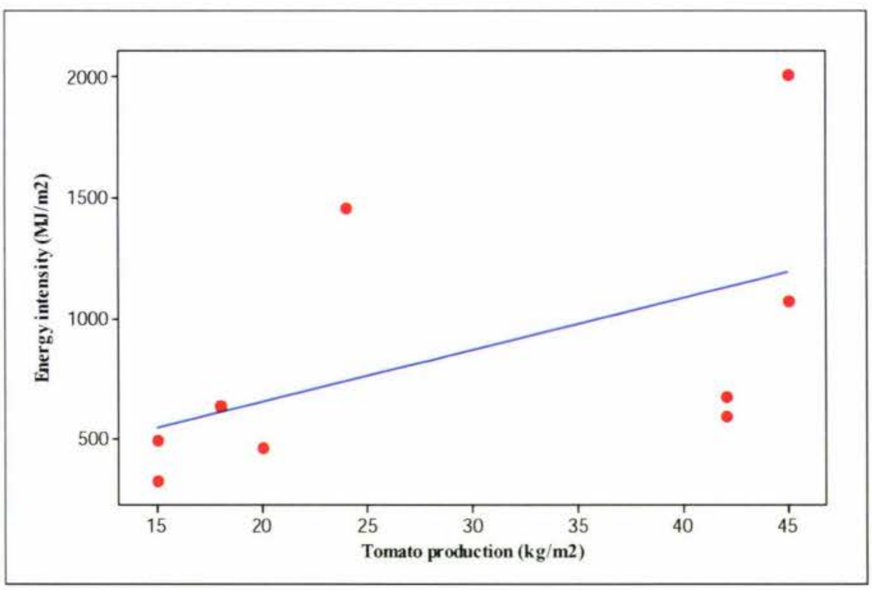

Figure 28. Scatter plot showing the correlation between tomato production and energy intensity.

The scatter plot for the secondary data shows a positive trend (see Fig. 30), the Pearson correlation value for the tomato production and the corresponding energy intensity for the secondary data was 0.329 and the P-value was 0.854, was not significant (P>0.05). These findings support the data collected.

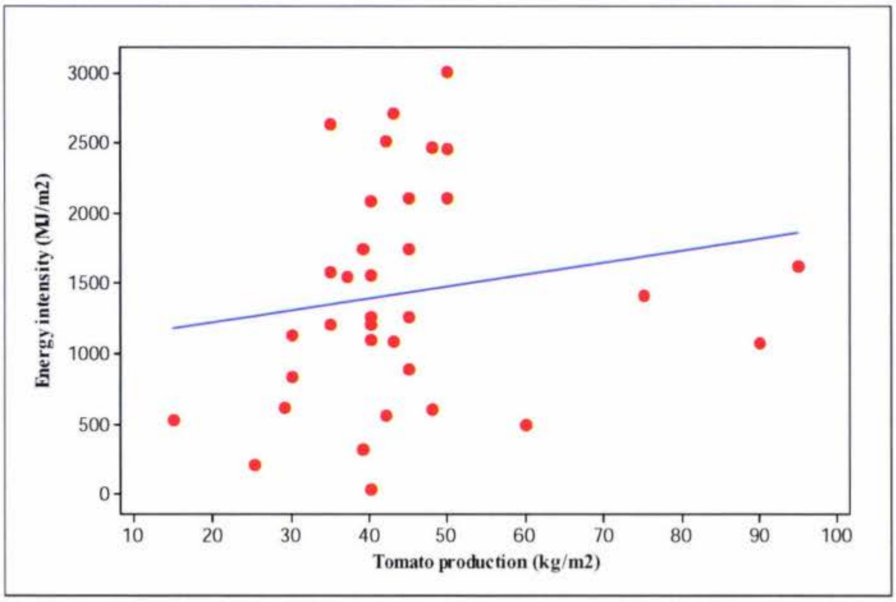

Figure 29. Scatter plot showing the correlation between tomato production and energy intensity for the secondary data.

In summary, while the correlation line of both the data collected and secondary data showed a positive correlation, the P-values were not significant and therefore there was insufficient evidence to accept the hypothesis.

Hypothesis 5: ***Greenhouses with a central heating system are more efficient than those with a local heating system in each house and therefore are less energy intensive.***

A 2 sample T-test was used to determine whether there was a significant difference between the energy intensities in greenhouses with central or local heating systems. The T-value was 0.64, while the P-value 0.539, this was not significant ($P<0.05$) (Table 26 and Fig.30). Therefore there is not enough significant evidence to accept the hypothesis.

Table 26. The measures of central tendency for the various heating systems.

Heater type	N	Mean	StDev	SE Mean
Central	10	1076	565	179
Local	6	855	722	295

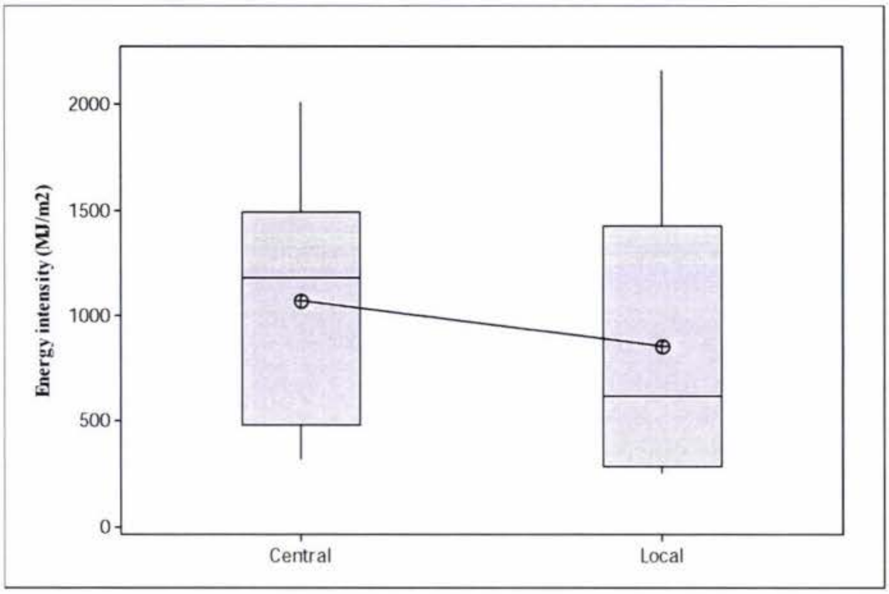

Figure 30. A box plot comparing the means of the energy intensities of various heating systems.

A cross-tabulation was used to determine whether the type of heat distribution system was linked to the heater production type (Table 27).

Table 27. A cross tabulation of the heater type with the method of heat distribution

Heater type	Central	Local
Method of heat distribution		
Unit heater with poly tubing	6%	38%
Bare hot water pipes	56%	-

In summary, while the box plot showed that greenhouse operations with central heating systems are slightly more energy intensive than greenhouses with local systems, there was not significant evidence to fully accept the hypothesis. The method of heat distribution was strongly linked to the heater type, with bare hot water pipes associated with central heating systems and air distribution associated with unit systems.

Hypothesis 6: ***Growers who use an automated climate control system will be less energy intensive than growers who don't.***

A 2 sample T-test was used to compare the mean energy intensities of greenhouses with and without automated climate control for both the collected data and the secondary data (Table 28 and Fig. 31). For the secondary data the tests were broken down into North and South Island to reduce the effect of location on the results.

The T-Value for the data collected was 0.66 and the P-Value was 0.52, this is not significant ($P<0.05$) as there was insufficient evidence to accept the hypothesis.

Table 28. Measures of central tendency for greenhouse operations with and without automated climate control systems from the collected data.

	N	Mean	StDev	SE Mean
With automated climate control	12	1000	670	193
Without automated climate control	5	780	604	270

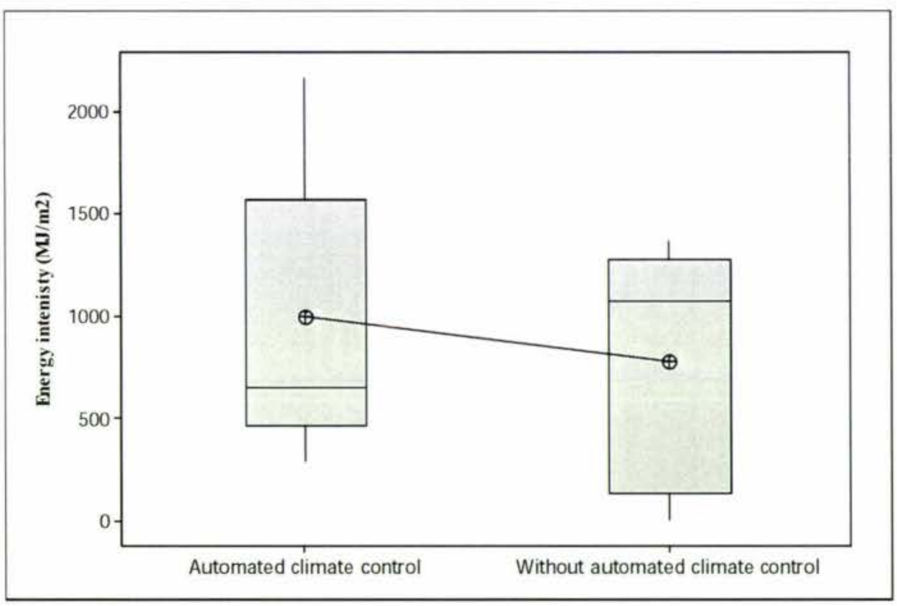

Figure 31. A box plot comparing the difference between the means for the energy intensities (MJ/m^2) of greenhouses operations with and without automated climate control for the data collected.

A 2-sample T-test was used to determine whether there was a significant difference between the energy intensity in North Island greenhouses with and without an automated climate control system for the secondary data (see Table 29 and Fig.32). The T-Value was 3.56 and the P-Value was 0.004. The P-value is significant ($P<0.05$), showing that growers without automated climate control are considerably less energy intensive than growers with automated climate control as clearly displayed in the box plot. This result refutes the hypothesis.

Table 29. Measures of central tendency for the energy intensities of North Island growers with and without automated climate control for the secondary data.

	N	Mean	StDev	SE Mean
With automated climate control	71	1136	777	92
Without automated climate control	9	372	581	194

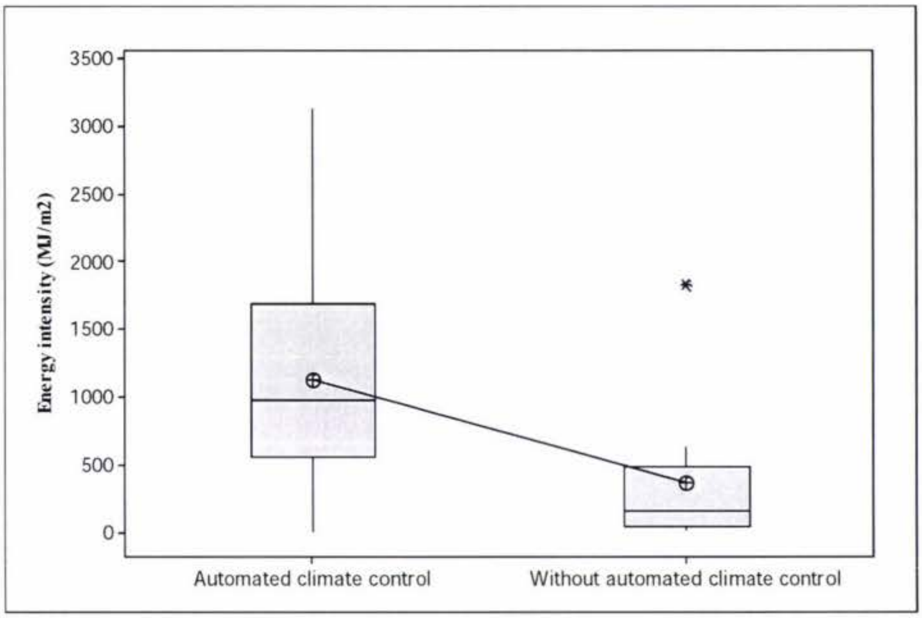

Figure 32. A box plot comparing the means of the energy intensities for North Island greenhouse operations with and without automated climate control.

A 2-sample T-test was used to determine whether there was a significant difference between the energy intensity in South Island greenhouses with and without an automated climate control system for the secondary data set (see Table 30 and Fig. 33). The T-Value was 5.85 and the P-Value (0.010) was significant ($P<0.05$), showing that South Island growers without automated climate control are considerably less energy intensive than growers with automated climate control as is clearly displayed by the box plot. This result also refutes the hypothesis.

Table 30. Measures of central tendency for the energy intensities of South Island growers with and without automate climate control systems.

	N	Mean	StDev	SE Mean
With automated climate control	50	1647	735	104
Without automated climate control	3	242	375	217

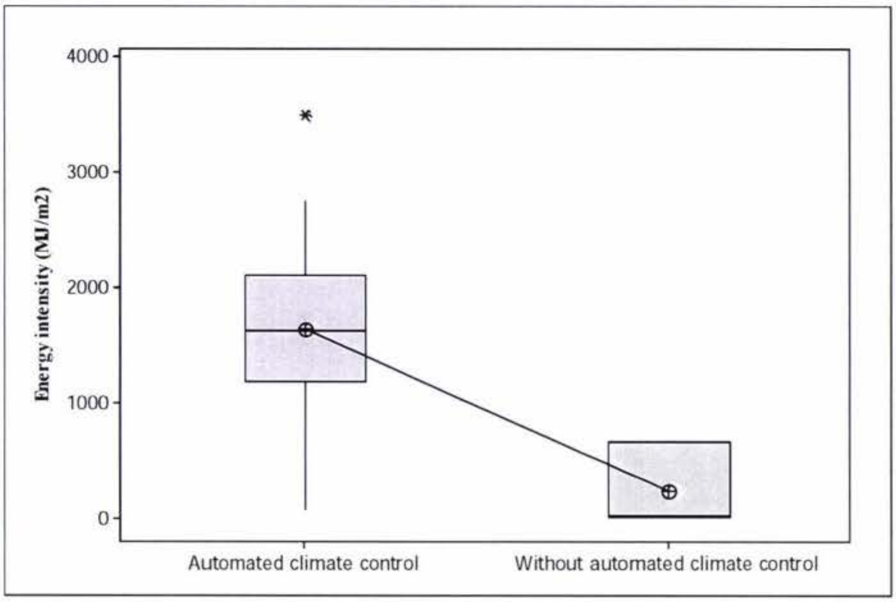

Figure 33. A box plot comparing the difference between the energy intensity means for South Island greenhouses with and without and automated climate control system.

A 2-sample T-test was used to determine whether there was a significant difference between the energy intensity for operations with and without an automated climate control system for the secondary data set (Table 31 and Fig. 34). The T-Value was 6.00 and the P-Value was 0.000. The P-value was significant ($P<0.05$), demonstrating that growers without automated climate control are considerably less energy intensive than growers with automated climate control; as is displayed in the box plot. This result refutes the hypothesis.

Table 31. Measures of central tendency for the energy intensities of New Zealand growers with and without automate climate control systems from the secondary data.

	N	Mean	StDev	SE Mean
With automated climate control	121	1347	798	73
Without automated climate control	12	340	524	151

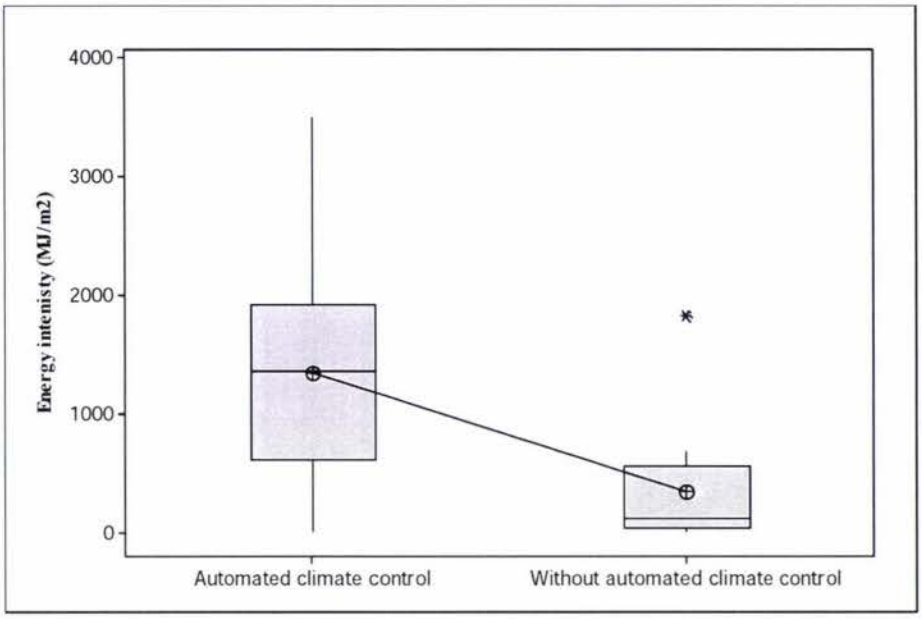

Figure 34. A box plot comparing the difference between the energy intensities for greenhouses operations with and without automated climate control systems for the secondary data.

In summary, the T-test for automated climate control was not significant for the data collected. The secondary data was split into the North and South Island and analyzed separately to reduce the location bias. Both tests returned significant P-values, refuting the hypothesis.

Hypothesis 7: ***Growers have negative opinions about the energy efficiency of their greenhouses and the proposed carbon charge***

Due to the nature of the data (i.e. Likert scale) descriptive statistics including quartiles and the mode are used to display the results from the data collected (see Table 32).

Table 32. Descriptive statistics of the grower's opinion on energy use and the carbon charge.

Questions	Q1	Median	Q3	Mode	Corresponding response (median)
i. Improvements could be made to increase the net productive area within my greenhouse e.g. tiered propagation; less wasted floor space for paths, storage etc?	2	2	3.5	2	Disagree
ii. Improvements could be made to the structure and/or cladding of my greenhouse/s that would significantly reduce heat loss e.g. re-cladding; use of twin skins	2	3	4	2	Neither agree nor disagree
iii. Improvements could be made to the central heating system that would significantly increase energy efficiency of my greenhouses e.g. cleaning out the boiler more often; changing to another fuel.	2	2	4	2	Disagree

iv. Improvements could be made to the heat distribution system within my greenhouses that would significantly increase energy efficiency and reduce heat loss e.g. lagging the hot pipes; placing closer to ground level.	2	3	3	2	Neither agree nor disagree
v. I am fully aware of the pending carbon charge and the possible effects on the costs of operating my business.	4	4	5	4-5	Agree
vi. I am considering changing heating fuel source to reduce the effect of the carbon charge on my business.	1	2	3	1-2	Disagree
vii. The carbon charge will have a negative impact on the New Zealand greenhouse vegetable industry.	3	4	5	5	Agree

In summary, growers could not see room for energy related improvements within their operation and are not considering changing fuel sources to minimise the effect of the carbon charge. Growers were aware of the effect of the carbon on their business and the industry as a whole.

7.0 Discussion

The findings from the analyses of the energy audits and the secondary data in the context of the literature are discussed. Case study perspectives of what growers are currently achieving in terms of reducing their energy demand along with growers comments and opinions on energy saving measures in greenhouse production and the pending carbon charge are also incorporated into the discussion. Limitations of the energy audit are also discussed.

Electricity used for activities other than heating, such as pumping, ventilation, the fertigation system and in the packing shed, averaged 4.5% of the total energy use for each operation audited. Barber (2003), in his pilot survey of the New Zealand greenhouse industry, found a similar result with 4% of the total energy used for activities other than heating. Therefore the focus of the following discussion is on methods by which growers could minimise their energy inputs required for greenhouse environmental control, specifically heating.

7.1 Limitations of the energy audit

The energy audit relied on growers' knowledge for production and energy figures, the area and age of the greenhouses. This may have introduced some inaccuracies into the data resulting from growers' possibly over or under estimating their production and floor area. Also participants who had taken over an established operation were typically not as well acquainted with the minor details as participants who had set up their own operation. This may have lead to minor errors when conducting the energy audit.

In terms of the analysis of the energy audit data, a larger number of energy audits than those undertaken would have provided a more robust data set with which to analyse and draw conclusions. The use of secondary data, as a result of Barber's (2003) survey, partially compensated for this. Had financial and time constraints not been an issue, the audits would have been extended to include the collection of detailed energy accounts and temperature logs from the previous 24 months to allow the researcher to evaluate each operation's energy usage profile. Metering could have also been conducted to supplement the energy use data and give greater insight into the major energy consuming activities and daily and annual variations. A detailed financial analysis could also have been performed for proposed energy saving measures based on detailed implementation and installation costs, actual operating cost savings, and the growers' investment criteria for each operation.

7.2 The effect of seasonality and location on energy demand

As highlighted in previous chapters a number of studies list climate and the outside ambient temperature as a major factor in the energy balance of a heated greenhouse structure (Hanan, 1998; Barber and Wharfe, 2004). Barber (2003) found South Island greenhouse operations were 50% more energy intensive than their North Island counterparts. The results from the energy audits support Barber's (2003) findings; with the difference between the means for the North and South Island for the collected data and the secondary data, 956 MJ/m^2 and 590 MJ/m^2 respectively. The effect of the average ambient temperature and climate on the energy required for greenhouse production was evident, based on location.

Time series graphs were used to plot the energy intensity for 12 months at a quarterly period for each operation. There was no pattern to electrical energy intensity which varied between each operation. This may be due to the significantly different pumping configurations, the use of fans and vents, and by the use of non-standard equipment such as shrink wrappers and refrigeration units. The time series graph for energy used for heating showed most operations had peak energy intensity over the winter quarter, as was expected. An energy saving opportunity identified by several growers was to alter their schedule by planting later in the season and thereby reducing the peak demand for heating in the winter period. In some cases, smaller growers stopped production altogether in the winter period. However for most this was not seen as an economically viable option or as a potential solution to reducing the impact of energy costs on their business.

7.3 Energy and yield

It was assumed that a greater investment in energy inputs for the purpose of heating would result in more favourable growing conditions and in a higher crop yield. Barber & Wharfe (2004) showed a very weak correlation between energy intensity and production. The findings from the energy audits and the secondary data showed a very similar result with both sets of data showing a weak positive correlation.

7.4 The potential for energy savings through greenhouse structure and design

It is well documented that the various aspects of greenhouse structure and design can affect both heating efficiency and crop yield. Minimising heat loss through improving poor cladding, seals and entrance way designs has been identified as one of the least expensive and effective energy saving measures that can be taken by growers (Breuer, 1985; Barber and Wharfe, 2004; Evans, 2004; Giacomelli, 2004; Bond, Gilroy *et al.*, 2005). A correlation between the average greenhouse cladding age per operation and the energy intensity was inconclusive for both energy audit and secondary data. It is conjectured that a relationship between these two variables may exist based on significant findings from the aforementioned literature. The underlying factors that may explain why the result differed from that expected based on the literature include:

- the effect of location on the energy intensity was not accounted for;
- energy intensity was based on the whole operation since the energy use of each separate structure could not be viewed on its own therefore the average age of greenhouses on site was used; and
- the type (ie. glass or plastic) and life span of the various types of claddings were not accounted for.

While every grower audited took steps towards maintaining the condition of the cladding through regular cleaning and replacing part or all of the material at regular intervals, the researcher observed that the level of this type of maintenance varied considerably from operation to operation. In many instances the grower responses when questioned regarding the condition of the cladding did not match what was observed by the researcher. This may potentially highlight an area where energy savings could be made within the industry by further educating growers on the cladding condition and the implications for energy wastage.

A cross tabulation between the condition of both seals and cladding and the greenhouse structure age showed that a greater proportion of newer greenhouses had a good-moderate rating for both seals and cladding, while a greater portion of older greenhouses had poor seals and cladding. With 52% of all greenhouses audited having good-moderate seals and were less than 10 years old, while 32% of all greenhouses audited had poor seals and were greater than 10 years old and 52% of all greenhouses audited having good-moderate cladding and were less than 10 years old, while 32% of all greenhouses audited had poor cladding and were greater than 10 years old. The results for the condition of the seals and the cladding were identical, showing that these two aspects of greenhouse structure are strongly correlated. As growers typically upgrade the seals whilst re-cladding, this result was expected.

While these results show that older greenhouses are more prone to heat loss through air leakage there are a number of steps recommended that can be taken by grower's to minimise this, such as regular repair of tears and breakages in the cladding, lap sealing the glass and adding an inner layer of polyethylene to the roof and sides of the greenhouse (Breuer, 1985; Bond, Gilroy *et al.*, 2005).

While only having a small effect on energy demand, the greenhouse frame may also influence production and long term capital investment of a structure. A cross tabulation between greenhouse age and structure material showed a high proportion of older greenhouses had wooden frames (30% of all greenhouses audited had wooden frames and were older than 10 years) while a high proportion of newer greenhouses have galvanized steel or aluminium frames (47% of all greenhouses audited had metal frames and were less than 10 years old). Wooden frames tend to be bulky and obstruct light; the high humidity levels may also deteriorate the wood, while the metal frames typically used in newer structures tend to be relatively inexpensive, long lasting and create less of a shadow which may increase light transmittance and improve yield (See Fig. 35).

Figure 35. On the left a traditional gable glasshouse with a wooden frame, on the right a Venlo desgined, gutterconnected glasshouse with an aluminium frame.

The effects of thermal screens on minimising heat loss and reducing energy consumption are well documented (Chandra and Albright, 1980; Pirard, Dellour *et al.*, 1994; Nederhoff, 2004). Only one greenhouse operation audited had a functioning thermal screen installed and while the grower did acknowledge reduced energy consumption, the payback period of the screen was not economically justifiable at the time the audit was conducted. When questioned as to whether they were considering installing thermal screens, many growers replied that the initial installation cost was a deterrent. Thermal screens are widely used in overseas countries and as the carbon charge further increases fuel costs it is expected that the use of thermal screens in New Zealand greenhouses will increase (Williams, 2004).

7.5 The potential for energy savings through improving the heat production system

On average 95-96% of the energy budget for the greenhouse operations audited was used for heating to maintain the greenhouse environment. It is therefore essential that the heat production system is run efficiently with as little heat loss as possible to avoid energy wastage.

Hanna & Henderson (2002) state that central boiler systems are more efficient than local or unit heating system. This study compared the energy intensity of those operations audited having central heating systems with those using local heating systems and found no significant difference between the energy intensity of the two different heater types, with the mean energy intensities for central and local systems 1076MJ/m^2 and 855MJ/m^2 respectively. This result was different to what was expected and may be attributed to coal being typically associated with central boiler systems, the main fuel source for the energy intensive South Island growers, while North Island growers predominantly use natural gas often used in conjunction with unit heaters (Barber and Wharfe, 2004). Therefore location and the distribution of various heater types based on the availability of fuel types may have influenced this result.

Methods for minimising energy use in heating systems currently utilised by New Zealand growers audited were divided into maximizing the efficiency of the boiler system or minimising heat loss through the flue.

Improving heating system efficiency

Van de Braak (1995) and Ozdemir (2004) identified proper operation and maintenance as essential to the economic and energy efficient operation of boiler systems, the same can also be applied to other heating systems.

The typical maintenance regime for a gas-fired system for the growers audited was a yearly check by a contractor, and replacement of parts as required. Many gas fired systems were used for CO_2 enrichment, as the main driver, rather than improving the energy efficiency of the system. The typical maintenance regime for coal and oil-fired boiler systems varied considerably, however for most, cleaning took place at least once a week. Regular cleaning was identified as being essential to proper boiler maintenance (Energy Star, 2004) to remove soot build up which can insulate heat transfer surfaces and reduce combustion efficiency. Other small maintenance steps that can be taken by growers are to minimise air infiltration through correctly adjusting the boiler, monitoring wear on linkages, and adding insulation to the boiler and the associated piping.

At the time the audit was conducted two operations had recently made large capital investments in their heating systems by installing efficient new condensing boilers and by retrofitting the existing boiler to improve the efficiency of the heating system. However for most growers timely maintenance of existing equipment is one of the most cost effective measures for improving energy efficiency and extending the life of the equipment.

In operations with more than one boiler serving the heat load using the most efficient boiler can improve overall system conversion efficiency. Running boilers at very low or over capacity should be avoided, as this can lead to excessive energy use, since the optimum efficiencies of most boilers lie fairly close to their rated capacity.

Minimising heat loss

Meijndert (1982) reported savings of up to 15% by means of flue gas condensers many growers with central boilers were not utilising this technology. Three growers audited were monitoring of stack gases as an indication of how much excess air was being used to give a gauge of boiler efficiency. The Pacific Gas and Electric Company (2004) recommend monitoring stack gases on a weekly basis.

The use of variable speed drives for air fans in both the North and South Island audited were relatively common particularly in central coal fired boilers, where they can increase burner turndown without compromising efficiency, resulting in reduced electrical energy use and heat loss (Ozdemir, 2004). Only one grower audited had a heat storage buffer tank installed, however Nederhoff (2005) suggested that they are increasing in popularity in New Zealand's larger greenhouses where natural gas is used for heating.

It was observed while conducting the energy audits that many of the greenhouse operations had complicated layout through the gradual expansion of the business and the addition of new structures. The addition of supplementary equipment may lead to inefficiencies, such as heat loss from distribution pipes leading from the boiler to the greenhouse. Infrared technology may provide a useful tool in the future for detecting areas of heat loss.

7.6 The potential for energy savings through improving the heat distribution system

Heat distribution systems should be designed to deliver heat to the crop by the most efficient means, the methods and set ups currently utilized by the growers audited varies widely. While steel pipes and poly tubes are most commonly used, there are a number of variations on these methods, including the use of radiator and various configurations of the heat distribution pipes.

Pipe heating is identified as the most efficient and effective means of warming crops both by convectively heating the greenhouse air and by radiating heat directly to the crop leaves. During the last decade interest has grown in alternative pipe sizes and alternative locations such as near to the crop growing point or near to substrates for root zone heating. Prenger and Ling (2004) recommend placing the pipes lower to the ground to remove moisture and create a uniform microclimate around the plants. While Teitel *et al.* (1999) claims that the most successful radiative heating from pipes occurs when placed at the mid-height of the mature crop. One grower audited was utilizing both of these techniques by placing pipes along the lower levels and the mid levels of a cucumber crop within a Venlo glasshouse (Fig. 36 and Fig. 37). This was providing favourable results in terms of production and energy use.

Figure 36. Alternative mid-height pipe configuration in a Venlo designed greenhouse.

(Source: Nederhoff, 2004)

Figure 37. Alternative hot water heating pipe configuration.

(Source: Nederhoff, 2004)

While the application of fins to steel pipes can provide a larger exchange surface with the air and may therefore transfer up to four times the amount of heat to the crop (Evans, 2004), none of the greenhouses audited had finned pipes as typically steel pipes double as transport rails in many New Zealand greenhouses. This has the benefit of reducing the area used for paths and increasing the area utilised for crop production.

Lagging or insulating the hot water pipes between the central heating system (boiler) and the greenhouse structure is well recognised as an effective energy saving measure. All of the growers audited who were using a central boiler system and steel water pipes had lagged the pipes to varying degrees. The degree of lagging, the age of the lagging and the effectiveness varied considerably between the various operations audited. This was identified by the researcher as an area where significant improvements could be made to many of the greenhouse operations audited. Infrared technology may become an important tool in the future for pinpointing areas of heat loss in lagging.

100% of the growers audited used polyethylene tubes to distribute heat when using gas fired unit heaters. As with pipe and floor heating, air heating systems can be improved by lowering the heating ducts. Hanna and Henderson (2002) reported savings of 27.1 % by placing the tubes in contact with grower bags than overhead of the crop. This also reduces condensation forming on the leaves and results in a better climate around the plant canopy.

7.7 The potential for energy savings through improved climate control

It is well documented that computerised climate control systems, such as Priva™ and Plant Plan™ are an effective tool in regulating the greenhouse environment to maximise production and minimise energy wastage (Garzoli, 1988; Hanan, 1998; Sigrimis, Anastasiou *et al.*, 2000). The results for the data collected did not support the literature as they did not show a significant difference between those greenhouse operations with a computerised climate control system and those without, with mean energy intensities of 1000MJ/m^2 and 780MJ/m^2 respectively. The results for the secondary data refute the hypothesis by showing that greenhouse operations that used a computerised climate control system were more energy intensive than those that did not. The mean energy intensities for those operations with climate control and those without were 1347MJ/m^2 340MJ/m^2, respectively. The effect of location in this instance was reduced by running separate tests for the North and the South Island, which returned a similar result. This unexpected result may be because many growers install and operate the computerised climate control systems to reduce the workload and improve production rather than for the purpose of energy conservation (Hectors, 2005). A 2 sample T-test could have been used to determine whether there is a significant difference in production between those greenhouses with climate control and those without to determine if this was the case.

7.8 Growers opinions on energy savings and the carbon charge

The median response when growers were presented with the statements regarding whether energy saving improvement could be made to their operation was between "disagree" and "neither agree or disagree". This indicates that in general the growers audited cannot see room for energy saving improvements within their operation, even when glaring inefficiencies were observed by the researcher. This may indicate a lack of readily accessible and applicable information on ways to reduce energy use in greenhouse production and may potentially act as a barrier to the uptake of energy reducing technologies.

The median response when growers were presented with statements regarding the effects of the carbon charge on their business and the greenhouse production industry as a whole was "agree". This indicates strong industry awareness and may provide an incentive to implement energy saving technologies and practices.

The median response when growers were presented with the statement "I am considering changing heating fuel source to reduce the effect of the carbon charge on my business" was "disagree". This may or may not indicate that growers have considered switching to fuel types that attract a lesser carbon charge as there is a high cost associated with changing fuel types (Christie, 2005).

8.0 Conclusions and recommendations

The research presented in this thesis addresses the problem of the increasing fuel cost and threat of the pending carbon charge on the New Zealand greenhouse industry.
The following chapter summarises the main findings of the research and discusses their implications for potential energy savings, recommendations are made based on these findings. Areas for further research are also discussed briefly.

The New Zealand greenhouse industry is a relatively energy intensive sector of the primary production industry. The energy end-use matrix highlights the lack of New Zealand specific studies investigating energy end uses within the greenhouse sector. The industry has grown significantly in size in the past 10 years, this combined with the uncertainties of the proposed carbon charge and future security of fossil fuel supplies has prompted bodies such as EECA and Vegfed into funding energy related research. It has also fuelled interest in the utilisation of energy saving technologies and practices within the greenhouse industry.

A recent study by Barber and Wharfe (2004) profiled the New Zealand greenhouse production industry, and identified further investigation into the application of energy saving technologies in New Zealand greenhouses. The aim of this research was to identify ways in which the New Zealand greenhouse vegetable production sector can implement energy saving technologies to reduce energy use and the concomitant carbon emissions. This was achieved through a review of energy saving technologies and conducting a walk through energy audit to determine the potential for the application of these technologies

8.1 Research findings

Climate by location, or more specifically the outside air temperature, was found to be a key factor in determining the energy demand of a heated greenhouse operation. This was reinforced by the higher energy intensities required to maintain production in the winter months.

One of the main causes of heat and energy loss in New Zealand greenhouses is through air leakage due to factors such as poor cladding and seals. While it was not proven that average cladding age and energy intensity are correlated, factors identified as contributing to heat loss such as poor seals and cladding were more widespread in the older structures. This indicates that older structures are typically less energy efficient.

No significant difference was found between the energy intensities between central heat production systems and local heat production systems. However through discussions with growers, a number of energy saving measures were identified which were grouped into 'improving efficiency' and 'minimising heat losses'.

Climate control is widely acknowledged as a tool that can reduce energy wastage and increase production by regulating the greenhouse environment. No significant difference was found between greenhouses with climate control installed and those without for the data collected, however the secondary showed a result opposite to what was expected. It is conjectured that for many growers energy saving is not the main consideration in the utilisation of these systems.

In general growers could not see energy saving potential within their business which may present a barrier to the uptake of energy saving technologies and practices. Growers were strongly aware of the carbon charge and its likely effects on their business and the industry as a whole.

8.2 Recommendations

The following recommendations follow on directly from the conclusions.

1. Climate and location is a major determinant in the energy required for heated greenhouse production and therefore should be carefully considered by growers entering the industry or relocating.

2. To minimise heat loss - Plastic covered houses generally require re-cladding approximately every 5 years, while glass panes should be replaced as required, and should be inspected regularly to check for tear, breakages and leaks. Seals

around the glass, vents and doorways should also be checked for air leakage regularly. Installation of thermal screens can also reduce heat loss considerably.

3. Minimise heat loss from the heat production system - Boiler and pipe insulation can reduce heat loss. Variable speed drives can reduce electrical energy required and reduce heat loss in a central boiler system; other devices such condensers, oxygen trim controls, economisers and turbulators may also reduce heat loss

4. Improve efficiency of the heat production system - Timely maintenance of the heat production system is essential to maintaining efficiency and extending the life of the equipment. The heat production system should be run as close to possible as the rated capacity.

5. Closely monitoring the greenhouse environment using a computerised climate control system can reduce energy wastage. The use of temperature integration strategies may further reduce energy use.

6. The industry should now be concerned with promoting energy saving techniques and the potential for energy savings within individual businesses.

8.3 Areas of further research

The energy audit relied on a single visit to the greenhouse operation. This level of detail was not sufficient for reaching a final decision on implementing energy saving measures for each operation. This research could be extended to include metering, recommendations and cost/benefit analyses specific to the operation.

Much of the research relating to the application of energy saving technologies in New Zealand greenhouses is dated. As new technologies are made available these should be tested to determine the actual potential value to New Zealand growers, including the application of alternative fuels, such as cogeneration and the utilization of waste heat in New Zealand greenhouses.

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Appendix 1. Energy end use matrices for the various agricultural sub-sectors

A review of the available literature on annual energy use for specific activities in the sheep and beef sector.

Energy demand for specific activities per hectare, per stock unit, or per tonne over a 12 month period					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Track construction and maintenance	0.2 GJ/ha (McCh/1979) 0.08 l/su (McCh/1983)	18 MJ/ha (McCh/1979)			
Fencing	1.8 GJ/ha (McCh/1979)	6 MJ/ha (McCh/1979)			
Electric fencing					
Land clearing & cultivation	7.5 GJ/ha (McCh/1979) 185 l/ha (McCh/1983) 0.15 l/ha (McCh/1983)	21 MJ/ha (McCh/1979)			
Fertilisers	0.7 GJ/ha (McCh/1979)				
Sowing	0.3 GJ/ha (McCh/1979) 0.27 GJ/ha (McCh/1979) (total energy for topdressing and sowing) 80 l/ha (McCh/1983)				
Aerial sowing	0.12 GJ/ha (McCh/1979)				
Fertilisers	0.65 GJ/ha (McCh/1979)				
Weed control					
Topdressing					
Aerial	11.9 l/tonne (McCh/1983)				
Ground	1.5 l/ha (McCh/1983) 0.3 l/su (McCh/1983)				
Irrigation					
Water pumps	80 MJ (McCh/1979)				
Water reticulation systems					
Pastures					
Conservation					
Production		3 MJ/ha (McCh/1979)			
Renovation					
Fodder crops					
Production					
Hay and silage production					
Drying					
Electricity					200 kWh/tonne (McCh/1983)
Liquid fuels			19 MJ/ha (McCh/1979) 26 l/ha (McCh/1983) 24.3 l/ha (McCh/1983)		
Cash cropping					
Electricity			6.7 GJ/ha (McCh/1979)		
Liquid fuels	18 l/ha		5 l/tonne		

	(McCh/1983)		(McCh/1983)
Stock management			
Feedlot systems/feeding out	0.08 l/su (McCh/1983)		
Shearing			0.02GJ/ha (McCh/1979)
Controlling parasite			
Dipping & drenching		5 MJ/ha (McCh/1979)	
Buildings & transport			
Lighting			
Heaters		0.1 l/su (McCh/1983)	
Coolers			
Transport	0.4 l/su (McCh/1983)		

A review of the available literature on annual energy use for specific activities in arable crop production sector.

Energy demand for specific activities per hectare or per tonne over a 12 month period					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Land development					
Land clearing	7.5 GJ/ha (McCh/1979) 5 GJ/ha (McCh/1979) 15 GJ/ha (McCh/1979)				
Conventional tillage					
Mouldboard plough	648MJ/ha (McCh/1983) 430-580 MJ/ha (McCH/1978)				
Chisel plough	360MJ/ha (McCh/1983)				
Cultivator (grubber)	216MJ/ha (McCh/1983) 160-200 MJ/ha (McCh/1978)				
Springtyne harrow	180MJ/ha (McCh/1983) 80-120 MJ/ha (McCh/1978)				
Single disc harrow	162MJ/ha (McCh/1983) 200-230 MJ/ha (McCh/1978)				
Offset/heavy discs	432MJ/ha (McCh/1983)				
Tandem disc harrow	188MJ/ha (McCh/1983)				
Roller	144MJ/ha (McCh/1983)				
Rotary cultivator	864MJ/ha (McCh/1983)				
Rotary harrows	288MJ/ha (McCh/1983)				
Spike tooth harrows	144MJ/ha (McCh/1983)				
Row crop cultivator	144MJ/ha (McCh/1983)				
Crop establishment	1.8GJ/ha (McCh/1979)				
Transport of fertiliser, seed and grain	252MJ/ha (McCh/1979)				
Transport for cultivation	1.85 l/ha (McCh/1979)				
Direct drilling tillage					
Drilling	108MJ/ha (McCh/1978)				
Crop establishment	216MJ/ha (McCh/1979)				
Transport of fertiliser, seed and grain	252MJ/ha (McCh/1979)				
Transport for cultivation	212 MJ/ha (McCh/1979)				
Pest and weed control					
Spraying	270MJ/ha (McCh/1983)				
Sowing					
Grain drill	144MJ/ha (McCh/1983)				
Potato planter	396MJ/ha				

	(McCh/1983)
Fertiliser application	
Fertilisers	
Aerial	428MJ/tonne (McCh/1983)
Ground spread	64.5MJ/ha (McCh/1983) 54MJ/tonne (McCh/1983)
Irrigation	
Diesel powered Spray guns	215 - 350 MJ/ha (McCh/1978) 85 MJ/ha cm (McCh/1978)
Electric irrigation	2200 kWh/ha (CAE/1996)
Water pumps	
Harvesting	
Combine harvester	
Electricity	1590 MJ/ha (McCh/1979)
Liquid fuels	6 l/tonne (McCh/1983) 625 MJ/ha (McCh/1979) 12 l/ha (McCh/1978)
Windrower	24 l/tonne (McCh/1983)
Stripper	8 l/tonne (McCh/1983)
Lifter harvester	2.5 l/tonne (McCh/1983)
Field packing	
Hay and silage production	
Haymaking	26 l/ha (McCh/1983)
Ensiling	38 l/ha (McCh/1983)
Maize silage	38 l/ha (McCh/1983)
Mowing	4 l/ha (McCh/1978) 4-8 l/ha (McCh/1983) 3 l/ha (McCh/1978)
Bailing	5 l/ha (McCh/1978)
Transportation	2 l/ha (McCh/1978) 1 l/ha (McCh/1983)
Forage harvesting	22 l/ha (McCh/1978)
Grain drying and conditioning	
Grain drying plant	550 MJ/ha (McCh/1979) 5-85 l/ha (McCh/1983)
Continuous	2436 MJ/ha (McCh/1979)
Batch	
Storage drying in Bin	
Storage drying on Floor	
Chilling	550 MJ/ha (McCh/1979)
Cooling	
Handling	
Storage	

A review of the available literature on annual energy use for specific activities in the greenhouse crop production sector.

Energy demand for specific activities per operation or per m² over a 12 month period					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Environmental Controls					
Heating					
Heating Pumps		3 kW (CAE/1996)			
Space Heaters					
Under floor Heating					
Infra-Red Heaters					
Cooling					
Lighting					
GLS Lighting		60-150 W (CAE/1996)			
Fluorescent Lighting		18 W (CAE/1996)			
Ventilation					
Sowing and Propagation					
Fertiliser					
Pest Control					
Harvest					
Storage					
Refrigeration					
Irrigation					
Hydroponic Production					

A review of the available literature on annual energy use for specific activities in the intensive pig and poultry production sector.

Energy demand for each operation per animal over a 12 month period					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Heating					
Infrared		2.2 w/chick (CAE/1996)			
Canopy brooder		2.5 w/chick (CAE/1996)			
Gas fired space heaters					
Electric radiant element		2.15 W/chick (CAE/1996)			
Under foot heating					
Electricity					
Quartz linear overhead		1 W/chick (CAE/1996)			
Heat pumps					
Heating panels					
Heat exchanger					
Piglet pads		30*0.15 kw (McCh/1982)			
Farrowing pen					
Rearing pen					
Fattening pen					
Ventilation					
Axial fans		0.37 kw (McCh/1982)			
Lighting					
Animal health					
Unspecified		12 GJ (McCh/1982)			
Water					
Wash down pumps		2.2 kW (McCh/1982)			
Main Water supply		1.1 kW (McCh/1982)			
Transport		250 GJ (McCh/1982)			
Repairs and maintenance					
Liquid fuels		23 GJ (McCh/1982)			
Solid/gaseous		63 GJ (McCh/1982)			
Unspecified		147 GJ (McCh/1982)			
Animal feeds					
Onsite grain milling	7.5 kW (McCh/1982)				
Onsite grain mixing	3.7 kW (McCh/1982)				
Meal distribution		6*5 kW (McCh/1982)			

A review of the available literature on annual energy use for specific activities in the orchard sector.

Energy demand for specific activities over a season or a 12 month period					
Inputs	**Preparation**	**Growth**	**Harvest**	**Storage**	**Processing**
Cultivation and tree establishment					
Tillage					
Planting					
Establish ground cover crops					
Field operations					
Tree spraying		225 l/ha,120 l/ha, 35 l/ha (CAE/1996)			
Trimming/pruning		65 l/ha, 20 l/ha, 20 l/ha (CAE/1996)			
Mowing		60 l/ha, 80 l/ha (CAE/1996)			
Weed spray		5 l/ha, 15 l/ha, 11 l/ha (CAE/1996)			
Topdressing		10 l/ha, 3 l/ha, 10 l/ha (CAE/1996)			
Shelter maintenance		10 l/ha, 2 l/ha, 35 l/ha (CAE/1996)			
Frost protection					
Bird netting					
Harvest					
Hydra ladder		50 l/ha (CAE/1996)			
Tractor		50 l/ha (CAE/1996)			
Materials handling		35 l/ha, 8 l/ha, 20 l/ha (CAE/1996)			
Transport		200 l/ha (CAE/1996)			
Processing					
Cooling facilities and refrigeration					
Storage					

Appendix 2. The postal survey: energy saving opportunities in the greenhouse production sector (2004)

Massey University

AVOID PAYING THE PROPOSED CARBON CHARGE !!!

ENERGY SAVING OPPORTUNITIES
IN THE GREENHOUSE VEGETABLE PRODUCTION SECTOR (2004)

New Zealand Vegetable Greenhouse Grower Survey

The carbon charge proposed for 2007 will increase energy costs significantly for fossil fuel users. The aim of this research study is to show how, by using energy more wisely, cost savings can result for greenhouse growers. Your assistance in answering this survey will help us determine the best means of saving energy costs which we can then demonstrate for the benefit of the industry as a whole.

The participants of this survey are greenhouse vegetable growers who are currently members of the Vegetable and Potato Grower's Federation, our client for this study.

The survey will take around 10 minutes for you to complete.

You are under no obligation to complete this survey. However if you decide to participate, you have the right to:

- decline to answer any particular question;
- provide information on the understanding that your name will not be used or business identified unless you give specific permission to the researcher to do so.

Completion and return of the questionnaire implies consent. You have the right to decline to answer any particular question.

The data collected from this survey will be used in a report which identifies ways in which the greenhouse industry can reduce its energy consumption. This report has been commissioned by Vegfed. Access to the project findings will be made available on the Vegfed website (www.vegfed.co.nz).

Thank you for taking the time to complete this questionnaire.

Anna Wilson
Centre for Energy Research
Massey University

Grower Survey

1. Location

i. What is the location of your greenhouse vegetable production business? Please tick.

Region	Tick	Region	Tick
Northland		Wellington	
Auckland		Tasman	
Waikato		Marlborough	
Bay of Plenty		West Coast	
Gisborne		Canterbury	
Hawkes Bay		Otago	
Taranaki		Southland	
Manawatu – Wanganui			

2. Greenhouse Area

i. How many separate greenhouse structures are you responsible for? ………………

ii. What is the total area under greenhouse cover? ……………...m^2

iii. What is the total heated area under greenhouse cover? ....m^2

3. The Propagation Shed

i. Do you have a propagation shed? …..Yes …..No

If **yes**, go on to the next question.
If **no**, go on to question 4.

ii. What is the floor area of the propagation shed? ....m^2

iii. Is the propagation shed tiered? …..Yes …..No

4. Crop Production. Please fill in the boxes for each different crop you produce.

Questions	**Crop Type**			
	Capsicums	**Tomatoes**	**Cucumbers**	**Other, Please State …………**
i. What is the floor area of each crop you produce? (m^2)				
ii. How many kgs do you produce in a 12 month period?				
iii. How many times in a 12 month period is this crop harvested?				
iv. What is the average summer harvest of this crop in kgs?				
v. What is the average winter harvest of this crop in kgs?				
vi. How many times in a 12 month period do you normally replace the plants?				

5. Building structure and design

Please fill in a column for *each separate greenhouse structure* on the property ticking the options provided as appropriate. (If you manage more than 6 separate structures please add additional columns on right of page).

	Greenhouse number						
	1	**2**	**3**	**4**	**5**	**6**	**Propagation shed**
i. What is the floor area of each greenhouse? (m^2)							
ii. What is the greenhouse frame material?							
Aluminium	□	□	□	□	□	□	□
Wood	□	□	□	□	□	□	□
Other (please specify)							
iii. What is the age of the greenhouse frame? (years)							
iv. What is the cladding material?							
Glass	□	□	□	□	□	□	□
Plastic	□	□	□	□	□	□	□
Rigid Plastic	□	□	□	□	□	□	□
Other (please specify).........	□	□	□	□	□	□	□
v. What is the age of the current cladding? (years)							
vi. How many layers of cladding are there?							
Single	□	□	□	□	□	□	□
Twin	□	□	□	□	□	□	□
vii. Is a thermal (energy) screen installed in the greenhouse?							
Yes	□	□	□	□	□	□	□
No	□	□	□	□	□	□	□
viii. Are any of the greenhouses artificially heated?							
Yes	□	□	□	□	□	□	□
No	□	□	□	□	□	□	□
ix. What temperature (°C) are the greenhouses maintained during a Winter/night?							

Winter/day? Summer/night? Summer/day?							

6. Main Heating System

i. How many heating systems (e.g. boilers) do you operate? ....

For each heating system please answer.

	Heating system			
	1	**2**	**3**	**4**
ii. Which greenhouses, as numbered in question 5, does each heating system supply?				
iii. What type of fuel is used to run the heater?				
Coal	□	□	□	□
Natural Gas	□	□	□	□
LPG	□	□	□	□
Electricity	□	□	□	□
Waste Oil	□	□	□	□
Diesel	□	□	□	□
Petrol	□	□	□	□
Wood	□	□	□	□
Other (please specify)	□	□	□	□
iv. What type of heating unit is used?				
Boiler	□	□	□	□
Furnace	□	□	□	□
Convection heater	□	□	□	□
Radiant heater	□	□	□	□
Unit heater	□	□	□	□
Other (please specify)....	□	□	□	□
v. What is the capacity of the unit according to the nameplate? (kW or BTU)				

7. Backup Power Supply

i. Do you have a back up power supply e.g. diesel generator? ....Yes ....No

If yes, go on to the next question.
If no, go to question 8.

ii. What is the capacity of the back up power supply? ....kW or ....hp

8. Energy Use

i. How much energy do you purchase for use in your greenhouse business in a 12 month period? Please fill in the amount; you can check previous energy bills to find out or contact your energy company.

Please **include** energy used for operating and maintaining the business up to the farm gate, but please **exclude** energy used by any residential dwellings on the site and any transport off the property.

Electricity	........kWh
Wood	........tonne
LPG	........GJ
Natural gas	........GJ
Coal	........tonnes
Waste oil	........litres
Diesel	........litres
Petrol	........litres
Other (please specify)	....

9. Minimising Energy Consumption and the Carbon Charge

Please circle the appropriate letter for each statement based on the scale given below.

1 – Strongly disagree
2 - Disagree
3 – Somewhat disagree
4 – No opinion
5 – Somewhat agree
6 - Agree
7 – Strongly agree

	Rating						
Improvements could be made to increase the net productive area within my greenhouse e.g. tiered propagation; less wasted floor space for paths, storage etc?	1	2	3	4	5	6	7
Improvements could be made to the structure and/or cladding of my greenhouse/s that would significantly reduce heat loss e.g. re-cladding; use of twin skins	1	2	3	4	5	6	7
Improvements could be made to the central heating system that would significantly increase energy efficiency of my greenhouses e.g. cleaning out the boiler more often; changing to another fuel.	1	2	3	4	5	6	7
Improvements could be made to the heat distribution system within my greenhouses that would significantly increase energy efficiency and reduce heat loss e.g. lagging the hot pipes; placing closer to ground level.	1	2	3	4	5	6	7
I am fully aware of the proposed carbon charge and the possible effects on the costs of operating my business.	1	2	3	4	5	6	7
I am considering changing heating fuel source to reduce the effect of the carbon charge on my business.	1	2	3	4	5	6	7
The carbon charge will have a negative impact on the New Zealand greenhouse vegetable industry.	1	2	3	4	5	6	7

10. Would you be willing for a researcher to visit your property and seek further information on your energy use and possible savings? ....Yes or ....No

If "Yes" please provide your contact information below

Name
....
Address..
....
Telephone..
Email..

Thank you for your time in completing this survey. Once the results are analysed it will help to identify practical means of reducing increasing energy costs to the New Zealand greenhouse growing industry.

Please add any comments relating to this topical issue in the space below should you wish.

Appendix 3. Information sheet and consent for energy audit

Massey University

INFORMATION SHEET AND CONSENT FORM FOR ENERGY AUDIT 2004

ENERGY SAVING OPPORTUNITIES IN THE GREENHOUSE VEGETABLE PRODUCTION SECTOR (2004)

The carbon charge pending 2007 will increase energy costs significantly for fossil fuel users. The aim of this research study is to show how, by using energy more wisely, cost savings can result for greenhouse growers.

Participant Involvement

Your name and contact details were selected from the Vegetable and Potato Grower's Federation database, our client for this study.

An energy audit will be undertaken on your greenhouse operation. This will involve permitting a researcher access to the greenhouses and answering questions relating to energy use in your greenhouse operation.

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to the research findings once the study is finished.

Data collected will be stored at the researcher's residence. The data will not be used for any other purpose than that stated in the information sheet.

If you agree to be in the study, all of your information will be kept private by:

- keeping your consent form separate from any other information you provide me with;
- only letting people on the research team look at your information;

Thank you for your time

Anna Wilson
Centre for Energy Research, Massey University

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time. I give permission for the data I provide to be used for the purpose stated.

Signature

Date

I give permission for photographs to be taken by the research and potentially be used in the final publication.

Signature

Date

Appendix 4. The greenhouse energy audit (2004)

Greenhouse Energy Audit 2004

Questionnaire number.....................

1. Grower's details

Date	
Grower's Name	
Postal Address	
Contact Phone Number	
E-mail	

2. Greenhouse area

i. How many separate greenhouse structures is the grower responsible for? ....

ii. What is the total area under greenhouse cover? ....m^2

iii. What is the total heated area under greenhouse cover? ....m^2

iv. Is there a propagation shed onsite?
1......Yes
2.......No

3. Crop production

	Crop type			
	[1]Capsicums	[2]Tomatoes	[3]Cucumbers	[4]Other ......
i. How many weeks last year was the crop not harvested? e.g. time used for planting and preparation				
ii. How many times is the crop harvested in a one week period?				
iii. How many kg of product is harvested in a 12 month period?				
iv. What is the average harvest of this crop in kg?				
v. What was the average January harvest last year?				
vi. What was the average July harvest last year?				

4. Greenhouse structure and design

	Greenhouse number						
	1	2	3	4	5	6	[7]Propagation shed
i. What is the floor area of each greenhouse?							
ii. What % of the floor area is not available for growing?							
iii. How large is the main path? (m^2)							
iv. What crop was grown in this greenhouse last year?							
v. What is the roof shape?							
1. Quonset	□	□	□	□	□	□	□
2. Gable	□	□	□	□	□	□	□
3. Cosecant curved	□	□	□	□	□	□	□
4. Other	□	□	□	□	□	□	□
vi. What is the glazing bar material?							
1. Aluminium	□	□	□	□	□	□	□
2. Wood	□	□	□	□	□	□	□
3. Steel	□	□	□	□	□	□	□
4. Other……….	□	□	□	□	□	□	□
vii. What is the greenhouse structure material?							
1. Aluminium	□	□	□	□	□	□	□
2. Wood	□	□	□	□	□	□	□
3. Steel	□	□	□	□	□	□	□
4. Other……….	□	□	□	□	□	□	□
viii. What is the age of the greenhouse frame? (years)							
ix. What is the cladding material?							
1. Glass	□	□	□	□	□	□	□
2. Plastic	□	□	□	□	□	□	□
3. Rigid Plastic	□	□	□	□	□	□	□
4. Other ………	□	□	□	□	□	□	□
x. What is the age of the current cladding? (years)							
xi. How many layers of cladding are there?							
1. Single	□	□	□	□	□	□	□
2. Twin	□	□	□	□	□	□	□
xii. Rate the cladding.							
1. Good condition, no tearing or broken panes, cladding clean.	□	□	□	□	□	□	□
2. Moderate condition, several tears or broken panes, cladding somewhat dirty.	□	□	□	□	□	□	□
3. Poor condition, large number of broken panes, cladding dirty.	□	□	□	□	□	□	□

xiii. Rate the seals 1. Good condition, no leakages. 2. Moderate condition, minor leakages. 3. Poor condition, major leakages.	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □
xiv. Is a thermal screen installed in the greenhouse? 1. Yes - go to question xi 2. No - go to question 5	□ □	□ □	□ □	□ □	□ □	□ □	□ □
xv. If so what material is the thermal screen made of?							

5. Main heating system

	Greenhouse Number						
	1	2	3	4	5	6	7 Propagation Shed
i. Are any of the greenhouses artificially heated? 1. Yes - go to question ii 2. No - go to question 7	□ □	□ □	□ □	□ □	□ □	□ □	□ □
ii. At what temperature does the artificial heating kick in?							

iii. How many separate heating systems (e.g. boilers) are there on the property? ....

	Heating system			
	1	2	3	4
iv. Which greenhouses does each heating system supply?				
v. How old is the system?				
vi. What type of fuel is used to run the heater?				
1. Coal	□	□	□	□
2. Natural Gas	□	□	□	□
3. LPG	□	□	□	□
4. Electricity	□	□	□	□
5. Waste Oil	□	□	□	□
6. Re-refined oil	□	□	□	□
7. Diesel	□	□	□	□
8. Petrol	□	□	□	□
9. Wood	□	□	□	□
10. Other	□	□	□	□
vii. What type of heating unit is used?				
1. Boiler	□	□	□	□
2. Furnace	□	□	□	□

3. Convection heater	☐	☐	☐	☐
4. Radiant heater	☐	☐	☐	☐
5. Unit heater	☐	☐	☐	☐
6. Other ……………………..	☐	☐	☐	☐
viii. What is the capacity of the unit according to the nameplate? (kW or BTU)				

ix. How many times a year is the heating system cleaned?

1……
2……
3……
4……

x. Do any of the heating systems have energy saving devices installed?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………

6. Heat distribution system

i. What is the method of heat distribution	**Number of greenhouses**						
	1	**2**	**3**	**4**	**5**	**6**	**[7]Propagation Shed**
1. Unit heater (fan equipped with a means to heat the air provided by a fan)	☐	☐	☐	☐	☐	☐	☐
2. Unit heater and inflated poly-tubing	☐	☐	☐	☐	☐	☐	☐
3. Bare hot water pipes	☐	☐	☐	☐	☐	☐	☐
4. Finned hot water pipes	☐	☐	☐	☐	☐	☐	☐
5. Hot water heated floor	☐	☐	☐	☐	☐	☐	☐
6. Electric propagation mats and cables	☐	☐	☐	☐	☐	☐	☐
7. Infrared radiant heating system	☐	☐	☐	☐	☐	☐	☐
8. Fans	☐	☐	☐	☐	☐	☐	☐
9. Other……………………	☐	☐	☐	☐	☐	☐	☐
ii. What is the temperature range for each greenhouse? °C							

iii. Has the grower taken any steps to maximise heat distribution efficiency?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………….

iv. What maintenance of the heating system is performed routinely?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………

7. Water pumps

i. Is the greenhouse operation on mains or tank/bore water? ………….

ii. How many main pumps are there? ………….

	Main water pumps				
	1	2	3	4	5
iii. What greenhouse does each pump supply?					
iv. What is the capacity of the pump? (kw)					

v. How many secondary reticulation pumps are there? …………

	Secondary water reticulation pumps				
	1	2	3	4	5
vi. What greenhouse does each pump supply?					
vii. What purpose of the pump? e.g. irrigation. **Exclude pump for nutrient circulation.**					
viii. What is the capacity of the pump? (kw)					

8. Humidity control, ventilation and lighting

	Greenhouse number						
	1	2	3	4	5	6	[7]Propagation Shed
i. How many ventilation motors in each GH?							
ii. What is the capacity of the ventilation motors? (kW)							
iii. Is artificial lighting used? 1. Yes - go to question xii 2. No - go to question 8	□ □	□ □	□ □	□ □	□ □	□ □	□ □
iv. If yes, what type?							
v. How many luminaries?							

vi. Wattage of each luminary? (W)							
vii. Is an automated climate control system used? e.g. Priva 1. Yes 2. No	 ☐ ☐	 ☐ ☐	 ☐ ☐	 ☐ ☐	 ☐ ☐	 ☐ ☐	 ☐ ☐

viii. Are integrated plant management techniques used, such as the use of biological controls?

1……Yes
2……No

ix. Is CO_2 enrichment used?

1….Yes
2.….No

9. Plant growth media

i. Is a soiless media system used to grow the crops?

1……Yes - go to ii
2……No - go to question iv

	Greenhouse number						
	1	2	3	4	5	6	[7]Propagation Shed
ii. What type of growth medium is used? (e.g. rock wool)							

iii. Are hydroponics used to grow the crop?

1……Yes - go to question iv.
2……No - go to question 9

iv. What temperature is the solution maintained at? …………..

v. How many mixing stations are there? ………………

	Hydroponic solution stations				
	1	2	3	4	5
vi. What greenhouse does each station supply?					
vii. What is the size of mixing tank (m^3)					
viii. What is the					

capacity of the pump? (kw)					
ix. What is the capacity of the water heater? (kW)					
x. What is the capacity of the mixer? (kW)					

10. Post harvest operations

i. Is there a packing and storage facility onsite?

1.....Yes - go to question ii
2.....No - go to question 11

ii. How many refrigeration units are there? ....

iii. What is the capacity of each unit?

1........kW
2........kW
3........kW
4........kW

iv. Is a forklift used?

1.....Yes - go to question v
2.....No - go to question vi

v. What is the engine size/capacity? ....kW

vi. Is artificial lighting used in the packing shed?

1......Yes - go to question vii
2......No - go to question 11

vii. If yes,
1. How many luminaries? ....
2. What type? ....
3. What is the capacity of each light? ....W

11. Backup power supply

i. Is there a back up power supply e.g. diesel generator?

1......Yes - go to question ii
2......No - go to question 12

ii. What is the capacity of the back up power supply generator?

…….kW or …….hp

iii. What type of fuel is used? …………..

iv. How many hours last year was the backup power supply in use? …………..

v. When is the back up power supply typically used?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

12. Energy use

i. How much energy is purchased for use in the greenhouse business in a 12 month period?

Please include energy used for operating and maintaining the business up to the farm gate. **Please exclude** energy used by any residential dwellings on the site and by any transport vehicles when travelling off the property.

Energy Source	a. Electricity (kWh)		b. Wood (tonne)		c. LPG (GJ)		d. Natural gas (GJ)		e. Coal (tonnes)		f. Waste oil (litres)		g. Re-refined oil (litres)		h. Diesel (litres)		i. Petrol (litres)		j. Other (litres)	
	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$
1. Month of January																				
2. Month of April																				
3. Month of July																				
4. Month of October																				
5. Total over the 12 month period																				

ii. How much energy is used for heating the greenhouses (only) over a 12 month period?

Energy Source	**a. Electricity (kWh)**		**b. Wood (tonne)**		**c. LPG (GJ)**		**d. Natural gas (GJ)**		**e. Coal (tonnes)**		**f. Waste oil (litres)**		**g. Re-refined oil (litres)**		**h. Diesel (litres)**		**i. Petrol (litres)**		**j. Other (litres)**	
	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$
1. Month of January																				
2. Month of April																				
3. Month of July																				
4. Month of October																				
5. Total over the 12 month period																				

13. Grower's views

	1.Strongly Disagree	2.Disagree	3.Neither Agree or Disagree	4.Agree	5.Strongly Agree
i. Improvements could be made to increase the net productive area within my greenhouse e.g. tiered propagation; less wasted floor space for paths, storage etc?					
ii. Improvements could be made to the structure and/or cladding of my greenhouse/s that would significantly reduce heat loss e.g. re-cladding; use of twin skins					
iii. Improvements could be made to the central heating system that would significantly increase energy efficiency of my greenhouses e.g. cleaning out the boiler more often; changing to another fuel.					
iv. Improvements could be made to the heat distribution system within my greenhouses that would significantly increase energy efficiency and reduce heat loss e.g. lagging the hot pipes; placing closer to ground level.					
v. I am fully aware of the pending carbon charge and the possible effects on the costs of operating my business.					
vi. I am considering changing heating fuel source to reduce the effect of the carbon charge on my business.					
vii. The carbon charge will have a negative impact on the New Zealand greenhouse vegetable industry.					

viii. What steps have you already taken to make energy savings?
(Fill in the sentences which apply)

1. I have installed energy saving technologies, such as ....
....

2. I have improved the efficiency of my greenhouse operation by..............................
....

3. I have reduced my energy demand by..
....

4. I have increased the production area by..
....

ix. What practical ideas for energy savings are possible in your business that you have not currently implemented?
....
....
....

To:..

From: Anna Wilson,
[redacted]

I.....................................give permission for Anna Wilson of Massey University to obtain fuel purchase figures for my business for account number ....for the period of..

Signed:.................................. Date:...........................

To the energy supplier: Please complete the appropriate section and return by mail or E mail to the address above. Thank you for your time.

Energy Source	a. Electricity (kWh)		b. Wood (tonne)		c. LPG (GJ)		d. Natural gas (GJ)		e. Coal (tonnes)		f. Waste oil (litres)		g. Re-refined oil (litres)		h. Diesel (litres)		i. Petrol (litres)		j. Other (litres)	
	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$	Units	$
1. Month of January																				
2. Month of April																				
3. Month of July																				
4. Month of October																				
5. Total over the 12 month period																				

To:..

From: Anna Wilson
[redacted]

I ....give permission for Anna Wilson of Massey University to obtain electricity usage figures for my business for account number ....from my power supply company

Signed:... Date:.............................

Total electricity consumption for year of .... in kWh and also monthly usage.

Thank you for your time.

Time Frame	Meter Number	Location (if known)	Tariff	Fixed supply charges per period ($)	Total cost of electricity($)
Month of January					
Month of April					
Month of July					
Month of October					
Total over the 12 month period					

Appendix 5. A summary of the greenhouse operations audited

Location By Region	Number of Structures	Total Area	Total Heated Area	Crop Type	Crop Production	Heating Fuel	Heating units per Year	MJ per year	Energy Intensity MJ/M2	Electricity kWh	Electricity MJ	Final Intensity
Sth Auckland	2	3000	3000	cucs	90 fruit/m2	Waste Oil	105000 Litres	4063500	1354.5	14406	51861.6	1371.7872
Sth Auckland	1	10000	0	fancy lettuce		No Heating		0	0	30012	108043	10.80432
Sth Auckland	1	6000	6000	tom	24 kg/m2	Natural Gas	8500 GJ	8500000	1416.6667	64970	233892	1455.6487
Northland	4	5575	5575	cucs	85 fruit/m2	Diesel	43200 Litres	1529280	274.31031	27600	99360	292.13274
Northland	2	1728	1728	caps	18 kg/m2	Diesel	12000 Litres	424800	245.83333	7000	25200	260.41667
North Auckland	1	4000	4000	toms	42 kg/m2	Natural Gas	2241 GJ	2241000	560.25	38600	138960	594.99
South Auckland	1	4100	4100	toms (cherry)	15 kg/m2	Waste Oil	48000 Litres	1857600	453.07317	43217	155581	491.0198
Hawke's Bay	10	7077	6927	toms (cherrry and table)	12-24 kg/m2	Natural Gas	4312 GJ	4312000	609.29773	24876	89553.6	635.41989
Bay of Plenty	1	4400	4400	toms	15 kg/m2	Natural Gas	1246 GJ + Thermal	1246000	283.18182	52247	188089	325.92936
Marlborough	5	3000	3000	cucs	100 fruit/m2	Coal	224 tonne	4726400	1575.4667	27518	99064.8	1608.4883
Marlborough	3	1000	1000	caps	16 kg/m2	Coal	60 tonne	1266000	1266	5944	21398.4	1287.3984
Canterbury	4	3000	3000	caps	15 kg/m2	Coal	160 tonne	3376000	1125.3333	47904	172454	1182.8181
Canterbury	2	3200	3200	toms	45 kg/m2	Coal	300 tonne	6330000	1978.125	27288	98236.8	2008.824
Bay of Plenty	2	775	775	toms	42 kg/m2	Diesel/Electricity	5000 Litres	177000	228.3871	96042	345751	674.51768
Marlborough	2	20000	20000	toms	45 kg/m2	Coal/LPG	1000 tonne	21100000	1055	99064	356630	1072.8315
Canterbury	5	10000	10000	cucs	105 fruit/m2	Coal	1025 tonne	21627500	2162.75		0	2162.75
Manawatu	4	8600	8600	toms (summer only)	20 kg/m2	Natural Gas	3713 GJ	3713000	431.74419	70996	255586	461.46344

Appendix 6. Break down of the data structure, including descriptive statistics

This section provides descriptive statistics and measures of central tendency for the questions asked in the audit. Due to the variation in the data type, e.g. ranked, continuous, binary, categorical, several methods of displaying the data have been used.

Table 33. Percentage and count of growers by location (Question 1).

Location	Count	Percentage
North Island	11	65
South Island	6	35

Table 34. Descriptive statistics for the number of separate structures in each operation (Question 2.i).

Variable	Maximum	Q1	Median	Q3	Maximum	Range	IQR
Separate Structures	1	1	2	4	10	9	3

Table 35. Descriptive statistics for the total size of each operation (Question 2.ii).

Variable	Mean	Minimum	Q1	Median	Q3	Maximum	Range	IQR
Operation Size (m2)	5615	775	3000	4100	7839	20000	19225	4839

Question 2.iii Out of the 16 growers that used heating for crop production only one grower had any area under greenhouse cover that was not heated. This area formed less than 5% of the total area of this operation.

Question 2.iv 35% of growers have a propagation shed.

Table 36. Descriptive statistics for the total greenhouse crop production, by crop type, over a 12 month period (Question 3.iii).

Crop Production	Mean	St Dev	Min.	Q1	Median	Q3	Max.	Range	IQR
Capsicum (kg/m2)	17.25	2.22	15	15.25	17	19.5	20	5	4.25
Tomato (kg/m2)	30.75	13.96	15	15.75	33	44.25	45	30	28.5
Cucumber (fruit/m2)	95	9.13	85	86.25	95	103.75	105	20	17.5

Table 37. Descriptive statistics for the floor area for each greenhouse (Question 4.i).

Variable	Number	Mean	StDev	Min.	Q1	Median	Q3	Max.	Range	IQR
Floor Area (m2)	51	1888	2458	120	360	1000	2000	12000	11880	1640

Table 38. Percentages for the roof shape of each greenhouse (Question 4.v).

	Quonset	Gable	Cosecant Curved	Other
Count	1	38	11	1
Percent	2	75	21	2

Table 39. Descriptive statistics for the glazing bar material of each greenhouse (Question 4.vi).

Glazing bar material	Aluminium	Wood	Steel
Count	6	17	28
Percent	12	33	55

Table 40. Descriptive statistics for the greenhouse structure material of each greenhouse (Question 4.vii).

Greenhouse structure material	Glass	Plastic
Count	19	32
Percent	37	63

Table 41. Descriptive statistics for the age of the frame of each greenhouse (Question 4.viii).

Variable	Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Range	IQR
Age of Frame (years)	12	6.6	1	9	10	18	40	39	9

Table 42. Percentages of the cladding material of each greenhouse (Question 4.ix)

Cladding Material	Glass	Plastic
Count	28	23
Percent	55	45

Table 43. Descriptive statistics for the age the cladding material for each greenhouse (Question 4.x).

Cladding material	Total count	Mean	StDev	Min	Q1	Median	Q3	Max	range	IQR
Glass	28	14.36	8.18	1	9.25	15	20	40	39	10.75
Plastic	23	7.043	2.364	3	5	6	10	10	7	5

Table 44. Cross tabulation of cladding material and the number of layers (Question 4.ix).

	Glass	Plastic	All
Single	49.02	5.88	54.9
Twin	3.92	41.18	45.1
All	52.94	47.06	100

Table 45. Percentage of the different condition ratings of the cladding (Question 4.xii).

Cladding condition rating	Good	Moderate	Poor
Count	19	14	18
Percent	37.25	27.45	35.29

Table 46. Percentage and counts of the different condition rating of the seals (Question 4.xiii).

Seals Condition Rating	Good	Moderate	Poor
Count	19	14	18
Percent	37.25	27.45	35.29

Table 47. Descriptive statistics for the heater size by fuel type in kW (Question 5.iv).

Fuel type	N	Mean	Min.	Q1	Median	Q3	Max.	Range	IQR
Coal	7	1957	600	750	1000	3000	5400	4800	2250
Natural gas	23	297	33	150	150	235	2000	1967	85
LPG	1	3000	3000	*	3000	*	3000	0	*
Electricity	1	*	*	*	*	*	*	*	*
Waste-oil	2	858	800	*	858	*	915	115	182
Diesel	6	108.8	2	16	117	198	250	248	*
Other	1	*	*	*	*	*	*	*	*

Table 48. Percentage and counts of the different types of heating units, both local and central (Question 5.vii).

Heater type	Boiler	Furnace	Convection	Unit	Other
Count	12	1	2	22	4
Percent	29	2	5	54	10

Table 49. Percentages and counts for the different types of heat distribution system (Question 6.i).

Heat distribution	Poly tubes	Steel pipes	Heat exchanger and fans	Other
Count	22	24	1	1
Percent	46	50	2	2

Table 50. Percentages and counts of the number of main pumps in each operation (Question 6.ii).

Main pump	1	2	3
Count	13	3	1
Percent	76	18	6

Question 7.i. There were at most 1-2 main pumps (ie. exterior to the greenhouse and fertigation system, generally used for the bore.) onsite, no smaller than .55 kW and 7.5 kW.

Question 7.v. Typically 2-4 secondary pumps (excludes fertigation pumps) are used. The number of pumps required depends on whether the greenhouse has undergone additions or whether the structures were built at the same time.

Question 8.iii. No artificial lights were used for production in any of the greenhouses audited.

Question 8.i-ii. The capacity of ventilation motors in all instances ranges between 0.9-1.1 kW.

Table 51. Percentages and counts for whether the grower's used automated climate control (Question 8.vii).

Automated control	Yes	No
Count	11	6
Percent	65	35

Table 52. Percentages and counts for whether growers use integrated pest management techniques (Question 8.viii).

IPM	Yes	No
Count	12	5
Percent	71	29

Table 53. Percentages and counts for whether growers use CO_2 enrichment (Question 8.ix).

CO2 Enrichment	Yes	No
Count	2	15
Percent	12	88

Question 9.i. All growers used a soil-less media system.

Table 54. Percentages and counts for the different types of growing media used (Question 9.ii).

Growing media	Pumice	NFT	Cocopeat	Sawdust	Rockwool
Count	3	3	1	8	2
Percent	18	18	6	47	12

Question 9.iv. The nutrient solution was not heated anywhere except in Christchurch, where every grower maintained the solution at 20 degrees.

Question 9.v. All growers except three had one nutrient station, supplying one or more greenhouses, while 2 growers had 4 and 1 grower had 5 nutrient stations.

Table 55. Percentages and counts for the packing sheds (Question 10.i).

Packing shed	Count	Percent
Yes	11	65
No	6	35

Question 10.ii. Only one grower visited had a working refrigeration unit.

Question 10.iv. Only two growers audited had forklifts.

Question 10.vi. Eight growers used artificially lighting in their packing sheds. These were either Philips fluorescent (40W) or standard light bulbs (60-100 W).

Table 56. Percentages and counts for backup power supplies (Question 11.i.).

Backup power	Count	Percent
Yes	7	41
No	10	59

Question 11.ii. Engine size ranged between 70 and 110 kW and were either diesel or petrol powered.

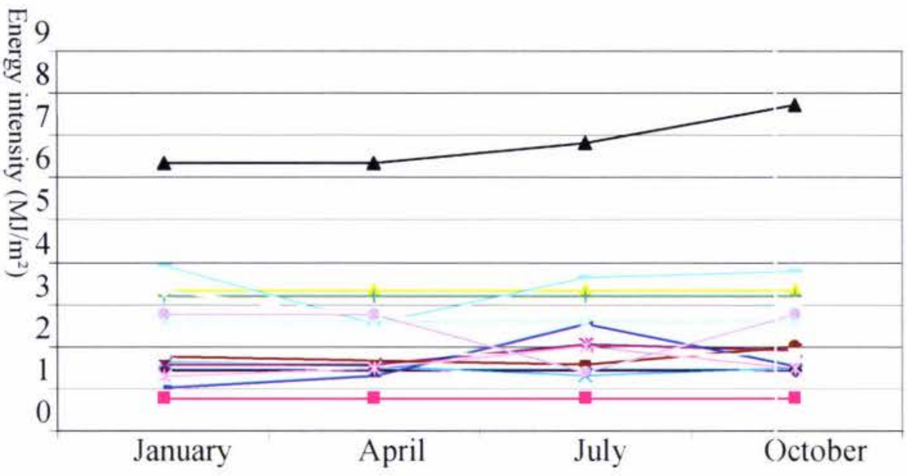

Figure 38. Seasonal electrical energy intensity in greenhouses (Question 12), where each line represents each greenhouse operation that took part in the audit.

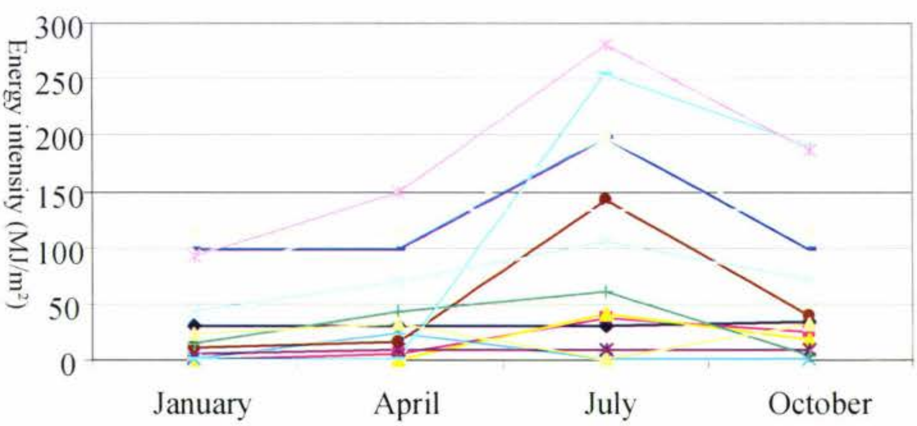

Figure 39. Seasonal energy intensity for heating only (Question 12), where each line represents a greenhouse operation that took part in the audit.

Table 57. Descriptive statistics of the grower's opinion on energy use and the carbon charge (Question 13).

Questions	Q1	Median	Q3	Mode	Corresponding response (median)
i. Improvements could be made to increase the net productive area within my greenhouse e.g. tiered propagation; less wasted floor space for paths, storage etc?	2	2	3.5	2	Disagree
ii. Improvements could be made to the structure and/or cladding of my greenhouse/s that would significantly reduce heat loss e.g. re-cladding; use of twin skins	2	3	4	2	Neither agree or disagree
iii. Improvements could be made to the central heating system that would significantly increase energy efficiency of my greenhouses e.g. cleaning out the boiler more often; changing to another fuel.	2	2	4	2	Disagree
iv. Improvements could be made to the heat distribution system within my greenhouses that would significantly increase energy efficiency and reduce heat loss e.g. lagging the hot pipes; placing closer to ground level.	2	3	3	2	Neither agree or disagree
v. I am fully aware of the pending carbon charge and the possible effects on the costs of operating my business.	4	4	5	4-5	Agree
vi. I am considering changing heating fuel source to reduce the effect of the carbon charge on my business.	1	2	3	1-2	Disagree
vii. The carbon charge will have a negative impact on the New Zealand greenhouse vegetable industry.	3	4	5	5	Agree

Appendix 7. The energy saving model

The purpose of developing this computer model was to encourage the greenhouse grower to think about energy savings that can be made within their greenhouse operation to avoid the potential cost of the carbon charge on to their business.

The objectives of the model were to:

- benchmark the user's energy use against other similar New Zealand greenhouse growers, taking into account the crop type and location;
- determine the future cost of the carbon charge to the user;
- identify where energy savings could be made through the implementation of technologies and energy wise practices; and
- provide growers with a method of quickly assessing which energy saving options available might best suit their specific situation.

The first section of the model focused on the potential cost of the carbon charge and also benchmarks each grower's energy use and production against other New Zealand growers. The second section concentrates on specific energy saving measures that could be applied to the grower's situation.

Section 1

Growers were are asked to input basic data such as the location of their business (North or South Island), crop type, heating fuel type and total covered area, the price per tonne of CO_2 and the amount of fuel used, by type over a twelve month period. The model then calculates the additional cost of the carbon charge over a twelve month period and the overall energy intensity of the greenhouse operation. The model benchmarks the user against other growers in terms of production and energy use by location. Determining the actual cost in $ of the carbon charge was based on the following values (see Table 1).

Table 57. Energy and carbon dioxide emission values used in developing the energy saving model.

Fuel Type	Units	Energy (MJ/unit)[a]	gCO_2/MJ[b]	gCO_2/unit
Natural gas	MJ/l	3.6	52.4	188
Diesel	MJ/l	35.4	69.5	2460
Coal	MJ/kg	21.1	91.2	1924
Waste oil	MJ/l	38.7	73.7	2852
Electricity	MJ/kWh	3.6	43.1	155
LPG	MJ/kg	26.5	60.4	1603
Wood (Wet)	MJ/kg	9.3		970
Wood (Dry		20.6	104.2	2141
Petrol	MJ/l	34.7	66.2	2297

Data source:

[a] NZ Energy Data File (The Ministry for Economic Development, July 2004)

[b] National Inventory Report: Greenhouse Gas Inventory 1990-2004 (NZCCO, 2005)

Benchmarking was based on a secondary data set. This data set was tested for normality. It was assumed that this sample of growers was representative of the New Zealand greenhouse vegetable industry.

Section 2

The model user is asked short answer questions regarding the various aspects of their greenhouse operation including the building structure, heating system and climate control system. Depending on the response, recommendations are made based on the literature, case studies and the findings from the analysis of the energy audit. The potential fuel and carbon charge savings of implementing these measures are shown where appropriate.

A copy of the model on CD ROM is attached to the document.