Using Semi-Closed Greenhouses to Maximise Production while Minimising Inputs and Waste

A Report for

By Keshav Timalsena

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Executive Summary

Increasing productivity in a conventional greenhouse through contemporary practices is a big task, especially when the optimal output has already been achieved. As conventional greenhouses cannot be stretched any further, Semi-Closed Greenhouse (SCG) technology may be the best option to maximise production while minimising inputs and waste.

This study assesses the commercial viability of SCG by addressing the key potential benefits and operational requirements. Written from the perspective of a commercial grower, this study provides an unbiased and informed assessment for current growers and future investors looking into state of the art semi-closed greenhouse technology.

The information provided in this report is derived from a variety of reference literature on greenhouse technologies and personal accounts gathered from visits to several world-class greenhouses producers (in four continents).

This study concluded that SCG technology provides a platform from which growers can achieve a greater level of climate-control, increasing energy efficiency while retaining more beneficial CO_2. Moreover, pest pressure is significantly reduced in SGC's as the active climate control creates a positive air pressure excluding external pest and disease vectors. Consequently, SCG infrastructure provides growers with superior opportunities to maximising productivity and minimising waste while also reducing carbon footprint. Currently adoption of SCG in Australia is in its infancy and growers are learning the European designs which do not necessarily translate to Australian conditions. Innovation in biodegradable growing supplies made in Australia would see an exponential growth in this industry. However, there is need to approach policy makers and lobby for subsidies to undertake newer infrastructure in a large scale.

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Foreword

After working in the hydroponics industry for more than 21 years, from the grass root level to a senior grower manager in two state-of-the-art greenhouses, I was provided with the once-in-a-lifetime opportunity of becoming a Nuffield Australia Scholar in 2014.

This has taken me to four different continents to observe, discuss and get actively involved in new types of greenhouses. I have been able to establish relationships with many other Nuffield Scholars and also shared my findings with greenhouse managers.

This journey has been more than just a learning curve for me - I am now creating awareness about the use of semi-closed greenhouses for increasing productivity and reducing waste. Mainstream greenhouses cannot be improved any further; the time for semi-closed greenhouses has come. This report advocates that, while making decisions about expansions in mainstream greenhouses, growers should make informed choices and not overlook the latest developments taking place in hydroponic technologies and plant care procedures. Semi-closed greenhouse infrastructure provides ample opportunities for maximising productivity and minimising waste.

The new breed of tomato growers and potential investors may find this report helpful. It will not be commercially viable for them to revamp the existing mainstream greenhouse to make room for the state of the art semi-closed greenhouse, although the capital cost of change may be high.

It is therefore advisable to plan for a new greenhouse with the latest infrastructure. To increase productivity one has to first learn and implement cost reduction methods. As Nikolas Tesla said, *"To make things move faster we need to reduce friction; a bigger motor and larger wheel may not be the right options."*

Acknowledgments

I would like to extend my gratitude to Nuffield Australia for the opportunity presented to me through this award. It is a great privilege to belong to such a prestigious and global horticulture network.

My cordial thanks go to Woolworths Australia Limited for their support and involvement as a sponsor to ensure the viability of the scholarship into the future.

I would like to thank Costa Group (Tomato Category) for allowing me to have time off for both the Global Focus Program (GFP) and individual study component.

My sincere thanks also go to Ray Nutt, Tal Kanety, Paul Butterworth and Winsome Rolling of Costa Group for making sure the workplace is kept running smoothly during my absence.

I am also thankful to all global agriculture industries, farm policy makers, greenhouse experts, greenhouse manufacturers, consultants, greenhouse software and hardware experts and greenhouse growers who generously shared their experience and knowledge with me during the period of both my Global Focus Program and individual study.

And, last but not least I am indebted to my family members - especially my wife Ganga and two sons - for providing their emotional support to complete the study.

Abbreviations

GH	Glasshouse
$C0_2$	Carbon Dioxide
GFP	Global Focus Programme
HA	Hectares
SCG	Semi-Closed Greenhouse
VLT	Variable Light Transmission
PCA	Protected Cropping Australia
PPM	Particles per Million
VPD	Vapour Pressure Deficit
IEA	International Energy Agency
ECES	Energy Conservation through Energy Storage

Chapter 1: Background and Objectives

In order to increase profits, it is imperative for growers to maximise production and minimise inputs and waste. This best way to boost potential yields is by avoiding conditions that restrain crop growth. The high value nature of crops growing under glass enables growers to invest in capital infrastructure that improves climate control essentially, giving the grower a barrier between the crop and the environment.

Over the years, improvements in production facilities have led to an increased ability to heat, cool and enrich the climate with additional carbon dioxide and supplementary lighting. Furthermore, advances in chemistry and chemical technology have given growers increased ability to control pests and diseases whilst also fertigating only the essential nutrients required for crop growth. As a result, production efficiency has been increased significantly.

Unfortunately, this level of climate manipulation, fertigation and crop protection requires a large volume of costly inputs further increasing the cost of production. Furthermore, an increased public awareness of the environmental impact of input intensive farming is forcing farmers to take a more sustainable approach to food production. (As a result, a considerable research effort has gone into augmenting the high-level input consumption and waste production in conventional glasshouse production facilities. One such development showing considerable promise in this area is the semi-closed glasshouse concept).

The aim of this study is to objectively assess the capacity of the semi-closed glasshouse (SCG) as a potential alternative over conventional glasshouse technologies. The study will focus on how profits can be sustainably increased in the long term by:

- Maximising production
- Improving input use efficiency
- Reducing waste

Chapter 2: Introduction

Across Australia, horticultural production is constrained by harsh climates, limited access to water and a lack of arable land. Over the past 30 years, significant breakthroughs have been achieved in hydroponic fertigation techniques and climate control technologies. Accordingly, the hydroponic greenhouse industry is now seen as a model of high volume efficient production, producing up to nine times more than conventional field grower with only 20% of the water. On the back of such efficiencies, adoption of hydroponic greenhouse technology has rapidly increased in the last five years. In the last year alone over 120 ha of high tech glasshouse was constructed taking the industry to a total of 385 ha.

Despite these efficiencies the Australian industry is still in its infancy, with the majority of greenhouse technology coming from Europe, North America and Asia. The Netherlands is recognised as world leaders when it comes to glasshouse production with over 10,000 ha under glass.

The main crops growing under glass in Australia are tomatoes, capsicums, eggplants and cucumbers. Currently greenhouse growers produce significantly more produce than field growers (Table 1). However due to increasing competition and cost-price squeeze, growers must continually improve production efficiencies.

Crop	**Tomato**	**Capsicum**	**Cucumbers**	**Lettuce**
Greenhouse kg/m^2	76	30	100	80
Field kg/m^2	18	12	20	10
Efficiency gains (Production %)	422 %	250 %	500 %	800 %

Table 1 Annual yields per square metre in conventional greenhouse and field grown production of horticultural produce Smith (2005)

According to modelling conducted by Ep Heluvelink and Tijs Kierkels (2013), *"Under continuous optimal conditions a tomato crop can produce 200kg of fruit per square metre per year instead of the current 60 kg/m2/year"*.

Whilst this is only a potential theoretical yield, it shows that there are still significant gains to be made in the greenhouse production system. In order to achieve a greater portion of this potential yield, it is imperative that growers avoid conditions that constrain crop growth. To do this, the grower needs to optimise his/her climate and irrigation strategies whilst minimising the negative impact of pests, disease and humans.

To achieve this level of control, growers require large volumes of costly inputs. The main inputs required for large-scale greenhouse production are water, energy and fertiliser. Unfortunately, a portion of these inputs comes from non-renewable sources placing pressure on the future sustainability of the industry. Furthermore, increased public awareness of the environmental impact of carbon intensive farming is forcing farmers to drastically reduce fossil fuel usage. As a result, it is imperative for glasshouse producers to increase their input use efficiency.

The high volume nature of glasshouse production results in large quantities of unwanted waste including produce, bio mass and non-recyclable growing supplies a lot of which goes to landfill. This undesirable image of the industry also hurts the bottom line.

To sustainably increase profits, growers need to look at alternative concepts to the conventional glasshouse structure to give more scope in environmental control to improve production. At the same time one must improve resource efficiency and reduce waste.

Chapter 3: Semi-Closed Greenhouse Overview

3.1 History

The Semi-Closed Greenhouse (SCG), also referred to as a next generation greenhouse, is believed to be a more economical and environmentally sustainable concept when compared with conventional glasshouses.

3.2 Early Innovation

The concept was initially developed as a practical approach to solving the problems of controlling humidity and pests in older plastic greenhouses in New Zealand. In the early eighties, an engineer and greenhouse builder called Donald McNally experimented with the idea of having fewer vents and a more active uniform airflow within the greenhouse. In 1983, McNally's company New Zealand Agricultural Engineering Services Ltd (Fielding, New Zealand) constructed a two ha greenhouse which was a fully enclosed.

Located in Drury, (South Auckland) which is renowned for high humidity and significant pest pressure, McNally avoided the negative impact of these climate constraints by limiting the volume of outside humid air entering the greenhouse. Instead McNally recirculated low-humidity air through large tubes just above the crop gutters, creating a more productive climate that excluded external pest and disease pressures.

Unfortunately, the concept never took off despite the fact it is still in operation today it was the only one of its type built. According to Greg Prendergast, an experienced grower from the region *"The concept never took off as Dutch technology was perceived to be more economically feasible at the time."*

Figure 1 Mr. Don McNally's Plastic Closed Greenhouse (inmid-80's) in Drury, South Auckland)

3.3 Latest Innovation

The next step in semi-closed technology came in 2006 when innovator and grower Cassey Houweling started to develop his own semi-closed designs and prototypes. At the time the

Houwelings hothouse group was one of the largest producers in North America with over 20 years' experience in glasshouse tomatoes. The company was originally established in Delta, British Columbia, Canada in 1985. A decade later the company constructed its first greenhouse in southern California taking advantage of the area's high light level and access to the American market. While extra light significantly increased yield potential, the company soon realised that growing produce in southern California also presented significant challenges including the dry Santa Anna wind and high pest pressure. Houweling found that over the season the persistent dryness was driving high water use and high pest pressure was significantly impacting on yield, quality and cost of production. Desperate to reduce the pest pressure the company experimented with screening the vents to exclude pest and disease vectors. While these screens were highly effective at keeping the pests out, they significantly impacted on climate and energy use efficiency. Houweling found that the screens reduced light transmission by 15% and reduced ventilation significantly, making it very hard to control the climate. Houweling soon realised that if he continued to screen his vents, he was going to need some type of active atmosphere control as conventional passive venting was not sufficient. To achieve this, Houwelings enlisted the help of experienced Dutch greenhouse builders Kubo. Together they came up with the idea of reducing passive air exchange by limiting the number of vents and adding multi-functional air exchange corridor at the end of the greenhouse giving the grower active atmosphere control. In this air exchange corridor, air flow from outside the greenhouse can be either shut off (internal circulation) or allowed into this section (external circulation) so it is controlled before entering the greenhouse. In the corridor, the grower has the option to heat, dehumidify and/or enrich the air with CO_2 before it is circulated through the glasshouse. Furthermore, the addition of a cooling pad system in the corridor allows growers to cool and humidify outside air as needed before it enters the glasshouse. As a result, the design offered ground breaking atmospheric control of temperature, humidity, oxygen and CO2.

Limiting the structural components of traditional vents increases that light transmission while the active nature of blowing air into the glasshouse creates an over pressure in the greenhouse, which keeps the pests out. After initial success with early prototypes Houwelings decided to build the first large scale commercial semi-closed glasshouse in 2007 including two, eight ha structures, and it went on to become the basis for the Kubo Ultra-Clima®. After realising the potential for the design to provide superior climate control and yield, Houwelings focused on protecting the design by applying for patterns in the Netherlands, Canada, Israel, the European Union, Australia, New Zealand and the USA.

Since 2007, Kubo has used the patented design to build 23 Ultra-Clima® glasshouses for 16 customers across the globe today totalling an area of over 147 ha (Kubo, 2014). With five years of constructing the first Ultra-Clima®, Kubo's major competitors began building their own next generation greenhouses all with active atmosphere control. By 2013, experienced Dutch glasshouse builders Van der Hoeven had built their first next generation glasshouse in France. Known as 'modular air' it works off the same principals as the Ultra-Clima®. Since it was released, several large modular air projects have been commissioned. Van Der Hoeven has gained vast international experience constructing large-scale commercial projects including Flavorite Hydroponic Tomatoes in Warragul, Victoria, and the 20 ha Sundrop Farms in Port Augusta, South Australia. Consequently, modular air system is now one of the main key competitors in the market.

Another manufacturer called "Apex Glasshouses" (formally known as Faber Glasshouses) based in New Zealand teamed up with an international greenhouse supplier Royal Brinkman and released their own next generation design known as a Hybrid:X Biofactory which again exploits the idea of active atmosphere control. A key innovation made by the Apex team is the additional option of traditional passive venting which can be used in emergencies when active exchange is not available. Unfortunately, this option reduced light transmission and increased the cost of the structure and to date only one Hybrid X facility has been built.

As semi-closed and closed greenhouse technology becomes more wide spread many growers are looking to retro-fit their existing structure, something which two Dutch companies called ActivAir and Air & Energy specialise.

Figure 2 Air tubes under the gutter in The First Faber HYBRID X GH built in South Australia featuring a gutter height of 7.3 meters, diffused glass and a white powder coated construction. Royal Brinkman supplied and installed the complete computer (Priva), electric and irrigation System (Source: www.fabergreenhouses.com.au)

Chapter 4: Basic Semi-Closed Infrastructure

The key difference between a traditional and semi-closed greenhouse is the method of atmospheric control. Traditional greenhouses use passive venting to exchange air in order to maintain the climate. On the other hand, semi-closed greenhouses use active atmosphere controls such as fans and mixing chambers to control air exchange within the glasshouse.

Structural differences between SCG's and conventional glasshouses can easily be observed from both above and within the structure. In figure 2 (below) you can see SCGs have fewer vents than conventional glasshouses. This adoption provides more light and helps to maintain a barrier between the crop and the external environment. The climate within the SCG is controlled by active air exchange through air tubes under the crop. This air is treated in the mixing chambers located at the ends of the glasshouse allowing the option of either air from within the glasshouse, introduced from outside or a mixture of both. Air passing through the chambers is treated to control temperature humidity and CO_2 levels. This usually achieved via hydronic heating and CO_2 injection. In hot climates an evaporative pad can be added to the system to cool and humidify the air. As the air escaping the structure is limited, the structure maintains a positive pressure. The positive pressure provides a key advantage by keeping the climate in and the pests out.

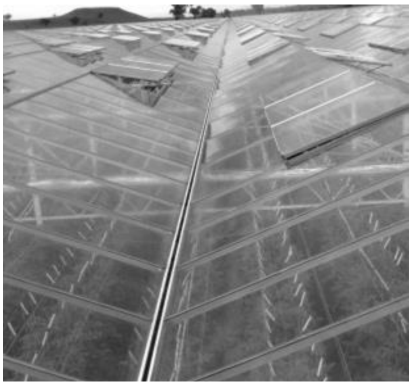



Figure 3 Left: Conventional glasshouse one vent per trellis Right: Semi-closed glasshouse with fewer vents (Source: www,vanderhoeven.nl and Costa Tomato exchange)

The main advantages of a semi-closed greenhouse are:

- More light transmission.
- Highly efficient at maintaining high CO_2 for crop fertilisation.
- A positive pressure within the glasshouse keeps pests out.
- Much greater control of external air exchange meaning better climate control with less heat and water inputs (up to half as much as conventional glasshouse).
- Increase crop yields of up to 39% (Ooteghem, 2007).

In a conventional greenhouse, the overall production suffers due to invading pests as well as inappropriate use of energy and water.

Pests easily get into the grow space through the ventilation system and if overlooked cause havoc for the plants requiring either an expensive spray program within the Health and Safety protocol or an Integrated Pest Management (IPM) system. Many growers try to use all available strategies and equipment, but still fall short of increasing productivity.

Higher production requires different tools such as precise and active climate control, more light and a higher CO_2 level to increase photosynthesis. In this way, improved energy management leads to a glasshouse full of healthy plants. Many growers strive for a disease-free growing environment but from time to time they still do get pathogenic invaders.

Precise climate control is achievable in a semi-closed greenhouse and pests can also be kept at bay due to the reduction of windows for ventilation. Moreover, the CO_2 levels are higher in a semi-closed greenhouse and the use of larger glass panes – and, hence, less shadow from the frame material – promotes more photosynthesis, especially for tomatoes. European growers have mentioned 15-20% increase in produce combined with a large saving in their energy bill.

The Village Farms in Marfa, Texas, USA, has reported a record-high tomato yield of 94 kg/m^2 in their 5400 m^2 research glasshouse in its first year of production. This has never before been achieved in a semi-closed greenhouse without supplementary lighting (Hortdaily.com).

Some of the disadvantages of the SCG infrastructure are that small growers may be put off due to the high upfront capital costs of building, high degree technical skills required and the higher level of maintenance and power consumption. It is hoped that further developments in material technology will reduce these costs to commercially acceptable levels ahead.

Solar panels on an either full or SCG is an option for Australian growers to gain a competitive advantage (Armstrong 2003; Hoes, et al, 2008). Australia is blessed with intense sunshine hours compared with European countries and solar panels should be considered as a major alternative energy source (Armstrong, 2003; Innogrow, 2008, Hoes et al., 2008). Solar energy can both heat the water and produce electricity.

Thermal energy storage systems are another option currently utilised in the Netherlands, whereby excess energy is saved and used when required. Despite involving a thermal energy expert at an early stage of infrastructure it can lower costs in the long run.

The term greenhouse or glasshouse is interchangeable when we start including energy management as a major aspect of the day to day running of horticulture activity. A greenhouse is 20 times more profitable than an outdoor growing operation with its weather dependence (Nedehoff et al., 2007). A greenhouse can be a 30 year investment, so early input should be sought from the planning stages. Making renovations and modifications to a conventional greenhouse is costly in terms of both time and money. Today's commercial greenhouses are not a simple technology as compared with the hothouses of the twentieth century and we now have a capacity to grow any imaginable crop, in or out of season.

4.1 Technical Specifications

Height: The height of the SCG depends on many factors and versatility can be achieved between 6.5-7.5m high. European manufacturers recommend 7.2m high for economical air and heat exchange. A 10m high greenhouse suits longer vines and creates a 'buffer zone' however the thicker frames increase costs. Taller greenhouses are still becoming popular not only because of the 'buffer zone' but they also lower the frequency of ventilation, fogging and CO_2 dosing. As a result, the temperature can be maintained and plant growth can easily be managed.

Gutters: Steel gutters have a 4.5m long bay length whereas aluminium gutters are 5m long with less wear and tear.

Truss widths: Trusses that are 6.4m and 8m wide are common in Europe, however the SCG utilises 9m wide trusses due to of the row layout and the ducts under the gutter.

Clading types: Glass cladding comes in many types including; Standard glass with 89% Variable Light Transmission (VLT) and Low Iron glass with 91% VLT, diffused glass has also been found useful as it spreads light evenly without ongoing maintenance. Lately, Hazed glass is replacing standard glass because it can transmit and evenly spread up to 94% of light. Another alternative is double-glazed polythene with heat insulation properties is proving to be the successful material for larger glasshouses (Campen et al., 2003).

Side Panels: The conventional set-up in Australia is to use side panels without a temperature control room and an energy distribution wall up to truss height with hinged valves.

Flooring: The standard flooring, the 8 or 9m long bays in conventional glasshouses, also suits SCG so some growers are using this opportunity to make improvements.

Screening: SCG we can use standard screens but the advent of 87% energy saving screens is now available.

4.2 Current models on the market

During the Nuffield study tour, the author visited five different types of greenhouse infrastructures with a similar working principle yet which all claim to produce a better outcome, including:

4.2.1 ModulAir

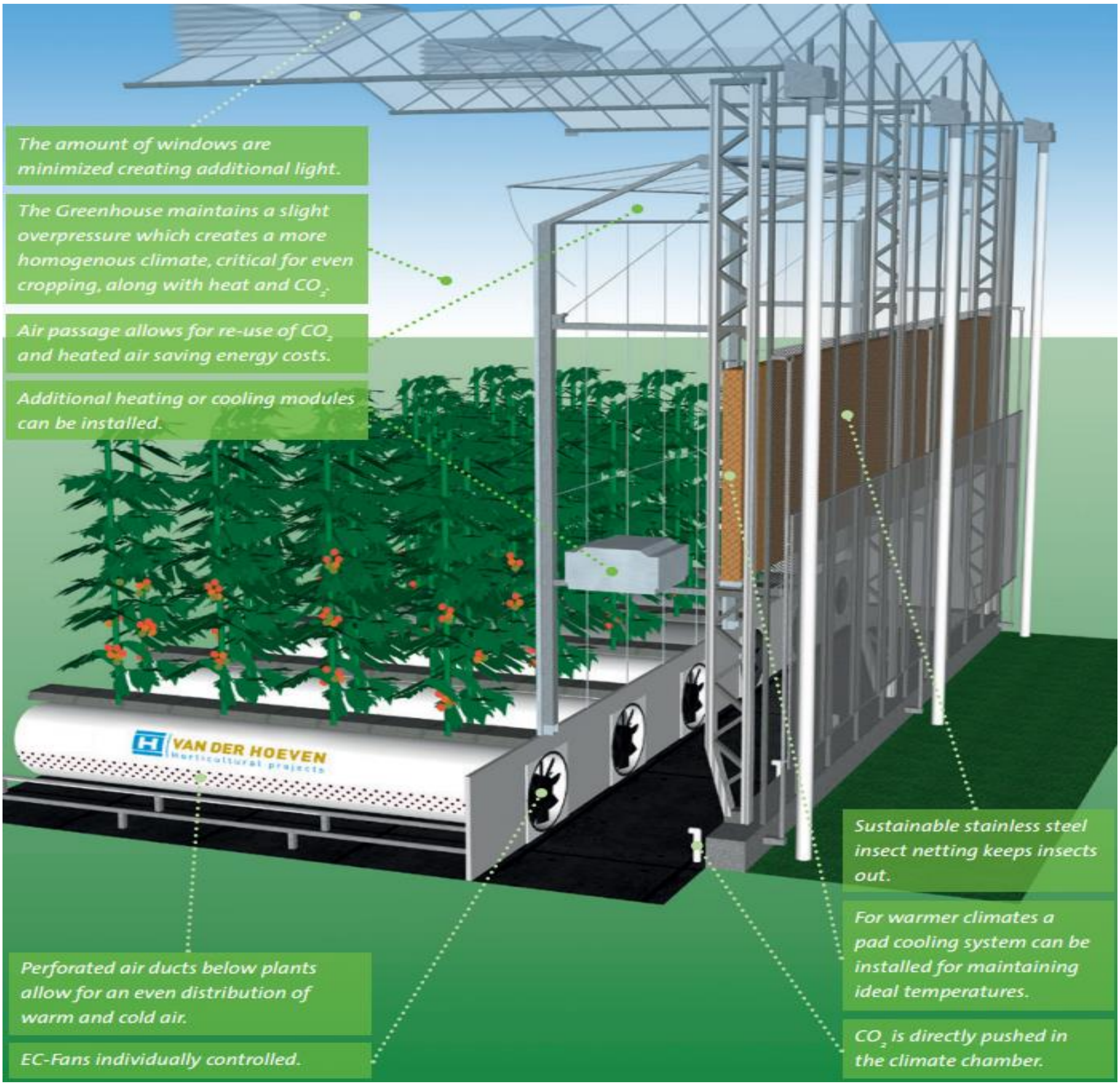


Figure 4 Van Der Hoven Design Semi-Closed Greenhouse (Source: www.vanderhoeven.nl)

The ModulAIR air treatment units are built as a small corridor, the ModulAIR corridor, located on the outer gable end walls of the greenhouse, uses outside air for cooling and dehumidification. This ModulAIR corridor is used as a mixing chamber, capable of mixing cool, dry air from outside with the warm, humid air from the greenhouse. When air is distributed back into the greenhouse the mixed air will be cooler and lower in humidity. Sustainable, stainless steel insect netting in front of the outside air inlet and integrated high quality nylon harmonica insect netting in the ModulAIR roof windows ensure that insects are kept outside of the greenhouse. This reduces pesticide reliance and the spread of disease within the crop. (This system is already in operation in Europe, US and Australia).

4.2.2 Ultra-Clima

Figure 5 Kubo Design Semi-Closed Greenhouse (Source: www.kubo.com.au)

Ultra-Clima is an entirely new growing concept. By using innovative technologies, the ability to control climate in the Ultra-Clima extends far beyond what is possible in conventional greenhouses. This makes it possible to grow crops in ideal conditions. The infrastructure is similar to the ModulAir but with heat exchanger in front of each fan.

***Advantages** are the uniform climate throughout the greenhouse and positive air pressure preventing insects from entering the growing space. The reduced disease and infestation burden lessen the need for crop protection. The Ultra-Clima also makes it possible to cultivate with minimal consumption of fossil fuels, or to use heating sources that do not impact the environment at all, such as geothermal heating. By burning less energy, CO_2 emissions are optimised while the reuse of water also ensures minimal use of this scarce resource.*

***Disadvantages** are similar to the ModulAir; that are, higher set up costs and the ongoing maintenance of the equipment.*

(This system is already in operation in Europe, US and Australia)

4.2.3 Bio-Factory Hybrid: X

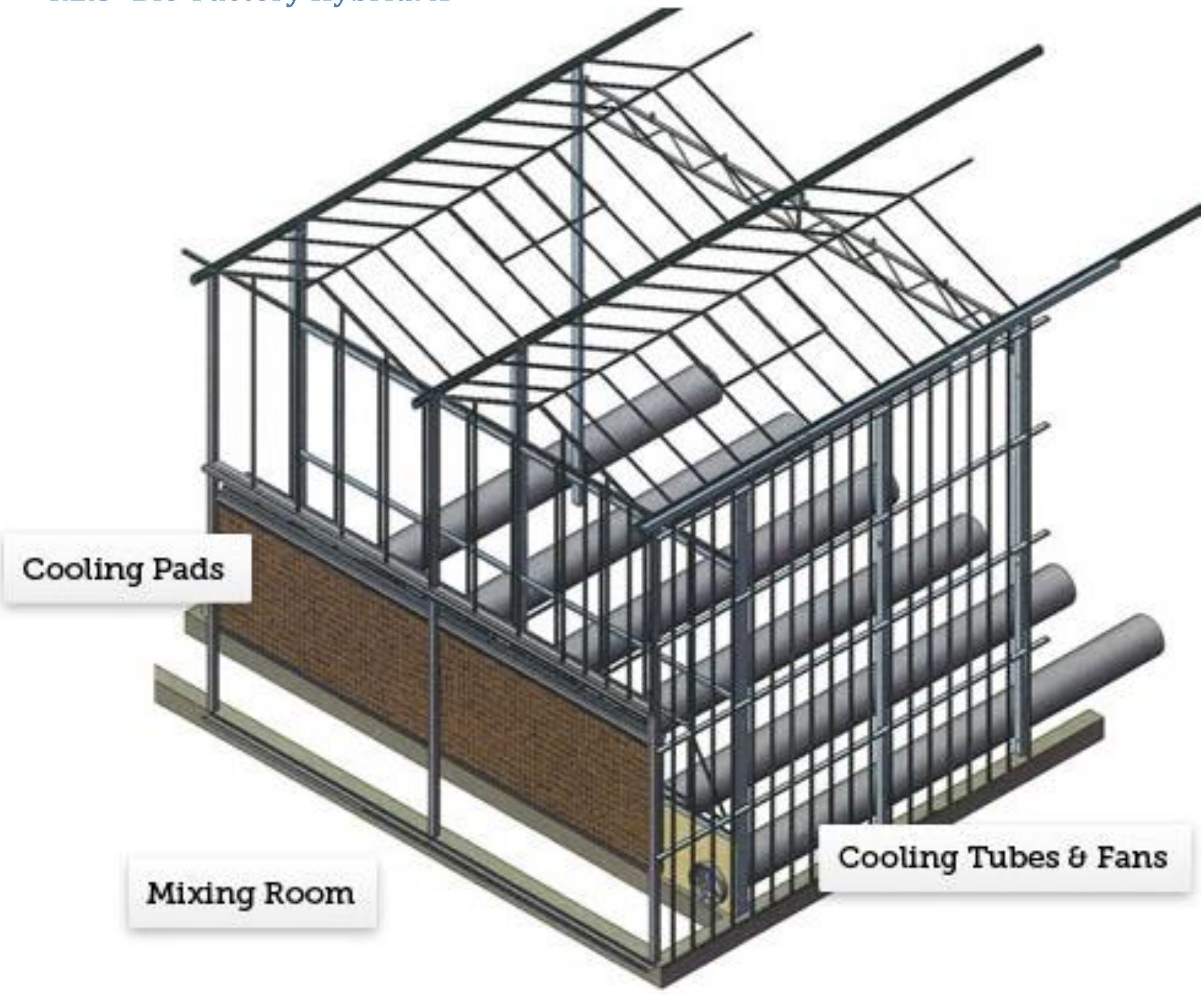


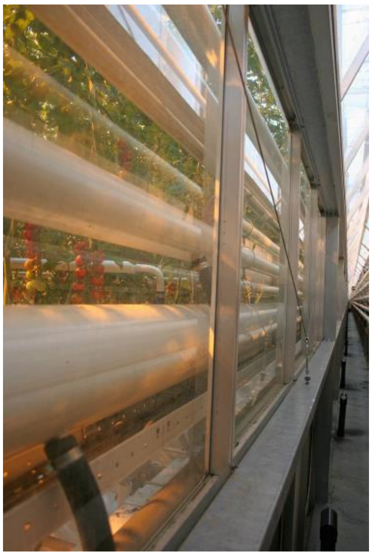
Figure 6 Faber Design Semi-Closed Greenhouse (Source: www.fabergreenhouse.com.au)

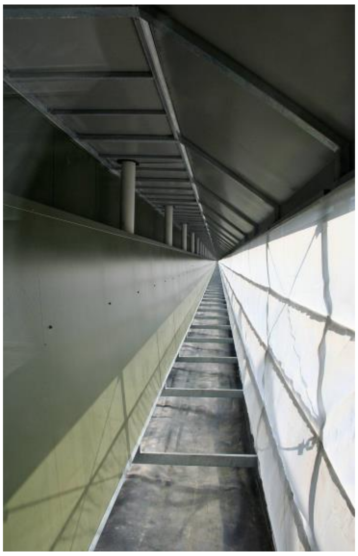
The Hybrid X greenhouse from Faber Greenhouses (Figure 6) utilises a forced air movement system with tubes underneath the substrate gutters as well as a mixing room in the gable end with a wet wall. Electronic Conductivity (EC) fans force air into the tubes depending on requirements based on climate conditions. The Hybrid X greenhouse is the first of its kind in the world to operate with full size vents in the roof. This was designed as an insurance policy in case of power failure and also to allow for a more efficient and uniform air exchange.

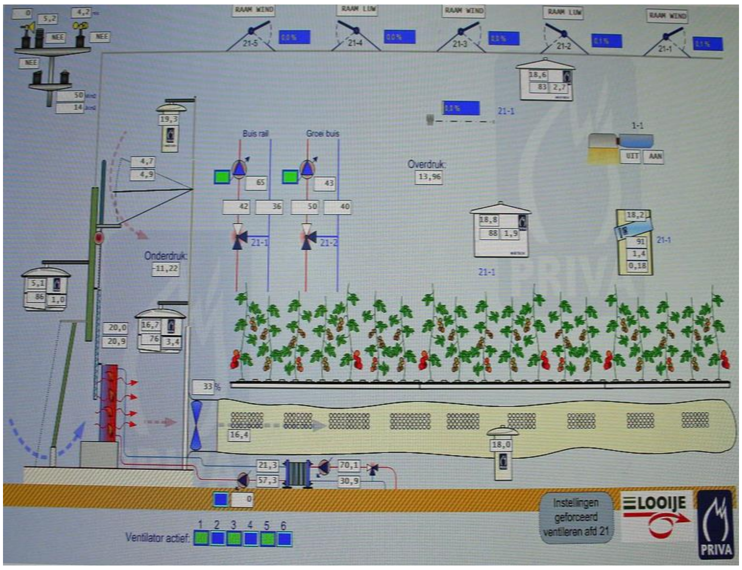
***Advantages**: This unique greenhouse combines the advantages of both the full traditional climate control and the semi-closed greenhouse possibilities with a modern pad wall & mixing room system. Depending on the external and crop conditions, climate control can be done with traditional ventilation, an almost closed greenhouse with modulated air circulation/ ventilation and Pad and Fan cooling or with an unlimited combination of options from both systems. It makes this greenhouse a real hybrid, combining traditional and future options like modern automobiles. The HYBRID X greenhouse is prepared for the future and can maximise profit out of this combination. The design saves a lot of electricity compared to greenhouses with a very limited number of vents needing year-round use of electricity consuming fans. The HYBRID X greenhouse is a big step forward and gives the grower the freedom to choose the most economical use of the greenhouse to reduce electricity costs.*

(This system is in operation only in Australia.)

4.2.4 ActivAir







A conventional Dutch-style “Venlo” type greenhouse (Figure 7), this type has vents in the roof of the glasshouse to enable natural ventilation. For warmer and more arid climates, these greenhouses are adjusted and equipped with a fan and pad system instead of vents. The ventilation is forced by creating low pressure with the fans. The ActivAir system is different in that it works with overpressure, an air-mixing-chamber and perforated tubes underneath the crop gutters. The glasshouse has an “air-mixing chamber” at the end gable, with external air entering the chamber through the gable. First passing through an insect net to keep out bugs, the air can then go through a heating element. With heating, the relative humidity of this cold outside air decreases. Inside the air-mixing chamber, the heated and dry outside air is mixed with hot, humid air from inside the glasshouse. With valves, temperature sensors and humidity sensors inside the chamber, the climate control computer is able to create the optimal air mixture. Using frequency controlled fans, the appropriate amount of mixed air is blown inside the glasshouse creating an overpressure environment. Some of this air is pushed out of the greenhouse through a small number of vents in the roof of the glasshouse. The unique feature of the ActivAir is the possibility to ‘bypass’ the heating element during warmer weather. The heating element causes friction in the air flow which usually results in a higher electricity demand from the fans. To obtain high volumes of ventilation, the fans usually need to be bigger compared to ActivAir and bigger fans are more expensive, less efficient and less accurate. In dry seasons or for locations with a dry climate, the air-mixing chamber can be equipped with a fogging system to increase the humidity level.

Figure 7 VEK Advices Group Design Semi-Closed Glasshouse at LOOIJE (Source: www.activeair.nl)

Advantages: Fewer vents in the glasshouse roof results in less shade and higher light levels for the crop and better controlled ventilation - fully monitored and computerised instead of less accurate natural ventilation. Using insect netting in roof vents usually creates significant amounts of shade but, with this system, the glasshouse is completely protected with insect netting with minimal shade impacts. Insect netting usually becomes filthy during use, especially with dust from outside air in combination with natural ventilation. With the ActivAir system, the overpressure prevents pollution of insect netting in roof vents and insect netting at the end gable is easy to clean and to replace. Preventing the entrance of bugs through roof vents, overpressure has a positive effect on temperature uniformity - with fewer differences in temperature and humidity than other systems. While crops grow better with higher levels of humidity levels that are too high or unstable can cause problems with fungal diseases. With ActivAir, the grower has a better "set of tools" to achieve good control on the climate circumstances. In summary, this system has "more tools", making it possible to change strategies for different seasons of the year or for different types of weather.

Disadvantages: In addition to a higher capital investment, a highly skilled grower is needed to achieve the saving on energy, higher yield and quality benefits of the system. Together with the right market circumstances, a higher turnover will compensate the costs and the system can be viable. Furthermore, more mechanical parts give rise to a need for more maintenance or an increased risk of malfunction.
(This system is in operation only in Europe and US.)

4.2.5 Air and Energy (Ammerlaan Construction, The Netherlands)

Figure 8 Ammerlaan Construction Design Semi-Closed Glasshouse (Source: www.glassconstructions.eu)

In all cases, the key feature delivering the most energy savings in 'the new way of growing' is the intensive insulation provided by the thermal screen. In this case, intensive insulation means thermal screening for more hours to achieve a high energy saving or even screening for more hours with a double thermal screen for an even higher energy savings (Figure 8). The aim is to be able to more or less stop dehumidifying using the pipe rail system and slightly open air vents. Excess humidity is removed by a controlled supply of dry outdoor air. Controlled air movement improves horizontal temperature, moisture and CO_2 distribution, reducing the risk of fungal infections.

Some of its **advantages** are better climate control, very high energy savings, low use of energy for the ventilation motors, lower disease pressure and constant 'slow' air flow which creates an even climate throughout the entire greenhouse.

(This system is in operation only in Europe.)

4.2.6 Closed Glasshouses

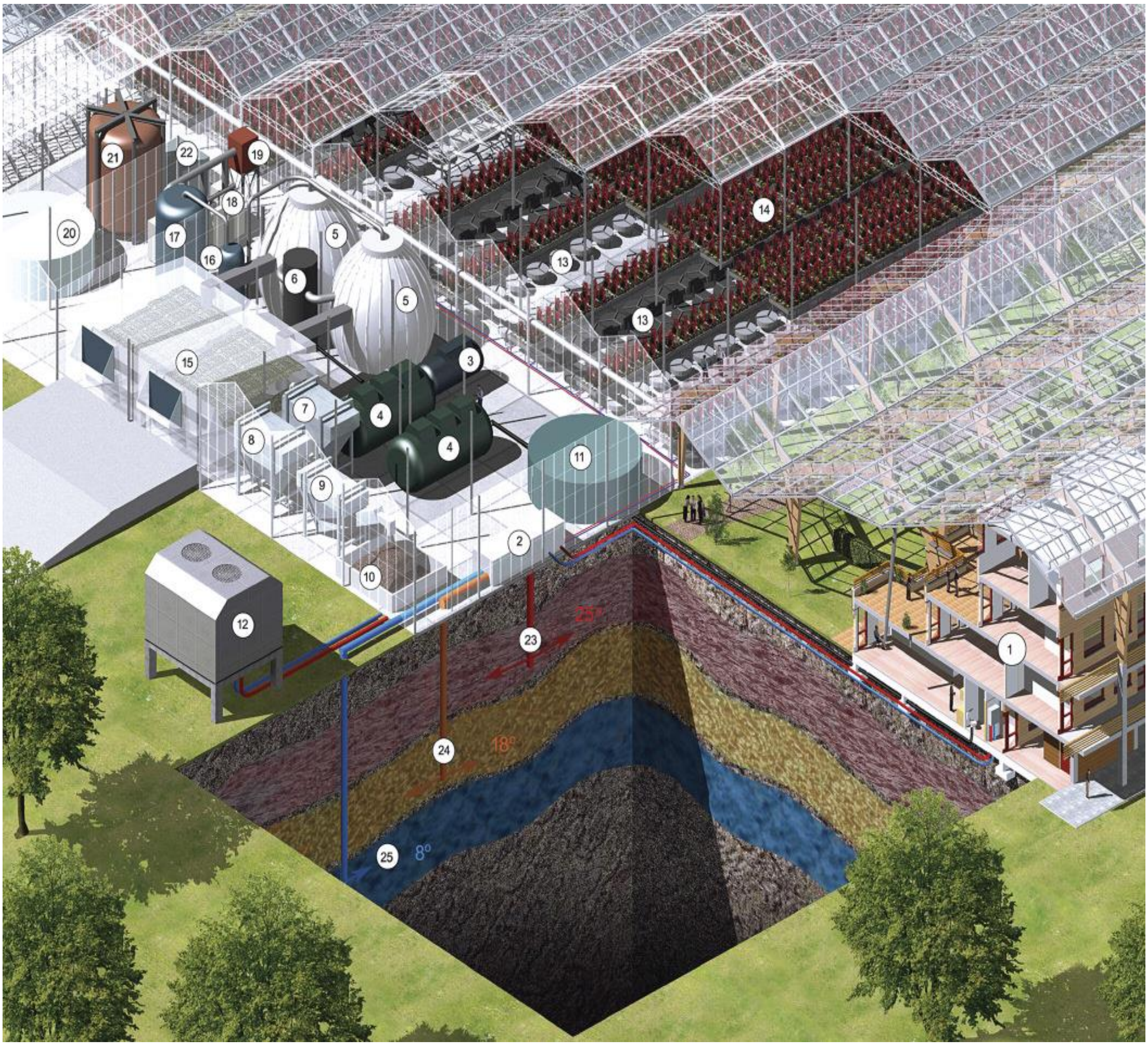


Figure 9 Closed Glasshouse Overview (Source. Practical Hydroponic Magazine, 2010)

While growers commonly refer to the semi-closed greenhouses, there are actually two types of closed greenhouses; fully closed and semi-closed. Though many growers consider them the same there are a few technical differences which give a semi-closed greenhouse some advantages over the fully closed greenhouse. The semi-closed greenhouse uses strategically located vents to provide peak cooling and employing mechanical cooling only when cooling load is lower. Since there are no ventilators in a fully-closed greenhouse, the excess latent heat needs to be removed through a heat storage system. As a result closed greenhouses use underground aquifers to buffer the climate. The technology of thermal storage improved dramatically since the turn of this century. The new thermal storage systems release heat when thermal load of the glasshouse requires it. Air passing through the mixing corridor is heated and cooled in closed glasshouse using air treatment unit's (ATU). Unlike the hydronic heating and cooling pads used in a SCG the ATU act like a radiator extracting heat energy to warm the hot aquifers and cool energy to cool the cold aquifer. While this system is the ultimate form of energy conservation it is also very expensive and requires very spersific geological conditions. Horticulture is one of the most energy hungry industries and the concept of a closed glasshouse was developed to minimise the power bill (Armstrong 2003). (This system is in operation in Europe and US.)

Chapter 5: Climate Control Systems

The term greenhouse applies to the fact that the shorter wavelength of the sunlight is absorbed by the plant for photosynthesis and longer wavelength is reflected back to the ceilings and eventually transformed into thermal energy. In turn, this helps the photosynthetic process to speed up and hence the plants grow faster. A plant management strategy which has been strategically planned and well discussed allows a grower to realise up to 20 times higher production as compared with outdoor crops of the same cultivar (REF). Controlled absorption of CO_2, optimum temperature and general plant care with micro adjustment can improve the output and quality of the produce. This can be called climate control management and it is mostly done by a senior grower through data gathering and requires lots of footwork.

Experts on thermodynamics and energy conservation do suggest installing climate control system to manage temperature, humidity and CO_2 concentration for a closed and semi-closed greenhouse (Nedehoff, 2008). A climate control system in a greenhouse has two main inputs: temperature and humidity. Dedicated software is used to trigger the mechanical modules to perform specific tasks for set amounts of time. All greenhouses need such a system to avoid human error. Automation equipment can be anything that is used to operate a greenhouse with ease. Dedicated computers and custom made software are tools that assist automation equipment. These tools read environmental fluctuations and trigger the automation equipment.

The basic process is simple; both inputs to the processor and feedback to output can be reset and adjusted. It should be noted that computers are static devices and they do rely upon authentic and reliable data. A routine physical inspection of all inputs must be carried out by an experienced staff member who can spot possible faults as quickly as possible. Having fool-proof inputs is every grower's dream because sensors often get tampered with or obscured due to sprays and moisture. Installing input sensors and networking needs to be well planned and involving an IT person is suggested by many growers. DIY-type technologists may cause more harm than good to the output. Brandsema, A. (2005) suggested that computers must be replaced frequently to make use of better technology.

What can be achieved with good climate control in a semi-closed greenhouse?

"On 16 January 2014, Adelaide was named as the hottest city on earth with temperatures reaching over 46 degrees!

The hottest and most critical moment at January 16th was around 14:00 hours. At that moment the sun's radiation was 1102 W/m^2 and the outside temperature 44. 2 degrees. Lee side vents were opened just 4%, the screen was 96% closed and the padwall and air fans were running the whole day. The Hybrid X system was able to keep the greenhouse conditions suitable for the tomato plants. At that hottest moment the maximum air and plant temperature only reached respectively 30 and 29 degrees for a short time. The plants stayed in very good condition and were 15.2 degrees cooler than outside temperature" (www.fabergreenhouses.com.au)

Climate control automation

Almost all European greenhouses have climate control automation. Such devices are standard and can be manipulated. Automation for the SCG may have one or two additional features to compensate for outside temperature.

The next generation grower will have customised software or an interface that can help make decisions based on modelling. In the past, these decisions were analysed by comparing outdoor and indoor temperature, relative humidity, solar radiation, dehumidification needs and heat storage capacity.

Better interface systems are easier to use and require inputs such as floor area, height, cultivar, glazing material, air exchange rate, solar transmittance, cooling and dehumidification ventilation, airflow rate and volume of the greenhouse.

Climate control is something growers need to be particular about at all times. A semi-closed greenhouse with strategically placed ventilators seems to be the most favoured by many growers since plants add moisture to the environment due to respiration. Respiration transfers extra water particles causing fluctuations in humidity. Researchers suggest 20oC as a desirable temperature for a tomato greenhouse (Both, 2008) while the desired humidity is 80% (Nedehoff, 1997). Note that these numbers depend on environmental factors and the type of cultivation.

The latest findings are that the heating mode and cooling mode should be set within the range 18oC-20oC and the relative humidity range (for controlling the humidification and dehumidification mode) should be 75 % - 85% respectively. Some growers, however, put more focus on humidity and less on temperature. The next generation grower is always willing to use the latest software and automation equipment. Select a computer and software from a company that provides round the clock support service and is willing to send an experienced IT representative to the greenhouse at a short notice. Computer glitches are known risks and do cause automation failures so selecting a suitable computer and trusted software is an important decision to be made right at the beginning.

Chapter 6: Irrigation Systems

Irrigation systems in a SCG are almost identical to those in a conventional greenhouse. In France, the irrigation needs are lower in a semi-closed greenhouse than in a similar size conventional greenhouse and it is also easier to recycle used water in a semi-closed greenhouse.

Plants seem to thrive in a semi-closed greenhouse due to less exposure to pests and minimal need for pesticides. Since there are no signs of invaders, some growers have not felt the need of chemical sprays for over a year in their semi-closed greenhouses. Reducing such inputs adds to the savings as spraying needs are minimised as well as the irrigation needs are reduced.

Sustainable horticulture businesses are required to conserve water and reduce energy costs by taking such measures. It is economical to install a system that has been made from quality hardware to reduce ongoing repair costs.

Chapter 7: Basic Technical Knowledge

7.1 Radiation

Light is considered to be one of the most important environmental factors affecting plant growth and development as it controls many underlying physiological factors such as photosynthesis, the energy balance, phase transition and morphology (Bakker 1994). The balance of light intensity is important primarily as it dictates the efficiency of Photosystem II. Limited intensities deprive this photosynthetic machinery of energy, whereas high irradiance leads to photosynthetic damage (photo-inhibition) (Czarnowski 1991; Tartachnyk and Blanke 2007). Maintaining optimal irradiance interception throughout the canopy is also important as factors such a leaf area index (LAI) and plant architecture can limit photosynthetic efficiency in the lower leaves (Logendra et al. 2001; Abukhovich et al. 2009).(Logendra et al. 2001; Abukhovich et al. 2009).

Less structural elements on the SCG roof means that light transmission is much higher. This is a key advantage of the concept as more light means significantly higher yields.

7.2 Temperature Management

In all tomato crops temperature affects energy production (photosynthesis), energy consumption (respiration) and energy distribution (carbon partitioning). Given adequate radiation, CO_2 and humidity energy production is optimised within 20-25° C and outside of this range production is constrained. Energy consumption is highly regulated by the 24 hour mean temperature. Given good light and strong crop tomatoes the optimal 24 hour temperature for a tomato crop is 18 - 22° C. Below this temperature growth is slow and energy is wasted. Above this, growth is fast and the plant soon becomes weak. Energy distribution is one of the most important elements of tomato growing. As a grower you get paid for fruits not leaves, therefore you want to send as much energy as possible to the fruit. This is done by steering the crop with temperature manipulations of up to -8° C/hour. The grower uses these tools to balance the crop with the aim of partitioning 70% of the plants dry matter in the fruit.

Many growers in conventional greenhouses do not have sufficient capacity to optimise energy production, consumption and distribution. In summer warm nights and limited cooling capacity means many growers in conventional glasshouses have uncontrollably high 24 hour temperatures and subsequently weak crops. Limited capacity to control temperature at critical times of the day can also lead to disruption in developmental process such as poor pollination above 27 °C.

The increased climate control capacity in SCG gives growers more tools to control these situations thus leading to better balanced higher yielding crops.

7.3 CO_2 Management

Plants produce oxygen during the day, depleting the CO_2 surrounding them and subsequently requiring the addition of CO_2 to the growing space.

Thus, carbon dioxide concentration has a significant effect on photosynthesis, growth and yield (Nederhoff and Graaf 1993). While low levels of CO_2 are not known to cause direct or indirect injuries to the plant, increased levels of up to 1000 µmol mol-1 have been shown to increase yields in most plants (up to 20%). Beyond 1100 µmol mol-1 gains in production are negligible (Kimball and Mitchell 1979). Increased greenhouse CO_2 levels have also be shown to alter the optimal temperature of photosynthetic activity in greenhouse tomato crops (Nilsen et al. 1983). Increased CO_2 may also decrease transpiration by roughly 7%, resulting in decreased levels in evaporative cooling and increased water use efficiency (Nederhoff and Graaf 1993).

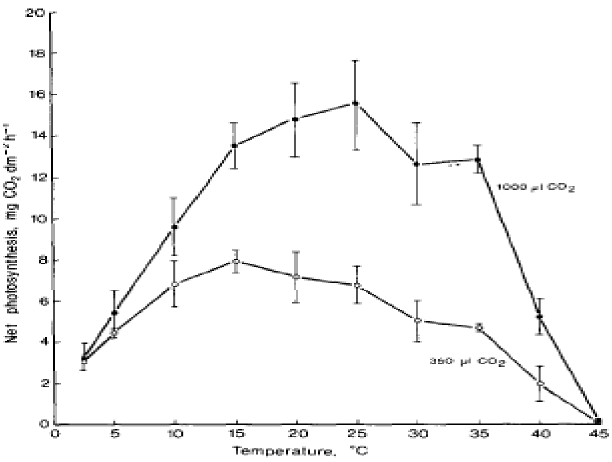


Figure 10: Net photosynthesis of leaf discs after adaptation to different temperatures and 2 different CO2 concentrations, 350 and 1000 ~1 CO 214. The actual photosynthetic rates were calculated at 2000ppm and 480ppm CO2, respectively.

Supplementary CO_2 is expensive and is usually derived from burning fossil fuels. It is in the growers' best interest to use supplementary CO_2 as efficiently as possible. A typical conventional greenhouse requires a large dosage rate of CO_2 to maintain optimal levels. A semi-closed greenhouse on the other hand requires lower dosages as the reduced ventilation means less CO_2 escapes during cooling and dehumidification. The forced ventilation of a conventional greenhouse defeats the very purpose of creating a greenhouse; replacing humid air with dry air from outside means a large amount of extra energy is required to reheat the greenhouse.

7.4 Humidity Control

Humidity in a conventional greenhouse depends on transpiration, evaporation, ventilation and condensation.

Humidity, in simple words, is a measure of water particles in the growing space which causes plants to transpire. Unfortunately the optimum level of humidity is poorly defined yet both low and high levels can significantly affect plant growth and production (Bakker 1994). High transpiration rates and low water potentials caused by extremely low humidity's (VPD >> 2.0 k Pa) may lead to a temporary reduction in photosynthesis or wilting (El-Sharkawy et al. 1985). Reduced transpiration under such conditions can have a large impact on the energy balance in the greenhouse as the associated evaporative cooling is limited (Leonardi et al. 2000). Humidity, among other things, also has a negative effect on mineral uptake (e.g. physiological deformities caused by calcium deficiencies under water stresses) and pollination (pollen tends to stick to the anther under humid conditions) (Bakker 1994; Körner and Challa 2003).

The most common production constraint at high humidity levels stems from the increase pathological pressure from fungal diseases (Grange and Hand 1987). A well-controlled growing space does not allow condensation on plants as less or no condensation also means less or no mould or fungi growth (Prenger and Ling, 2001).

Removal of extra water in the growing space is conventionally done by ventilation and/or heating. In a SCG active air exchange gives the grower much more options to improve humidity in a much more efficient fashion. Hydronic heating in the mixing corridor dehumidifies the air before it re-enters the growing climate. Active air exchange also reduces stratification in the glasshouse by mixing the air more efficiently. This act of mixing air removes the dead zones in the glasshouse which may normally have lower production or higher pest pressure.

7.5 Pests

Pests not only drain out the vital fluids and nutrients from the plants but they also leave behind white honeydew which attracts other insects and helps fungi to grow. These helipterum fungi, in fact, become a secondary attacker and kill the otherwise healthy plant.

In a standard, conventional greenhouse a grower must constantly spray to minimise the damage caused by whiteflies, thrips, caterpillars and mice as well as rodents and other insects which get into the growing space through the ventilation system. The manpower used for spraying, the cost of chemicals and the removal of damaged crop or produce can be huge. It can even multiply more if seasonal bugs get through these vents.

Whitefly is a small insect with 1-1.5 mm long silvery-white wings. A known greenhouse pest that transmits viruses, it also excretes a sticky chemical which makes sooty mould grow on tomatoes. A female whitefly can lay more than 200 eggs on the underside of the leaf and these eggs remain unseen for some time. Unfertilised eggs will grow into male and fertilised eggs into female insects (Ross Piper, pers. Comm., 2011). These eggs go through an interesting series of hatching stages until a plant feeder nymph is evolved and visible damage starts to occur. Identifying the first nymph as soon as it hatches and quickly spraying can stop a series of spraying operations. Many growers miss that early stage because the early infection stages are difficult to detect.

Damaged produce causes two main loss aspects: it has low sale value and it retains high picking and packing costs due to a more costly grading process. If the infection is untreated, then the plant itself will not thrive and the yield target cannot be met. Having whiteflies in a conventional greenhouse is a nightmare for any grower. Since the SCG has limited vents, lined with fine micro gauze, the chances of having this pest in the greenhouse is remote. Absence of this pest allows plants to grow with full vigour and hence produce a better quality fruit without any mould. The higher price received for the produce also reduces labour cost as a proportion of revenue. Health conscious consumers seem to be more than willing to pay a good price for such unblemished produce.

Thrips pose many problems by spreading tomato spotted wilt virus to fruit crops and the greenhouse crops are prone to this virus more than outdoor crops. Thrips are around 1mm long and transport all sorts of viruses to plants. Plants affected by wilt virus must be pulled out. To avoid this loss, many growers have to spend a significant portion of their crop maintenance budget on eradicating thrips but still cannot fully get rid of this pest. The manpower and costs of spraying can be disproportionately high. In a conventional greenhouse, spending a large amount of time and money on chemicals is a necessary evil. Thrip-affected crops have a reduced output, control takes a great deal of work. Extensive spraying programmes some times are to no avail in completely eradicating thrips.

A closed greenhouse eliminates these pests due to its infrastructure, specifically by not having exposed ventilation. This is another reason that makes many growers opt for semi-closed greenhouse in Europe. As mentioned above, there is more than one way to increase productivity by minimising inputs, such as removing the need for extensive spraying.

Caterpillars eat almost all parts of fruit plants. Moths manage to enter into the glasshouse through vents and then lay eggs on healthy plants. These eggs hatch into caterpillars and feed on any part of the plant. They can camouflage easily and some can be 3-7mm long. The damaged plant cannot sustain its growth and soon falls victim of these small caterpillars. It needs more than two rounds of spraying to control caterpillars; in a semi-closed greenhouse they can be completely avoided.

7.6 Diseases

There are several fungi-related diseases in the greenhouse but two main diseases can spread through rapidly if the greenhouse environment is not well maintained for a long period of time. Botrytis and powdery mildew infections are due to the greenhouse climate; powdery mildew is mainly due to temperature and humidity being either too low or too high.

Botrytis occurs due to a fungus that infects all exposed parts of a healthy plant. One can often see irregularly shaped lesions on stems. Humidity causes these lesions to become grey and eventually the plant is killed by the mouldy growth on it. Pruning or deleafing and general tidying up below the plants should be done without causing any bruises on the plant. Fungus enters into bruised stems which, in turn, kills tissues above the canker. Young fruit gets diseased firstly at the calyx end and then it spreads rapidly into all healthy parts of the plant. Cool but moist conditions normally spread the disease even faster.

Powdery mildew has become a new threat for greenhouse crops more than the outdoor crops. Experts suggest (Sharon M Douglas) that sprays only work effectively at early stages of infection. It is hard to find a chemical that can work effectively on all crops due to the wide range of fungal infections on plants. An experienced grower can easily spot light green or yellow spots on top of the leaf. If untreated, these spots quickly turn into white powdery mildew. Tomato mildew is more aggressive (Sharon M Douglas) and requires immediate attention as leaves turn brown and shrink on the plant. Spores from infected plants are easily carried to next healthy plant during plant care or air flow.

Several factors can cause powdery mildew, mainly: relative humidity, water on leaf surfaces and temperature fluctuations. Possible preventative measures are humidity control and having more spacing between plants.

Some experts suggest increasing air circulation under the plants but this could worsen the situation when infection has taken hold on some plants as spores could more easily get transmitted on to nearby healthy plants.

Having a uniform air flow in a conventional greenhouse is difficult to achieve but a semi-closed greenhouse takes care of the uniform air flow. Pruning and removing diseased plants can also spread the disease so the whole growing space needs to be cleaned thoroughly and immediately.

Some experts suggest heavy use of bicarbonates and sulphur and others recommend expensive cupric hydroxide. However, it was noted that these chemicals work only at the onset stages.

In the SCG, these measures become a secondary concern because the climate is well maintained and air circulation under the plants is more than ample. A potential threat can be kept at bay by simply eliminating opportunities for fungi to grow on any part of the plant; huge savings are then made by not spraying the crop and not spending time and manpower on pulling out diseased plants.

Semi-closed greenhouses have extra advantages when it comes to pest and disease control. SCG provides a crucial ability to assist growers in adjusting the climate precisely and both a positive pressure & micro-gauze; insect netting on vents keeps insects out of the growing space thus very minimal spraying is required. Next generation growers will, in the not too distant future, fetch a premium price point through marketing their produce as pesticide and fungicide free.

Chapter 8: Reducing Inputs

8.1 Energy management

Trimming the energy bill is going to be one major factor in increasing profitability. Knowing that greenhouses are energy hungry installations, the next question to arise is which approach should be used. What improvements are working well and what would work better for Australian growers in particular? Literature based on research done in cooler European countries may present a different financial picture to that which applies in Australia. The Australian climate, with extended sun light hours and higher temperatures, can be an advantage for next generation growers and investors. In addition, geographical separation and strict import/export rules provide a good buffer against plant diseases for both outdoor and indoor growers. All this means that Australian semi-closed greenhouses have further advantages to similar operations in Europe.

Growers prefer LPG or natural gas as an energy source. Their argument is simple: LPG's CO_2 by-product is needed for photosynthesis and an average greenhouse requires an ambient CO_2 level of at least 350 ppm. CO_2 can be increased above this ambient level for better production. Va Onna (2006) states that at 1000ppm CO_2 uptake can reach up to 70kg/hectare/hour given optimal CO_2 and adequate radiation (provides yield benefits of greater than 20 %.). This is a key advantage of the SCG as less ventilation provides results in comparatively higher CO_2 concentrations.

Growers are always looking to new technology on the market but manipulating the climate in the growing space will always be the best way to save on energy. Knowing how crops react to different conditions over the day will help to best utilise available energy sources. Experienced growers often use their foresight to rectify expensive plant care issues at a very early stage, thus reducing energy input use over the long term.

8.2 Chemical application

Though the greenhouse is a good growing space for tomatoes, it is prone to many diseases due to humidity and temperature ranges. Air movement circulates spores and surface water on leaves and moisture on the floor provides a breeding ground for a broad range of fungi to grow. In the open air, pests have natural enemies which keep their numbers down on outdoor crops. Once these pests arrive in a glasshouse through the vents then they are on their own and quickly invade the whole growing space. Natural enemies of the pests then need to be replaced by a strict expensive chemical spray program. Applying these pesticides poses additional problems which include workplace safety standards, timetabling and the employment trained staff. Despite training, there are still many instances of workers reporting injury due to chemical exposure. Expensive safety equipment also adds to overhead costs. Phyto-toxicity increases many-fold in conventional growing spaces. Overly-sprayed glasshouses lose the marketplace premium sale value. Plant pathologists John Hartman and William C. Nesmith of the University of Kentucky warn about the risks of spraying a known chemical on a different crop and accept favourable results. Many spray manufacturers do not take liability for their product for this very reason. It has been noted that some sloppy practices of spray mixing or casual spraying programmes did not produce desired outcome. Often, spraying was delayed with a 'wait and see' approach or the concentration of the spray mixture was not calculated properly due to lack of technical knowledge or not having a strict spraying checklist at hand.

A grower must take into consideration many points, such as: the invading pest, stage of infection, possible level of damage and rate of spread to other growing areas before selecting a suitable pesticide. Some glasshouses have expensive robotic spraying units operating with the hope of eradicating pest-caused diseases with health and safety standards in mind. However, these automated systems still have to rely upon technicians for proper mixing of the right pesticides. All of this requires advanced technical knowledge of pesticide and pests. A semi-closed glasshouse thus seems preferable to a conventional glasshouse as it does not allow the invading pests to enter into the growing area. Since expensive spraying is not in use, the saving itself is a relief.

Chapter 9: Minimising Waste

It is up to the next generation grower to list what they consider is waste from their glasshouse. Some growers consider some of the plant and produce material as by-product and justify their reasoning with arguments such as its usefulness for another purpose, for example: third grade tomatoes can be used for making tomato sauce. As a general rule glasshouse waste includes:

- Poorly labour hours.
- Inappropriate use of electric power.
- Excessive use of gas.
- Excessive use of water.
- Poor quality produce.
- Over-use of pesticides.
- Removal of plant material due to pests.

If a medium sized greenhouse operation proves that it is environmentally “green”, then optimum production is achieved through better climate control methods (Bakker, et al., 1995).

Water restrictions and water conservation force growers to improve water management as it is one of the measures which reflects the ‘green’ credentials of any operation. Water should be considered as a part of the energy bill and in a closed glasshouse this is easily achievable.

Although high productivity depends on precise climate control, an accurate climate control system can reduce the energy bill to a pleasing level.

For Australian greenhouses, water conservation processes, in conjunction with energy saving strategies, are the key to decreasing costs and improving production. A conventional glasshouse has many constraints; therefore, a grower has a limited number of options and very few energy conservation strategies that can be put into practice.

Planning labour hours in advance and allocating tasks at the key stages is a huge task and with some experience it can be achieved. Team work and incentives often work effectively and a lot more is achieved in less time. Staff morale and workplace environment also help to create a culture of productivity and pride.

The bottom line is that everything we do in our greenhouse impacts the internal climate and thereby productivity.

One or two new measures may not influence production but a carefully planned system will. Having a custom-built greenhouse seems an enticing thought and should be examined when it comes to expansion.

There is one significant caution, however; if the climate variations are larger than the closed or semi-closed greenhouse can cope with, management can be challenging and will require ongoing fine tuning and rearrangement of the air circulation modules.

Sizable savings can be made in reduced CO_2 loss by eliminating the ventilation system. In some cases, 90% CO_2 can be lost during cooling and dehumidification through the ventilation system - this CO_2 can be saved in a semi-closed greenhouse.

9.1 Produce Waste

Produce wastage costs tomato growers a large sum of money and, therefore, reduces profit. Along with the loss of product, extra labour hours are required to dispose of the produce. The factors that affect the produce wastage are complex and reducing it profitably needs a different kind of approach. It is obvious that the size of the fruit in a conventional greenhouse will always vary as compared to an SCG. Since the same temperature can easily be maintained in each region of the greenhouse through the climate control system, the size and shape of the produce does not vary as much.

Climate control in the SCG seems to reduce crop damage, because of the reduced need to work on the plants.

Pests cannot get into the grow space so no common diseases were seen in closed greenhouses during the study tours in several locations. This also means minimal produce waste.

9.2 Bio-mass and grower supplies

Reducing greenhouse waste needs a multi-pronged approach. Not producing any waste would be the most desirable outcome for all greenhouse businesses but, realistically, it is not possible to have such an operation in place.

Many growers strive to reduce the waste through conventional means. A multi-pronged approach involves working on ways of making use of the waste in terms of by-products. For example:

- Converting organic material removed during deleafing into biomass or compost and producing by-products which can be marketed to home gardeners or for making methane gas. Auckland Zoo Do product is a successful example of making a niche use of animal waste material in pot plant mix.
- With some expert help a digester can be set up beside the greenhouse to convert all plant waste material and used biodegradable growing supplies into compost and methane gas.
- A niche 5cm thick grow material can be produced on which to grow salads and herbs.

All plant care supplies should therefore be biodegradable - made from a material that can degrade and become part of the compost.

Installing a digester does not cost much but saves a lot. Transporting plant material to landfill often represents a good percentage of a plant care budget. Having a biomass digester on the premises not only saves money but can also become a source of secondary greenhouse activity and a supplementary source of heat energy.

In cluster farming this works even better as the heat generated during the decomposition can be used for priming hot water or as a general heating source for the central heating of nearby homes. Methane gas produced can be collected and bottled. Several pig farmers in Australia are known to have such digesters on their farms. A medium sized glasshouse generates ample amounts of biodegradable growing supplies and plant waste material all year round, enough to make a biomass unit -a viable activity.

Reducing waste through this additional activity is simpler than most growers think and it ticks all the boxes for the reducing the carbon footprint checklist.

10: Labour

A safe and happy workplace is more productive and runs smoother than the one riddled with random procedures. Health and safety guidelines and workplace safety constraints, for example during spraying chemicals, do slow down many tasks usually performed by workers in a conventional greenhouse. Some people are allergic to sprays and others have to quickly adjust to the sudden fluctuations of temperature and humidity in the greenhouse.

Pest-ridden, diseased plants must be pulled out and removed whilst maintaining health and safety practices and often mishaps happen during this activity. A diseased plant being removed comes in contact with healthy plants; in spite of all precautions a worker may accidentally touch a healthy plant while attending to a diseased plant. Transmission of spores or viruses can only be completely eliminated by having an innovative infrastructure like SCG.

There seems to be no need for overly protective safety gear and stringent health and safety procedures in a place with spraying programs as such chemicals will not be needed. During the study tour the author has met growers who have not sprayed for 18 months because they had no pests in their SCGs. One can easily see how savings in inputs can be made and overheads can be reduced, not to mention the cleaner and more user-friendly workplace which is created.

Despite all the micromanagement of labour issues, one simply cannot make a conventional greenhouse completely pest free or work-friendly. So, the SCG takes care of this dilemma.

Increasing productivity is a multi-layered task and there is more than one way to achieve this. Having an SCG seems a better choice. It is cleaner, completely pest and disease free and has very minimal climate fluctuations.

Chapter 11: Conclusions

Australian growers are operating in isolation, not just due to their geographical location but also because of the fear of their peers, which they consider as competition. This has kept hydroponics as a cottage industry, whereas European growers interact with each other freely and openly on all matters of plant care and productivity, thus creating a healthy competition.

Successful European growers are using alternative strategies and climate control procedures which are mainly based on capturing CO_2 produced in the greenhouse, the minimal use of pesticides and the efficient use of energy. Implementing these strategies in a closed or semi-closed greenhouse is attainable due to precise climate controls and adjustments.

SCG proves to be more climate-control friendly and meets the original concept of the greenhouse by retaining all the heat and CO_2. Moreover, the active climate control provides positive pressure and eliminates pests and other invaders. This, in turn, reduces the use of chemical sprays and maintains a cleaner work environment. All these factors contribute towards productivity by reducing inputs. A grower may like to use the SCG to improve on waste reduction methods and convert waste plant material and growing supplies to generate heat, methane gas and compost as by products.

Since the SCG has only a few strategically located vents for air exchange, pests cannot get in. Moreover, these vents are lined with a fine-micron screen preventing plant diseases. This results in increased production as well as a saving on crop protection chemicals, health and safety issues and enables a higher CO_2 concentration.

Though some experts mention that controlling temperature and humidity are the main challenges in the closed greenhouse (Date and include in References) the author of this report found exceptions to this in France and the USA.

Chapter 12: Recommendations

The variations between growing conditions in Australia and Europe suggest that an understanding of local weather, along with greenhouse type and structure, are important factors in deciding whether a completely closed or semi-closed greenhouse is suitable for local application. Therefore, a decision support tool for analysing potential benefits of SCG operation at specific locations using local climatic data would be useful to greenhouse owners and operators.

Energy use for heating and cooling depends on local climate and types of aquifers. The SCG thus seems more suitable for Australian growers.

There is a need for an Australian horticulture online forum where prudent growers air their concerns and share findings regularly.

Encouraging young high school graduates into the hydroponics industry through enticing support such as internships, scholarships and open days, as well as backing university undergraduates to innovate biodegradable growing supplies made in Australia, will see an exponential growth in this growing industry.

Using experienced Australian growers as consultants and promoting greenhouse produce as premium quality product through marketing tools will raise the profile of the industry. A high profile industry does not have to sell volume but premium quality products and services.

Approaching policy makers and lobbying for subsidies to start newer infrastructures in regional centres will solve many workforce problems as well as reduce the cost of transportation of the produce to the nearby market.

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Plain English Compendium Summary

Project Title:	Use of Semi-Closed Greenhouse Maximise production while minimising inputs and waste
Project No.:	1406
Scholar:	Keshav Timalsena
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Phone:	+61 447 448 588
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Objectives	The objective of this project was to convince current growers and future investors to look into a state of the art semi-closed greenhouse system as a proven mean to increase productivity with less input. This report may entice mainstream growers to make informed decisions when planning for the further expansion to their greenhouse operation. All creative and emerging greenhouse businesses are expected to be sustainable as well as ready to embrace new technologies and best practices
Background	After working in the horticulture industry for two decades, right from the grass root level to senior grower manager in two state of the art greenhouses, I was provided with a once in a life time opportunity of becoming a Nuffield Australia scholar in 2014. This has taken me to four different continents to observe, talk to and get actively involved in new types of greenhouses.
Research	We need to be creating awareness about semi-closed greenhouses for increasing productivity and decreasing waste. Conventional greenhouses have constraints and can only be stretched to a certain limit of productivity.
Outcomes	Semi-closed greenhouse infrastructure provides an ample opportunity for maximising productivity and minimising waste. The new breed of tomato growers and ambitious investors may find this report helpful.
Implications	It will not be commercially acceptable to revamp the existing mainstream greenhouse to make a room for the state of the art semi-closed greenhouse. The capital cost may pose a hindrance in making a favourable choice. To increase productivity one has to learn and implement the ways of reducing cost first.
Publications	PCA soil-less Australia magazine V. 4/2014. July 2015. Nuffield National Conference, September 2015.