DESIGNING A COMPOST-HEATED GREENHOUSE TO FOSTER SUSTAINABLE FOOD SECURITY

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ABSTRACT

Communities across the country have limited food security and rely heavily on imports to feed themselves even in the best growing seasons. The food insecurity of Canadians is amplified by continuing threats of rising fuel costs. Fossil fuels are deeply intertwined in today’s agricultural system and do not allow for any long term sustainable solutions. In order to foster food security in communities across Canada, a system that allows for sustainable, local food production year round must be implemented. By harvesting the heat produced during organics decomposition, a greenhouse can be sufficiently heated to grow food 12 months a year. This technology is not exclusive to the economically elite. By partnering the information required to construct and maintain a compost heated greenhouse along with pertinent information on specific crop requirements, this design can be utilized across the country in various climate zones to grow fresh, local and nutritious food.

Greenhouses allow for fresh vegetables to be grown year round. However, the energy required to operate a conventionally heated greenhouse can be resource intensive, polluting, and prohibitively expensive¹. By developing an ecologically sustainable greenhouse operation, local food security can be strengthened and reliance on fossil fuels can be diminished.

As micro and macroorganisms decompose organic matter, they convert carbon and nitrogen into usable compounds and in the process they generate metabolic heat. This heat can be translated into ambient heat for a greenhouse using a hydraulic system in a closed loop of recirculating pipes. The metabolic heat in the compost can be transported by continuously

pumping water through pipes from the compost, to the greenhouse and back again. In the greenhouse, the warmed water would be fed through a recycled radiator panel which in turn connects to a system of refurbished ductwork. In the greenhouse a fan can blow air across the radiator panel into the ductwork, in effect, heating the air of the greenhouse. By using relatively inexpensive infrastructure and a little ingenuity, the heat generated from the decomposition of organic material can be harvested and transferred into ambient heat\(^2\) in a greenhouse for year round food production.

There are many greenhouse appropriate crops that can be grown in a heated greenhouse in Canada year round. This thesis will examine the specific heat and light requirements of some common crops likely to be grown for the Canadian plate. With the combined understanding of compost heat generation, important greenhouse structural components and specific growth requirements of some crops, small to large scale food producers can aid in bringing Canadian communities to a place of food security and vitality.

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CHAPTER ONE: INTRODUCTION

1.0 Key Questions

How might a year-round sustainable greenhouse be built in a way to foster sustainable food security?

What information or tools will people need to implement this design?

1.1 Rationale- Why Compost Heating is an Important Topic

In today’s food system, vast amounts of foods are imported into regions like Southwestern Ontario; here, cold winter climates prevent local agricultural production from meeting consumer’s needs. The global food system requires extensive use of energy, transportation and storage infrastructures. In this scenario, there is little local food security and limited opportunity for eating locally produced food. In the past 40 years, the value of international food trade has tripled while the tonnage of international trade has quadrupled³. International foods use far more than four times the fuel and generate four times the GHG emissions³. According to Donald Ecobichon (2001), developing nations that grow many of the fruit and vegetables sold across Canada have associated health risks because:

  many older, nonpatented, more toxic, environmentally persistent and inexpensive chemicals are used…creating serious acute health problems and local and global environmental contamination.

As an alternative to importing such foods, the use of greenhouses allows for year–round local food production.

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Greenhouses use indoor climate controls to create a growing environment that is ideal for vegetable production. Greenhouses present a great option to produce food locally. However, “the energy required to produce foods locally in the cold season using conventional greenhouse technologies is resource intensive, polluting, or prohibitively expensive”\(^1\). By developing a sustainable greenhouse operation, local food security can be strengthened and reliance on fossil fuels (which are extensively used in modern agricultural practices) can be diminished.

By using relatively inexpensive infrastructure and a little ingenuity, the heat generated from the decomposition of woody material can be harvested and translated into ambient heat for a greenhouse. Microorganisms and fungi present in a compost pile generate heat as they convert carbon and nitrogen into usable compounds. There are multiple classes of microorganisms that thrive in different temperature ranges, this allows for various populations to continue the decomposition process throughout various stages during heat production\(^4\). Common microorganisms in compost can generate heat upwards of 65°C\(^5\).

One method to capture and utilize this heat is a hydraulic system in which water is passed through the compost in a system of recirculating pipes traveling into the greenhouse and back to the pile (See Figure 1: Heat Capture System and Figure 2: Heat Exchange System). When the water reaches the greenhouse, it would pass through a heat exchanger to warm the air of the greenhouse. It has been suggested that compost-heating could be applied to existing greenhouse

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operations at a relatively low cost\textsuperscript{5}. This technology is important in today’s economic climate of instability. The prospect of local food production is appealing as transport and food costs continue to rise across North America.

The assumptions of this framework are that the current food system is unsustainable and short sighted. Today’s global food system has been lead by advances in processing technology, economies of scale, exploitation of cheap labour and relatively cheap transportation costs. These factors present the illusion of economic feasibility but they overlook the associated environmental, health and social costs\textsuperscript{3}. Local food production does not have the same associated GHG emissions and fuel consumption. Canadian produced food is also less apt to abuse cheap labour and has higher standards for allowed agricultural inputs such as herbicides and pesticides.

\textbf{Figure 1: Heat Capture System}  
With permission from Brad Booker.

\textsuperscript{3} Halweil and Prugh, \textit{Local Food}
1.2 Significance of Compost Heating and its Applications

Provinces and territories across Canada are in a position of local food insecurity due to increasing threats of unaffordable fuel costs, heavy dependence on the global food trade regimes and an unstable global market. By creating a sustainable greenhouse, families and businesses can be supplied with safe, local, fresh produce on a year round basis. This research is important for citizens and policy makers alike who are concerned about having a supply of reliable fresh produce. As non-renewable fossil fuels are so intimately related with current agricultural practices, alternative production and harvesting methods are essential for any type of long term food security.
Current agricultural systems use fossil fuels for synthetic nitrogen fertilizers, to fuel farm equipment for planting and harvesting, transportation from farm to plate and all the energy required for storage in between. Another grave problem with current agricultural practices is the loss of top soil and soil fertility. Soil is being lost due to poor agricultural techniques at a rate of 10 to 40 times faster than the rate of soil renewal; this process threatens soil fertility and the future of human food security. In a greenhouse environment, soil fertility and soil loss will be guarded to a much greater degree. A transition to responsible, sustainable agricultural and away from environmentally destructive practices is necessary for long term community viability.

As Canadians, we do not have a sustainable food system to provide citizens with local food throughout the year. Massive amounts of time, money and energy are spent in producing, transporting and storing foods. In the near future, the shortage and rising cost of fossil fuels will have a remarkable impact on the aptitude and performance of intensive agriculture impacts are likely be seen in food costs and availability. Historically, it has been believed that due to our cold winter climate, the operation of a year round greenhouse would be too energy intensive to be feasible, and thus has not been readily explored. However, with the use and development of a well designed compost-heated greenhouse, year round production can become a viable option.

Typically, greenhouses are heated via boilers and fossil fuels. This is not a sustainable operation and there is a need for ‘greener’ alternatives. Replacing fossil fuel energy with a renewable energy is essential to increasing the sustainability of greenhouse organic production and this service can be provided by harvesting the heat produced in the process of decomposition of organic matter. The interior climate of a greenhouse is extremely important for successful food production. It is crucial to the success of greenhouse operation that the interior temperature remains warm. By harvesting heat energy from an onsite composing system, an opportunity for sustainable greenhouse agriculture exists. The design of the compost pile, heat transfer system, greenhouse structural components and specific growth requirement of some commonly eaten crops in Canada will be examined in this report.

1.3 Current State of Public Interest in Local Food: A Case Study of The Region of Waterloo, Ontario

In April of 2007, the Region of Waterloo Public Health Department created a document that outlines the personal and environmental health issues associated with today’s food system. “A Healthy Community Food System Plan for Waterloo Region” was a collaborative effort that aims to insure that “all residents have access to, and can afford to buy safe, nutritious, and culturally-acceptable food that has been produced in an environmentally sustainable way that sustains our rural communities.”

A few of the objectives of this project are to “strengthen food-related knowledge and skills among consumers”, “increase viability of farms that sell food to local markets” and to strengthen the local food economy\textsuperscript{11}. Some of the key strategies to achieve these objectives are to “increase farm gate sales”, “encourage local food distribution sector” and to “expand local farmers’ markets\textsuperscript{11}”. This report demonstrates a strong interest in the Region of Waterloo to address the issues associated with importing long range foods. A compost-heated greenhouse would help to meet many of the goals outlined in this report and would be part of a growing interdisciplinary approach to solving the food system issues of Waterloo Region. This project could be of value to not only the local community but organic and sustainably-minded farmers across Canada.

An assumption of this thesis is that public interest demonstrated in the Region of Waterloo is a common Canadian characteristic. The basis of this assumption is that since many locations are even less well equipped to produce local food than the Region of Waterloo, other regions will have an even stronger understanding of the need to strengthen localized food security.

\subsection*{1.4 Conceptual Frameworks for Designing a Compost Heated Greenhouse}

This project will work within the framework of sustainable food security. The framework has been designed around four categories: local food security, lifecycle analysis (LCA), alternative energy sourcing and a soft systems approach. See Appendix I for further explanation of these terms.
Local Food Security

Current food production, distribution and storage systems are wasteful and short-sighted. They do not meet the needs of local food initiatives and they offer little support to local food producers. This project will function to meet the needs that are overlooked by modern food systems. As noted by the Region of Waterloo in a study conducted between 2005 and 2007, “Canada imports approximately 40% of its vegetables and 80% of its fruits” and in addition, even during our growing season, large scale grocers offer little locally grown/produced foods. The construction and operation of this type of greenhouse would foster support for local food systems.

The Region of Waterloo, through the Public Health department, has been investigating the food system that operates in their region. A series of documents has been created that are of value here: “Food Miles: Environmental Implications of Food Imports to Waterloo Region”13, “Towards a Healthy Community Food System for Waterloo Region”12 and “A Healthy Community Food System Plan for Waterloo Region”11. These documents outline the growing concerns related the human and environmental health effect of a global food system. The Region of Waterloo has both the capability to grow healthy food and the public support for such products. Partnerships work to promote local organic food as economically and socially superior to typical long range fruits and vegetables. Similar initiatives across the country could change the ways in which Canadians eat. The current food system is inadequate and short sighted- changes can and must be made.

11. Maan, Meieddema, J and Pigott, K. Food System Plan 4, 6,7
12. Maan, M Meieddema, J and Pigott, K, Food System Plan
Life Cycle Analysis (LCA)

Life cycle analysis is the consideration of feedback loops of inputs and outputs. It is a system for assessing “the environmental impacts of a product (or service), from ‘cradle to grave’\textsuperscript{14\textsuperscript{+}}. For example, by using a sustainably managed woodlot, excess or refuse timber can be made into wood chips for the compost feedstock. The compost then makes two necessary products, heat for the greenhouse and high quality compost. This newly made compost can be used for plant nutrition within the greenhouse and in the woodlot to promote growth. Thoughtful consideration and planning through life cycle analysis allows for waste products to become necessary inputs in a closed loop of materials.

Alternative Energy Sourcing

An alternative energy source is the heart of this project. By harvesting the heat generated in a compost pile, it is feasible to heat a year-round food-production greenhouse. This greenhouse would not use fossil fuels or grid energy to heat the space. Backup heat sources could include a wood stove or perhaps a solar powered generator. Other operational energy needs should be met with renewable energy as much as possible.

Soft Systems Approach

A soft systems approach has been used to address the key design components of the greenhouse. A soft systems approach is a holistic way of analyzing the necessary inputs of a

\textsuperscript{11} Maan, M Meieddema, J and Pigott, K, Food System Plan
\textsuperscript{12} Xuereb, M and Desjardins E. Healthy Community Food System
\textsuperscript{13} Xuereb, M. Food Miles
system. For example a soft systems approach to water would promote the use of a rain barrel instead of using tap or well water. Other design considerations include a soft systems approach to energy, transportation of produce, selection of building materials, and storage. Using compost for a heat source instead of fossil fuels along with the use of solar panels instead of electricity from the grid is the soft systems approach to energy.

Other soft systems considerations will include supplying citizens with local produce instead of the consumers relying on long-range foods, using second hand and refurbished building materials and using onsite storage facilities such as cellars and cold rooms which require minimal energy inputs beyond initial construction. By taking these steps the design and function of the compost-heated greenhouse can have a much reduced ecological footprint.

1.5 Topics to be Addressed

The key components of this thesis include; a review of the academic history of compost heating, a detailed section outlining the essential components of composting, the design features of the compost heat production and capture system, key structural components of a greenhouse, as well as produce considerations. The subsequent chapters will detail the geographical applicability and the economic accessibility of this design and barriers to success.
CHAPTER TWO: REVIEW OF COMPOST HEATING

2.0 Academic Setting of Compost Heating: Past and Present

Compost heating is a relatively new science with research emerging approximately 35 years ago in Europe and 25 years ago in the United States. In 1972, Pain and Pain and in 1984 Schuchart did studies in Europe on the feasibility of compost-heated structures. “Both employed matrices of polyethylene or PVC tubes in large piles through which water was circulated by a pump, and then into a nearby greenhouse for heating\(^{15}\). Between 1983 and 1989 the National Alchemy Institute produced a series of documents on compost-heated greenhouses. They conducted research on several prototypes that were ultimately abandoned due to complications with having the compost pits inside the greenhouses and over abundant production of ammonia and carbon dioxide\(^{16}\). As compost feedstocks decompose, large amounts of heat, ammonia and carbon dioxide are produced. Excessive amounts of ammonia and harmful volatile organic compounds lead to leaf damage and stunted growth. The proposed design will have the compost pit outside of the greenhouse avoiding these threats entirely.

It is important to include a brief summary of these projects to gain an appreciation of what does, and does not work in terms of appropriate and effective greenhouse designs. Much can be learned from the success and failures of these greenhouse/compost system designs.


2.1 The Evolution of Compost Heating & its Applications: A Literature Review

Jean Pain Method 1972

In 1972 in the south of France, Jean and Ida Pain developed a system for heat and methane capture from a large compost heap. Provoked by interests in forest conservation and efficient use of resources, Pain and Pain created a system founded on sustainable forest management. Now accessible online, an English translated version of their 1972 manual “The Methods of Jean Pain: Another Kind of Garden” outlines their process for compost heating and methane capture.

“The Jean Pain Method” as it has come to be called, involves the sustainable harvesting of forest underbrush and small branches. The biomass material is recommended to be no larger than 8mm in diameter and a variety of plant material is touted as the key to producing a high quality compost. Prior to heaping the compost materials, everything is soaked for one to three days until all the material is saturated. A volume of \(4\text{m}^3\) (141\text{ft}^3) of material is cited as a minimum recommended batch size. In fact, Pain and Pain suggest that “a 50 ton heap is capable of producing hot water at 60°C (it entered at 10°C) at a rate of 4 liters per minute, for 6 months, without this interfering with or harming the compost”. Pain and Pain even go on to say that a 50 ton heap is capable of heating a structure of 100\text{m}^2 or 1076\text{square ft} for 6 months!

Further research was conducted by Jean Pain regarding the feasibility of harvesting and utilizing the methane produced during compost production. Although he found this to be quite successful and very feasible, this thesis will not investigate its applicability. Since it is intended

\(^{2}\) Pain and Pain, Another Kind of Garden, 26, 27
that the design presented here be as simple and accessible as possible, the complication of methane capture and concentration will not be investigated. For more information on methane capture, *The Methods of Jean Pain: Another Kind of Garden* is a good source of information.

**New Alchemy Institute Design 1983-1989**

Driven by an interest to lower the costs associated with heating a year round food production greenhouse, the New Alchemy Institute developed several greenhouse prototypes heated with internal compost heaps, called “composting greenhouses”. The designs incorporated compost heaps inside the greenhouses for two reasons. First, by having the compost inside, both heat and CO$_2$ produced by the composting process were already benefiting the crops. Since CO$_2$ is a necessary gas for the process of photosynthesis, it was seen as an added benefit for the plants. Secondly, by producing the compost inside, it was hoped that on-farm nutrient management would be improved and problems associated with poor nutrient management would be avoided, such as groundwater pollution and an additional nutrient export$^{15}$.

$Linda Brewer and Dan Sullivan, Compost of Yard Trimmings 2003$

A relevant study was conducted in which the heat production of yard trimmings was recorded. The study design included a passive aeration study and a forced air study. The

$^{15}$Fulford, *Composting Greenhouse*, 2

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composting process lasted 133 days - the compost was initially processed to break large materials in effect speeding up the decomposition process. In the passive aeration study temperatures ranged from 32°C to 75°C in an open air windrow compost design. According to this study passive aeration leads to much higher temperatures than does forced aeration. Figure 3: Temperature of Passively Aerated Yard Trimmings Compost, is a graphical representation of the compost heat production of yard waste trimmings over a 133 day period in open windrows.

**Zac Adams, Biothermal Greenhouse Modeling 2005**

In 2005, Zak Adams presented his thesis to the University of Vermont entitled *Biothermal Greenhouse Modeling*. His thesis is a comprehensive overview of the mechanical and biophysical processes of compost-heating and presentation of a design in which forced air transports heat, CO₂ and water vapour from a compost source to a commercial scale greenhouse operation. This is a fairly comprehensive design, however it fails to address the essential components of greenhouse design and biological and physical requirements of food crop plants. Adams’s thesis has been extensively reviewed and has been an excellent source of information, providing a good bibliography depicting relevant works.

As opposed to Adams’s work, this thesis will focus on a hydraulic system to transport heat as opposed to a forced air system for two reasons: first, a forced air system requires biological filters to scrub VOCs, NH₃ and other harmful trace emissions produced in the compost. As this design is intended to be accessible to as many as is possible, maintaining a simple design is essential. Secondly, should a scrubber system fail or malfunction, NH₃ emissions can kill plant leaves and cause unhealthy working conditions for workers.
Brad Booker, Undergraduate Thesis, Compost Heat Generation 2009

Research conducted by Brad Booker as part of an undergraduate thesis at the University of Waterloo demonstrates that an 18,000L compost pile, approximately 8’X12’ and 3’ tall would produce approximately 39,000MJ of energy over a one year period. Booker suggests that this is enough energy to meet 44% of a household’s water and heating needs when continually stocked to maintain temperatures above 40°C. Booker has estimated the set-up costs of this design at $8,050 with $5,350 being the cost of a heat pump. A heat pump monitors the heat/energy required to meet a pre-programmed thermostat temperature and would supplement compost heat with electrical heat. Using this design would ensure that the greenhouse would not fall below the desired temperature, but does rely upon conventional energy sourcing. Alternatively, the heat pump could be powered by a series of solar panels or by using wind energy at an additional cost.

2.2 Gaps and Barriers from the Literature on Compost Heating

Unfortunately, not much has been made in the way of progress in understanding the economic feasibility of building a compost-heated greenhouse. Although there have been a handful of these operations, little can be drawn in conclusions between case studies since there is wide variation between research methods and end goals\textsuperscript{1}. Biothermal Greenhouse Modeling by Zac Adams represents the most up to date and thorough examination of compost heating for greenhouse application. What it lacks, is the information required by a reader to successful apply the compost heating design to successful crop production. This thesis will aim to present relevant information on the design and set up of a compost heated greenhouse system as well as specific crop requirements for successful growth. Components of the design will be evaluated for their

\textsuperscript{1} Adams, Biothermal, 5
environmental impact through the analysis tools of life-cycle analysis, soft-systems approach and short and long term costs.
CHAPTER THREE: DESIGN OF A COMPOST HEATED GREENHOUSE

3.0 Composting Basics

The Practical Handbook of Compost Engineering defines composting as:

The biological decomposition and stabilization of organic substrates, under conditions that allow the development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to the land.\textsuperscript{17}

There are two essentially different composting scales/techniques- that of backyard composters deemed a feed system and that of municipal composting stations termed "batch" composting\textsuperscript{18}. In a feed system, fresh substrate is intermittently added to an active compost pile, in batch composting, a feedstock of compostables are processed together from start to finish and produce a peak in heat generation. In the design of a compost heated greenhouse, batch composting is the more viable option; however the technique adopted will have to be altered to best meet the needs of greenhouse heat production. A singular feedstock pile that is not added to is more feasible since intermitted additions of compost would be time consuming and burdensome. However, since the goal here is to generate heat over an extended period of time, the composting process will not be pushed to completion within a few short months as is done in municipal facilities.

\textsuperscript{17} Huag, \textit{The Practical Handbook of Compost Engineering}. Lewis Publishers, FL USA. (1993).Pp 1
There are four recognized phases of batch composting; the mesophilic phase, the thermophilic phase, the cooling phase and the curing phase\textsuperscript{19}. The mesophilic phase is the early composting stage initiated by mesophilic bacteria that raise the compost temperature to 44°C. Between the temperatures of 44°C and 52°C mesophilic bacteria become increasingly temperature inhibited and the compost feedstock transitions to the second stage: the thermophilic phase. The thermophilic phase can increase compost temperatures to 70°C (such high temperatures are neither ideal nor common)\textsuperscript{19}. Temperatures into the mid 60s are desirable after which the compost pile typically begins the cooling phase.

During the cooling phase organisms that were previously heat inhibited will return to the organic material to digest larger components. This can largely be done by macroorganisms such as nematods, insects and fungi. What remains in the compost pile beyond this point is likely lignin and other digestion resistant materials. These components can take months to completely degrade in the final curing phase. A long curing phase after the thermophilic phase will eliminate any pathogen risks associated with some composting processes. Pathogens are not major a concern for this project unless human or livestock wastes become incorporated into the compost feedstock.

In order to best harness the heat energy from the composting process it is important to align the mesophilic, thermophilic and curing phases with the coolest months of the year when greenhouse heat demand it at its peak. With this in mind, special considerations will need to be taken into account to ensure that the compost is not cooled by ambient winter temperatures.


\textsuperscript{19} Jenkins, Humanure, 42
preventing successful mesophilic and thermophilic phases. An uninsulated compost heap could potentially loose 80% of its heat to the surrounding environment, with 45cm thick insulation heat loss can be reduced to less than 10%\textsuperscript{18}. Insulation and design features of the compost pile are examined in section 3.2 Compost Heat Capture and Transfer.

The metabolic heat produced can either remain in the compost mass resulting in an increased temperature, or exit the compost through radiation from the surface, or by circulation of air flow\textsuperscript{18}. An alternative method to heat removal via air circulation is through conduction. By using a system of coiled piping that circulates liquid, internal heat removal can be achieved via heat exchange. Removing heat from the compost pile will not halt decomposition, but will slow the process. Since extended heat production is an asset for the application of greenhouse heating, increasing the duration of the composing process is essential. In order to maximize compost heat production several key components (discussed below) will need to be monitored and manipulated as necessary.

3.1 Compost Heat Production

The process of heat production in composting is well understood and can be explained through the study of microbial activity. Composting has been described as the “aerobic degradation of organic wastes where heat is released in the oxygen-consuming microbial metabolism\textsuperscript{18}”. The heat released in this process is variable depending upon a variety of factors and much research has been done to understand ideal conditions that promote decomposition. Elements to consider include the presence of soil organisms, aerobic/anaerobic conditions, oxygen content, optimal temperature, moisture content, and carbon to nitrogen ratio. These

\textsuperscript{18} Sundberg, Food waste composting. 22, 12, 11
elements can be manipulated in various ways including thoughtful organic feedstock selection and compost storage facility and infrastructure design.

**Soil Microorganisms**

Compost-heating is a process that exploits microbial self-heating through metabolic heat production. The heat produced by the microbes is essential for providing ideal living conditions for the success of those organisms\(^{20}\). The compost feedstock serves as the microbes’ life matrix: it is a source of nutrients, water and serves as its own waste sink and thermal insulation\(^{20}\). The metabolically generated heat elevates the interior temperature of the compost dictating the productivity and type of organisms that survive in the compost. As metabolic heat is created, the internal heat of the organics increases to an extent that is limiting to certain kinds of organisms. Each microbial species can only survive within certain temperature range. Populations therefore, reflect the thermal condition of the compost\(^{18}\).

Two categories of composting organisms are typically recognized: mesophilic and thermophilic. Mesophilic microorganisms are active up to 44°C and become increasingly inhibited beyond 52°C\(^{19}\). Thermophilic organisms have optimum temperatures above 45°C and become inhibited beyond the mid 60s\(^{19}\). In the early stages of decomposition, the mesophilic organism dominate, slowly becoming replaced by thermophilic species as the heat mesophils create becomes self-inhibitory.

**Anaerobic Versus Aerobic**

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18. Sundberg, *Food waste composting*, 12
Aeration is necessary for a healthy aerobic compost pile. Anaerobic compost production involving bacterial decomposition is both cooler and slower than aerobic composting\(^{19}\), and produces harmful gases. This design will focus on aerobic composting. There are several ways to manipulate the oxygen levels of a compost pile: using forced air fans, creating holes with pipes or by physically turning the compost pile. According to Rodale (1960), good compost can be made without it being turned or manipulated. In fact, research from the late 1990s has found that the process of turning compost only adds an increased oxygen level for a matter of minutes until \(O_2\) levels return to their pre-turned levels\(^{21,22}\). The inclusion of bulky materials creates tiny interstitial air spaces promoting aerobic bacteria and thermophilic decomposition\(^{18,19}\).

It is important that the compost pile not exceed a temperature of 60 degrees Celsius for any extended period of time as many of the organisms responsible for organics decomposition cannot survive in these conditions. Fungi are often absent from compost piles which are more than 60 degrees Celsius and actinomycetes (another class of decomposing organism) are absent from pile more than 70 degrees Celsius\(^{19}\). Aerating or turning a compost pile can be an effective strategy to reduce high temperatures and redistribute moisture. However, for this application of compost heat it is important to find a balance between thermal regulation for optimal decomposition and generating a lasting or at least predictable heat production curve. As the population of micro and macro organisms shifts in the pile, so too does the heat production. Aligning the heat production of the compost with the heat demand of the greenhouse will be the ultimate key to a successful compost greenhouse design.

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18. Sundberg, *Food waste composting*, 18  
Anaerobic decomposition is generally considered to be undesirable as it is cooler, slower, and produced foul gases\textsuperscript{19}. Free air is very important to aerobic microbial success, as is water and with an increase in ventilation, compost piles have the tendency to dry out\textsuperscript{18}. The use of passive aeration with perforated pipes in the compost pile achieves the goal of aeration without having significant water and heat loss associated with turning.

**Optimal Temperature**

There is slight discrepancy among the research community on the optimal temperature for organics decomposition. The ranges promoted as "optimal" vary from 35\textdegree{}-45\textdegree{}C\textsuperscript{23}, 45\textdegree{}-55\textdegree{}C\textsuperscript{23}, 45\textdegree{}C\textsuperscript{24} and 55-59\textdegree{}C\textsuperscript{25} and even as high as 55-65\textdegree{}C\textsuperscript{26}. Although these numbers are valuable to be aware of, the process of composting is less than exact. Composting has various stages and associated optimal temperatures that relate back to the microbial population occupying the pile during a given stage in the composting process. What is very important to evaluate is that the compost not exceed a temperature threshold at which beneficial decomposers being to die\textsuperscript{26}. If this over-heating occurs, not only will the composting process be longer to complete but it is also more prone to colonization from harmful bacteria such as *Samonella*\textsuperscript{19}.

\textsuperscript{19} Jenkins, Humanure, 31
\textsuperscript{18} Sundberg, *Food waste composting*
\textsuperscript{24} Brock, T. *Thermophiles- General, Molecular and Applied Biology*. John Wiley and Sons. 1986. Pp 244
Optimal Moisture Content

It is likely that moisture will need to be added to the compost matrix to promote continual decomposition and prevent the compost from drying out. Dehydration will cause microorganisms to halt their digestion of the organic waste. The water required for compost making may be around 200-300 gallons for each cubic yard of finished compost. Jenkins (2005) suggests that a moisture level of 50-60% is necessary for productive decomposition. Should the compost pile dry out to 25-45% moisture it will become prone to spontaneous combustion.

Optimal Carbon to Nitrogen Balance

Another key feature in the feedstock of compost is the ratio of carbon to nitrogen (C:N). The carbon to nitrogen balance is essential to provide a highly useful compost material but also to ensure a stable environment for the microorganisms. A ratio of 30 parts carbon to 1 part nitrogen is an optimal balance. Carbon is the basic building block of life and is a source of energy for microorganisms. Nitrogen is necessary for the production of proteins, genetic material and cellular structure. If there are limited supplies of nitrogen, the microbial population will not grow to its optimum size, and the composting process will slow down. In contrast, too much nitrogen allows rapid microbial growth and accelerated decomposition, this leads to serious odour problems as oxygen is used up and anaerobic conditions ensue. Given these circumstances, it is important to use a combination of materials in a compost system that has a ratio of close to 30:1 of C:N. Also important is the pH, finished compost should be neutral or...
slightly alkaline. Manipulation of compost pH rarely requires attention since aerobic decomposition is largely self regulating in this regard\textsuperscript{30}.

**Optimal Feedstock Options**

Given that the optimal C:N ratios are cited as 30:1, the following is a list of plant products that come close, however, as noted by Pain and Pain, for an optimal end product, a diversity of raw materials is very desirable.

<table>
<thead>
<tr>
<th>Material</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Sawdust</td>
<td>511:1*</td>
</tr>
<tr>
<td>Hardwoods</td>
<td>511:1</td>
</tr>
<tr>
<td>Potatoe tops</td>
<td>25:1</td>
</tr>
<tr>
<td>Turnip tops</td>
<td>19:1</td>
</tr>
<tr>
<td>Yard Trimmings\textsuperscript{31}</td>
<td>22:1</td>
</tr>
<tr>
<td>Grass Clippings</td>
<td>18:1</td>
</tr>
<tr>
<td>Vegetable Waste</td>
<td>12:1</td>
</tr>
<tr>
<td>Leaves</td>
<td>60-1</td>
</tr>
<tr>
<td>Livestock Manure</td>
<td>10-20:1</td>
</tr>
</tbody>
</table>

\textsuperscript{*}Has a moisture content of 40-65% which is ideal

3.2 Compost Heat Capture and Transfer

Metabolic heat produced during decomposition can be transferred to become ambient heat for a greenhouse using a hydraulic set-up that pumps water though a system of recirculating pipes. These pipes can carry warmed water away from the compost pile to the greenhouse where it would travel through the pipes of a refurbished radiator panel; this panel in turn would be located between a small fan and a system of ductwork. As the warmed water passes through the heating coils of the radiator panel, the small fan would blow the warmed air into the ductwork in effect warming the ambient air of the greenhouse. See Figure 2: Heat Exchange System on page 10.

19. Jenkins, Humanure, 34,37
According to Adams (2005), approximately 75% of heat produced during the composting process is accessible to greenhouse heat demands, and even higher when the composting pile is insulated, as is suggested in this design. Adams goes on to suggest that in order to heat a food production greenhouse, the footprint of the compost pile needs to be 27% of that of the greenhouse footprint. For example, a 100sqft greenhouse would require a 27sqft compost pile. However, Adams’ compost-heated greenhouse design utilizes a forces air heat retrieval system, with open windrow composting. Here, an insulated, thermal conduction/convection system is promoted as a superior design. Since 40-80% heat loss can be expected from an open air window compost pile\textsuperscript{18} 10.8% (40% of 27) can be removed from Adams suggested 27% greenhouse footprint to compost footprint. This promotes an approximate 16% suggested footprint ratio.

A study conducted in the early 1980s by Schuchardt found that the composting of woodchips could produce 111 kilowatt-hours per cubic meter (496,000 Btus/yd3 or 4.00 x 108 J/m3) over a six month period with water temperatures remaining between 30 and 40 degrees Celcius\textsuperscript{16}. Likewise, White\textsuperscript{32} reports that from 0.6 to 2.2 square meters (6-24ftsq) of greenhouse space can be heated by a ton of externally located compost, in his design which utilized synthetic rubber heat-exchange mats. Woodchips/ yard waste was also promoted by Booker as an ideal compost medium for structural heating due to its relatively high heat production and the decent duration of its composting timeframe.

\textsuperscript{16} Schonbeck, M. \textit{Composting Greenhouse Update}
\textsuperscript{18} Sundberg, 22
**Structural Design**

The structural design of the compost pile should take into consideration two key components: minimizing heat loss, and ease of removal of the finished compost. To address the first consideration, the compost pile should be insulated as efficiently as possible. Thermal insulation can be best provided by building the compost container into the ground. However, in order to meet the second consideration, the compost must not be sitting deep in the ground as this would be very difficult to harvest and replace. Instead, an ideal design would find a compromise between these two requirements by building the compost pile into the side of a hill (See Figure 4. Hillside Compost Storage Area). In this way, four sides of the compost container will be protected, and ease of access is greatly increased. A heavily insulated and removable cover for the top and front of the compost storage area are also highly necessary.

**Connecting Heat Source to Heat Sink**

In order to capture the heat produced by the metabolism of the soil microorganisms, there must be a system of recirculating pipes which transport water to and from the greenhouse. This warmed water will interface with a radiator panel and a small fan which in effect will raise the ambient temperature of the greenhouse. The materials used to transport the warmed water should be a recycled/recyclable material, they should have a long life span, be heat and moisture tolerant and perhaps most importantly, the chosen material needs to be able to withstand a high amount of pressure/ tension during the process of compost removal.
In keeping with the above noted constraints, recycled household radiators could be considered. Used cast iron radiators are abundant from their high use during the mid nineteen hundreds. These systems could be a viable option for the connection of compost heat production to greenhouse heat sink. Cast iron radiators are generally fitted with steel piping that transports either steam or water through the system metal coils. See Figure 5: Recycled Cast Iron Radiators. New fittings could be made to connect a few of these radiators together and to a system of piping that would travel back and forth to the greenhouse. Since the compost pile will need to be replaced periodically, either the entire heat-transport system needs to be static and durable enough to be worked on/around, or it needs to be flexible and mobile. If a cast iron radiator is to be used, a fixed design is more logical since these radiators can weight hundreds of pounds. If it is to be fixed, recycled steel piping can be acquired from Canadian companies like National Salvage. A welder will be required to connect all the components of the system.

An alternative “mobile” design could involve a single-continuous loop of PVC piping. See Figure 5: Coil of ½ inch PVC Flex Pipe. A recycling market is beginning to develop for PVC piping (the Regional Municipality of Niagara is currently running a recycling pilot program) and it is relatively inexpensive to purchase new. PVC piping has a high ability to flex with water pressure and contraction/expansion. Although PVC is likely to have a shorter life-span than steel piping, it may be more realistic to work with especially for individuals planning to operate a compost heated greenhouse on their own. Fastening the PVC to the radiator
panel will require a few high quality clamps and some careful placement. Overall, a system involving PVC piping is likely to be less expensive and more manageable on the short term than a system involving cast iron radiators.

**Insulated Compost Pit**

Since composting will need to occur during the coldest winter months in order to heat the greenhouse for year-round food production, heat loss due to ambient temperatures is a concern. With compost pile insulation of 0.05m surrounding the pile, 40-80% heat loss can be expected, 0.12m insulation protects up to 20-40% heat loss, and to minimize heat loss to below 10% 0.45m of insulation will be required\(^\text{18}\). Appropriate insulation materials include glass wool (a recycled product), foam insulations, or as is suggested here, a temperature controlled space can act as an appropriate insulator. Using recycled foam insulation in a semi-sub terrain container will remove the compost from winter winds and freezing temperatures.

**Estimated Compost Heating System Infrastructure Costs**

As is indicated in Table 2: Estimated Heating System Infrastructure Costs, there is a significant range in estimated costs. This reflects the broad range in material choices and design implemented. A heating system that uses a small car radiator fan, inexpensive recycled ductwork, an inexpensive wood chipper, PVC piping and a systolic pump could cost $900 or less. Alternately, a system that employs a heat pump, an expensive wood chipper, recycled radiators and a larger radiator panel could costs upward of $7500. These figures represent the broad range of potential costs for a compost heating system.

\(^{18}\) Sundberg, Composting Food Waste, 22
Table 2: Estimated Heating System Infrastructure Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimated Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled radiator panel with car fan</td>
<td>$25 mazda radiator $75 truck radiator and fan</td>
<td><a href="http://www.kijiji.ca%5E5%5E3">www.kijiji.ca^5^3</a></td>
</tr>
<tr>
<td>Recycled duct-work</td>
<td>$5-10 for a 4’ section of 10” ductwork (9sections)</td>
<td>Re-Store Waterloo^4^4</td>
</tr>
<tr>
<td>3-4 Recycled household radiators</td>
<td>$75-100each</td>
<td><a href="http://www.kijiji.ca%5E5%5E3">www.kijiji.ca^5^3</a></td>
</tr>
<tr>
<td>15m of PVC piping</td>
<td>$25 ½ inch riser flex pipe (50ft)</td>
<td><a href="http://www.HomeDepot.com">www.HomeDepot.com</a></td>
</tr>
<tr>
<td>Wood chipper</td>
<td>$300-$1800</td>
<td><a href="http://www.kijiji.ca%5E3%5E3">www.kijiji.ca^3^3</a></td>
</tr>
<tr>
<td>Systolic pump or Heat pump</td>
<td>$513- $5350</td>
<td>Pulse Instruments^3^5/ Brad Booker^3^6</td>
</tr>
<tr>
<td>TOTAL ESTIMATED COST</td>
<td>$900-$7500</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Greenhouse Structure

When designing and building a greenhouse, components of the greenhouse structure should be analysed under three categories: soft systems approach, life cycle analysis and short and long-term costs. As earlier noted, a soft systems approach attempts to maximize positive and minimize negative outcomes while limiting resource inputs. Under this category, building materials would ideally be recycled from and previous function and at the end of their usable life as a part of the greenhouse, the materials should again be recyclable. In this way resources are maximized and any true waste is limited.

Life cycle analysis is a system to evaluate a product “from cradle to grave”\(^{14}\). Under the life cycle analysis category, building materials will be examined from initial creation, throughout functional life to what happens with broken or damaged materials and finally what can be done with these materials after they no longer serve a purpose in the greenhouse. All materials chosen for the greenhouse design will ideally have minimal energetic production and transportation costs, long life expectancy, and at the end of this long life, materials ought to be recyclable.

The final category for evaluation is the short and long term costs of materials. Selected building materials may have a high initial cost, but costs should not be disassociated with lifespan. Generally, “cheap materials will have... a short lifetime”\(^{37}\). Materials should allow for selective replacement, should the need arise. Labour costs should also be considered when selecting building materials.

**External Material Options**

The external building material of a greenhouse will have greater costs than any other aspect of this design. The design of the greenhouse should represent a balance between the idealistic design (soft systems approach, life cycle analysis and short and long term costs) as well as “the mechanical and physical properties of the cladding materials and the specific agronomic requirements of the crop”\(^{37}\). Specific growth requirements for various crops are outlined in section 3.4: Produce Considerations.

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Planning and Building a Greenhouse is a comprehensive document written by D. Ross in 2008. It is suggested here that the lowest cost per square foot of greenhouse growing space is that of a 17 to 18 feet wide structure. This width can accommodate a central bench and two side benches, “the ratio of cost to the usable growing space is good”\textsuperscript{38}. Small greenhouses have a small volume of air relative to covering material. This means that heat is gained and lost fairly rapidly and the temperature inside the greenhouse is much harder to regulate. With these components in mind, it is suggested that a greenhouse should not be constructed smaller than 6’x12’\textsuperscript{38}.

**Frame**

Construction materials for the greenhouse frame need to be selected in conjunction with the greenhouse covering materials. The frame needs to be able to physically support the covering materials, and the lifespan of the frame must not be less than that of the covering materials. Although wood is a relatively inexpensive and accessible material, due to the moist conditions of a greenhouse, it is not an ideal building material. If wood is to be used, it must be treated to reduce rotting and structural degradation. Alternately, steel is a less accessible, more expensive material, but is well suited to the conditions of a greenhouse. Unlike wood, it needs to be constructed and installed by a labourer specialized in welding- a less common trade than carpentry.

**Wood**

If one is to use wood as the frame construction material, the following considerations should be taken:

- Internal moisture contact should be minimized by using pressure treated wood and sealed with exterior oil-based paint.
• External moisture contact should be minimized by reducing the surface area of wood on
which rain or snow can sit. When building with glass panels there should be a limited
amount of exposed wood between pains, and steep angles along the roof are
recommended, no less than a 8/12 pitch.

**Steel**

When a steel frame is used, consulting with a greenhouse construction company is
recommended, especially when glass is the selected cover material. Tight seals need to be made
between framing and covering material, this requires a skilled labourer. The major benefit of
using a steel frame is the permanency of the structure. Steel is also a very valuable metal, and it
is highly recyclable.

**Aluminum**

Aluminum is another viable frame construction material. Its maintenance is inexpensive,
and the structure will have high degree of permanency. “An aluminum frame with a glass
covering provides a maintenance-free, weather-tight structure that minimizes heat costs and
retains humidity”38. Not unlike steel, aluminum needs to be installed by a skilled tradesperson
and may add additional investment costs relating to specialized labour.

**Foundation**

The foundation of the greenhouse must reach below the frost line in the ground so as to
protect the greenhouse structure from damage caused by heaving. This means that the frame of
the greenhouse will need to be fastened to concrete footings that are a meter deep. Alternatively,
if a concrete pad floor is to be used, it will need to be accompanied by concrete footings.

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37. Briassoulis et al, *Mechanical Properties*
38. Ross, *Planning and Building a Greenhouse*
Glazing
There are three important elements to evaluate when selected greenhouse glazing materials. First, insulation and heat loss factors must be considered. Since the greenhouse design includes a heat input, it is important that heat loss is reduced and insulation is maximized. The second consideration is the ability of the glazing material to withstand weight loads, this includes wind and hail, but most importantly snow loads. The third consideration is the lifespan of the material. Each option must also be examined under the earlier headings of soft-systems approach, life-cycle analysis and short and long term costs.

Insulation and Heat Loss Factors

Table 3: Insulation and Heat Loss Factors of Greenhouse Covering Materials, provides the R-factor and U-Factor for 5 greenhouse covering materials. R-Factor is the insulation value of the material. A higher R-Factor indicates a greater insulation value. U-Factor is the heat-loss value of the material. A lower U-Factor indicates less heat-loss. We can see in this table that both single layer glass and single layer polycarbonate have poor insulation and heat loss attributes. It is also evident that double pane glass and triple layer polycarbonate are comparable.

Table 3: Insulation and Heat Loss Factors of Greenhouse Covering Materials

<table>
<thead>
<tr>
<th>Greenhouse Covering Material</th>
<th>R-Factor</th>
<th>U-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Pane Glass, 3mm</td>
<td>0.95</td>
<td>1.05</td>
</tr>
<tr>
<td>Double Pane Glass</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Single Wall Polycarbonate</td>
<td>0.83</td>
<td>1.20</td>
</tr>
<tr>
<td>6mm Double Wall Polycarbonate</td>
<td>1.54</td>
<td>0.65</td>
</tr>
<tr>
<td>8mm Triple Wall Polycarbonate</td>
<td>2.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Load Bearing

Greenhouse construction in Canada must take snow loads into consideration. The covering material must be able to bear the weight of heavy snow and strong winds. Impact resistance may be a consideration also in the case of heavy hail storms, and bending/tensile properties in the case of high winds and heavy snow\textsuperscript{37}. Load bearing may also relate to any additional weight of crops that may be hung from the inside of the greenhouse (e.g. tomato plants). As with the construction of any other structure, a building permit and engineer design/approval are necessary for the construction of a greenhouse. \textit{Ortho’s All about Greenhouses} by M. McKinly is a helpful resource for greenhouse construction tips and techniques.

Lifespan

Various building materials each have a unique ‘life expectancy’. Lifespan on its own is not an ideal evaluative quality. Instead, lifespan should be taken into consideration along with costs and ease of replacement and installation. Each covering material has its advantages and disadvantages, finding a balance between all of these qualities will lead to an ideal design.

Glass

The distinct advantages of using double layer glass covering include its high insulation value, its low heat loss value, its accessibility from new and used sources, its value as a recyclable material and its long lifespan (15 years according to Briassoulis et al, 1997). When using glass as a covering material, many panes are used allowing for selective replacing. Since glass panes have a poor ability to bend or flex on impact, glass panes are liable to break on

\textsuperscript{37} Briassoulis et al, Mechanical Properties, 89
\textsuperscript{39} The Greenhouse Catalog. \textit{Greenhouse Cover}
impact of heavy hail or excessive snow loads. A distinct advantage of glass as a glazing material
is that waste glass panels are recyclable as low quality glass for insulation or a similar product.
Since glass panes are liable to break/crack it is important that replacement panes be easily
accessible and relatively easy to install. The disadvantages of glass panes include the high initial
costs of purchase and installation and the inability of glass to flex in strong winds or on high
impact.

Advances in glass production technology have greatly improved its flex and tensile
properties. Tempered glass is quickly cooled after manufacturing which greatly increases its
strength and resilience.\(^\text{37}\)

In Southern Europe, the most widely used type of glass for greenhouses is the
‘hammered glass’. Hammered glass defines a cast glass with one face smooth and the
other one (interior face) rough, designed in that way in order to enhance light
diffusion. Coatings for glass, such as metal oxide with a low emissivity have been
introduced to combine energy savings with adequate light transmittance.

Double Glazed Glass greenhouse kits can be purchased online which are very expensive
not necessarily local. They are available in many sizes and styles including 20X20 which are
$25,000; whereas, a similar model, again 20X20 but using a double polycarbonate glazing costs
about $15,000.

**Polycarbonate**

Plastic covering offer a number of benefits for certain greenhouse applications. The most
prominent bonus is economical. Polyethylene, single or double layers are much less costly than
glass and can be installed by the buyer with relative ease. Comparatively, glass panes are
expensive and should be installed by a professional adding additional cost. However, as it is the

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\(^{37}\) Briassoulis et al, Mechanical Properties, 89

\(^{37}\) Briassoulis et al, Mechanical Properties, 94
aim of this design to take full life cycling into account, polyethylene will not be further explored. Plastic glazing has a 1-3 year lifespan after which it becomes cracked and foggy—reducing light infiltration and must then be disposed of as a non-recyclable material.\textsuperscript{37,40}

**Fiberglass**

Fiberglass is a viable alternative to glass. It is “lightweight, strong and practically hailproof.”\textsuperscript{38} It is important to note that low grades of fibreglass become discoloured and light penetration becomes drastically reduced. There are high quality grades of fibreglass that are clear, transparent or translucent which have a 15-20 year lifespan, after which a new coat of resin must be applied or panels must be replaced (ibid). High quality grades of fibreglass can have light penetration levels similar to that of glass. However, fiberglass is available only as single layer thickness and its insulation value (R-Factor) is low at 0.83.

**Internal Material Options**

When selecting internal building material heat retention value is very important. As earlier discussed, the flooring material needs to take into consideration the potential damages that can be caused by frost heave. A concrete pad has a very high initial cost, but does not have a longer lifespan than \(\frac{3}{4}\) inch gravel which is considerably less expensive. The benefit of using a concrete pad is that it has a high heat retention value and will conduct less heat with the soil. A concrete pad may extend the lifespan of the entire greenhouse since it provides greater structural support and a moisture barrier between the earth and the greenhouse structure. However, a concrete pad may not be suitable for all growers since there is a very high site preparation and

\textsuperscript{38} Ross. *Planning and Building a Greenhouse*

installation fee and a very high degree of permanence. Some growers may also wish to consider direct planting in the soil in which case a greenhouse floor is not appropriate.

**Building Orientation**

When constructing a greenhouse in North America, the building must be oriented with the roof line running from east to west. This provides an additional 25% incoming solar radiation as compared to a north-south running structure. The location of the greenhouse should also take into consideration the surrounding obstructions of light such as buildings, trees or other natural features. See Figure 7: Summer and Winter Shade Lines.

![Figure 7: Summer and Winter Shade Lines.](image)

Select a location carefully. Note: the shade lines of both summer and winter.

**Optimal Internal Temperature for Plant Productivity**

The optimal temperature range for a food production greenhouse is between 21º and 24ºC\(^1\). The following table is a modified version of a similar table provided by Eliot Coleman in *The Winter Harvest Handbook*, in appendix B, which suggests some optimal temperatures to be used as guidelines in vegetable production.

Compost heat production has the capability to provide adequate thermal insulation for food

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1. Adams, *Biothermal*
production. As earlier noted, more than 75% of compost heat is available for greenhouse heating application\(^1\) and compost regularly reaches 65 °C and remains above 40 °C for extended periods of time.

### Additional Design Components

The additional design components take into account the vast amount of social and industrial knowledge of optimal greenhouse techniques. This includes the use of vents and fans, shade cloths, rain barrels, back up heating sources and automated temperature response controls.

### Air circulation and Ventilation

Two other important design details include the placement and design of side and roof vents, and the necessity of air circulation. These are important features of a greenhouse as they can prevent plants from overheating and reduce the risks of disease\(^41\). Stagnant warm air significantly increases the risks of disease in a greenhouse, this is particularly true with tomatoe plants. “Over the last decades, considerable efforts have been made to acquire a better understanding of ventilation systems” in greenhouses\(^43\).

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15. Fulford, *Composting Greenhouse*, 2
41. Murray, Personal Conversation
During the summer months, a greenhouse can easily exceed desired temperatures and so it is necessary to have a system in place to automatically allow for ventilation. BC Greenhouse Builders recommend automatic vent openers, these units require no electricity. On warm days, heat builds up around the cylinder mechanism, and the vent slowly opens. Likewise, cool air around the cylinder causes the vent to close. In this way temperature can be controlled. Bournet et al., (2007) found that greenhouse designs with only side and windward roof vents provide the “highest ventilation rates with good air mixing inside the greenhouse”. Across all of Canada, the prevailing winds are the westerlies so vents should be placed on the western facing walls and roof surfaces. Automated venting systems are also important for reducing labour costs—automated watering systems are also available and are heavily used by commercial greenhouse operators to reduce labour costs. Automated venting systems that require no electrical input are an important design feature, approximately $170 each from BC Greenhouse.

Proper air circulation is another important consideration for the operation of a successful greenhouse. Constant air circulation with a fan can control temperature and evenly distribute the air within a greenhouse. Circulation is important to avoid the build up of condensation. Condensation and high humidity levels can lead to problems of mold and disease. Condensation can be controlled with a circulating fan, which can be turned on or off as required.

**Shade Clothes**

Another necessary design consideration is the prevention of overheating by using a shade cloth. Direct sunlight can quickly overheat a greenhouse, damaging both plants and seedlings.

and seriously setting back plant productivity. A shade cloth works much the same way a shade umbrella works at the beach. By blocking direct sun contact, the temperature of the greenhouse can be managed. Shade cloths are relatively inexpensive, ranging from ~75 to 87cents per foot of width (standard 8’ long).

Warm greenhouses, ie: greenhouses designed for year round growth of non-tropical plants, require a night temperature of 13ºC, this temperature can be met and managed through the combined technologies of compost heating, ventilation systems and air circulation management. By using the knowledge and understanding of greenhouse operations from various groups, a sustainable, long-life greenhouse can be created that can provide local food security and self sufficiency.

**Heat Sinks: Water Barrels and Rock Walls**

Usefulness of rain barrels in a greenhouse are twofold. First they act as a heat sink in the winter and a cool sink in the summer. Since water has a high heat capacity, it is an effective sink for incoming solar radiation during the day, but will not easily loose energy throughout the night. Passive solar heat gain can easily raise the temperature of a 55 gallon water barrel to 21ºC. Once this heat is ‘stored’ it escapes only as long wave lengths that are more likely to bounce around inside the greenhouse walls. There are simple strategies that can be used to store this heat for longer periods of time. By placing several large, darkly colour water barrels in the greenhouse, temperatures close to that of the day-time can be maintained during the night. Using a concrete floor or ¾ inch pea gravel can also aid in storing incoming solar energy.
Another strategy to storing incoming solar radiation is to build a rock wall on the north side of the greenhouse. In the winter this rock wall can intercept solar radiation and bounce it toward the greenhouse. This offers another inexpensive source of heat energy to warm the internal temperature of a greenhouse.

**Back-up Heating System**

As a back-up heating system a wood burning stove coupled with an automated temperature monitor system is recommended and an inexpensive alternative to a heat pump. A wood-burning stove located near to the refurbished radiator coil and fan set-up could take advantage of the existing heat distribution system. The wood burning stove would require the same damper system used in home wood stoves preventing smoke build-up in the greenhouse and allowing for proper oxygen allowance for the fire.

**Automated Temperature and Response Controls**

According to Nathan McBride of Absolute Automation, the Sensaphone FGD400 is an automated response control device that can be programmed to monitor temperature, humidity, moisture, motion and power loss. This device can be programmed to call up to four numbers in the case of a breach in programmed parameters. This type of technology can be especially important during the coldest winter months when a drop in temperature can come quickly, potentially killing an entire crop over night. The Sensaphone FGD400 is available online for $428. There are less expensive devises that monitor only one parameter which can be purchased

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for 210.60, such as the Freeze Alarm Intermediate. This device has the ability to call a personal line in the event of a breech in parameter settings\textsuperscript{46}.

**Estimated Greenhouse Infrastructure Costs**

Costs are estimated below for an 18x30’ greenhouse constructed out of glass with wood and glass with wood framing with a \(\frac{3}{4}\) inch gravel floor.

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimated Cost</th>
<th>Source</th>
</tr>
</thead>
</table>
| Glass                               | 6,000-(35,000 includes frame and construction) | o Dans Discount Windows and Doors\textsuperscript{47}  
o Re-Store Waterloo\textsuperscript{34}  
o BC Greenhouse Builders\textsuperscript{44} |
| Frame/Footings                      | $2100                           | o Allan Booker\textsuperscript{48}               |
| Construction Labour                 | $1800                           | o Allan Booker\textsuperscript{48}               |
| Vents and Fans                      | $95-170 each                    | o BC Greenhouse Builders\textsuperscript{44}     |
| Fan exhaust ventilation package for 120ft\textsuperscript{2} | $640                             | o BC Greenhouse Builders\textsuperscript{44}     |
| Shade cloths                        | ranging from ~75 to 87cents per foot of width (standard 8’ long) | o BC Greenhouse Builders\textsuperscript{44}     |
| Water barrels                       | 55 gallon $5                    | o www.kijiji.ca\textsuperscript{33}              |
| Wood stove options                  | $100-350                        | o www.kijiji.ca\textsuperscript{33} some with and without piping |
| Automated temperature controls      | $428 OR $206.10                 | o Absolute Automation\textsuperscript{46}       |
| Gravel flooring                     | $9/yard (3.65yards to cover 540sqft) $44 | o Dufferin Aggregates\textsuperscript{49}       |

**TOTAL ESTIMATED COST $10,650 – $36,500**

\textsuperscript{33}www.kijiji.ca Accessed October 2009. Under item name search.  
\textsuperscript{34} Re-Store, Waterloo. Personal Conversation. September 2009. Sales Representative of Re-Store Waterloo.  
\textsuperscript{44} BC Greenhouse Builders Limited, *Custom Greenhouses*  
\textsuperscript{47} Dan’s Discount Windows and Doors. Personal Conversation. Sales Representative of DDW&D  
3.4 Produce Considerations

There are a number of things that need to be evaluated when deciding which crops are best suited to greenhouse growth conditions. These include the photoperiodism, specific heat and light requirements and understanding the specific needs of each cultivar. Each crop has its own set of optimal growth conditions, but some crops with similar requirements can be partnered or grouped, such as peppers, tomatoes and cucumber, or spinach, swiss chard and beet greens.

Photoperiodism

70 years ago two employees of the U.S. Department of Agriculture discovered that flowering plants can be dependent on specific light conditions to induce flowering. Garner and Allard discovered that “neither tobacco nor soybeans would flower unless the day length was shorter than a critical number of hours”\(^\text{50}\). This phenomenon is called photoperiodism and plants that are governed by this process are said to be photoperiodic. Photoperiodism is the “biological response to a change in the proportions of light and dark in a 24 hour daily cycle”\(^\text{50}\). From this discovery, plants can be classified into three categories; short-day, long-day and day-neutral.

*Short-day Plants*

Short-day plants flower with a daily light cycle shorter than a critical period. Short-day plants actually ‘measure’ night length, not day length and generally require a night length of between 14 and 16 hours\(^\text{51}\). These plants typically flower in spring and fall and include strawberries, soybeans and onions.

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**Long-day Plants**

Long-day plants generally flower in the summer and will only come to blossom beyond a critical number of daylight hours, these plants also measure night length, not day length and will require somewhere between 10 and 12 hours of night\(^1\). These plants include spinach, some potatoes varieties (photoperiodism also signals tuber development), lettuce, beet, rye, wheat, mustards. In crops such as lettuce and spinach, flowering (or bolting) is an undesirable state. Since it is the leaves of these crops and not the fruits that are eaten, these crops should be grown in conditions that avoid flower production and can be considered ‘facultative short-day plants’.

**Day-neutral Plants**

Day-neutral plants flower regardless of light, after an appropriate acquisition of nutrients and growth. Some examples of these plants include corn, cucumber, peas, beans and sweet bell peppers.

**More on Photoperiodism**

Another important component of photoperiodism is that flowering can be induced without uninterrupted light provision. That is, by providing light ‘triggers’ a photoperiodic plant can be manipulated into flowering without its naturally required 24 hour light cycle. The following image has been created to demonstrate the effect of supplying short-day and long-day plants with red and far red light “triggers” and the induction of flower production. Figure 9: Photoperiodism demonstrates that if the length of darkness is interrupted with red light, long-day plants will begin flower production and if short-day plants experience a night interrupted by far red light they will be induced to begin flowering. Using this knowledge, cultivars can be manipulated into flower production outside of their natural cycles.

Why Photoperiodism is Important in Greenhouse Operation

Some commonly cultivated crops in Canada are in fact long-day plants and therefore will either need to be supplemented with unnatural light to induce flowering in the winter, or crops must be selected that are either short-day plants or day-neutral plants. Table 5: Photoperiodic Classification of Commonly Cultivated Crops presents a list of commonly cultivated crops and their photoperiodic classification.

**Fruit Bearing Plants**

Fruit bearing crops include tomatoes, peppers, eggplant, and cucumbers. If artificial light it not going to be provided to crops, short-day (or facultative short-day) and day-neutral crops should be selected for winter crop rotations. When selecting a fruit bearing crop as a part of a crop rotation
for a greenhouse, the importance of light and heat requirements should not be underestimated. See Maximizing Plant Productivity for more information on specific crop requirements.

Non Fruit Bearing Plants

These crops include all plants which are grown for their leaves or roots, but not the fruit or seed of the plant. Non-fruit bearing plants of course produce a seed, but that is not what they are cultivated for. Non fruit bearing crops include leafy greens such as spinach, lettuce, broccoli, chard, cabbage as well as onions, carrots and potatoes. Non fruit bearing crops, especially the leafy greens, are perhaps more suited to a winter time slot in a greenhouse rotation for two reasons: first, since these crops are not cultivated for their fruit, light requirements of photoperiodism are less important. Regardless of the day or night length, if appropriate thermal and nutritional conditions are provided, these crops will produce the desired structures (although more slowly than with ideal light conditions). Secondly, non fruit bearing crops will generally be more cold-hardy than fruit bearing crops rendering them more appropriate to winter conditions. Both leafy greens and root crops are more tolerant to low temperatures, this is an important characteristic to consider when designing a crop rotation. However, tubers such as potatoes and carrots store extraordinarily well throughout the winter so better space management may promote the pairing of leafy greens with day-neutral crops throughout the winter.

Maximizing Plant Productivity

The following is a table that outlines some of the most commonly grown food crops in Canada with information on specific light and heat requirements, as well as addition points for
successful cultivation. Following the chart are a number of fast facts that should be helpful in successful vegetable cultivation in a greenhouse.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Planting Depth/ Spacing</th>
<th>Days to Maturity</th>
<th>Heat/Light</th>
<th>Helpful Hints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beets</td>
<td>1.25cm deep</td>
<td>Leaves can be harvested within 4-5 weeks and tubers take 53-80 days to mature&lt;sup&gt;52&lt;/sup&gt;</td>
<td>Can be grown for their young leaves for fresh salads, or for their very sweet and nutritious tuber. Tubers are best harvested between 2.5-7.5cm in diameter. A beet seed is really a fruit which contains a cluster of seeds; this means that when the seeds begin to germinate, there is a dense system of young beet plants. These can be thinned for the young leaves, “baby beets with beet greens” or they can be thinned as the tubers develop making more room for expansion as they are harvested.&lt;sup&gt;52&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td>1.25cm deep, 35cm apart</td>
<td>80-100 days to mature&lt;sup&gt;52&lt;/sup&gt;</td>
<td>Plants will bolt if the temperature becomes too warm. After the primary head is harvested, secondary heads will develop for a month or so after the first harvest.</td>
<td></td>
</tr>
<tr>
<td>Carrot</td>
<td>Plant ½ cm deep with good compost or fertilizer</td>
<td>70-90 days to mature</td>
<td>Require deep sandy, soil with lots of organic matter. Fresh animal manure may cause carrots to split or develop hair surfaces, avoid this by composting manure for 1-2 months prior to application&lt;sup&gt;42&lt;/sup&gt;. Maintain soil moisture for sweet bulky carrots.</td>
<td></td>
</tr>
<tr>
<td>Chard</td>
<td>1.25cm deep, 10cm apart (or plant more thickly and thin juvenile plants)</td>
<td>55-60 days to mature</td>
<td>A cold hardy crop appropriate for the greenhouse during the coldest months. This crop will re-grow if leaves are harvested 2.5-5cm above the crown. Harvest when leaves are 18-23cm tall.</td>
<td></td>
</tr>
<tr>
<td>Cucumber</td>
<td>Plant seeds 2.5cm deep, 10 cm apart</td>
<td>Mature in 55-65 days from seed&lt;sup&gt;42&lt;/sup&gt;</td>
<td>Germinate seeds at 29°C. Some varieties can tolerate 10°C but 3-16°C. Cucumbers, and other members of the cucurbit family (melons, squashes and gourds) do not thrive in conditions where a cucurbit has been grown in the previous year. Consider a rotation in the greenhouse of various crops&lt;sup&gt;41&lt;/sup&gt;.</td>
<td></td>
</tr>
</tbody>
</table>

<sup>42</sup> Coleman, Winter Harvest, 75
<table>
<thead>
<tr>
<th>Vegetable</th>
<th>General Cultivation Tips</th>
<th>Harvest Period</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggplant</td>
<td>Generally, plant seeds 0.6cm to 1.25cm deep and 25cm apart</td>
<td>Will produce for about 6 weeks after first fruits</td>
<td>May provide better establishment and growth&lt;sup&gt;42&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Depending on the cultivar, plants will reach maturity between 50 to 95 days &lt;i&gt;after&lt;/i&gt; transplanting.</td>
<td>Germinate seeds at 27ºC</td>
<td>In the beginning, prune every sucker and every female flower until the plant reaches 90cm tall. At that point the plant has enough roots established to support fruit production&lt;sup&gt;52&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plant seeds in peat pots six to nine weeks before the weather is expected to reach 21 ºC night and day.</td>
<td>Grow vertically on trellis system&lt;br&gt;Heavy feeders, requiring good soil fertility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Come in many different shapes, sizes and colours. These have various development times and heat requirements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prune all suckers, but allow for two main stems instead of just one as is done with tomatoes and cucumbers&lt;sup&gt;52&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>In the first and second month after transplanting top up soil with compost or fertilizer&lt;sup&gt;52&lt;/sup&gt;</td>
</tr>
<tr>
<td>Garden Pea</td>
<td>Plant seeds 5cm deep and 45-60 cm apart</td>
<td>65-85 days to mature</td>
<td>Can be difficult to harvest</td>
</tr>
<tr>
<td></td>
<td>For baby leaf greens, leaves will mature in 30-45 days, for larger leaves or head lettuce expect 45-60 days&lt;sup&gt;52&lt;/sup&gt;</td>
<td>Peas will produce when temperatures exceed 21ºC&lt;sup&gt;52&lt;/sup&gt;</td>
<td>Peas require vertical support for strong production and easier harvesting</td>
</tr>
<tr>
<td>Lettuce/</td>
<td>Plant seed ½ cm deep or sprinkle thickly over the surface of planting bed/box</td>
<td></td>
<td>Lettuce has a very high ability to intercept light and bulks up quickly during early development, however, with time lettuce become less efficient due to shading from other leaves&lt;sup&gt;50&lt;/sup&gt;</td>
</tr>
<tr>
<td>Baby Greens</td>
<td>For baby leaf greens, leaves will mature in 30-45 days, for larger leaves or head lettuce expect 45-60 days&lt;sup&gt;52&lt;/sup&gt;</td>
<td>A shade cloth is necessary if temperatures exceed 27ºC.</td>
<td>Baby leaf salads are an ideal crop for winter production as young leaves are far more cold tolerant than mature ones&lt;sup&gt;42&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>A shade cloth is necessary if temperatures exceed 27ºC.</td>
<td>These crops will bolt in heat and thrive in cooler conditions.</td>
<td>Baby leaf greens include: red lettuces (eg Red Salad Bowl), green lettuces (eg Black Seeded Simpson), broad leaf arugula, sylvetta arugula, endive, narrow stem chard, claytonia, minituna, spinach, mache, water cress and baby beet leaves.</td>
</tr>
<tr>
<td>Peanuts</td>
<td>Plant the seeds 2.5cm deep and 15cm apart</td>
<td>110-145 days to mature</td>
<td>Plant in hills or large pots, about 2 inches deep, 3 seeds per hill/pot.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Require 4-5 months to mature with temperatures not dropping below 10ºC</td>
<td>Plants produce 50-60 peanuts each&lt;sup&gt;52&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plants are leafy and about 20 inches tall</td>
</tr>
<tr>
<td>Peppers</td>
<td>Plant seedlings ½</td>
<td>Start seeds six to eight weeks</td>
<td>Prune all suckers, but allow for two main stems instead of just one as is done</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Germinate seeds at 21ºC,</td>
<td></td>
</tr>
</tbody>
</table>

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41. Murray, Personal Conversation  
52. (Heriteau, Guide to Vegetables, 112, 250, 121, 230  
42. Coleman, Winter Harvest 96,100  
50.  

<table>
<thead>
<tr>
<th><strong>Snap Beans</strong></th>
<th><strong>cm deep</strong></th>
<th>Before planting weather, mature in 45 days and produce for 6-8 weeks weather permitting 52</th>
<th>With tomatoes and cucumbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spinach</strong></td>
<td><strong>Plant seeds 1.25cm deep</strong></td>
<td><strong>40-65 days to mature</strong></td>
<td>Harvest leaves and not the whole plant to maximize the plants productivity.</td>
</tr>
<tr>
<td><strong>Tomatoes</strong></td>
<td><strong>Plant seeds 1.25cm deep in peat pots</strong></td>
<td><strong>Plants will take 65-100 days to reach fruit production.</strong></td>
<td>There are determinant and indeterminant varieties, indeterminant are more suited to greenhouse conditions because these plants grow continuously until it becomes too cold. These plants will continue to produce fruit over an extended period of time 52</td>
</tr>
</tbody>
</table>

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41. Murray, Personal Conversation  
42. Coleman, Winter Harvest, 96, 100  
52. Heriteau, Guide to Vegetables 204,129, 130, 210
A lack of calcium can cause blossom-end rot, a condition of a leathery scar on the underside of the tomato. Prune to a single stem by removing all suckers. Use commercial tomato clips about every 30-40cm. Limit fruit clusters to 4 in a bunch, 5th often becomes “catfaced.” Remove lower branches as fruit develops and are harvested allowing for greater airflow and concentrating plant resources on newer tissue.

**Zucchini**

- Plant seeds 4 to 5cm deep
- Produce large plants, which require a good 60cm of space between plants
- 45-55 days to mature depending on variety
- Heat loving crop, does best in a fairly dry environment
- A good choice for summer cultivation
- Gold Rush is a nice variety, 18-20cm long
- Plants produce copious amounts of fruits
- Mid season application of compost is recommended for extending production

**Fast Facts**

- Crop rotations are a good way to promote soil health and decrease the incidence of disease and pest problems. Crop rotations are especially important in greenhouses where crops are planted directly in the greenhouse soil.

- A soil pH of 4.5-5 is ideal for plants to uptake nutrients. Soil pH can be manipulated for greater acidity using nitrogen rich compost and for greater alkalinity with lime or bone meal.

- Bone meal and crab meal are good sources of calcium which can be added to soil additives like compost or fertilizer.

- For coastal growers, seaweed is a great source of N, and a great addition to a compost matrix

- Cucurbit plants (cucumbers, melons, squashes and gourds) produce individual male and female flowers, and some cultivar of cucurbits have plants that are monoecious, that is, one plant is either male or female, but a single plants does not produce both male and

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42. Coleman, *Winter Harvest* 96, 100
52. Heriteau, Guide to Vegetables, 112, 250, 121, 230
female flowers. It is the female flowers that produce the fruit, however, without the male flowers, the fruit will not develop since they will not be fertilized. When planting monoecious plants, one male plant is required for every 5-6 female plants\textsuperscript{52}

\begin{flushright}
\textsuperscript{52} Heriteau, \textit{Guide to Vegetables}, 106
\end{flushright}
CHAPTER FOUR: GEOGRAPHICAL APPLICATIONS OF COMPOST HEATED GREENHOUSES

4.0 Adapting Compost Heated Greenhouses to Different Climate Zones

Across Canada, climate zones range from 0 (the coldest) to 8 (the mildest). See Figure 10: Plant Hardiness Zones of Canada 2000: Agriculture and Agri-Food Canada. These values aid in the understanding of vegetation distribution across the country. In order for this design to be useful for people in many regions of Canada, it is important to understand the specific requirements of various crops. This includes thermal requirements (to be met by an appropriately constructed compost pile), light requirements and nutritional requirements. The ability of compost to produce enough heat is not the limiting factor for successful food production in this design; in fact it is more likely that heat will be produced in excess of heating demands. In remote communities in the far north, a more likely limiting factor will be access to woody brush material for composting. In other parts of the country, limiting factors may include day light, and healthy soils.

Communities in climate zones 0-3 will need to design their greenhouses to account for extreme cold, heavy snow loads and high winds. In northern communities especially, plants should be selected which require minimal light to produce fruits or leafy green material. Likely selections will include cold-hardy greens such as chard, kale, spinach, mache (corn salad), arugula, beet greens and broccoli. Long-day plants are not likely to be successful without much additional heat and artificial light. The following image has been taken from the Agriculture and

1. Adams. Biothermal, 68
5.0 Barriers to Practical Scenarios for Compost Heated Greenhouse Application

Although this design is intended to be economically accessible, there is still considerable initial cost to acquire the necessary materials and construct a compost heated greenhouse. Cost is likely to be the greatest barrier to the extensive implementation of this design. The second largest barrier to success will be the lack of specific knowledge of how to operate a food production greenhouse. This thesis provides a solid base of information to be built upon, however, a practical understanding needs to accompany this theoretical framework and must be acquired hands-on.

5.1 Recommendations for Future Research in Compost Heated Greenhouses

The next step for the successful implementation of this design across the country will be the construction and operation of compost-heated greenhouse prototypes which takes into account the important considerations covered in this thesis. Past and current research into the heat potentials of various compost materials have been completed and suggest that the metabolic heat produced in decomposition can adequately meet the thermal requirements of vegetable crops. A series of compost-heated greenhouse prototypes across the country would be of great value in solidifying these claims.
CHAPTER SIX: CONCLUSION

The food system that is in place in Canada today was designed when oil was cheap and plentiful. The industrial scale of food production involves fossil fuels at nearly every stage of production, from the synthetic fertilizers, pesticides and herbicides to the machinery that prepares the soil, plants the crops, harvests and processes the crops, to the packaging, transportation and refrigeration along the way. This is not a sustainable system, it leaves communities across the country in a state of food insecurity and it discourages the support of local food production through supplying overabundant, easily accessible, cheap produce year-round. In order to attain sustainability we must recreate the food system. This new system must be based upon local food production, maximizing local resources and minimizing dependence on fossil fuels.

In order to produce food year round in communities across Canada, greenhouses can be used to maximize the growth of produce. In keeping with a sustainable design, an ideal greenhouse would be heated and maintained with renewable resources. A compost-heated greenhouse design manipulates the metabolic heat produced in the breakdown of organic material for the application of greenhouse heating. By providing interested individuals with the necessary information of such a design as well as specific information of crop requirements, local food production can hopefully be strengthened in a sustainable way.

Heat production values of compost vary according to compost feedstock, moisture level and size. As such is the case, there is no simple equation to derive how large a compost pile must be to heat a greenhouse of a specific size. However, a number of studies have been conducted
since the mid nineteen seventies on the use of compost generated heat to warm a variety of structures. From these studies it is understood that it is very feasible to heat a year-round food production greenhouse through the use of metabolic heat production of decomposition. Since no hard rule exists, there will be a need for a back-up heat source especially during initial operational years. There will perhaps always be a need for such back-up heat since many plants cannot tolerate temperatures below -9°C and often die at much warmer temperature than that.

A compost-heated greenhouse design involves the capture and transfer of metabolic heat from compost to the ambient air of the greenhouse. This transfer can be accomplished by using a system of recirculating pipes that travel from the greenhouse, to the compost pile and back again. PVC piping or recycled household cast iron radiators could be set inside the compost pile where water would be pumped through the coils warming the water and transporting that warmed water to the greenhouse. At the greenhouse, the piping would connect to a radiator panel where again the water would travel through these coils, but here a fan would blow the now warmed air into a system of duct work that in effect would raise the ambient temperature of the greenhouse. See Figure 2. Heat Exchange System on page 11.

It has been suggested that the organic biomass feed stock could last for several months to as much as 2 years in length. The compost pile used by Jean Pain in 1972 in France was 50 tonnes and heated his 5 bedroom home for 18 months. White’s trials from the 1980s demonstrated that between 6-24ftsq of greenhouse space can be heated by one ton of externally located compost. Also in the mid ‘80s, Schuchardt found that the composting of woodchips could produce 111 kilowatt-hours per cubic meter of compost over a six month period with water temperatures remaining between 30 and 40°C. These systems promote the success of the
concept. By using this information in combination with a great social accumulation of knowledge and understanding of greenhouse efficiencies and crop requirements, it is believed that a very sustainable food production greenhouse can be created.

An ideal greenhouse design runs east to west and includes double pane glass for high light infiltration, low thermal loss and the great ability of glass to be recycled and replaced as panes are broken or damaged. A frame can be constructed out of pressure treated wood or welded from steel or aluminum. Depending upon the availability of materials and skilled labour, individual greenhouse builders will need to decide upon appropriate frame construction materials. Another important decision for the greenhouse builder will be the type of flooring material selected; both ¾ inch gravel and concrete have their advantages but must be selected in accordance with resource availability and cost considerations. Other important design features include the use of vent and fans, shade cloths and heat sinks.

The cost of a 18x30’ compost heated greenhouse design could range from 11,550 to 44,057 depending on selected building materials and heat-system design. These estimated costs are the result of combined estimations for the various building materials from sources such as the online trading site Kijiji, the Re-Store Waterloo, Dans Discount Windows and Doors and a contracting company was contacted for an estimation of frame and construction costs. The cost of other design elements comes from BC Greenhouse Builders who have a comprehensive online store. This greenhouse could ultimately cost more or less than these estimated figures should a builder decide to stray from the recommended design. For example, the use of a plastic covered hoop-house with this design could cost as little as $2800.
Beyond the physical design of the greenhouse, another key component to the successful operation of a year-round food producing greenhouse, is the provision of information on how to cultivate common crops. Important considerations include the photoperiodism of various plants and their specific heat and light requirements. Such information has been provided as a guideline for new growers, as well as a list of recommended books and manuals which contain massive amounts of information on successful vegetable cultivation. Compost generated heat has the ability to warm the ambient temperature of a greenhouse, however, it is essential that growers understand the specific heat requirements of their crops in order to successfully supplement or reduce heat as required. Climate zones across the country vary significantly, communities in the north will ultimately need larger compost heat sources and more stringent monitoring of heat output. There are many crops that will grow successfully in the low light conditions of the north, but appropriate heat must be provided. Likewise, in the warmer regions of the country, compost piles will not need to be as large and closer attention may be needed in ventilation and air circulation to avoid the spread of disease and molds, especially in the summer months.

The compost heated greenhouse design has the potential to change the way that Canadians grow and purchase their food. In an era of rising fuel costs, economic instability and food insecurity, the compost heated greenhouse design provides hope for change. Our food system is ill suited to meet the demands of the Canadian population, provided here is the information needed for new and seasoned growers alike to begin a new phase of Canadian agriculture; one that will strengthen local economies and move away from dependence on a food system that cannot be sustained.
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Horticulture Research International


TERMS AND DEFINITIONS

Life Cycle Analysis

“Life cycle analysis is an apparently straightforward methodology for assessing all the environmental impacts of a product (or service), from ‘cradle to grave’”14.

Ecological Footprint

“Ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area”54.

Sustainable food security

“Sustainable food security exists when all people have and exercise a stable access (physical and economic) to healthy and culturally-appropriate food, in a food system that contributes to biophysical sustainability, social integrity and social justice, and which offers favourable conditions for attitudes and choices that help promote these goals”55.

14. Ayers. Life-cycle Analysis