Produce Productions for A Remote Community

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Abstract

Much of Canada's Northern population consists of small communities with populations of a couple hundred to slightly over 1000 people. These towns and villages exist in harsh climatic regions where the ground is frozen solid all year round and the temperature is below O degrees for most of the year. The people living in such places eat very little fresh produce, this is because vegetables are not part of their traditional diet and also more importantly, fresh produce is non-existent or extremely hard to come by.

Any Fresh food has to be flown in by plane due to the fact that there are no complete road networks in that area because of the permafrost. This additional transport cost greatly increases the price of vegetables in these communities.

To deal with this problem, we will design a greenhouse which can withstand the harsh conditions up north. More specifically, we have chosen the city of Cape Dorset. With a population of 1236 people, we believe a facility capable of growing produce locally would benefit the community greatly.

About the area

→General background

Cape Dorset is a small Inuit town located on the northwest shore of Dorset island in the Qikiqtaaluk region of the province of Nunavut, north of Canada. It is located in Latitude: 64:15:03 N and Longitude: 76:32:35 W.

Cape Dorset is considered the Inuit art capital for its world famous prints and soapstone carvings. Its Inuktitut name means “tip of the island.” The only method to get there is by plane because it is very challenging for them to develop a decent road system. The population was 1236 with around 250 residential housing units as of the 2006 Census with an estimated increase of about 7.7% per year. Cost of living there is 65% higher than Montreal due to the high transportation cost of goods and scarcity of materials. Major activities to make a living for people who reside there are carving, print-making and hunting. The power there is supplied by Nunavut Power Corporation and water is taken from pipelines connecting Tee Lake, chlorinated before trucking to houses.

Picture of a few Cape Dorset residents, taken during winter

→Climate of the area

The climate of Cape Dorset is harsh just like any other Arctic regions. The daily average temperature is around -24 Degrees Celsius during winter and 5 Degrees Celsius during summer; the lowest temperature recorded was -43 whereas the highest recorded was 25. Furthermore, there is a great fluctuation in temperature between daytime and nighttime.

→Sunshine hours

With the aid of **{**Taylor, W. (1996). Sunshine.} method of calculations for Sunshine hours, the estimated sunshine hours for Cape Dorset during April is approximately 14 hours, for May, it's ~17.5hours, ~20.2hours during June, ~19.8 hours during July, ~17 hours during August, ~13.5 hours during September and ~10 hours during October.

Literature reviews

Types of Greenhouse Produce

→Tomatoes

Tomato is a popular fruit grown all around the world due to the belief that their consumption is very beneficial to human health. It is an herbaceous plant native to the central and south of North America. Tomato plants are indeterminate to growth which means they continue producing fruit upon new growth. They can be seeded into various types of soils as well as other soilless mediums such as rock wool or foam cubes. During germination, the temperature to be kept is around 22-26 degrees Celsius and the relative humidity should be kept between75%-90%. The expected duration for tomato seedlings to emerge is 7-10 days and the seeds should be planted 1/4 inch deep, separating each seed with a distance of 8 inches. The fresh sprouts should be kept under a fluorescent light which should be kept on 20 hours a day. When they are 1 1/2 inches tall, it is better to transplant them into their individual 6 inch containers. The medium in which the plants will be grown should be kept in a moist condition and the nutrient solution with fertilizer dissolved in water should be held at a pH between 5.6→5.8 for optimal growth. The totally yield of each individual plant is about 22 to 26 pounds of fruits annually and the total growing process takes about 14 weeks to complete.

→Cucumbers

Greenhouse cucumber production is very common throughout the world, like the tomato, it is a warm season crop with requires a growing temperature of 26-29 degrees Celsius and plenty of light. Optimal germination occurs at 29-33 degree Celsius and a relative humidity of 80%. Another similarity to tomato is that cucumber plants are indeterminate in growth, which means they continually produce fruit on new growth. However, Cucumbers are very sensitive to low temperatures; the minimum temperatures should not be lower than 18 degrees Celsius for sustained production. Also like the tomatoes, cucumbers can be seeded in flats of rock wool or foam blocks and they should be each transplanted to an individual pot in the greenhouse when they are large enough, which usually takes around two to three weeks after proper seeding under ideal conditions. Each plant should be provided 6 square feet of space in the greenhouse. The total expected yield will depend on the growing conditions, each well managed crop can yield up to 100-120 pounds of fruits annually. The process from seedling to harvesting takes around 12 weeks.

→Peppers

Pepper is also a very popular greenhouse crop grown around the world. It requires a long growing period (1-3months) to reach transplant size depending on the greenhouse conditions; therefore, fertility is mandatory after seedling is completed. Like tomato and cucumber, the optimal temperature for germination of pepper seeds lies between 26 and 29 Degrees Celsius and relative humidity should be kept at about 75%. After the plants reach the size to be able to transplanted, the temperature of the greenhouse can fluctuate a little bit more (from 16-32degrees Celsius). Like the tomatoes or cucumbers, peppers can also be seeded in rock wool medium, but it also likes nutrient-rich soil so we will have to ship in the soil which enables optimal growth for pepper. Pepper is also an indeterminate plant which continually grows new stems and leaves. For this reason, the plants have to be pruned and trained on a regular basis in order to ensure an optimal growth environment for maximum fruit production. The average yield for greenhouse pepper is 10.5kg/m^2 in a growing cycle of approximately 20 weeks which makes an annual yield of 27.5kg/m^2.

→Raspberries

Greenhouse Raspberry production is a relatively new concept in North America with the first commercial raspberry greenhouses only having come into existence within the last 20 years. The demand for greenhouse raspberries stems the fact that raspberries available to consumers during winter months are mostly grown in Central and South America. The raspberries that arrive are then usually very expensive and of poor quality because Raspberries are a delicate fruit that are easily damaged during the shipping process.

It should be noted that there two distinct types of raspberries; primocane-fruiting and fluoricane-fruiting each have their own distinct life-cycles, plant density, harvest yields and growing requirements. For the purposes of this project we shall only be referring to the primocane-fruiting variety.

Raspberries are very different from the other greenhouse plants previously discussed. First off they are a cool season vegetable, for optimal germination and early growth the greenhouse should be kept at a temperature of 10 degrees Celsius during the night and 18 degrees Celsius during the day. Each plant should be in its own potted soil container with rows of containers 0.6m between containers and 1.6 m between rows for an average of 0.77 m^2 per plant. Once the plants begin to leaf-out and develop an extensive canopy the temperatures should be raised to 13 nighttime and 21 Celsius daytime and should be kept at such until time to harvest. The harvest season for primocane varieties can last for as long as two months. After harvest, the plant should be cut to below the fruiting zone so the cycle can start over again. During the first year of harvest the plant will only produce around 500g however in subsequent years each plant has an average yield of 1.7 kg

Power, Water and Labor Supply

The local power supply is provided by the Qulliq Energy corporation where energy costs 48.49cents per kilowatt hour, this makes it 7 times more expensive than Montreal. Quality of water is critically important in greenhouse production; dissolved minerals in water (Calcium and Magnesium in particular) can create serious problems for plants. Moreover, chlorinated water is proved to be harmful for plant growth especially for lettuce. Therefore, quality of water supply should be inspected. {George E. Boyhan, D. G. a. W. T. K. (2000).}

Although much of the work in crop production is repetitive and tedious, quality of labor should not be neglected. {George E. Boyhan, D. G. a. W. T. K. (2000).} One should hire greenhouse keeper with adequate knowledge on plant characteristics as well as basic knowledge on machineries like power generator and artificial lightings.

Irrigation

Since the 1980s, subsurface Drip Irrigation (SDI) has become popular as the most efficient irrigation system (Camp, 1998). Dripping irrigation is a low-pressure system that delivers water slowly and accurately to plant roots, drop by drop. {Northern garden supply} It has many potential advantages, namely minimizing soil water evaporation and nutrient leaching into soil, maintaining a uniform water distribution thus results in greater control of irrigation water and nutrients, increasing flexibility to match various soil type and plant rooting depth e.t.c, ([Camp et al., 2000], [Trooien et al., 2000] and [Hillel, 2004]). The system is used to irrigate many areas such as gardens, trees, greenhouses, row crops, e.t.c.

For greenhouse usage, a programmable timer can be integrated into the irrigation system to ensure that the plants are irrigated in the right time and to avoid over or under-irrigation. Furthermore, drip irrigation keeps the leaves dry to avid the development of molds and fungus on the crop.{Northern Garden supply}

Heat loss and Coverings

Heat loss in a greenhouse is a very important consideration and is one of the most expensive costs of any greenhouse facility. There are several types of heat loss to consider when choosing which type of material to use during construction. The three main types of heat losses are conduction, infiltration and radiation.

Heat loss through conduction is where most of your heat loss occurs; this amount depends primarily on the material used to cover the greenhouse. Heat loss through conduction can be calculated using the formula Ht=A*U*(Ti-To) where Ht is your transmission heat loss, Ti is the temperature inside, To the temperature outside, A is the total area covered by your material, U is your heat loss factor measured in $W/m^{\wedge 2}/K$ (metric) and (Btu/hr)/ft^2/^{o}F (imperial) so for example something with a U value of 4 would need would require 4 extra watts of heating for every exposed square meter for every 1 ^{0}C rise in temperature. Every material has its own specific heat loss factor and the lower the better. Double layer glass has a U value of 3.97 $W/m^{\wedge 2}$ most greenhouse materials coverings range between 3-7. Also it is important to note that for calculating conduction heat loss for floors and walls of the greenhouse you would modify this formula to Ht=A*U*(Ti-Te) where Te is the temperature of the earth.

The heat loss through walls, windows, doors, ceilings, floors etc. can be calculated as

$H_t = A\ U\ (t_i - t_o)$ *(2)*

where

H_t *= transmission heat loss (W)*

A = area of exposed surface (m^2)

U = overall heat transmission coefficient (W/m^2K)

t_i *= inside air temperature* (^oC)

t_o*= outside air temperature* (^oC)

Heat loss through roofs should be added *15%* extra because of radiation to space. (2) can be modified to:

$H = 1.15\ A\ U\ (t_i - t_o)$ *(2b)*

For walls and floors against earth (2) should be modified with the earth temperature:

$H = A\ U\ (t_i - t_e)$ *(2c)*

where

t_e*= earth temperature* (^oC)

The second most important loss is through air infiltration. No greenhouse can ever be perfectly airtight and so air cold air from outside will slowly infiltrate and replace warm heated air inside. The amount of heat loss can be calculated as follows:

$$\mathbf{Q = c_p\ \rho\ n\ V\ (t_i - t_o)}$$

where

Q= heat loss infiltration (W)

c_p = specific heat capacity of air (J/kg/K)

ρ = density of air (kg/m^3)

n = number of air shifts, how many times the air is replaced in the room per second

V = volume of room (m^3)

t_i = inside air temperature (^{o}C)

t_o = outside air temperature (^{o}C)

Now the way material will affect heat loss will be the difference in your **n** values or how often all the air in your greenhouse is completely exchanged with outside air. For example new Double-film plastic will have approximately 0.5 air exchanges per hour whereas an old glass greenhouse can have as many as 3 or 4 air exchanges an hour giving an **n** value 6 to 8 times greater.

Finally the last area to consider would be heat loss due to radiation there all buildings experience heat loss by radiation but some materials prevent radiation heat loss more than others. Glass for example is relatively opaque to radiant energy and prevents much of the heat loss due to radiation (less than 5% of total heat loss) in comparison Polyethylene can lose almost as much heat from radiation as from conduction. (Nelson, Paul V. 1997). Here is a table listing the pro’s and cons of some of the most popular greenhouse coverings.

Covering	Advantages	Disadvantages	Light Transmission	"U" Factor	Insulating Value "R"	Estimated Lifetime	Cost per Sq./Ft.**
Single Layer Polyethylene Film	Inexpensive Easy to install	Short life	85 %	1.2	.83	1 to 4 years	$.10
Double Layer Polyethylene Film	Inexpensive Saves on heating costs Easy to install	Short life	77%	.70	1.43	1 to 4 years	$.19
Glass Double Strength	High light transmittance High UV resistance Resists scratching	High cost Difficult installation Low impact resistance High maintenance	88%	1.1	.91	25 plus years	$2.00
Glass Insulated	High light transmittance High UV resistance Resists scratching	Very high cost Difficult installation Low impact resistance	78%	.70	1.43	25 plus years	$5.00

5mm Twin Wall Solexx Polyethylene	Diffuses intense sunlight More flexible than polycarbonate Easy to cut	Comes only in translucent white Less rigid than polycarbonate	70-75%	.43	2.30	15 plus years 8 year warranty	$1.59
Clear 4mm Twin Wall Polycarbonate	High impact resistance Saves on heating costs	Requires glazing system to install Scratches easily	82%	.70	1.43	15 plus years 10 year warranty	$1.50

Greenhouse coverings comparison

Permafrost and Building foundations

Permafrost is defined on the basis of temperature alone and any material whether sand, gravel, silt, peat, refuse piles or bedrock that has been below freezing continuously for more than one year is called permafrost. In Canada's far north above the 60th parallel permafrost is found everywhere under the ground surface and may extend to depths exceeding 1000 feet. Just above the permafrost table there is the active layer which freezes in winter and thaws in summer, in the far north this layer is usually only a few cm in depth.

Permafrost actually provides excellent bearing for structure provided of course that it stays frozen. Permafrost is actually quite sensitive to thermal changes. Any natural or man-made change, however slight, in the environmental conditions under which permafrost exists will greatly affect the delicate natural thermal equilibrium. The strength of permafrost is greatly reduced with increase in temperature and if thawed, may be lost to such an extent that it will not support even light loads. Therefore it is important to that when constructing a building on permafrost soils only minimal amounts of heat should be dissipated through the ground.

There are 4 commonly used solutions to used to overcome the difficulties involved with building on permafrost.

1. Permafrost conditions can be neglected when structures are sited on well-drained granular soils or solid rock. These materials usually contain little or no ice in the frozen condition and changes in the ground temperature regime will have little influence on their properties. Thus conventional design and construction methods are possible.
2. The frozen condition can be preserved and utilized to support a structure. In the continuous permafrost zone, particularly when fine-grained materials with high ice content are encountered, every effort must be made to preserve permafrost. This is usually accomplished by either ventilation or insulation construction techniques the former is commonly used with heated buildings. Foundations are well embedded in the permafrost and the structure is raised above the ground surface to permit air circulation beneath and to minimize or prevent heat flow to the ground. Pile foundations placed in steamed or drilled holes to depths of from 15 to 30 ft. depending on the foundation material and building and heat loads, have proved well suited to this method and have been used extensively. Where pile placing may be difficult as in very stony soils, alternative foundation designs may prove more economical. Insulation to prevent thawing of the underlying frozen material may be achieved by placing a gravel blanket on the ground surface. Depending on the structure and the heat load, the gravel fill may range in thickness from 1 to 2 ft for small unheated buildings, which can tolerate some movement, to 10 ft or more for larger heated structures.
3. When foundation soils contain excessive amounts of ice and it is not possible to preserve the frozen condition it may be convenient to thaw and then consolidate this material prior to construction. It may be advantageous in some cases, to remove and replace it with compacted, well drained, non-frost-susceptible material. The depth to which pre-construction thawing is carried out will depend on the estimated rate of subsidence that will result from further thawing when the structure has been completed. This method may be adopted in both the continuous and discontinuous zones but it is probably more applicable in the latter particularly if a suitable load bearing stratum is at relatively shallow depth. Frozen materials are more readily thawed and excavated in

areas where ground temperatures are close to 32°F. Normal design and construction methods can then be employed.

4. At some locations foundation designs must take into account anticipated settlement. This is particularly true in the southern fringe area (but also in the continuous zone) where considerable consolidation of the foundation material is to be expected and thawing of the ground is inevitable during the life of the structure. "Flexible" foundations, which can be adjusted to eliminate structural deformation as differential settlement occurs, can be used. Special settlement joints that permit individual sections of the building to move (settle) without producing deformations in adjacent sections can also be employed to ensure stability. { Johnston, G.H.}

Type of Structure

Traditional greenhouses come in many shapes and sizes and are influenced by 2 main factors, the physical location (terrain, climate etc.) and the type of coverings you wish to use. For example if you want to use glass coverings you probably won't want a structure with a curved ceiling and walls. While there are many slight variations in greenhouse design there are 5 main structures from which they are mostly all derived. They are the Rigid-Frame, the Quonset, the A frame, the Gothic and the Post and Rafter Frame styles all illustrated below.

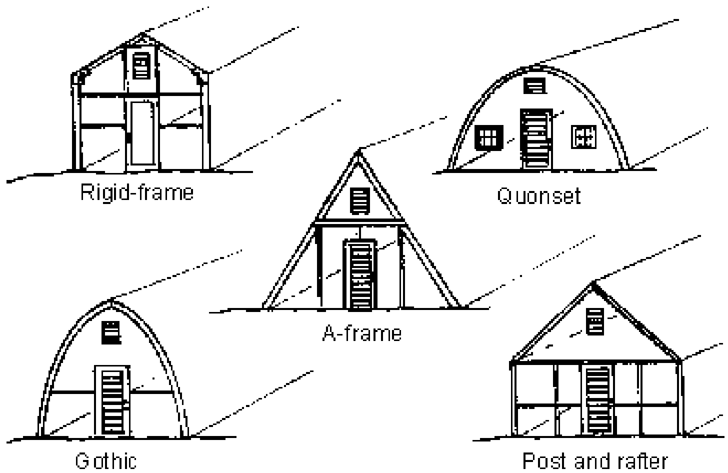


Figure 3. Greenhouses can have a variety of different structural frames.

As you can see both the gothic and Quonset are designed to be used with plastic coverings, while the other three are more appropriate for glass coverings. Other advantages and disadvantages include the fact that the Quonset and Gothic are cheaper to build because their frames don't require a very solid foundation, however they have poor air circulation and are not suitable for high wind velocities and harsh climate conditions. The Post and Rafter and Rigid-Frame greenhouse require more construction material for their frames and also need a strong foundation to support the lateral loads on the sidewalls. Subsequently however they are much sturdier structures and can withstand strong wind pressures.

Lighting

Watt is the measure of energy used by a lamp each second, light energy is measured by joules where 1 watt=1 joules/second. However, none of the existing light bulb has an efficiency of higher than 40%. For example, a 100 watt light bulb has an efficiency of 10%, so only 10 watt will be used to illuminate, the rest would be dissipated mainly as heat. Plants use light with wavelengths between 400 to 700 nanometers and light in this region is called Photosynthetically Active Radiation (PAR). PAR watt basically shows the amount of light energy available for plants to use in photosynthesis. Another way to calculate light intensity is by using PPF (photosynthetic photon flux), this actually counts the number of photons falling per second.

High-pressure sodium lamps (HPS) came in the 1970's and are much more efficient (38%) than the fluorescent and high pressure metal halide lamps in transforming energy to PAR for growth. It soon became widely used in greenhouse artificial lighting systems. It has an orange-red glow, which is the specific wavelength needed for optimal growth of plants. Moreover, a HPS lamp has a life span of around 3 years and each 1000 watt HPS lamp costs about $300.

Heating system

There are 3 main common heating systems associated with the commercial greenhouse: The Unit Heater System, The Boiler and Radiant Heater Systems.

The Unit heater system pretty much speaks for itself, you have many small unit heaters spaced equidistantly throughout the greenhouse, heat is distributed by fans that blow the warm air over the plants. This system is used for smaller scale commercial greenhouses. For larger projects a more centralized method of heating like a boiler is required. With a boiler you can burn cheaper combustible materials; unit heaters require special light oils or gas. In a boiler your combustion takes place outside of the greenhouse and heat is transferred to water which is pumped into the greenhouse where it passes through a heat exchanger and warms the greenhouse air. Finally there is the Radiant Heating System this system is the most expensive of all but it is the most efficient in the long run, here the air in the greenhouse is not heated directly. Instead infrared radiation strikes objects in the greenhouse such as the plants and the soil and warms them up directly, since it is the plant temperature and not the air temperature that is important to growth greenhouses with radiation heaters can be kept almost 5^{o}C cooler than other greenhouses. However this system only uses natural gas as a fuel.

(Nelson, Paul. V. 1997)

Design process

→Initial ideas

At first, we decided to design a greenhouse to supply a community with a much smaller population (i.e. 250 people), and we were planning on supplying enough produce to feed every person in the community for the entire year.

However, seeing as how vegetables are not part of the traditional diet in this region, using the Canadian average of 136 kg /year per person is not really applicable. Therefore we changed our goal into designing a greenhouse for a larger community but one that produces a smaller quantity of vegetables with hopes of educating the community and possible future expansion.

At first we were planning to design a traditional greenhouse, and we were going to do a cost analysis to see which frame and covering would be the most economical. We were expecting it to be a double layer glass with a rigid-frame or post and rafter frame structure simply because of the durability of this design. After getting feedbacks from our presentation, it was brought to our attention that for such a remote location we might consider designing a non-traditional greenhouse in the sense that instead of using transparent greenhouse coverings to take advantage of the extended daylight hours that it might be more practical to design an opaque structure made with well insulated materials having U values far lower than any traditional greenhouse coverings and we would simply supply artificial light. Furthermore, the infiltration would be much lower without any leaks caused by joints between the frame and glass panels. Now we will have to do a cost analysis between a traditional greenhouse and this new artificial light greenhouse.

We went to the Centre of Nutrition from the school of Dietetics and Nutrition to find out the traditional diet for people up north and what we should grow in our greenhouse. From the consultation, we learned that vegetables are not a part of their traditional diet except berries because they grow in the relative areas, so we can basically grow anything nutritional. Also we learned that the other greenhouse in Inuvik operates by renting plots, so we decided to operate our greenhouse in a similar manner.

→Our new choice of produce

Our choices of vegetables are tomatoes, cucumbers, peppers and raspberries. Tomatoes, cucumbers and peppers are warm season crops with similar optimal growing conditions. Furthermore, these are the typical North American greenhouse vegetables with high market values. Berries are grown in a separated room because it has a different temperate, humidity and lighting requirements. Below is a table summarizing their ideal living conditions.

Type of produce	Growing medium	Optimal temperature(Degrees Celsius)	Optimal Humidity (%)	Duration of 1 growing cycle (weeks)	Annual yield
Tomatoes	Rock wool, foam cubes or soil	22-26	75-90	14	13.3kg/plant

Cucumbers	Rock wool, foam blocks or soil	26-29	80	12	46.7kg/plant
Peppers	Rock wool or soil	26-29	75	20	27.5kg/m^2
Raspberries	Potted soil	15-20	65-70	25	1.7kg/plant

As you can see from the table above, the room for tomatoes, peppers and cucumbers should be maintained in a temperature of 24-29 Degrees Celsius and a relative humidity of 75-80% in order to maintain an ideal environment of growth for every type of crop. The medium of growth for them are rockwool, foam blocks and soil. The room for raspberries should be maintained in a temperature of 15-20 Degrees Celsius with a relative humidity of 65%.

→Size of greenhouse

We plan to supply 12000kg of produce/year assuming that half the population (~600 people) will be interested in the project, this makes the production of produce 20kg/person/year. The division of produce is as follows;

Raspberries 1000kg (8.3%)
Tomatoes 4000kg (33.3%)
Cucumbers 3500kg (29.2%)
Peppers 3500kg (29.2%)

Notice that raspberries take a little portion of the total production because each plant only yields 1.7kg/year, in order to grow 1000kg, we need 588 plants and each plant takes about 0.77m^2 space, the total growing space required for raspberries is 451m^2. With the walking space, the room for raspberries has to be **600m^2.** {Kurt K. 2003}

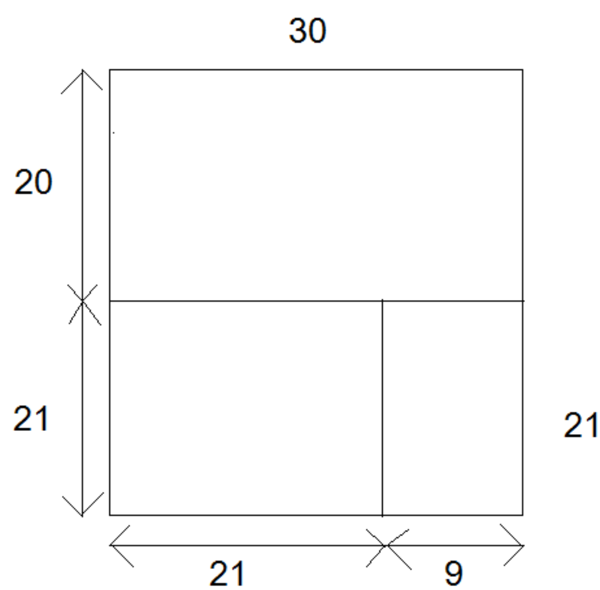
Tomatoes yield about 13.3 kg/plant annually, so we need 300 plants to grow 4000kg. Each plant takes about 0.37m^2 growing space, so the total space needed for tomatoes comes up to be 111m^2. { Dr. Richard G. Snyder.(2003).}

Cucumbers yield 46.7kg/plant annually, so we need 75 plants to grow 3500kg. Each plant takes about 0.56m^2 growing space, so the total space needed equals to 42m^2.{ Hochmuth, R. C. (2008).}

Peppers yield 27.5kg/m^2 growing space annually, so to grow 3500kg, we need a total growing space of 127.7m^2. {Government of Alberta, 2007}

The total growing space of tomatoes, cucumbers and peppers adds up to be 280.7m^2. The room has to be **441m^2** because walking area between each plot is mandatory.

The floor plan is as follows; the height of the building is 5 meters.



→Plot system

After consulting with the center of nutrition, we were told that two other greenhouses are located in the relative area where one is in Inuvik and the other one is in Iqualuit. The one in Inuvik is modified from a former hockey arena and the one in Iqualuit is a traditional glass greenhouse. The Inuvik greenhouse is non-profit and is funded by government, it basically rents plot to different individual and each full plot (10'by4') cost$100 per operating season. We find this idea interesting, so we decided to operate our greenhouse in a similar manner. Renting plots to people not only helps to cut off costs, but It might also stimulate the community's interest for the project as people usually enjoy eating fruits they grow.

This plotting system will be introduced to the room growing tomatoes, cucumbers and peppers, 77(10 by 4 feet) plots will be available to rent. For the bigger room, the plotting system is not applicable as each raspberry grows individually. Whoever that's interesting in growing raspberries can rent as many plants as they want as there are 588 plants in total available.

→Foundation

In order to preserve the permafrost soil every effort must be made to insulate and prevent the transfer of heat from the structure into the soil. For this reason the foundation of our structure will consist of 3m of gravel rock. According to Johnston this amount of material should be sufficient for large heated buildings. While the most optimal solution would have been to remove the permafrost and replace it with other material this would be extremely costly seeing as how our structure takes up such a large surface area. Adding gravel not only creates a thermal insulating foundation but it almost creates conditions similar to solution #1 of Johnston's permafrost construction guide because gravel is very granular and extremely permeable.

→Air circulation and ventilation

Air circulation in a greenhouse serves two main purposes:

1. When circulating air through the foliage of plants you deliver a fresh supply of needed carbon dioxide to the leaves. Air circulation also prevents diseases that like to start in areas of cold and stagnant air.

2. Because warm air rises, a small fan is needed to pull warm air off the ceiling and push it down to the plants on the benches and floor. This is very important in the winter months, and helps reduce heating costs.

The air circulation requirements (in cfm) for a greenhouse of typical height is equivalent to twice the floor area .

(Nelson, P.V.)

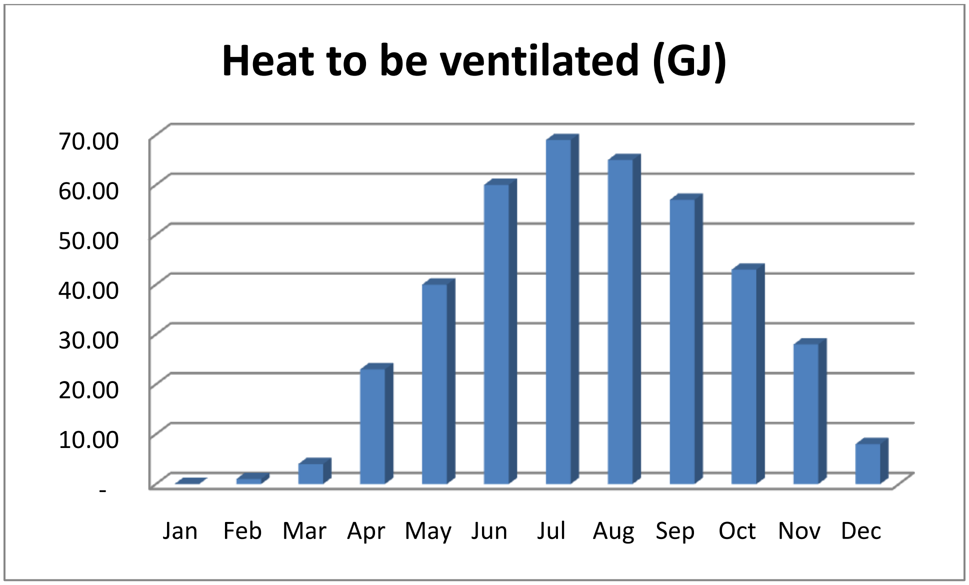
Our greenhouse has a floor area of 1041 m^2 which when converted to square feet gives 11205 ft^2 which would therefore require an airflow rate of 22410 cfm. Once the air flow rate was calcualated we just had to choose the appropriate size HAF (horizontal air flow) fans for our greenhouse. We decided upon 8 ¼ horsepower HAF fans each with a ventilation rate of 3500 cfm there were larger size fans but you don't want 1 or 2 large fans because then your wind speed will be too high and your plants will dry out. Also the fans have to be split between the large and small rooms and this way you can have 3 fans in the small one and 5 in the large which meets the air circulation requirements for both.

Ventilation is used mostly as a form of cooling as well as a means to replenish CO2. If you keep the same air in a greenhouse for too long the atmospheric CO2 concentration will start to fall and if it falls below 300 ppm your plants may grower at a slower rate than expected.

Ventilation can either be obtained by using a ventilation system that in involves an exhaust fan which exchanges air at a desired rate or ventilation may be done using natural ventilation where sidewall and ridge vents allow air to circulate based an pressure and thermal gradients. The advantage of a mechanical system is that you have much greater control of ventilation rates, but if done properly natural convection can be quite effective as well.

> To be ventilated satisfactorily, the structure must have both sidewall and ridge vents. If a house has only side vents, then it can only be ventilated during periods of wind movement outside. Using ridge vents and side vents permits the greenhouse to be vented by both wind pressure and thermal gradients. Thermal gradients generally are created within the greenhouse by energy heating the materials inside, which in turn heats the air. As air is heated, it becomes lighter and rises through the ridge vents, with the makeup air coming from outside through the sidewall vents. If sidewall and ridge vents are properly sized, quite satisfactory ventilation rates can be achieved with some degree of temperature control.
>
> (Buffington. et al)

Below is a graph of the heat that must be ventilated each month based on the difference between the heat generated from the lights and the heat loss from the structure.



January is actually the only month where no ventilation is required because more heat is lost than is produced but it is by a very small amount (3 GJ over the entire month) rather than buy an entire heating system for that one month, leaving a few lights on for an hour more each day is sufficient to balance the heat load. SEE Appendix D.

→Lighting

As we mentioned previously, HPS(High pressure sodium) light has many advantages so we decided to use it as our artificial lighting source. To determine how many HPS lamps we need in our greenhouse, we need to know the photosynthetic photon flux for each plant to determine the PAR value, then we can calculate how many watts of light the rooms need.

Tomatoes, cucumbers and peppers need a PPF of 250 µmol m^-2 s^-1 and they need about 20 hours/day of PAR lights (Grimstad, S.O. and Gislerod, H.R. 2006). From the table below;

Conversion factors for typical metal halide sources

Typical lighting level (can vary widely based on application)	PAR Watts/sq. meter watts-m^{-2}	Micro-einsteins or μ-mol-m^{-2}.s^{-1}	Lux lumens- m^{-2}	Foot-candles lumens- ft^{-2}
Dark	Variable	Variable	Variable	Variable
Low	22	100	6,000	550
Medium	45	200	12,000	1100
High	75	350	21,000	1900
Very High	135	600	36,000	3300

they need ~51.6 watts/m^2 PAR light, so the total amount of light they need is 51.6watts/m^2 *441m^2(room size) =22704Watts. The 22704 Watts has to be multiplied by a factor of 1.1 because some of the light energy is dissipated to the surroundings. So the total light energy needed is 24974.4Watts. Each 1000Watts HPS light gives 380Watts as light energy because it has an efficiency of 38%, the rest is dissipated as heat. To determine the number of 1000watts HPS lamps needed, we simply do the following; 24974.4Watts/380Watts=65lamps.

For the raspberries, they need a PPF of 136.4 µmol m^-2 s^-1; from the table above, The PAR value is 30Watts/m^2. To calculate the total light energy for the room, we do as follows; 30Watts/m^2*600m^2(room size)=18000Watts. 18000Watts*1.1=19800Watts, total number of lamps needed=19800Watts/380Watts=53lamps.

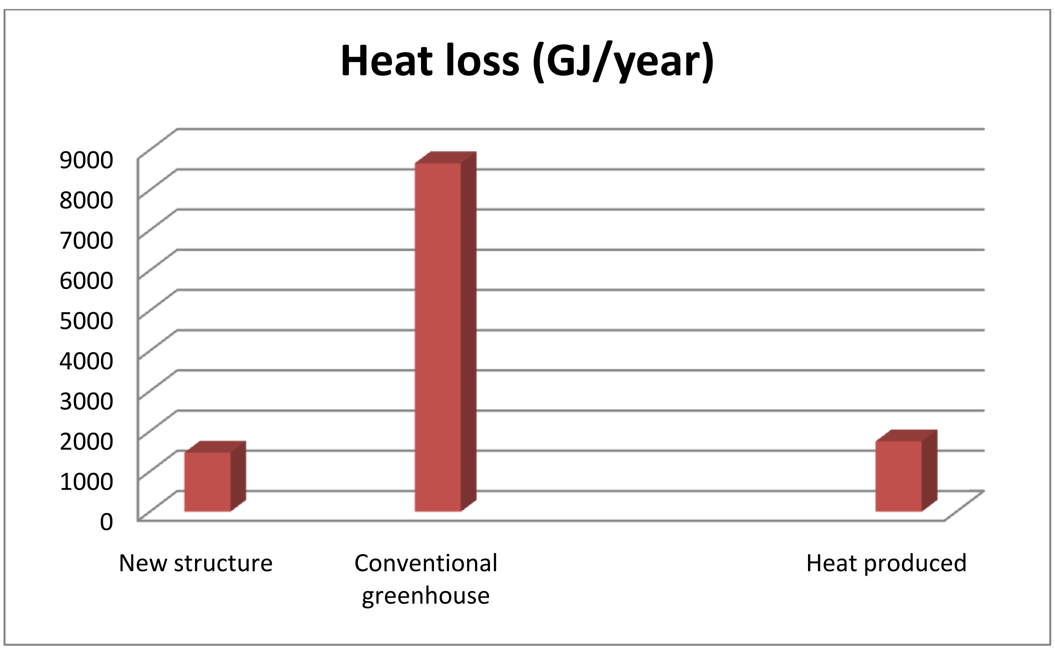
Summary of the lighting requirements

Type of produce	PAR value(Watts/m^2)	PPF(µmol m^-2 s^-1)	Number of lights needed
Tomatoes, cucumbers and peppers	51.6	250	66
Raspberries	30	136.4	52

In order to power our lights which have a total power load of 108 kW and othere smaller appliances such as the fans which will be discussed shortly we will need a 100 KW Diesel generator, the reason we can use this size generator is that not all 108 lights will be on at the same time. The day/night cycles will be staggered to reduce the load on he generator and avoid unequal heating.

→Heating

The heating is where having an insulated structure really helps, the heat loss through the floor is the same for both a traditional greenhouse constructed with glass coverings and our insulated steel structure and there is very little difference in the heat due to air infiltration but because the U value for insulated steel at 8" thick (0.1 w/m^2k) is several times smaller than the U value for glass (5.5 w/m^2k) the overall heat loss for a traditional greenhouse ends up being approximately 10 times greater than our insulated structure as you can see from the attached excel tables and the following graph.



It is also worth noting that with our current design we actually produce just slightly more heat than we need from the lighting alone. If we were to build a traditional greenhouse we would need a separate heating system as well as all the lights because although there is plenty of sunshine during the summer, there is virtually none during the winter.

See Appendix A, B and C

→Irrigation

Water supply in the area is relatively expensive in the area, so it is more economical to choose an irrigation system that limits water usage, which in our case will be the drip irrigation system. This system won't be applied in the small room as plots will be managed by the tenants, but it will be installed in the large room growing raspberries. We have a total of 588 plants in the large room, components to set up the drip irrigation system are as follows;

*3/4 inch Hose Thread Screen T Filte*r(1 needed)- A basic inexpensive high-volume filter to capture scale and sediment before it reaches the small orifices of drippers or sprayers, it increases the lifespan of the system.

3/4 inch outlet pressure regulators(1 needed)- Essential for each drip irrigation circuit to reduce water pressure.

Timer- Used to time the irrigation

1/2 inch Tubing(337feet long)- Heavywall industrial polyethylene mainline tubing (lifespan of 15 years)

1/4 inch Tubing(346feet needed)- Splitting from the ½ inch mainline tube, each plant needs 3 feet length of tubing

Barbed elbow(4 needed)- Put in the four corners to make a turn for the ½ tubing

¼ inch Barbed coupler(588 needed)- Used to irrigate individual plants, connects to the ¼ inch tubing.

Support stakes(588 needed)- Used to hold the tubing off the soil

To set up a drip irrigation system, first we have to install standpipes into the greenhouse, each equipped with two faucet. The faucet will be connected to the water tank located in the small room where the generator is located. {Kurt K, 2003} On the lower faucet of the pipe, a timer is installed and a filter can be installed in the upper faucet. The pressure regulator is installed in the bottom of the faucet connecting the ½ inch mainline tubes.

Standpipe installed with timer and filter

Then we can install the ½ inch mainline tubes along the walls, holes have to be punched along the mainline tube to install the ¼ inch branch tubes. From the ¼ inch branch tubes, barbed coupler has to be installed connecting each plot to provide irrigation on individual plots. Above every plot, a support stake is needed to keep the tubing off the soil. {Northern garden supply}

Raspberries need plenty of water to grow, the greenhouse keeper will check the soil everyday and he will turn on the system if the soil seems dry. The soil has to be wet, but not saturated.

→Cost Analysis

As we can see from the table the initial cost for the insulated structure is much higher than the traditional greenhouse due to the fact that one is made entirely out of steel, while the other only has steel members for the frame.

The lights will also last twice as long in a glass greenhouse because they are not being used as much seeing as how natural light will be used as much as possible. This also means that less fuel is required to power the lights. However the total annual cost is higher due to the fact the glass building has a heat deficit of 6000 GJ annually (see appendix E) and that there is an additional cost for heating oil that is not found in our insulated structure. Due to this extra heating cost the traditional greenhouse will never break even because the annual operating costs are slightly higher than the value of the yearly produce. Whereas the insulated structure has an operating cost that is slightly lower than the value of annual produce.

Conclusion

→Feedback and alternate possibilities

Our project evolved and changed many time over the course of the last two semestersAt first we were planning to design a traditional greenhouse, and we were going to do a cost analysis to see which frame and covering would be the most economical. We were expecting it to be a double layer glass with a rigid-frame or post and rafter frame structure simply because of the durability of this design. But after getting feedbacks from our presentation, it was brought to our attention that for such a remote location we might consider designing a non-traditional greenhouse in the sense that instead of using transparent greenhouse coverings to take advantage of the extended daylight hours that it might be more practical to design an opaque structure made with well insulated materials having U values far lower than any traditional greenhouse coverings and we would simply supply artificial light.

We ended up doing exactly that; we designed a steel structure 30m x 41m x 5m insulated with polyurethane foam and showed how it was more economical to provide artificial lighting than heating given the location. While our operation was never meant to be profitable we have shown that a full season greenhouse for such a harsh region is feasible and can earn about as much as it costs to run. The produce that was picked were vegetables that are easy to grow and suitable for greenhouse condition since our visit to the centre for indigenous nutrition let us know that the native people didn’t really have any preferences except maybe raspberries which we then decided to devote more than half our growing space to. In addition to growing

Raspberries we tried a plot system that was developed in Inuvik all in the hopes that should a greenhouse like the one we proposed ever be constructed there would be ways to get the community involved in such a project.

The most challenging part we find in the design project is to calculate the heat loss through various medium and to end up finding the appropriate “heating system”, which is technically the artificial HPS light. Also, the irrigation was also challenging because other case studies for drip irrigation systems are done in small greenhouses.

Appendix

→Appendix A

Heat loss by transmission through walls, roofs, floors etc.(smaller room 21mX21mX5m)		
Ht=AU(ti-to)		watts
Ht=transmission heat loss		watts
A=Exposed area for the small growing room	210	m^2
U for foundation	0.566666667	w/m^2 K
U=Overall heat transmission(K/d)	0.115	w/m^2K
ti=Inside temperature	25	o'c
to=outside air temperature		
te=Earth temperature	-9	o'c
K value for gravel foundation	1.7	W/mK
K value for polyurethane(insulating material)	0.023	w/mK
Thickness of foundation	3	m
thickness of the insulating material(d)	0.2	m
Resistance to heat loss (R value)	8.695652174	m^2K/w
Ar=Area of roof	441	m^2
Af=Area of floor	441	m^2

Months	Jan	Feb	March	April
Avg.temp(to)	-25	-26	-21.6	-14.
Ht=AU(ti-to)*Walls*	1207.5	1231.65	1125.39	944.26
Ht=1.15ArU(ti-to)*Roof*	2916.1125	2974.43475	2717.81685	2280.39997
Ht=AfU(ti-te)*Floor*	8496.6	8496.6	8496.6	8496.
Total Ht(watts)	12620.2125	12702.68475	12339.80685	11721.2649

May	June	July	August
-5.5	2.3	7.4	5.7
736.575	548.205	425.04	466.095
1778.828625	1323.915075	1026.4716	1125.619425
8496.6	8496.6	8496.6	8496.6
11012.00363	10368.72008	9948.1116	10088.31443

Sep	October	Nov	Dec
1.5	-4	-11.7	-20.2
567.525	700.35	886.305	1091.58
1370.572875	1691.34525	2140.426575	2636.1657
8496.6	8496.6	8496.6	8496.6
10434.69788	10888.29525	11523.33158	12224.3457

Heat loss through walls, roofs, floors etc.(Bigger room 20mX30mX5m)

Ht=AU(ti-to)		watts
Ht=transmission heat loss		watts
A=Exposed area for the small growing room	350	m^2
U=Overall heat transmission(K/d)	0.115	w/m^2K
ti=Inside temperature	25	o'c
to=outside air temperature		
te=Earth temperature	-9	o'c
k value of steel		
K value for polyurethane(insulating material)	0.023	w/mK
thickness of the insulating material(d)	0.2	m
Resistance to heat loss (R value=1/U)	8.695652174	m^2K/w
Ar=Area of roof	600	m^2
Af=Area of floor	600	m^2

Months	Jan	Feb	March	April
Avg.temp(to)	-25	-26	-21.6	-14.
Ht=AU(ti-to)*Walls*	1,730.75	1,771.00	1,593.90	1,292.03
Ht=1.15ArU(ti-to)*Roof*	3,412.05	3,491.40	3,142.26	2,547.14
Ht=AfU(ti-te)*Floor*	9,180.00	9,180.00	9,180.00	9,180.00
Total Ht(watts)	14,322.80	14,442.40	13,916.16	13,019.16

May	June	July	August
-5.5	2.3	7.4	5.7
945.88	631.93	426.65	495.08
1,864.73	1,245.80	841.11	976.01
9,180.00	9,180.00	9,180.00	9,180.00
11,990.60	11,057.72	10,447.76	10,651.08

Sep	October	Nov	Dec
1.5	-4	-11.7	-20.2
664.13	885.50	1,195.43	1,537.55
1,309.28	1,745.70	2,356.70	3,031.17
9,180.00	9,180.00	9,180.00	9,180.00
11,153.40	11,811.20	12,732.12	13,748.72

Total heat loss of both rooms(WATTS=J/s)	26,943.01	27,145.08	26,255.97	24,740.42	23,002.60	21,426.44	20,395.87	20,739.39	21,588.10	22,699.50	24,255.45	25,973.07	
Total heat loss of both rooms per month	72,164,164,680.00	65,669,389,027.20	70,323,981,611.04	64,127,181,535.2	61,610,173,549.20	55,537,332,674.40	54,628,302,493.44	55,548,394,027.92	55,956,349,692.00	60,798,328,077.60	62,870,130,482.40	69,566,259,170.88	
Total heat loss per year(J/year)													748,799,987,021.28

→**Appendix B**

Heat loss through infiltration

density of air in greenhouse (25 C)	1.18	kg/m^3
specific heat of air (25 C)	1.005	kJ /kg * K
18 degrees	1.22	kg/m^3
18 degrees	1.05	kJ/kg*K

n (# of air exchanges per hour) 0.38 per hour

	Small room	Large room
Volume (m^3)	2205	3000
Temp. in	25	18

Month	Jan	Feb
T out	(25.000)	(26.000)
Qlarge [Cp*ρ*n*V*(Ti-Tout)]	16,148.005	16,523.540
Qsmall [Cp*ρ*n*V*(Ti-Tout)]	13,800.911	14,076.929
Avg heat loss per day Small (J)	1,192,398,732.000	1,216,246,706.640
Heat loss for entire month Small (J)	35,771,961,960.000	36,487,401,199.200
Avg heat loss per day Large (J)	1,395,187,632.000	1,427,633,856.000
Heat loss for entire month Large (J)	41,855,628,960.000	42,829,015,680.000
Sum of both rooms	77,627,590,920.000	79,316,416,879.200

mar	April	May
(21.600)	(14.100)	(5.500)
14,871.186	12,054.674	8,825.073
12,862.449	10,792.313	8,418.556
1,111,315,618.224	932,455,808.424	727,363,226.520
33,339,468,546.720	27,973,674,252.720	21,820,896,795.600
1,284,870,470.400	1,041,523,790.400	762,486,264.000
38,546,114,112.000	31,245,713,712.000	22,874,587,920.000
71,885,582,658.720	59,219,387,964.720	44,695,484,715.600

June	July	Aug
2.300	7.400	5.700
5,895.900	3,980.671	4,619.081
6,265.614	4,857.921	5,327.152
541,349,024.328	419,724,353.664	460,265,910.552
16,240,470,729.840	12,591,730,609.920	13,807,977,316.560
509,405,716.800	343,929,974.400	399,088,555.200
15,282,171,504.000	10,317,899,232.000	11,972,656,656.000
31,522,642,233.840	22,909,629,841.920	25,780,633,972.560

Sep	Oct	Nov
1.500	(4.000)	(11.700)
6,196.328	8,261.770	11,153.390
6,486.428	8,004.529	10,129.869
560,427,404.040	691,591,264.560	875,220,669.288
16,812,822,121.200	20,747,737,936.800	26,256,620,078.640
535,362,696.000	713,816,928.000	963,652,852.800
16,060,880,880.000	21,414,507,840.000	28,909,585,584.000
32,873,703,001.200	42,162,245,776.800	55,166,205,662.640

Dec	**Yearly Avg**
(20.200)	(9.267)
14,345.437	10,239.588
12,476.024	9,458.225
1,077,928,453.728	817,190,597.664
32,337,853,611.840	
1,239,445,756.800	884,700,374.400
37,183,372,704.000	
69,521,226,315.840	-

	Yearly total
Small	298,274,568,147.360
Large	322,915,636,656.000
Sum	621,190,204,803.360

Total heat loss via transmission per year(J/year)	849,000,000,000.000	
Total heat loss including inflitration and transmission	1,470,190,204,803.360	Joules/year

→Appendix C

Heat generated by light

			20 hours/day	16 hours /day
Total number of lights needed	148.00		65.00	53.00
Heat generated per light	620.00	watts		
Total heat generated by lights	91,760.00	J/s		
Yearly total(J)	1,749,932,640,000.00	J	1,059,084,000,000.00	690,848,640,000.00
Monthly average	145,827,720,000.00			

→Appendix D

Month	Heat produced GJ	Heat lost GJ	heat to be ventilated GJ
Jan	146	149	0.00
Feb	146	145	1.00
Mar	146	142	4.00
Apr	146	123	23.00
May	146	106	40.00
Jun	146	86	60.00
Jul	146	77	69.00
Aug	146	81	65.00
Sep	146	89	57.00
Oct	146	103	43.00
Nov	146	118	28.00
Dec	146	138	8.00

→Appendix E

Heat loss by transmission through walls, roofs, floors etc.(smaller room 21mX21mX5m)

Ht=AU(ti-to)		watts
Ht=transmission heat loss		watts
A=Exposed area for the small growing room	210	m^2
U for foundation	0.566666667	w/m^2 K
U=Overall heat transmission(K/d)	4.5	w/m^2K
ti=Inside temperature	25	o'c
to=outside air temperature		
te=Earth temperature	-9	o'c
K value for gravel foundation	1.7	W/mK
Thickness of foundation	3	m
thickness of the insulating material(d)	0.2	m
Resistance to heat loss (R value)	0.222222222	m^2K/w
Ar=Area of roof	441	m^2
Af=Area of floor	441	m^2

Months	Jan	Feb	March
Avg.temp(to)	-25	-26	-21.6
Ht=AU(ti-to)*Walls*	47250	48195	44037
Ht=1.15ArU(ti-to)*Roof*	114108.75	116390.925	106349.355
Ht=AfU(ti-te)*Floor*	8496.6	8496.6	8496.6
Total Ht(watts)	169855.35	173082.525	158882.955

April	May	June	July
-14.1	-5.5	2.3	7.4
36949.5	28822.5	21451.5	16632
89233.0425	69606.3375	51805.3725	40166.28
8496.6	8496.6	8496.6	8496.6
134679.1425	106925.4375	81753.4725	65294.88

August	Sep	October	Nov	Dec
5.7	1.5	-4	-11.7	-20.2
18238.5	22207.5	27405	34681.5	42714
44045.98	53631.1125	66183.075	83755.8225	103154.31
8496.6	8496.6	8496.6	8496.6	8496.6
70781.08	84335.2125	102084.675	126933.9225	154364.91

Heat loss through walls, roofs, floors etc.(Bigger room 20mX30mX5m)

Ht=AU(ti-to)		watts
Ht=transmission heat loss		watts
A=Exposed area for the small growing room	350	m^2
U=Overall heat transmission(K/d)	4.5	w/m^2K
ti=Inside temperature	25	o'c
to=outside air temperature		
te=Earth temperature	-9	o'c
k value of steel		
thickness of the insulating material(d)	0.2	m
Resistance to heat loss (R value=1/U)	0.222222222	m^2K/w
Ar=Area of roof	600	m^2
Af=Area of floor	600	m^2

Months	Jan	Feb
Avg.temp(to)	-25	-26
Ht=AU(ti-to)*Walls*	67,725.00	69,300.00
Ht=1.15ArU(ti-to)*Roof*	133,515.00	136,620.00
Ht=AfU(ti-te)*Floor*	9,180.00	9,180.00
Total Ht(watts)	210,420.00	215,100.00
Total heat loss of both rooms(WATTS=J/s)	380,275.35	388,182.53
Total heat loss of both rooms per month	1,018,529,497,440.00	939,091,164,480.00

March	April	May	June
-21.6	-14.1	-5.5	2.3
62,370.00	50,557.50	37,012.50	24,727.50
122,958.00	99,670.50	72,967.50	48,748.50
9,180.00	9,180.00	9,180.00	9,180.00
194,508.00	159,408.00	119,160.00	82,656.00
353,390.96	294,087.14	226,085.44	164,409.47
946,522,333,872.00	762,273,873,360.00	605,547,235,800.00	426,149,352,720.00

July	August	Sep	October
7.4	5.7	1.5	-4
16,695.00	19,372.50	25,987.50	34,650.00
32,913.00	38,191.50	51,232.50	68,310.00
9,180.00	9,180.00	9,180.00	9,180.00
58,788.00	66,744.00	86,400.00	112,140.00
124,082.88	137,525.08	170,735.21	214,224.68
332,343,585,792.00	368,347,167,576.	442,545,670,800.00	573,779,369,520

Nov	Dec
-11.7	-20.2
46,777.50	60,165.00
92,218.50	118,611.00
9,180.00	9,180.00
148,176.00	187,956.00
275,109.92	342,320.91
713,084,919,120.	916,872,325,344.

total transmission	8,045,086,495,824.00 J
infiltration	621,190,000,000.00 J
Total	8,666,276,495,824.00 J

Reference

David S. Ross.(2004).Planning and Building a Greenhouse
http://www.wvu.edu/~Agexten/hortcult/greenhou/building.htm

Weather,E.D.(2008).

http://www.eldoradocountyweather.com/canada/climate2/Cape%20Dorset%20A.html

Qikiqtani School Operations.(2005).
http://mailhub.edu.nu.ca/qikiqtani/orientation/CapeDorset.html

Municipal government, Cape Dorset. **http://www.capedorset.ca/en/index.asp**

Nunavut Communities.
http://www.gov.nu.ca/english/about/Nunavut%20Communities%20Jan%2008.pdf

Taylor, W. (1996). Sunshine. **http://taylormade.com.au/billspages/sunshine/sunshine.html**

Harrison, J. (2004). Vegetable growing advice, vegetable guide.
http://www.allotment.org.uk/vegetable/index.php

Dr. Richard G. Snyder.(2003). Greenhouse Tomato Handbook
http://msucares.com/pubs/publications/p1828.htm

Hochmuth, R. C. (2008). "Greenhouse Cucumber Production." **3**.
http://edis.ifas.ufl.edu/CV268

George E. Boyhan, D. G. a. W. T. K. (2000). "Greenhouse Vegetable Production."
http://pubs.caes.uga.edu/caespubs/pubcd/B1182.htm

Demers, D.A. and Gosselin, A. 2002. GROWING GREENHOUSE TOMATO AND SWEET PEPPER UNDER SUPPLEMENTAL LIGHTING: OPTIMAL PHOTOPERIOD, NEGATIVE EFFECTS OF LONG PHOTOPERIOD AND THEIR CAUSES. Acta Hort. (ISHS) 580:83-88
http://www.actahort.org/books/580/580_9.htm

Government of Alberta.(2007). “Production of Sweet Bell Peppers”
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/opp4523?opendocument#1

Elmhirst,J.(2006). “Crop Profile for Greenhouse Lettuce in Canada”
http://www4.agr.gc.ca/resources/prod/doc/prog/prrp/pdf/greenhouselettuce_e.pdf

Nelson. V Paul. Greenhouse Operation and Management; Fifth Edition, Simon and Schuster

New Jersey. 1997.

Qulliq Energy Corporation
http://www.nunavutpower.com/home/index.php?option=com_content&task=view&id=107&Itemid=0

Greenhouse Growing Tips
http://www.backyardgardener.com/greenhouse/Fan-Shutter_tips.htm

Concrete or Steel- The choice of Frame for Ofiicial Buildings. RICS, 2003
http://www.rics.org/NR/rdonlyres/C04BEB03-6271-4A12-8ABB-C503258905C0/0/concrete.pdf

Heat Loss from Buildings. Engineering toolbox
http://www.engineeringtoolbox.com/heat-loss-buildings-d_113.html

Watts, Lumens, Photons and Lux. Venture Lighting (2004)
http://www.sunmastergrowlamps.com/SunmLightandPlants.html (light tables)

Kurt, K. Marvin.P, 2003. *Greenhouse raspberry production guide,* departmentofHorticulture, Cornell university*Http://*www.fruit.cornell.edu/Berries/bramblepdf/high_tunnel_**production_guide**.pdf

Moe, R. Grimstad, S. O. and Gislerod, H. R. 2006. THEUSEOFARTIFICIALLIGHTINYEARROUNDPRODUCTION OF GREENHOUSE CROPS IN NORWAY. Acta Hort. (ISHS) 711:35-42 http://www.actahort.org/books/711/711_2.htm

Nalliah, V., R. S. Ranjan, et al. (2009). "Evaluation of a plant-controlled subsurface drip irrigation system." Biosystems Engineering **102**(3): 313-320.

Northern Garden supply.(2004) *drip irrigation*
(**http://www.dripirrigation.ca/introduction.asp**)

Camp, 1998 C.R. Camp, Subsurface drip irrigation: a review, *Transactions of the ASAE* **41** (5) (1998), pp. 1353–1367. Camp et al., 1999 C.R. Camp, P.J. Bauer and W.J. Busscher, Evaluation of no-tillage crop production with subsurface drip irrigation on soils with compacted layers, *Transactions of the ASAE* **42** (4) (1999), pp. 911–917.

Camp et al., 2000 C.R. Camp, F.R. Lamm, R.G. Evans and C.J. Phene, Subsurface drip irrigation – past, present and future, *National Irrigation Symposium, November 14–16, Phoenix, Arizona*, ASAE, St. Joseph, MI, USA (2000), pp. 363–372.

Trooien et al., 2000 T.P. Trooien, F.R. Lamm, L.R. Stone, M. Alam, D.H. Rogers, G.A. Clark and A.J. Schlegel, Subsurface drip irrigation using livestock waste water: drip line flow rates, *Applied Engineering in Agriculture* **16** (5) (2000), pp. 505–508.

Hillel, 2004 D. Hillel, Introduction to Environmental Soil Physics, Academic Press, New York, NY (2004).