GEOTHERMAL HEAT IN AGRICULTURE: PRELIMINARY RESULTS OF AN ENERGY INTENSIVE SYSTEM IN ICELAND

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EDITOR'S NOTE

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ABSTRACT

A new energy intensive outdoor shallow system of geothermal heated ground agriculture was constructed and has been tested at the Agricultural University of Iceland in Hveragerdi since 2007. The 5 by 10 square meter experimental heated garden and a 5 by 5 square meter control garden both have three different soil mixtures and depths of 10 and 20 centimeters (cm) over a piping system that is analogous to a heated sidewalk. A geothermal borehole supplies steam and steam condensate at temperatures from 100°-125°C. A traditional shell and tube heat exchanger circulates a mixture of water and automotive anti-freeze continuously throughout the year in a closed loop at temperatures between 45-65°C. Soil temperatures at 10 cm depth range from 25-40°C. A similar system in New York City is incorporated into green roofs. Both heated bed systems have extended growing seasons and an average seasonal increase in plant growth of 20%. In Iceland out of range cultivars grow in the heated beds and either die or grow poorly in the control plot. Some heated grass areas are green throughout the winter. In New York City early and enhanced tomato harvests and winter flowers have been documented. In both plots weed growth patterns produced similar results. These preliminary results warrant further study. The growing season was increased both in Iceland and New York City by a minimum of four weeks.

INTRODUCTION

The trend in the geothermal energy industry is to extract 160-350°C steam from bore holes in high temperature areas. The waste heat left after electricity production still has a temperature of up to 130-160°C. In Iceland most of this waste heat can be applied toward cascaded utilization in district heating and the heating of greenhouses. Swimming pools and spas can also use part of this energy. The planned electrical power plants in Iceland will produce substantially more of this low temperature energy than the projected demands.

Geothermal heated swimming pools are very common in Iceland. Geothermal heated greenhouses are still common in locations such as Hveragerdi. Many of the older style greenhouse operations are being abandoned. This may be caused by higher costs of energy, materials, and labor. However, there appear to be some new efforts to revitalize this industry.

Another common cascaded utilization of geothermal energy in Iceland is the heating of sidewalks and streets. The basic engineering data used to construct these systems is based upon American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) specifications for heated sidewalks (ASHRAE, 1999), which is used as the basis for Iceland's heated sidewalks.

In Iceland there have been trials with the outdoor heating of soil (bottom heat) for agricultural purposes. A few existing outdoor heated ground agricultural systems have pipes that are about 40-80 centimeters below the surface and up to a meter apart. These approaches create minimal soil heating in the range of 6-12°C. They were heated for only a few months in the spring. There is additional current research toward the use of geothermal energy to heat golf course greens and athletic fields to extent the playing season.

We have developed and have been testing in Iceland since 2007 a more energy intensive shallow system of heated ground agriculture that is analogous to a heated sidewalk. In New York City, Consolidated Edison's district heating steam has no recirculation system. The waste heat, in the form of hot water or steam condensate is mixed with and cooled by the municipal water supply, thus wasting both energy and potable water. Since 2006, The Laboratory for Energy Reclamation and Innovation has been developing a system to use this thermal pollution to heat the soil of green roofs. As the waste level is decreased, less potable water is needed to cool the waste steam condensate, thereby preserving this resource for other purposes.

MATERIALS AND METHODS

Heating System

In Hveragerdi, a geothermal bore hole supplies steam and steam condensate at temperatures from 100 to 125°C. It is piped to a traditional shell and tube heat exchanger, manufactured in Iceland, which has a pump to circulate a mixture of water and automotive anti-freeze continuously throughout the year in a closed loop at temperatures between 45°C in the summer and 65°C in the winter. It has standard gate valves to control the flow. A Danfoss AVTB T self-acting temperature controller automatically controls the flow rate of the steam and steam condensate that reheats the hot water. A dial thermometer and pressure gage manufactured by Flexcon is mounted on the top of the heat exchanger to determine the water out temperature. A Rexotherm KL 2,0 dial thermometer with a temperature range of 0-120°C, was connected to the retour just above the flow meter. The Brook Crompton Parkinson KP6736 1-HP hot water circulator pump creates a flow rate of 10 liters per minute as measured by a Blue-White F-410N 1-inch NPT vertical float type flow meter.

The heat exchanger, shown in Figure 1 is 1.5 meters higher in elevation than the heated gardens; a simple semi sealed expansion chamber is used for surcharging the system. The working fluid is water with 20% automotive anti-freeze to prevent freezing of the hoses in the event of a system failure. The soil receives the fluid at 60-68°C in the colder months and between 40-50°C during the summer months. The winter energy consumption per square meter of heated garden is approximately 0.17kWh per square meter.

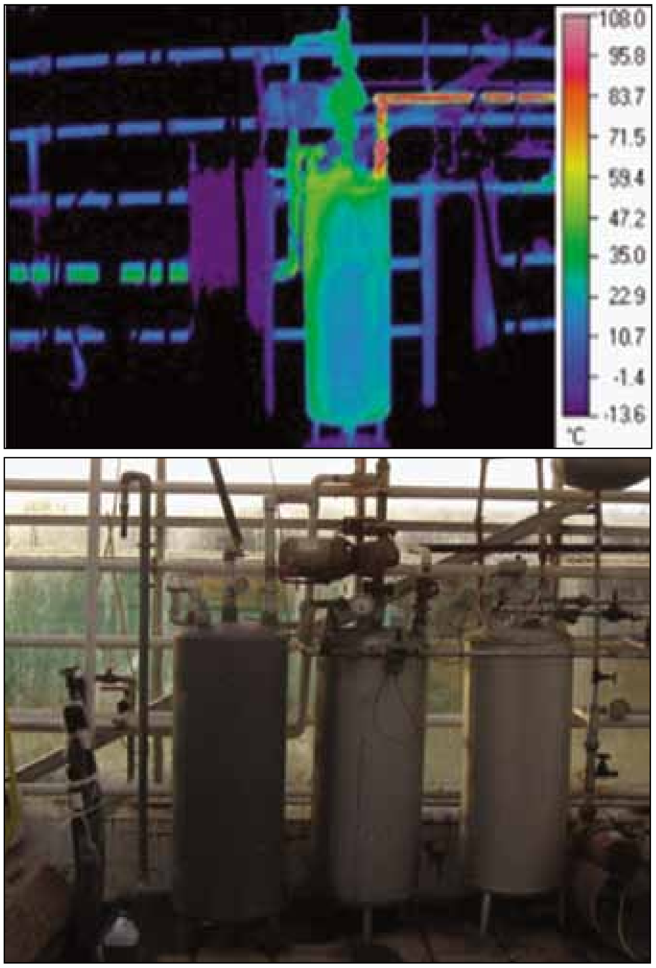

Figure 1: Mikron infrared image of the Hveragerdi heat exchanger (top), standard digital image (bottom)

Iceland Heated Garden

A 5 by 10 square meter experimental heated garden and a 5 by 5 square meter control garden were constructed, as shown in Figure 2. Both gardens were constructed, maintained, and monitored in the same manner and using the same materials, with the exception that no hot water circulates through the pipes of the control garden.

The 2.5-cm polypropylene plastic pipe, manufactured by Set Ehf in Selfoss, Iceland, was selected because of its workability, resistance to puncture and its ability to withstand several freeze-thaw cycles. Approximately 260 meters of pipe was installed in a spiral pattern to provide a more even heating profile. The plastic pipes are placed at 25 centimeters centers in the gardens. This distance is maintained by using polypropylene spacer clips manufactured by Bergplast Ehf in Hafnarfjördur. Both products are manufactured in Iceland and commonly used in heated sidewalks.

The pipes were placed on a 20-30 centimeters bed of compacted sand. They were then covered by an additional compacted sand over-layer of 4-5 centimeters. Above this layer either garden soil, peat soil or peat and sand soil were placed in the heated and the control garden at 10 and 20 centimeters depth (Figure 2). The system currently circulates the working fluid for the entire year.

Figure 2: Hveragerdi spiral piping layout (top left), sand over layer construction detail (top center), soil top layer and gravel compaction construction detail (top right), soil depths, types and location (Bottom)

Tomatoes (Lycopersicon esculentum Mill. cv. Fourth of July, cv. Bestboy and cv. Steak Sandwich) and cucumber (Cucumis sativus L. cv. Burpless) were sown on June 7 and seedlings were transplanted in 10 cm plastic pots in a heated greenhouse. Tomatoes and cucumbers were transplanted in the garden on July 1 with an average plant height of 20 centimeters for tomatoes and 10 centimeters for cucumbers. All plant selections and plant locations in the heated and control gardens were determined by using assigned numbers drawn from a hat in a double blind process. All beds were treated the same, no special watering frequencies or amounts were instituted for the heated or the unheated gardens. No fertilizers or artificial lighting were used.

New York City Heated Garden

In New York City, Consolidated Edison's municipal steam district system is analogous to the geothermal systems in Iceland. Because of the inherent problems with low temperature steam, there is no recirculation system. The waste steam and steam condensate must be cooled before it is sent to the sewer system, so it is first sent to chillers where it is cooled by the municipal potable water system, wasting both energy and water. When used to heat the growth medium of green roofs, the increased plant growth, cascade energy utilization, water savings and other benefits have great potentials. Before the heat exchanger system is finalized, tests using a conventional hot water system in a closed loop similar to what was eventually used in the Hveragerdi gardens was developed.

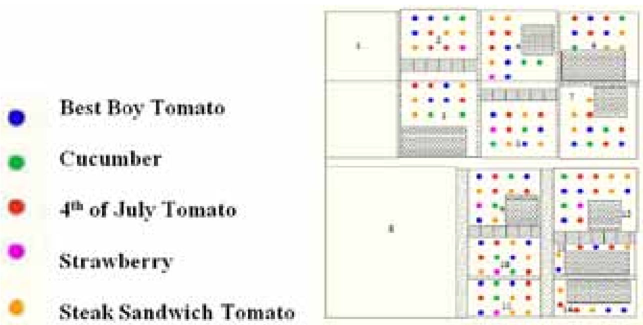

Figure 3: Crops and their locations in Hveragerdi

The first heated and control beds were built on metal frames with wheels and were 1 meter in height. The soil was contained by PVC plastic extruded tube raised exterior garden bed frames made by Pharmtec Corporation. Each bed had a 2-cm copper, PVC, and two stainless steel pipes running lengthwise that were covered with 25 centimeters of Premier Tech Ltd. PRO-MIX potting soil. The soil is 75-85% spagum peat moss with vermiculite, pearlite.

On the second story roof at the Albert E. Nerken School of Engineering at The Cooper Union, six - two square-meter green roof plots were placed on 4x8 foot ¾ inch treated plywood with 2x4 inch treated wood reinforcements on 16 inch centers, in accordance with standard United States construction practices. Four of the plots were heated, two were unheated control plots. The PVC plastic extruded tube raised exterior garden bed frames were made by Pharmtec Corporation. The tube voids were filled with 3 pound polyurethane expanding foam, manufactured by Urethane Technology Inc.

Stevens EP 60-mm reinforced TPO (thermoplastic polyolefin) single ply roofing membrane was installed, as per green roof specifications (see Figure 4). Above this layer, Stevens Garden Top Drain was installed, as per the manufacturer's specification. The rooftop garden hoses Nylobrade Braidreinforced PVC hose, ¾ inch inside diameter were placed on the top of the drainage membrane. The polypropylene spacer clips manufactured by Bergplast Ehf in Hafnarfjördur were also used on these gardens to maintain the same 25 centimeters distance between the pipes. This was covered by 10 centimeters of Skyland USA LLC, roofliteTM extensive mc growth medium for extensive green roofs in multicourse construction. The material is a mixture of mineral light weight aggregates and organic components that meets the German FLL-Guidelines.

The working fluid mixture, temperature, and flow rate is identical to the Hveragerdi gardens. The water is heated by a conventional electrical resistance Kenmore 32936 home 40 gallon 240 volt 30 amp hot water heater that is surcharged to 25 psig by the municipal water system. A Blue-White F-410N ½ inch NPT vertical float type flow meter and a Watts dial temperature and pressure gage monitor the hot water system. The pump is a Taco 009 bronze cartridge circulator.

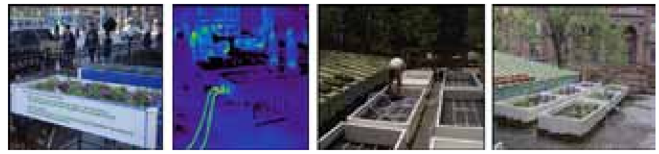

Figure 4: New York City gardens: first heated gardens; ibid infrared image; heated green roof construction detail; finished gardens.

According to ASHRAE, New York City needs 222 BTU's per square foot to keep sidewalks free of snow. Both the New York City and the Hveragerdi heated gardens consume approximately 55 BTU's per square foot, almost exactly one fourth as much heat energy.

Tomatoes (Lycopersicon esculentum Mill. cv.. Bestboy and cv. Steak Sandwich) were sown on or about April 1 and seedlings were transplanted in 10 centimeters plastic pots at D'ercole Farms, a commercial garden center, in a heated greenhouse. Tomatoes were transplanted on April 26 with an average plant height of 20 centimeters. Pansies (Viola wittrockiana cv. Atlas purple) were sown on or about October 10 in plastic trays at D'ercole Farms in a heated greenhouse. They were transplanted on December 23 with an average plant height of 20 centimeters. Randomisation and treatments were done according to Iceland.

MEASUREMENTS

Plant growth was measured by total plant height and width using Mitutoyo digital calipers and meter measuring sticks. A 4x4 cm rigid 3-mm plastic square was placed near the plant stems during measurements to serve as a level surface for plant vertical dimensions and stem diameters taken at 2 centimeters height.

In addition to the dial indicators, temperatures were measured using a variety of systems including: a Linear Labs C-1600 non contact infrared thermometer, a Fluke 867B graphical multimeter with a temperature probe, and a Mikron 7200 thermal camera. For longer term soil temperature monitoring, an Onset Computer Corporation Hobo Water Temp Pro v2 Data Logger system was used in Hveragerdi and an Omega HH309 4-channel data logger in New York City. The beds' soil moisture content is being monitored by a Delmhorst KS-D1 Digital Soil Moisture Tester, used with the GB-1 Gypsum Soil Blocks.

RESULTS AND DISCUSSION

At a depth of 8 centimeters, the soil temperature average is between 20-35°C, depending on the weather conditions and the season. Figures 5-7 show the soil temperature from the Hveragerdi experiment.

The Hveragerdi and the New York City heated gardens experienced heating system problems. Both were subject to system interruptions due to steam bore hole temperature inconsistencies; failures in Hveragerdi from earthquake activity, and non-authorized equipment shutdowns and tamperings in New York City. Both also had problematic soil overheating exceeding 45°C at 10 centimeters depth. The Hveragerdi gardens also suffered from wind damage and vermin. The New York City gardens experienced vermin and minor vandalism.

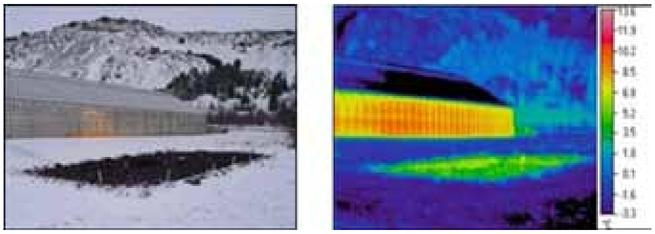

Figure 5: Winter snow cover melted on garden area (left), February infrared image(right)

Despite these limitations, and both location's lack of a sophisticated temperature control and irrigation systems, there were dramatic increases in overall plant growth and yields that mirrored the results of the Harvard Forest soil heating studies (Farnsworth et al., 1992)(Lux et al., 1991).

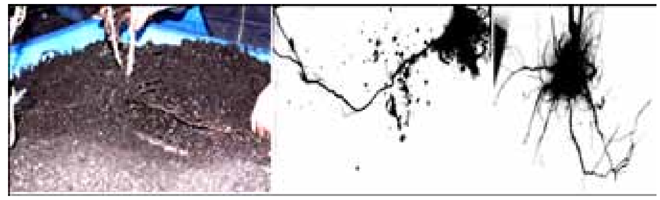

Figure 8: New York City heated garden roots follow pipes; heated bed roots (center); unheated roots (right)

As shown in Figure 8, the tomato plants from the heated beds all had one or two main roots that followed the pipes. The unheated beds produced normal root systems. A United States Department of Agriculture SSL analysis of the New York City 3-year heated garden, when compared to the control garden showed no significant differences (USDA, undated).

In Hveragerdi, as shown in Figure 9, in 2008, the hot water circulated through the heated garden on February 22 had a temperature of 68°C. There was a highly visible strip of green grass directly over the buried hot water pipes. On February 2009 when the water temperature was 48°C, there was no readily noticeable green grass. Both years had similar winter severities.

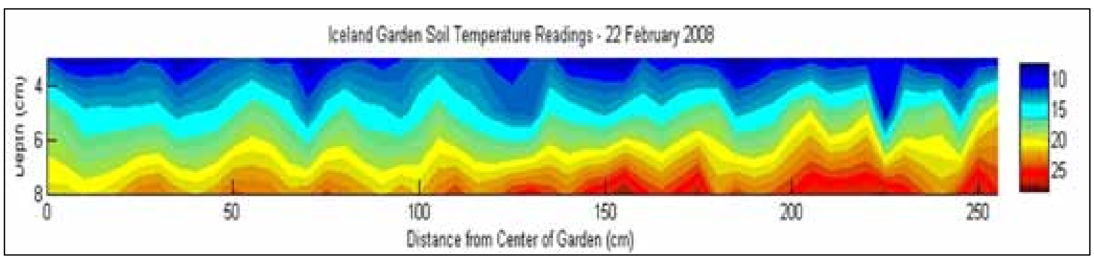

Figure 6: Thermal soil temperature profiles; the temperature peaks are located over the pipes

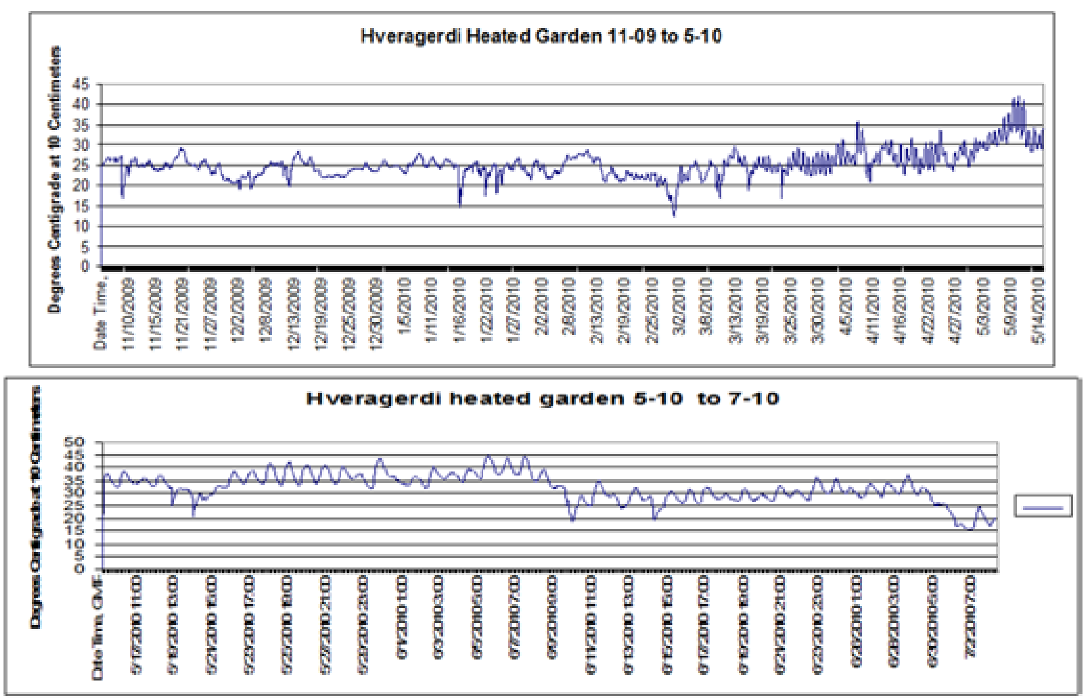

Figure 7: Hobo data logger Hveragerdi soil temperature readings at 10 cm depth from November 10, 2009 through July 2, 2010.

Figure 9: On 02/22/08 temperature reading 68°C, green grass (left two); On 02/22 09 temperature reading 48°C, no green grass (right two).

The heated tomatoes grew by 32% over the duration of the data collection, while the cucumbers grew 7.11% in the same time. The unheated tomatoes had gotten smaller by 13.2% and all the unheated cucumbers had died (Figures 10-21).

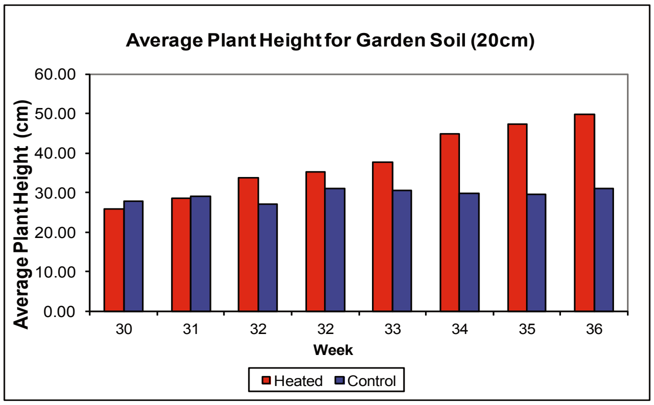

Figure 10: Average plant height for garden soil (20 cm) after 6 weeks (09/06/09).

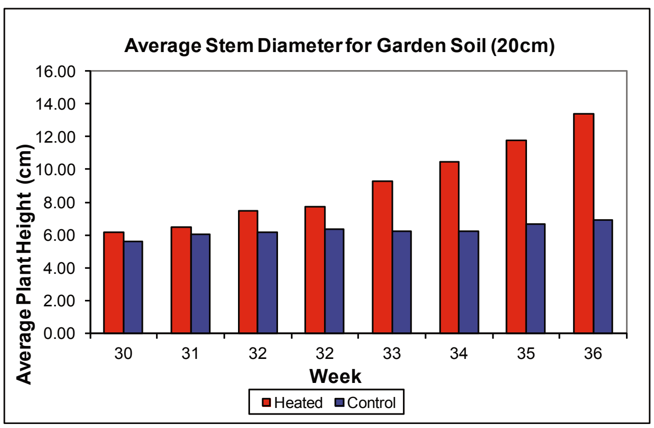

Figure 11. Average stem diameter for garden soil (20 cm) after 6 weeks (09/06/09).

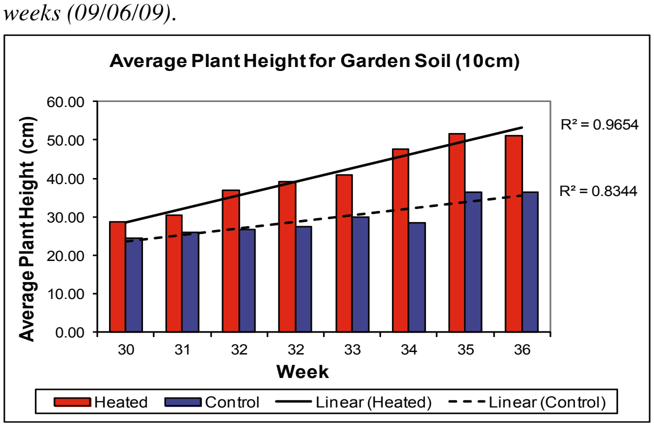

Figure 12: Average plant height for garden soil (10 cm) after 6 weeks (09/06/09).

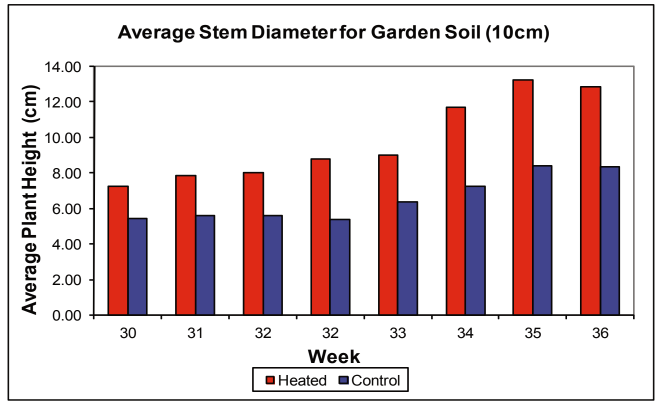

Figure 13. Average stem diameter for garden soil (10 cm) after 6 weeks (09/06/09).

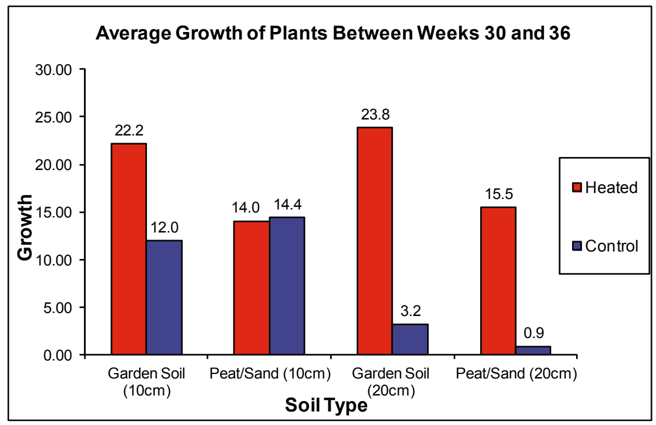

Figure 14: Average tomato plant growth between week 30 and week 36 plant growth.

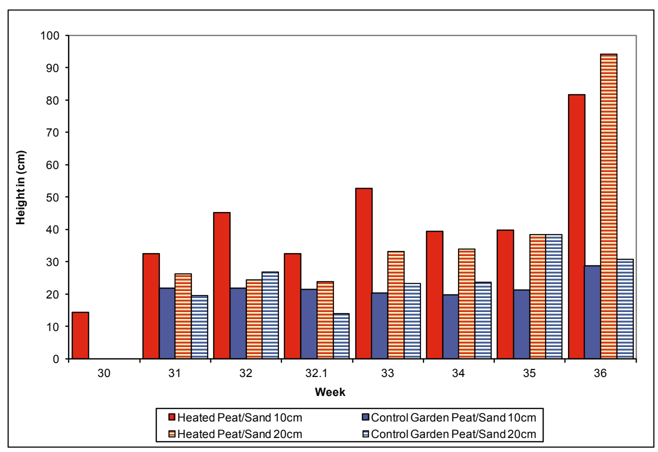

Figure 15: Average plant height for garden Lolium perenne Corvus (grass) between week 30 and week 36.

Figure 16: Iceland garden images. September 20, 2009 after first heavy frost 10 cm heated peat soil tomato and grass (left). September 20, 2009 10 cm control peat soil heated tomato and grass (right).

Figure 17: Iceland tomatoes in 20 cm heated garden soil on September 14, 2009, after 6 weeks in garden, seedling initial height.

The heated tomato plants produced 176% more tomatoes and 63% more fresh weight than the control tomato plants in the 2008 harvest (Figures 18-19).

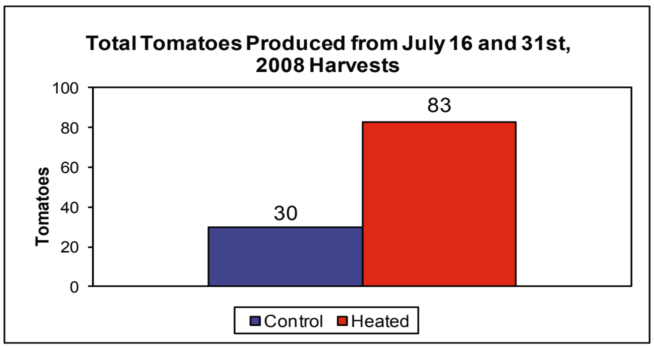

Figure 18: New York City 2008 results for total tomato production from July 16 and 31st.

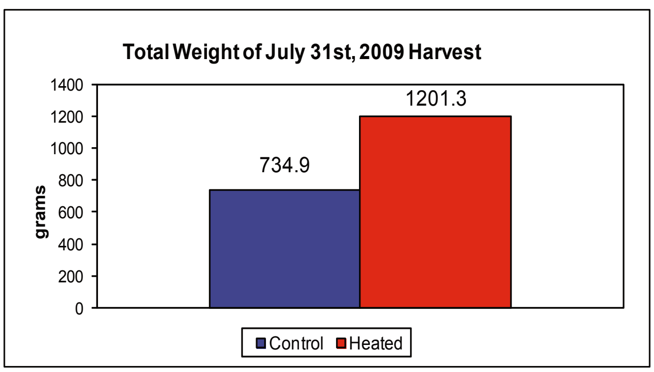

Figure 19: New York City 2008 results for total weight of July 31st harvest.

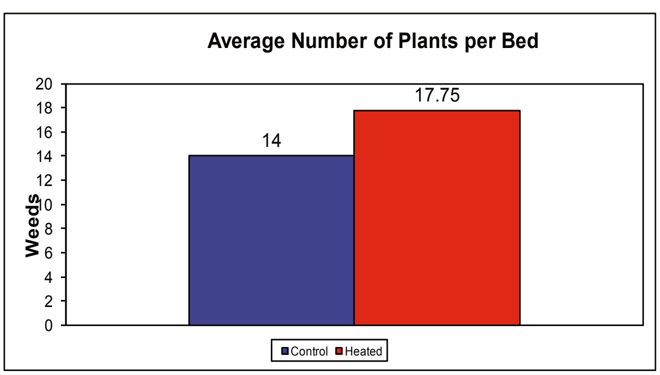

Figure 20: New York City 2008 results for average number of plants per bed.

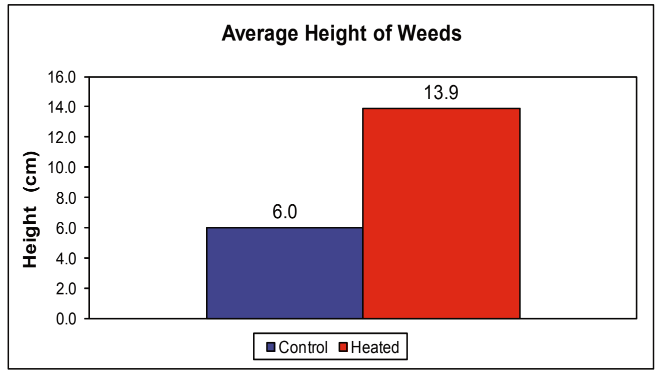

Figure 21: New York City 2008 results for average height of weeds.

Figure 22: New York City garden images. January 20, 2009 Pansies (left). January 20, 2009 control and heated beds (right).

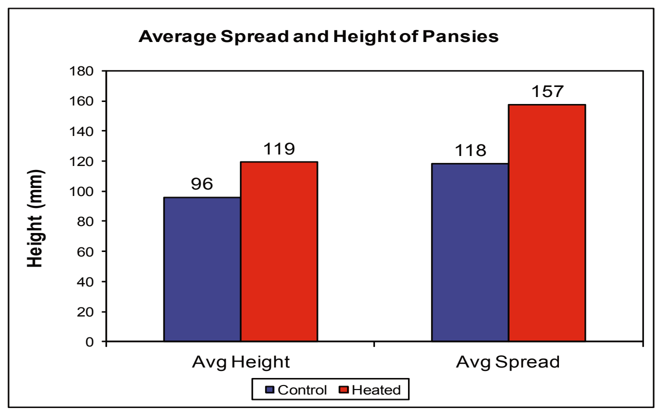

Figure 23: New York City results for Pansy, 4/10/09 average spread and height.

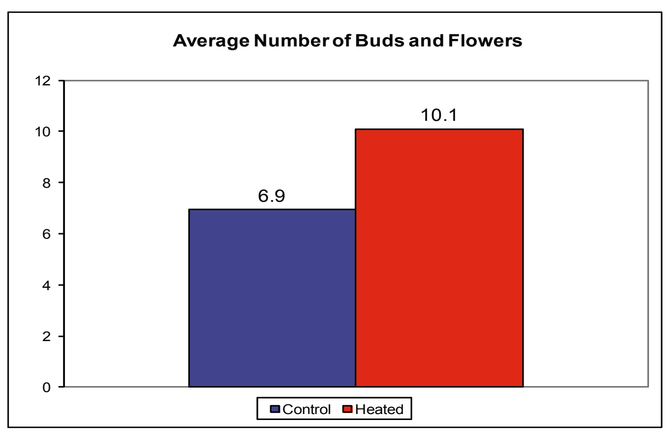

Figure 24: New York City results for Pansy, 4/10/09 buds and flowers surviving over winter.

Pansies are winter hardy in zones 4-8 (Figure 25). They can survive light freezes and short periods of snow cover, in areas with prolonged snow cover they survive best with a covering of dry winter mulch. In warmer climates, zones

9-11, pansies can bloom over the winter, and are often planted in the fall. Their normal blooming season is autumn, early spring and spring.

The New York City pansies in the heated bed were 24% taller, had 33% wider spread, and had 45% more flowers and buds than the pansies in the control bed. They also produced flowers throughout the winter (Figure 23 and 24).

CONCLUSIONS

Tomatoes are only grown in greenhouses in Iceland. The results indicate the outdoor survival of out of region cultivars, such as tomatoes during the growing season in Iceland, (May 15 through September 15), that are normally grown outdoors in warmer climates until the heavy frosts. Average plant growth increases greater than 20% more than the control gardens have been noted. The growing season was increased both in Iceland and New York City by a minimum of four weeks.

The heated garden plants were consistently larger, produced more flowers, and fruit in both Iceland and New York City. The growth and maturation rate of the heated was consistently greater throughout the growing season. The heated tomatoes in New York City had a second flowering cycle, but the cold weather stopped all growth. The grass stayed green throughout the winter in Iceland. The pansies in New York City bloomed in the winter as if they were in Florida.

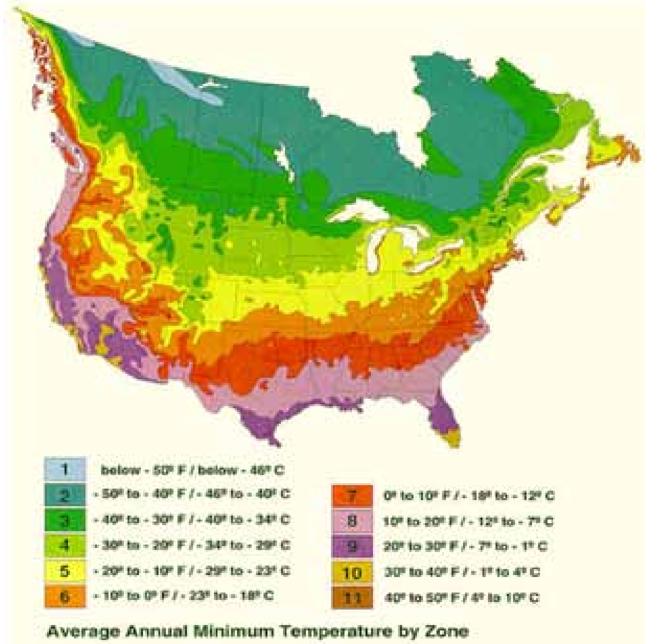

Figure 25: US climate zone map, http://toxipedia.org/download/attachments/15847/zone%20map.jpg

Based up on above results, new heated gardens without heat exchangers are under construction in Iceland at the NLFI Rehabilitation and Health Clinic in Hveragerdi using waste hot water that is currently discharged into the Varma

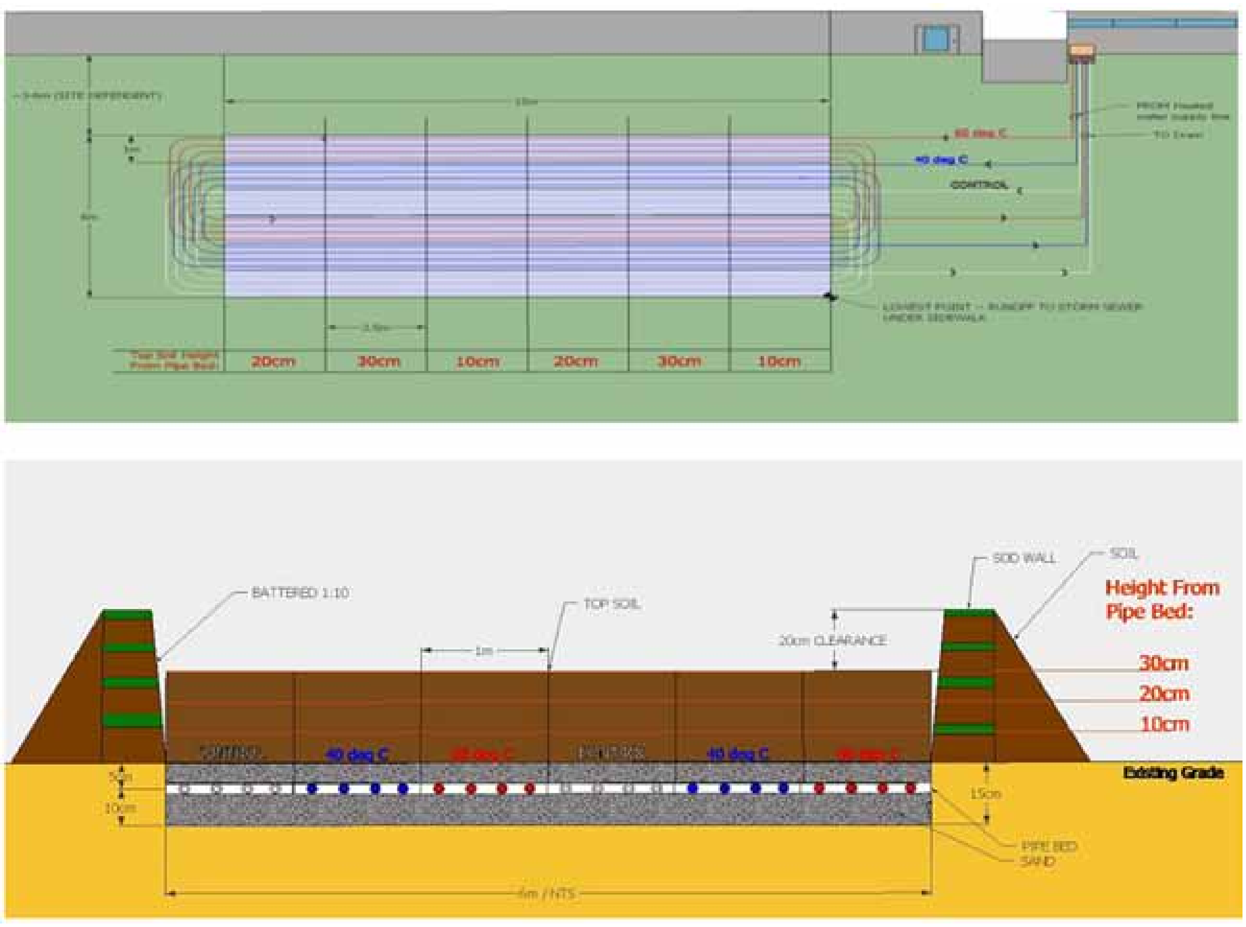

Figure 26: Keilir Institute of Technology Garden Schematics

River. The gardens at the Agricultural University in Hveragerdi will continue with modifications. New gardens at the Cooper Union are under construction. At the Keilir Institute of Technology (KIT) at Asbru in Reykjanesbaer a 16 x 6 square meter garden, as shown in Figure 26, is being constructed to investigate the potential of utilizing the waste geothermal hot water from Icelandic houses to enhance the growth of trees, flowers and vegetables. The garden will have variable water temperature zones from 20-60℃ within individual plots having a soil depth of 10-30 centimeters. Different soil types will be tested. The results will be used for gardens around the buildings in Asbru to increase tree growth.

The increased plant growth, increased bloom and fruit production, coupled with the out of region growth potentials warrants further study on a larger scale.

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