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GEOTHERMAL ENERGY IN HORTICULTURE

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ABSTRACT

Heating of greenhouses by geothermal energy has been practiced in many countries over a long period of time, especially in Europe. Access to geothermal water makes it possible to keep the climate inside the greenhouses as close to the optimum growth conditions for the plants as possible. In addition to heating, artificial lighting and CO_2 enrichment in greenhouses is common. This makes it possible to keep optimum growing conditions in the greenhouses throughout the year, independent of the outdoor climate conditions. Geothermal energy requires relatively simple heating installations, although modern greenhouses are equipped with advanced computerized installations for controlling the climate inside the greenhouse. The paper describes the activities at the Fridheimar greenhouse farm in Iceland. There, in addition to growing different varieties of tomatoes and other crops in well-equipped greenhouses totalling 4,200 m^2, tourist services play an important role in the daily business.

1. INTRODUCTION

Utilization of geothermal energy in horticulture has a long history, especially heating of greenhouses. Many countries in Europe and other parts of the world are using geothermal energy extensively for commercial production of vegetable, flowers and fruits. Geothermal energy requires relatively simple heating installations, although modern greenhouses are equipped with advanced computerized installations for controlling the climate inside the greenhouse. Where geothermal resources are available for greenhouse heating it has substantial economic benefits compared with alternative energy sources for heating.

The purpose of protected crop cultivation is to keep the climate inside the greenhouse as close to the optimum growth conditions for the plants as possible. The photosynthesis process uses sunlight to convert carbon dioxide and water into building material for the plants such as sugars. Also, each type of plant needs a specific quantity of energy in form of heat. The optimum growing conditions are usually available naturally only a part of the year but geothermal heating and artificial lighting make it possible to keep optimum growing conditions in the greenhouses throughout the year, independent of the outdoor climate conditions (Dickson and Fanelli, 2005).

According to data presented at the World Geothermal Congress in Bali 2010 (WGC2010) the total geothermal energy used for greenhouse heating worldwide increased by 13% in annual energy use in the five year period of 2005-2010, from 20,661 to 23,264 TJ/year. In the same period the total installed capacity for greenhouse heating increased by 10% from 1,404 MWt to 1,544 MWt. A total of 34 countries reported geothermal greenhouse heating compared to 30 five years earlier. The leading countries were Turkey, Hungary, Russia, China and Italy. The main crops grown in greenhouses are vegetables and flowers (Figure 1). A large part of the costs of operating greenhouses is labor costs and this has led to increasing imports of greenhouse products from the developing countries to developed countries. Reliable data for the total area of geothermally heated greenhouses does not exist, but based on the average energy requirement of 20 TJ/year/ha, determined from the WGC2000 data, it can be estimated that about 1,163 ha of greenhouse area was heated by geothermal energy worldwide in 2010. This corresponds to a 16.3% increase since 2005. A few parameters describing the worldwide development in the greenhouse sector during the period 1995-2010 are presented in Table 1 (Lund et al., 2010).

TABLE 1: Greenhouse heating by geothermal energy worldwide (data from Lund et al., 2010)

	1995	**2000**	**2005**	**2010**
Installed capacity (MWt)	1,085	1,246	1,404	1,544
Energy utilization	15,742	17,864	20,661	23,264
Capacity factor	0.46	0.45	0.47	0.48

FIGURE 1: Gerbera production at Espiflöt flower farm, Iceland

2. HEATING SYSTEMS

2.1 Heat loss from greenhouses

Greenhouses are uninsulated buildings where the cover material is in most cases single glass or a plastic cover. This is required since light is an important factor in the cultivation and natural light from the sun must penetrate as easily as possible through the cover material to the plants inside. This is important even if artificial lighting is used in the greenhouse. The heating system is designed to compensate for the heat losses to the environment and keep the air temperature inside the greenhouse close to the optimal temperature for the crops.

Most greenhouses in Iceland have a heating system based on steel pipes transferring the geothermal water in long loops through the greenhouse. Increased use of artificial lighting and more advanced control of the cultivation process has required better control of the heating in greenhouses.

When an artificial lighting of 250 W/m^2 is switched off the heating demand will increase suddenly and a quick response from the heating system is needed. One problem with intensive artificial lighting is that heat emitted from the lamps makes it necessary to open the windows frequently to get fresh air in, with the exception of very low outdoor temperatures. This can cause the top of the plants to be cooled down too much and also create an uneven vertical temperature distribution in the greenhouse which again can slow down the growing rate of the crops. Experiments have been carried out in the Netherlands on cultivation in closed greenhouses where the need for cooling is met by water or air cooling instead of air change by opening the windows. In doing so it should be possible to use the lighting and CO_2 enrichment in a more efficient way to increase the growth.

For a typical greenhouse in Iceland the transfer of heat from the inside of the house to the environment can be divided into different processes as shown in Table 2 and Figure 2.

TABLE 2: Main heat transfer processes in a greenhouse (Ágústsson, 2008)

Outdoor	Forced convection, depending on the wind	60%
	Radiation	40%
Indoor	Convection	38%
	Radiation from the heating pipes	34%
	Radiation from plants and ground plus condensation of water	28

In clear weather the share of radiation in the outside heat transfer can be as high as 60% of the heat loss and as low as 10% when it is cloudy. In addition to this there is a heat loss due to air change in the greenhouse as hot air inside the house is constantly replaced by cold outside air that needs to be heated up. As a design condition for the heating demand of a greenhouse in Iceland it is common to assume that the total heat loss per square meter is given by a U-value of 7.6 W/m^2/°C (Ágústsson, 2008).

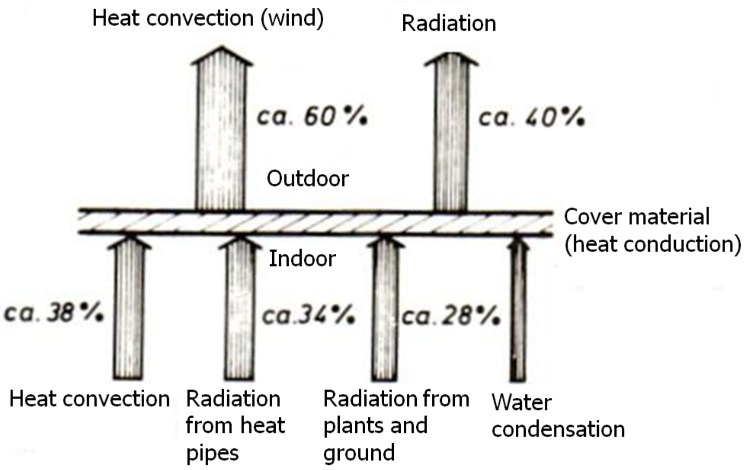

FIGURE 2: Heat transfer processes through a greenhouse cover material

2.2 Heating pipes

Heating pipes in greenhouses can be divided into four main categories. Some of them are more important than others. These are (Ágústsson, 2008):

1. Floor pipes (commonly 40-60% of the heating system);
2. Aerial pipes;
3. Wall pipes;
4. Soil heating.

In general the following requirements are made regarding the heating system in a greenhouse:

a) Keep the desired temperature in the greenhouse;
b) Respond quickly to changes in heating demand;
c) Keep as even a temperature in the greenhouse as possible;
d) Utilize the heat efficiently;
e) Fit into the building and the cultivation system.

The heat transfer processes from the heating pipes to the air inside the greenhouse are mainly of two types, radiation and convection (Figure 3). The radiation can cover up to 50% of the heat transfer, depending on the surface of the pipes. Pipes covered with aluminium bronze and galvanized pipes radiate only about 25% of the heat that is radiated from white painted pipes.

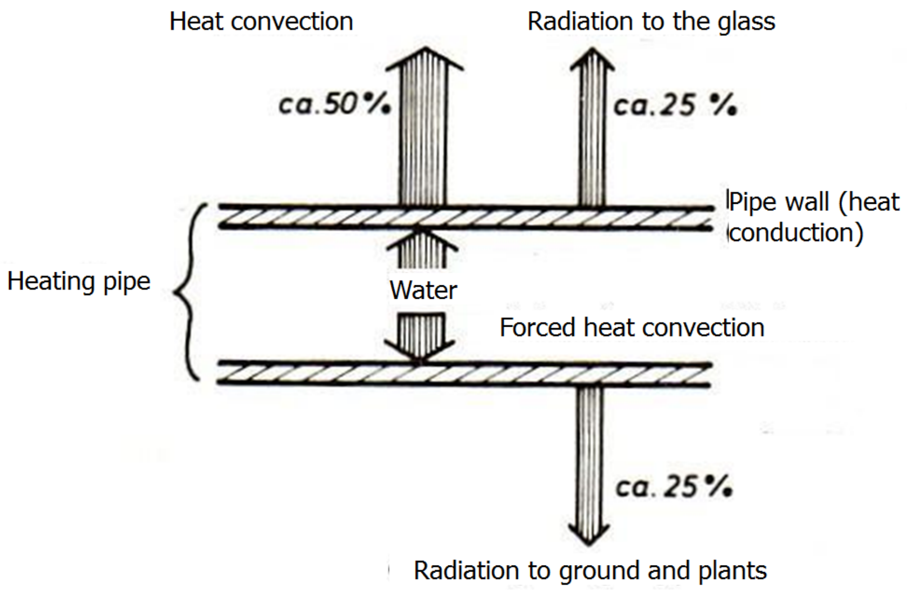

FIGURE 3: Heat transfer from heating pipes in a greenhouse

Floor pipes are the most important part of the heating system for most types of crop cultivation. The purpose of the floor pipes is to make the vertical temperature distribution as even as possible, heat up the lower part of the plants and increase air circulation. They are also used to reduce the humidity of the air by increasing the pipe temperature at the same time as the windows are opened up.

It should be possible to operate floor pipes as a separate heating system independent of other heating systems in the greenhouse. This is because the demand for heating from the floor pipes varies a lot, sometimes there is a need for intensive heating and sometimes not. The floor pipes should be placed at a minimum distance of 10 cm from the floor to ensure a free flow of air around the pipes. The difference between the temperature of the water at the inlet to the heating system and the outlet should preferably be about 10°C to give relatively even heat output from the pipes in the whole greenhouse. The average water temperature in the system is commonly about 60°C and a typical pipe diameter is 50 mm.

Aerial pipes are, as the name indicates, placed relatively high in the greenhouse above the plants. Their main purpose is to heat up the glass and the structural frame of the house and thus reduce the heat radiation from the plants to the glass. This is important since radiation from the plants can cool them down to a temperature considerably lower than the inside air temperature. In addition to being an obstacle to the growth of the plants it can cause dew formation on the plants which again increases the risk of diseases. Heating up the glass also reduces condensation of water on the glass surface which helps to maintain the humidity level and reduces the loss of light due to condensed water on the glass. The aerial pipes should be a separate heating system that can be controlled independent of other heating systems in the greenhouse. They should be placed so that they do not reduce the solar radiation to the plants too much.

Wall pipes are placed along the walls of the greenhouse and can be considered to be a supplementary heating system that is activated when the other systems cannot fulfil the heating demand. The vertical distance between the pipes should not be less than 30 cm to ensure free air flow around the pipes.

The design of heating systems for greenhouses in Iceland is usually based on the experience of the contractor and the wishes of the greenhouse farmer. Commonly between 2 and 5 m of pipeline is required per m^2 floor area depending on the pipe diameter and water temperature (Ágústsson, 2008).

3. GREENHOUSES IN ICELAND

Heating of greenhouses is one of the oldest and most important uses of geothermal energy in Iceland after space heating. Naturally warm soil had been used for growing potatoes and other vegetables for a long time when geothermal heating of greenhouses started in Iceland in 1924. The majority of the greenhouses are located in the south, and most are enclosed in glass. The heating installations are of unfinned steel pipes hung on the walls and over the plants. Undertable or floor heating is also common. It is also common to use inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. By using electric lighting the growing season is lengthened compared with natural lighting only, which improves the utilization of the greenhouses and increases the annual production per square meter of greenhouse area. Artificial lighting, which also produces heat, has contributed to a diminishing demand for hot water supply to greenhouses. As a consequence of the lengthening of the growing season the need for new constructions is less than before. CO_2 enrichment in greenhouses is common, primarily by using CO_2 produced in the geothermal plant at Haedarendi. Outdoor growing at several locations is enhanced by soil heating with geothermal water, especially during early spring (Ragnarsson, 2010).

The total surface area of greenhouses in Iceland was about 194,000 m^2 in 2012 including plastic tunnels for bedding and forest plants. Of this area, 50% is used for growing vegetables (tomatoes, cucumbers, paprika etc.) and the rest mainly for growing cut flowers and potted plants. The total production of vegetables in 2011 was about 18,000 tons. The share of domestic production in the total consumption of tomatoes in Iceland is about 75% and for cucumbers about 90%.

Most of the greenhouses in Iceland have automatic control of the indoor climate and thus, for example, the temperature can be adjusted to the optimum temperature for different kinds of crops, ranging from 10-15°C in nurseries up to 20-25°C for roses. Also, the temperature is commonly adjusted to follow the optimum daily variations. The main parameters that influence the heat loss from greenhouses and thereby the heating demand are the outdoor temperature, wind speed, greenhouse cover material, indoor temperature, artificial lighting, heating system arrangement and opening of the windows. A study made on energy consumption for heating a group of typical greenhouses in Iceland resulted in an average energy consumption of 3.67 GJ/m^2 in greenhouses with artificial lighting and 5.76 GJ/m^2 in greenhouses without artificial lighting (Haraldsson and Ketilsson, 2010).

4. FRIDHEIMAR GREENHOUSE FARM

Fridheimar is the name of a greenhouse farm located in SW-Iceland. They have their own website, which is the source of information for the description of their activity presented below (Fridheimar greenhouse farm, 2014).

Fridheimar is more than a greenhouse farm since an important part of their activity is the operation of a small restaurant and other tourist services (Figure 4). Fridheimar has specialised in tomatoes which they grow all year round in greenhouses under artificial lighting. Visitors are welcome to see the greenhouses and even taste the crop. They can also buy different kinds of food made from the local production, mainly tomatoes and cucumbers. In addition to the greenhouse farm the owners of Fridheimar are active in horse breeding and tourist services related to that. Different varieties of tomatoes are produced like plum tomatoes, cocktail tomatoes and piccolo tomatoes. The farmers state that the key factors in their production of tasty and healthy tomatoes is the green energy, pure water and biological pest controls. The pest control is based on a bug which devours all the main pests that damage the tomato plants.

FIGURE 4: From the Fridheimar greenhouse farm

The total area under glass is 5,000 m², of which about 4,200 m² are used for cultivation. The plant nursery accounts for 300 m², the atrium for visitors 300 m², and about 200 m² are used for packing etc. The greenhouses were built in the period between 1986 and 2011 and all of them have artificial lighting for year-round cultivation. Fridheimar has about 10,000 plants in their greenhouses that need weekly trimming and picking. The production is about one ton per day.

Seeds are planted in the nursery greenhouse where the plants grow in pots for the first six weeks. Then they are transplanted into the greenhouse and seven to eight weeks later the first tomatoes are harvested. At Fridheimar the tomatoes are cultivated in turf and the plants are renewed twice a year. Young plants are planted in between older plants during the whole growth period. Thus, as the last tomatoes are ready to pick on the older plants the first tomatoes on the young plants are turning red.

Abundant geothermal water for heating the greenhouses is available from a well located about 200 m from the greenhouses. The temperature of the water is about 95°C. In order to maximise sunlight in the greenhouses the glass windows are only 4 mm thick. Thus, a huge amount of hot water is needed for heating or totally about 100,000 tons per year. This amount corresponds to the annual hot water consumption of about 130 single family houses in Iceland. The electricity for artificial lighting in the greenhouses, which is necessary for year round growing, comes from renewable energy sources, partly hydropower and partly geothermally generated electricity. Another important part of the cultivation is enhancing photosynthesis by adding carbon dioxide into the greenhouses. This additional carbon dioxide comes from a factory that utilizes carbon dioxide rich fluid from a geothermal well for their production.

Each greenhouse is equipped with a climate-control computer system for temperature, humidity, carbon dioxide and lighting. The computer is connected to a fertiliser mixer, which waters the crop according to a programmed system. A weather station located on the roof provides data on outdoor temperature and light as well as wind speed and direction. The electrical lighting in the greenhouses is automatically switched on when the natural light goes below a certain limit and switched off again when the natural light has reached the required limit again. The whole control system is connected to the internet which makes it possible for the owners to monitor and adjust the conditions in the greenhouses from anywhere in the world.

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