Abstract: Greenhouse heating systems in the economic approach. Greenhouse production enables to get agricultural crop outside the normal vegetation period with higher yield in comparison to open field production, by controlling environmental factors such as temperature, light and relative moisture. Among these factors, temperature has very important effects on plant growth. Temperature controls many physiological activities in plant life as well as affects the soil as plant life environment. Maintaining temperature at desired level in greenhouse by using suitable systems is needed for modern production. But the share of heating in total greenhouse production cost is very high and it can go up to 60 percent. Due to that, it is very important to reduce heating cost for a profitable greenhouse production by using renewable energy resources and providing energy conservation. In this study, factors affecting greenhouse heating cost and the ways of decreasing cost were examined.

Key words: greenhouse heating systems, cost of heating systems, economic efficiency.

INTRODUCTION

Greenhouse production is a very important agricultural activity in social and economic terms, and because of the opportunity of getting crop outside the normal vegetation period it is generally profitable growing method. The basic reasons for increase in greenhouse areas in the world are generally high demand for early vegetables, dominion of family managership, attractive product prices and government supports. Greenhouses meet an important part of world food demand and the distribution of greenhouse areas can be seen in Figure 1.

Getting agricultural products in adequate quantity and quality can be possible by using convenient heating systems especially in countries having cold climate. It is known that when other factors composing greenhouse climate are suitable, the increase of 10°C in greenhouse temperature rises plant growth two fold with the condition of not exceeding maximum temperature allowed (Yağcıoğlu 2005). Heating greenhouses with optimum plant demands also enables production without hormone because of ideal internal temperature and prevents the diseases depending on high humidity. The im-
portant thing in this point is being able to realize an economical application by reducing energy costs (Harzadin 1994). There are many different factors affecting the profitability in greenhouse production. Heating greenhouses is one of the major cost elements and reducing heating cost means transforming the greenhouses into more profitable production structures. Energy used to heat a greenhouse is usually provided by the combustion of some fuel on site, but energy can be provided also by electricity or in many cases alternative energy sources such as solar or geothermal can be used. Utilisation of renewable energy resources like geothermal, sun and wind energy and energy conservation applications should be thought for reducing heating cost. Coal, oil and gas are the most common forms of energy used for greenhouse heating. The choice of which of these to use is based primarily on economics. The delivered cost of fuels is shown below in Table 1.

The amount of energy used to heat a greenhouse depends on the desired inside temperature, the surface area of the building, the thermal resistance of the material covering the building and the outside weather conditions and depend on delivered cost of fuels and energy demand. Energy demand will rapidly increase in the nearest years in all category of fuels (Borowski 2008).

GREENHOUSE HEATING METHODS

The main two systems of heating practical for greenhouses are hot water and steam. Heating systems may utilize hot water or hot air to increase air temperature during the cool season. Hot water systems are generally used in smaller greenhouses. In larger greenhouses hot steam systems should be used. There are numerous systems to generate the heat, such as with direct-fired unit heaters within each greenhouse bay, or centralized hot water boilers that pump hot water to multiple greenhouse units. There are also various heat distribution systems that heat the greenhouse air (air-to-air, and water-to-air heat exchangers), the soil and plant root zone (bench and flo-

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Total all sectors</th>
<th>Electric power sector</th>
<th>Commercial sector</th>
<th>Industrial sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Electric utilities</td>
<td>Independent power producers</td>
<td></td>
</tr>
<tr>
<td>Total coal (cents per MMBtu)</td>
<td>177</td>
<td>178</td>
<td>171</td>
<td>267</td>
</tr>
<tr>
<td>Total petroleum (cents per MMBtu)</td>
<td>717</td>
<td>712</td>
<td>754</td>
<td>1 404</td>
</tr>
<tr>
<td>Total natural gas (cents per MMBtu)</td>
<td>711</td>
<td>747</td>
<td>692</td>
<td>799</td>
</tr>
</tbody>
</table>

Source: www.eia.doe.gov
or heating), and the leaf surface (radiant heating) (Giacomelli 2002).

Heating systems basically can be classified as given below:
- Heating by stove
- Central heating
- Heating by hot air
- Heating by sun energy
- Heating by geothermal energy

The cost of heating system: natural gas, electricity and other greenhouse supplies became major concerns during last years, so the reduction in heating cost should be made in the greenhouse production. Which fuel is the best to heat greenhouses? The right answer depends on price, convenience and availability. Some fuels have a higher heat value than other and some heating units have a greater efficiency. A detailed economic study should be done before purchasing a system.

Greenhouse heating systems should have some specifications technically and temperatures should be uniform as far as possible and the automatic control of the system should be easy. In point of plant photosynthesis activity, leaf temperature is not only parameter and also air flow velocity and direction is important.

In all greenhouse heating systems, it is important that the exhaust should not contact the crop. When the fuel source is of high purity and is thoroughly combusted, only carbon dioxide and water vapour are produced but it is rare that fuels are completely combusted. Products of incomplete combustion, including ethylene gas are injurious to plants (Nelson 1998).

In greenhouse heating systems, heat can be distributed to greenhouse air directly or by pipes. In both methods, heat should be spread homogenously inside greenhouse. In tubular heating, one way of facilitating climate control is placing pipes close to plants. Placing heating pipes below plant level stimulates in point of plant growing. All systems given above should be able to provide the temperature needed for the whole climate conditions. Air, plant and soil the air movement in plant cover. Hot air ascending removes the moisture from plant cover and composes a uniform microclimate around plants (Başçetinçelik
Different pipe arrangements for heating greenhouses can be seen in Figure 2 (Dickson and Fanelli 2004).

In central greenhouse heating systems, there are two different applications depending on fluid temperature in heating pipes as hot water and steam. Steam central heating systems have more complicated structure than hot water systems and due to high installation cost they can’t generally be used economically except big greenhouse operations. Central heating systems are suitable for greenhouse operations bigger than 2–2.5 da area (Yağcıoğlu 2005).

Especially in recent years, renewable energy resources such as sun, wind and geothermal energy can be used in greenhouse heating. Researches focused on sun and geothermal energy utilization among these resources. Sun energy can be used in two types as active and passive for greenhouse heating. In active systems a fluid is heated by means of solar radiation and used for increasing greenhouse temperature. In passive heating, polyethylene tubes filled with water are generally placed on soil between plant rows. In these systems water capacity is 60–100 m³ per 1000 m² greenhouse area (Başçıtnçelik ve Öztürk 1996).

Another way of passive solar greenhouse heating is putting barrels painted in black in greenhouse and filling them with water. Heat energy stored by barrels during day is given to greenhouse environment by natural convection and thermal radiation during night (Fig. 3).

Geothermal energy which is another alternative energy resource can be used in greenhouse heating directly or indirectly using a heat exchanger. Heating greenhouses by geothermal energy may include some technical and economical difficulties. One of these difficulties is preliminary survey and drilling work for reaching resource. Geothermal fluid should be reinjected to deep layers after using in greenhouse heating due to their harms to environment and feeding resource. Heat pumps work like a refrigerator in reverse taking the heat from the ground source and transferring it to the greenhouse. Earth tubes capture the heat in ventilation air that is then blown into the greenhouse. The cost of most geothermal systems is fairly high and many things need to be considered before installing such a system (Bartok 2005).

FACTORS AFFECTING SELECTION OF GREENHOUSE HEATING SYSTEMS AND ECONOMICAL ASPECTS

There are many types of greenhouse designs, materials, construction and production methods. There are two basic types of greenhouses: attached and free-
Greenhouse heating systems in the economic approach

A free-standing type is usually even-span (symmetrical roof). Greenhouses have supporting framework made of wood, aluminium, iron, or galvanized pipe. Some have curved eaves; others have flat eaves. Some are glass or plastic from the ground up. Each type of construction has advantages and disadvantages. A greenhouse structure is advantageous when low initial cost is required or when it is planned for a building to be in use for only a year or two. A wood or metal frame building has advantages when a permanent building is planned and operating costs are most important. The main difference in operating costs is caused by the energy used to heat the structure and water during cold weather. The energy lost through the walls of a structure during cold weather must be replaced by the heating system in order to maintain a stable temperature inside a structure. The amount of energy that must be supplied is related to the difference between inside and outside temperatures and the thermal resistance or "R" value of the building’s roof and walls (Fowler 1997).

The selection process of a particular heating system should not only depend on cost, but also on its effective integration within the crop production system and management procedure. However, the first requirement in the design of a heating system is to determine the size needed, in terms of energy requirement or heat load of the greenhouse (Giacomelli 2002), in order to describe the economic performance of the greenhouse production, including total annual production costs. Fixed and variable expenses should be also calculated. The capacity of the system depends on the size of greenhouse, whether it is covered with a single layer or a double layer of plastic or glass, and the maximum difference between inside and outside temperatures.

There is a wide variety of greenhouse supplies, equipment and accessories to help operate, maintain and improve greenhouse. The biggest factor affecting the cost of greenhouse heating is type of energy resource used for producing heat needed. A lot of various low-temperature water sources are available for greenhouse heating and they are generally cheaper than heat from conventional fossil energy sources, but their disposability and continuity are not always warranted. Among these heat sources the most frequently cited are geothermal energy, industrial heat effluents or waste heat from thermal power plant, water from solar collectors and low-temperature heat generators such as heat pumps, condensation boilers (Baille 1988).

In this point, technical, regional and economical factors should be considered altogether. Especially regional advantages should be benefited in terms of renewable energy resources. For example, in the regions having important geothermal energy potential, total costs can decrease in comparison to fossil fuelled systems. In regions having much solar radiation, solar systems could be used as the main or auxiliary heating systems.
with economical advantages. But studies mostly show that meeting all of heat requirements with sun energy is not economical.

The application of geothermal energy of low temperature has excellent economical prospects as a heat source for protected cultivation especially in mild weather areas which have the advantage of high temperatures and solar radiation during most part of the year. To utilize usefully geothermal water in commercial greenhouses, it is very important to make the use of low cost technologies suitable for plant growing in greenhouses (Campiotti and Picciurro 1988).

The economy of heating greenhouses by geothermal energy depends on availability ratio and heat requirements per unit area in addition to geothermal fluid temperature, depth and flow rate of geothermal resource and transmission distance of geothermal fluid. Installation cost of geothermal heating systems is high and it should be recovered in short term by distributing geothermal fluid to wide greenhouse areas (Başçetinçelik et al. 1994).

Karacabey (2008) made a research on comparison of utilization of geothermal and solid fuel heating systems in a sample greenhouse operation which has 12 da total area and glass cover material and the results are in Table 2.

As it can be understood from Table 2, geothermal heating systems have important advantages especially in terms of variable operating costs. Installation costs in fossil fuel heating systems are 27% bigger than geothermal heating

<table>
<thead>
<tr>
<th>Heating system</th>
<th>Installation costs (USD)</th>
<th>Operating costs (USD/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed operating costs</td>
<td>Variable operating costs</td>
</tr>
<tr>
<td>Geothermal heating system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>10 000</td>
<td>Amortization + Interest</td>
</tr>
<tr>
<td>Heating pipes</td>
<td>14 749</td>
<td>4 464</td>
</tr>
<tr>
<td>Circulation pumps</td>
<td>1 942</td>
<td>Hot water cost</td>
</tr>
<tr>
<td>Other system elements</td>
<td>6 652</td>
<td>Cost of electricity</td>
</tr>
<tr>
<td>TOTAL</td>
<td>33 343</td>
<td>consumption</td>
</tr>
<tr>
<td>Fossil fuel heating system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating boiler</td>
<td>23 846</td>
<td>Amortization + Interest</td>
</tr>
<tr>
<td>Heating pipes</td>
<td>14 749</td>
<td>6 163</td>
</tr>
<tr>
<td>Circulation pumps</td>
<td>788</td>
<td>Fuel cost</td>
</tr>
<tr>
<td>Other system elements</td>
<td>6 652</td>
<td>Cost of electricity</td>
</tr>
<tr>
<td>TOTAL</td>
<td>46 035</td>
<td>consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance and repair cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>768</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TOTAL 68 632</td>
</tr>
</tbody>
</table>
systems. Total operating costs in geothermal heating systems are 86% lower than fossil fuel heating systems although there is no so much difference in fixed operating costs.

Heat conservation in greenhouse is very important for decreasing the heating cost and different techniques such as thermal screen application could be used for that. Thermal screens are generally regarded as being one of the most effective methods of energy conservation. A very wide range of screen material is available, such as polyethylene (PE), polyester, cloth or film. Nowadays, the most modern thermal screens are made of a combination of polyester and aluminium (Öztürk ve Başçıntçelik 2003).

Glass and plastic cover materials in different types are used in greenhouses. One of the ways of providing heat conservation and decreasing cost is using greenhouse cover material which has high insulation value. Insulation value can also be increased via double cover material. Djevic and Dimitrijevic (2004) made a research on heating requirements and fuel oil amount needed for heating in different greenhouse constructions in Serbia and the results obtained are presented in Table 3.

As seen in Table 3, double plastic cover material has air-tight and high insulation feature and it provides energy saving up to 40%.

<table>
<thead>
<tr>
<th>Greenhouse type</th>
<th>Tunnel type (single plastic)</th>
<th>Tunnel type (double plastic)</th>
<th>Arch-roof type (single plastic)</th>
<th>Arch-roof type (double plastic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat requirement (kW)</td>
<td>103.0</td>
<td>72.0</td>
<td>107.23</td>
<td>75.0</td>
</tr>
<tr>
<td>Fuel oil needed (kg/h)</td>
<td>8.9</td>
<td>6.22</td>
<td>9.26</td>
<td>6.46</td>
</tr>
</tbody>
</table>

Record keeping is an important factor in cost management in greenhouse heating. A grower can prevent repeating the same errors by keeping records in production system. Records and cost accounting is a system for assessing the costs of conducting a business. The costs of each input labour, utilities and materials are determined and compared to a reasonable proposal of costs. The overall profitability of the system is then determined (Nelson 1998).

CONCLUSION

It is obvious that expansion and progress of greenhouse production is mostly dependent on decreasing heating cost and studies focused on energy conservation technologies and utilization of renewable energy sources in greenhouse production. Although there are different ways of reducing heating cost, a certain
system can’t be suggested for a greenhouse operation. As mentioned above, all regional and technical opportunities should be evaluated while choosing and operating heating system. The elements dependent on region and operation like cost difference between conventional fuel and renewable energy utilization, crop grown, market prices of technical components of greenhouse heating systems entails constituting own cost strategy for a greenhouse operation.

REFERENCES


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Streszczenie: Ekonomiczne aspekty systemów ogrzewania szklarni. Produkcja szklarniowa pozwala uzyskać produkty roślinne poza normalnym okresem vegetation, zapewniając jednocześnie użyczenie wyższej wydajności w porównaniu z produkcją połową dzięki kontroli takich czynników środowiskowych, jak temperatura, światło i wilgotność. Wśród wymienionych czynników temperatura ma kluczowy wpływ na wzrost roślin. Utrzymanie temperatury na pożądany poziom w warunkach szklarniowych jest możliwa
poprzez wykorzystanie odpowiednich systemów grzewczych. Udział ogrzewania w całkowitych kosztach produkcji jest bardzo wysoki i może sięgać nawet do 60%. W celu uzyskania rentownej produkcji w systemie ogrzewania można wykorzystywać odnawialne źródła energii. W artykule zaprezentowano wyniki badań z uwzględnieniem czynników wpływających na koszty ogrzewania i zaproponowano sposoby ich obniżenia.

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Authors’ addresses:
Ersin Karacabey – Ege Üniversitesi Ziraat Fakültesi Tarım Makinaları Bölümü
35100 Bornova-İzmir
TURKEY
e-mail: ersin.karacabey@ege.edu.tr

Piotr F. Borowski
Katedra Organizacji i Inżynierii Produkcji SGGW
02-787 Warszawa, ul. Nowoursynowska 164
Poland
e-mail: piotr_borowski@sggw.pl