Greenhouse Energy Consumption and Energy Efficiency

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Greenhouse production is still among the most energy-consuming branches of agriculture. Producers are faced with high cost of the operations involved in greenhouse production processes (climate control, fertilizing, irrigation). This is the reason why an optimal combination of energy inputs that will make this production more energy efficient needs to be found. In this paper analyze types of energy inputs in greenhouse production and their share in total energy consumption by using their energy equivalents. Knowing all this inputs enabled calculating of energy efficiency and energy ratio for greenhouse winter lettuce production. Some examples and suggestions for reducing the energy input value are also given.
Key words: energy, greenhouse, energy input, energy output, efficiency

INTRODUCTION

Energy, economics and environment are three important factors for defining the behavior of agricultural production systems. In recent years, there has been a great increase in energy consumption in agriculture. This is due to continuous growth of population and development of new production technologies. Greenhouse production, as one of most intensive plant production system, is the most energy-consuming branch in agriculture. Producers are faced with high cost of operations involved in greenhouse production process. So, it is of great importance to define all energy inputs in greenhouse production, in order to find their optimal combination that would make this production more energy efficient.

MATERIAL AND METHODS

The aim of this paper was analysis of greenhouse energy efficiency regarding the greenhouse construction, covering material and plant production. Winter lettuce production under plastic covered multi-span greenhouse in climatic conditions of Belgrade, Serbia and Montenegro was used. Calculations were based on standard minimal temperature for this region of -18^0 C, and optimal temperature for lettuce production of 20^0 C.

The method used, is based on energy input analysis (definition of direct and indirect energy inputs), energy consumption for given plant production, and energy efficiency. On the basis of lettuce production output (kg of lettuce, heads of lettuce) and energy input, energy input/kg of product, energy out/in ratio and energy productivity were estimated as follows:

$$\text{Energy input/kg of product} = \frac{\text{energy input for production [MJ/ha]}}{\text{output [kg/ha]}} \quad (1)$$

$$\text{Energy out/in ration (ER)} = \frac{\text{caloric value of production [MJ/ha]}}{\text{energy input for the production [MJ/ha]}} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{production [kg/ha]}}{\text{energy input for the production [MJ/ha]}} \quad (3)$$

One part of analysis included finding the possibilities for energy savings in greenhouse production systems. The influence of greenhouse structure and covering material on heating requirements and fuel consumption for most common structures (Quonset and Arch type) and coverings (single PE, double PE) for the climatic conditions of Belgrade, Serbia and Montenegro were analyzed. Heating requirements were calculated based on [7]. Other methods for energy savings were also discussed.

REZULTS AND DISCUSSION

Definition of energy inputs for greenhouse production

Energy consumption in greenhouse is associated with all inputs that take part in production processes. These inputs can be classified in two main groups [8]: direct and indirect energy inputs.

Direct energy inputs

These inputs represent one third of the total energy consumption. These are fossil fuel energy inputs and renewable energy source inputs. Direct energy inputs for heating a greenhouse are of greatest importance for the producer because they determine production efficiency and market price of the product.

Solid, liquid and gaseous fuels represented by wood, coal, oil and gas, are used for greenhouse heating. Each of these has its advantages and disadvantages. The choice of fuel is based either on economic or on ecology factors. In order to establish energy input for greenhouse heating it is necessary to consider their heating value and the energy needed for making their energy available directly to the producer. In the case of natural gas [8], that would be 41.4 MJ/m^3 for energy content, and 8.1 MJ/m^3 for the production. Total energy equivalent would be 49.5 MJ/m^3. From energetic and economic aspect, natural gas can be described as most desirable fuel. System installation is cheaper, storage tanks are not needed, gas burns clear thus reducing labor input energy in adjusting and cleaning of burner. Oils systems are generally energy more consuming systems in question of labor and storage facilities. Same story is with coal that requires considerable storage space, much handling labor and produces large volumes of ash that has to be removed and disposed of. Used motor oils are energy very efficient but in order to use this advantage, lot of pre work needs to be done (reprocessing of the oil, specialized burners and positioning of the burners). Burners for burning the wood are commercially available. Systems can be completely automated. From the economic part of view, concerning the price of wood (green chips, dried pallets) this can be an optimal solution for the producer but labor input energy and storage facilities problems can't have any better solutions.

The heat required can easily be calculated for a given construction, shape and covering material of a greenhouse. Table 1. gives calculated heating requirements for most common greenhouse structures and materials used in Serbia and Montenegro region. These values represent amount of heat that has to be applied to the greenhouse each hour in order to maintenance the desired temperature, if the heater is located in the greenhouse. Objects are shown in Figure 1.

Table 1. Heating requirements for various greenhouse structures

Heat needed [kW]	**Type of greenhouse construction**	
Covering material	Quonset type	Arch type
Single plastic	103	107.23
Double plastic	72	75

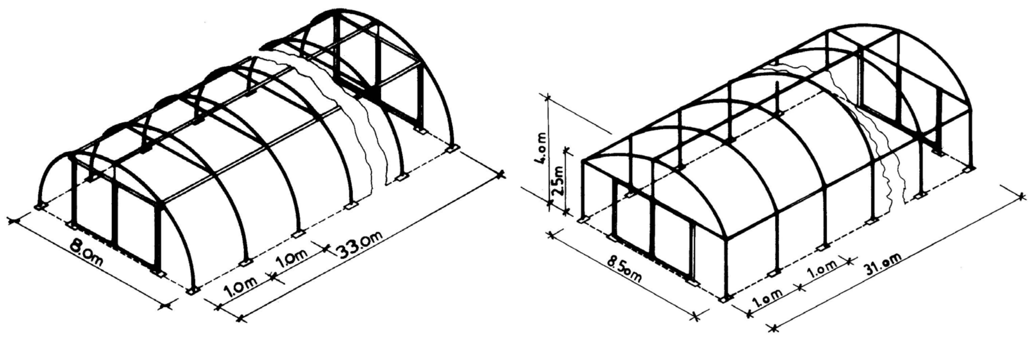

Figure 1. Quonset and arch type of greenhouses construction

The amount of fuel needed for a given period of time, can be calculated knowing the heat value of the fuel, the thermal efficiency of the burner and heat required for a given greenhouse. The amount of fuel needed for heating in this case, if fuel oil is used, is given in table 2.

Table 2. Quantity of fuel needed for heating

Fuel [kg/h]	**Type of greenhouse construction**	
Covering material	Quonset type	Arch type
Single plastic	8.9	9.26
Double plastic	6.22	6.46

Indirect energy inputs

Two thirds of all energy inputs are indirect energy inputs. These include energy used for producing equipment and other materials that are used in production processes (fertilizers, chemical biocides, labor and transportation).

Fixed equipment

The energy input for the fixed equipment amounts from 7 to 10% of the total [9]. To evaluate these inputs it is necessary to know weight of the machinery, its life span and the average surface on which it is used, or the number of working hours.

Fertilizers

The most important indirect use of energy is by fertilizers. In greenhouse production twelve main elements must be supplied during production process, six macro and six microelements. The most important of all is nitrogen. Average values for energy intensities for most important fertilizers are given in table 3. Overall energy includes production, packaging, transportation and application.

Table 3. Energy content in main mineral fertilizers*

Energy [MJ/kg]			
Fertilizer	**Production**	**PTAA**	**Total**
N	69.5	8.6	78.1
P_2O_5	7.6	9.8	17.4
K_2O	6.4	7.3	13.7

* adopted from [6]

It is possible to add all essential macro elements, except nitrogen and potassium, during preparation of root substrate. Nitrogen and potassium can be alternatively applied through single application of a dry slow-release fertilizer that can provide N-P-K for 3-14 month. This means that no additional application system is needed during the crop development. This can reduce labor energy input end investments in fertigation systems. The possibility for optimization for this type of energy inputs also lies in their precise and controlled application that involves some type of agricultural computerized control systems.

Chemical biocides

In the past few years consumption of chemical biocides has increased. In greenhouse production these are used for controlling weeds, pests, diseases and for growth regulation. The energy embodied in active ingredient production includes production, formulation and packaging. To establish total energy amount it is necessary to add transportation and application. For example, energy input for 1 kg of Malathion would be 229 MJ. Possible ways for reducing the use of chemical biocides would be applying an IPM method (Integrated Pest Management) that present an integration of chemical, biological and mechanical control measurements with solarization, pasteurization and sanitation technologies. Insect screens showed great results in decreasing the number of insect and their varieties, reducing the need for pesticide application and counteracting insect resistance to pesticide.

Crop propagation

Agricultural crops can be propagated by seeds, seedlings, bulbs, tubers, etc., so in the energy analysis, the energy required for their production must be included. Unfortunately, not much information about this is available. On the other hand, for the same input, the associated energy depends on processes to be obtained later. For example, different energy rates are required for seed production, depending on whether it is produced on the farmer's own farm or purchased from a seed producer company. Heichel [5] stated different methods for its assessment. He considers that all steps, pre harvest and post harvest, must be taken into account for different inputs and processes in each case.

Irrigation

Energy assessment in irrigation systems depends on both the direct use (DE) and the indirect use (IE). The former includes the energy consumption to pressurize (*H*) the overall rate of water required by crop considered per hectare. Direct energy can be expressed by the following equation:

$$DE = (\delta \; g \; H \; Q)(\eta_1 \, \eta_0) \qquad (4)$$

where DE is direct-use energy (J/ha), δ is the water density (1000 kg/m^3), g is gravity (9.8 m/s^2), H is the total dynamic head, including friction losses (in meters), *Q* is the overall rate of water, including losses by evaporation, drainage run-off, etc. (m^3/ha^{-1}), η_1 is the pump efficiency, and η_0 is the overall efficiency of the power device, electric or diesel. Pump efficiency is a function of vertical height to lift, speed, and flow water pumped. It ranges between 70% and 90%. Overall efficiency is considered for both electric- and fuel-powered devices; it ranges between 18% and 22%. In this factor, for the electric motor, the generating plant, the transmission line, and the motor efficiency are included. Diesel efficiency is approximately 25%–30%, but the energy to produce and transport fuel must also be considered. Indirect energy includes raw materials, manufacturing, and transportation of the different elements that constitute an irrigation system with the same treatment as other infrastructures in their expected total life. It is difficult to establish this value so that a percentage of direct-use energy can be considered for the irrigation systems, ranging from 18% [8] for the traveling sprinkler to 375% for the surface with a run-off recovery system.

Transportation

Horticultural production can't be imagined without well-organized transportation services. Energy is required for moving inputs to the farm from their point of origin, for moving labor, machinery, and products to and on the farm, and for moving farm products to market. Energy requirements in transport are normally expressed as energy intensity, the energy needed per unit of weight and per unit of distance traveled (in $MJ\ t^{-1}\ km^{-1}$). If transportation is done by truck the established value of energy intensity is 1.6–4.5 $MJ\ t^{-1}\ km^{-1}$.

The possibilities for reducing the energy input in transportation processes lie in:

- the choice of the most economical vehicles for the load to be carried, with minimum fuel consumption
- proper maintenance of vehicles
- good planning in order to reduce trips

Vehicle loading is also important factor for efficient energy use. Loading the vehicle up to its maximum capacity reduces energy intensiveness.

Energy of human labor

Labor energy input in horticultural production still has high value in developing countries. There are many different methods for estimating this input value. Most authors calculate the nutritional calories per agricultural laborer. Others say that it depends on calories needs during the working hours. All agree that labor energy input does not depend only on nutritional customs, but also on the agricultural production systems. The energy of human labor in greenhouse production [9], assuming 1000-2000 working hours per $1000m^2$, will be 750 MJ to 1500 $MJ/1000m^2$.

Energy analysis

When determining an energy consumption of a production system, it should be mentioned that energy analysis methods depend on the purpose of analysis. The conventional method is to determine the total non-solar input needed for producing a particular product. Table 4. presents energy input in winter lettuce production (running cost only), up to the point when product leaves the farm. So transportation input is not included in the calculation. These energy inputs are estimated according to their energy equivalents.

Table 4. Energy analysis of winter lettuce production in heated greenhouse*

Input	Quantity	Energy	
		GJ/1000m^2	%
Heating, fuel oil	10-20 t	834	92.9
CO_2 enrichment, fuel oil	900 kg	37.5	4.2
Fungicides,	10 kg	0.95	0.1
Fertilizers N P_2O_5 K_2O	 43 kg 5 kg 13.25 kg	 3.36 0.087 0.18	 0.37 0.01 0.02
Seeding sprays	1.3 kg	0.124	0.01
Boxes	2334	16.23	1.81
Seed and blocking compost	30	4.5	0.5
Labor**		0.75	0.08
Total	897.68	897.68	100.00

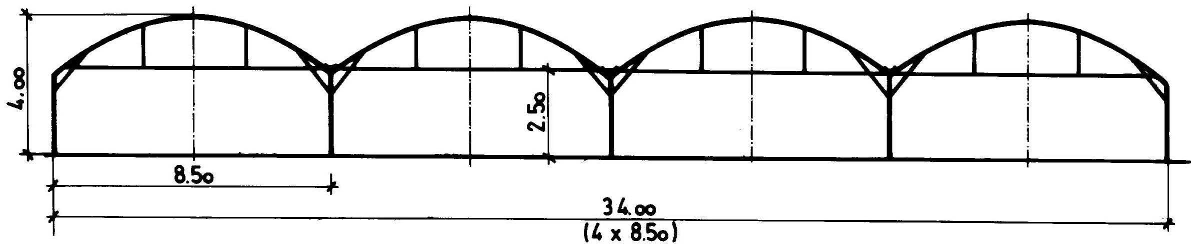

Figure 2. Multispan plastic covered greenhouse

Output: 3.5 kg/m^2 lettuce = 3500kg lettuce

2334 boxes x 12 heads/box = 28008 heads of lettuce

Ratio: Energy input/kg lettuce $$\frac{897.68\ \text{GJ/1000m}^2}{3500\ \text{kg/1000m}^2} = 256.48\ \text{MJ} \quad (5)$$

Energy input/head lettuce $$\frac{897.68\ \text{GJ/1000m}^2}{28008\ \ \text{heads/1000m}^2} = 32\ \text{MJ} \quad (6)$$

Concerning the caloric value for lettuce, ER can be calculated as follows:

Energy out-in ratio [ER] $$\frac{1.46\ \text{GJ/1000m}^2}{897.68\ \text{GJ/1000m}^2} = 0.002 \quad (7)$$

Energy productivity for horticulture and greenhouse production can be calculated as relation between output energy of production and energy input for the production.

Energy productivity $$\frac{3500\ \text{kg/1000}^2}{897.68\ 10^3\ \text{MJ/1000m}^2} = 0.004\ \text{kg/MJ} \quad (8)$$

* plastic covered greenhouse with production area of 1000m^2. Four gables, 250m^2 each, fig. 2
** adopted from [9]

In this example direct energy inputs represented by fuel for heating and for CO_2 enrichment, have greatest share in total energy consumption. It can be also seen that attention has to be paid on packaging of product because boxes and palettes can embody much energy quantities.

Possibilities for energy savings in greenhouse production

The purpose of energy analysis is to find such a solution that would be able to deliver the plant product to the consumer at the smallest energy input per kg of yield.

There are two main strategies in reducing greenhouse energy consumption [8]. The first one is to try to reduce amount of fossil fuel energy input by developing insolation equipment (double glass etc.), by long term storage of surplus energy occurring during the summer, by using alternative source of energy (biomass, geothermal water, solar radiation, waste industry water, etc.). Double-layer polyethylene covered greenhouses can consume 40% less fuel than single polyethylene covered [7]. Double polycarbonate panels will have approximately 50% lower heat requirements than single layer greenhouses. In spite of these advantages, there are some questions that must be considered such as effect of reducing CO_2 concentration, reduced nutrient uptake, internal air pollution, etc. These can lead to lower production quality and quantity. Using the thermal screens technology showed 60% savings compared to conventional systems at night, and seasonal savings of 25-30% [4]. Thermal screens results in lower temperature of greenhouse cover thus reducing the chance for snow to melt of. This can lead to collapsing of structure. Another problem is condensation on screen material, but this can be fixed with porous screen materials. The problem that still remains is temperature difference of crop and air when screens are being opened. Table 5. shows the possibilities of using biomass for heating a greenhouse in large production areas.

Choosing a quonset construction, double covering and east-west orientation can improve light and temperature conditions in the object, thus reducing the energy input for artificial lighting and heating.

Table 5. Yearly mass of straw and agricultural area needed for heating a 1000m^2 greenhouse*

Inside temperature day/night, ^{0}C	**Straw kg/1000m^2**	**Area ha/1000m^2**
14/10 single covering	149 000	37.3
18/16 single covering	271 000	67.8
14/10 double covering	94 000	23.5
18/16 double covering	172 000	43.0

*adopted from [10]

The other strategy is extensifying the winter cropping in greenhouses by developing a low cost greenhouse construction, to save energy during the remaining cropping season, to use low temperature systems in order to extend cropping season during spring and autumn. Reduced temperatures lead to longer growing period for radish and lettuce. The energy input per m^2 and per working hour is significally reduced by 1/3 and more [9], but with reduction of turnover of 15%. This means a considerable savings in energy but to the expense of reduced capital and labor productivity.

CONCLUSION

Greenhouse production stays as most intensive but most energy consuming branch in agricultural production system. This is the reason that energy analysis has to be more detailed in order to find more optimal solutions for this intensive plant production system. Great attention should be given to direct energy inputs, represented by fuel energy needed for heating and CO_2 enrichment, which are approximately 80% of the total energy input. Other high energy consumers are fertilizers. Their application is highly accurate and precise so there is no way for reducing their amount that has been prescribed by technologists. Reduction of chemical biocides input can be achieved with applying IPM methods together with soil solarization, soil pasteurization and high level of sanitation measures.

Given example of energy analysis and established ER values are similar with those obtained in [1]. These show that energy efficiency of greenhouse production is very low [1] comparing to animal production (ER=0.59) or to grain production (rice ER=1.3-5, cereals ER=1.9). This method of production energy analysis can be useful for defining a new production technology for given crop and climatic parameters of production area, or in finding most profitable and less energy consuming solutions for already established production areas. Calculation of the optimal production program can be carried out by using of linear programming methods where optimization criteria can be minimizing the energy inputs or fuel consumption or even cost of production.

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