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AN ENERGY EFFICIENCY PROJECT FOR A GLASS GREENHOUSE

Georgi KOMITOV[1], Violeta RASHEVA[2], Georgi VALTCHEV[2]

[1]Agricultural University of Plovdiv, 12 Mendeleev Blvd., Plovdiv, Bulgaria
[2]University of Food Technologies, 26 Maritza Blvd., Plovdiv, Bulgaria

Corresponding author email: gkomitov@abv.bg

Abstract

Increasing energy efficiency and reducing greenhouse gases is a central issue in the European energy strategy. The challenge of significantly reducing in primary energy consumption is great. It can only be achieved if we all work together and share good experiences and practices. Vegetables are undoubtedly one of the healthiest foods with high energy content. They are rich in amino acids, easily digestible sugars, enzymes, minerals, vitamins, chlorophyll, organic water and other nutrients. Therefore, the production of fresh vegetables is a vital necessity, even in winter. Naturally, winter production of vegetables requires that they be grown in heated greenhouses. Energy costs for greenhouse heating and ventilation form a significant share of their total production costs. The purpose of this paper is to identify the incoming and outgoing energy flows from a glass greenhouse for vegetables production and to propose a methodology for defining the energy for the greenhouse heating while providing the necessary parameters of the environment for fresh vegetables growing.

Key words*: energy consumption, glass greenhouses, microclimate, vegetables.*

INTRODUCTION

A global warming becomes too serious problem recently. Because of the need for urgent actions to combat climate change, the European Council supports the goal of achieving the climate-neutral EU by 2050, in line with the Paris Agreement. However, achieving climate neutrality will require overcoming serious challenges and considerable investments. The European Council recognizes the need to ensure energy security and respects the right of Member States to choose the most appropriate energy technologies (European Council meeting, 2019).

Europe's energy policy forms part of the overall objectives of the EU's economic policy. The starting points of the European energy policy are three: limiting climate change, promoting growth and jobs, and limiting EU dependence on imported natural gas and petroleum products. European policy is geared towards ensuring security of energy supply and introducing an integrated approach to energy efficiency. Energy saving is the most direct and economically effective way to address these energy challenges (energy strategy 2030; www.seea.government.bg). That is why the Bulgarian national policy follows the priorities and the long-term goals of the European policy for sustainable energy development (*Law of energetics*; *Law on energy efficiency*).

The sector of greenhouse farming in the EU faces a trend that meets the changing needs of consumers in society. This global trend is having a negative impact - high demand for fossil fuels, increasing energy consumption and carbon dioxide emissions (Bibbiani et al., 2016).

Greenhouses are the commonly used systems for growing plants under cold climatic conditions. In winter months when the agricultural production cannot be climatically performed, plants are cultivated under optimal conditions set up in greenhouses. Greenhouse cultivation, in this respect, has an important function for the agricultural economy. Nevertheless, under the climatic conditions with low daylight and night temperatures, the greenhouses are heated up by means of commercial heating systems. Apart from the installation and labor costs, such as the covering and construction materials, greenhouse heating comprises the major operational expenses (Başak & Sevilgen, 2016).

Heating provides many other benefits besides its positive influence on productivity, earliness and quality. It is much easier to control high humidity, which is the primary cause of plant

diseases, in heated greenhouses than in unheated ones (Baytorun & Zaimoğlu, 2016).
In order to improve the energy efficiency of the greenhouse, it is important to predict its energy consumption (Shen et al., 2018).
The thermal energy requirement of a greenhouse depends on many factors as the solar radiation, the inside and outside air temperature, the wind speed, the soil temperature, the greenhouse area, the geometry and orientation, the thermal proprieties of covering materials, the air ventilation and loss, and so on (Anifantis et al., 2016).
A number of studies have been carried out on greenhouse cultivation and heating so far. A design of a greenhouse using renewable energy for its optimal operation for chilly plants over the year is presented in (Fahmy et al., 2016). The effect of a greenhouse heating system by a tank fillet rocks placed on the ground of the greenhouse is studied in (Gourdo et al., 2018). During the day these rocks store the heat coming from the air of the greenhouse and release it into the air inside the greenhouse overnight.
Some vegetables and flowers for greenhouse cultivation have been investigated according to the optimal growth temperatures - such as strawberry, chrysanthemum, rose and eggplant (Yang et al., 2012.2); tomatoes (Pevicharova et al., 2013; Shamshiri et al., 2018); salad (Kostadinov et al., 2019); pepper (González-Briones et al., 2018); peppers, tomatoes, cucumber, lettuce, poinsettias, carnations and geraniums (Bošnjakovi et al., 2013).
The application of classical and generalized predictive control to greenhouse heating is examined Ramírez-Arias et al., 2005) in order to analyze and compare the energy savings.
The purpose of this paper is to determine the amount of energy required for heating a greenhouse based on energy efficiency normative documents.

MATERIALS AND METHODS

The study object of this work is a greenhouse, located in town of Plovdiv, Bulgaria at 42°9′ north latitude and 24°45′ east longitude.
The experimental greenhouse is an even-span single-layered glass (4 mm thick) as shown in Figure 1. The roof slope is 26.5°. The greenhouse is dedicate for growing various types of vegetables and flowers.

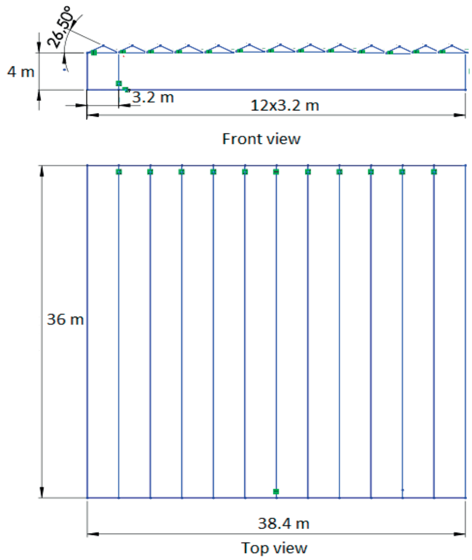

Figure 1. General view of greenhouse

Dimensions of the greenhouse structure are 36 m for width, 38.4 m for length and 4.0 and 4.7 m for height at the side walls and ridge, respectively. The greenhouse is equipped with retractable thermal screening systems for the both side walls and a plane at the height of 3.5 m. The air volume of the greenhouse is approximated to be 6010.5 m^3 and is reduced to 4200 m^3 at night time by spreading the screens. The specification of the experimental greenhouse is present in Table 1.

Table 1. The greenhouse specification

Item	Description
Orientation	Nord-South
Floor area	1382.4 m^2
Roof area	1507.42 m^2
Wall area	621.91 m^2
Shape	Multi-span roof
Wall and roof material	Single glass 4 mm

The heat balance of the studied greenhouse is presented in Figure 2. According to the first principle of thermodynamics, the energy gained by the greenhouse is balanced by the energy loss by it.

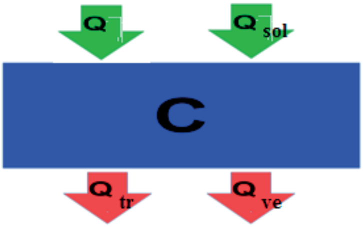

Figure 2. Greenhouse heat balance model
Q - Thermal energy required for greenhouse heating, Qsol - Heat gain from solar radiation, Qtr - Heat loss from heat transfer, Qve - Heat loss from ventilation, C - Space of the glasshouse

The heat loss is composed mainly of two components – transmission heat loss through the roof and walls and infiltration (ventilation) heat loss. The heat loss from perspiration and respiration of plants are neglected, since they are relatively small compared to those by transmission and infiltration. The heat gains are mainly due to solar radiation. The air change method is the general method for infiltration heat loss calculation. A common assumption is that ventilation loses are calculate for 20 air changes per day (Ikonomopoulos & Tsilingiridis, 2016).

For the purpose of this study meteorological data (solar radiation, ambient air temperature) for 3 years period before this year are used. The average indoor night temperature and minimal outside temperature are considered to be 16^0C and -15^0C, respectively and the air exchange is 1 h^{-1}.

RESULTS AND DISCUSSION

The total heat losses Q_{ht} from the greenhouse are defined as the sum:

$Q_{ht} = Q_{tr} + Q_{ve}$, kWh (1)

where:

- Q_{tr} - heat loss from heat transfer, kWh;
- Q_{ve} - heat loss from ventilation, kWh.

During the heating period heat loss from heat transfer through the greenhouse envelope Q_{tr} depends on the thermal properties of these elements. The exterior walls of the greenhouse are made of glass with a thickness 0.004 m. The area of the external walls is 621.91 m^2, and their coefficient of heat transfer is 6.66 W/(m^2K) - as a single-pane glass with metal frame (Kaloyanov, 2006).

The roof of the greenhouse is a warm roof without an air layer. The roof is multi-span and is made of glass with a thickness 0.004 m. The area of the roof is 1507.42 m^2. The heat transfer coefficient of the roof is 6.66 W/m^2K.

The floor is the land on which plants are grown. The floor area is 1382.4 m^2, and its perimeter is 148.8 m. The heat transfer coefficient from the heated area to the outside air is determined according to (Regulation № 7, 2004). The spatial characteristic of the floor B' is determined by equation 2:

$B' = A/(0.5*P) = 18.58$ m (2)

where:

- A - the floor area (m^2);
- P - the perimeter of the floor (m).

Equivalent floor thickness d_t is determined by the equation 3:

$d_t = w + \lambda*(R_{si} + R_f + R_{se}) = 0.57$ m (3)

where:

- w - the thickness of the overhead part of the vertical walls above the level of the terrain (m);
- λ - the coefficient of thermal conductivity of the Earth. Assume that $\lambda = 2$ W/(mK);
- R_{si} - heat transfer resistance from the inner surface, $R_{si} = 0.17$ m^2K/W;
- R_f – heat conductivity coefficient of the floor, m^2K/W;
- R_{se} - heat transfer resistance from the outer surface, $R_{se} = 0.04$ m^2K/W.

If $d_t < B'$ the heat transfer coefficient through the floor is evaluating according to the equation 4:

$U = [(2\lambda)/(\pi B'+d_t)] \ln(\lambda B'/d_t+1) = 0.315$ W/(m^2.K) (4)

The coefficient of heat transmission through heat transfer H_{tr} is determined by the equation (5):

$H_{tr} = H_D + H_g + H_U + H_A$ (5)

where:

- H_D - the coefficient heat transmission by heat transfer through the enclosing elements, bordering the outside air (W/K);
- H_g - coefficient heat transmission by heat transfer through the Earth in the stationary regime (W/K);
- H_U - coefficient heat transmission by heat transfer through the elements bordering on non-heated or non-cooled areas (W/K);

- H_A - coefficient heat transmission by heat transfer through the elements, bordering clinging buildings (W/K).

The coefficient heat transmission by heat transfer through the enclosing structures bordering the outside air H_D is given by the equation 6:

$$H_D = \Sigma_i(U_iA_i) + \Sigma_k(l_k\psi_k) + \Sigma_j\chi_j, \quad (6)$$

where:

- i, j, k - numbers of elements, of linear thermal bridges and of point thermal bridges;
- U_i - coefficient of heat transfer of the i^{-th} enclosing element, bordering the outside air (W/(m^{2}K));
- A_i - the surface area of the i^{-th} enclosing element (m^2);
- l_k - the length of the k^{-th} linear thermal bridge (m);
- ψ_k - linear coefficient of heat transfer of the k^{-th} linear thermal bridge (W/(mK));
- χ_j - coefficient of heat transfer in j^{-th} point thermal bridge (W/K).

Because the walls and roof of the greenhouse are made of the same material - single glass with metal frames the coefficient of heat transfer by heat transfer through the walls and roof H_D is determined by an equation 7. The impact of thermal bridges has been taken into account when calculating the heat transfer coefficient through the walls. For this reason, second and third member of the equation will be ignored.

$$H_D = U_WA_W = 6.66*2129.34 = 14181.4 \text{ W/K}... \quad (7)$$

The coefficient of heat transfer through the floor (Earth) H_g is calculated by equation 8.

$$H_g = U.A_f = 0.315*1382.4 = 435.34 \text{ W/K} \quad (8)$$

Therefore, the coefficient of heat transfer through the heat transfer calculated in equation 9 is:

$$H_{tr} = H_D + H_g = 14616.72 \text{ W/K} \quad (9)$$

The heat loss from heat transfer Q_{tr} are calculated for the duration of the heating period for each month by equation 10 and are shown in Table 2:

$$Q_{tr} = 1/1000*[(H_{tr} + \Phi_g)*(\theta_{i,H} - \theta_e)]*t \quad (10)$$

where:

- H_{tr} - coefficient of heat transfer in the surrounding area elements when temperature difference is 1 K (W/K);
- Φg - heat flow through the Earth at temperature difference 1 K, caused by the thermal inertia of the Earth (W/K);
- $\theta_{i,H}$, - temperature in the greenhouse in the heating period (^{0}C). Middle volume temperature of the greenhouse air is 16^{0}C;
- θ_e - the average monthly value of the ambient temperature (^{0}C);
- t - month's duration (h).

Table 2. Heat loss by heat transmission

Month	Days	$\theta_{i,H}$ ^{0}C	θ_e, ^{0}C	$\theta_{i,H}$ -θ_e, K	Htr, W/K	Qtr, kWh
1	31	16	-15	31	14,616.72	337,119.94
2	28	16	-15	31	14,616.72	304,495.43
3	31	16	-15	31	14,616.72	337,119.94
4	6	16	-15	31	14,616.72	65,249.02
10	8	16	-15	31	14,616.72	86,998.69
11	30	16	-15	31	14,616.72	326,245.10
12	31	16	-15	31	14,616.72	337,119.94
Total						1,794,348.06

Heat losses from ventilation for the heating period are determined by the equation 11 and are presented in Table 3:

$$Q_{ve} = [H_{ve}*(\theta_{i,H} - \theta e)*t]/1000 \quad (11)$$

where:

- H_{ve} is coefficient of heat transfer with the ventilation air, calculated by equation 12:

$$H_{ve} = (\rho c)_a*n*V = 0.34*1*6010.5 = 2043.56 \text{ W/K} \quad (12)$$

where:

- $(\rho c)_a$ = 0.34 Wh/(m^3.K) is specific volume heat capacity of the air;
- n - average air exchange, h^{-1}, n = 1 h^{-1};
- V - net heated volume, m^3, V = 6010.5 m^3.

Total heat losses Q_{ht} from the greenhouse calculated by equation (1) is 2045215.37 kWh.

They have to be reduced by heat gains from solar radiation through transparent enclosures.

The total heat gains from solar radiation for each month of the heating period are calculated by the equation 13:

$$Q_{sol} = (\Phi_{sol,k}*t)/1000, \text{ kWh} \quad (13)$$

Table 3. Heat loss by ventilation

Month	Days	$\theta_{i,H}$, ^0C	θe, ^0C	$\theta_{i,H}$ -θe, K	H_{ve}, W/K	Q_{ve}, kWh
1	31	16	-15	31	2,043.56	47,132.65
2	28	16	-15	31	2,043.56	42,571.42
3	31	16	-15	31	2,043.56	47,132.65
4	6	16	-15	31	2,043.56	9,122.45
10	8	16	-15	31	2,043.56	12,163.26
11	30	16	-15	31	2,043.56	45,612.24
12	31	16	-15	31	2,043.56	47,132.65
Total						250,867.31

Heat flow $\Phi_{sol,k}$, of solar radiation through the transparent greenhouse enclosure element k is given by the equation 14:

$\Phi_{sol,k} = F_{sh,ob,k} * A_{sol,k} * I_{sol,k}$, W (14)

where:

- $F_{sh,ob,k}$ - the shading of the host solar energy for external obgekts, $F_{sh,ob,k} = 1$ as there is no shading from external objects;
- $A_{sol,k}$ - effective area of the host solar energy surface (m);
- $I_{sol,k}$ - middle daily intensity of sunshine on the host surface (W/m^2).

The effective receiving surface of a transparent envelope (walls and roof) A_{sol} is determined by the formula 15 and the values obtained are shown in Table 4:

$A_{sol} = F_{sh,gl} * g_{gl} * (1-F_F)*A_{w,p}$ (15)

where:

- $F_{sh,gl}$ - the shading factor (from moving shadows);
- g_{gl} - the total throughput of the transparent part of the element;
- F_F - the frame factor of the element k (the part occupying the frame);
- $A_{w,p}$ - the total area of element к (m^2).

When the Sun's rays do not fall perpendicular to the surface, the value of g_{gl} is determined by the equation 16:

$g_{gl} = F_W*g_{gl,n} = 0.9*0.85 = 0.765$ (16)

where:

- F_W is the correction factor for no perpendicular radiation. $F_W = 0.90$;
- $g_{gl,n}$ - the actual ratio of total solar transmittance at normal radiation, account from (Regulation No 7, 2004).

Table 4. Effective host surface of transparent enclosing elements

$A_{w,p}$	$1-F_F$	$F_{sh,gl}$	$g_{gl,n}$	Fw	A_{sol}
2,129.34	0.9	1	0.85	0.9	1,466.05

The values of heat gains from solar radiation through transparent enclosures Q_{sol}, calculated according to equations 13 and 14 are presented in Table 5.

Table 5. Heat gain by solar radiation

Month	Days,	$A_{sol,k}$, m^2	$I_{sol,k}$, kW/m^2	Coefficient, 24/1000	$Q_{H,gn}$, kWh
1	31	1,466.05	67.76	0.024	73,908.62
2	28	1,466.05	91.03	0.024	89,681.44
3	31	1,466.05	118.40	0.024	129,143.76
4	6	1,466.05	147.40	0.024	31,117.79
10	8	1,466.05	102.10	0.024	28,739.27
11	30	1,466.05	67.90	0.024	71,672.25
12	31	1,466.05	54.20	0.024	59,118.17
Total					483,381.31

Energy required for heating the greenhouse for the winter period is calculated by equation 17:

$Q_A = Q_{ht} – \eta_{gn} * Q_{sol}$, kWh (17)

where:

- Q_{ht} - total heat loss (kWh),
- Q_{sol} - heat gains from solar radiation (presented in Table 5) (kWh),
- η_{gn} - dimensionless factor of utilization of heat gains.

The factor of utilization of heat gains depends mainly on the "heat gain/heat loss" ratio χ for the greenhouse: $\chi = Q_{sol}/Q_{ht} = 0.24$.

The dimensionless factor of utilization of heat gains is defined by the equation 18:

$\eta_{gn} = (1-\chi^{\wedge a})/(1-\chi^{\wedge(a+1)}) = 0.81$ when $\chi>0$ (18)

where: a is a numerical parameter that is determined by the equation 19:

$a = a_o + \tau/\tau_o = 1$ (19)

where:

- $a_o = 1$;
- $\tau_o = 15$;
- τ is the time constant, which is determined by the equation 20:

$\tau=Cm/(Htr+H_{ve})=42246.14/2045215.37=0.021$ h (20)

where:

- Cm - effective heat capacity of the heated area, Wh/K. Its value depends on the massiveness of the building and

$Cm=30.56*A_f=30.56*1382.4=42246.14$ Wh/K.
The required energy for heating the greenhouse $Q_A=2045215.4–0.81*483381.3=1654045.85$ kWh. It is necessary to turn the energy in power through its division by the number of heating days in the year (they are 165) and for a period of 24 hours per day. Therefore, the peak required power for the studied greenhouse is 417.7 kW.

CONCLUSIONS

A methodology for defining the required energy for heating a greenhouse and providing the necessary parameters for plants growing has been developed. The calculations are made on the basis of the European and national energy efficiency legislation so that the energy consumption and the respective CO_2 emissions are minimized. The methodology coud be used for greenhouses designin with different parameters than those specified in the publication.

REFERENCES

Anifantis, A., S., Pascuzzi, S., Scarascia-Mugnozza, G. (2016). Geothermal source heat pump performance for a greenhouse heating system: an experimental study. *J. of Agricultural Engineering,* Vol. XLVII:544, 164-170.

Başak, M.Z., Sevilgen, S.H. (2016). A techno-economic model for heating of a greenhouse site using waste heat. *Arab J Sci Eng, 41,* 1895-1905.

Baytorun, A., N., Zaimoğlu, Z. (2016). Determining required heat energy and CO_2 emissions resulting from fuel consumption in different greenhouse installations in Mediterranean climate conditions. *Int.l Journal of Advanced Research,* Volume 4, Issue 4, 748-758.

Bibbiania, C., Fantozzib, F., Gargarib, C., Campiotti, C.A., Schettinid, E., Voxd, G. (2016). Wood biomass as sustainable energy for greenhouses heating in Italy, *Agriculture and Agricultural Science Procedia 8*, 637-645.

Bošnjakovi, M., Lackovi, I., Grdi, I. (2013). The greenhouses soil heating by geothermal energy, 5th International Scientific and Expert Conference "Technique, Education, Agriculture & Management", Prešov, 138-141.

Fahmy, F., Atia, D., Madany, H.El, Farghally, H. (2016). Greenhouse Heating Systems Based on Geothermal Energy. *International Journal of Energy*, Volume 10. Retrieved February 24, 2020, *from* https://www.researchgate.net/publication/329906299.

European Council meeting - Conclusions (2019, Desember 12). Retrieved Jenuary 24, 2020, from https://www.consilium.europa.eu/media/41768/12-euco-final-conclusions-en.pdf.

Gourdo, L., Bazgaou, A., Ezzaeri, K., Tiskatine, R., Wifaya, A., Demrati, H., Aharoune, A., Bouirden, L. (2018). Heating of an agricultural greenhouse by a reservoir filled with rocks, *J. Mater. Environ. Sci*., Vol. 9, Issue 4, Page 1193-1199.

González-Briones, A., Chamoso, P., Rodríguez, S., Yoe, H., Corchado, J.M. (2018). Reuse of waste energy from power plants in greenhouses through mas-based architecture, *Wireless Communications and Mobile Computing*, Vol. 2018, Article ID 6170718, 12 pages.

https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

htpp://www.seea.government.bg/.

Ikonomopoulos, A., Tsilingiridis, G. (2016). Greenhouses: Heating or Cooling? Renewable Energy Sources & Energy Efficiency - New Challenges, Conference Proceedings, 493-502. Retrieved January 24, 2020, from www. mse.com.cy/energy.

Kaloyanov, N., Sharankov, V., Hadgieva, I., Bratanov, M. (2006). Guide to energy efficiency audits and certification of buildings, TU - Sofia, Sofia.

Kostadinov, K., Filipov, S., Kuneva, V., Almaliev, M., Shopova, T., Radev, R. (2019). Influence of seedling quality on the biological manifestations and productivity of greenhouse salad, *Scientific Papers, Series B. Horticulture,* vol. LXIII, No 1, 285-290.

Law of energetics, https://www.me.government.bg/ bg/ library/zakon-za-energetikata-256-c25-m0-1.html

Law on energy efficiency, http://www.seea.government.bg/documents/ZEE_30.12.2016.pdf

Pevicharova, D., Kostadinov, K., Filipov, S. (2013). Influence of the substrate on the greenhouse tomatoes quality. *Scientific works of UFT - Plovdiv,* Volume IX, Plovdiv, 674-678 (in Bulgarian).

Ramírez-Arias, A., Rodríguez, F., Guzmán, J., L., Arahal, M., R., Berenguel, M., Juan Carlos López, J., C. (2005). Improving efficiency of greenhouse heating systems using model predictive control, 16th Triennial World Congress, Prague, Czech Republic, 40-45.

Regulation № 7 of 2004 on Energy Efficiency of Buildings. Retrieved January 24, 2020, from https://www.mrrb.bg/bg/naredba-7-ot-2004-g-za-energijna-efektivnost-na-sgrad

Shamshiri, R., R., Jones, J., W., Thorp, K., R., Ahmad, D., Man, H., C., Taheri, S. (2018). Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: a review, *Int. Agrophys., 32,* 287-302.

Shen, Y., Wei, R., Xu, L. (2018). Energy consumption prediction of a greenhouse and optimization of daily average temperature. *Energies*, 11, 65; Retrieved Jenuary 24, 2020, from www.mdpi.com/journal/energies.

Yang, S.H., Lee, Ch., G., Lee, W.K., Ashtiani, A.A., Kim, J.Y., Lee, S.D., Rhee, J.Y. (2012.2). Heating and Cooling System for Utilization of Surplus Air Thermal Energy in Greenhouse and its Control Logic, *J. of Biosystems Eng. 37*(1), 19-27. Retrieved January 24, 2020, from http://dx.doi.org/10.5307/JBE.2012.37.1.019