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SOLAR ENERGY IN FAVOR OF SUSTAINABLE INDOOR PLANT CULTIVATION

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Abstract: *Integrating solar energy into indoor plant cultivation represents a promising solution for sustainable farming. This article presents the potential benefits of using renewable energy sources to reduce the environmental footprint associated with indoor farming. By using solar energy, indoor farms can significantly reduce their reliance on fossil fuels, thereby reducing greenhouse gas emissions and promoting energy efficiency.*

Keywords: *Sustainable Plant Growing, Solar Thermal Energy, Photovoltaics, Indoor Cultivation, Thermal Water Collectors, Thermal Air Collectors, Ventilation, Energy Efficiency, Optimal Plant Conditions, Collector Comparison, Sustainability*

INTRODUCTION

Sustainable indoor plant cultivation is becoming increasingly important in the context of a growing population and the need for efficient use of resources. Solar energy is key in this process, providing a clean and renewable energy source. This report examines the application of photovoltaic systems, thermal water, and air collectors in indoor plant cultivation. The advantages and disadvantages of each listed technology are considered, as a comparison between thermal water and air collectors is made. This is done to identify potentially the most effective technical solutions for maintaining optimal microclimate conditions for plants, as well as to reduce greenhouse emissions associated with plant cultivation and improve energy efficiency.

EXPOSITION

Description of the object of study

In this report, the subject of research is a production base for growing mushrooms and macroplants. The building is existing with dimensions of 60x60x6m. The surrounding surfaces floor walls and roof have a heat transfer coefficient of Uf=0.8W/m^{2}K, Uw=1.5W/m^{2}K, Ur=1.2W/m^{2}K, respectively. The building has no windows, and the doors have a heat transfer coefficient of Ud=2.1W/m^{2}K. The relative area of the doors to the surrounding wall surface is 16%.

The roof of the building has a slope of 6° and on it is initially planned to build a solar photovoltaic installation installed in the roof plane. The building has an azimuth of 60° in the southeast direction and is positioned at the following coordinates in 43.73° 25.97° near the town of Ruse. The roof of the building is gable and respectively the orientation of the two slopes is 60° in the southeast direction and 30° in the northwest direction.

Subsequently, it is planned to build a solar thermal installation also in the roof plane, which will meet the thermal energy needs in the building.

This report assesses the energy obtained, efficiency and solar fraction of the PV installation and solar thermal installations with water and air collectors, respectively.

The assessment of the energy yield from the photovoltaic installation was carried out based on the Phi method, and the main input data are as follows:

- 102 photovoltaic panels model - Longi/LR5-72HTH-580M, 580Wp;
- 3 hybrid inverters each with a single power of 20kW;
- Efficiency of inverters - 95%;
- AC load 60kW with daily use 6 hours/day 7 days a week;

- Grid energy absorption – 95%;
- Rechargeable battery, with a capacity of 35kWh;
- Battery temperature control;
- Battery maximum discharge rate – 70%;
- Battery efficiency – 85%;
- Additional dust losses on the panels, etc. -5%.

The estimation of the energy yield of solar thermal installations is based on the f-method. The main input data used for modelling solar thermal installations are presented in Table 1.

Table 1. Properties of solar water and air thermal installations

Parameter	**Water Thermal Collectors**	**Air Thermal Collectors**
$Fr\tau\alpha_n$	0,74	0,82
UL, W/m^2K	4	4,2
Nc, бр.	140	126
Ac, m^2	2	2,3
α_n	0,96	0,93
Operating Parameters		
ε_{hx}	0,7	1
Cp_{col} , J/kgK	2350	1005
m_{col} , kg/s	0.0139 kg/s	10 l/sm^2
Store_cap, l/m^2	75 , l/m^2	0.15 m^3/m^2
Losses, %	3	3

The heating load of the building depends on a change in conditions that are directly related to the type of plants grown and air exchange rate.

The temperature regime in the building is maintained within the range of 14 to 29°C, depending on the type of plants grown and their phase of growth.

Providing fresh air to maintain relative humidity and CO_2 concentration depending on the type of plants grown and their phase of growth.

As a basic condition for assessing the effect of the use of solar thermal installations, the cultivation of mushrooms is accepted - the most severe conditions possible in terms of heat consumption and requirements for microclimate parameters.

Main phases and parameters of the microclimate:

- Phase 1 – duration 17 to 22 days, indoor air temperature in the range of 27 to 29°C, relative humidity – no requirements, CO_2 concentration up to 3000 ppm;
- Phase 2 – duration 15 to 20 days and indoor air temperature in the range of 14 to 17°C, relative humidity in the range of 90 to 95%, CO_2 concentration in the range of 900 to 1000 ppm;
- Phase 3 – duration 6 to 8 days and indoor air temperature in the range of 16 to 17°C, relative humidity in the range of 80 to 85%, CO_2 concentration in the range of 700 to 800 ppm.

The schematic diagram of the installation with water thermal collectors is presented in Fig.1

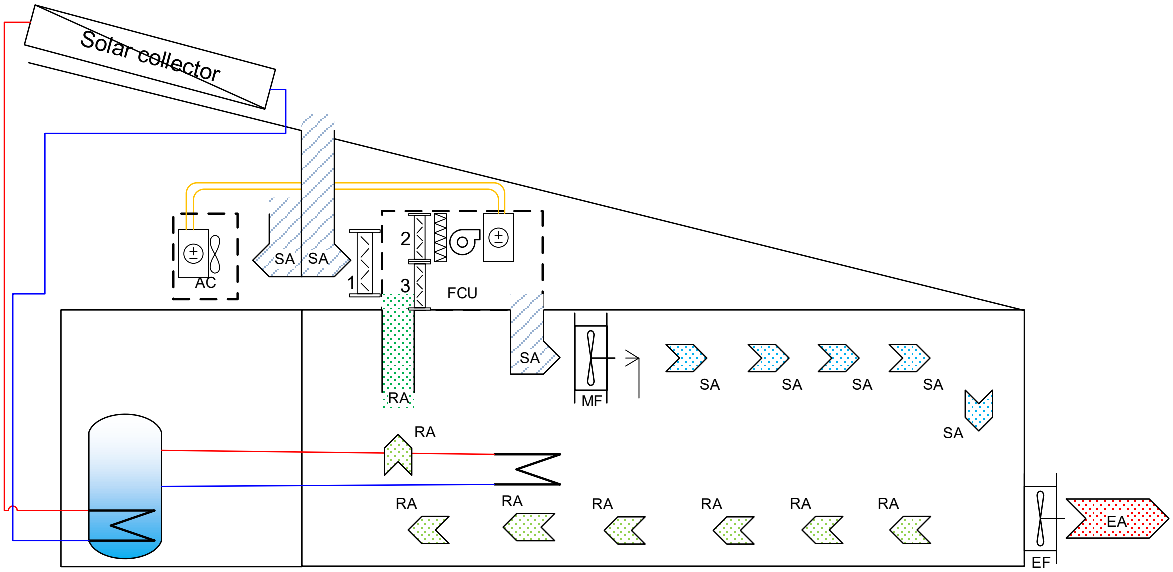


Fig. 1. Scheme of solar thermal installations with liquid collectors
EA – extract air; SA – supply air; RA – return air /recirculation air/; AC- air conditioner; FCU – fan coil unit, MF – Mixing fan; EF – Extract fan

The schematic diagram of the installation with air thermal collectors is presented in Fig. 2

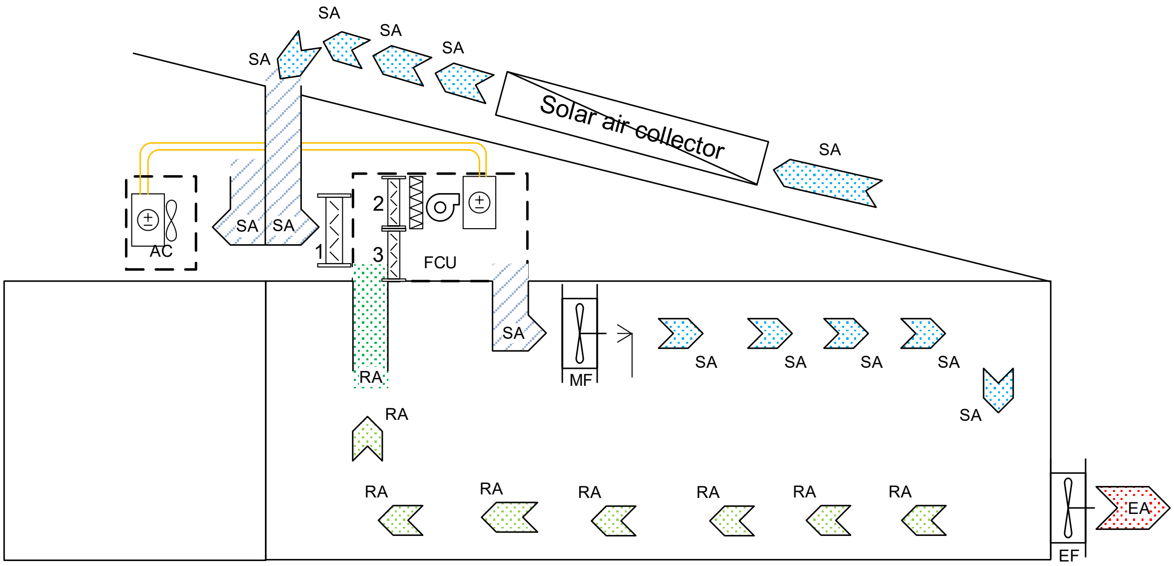


Fig. 2. Scheme of solar thermal installations with air collectors
EA – extract air; SA – supply air; RA – return air /recirculation air/; AC- air conditioner; FCU – fan coil unit, MF – Mixing fan; EF – Extract fan

RESULTS

Applying the Phi method, an assessment of the amount of solar radiation in the roof plane, the solar fraction, the electricity produced, and the efficiency of the installation was carried out.

The results are presented in graphical and tabular form respectively in Fig.3 and in Table 2.

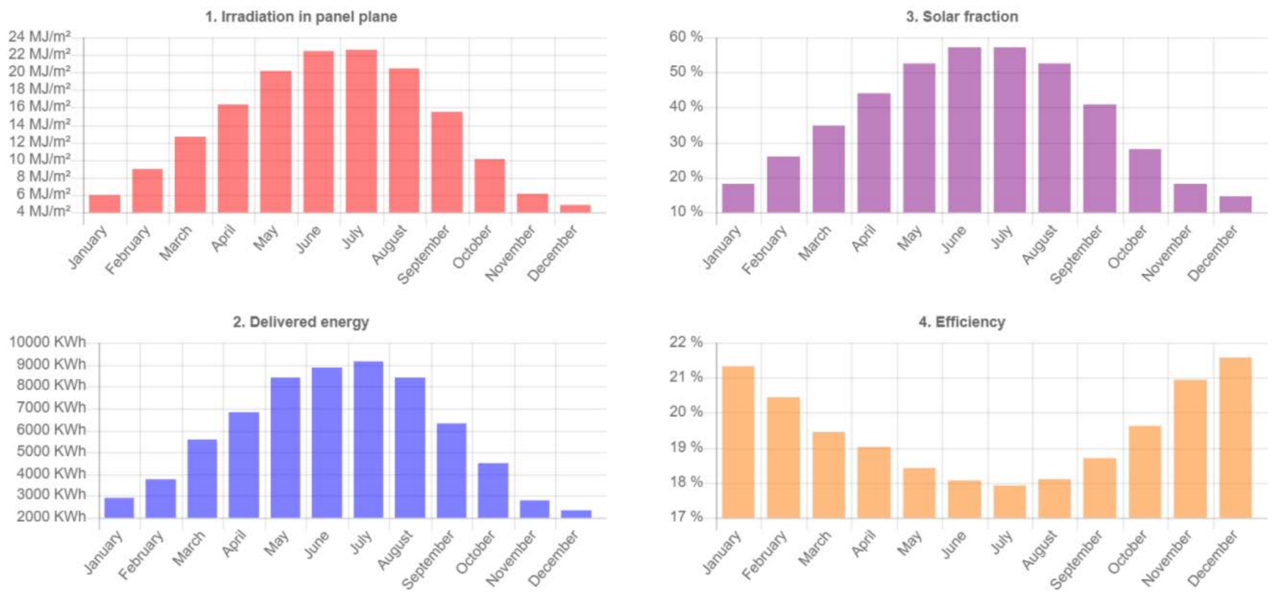


Fig. 3. PV installation simulation results

Table 2. PV simulation results

Month	Irradiation [MJ/m²]	Delivered energy [KWh]	Solar fraction [%]	Efficiency %
1	5.989	2895.443	18.05	21.33
2	8.958	3748.748	25.87	20.45
3	12.619	5565.931	34.69	19.46
4	16.409	6849.671	44.11	19.03
5	20.157	8411.194	52.42	18.41
6	22.383	8858.747	57.05	18.05
7	22.573	9162.347	57.1	17.91
8	20.497	8408.368	52.41	18.1
9	15.447	6337.005	40.81	18.71
10	10.165	4524.916	28.2	19.64
11	6.109	2806.423	18.07	20.95
12	4.798	2347.57	14.63	21.59

The assessment of the maximum and minimum heating load of the building by months was carried out according to dependence (1) and the temperature in the premises was kept constant respectively +29°C and +14°C.

$$Q_{HL,Building} = Qt + Max\ (Qinf, Qvent) \quad (1)$$

The variations of the heating load at maximum and minimum temperatures inside the building are shown in Fig.4

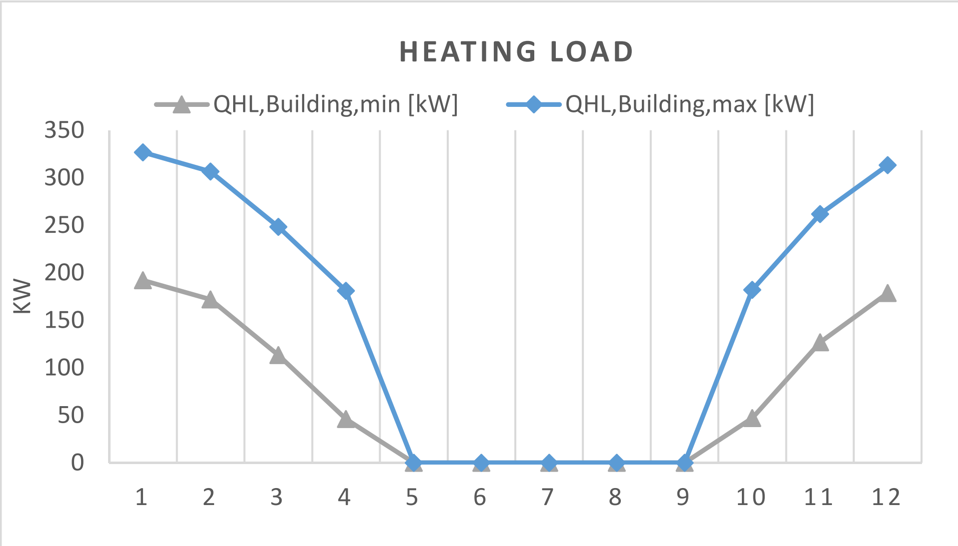
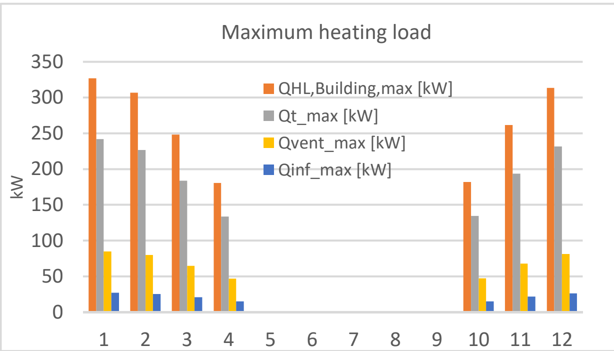
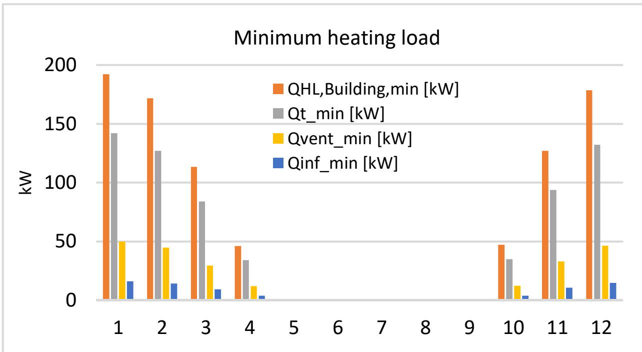


Fig. 4. Building maximum and minimum heating load

The distribution of the individual components of the heating load in terms of maximum and minimum air temperature inside the building is presented respectively in Fig. 5a and 5b.



5a



5b

Fig. 5. Distribution of heating load components at maximum and minimum temperature

The average distribution of heat loss in a building is 68% for heat transfer, 24% for ventilation and 8% for infiltration.

The distribution of the heating load and the energy obtained respectively from the thermal installation with water and air collectors is presented in Fig.6.

The monthly distribution of useful energy from solar thermal installations is obtained by applying dependence (2)

$$\mathrm{Q_u} = \mathrm{F_R A_C} Nc[\mathrm{S} - \mathrm{U_L}(\mathrm{T_i} - \mathrm{T_a})] \qquad (2)$$

F_R - heat removal factor equation (3)

$$F_R = \frac{\dot{m} \cdot C_p}{Ac \cdot U_L} \cdot \left[1 - e^{\left(-\frac{A_C U_L F'}{\dot{m} C_P}\right)}\right] \qquad (3)$$

In the equation (3) the value of the mass flow rate is $\dot{m}$ is for the overall solar thermal collector.

The mass flow rate for each solar thermal installation isn't the same in equation (3) there are also different values for Cp and F' depending on used heat carrier in the installation.

The flat plate solar thermal collectors used in each type installation have characteristics according to the table 1.

The operating parameters of the water and air-based installations are as follows:

- specific mass flow rate of a heat transfer medium through the water solar thermal collectors is 0.0139 kg/s;
- specific mass flow rate of a heat transfer medium through the air solar thermal collectors is 10 $l/s.m^2$;
- The efficiency of heat exchanger in the water heat accumulator is 70%;
- Air based solar thermal installation is direct and the efficiency of heat exchanger is 100%;
- The thermophysical properties of 50% solution of propylene glycol and water is Cp_{col} =2350J/kg.K;
- The thermophysical properties of air is Cp_{col} =1005 J/kg.K;
- Specific storage capacity for each solar thermal installation is different according to the table 1 – depends of heat carrier in the installation.
- Additional heat losses from the pipes connecting the heat storage and the solar thermal collectors, from the dust on the glass surface and e.c.t is assumed to be 3%.

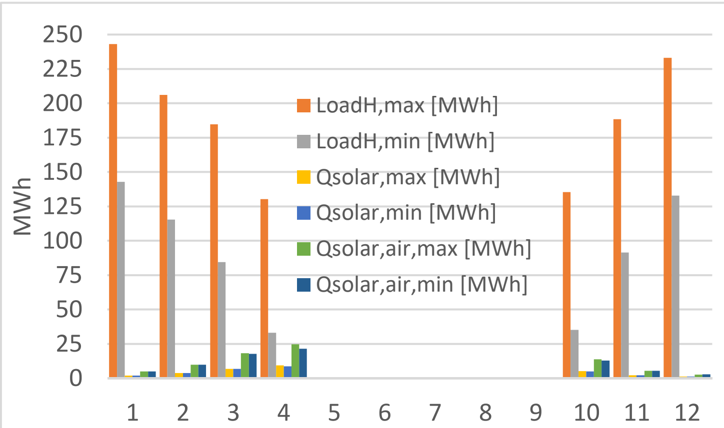


Fig. 6. Heat energy demand and production

Applying the f-method, the solar fraction of the solar thermal installation with water and air collectors and at the maximum and minimum air temperature in the building was evaluated.

The results are presented in Fig. 7.

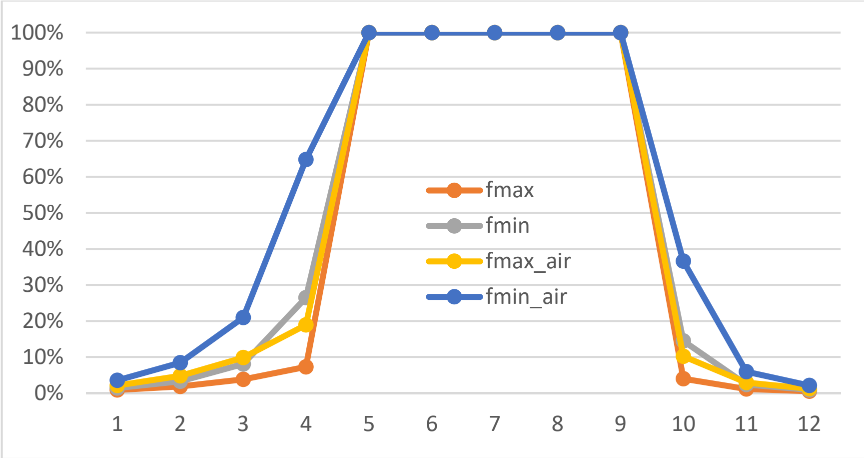


Fig. 7. Solar fraction of water and air-based installations

The average annual solar fraction of water and air solar thermal installations is presented in Figs. 8a and 8b.

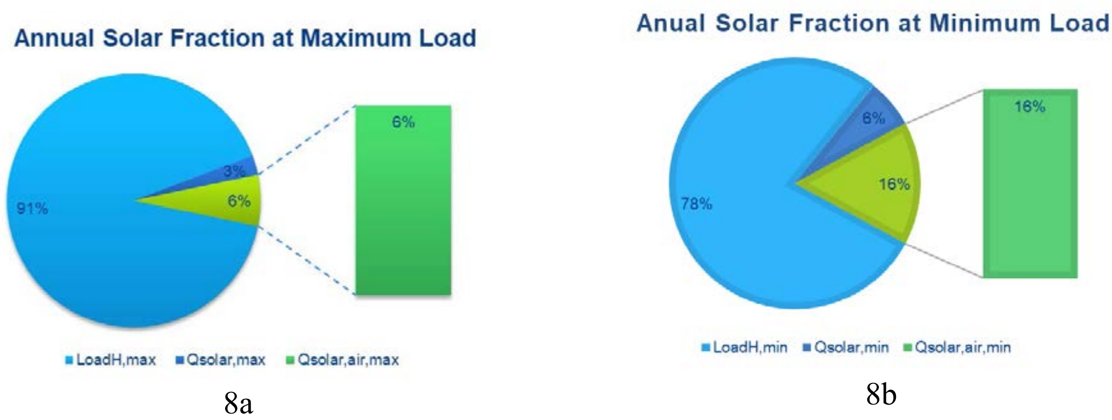


Fig. 8. Annual solar fraction at maximum and minimum heating load of the building

CONCLUSION

From the model study of the photovoltaic and both types of solar thermal installations, it was found that:

The photovoltaic installation will be able to satisfy between 18 and 57% of the required electrical energy used on the site.

The solar thermal installation with water collectors will be able to provide from 0.8% to 26% of the required thermal energy depending on the operating phase and the period of the year.

The solar thermal installation with air collectors will be able to provide from 1% to 64% of the required thermal energy depending on the operating phase and the period of the year.

Combining the solar thermal installation with heat pumps to maintain the microclimate parameters will significantly improve energy savings.

Of the two types of solar thermal installations, the one with air collectors has better performance.

It is necessary to analyse in more detail the operation of the solar thermal installation with air collectors during the summer months, when excess thermal energy can be directed to sterilization processes, which are not addressed in this report, but represent a significant share of energy consumption.

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