ASPECTS REGARDING THE USE OF SOLAR ENERGY IN SMALL AND MEDIUM FARMS

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ASPECTE PRIVIND UTILIZAREA ENERGIEI SOLARE ÎN FERMELE MICI ŞI MEDII

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ABSTRACT

Considering that every day the sun generates more energy than the planet needs for daily consumption, harnessing solar energy represents one of the future solutions for clean, sustainable energy, obviously with the technological limitations related to the ability to transform this energy into electricity. The paper presents a functional model of equipment that allows the capture of solar energy using special panels, which can rotate both horizontally and vertically according to the sun, so that the incidence of rays with the radiating surface of the panels is maximum and the yields obtained at different angles of inclination in the vertical plane at 60°, respectively in the horizontal plane at 0°.

REZUMAT

Având în vedere că în fiecare zi soarele generează mai multă energeie decât planeta are nevoie pentru consumul zilnic, valorificarea energia solare reprezintă una din soluţiile de viitor pentru o energie curată, sustenabilă, evident cu limitările tehnologice legate de capacitatea de a transforma această energie în electricitate. Lucrarea prezintă un model funcţional de echipament care permite captarea energiei solare utilizând nişte panouri speciale, care se pot roti atât în plan orizontal cât şi verticla după soare, astfel încât incidenţa razelor cu suprafaţa radiantă a panourilor să fie maximă şi randamentele obţinute la diferite unghiuri de înclinaţie în plan vertical la 60°, respectiv în plan orizontal la 0°.

INTRODUCTION

Among the various possible ways, open-air sun drying is the most popular in tropical countries due to its low cost, particularly for smallholder farmers in rural areas. However, the drying process is heavily reliant on ambient circumstances and is highly susceptible to contamination from dust, rain, wind, pests, and rodents (*El Hage et al., 2018; Singh et al., 2018; Aresenoaia et al., 2019a*), resulting in low-quality goods and a reduction of farmers' income. To address these issues, numerous systems have been created, such as the greenhouse dryer (*Janjai et al., 2007; Azaizia et al., 2017; Iskandar et al., 2017; Hamdi et al., 2018*) and the hybrid solar dryer (*Amer et al., 2018; Eltawil et al., 2018*). These systems are faster, more efficient, and more sanitary, resulting in lesser crop losses compared to the traditional open-air sun drying process (*Muehlbauer, 1986; Chua and Chou, 2003; Karim and Hawlader, 2004; Tomar et al., 2017; Cârlescu et al., 2018; Arsenoaia et al., 2019b*). Moisture in raw agricultural materials is removed during solar drying using heat transfer modes such as conduction, convection, and radiation. Solar radiation travels through a transparent sheet and is kept as heat in a drying chamber or solar collector at 30-60°C.

Drying is one of the first unit activities farmers conduct in the processing chain to either increase the shelf life of their products for storage or prepare them for further processing *Ndukwu et al., 2022; Ihediwa et al., 2022a*). However, research has revealed that drying is a substantial energy consumer in many countries, accounting for 12-15% of total global agricultural energy consumption (*Samimi-Akhijahani and Arabhosseini 2018*; *Ihediwa et al., 2022b*; *Catorze et al., 2022*).

Furthermore, drying has been shown to use 6 to 30 times more energy than cooling and freezing (*Machala et al., 2022*). As a result, reliance on fossil fuels to meet heat demand during drying will emit considerable amounts of carbon into the atmosphere (*Ndukwu et al., 2023*). Thus, it is vital to switch from fossil-fueled dryers to clean energy sources (*Chowdhury et al., 2020*).

To protect the environment, most countries currently urge for a transition from fossil fuel-based dryers to renewable energy sources (*Kumar et al., 2023*). Clean technologies are being embraced in all energy sectors because they are critical to addressing and achieving the sustainable development goal, especially in rural farm areas (*Messina et al., 2022*). These goals include reducing air pollution, conserving resources, and addressing climate change. According to *Rahman et al. (2022)*, the following renewable sources are currently available: solar thermal, solar photovoltaic, wind energy, geothermal, tidal, and wave energy.

Greenhouses typically rely on carbon-based fuels, which contribute to climate change impacts, high production costs, and growing concerns about fossil fuel depletion (*Esen and Yujsel, 2013; Cabeza et al., 2014; Semple et al., 2017; Forough and Roshandel, 2018; van Beveren et al., 2019; Burg et al., 2021*). These issues require the exploitation of renewable energy resources (*Cabeza et al., 2014; Forough and Roshandel, 2018*). Solar energy is a clean, renewable, and necessary component of agriculture's sustainable energy future, including greenhouse applications *(Bakirci and Yuksel, 2011; Zhang et al., 2015; Esmaeli and Roshandel, 2020)*. However, solar energy is a recurring source of energy. Summer produces the most solar energy, whereas the biggest heating demands occur in winter (*Esen, 2000; Hesaraki et al., 2015*). Seasonal thermal energy storage is a promising approach to storing the summer heat for winter consumption (*Antoniadis and Matinopoulos, 2019; Yang et al., 2021*). Thus, heat storage devices can compensate for the mismatch between greenhouse heating demand and solar thermal energy supply (*Cabeza, 2014*).

MATERIALS AND METHODS

The solar energy capture and conversion module (figure 1) is located in an area with exposure to the sun throughout the day, at a distance that ensures minimal losses on the heat transfer network (air), from solar collectors to possible users such as a fruit drying facility. The main component sub-assemblies of the solar energy capture and conversion module are: the support frame, the solar collectors and the air tubes with a low-pressure centrifugal fan. The rotation of the solar collectors around a central pivot by 45° left-right concerning the initial south orientation position and also the orientation of the solar collectors in the vertical plane at fixed angles of 60° is done manually and checked each time with the corresponding measuring instruments. With these facilities, the variation of solar energy can be highlighted throughout the day by orienting the panels according to the position of the sun, and adjustments can be made to optimize the system's operating regime.

The solar energy capture and conversion module is composed of: a support frame; solar collectors; low-pressure centrifugal fan air ducts.

Fig. 1 – Solar energy capture and conversion module, rear view

The absorbent plate absorbs solar radiation, heats up to a temperature of 80÷120°C and radiates in the far infrared. The module has a pull-type device (figure 2) for changing the angle of inclination of the collector in the vertical plane within the limits of 30 and 60 degrees compared to the horizontal plane of the ground, for which there is an angle indicator (figure 4) with three positions of work (30, 45 and 60 degrees). The measurement of the angle of rotation in the horizontal plane is done with an indicator, with a position indexer of 15 in 15 degrees, the module being able to rotate towards sunrise or sunset depending on the position of the sun to obtain maximum efficiency of its radiation.

Fig. 2 - Angle indicator, for the vertical tilt of the pickup

The heated air ducts (figure 3) have transducers along the route to measure the temperature and air flow.

Fig. 3 – Air duct

The main characteristics of the installation are those described in part I of the article. The experiments were carried out with the installation adjusted at **an angle of 60° in the vertical plane** (maintaining at 0° in the horizontal plane), simultaneously with their rotation in the horizontal plane at 30°, 45° and 60°.

RESULTS

Experiments with tilting the collectors in the vertical plane at 60°

Figure 4 shows the results of the temperature measurement for each panel, the temperature of the environment, the calculation of the differences between the input temperature and that of the environment, as well as their average variation over a whole day (based on the measurement of the speed of the air current at the exit from the solar collectors).

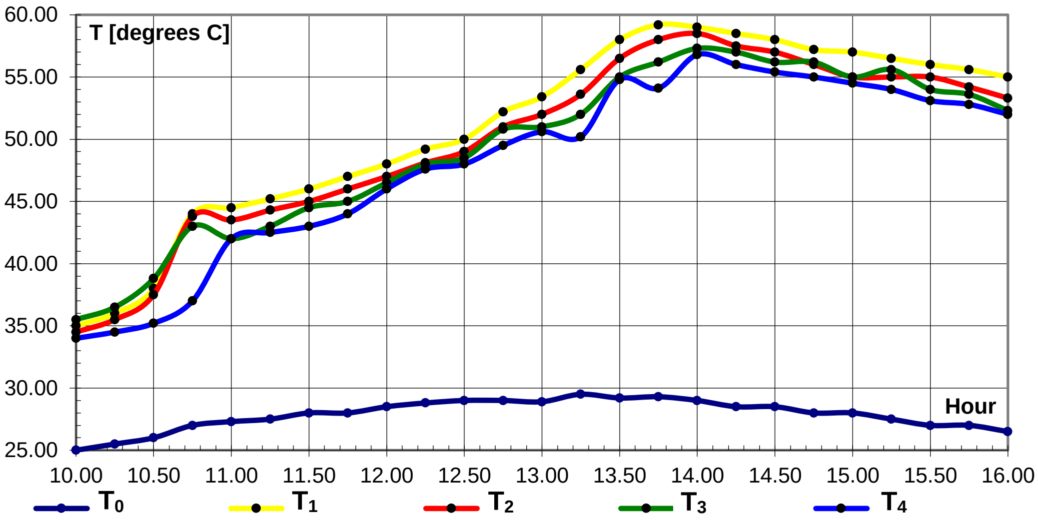

Fig. 4 - The temperature variation of the panels for tilting in the vertical plane at 60° from the horizontal
T_0 – environment temperature; T_1 - temperature panel 1; T_2 - temperature panel 2;
T_3 - temperature panel 3; T_4 - temperature panel 4

Figure 5 shows the variation of airflow rates for panels inclined in the vertical plane at 60° from the horizontal over a whole day and Figure 6 - the variation of the heat accumulated on the panels for the inclination in the vertical plane at 60° from the horizontal, at the level to each panel.

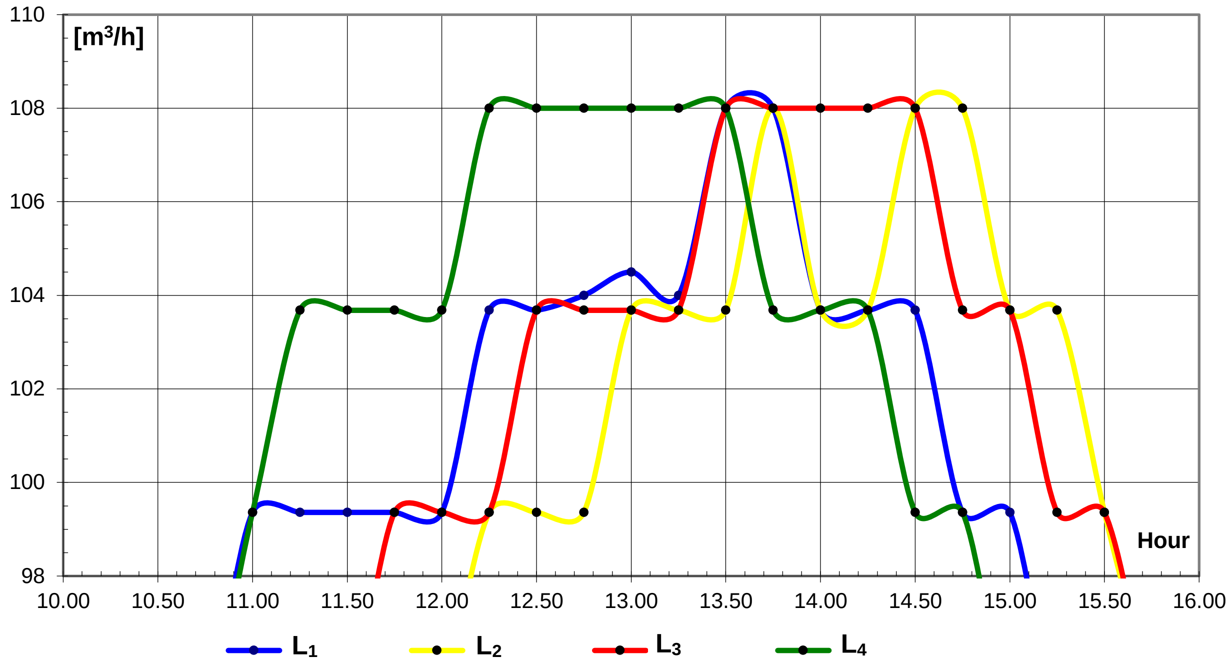

Fig. 5 - The variation of air flows at panels inclined in the vertical plane at 60° from the horizontal
L_1 – air flow to panel 1; L_2 – air flow to panel 2; L_3 – air flow to panel 3; L_4 – air flow to panel 4

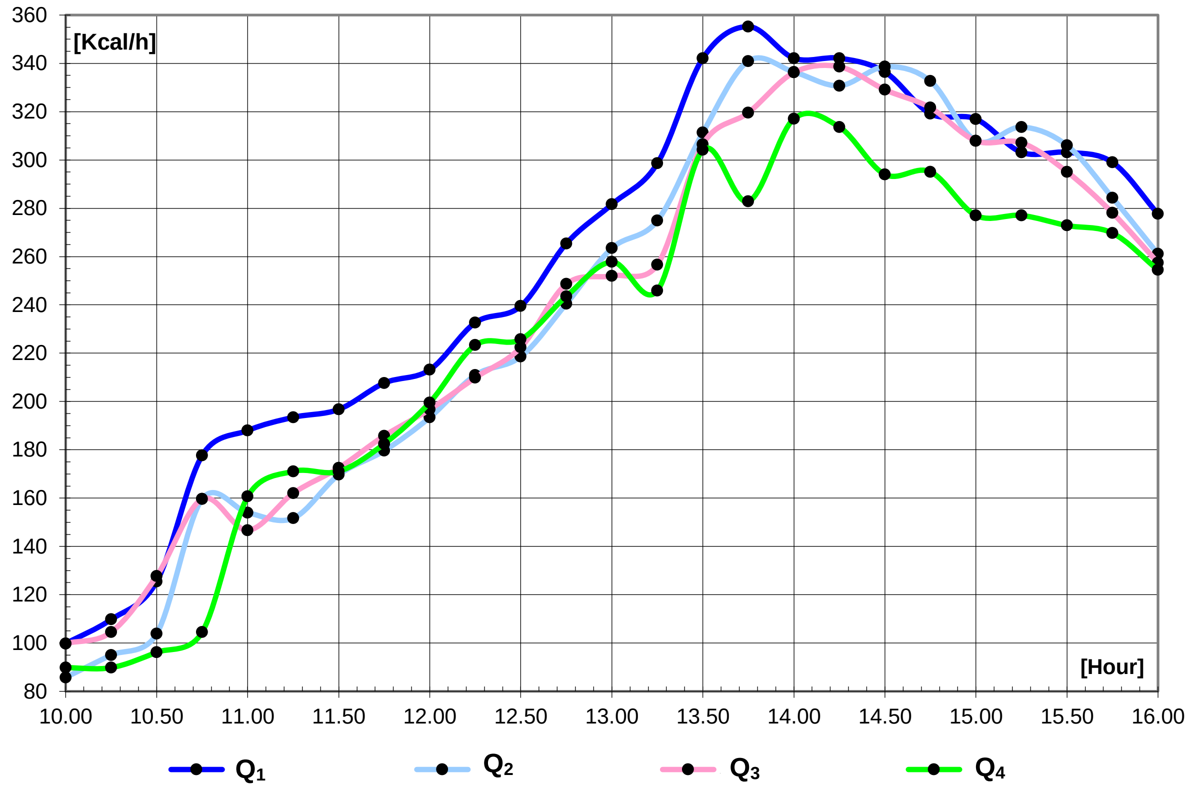

Fig. 6 - The variation of the heat accumulated on the panels for tilting in the vertical plane at 60° from the horizontal
Q_1 – heat accumulated on panel no. 1; Q_2 – heat accumulated on panel no. 2
Q_3 – heat accumulated on panel no. 3; Q_4 – heat accumulated on panel no. 4

Table 1

Hour	Temperature differences ($T_{panou} - T_{mediu}$) [°C]				Air flows [m^3/h]				Accumulated heat [Kcal/h]				Average radiation intensity [$Kcal/m^2 h$]	Heat received [Kcal/h]	Yields [%]			
	pan.1	**pan. 2**	**pan.3**	**pan. 4**	**pan.1**	**pan. 2**	**pan.3**	**pan. 4**	**pan.1**	**pan.2**	**pan.3**	**pan.4**	-	-	**pan.1**	**pan.2**	**pan.3**	**pan.4**
10.00	10.00	9.50	10.50	9.00	90.72	82.08	86.4	90.72	99.792	85.77	99.792	89.813	270	364.5	27.38	23.53	27.38	24.64
10.25	10.50	10.00	11.00	9.00	95.04	86.4	86.4	90.72	109.77	95.04	104.54	89.81	280	378	29.04	25.14	27.68	23.76
10.50	12.00	11.50	12.80	9.20	95.04	82.08	90.72	95.04	125.45	103.83	127.73	96.180	290	391.5	32.04	26.52	32.63	24.57
10.75	17.00	16.80	16.00	10.00	95.04	86.4	90.72	95.04	177.72	159.67	159.67	104.54	320	432	41.14	36.96	36.96	24.2
11.00	17.20	16.20	14.70	14.70	99.36	86.4	90.72	99.36	187.99	153.96	146.69	160.67	325	438.75	42.85	35.09	33.43	36.62
11.25	17.70	16.80	15.50	15.00	99.36	82.08	95.04	103.68	193.45	151.68	162.04	171.07	355	479.25	40.37	31.65	33.81	35.70
11.50	18.00	17.00	16.50	15.00	99.36	90.72	95.04	103.68	196.73	169.65	172.50	171.07	380	513	38.35	33.07	33.63	33.35
11.75	19.00	18.00	17.00	16.00	99.36	90.72	99.36	103.68	207.66	179.63	185.80	182.48	390	526.5	39.44	34.12	35.29	34.66
12.00	19.50	18.50	18.00	17.50	99.36	95.04	99.36	103.68	213.13	193.41	196.73	199.58	392	529.2	40.27	36.55	37.18	37.71
12.25	20.40	19.30	19.20	18.80	103.68	99.36	99.36	108	232.66	210.94	209.85	223.34	395	533.25	43.63	39.56	39.35	41.88
12.50	21.00	20.00	19.50	19.00	103.68	99.36	103.68	108	239.50	218.59	222.39	225.72	400	540	44.35	40.48	41.18	41.8
12.75	23.20	22.00	21.80	20.50	104	99.36	103.68	108	265.41	240.45	248.62	243.54	450	607.5	43.69	39.58	40.93	40.09
13.00	24.50	23.10	22.10	21.70	104.5	103.68	103.68	108	281.63	263.45	252.05	257.80	475	641.25	43.92	41.08	39.31	40.20
13.25	26.10	24.10	22.50	20.70	104	103.68	103.68	108	298.58	274.86	256.61	245.92	500	675	44.23	40.72	38.02	36.43
13.50	28.80	27.30	25.80	25,60	108	103.68	108	108	342.14	311.35	306.50	304.13	555	749.25	45.66	41.56	40.91	40.59
13.75	29.90	28.70	26.90	24.80	108	108	108	103.68	355.21	340.96	319.57	282.84	600	810	43.85	42.09	39.45	34.92
14.00	30.00	29.50	28.30	27.80	103.68	103.68	108	103.68	342.14	336.44	336.20	317.05	590	796.5	42.96	42.24	42.21	39.81
14.25	30.00	29.00	28.50	27.50	103.68	103.68	108	103.68	342.14	330.74	338.58	313.63	585	789.75	43.32	41.88	42.87	39.71
14.50	29.50	28.50	27.70	26.90	103.68	108	108	99.36	336.44	338.58	329.08	294.01	575	776.25	43.34	43.62	42.39	37.88
14.75	29.20	28.00	28.20	27.00	99.36	108	103.68	99.36	319.14	332.64	321.62	295.10	560	756	42.21	44	42.54	39.03
15.00	29.00	27.00	27.00	26.50	99.36	103.68	103.68	95.04	316.96	307.93	307.93	277.04	550	742.5	42.69	41.47	41.47	37.31
15.25	29.00	27.50	28.10	26.50	95.04	103.68	99.36	95.04	303.18	313.63	307.12	277.04	530	715.5	42.37	43.83	42.92	38.72
15.50	29.00	28.00	27.00	26.10	95.04	99.36	99.36	95.04	303.18	306.03	295.10	272.86	520	702	43.19	43.59	42.04	38.87
15.75	28.60	27.20	26.60	25.80	95.04	95.04	95.04	95.04	299.00	284.36	278.09	269.72	500	675	44.30	42.13	41.20	39.96
16.00	28.50	26.80	25.80	25.50	88.56	88.56	90.72	90.72	277.64	261.07	257.46	254.47	490	661.5	41.97	39.47	38.92	38.47
Average yield [%]															**41.1**	**38.00**	**38.15**	**36.03**

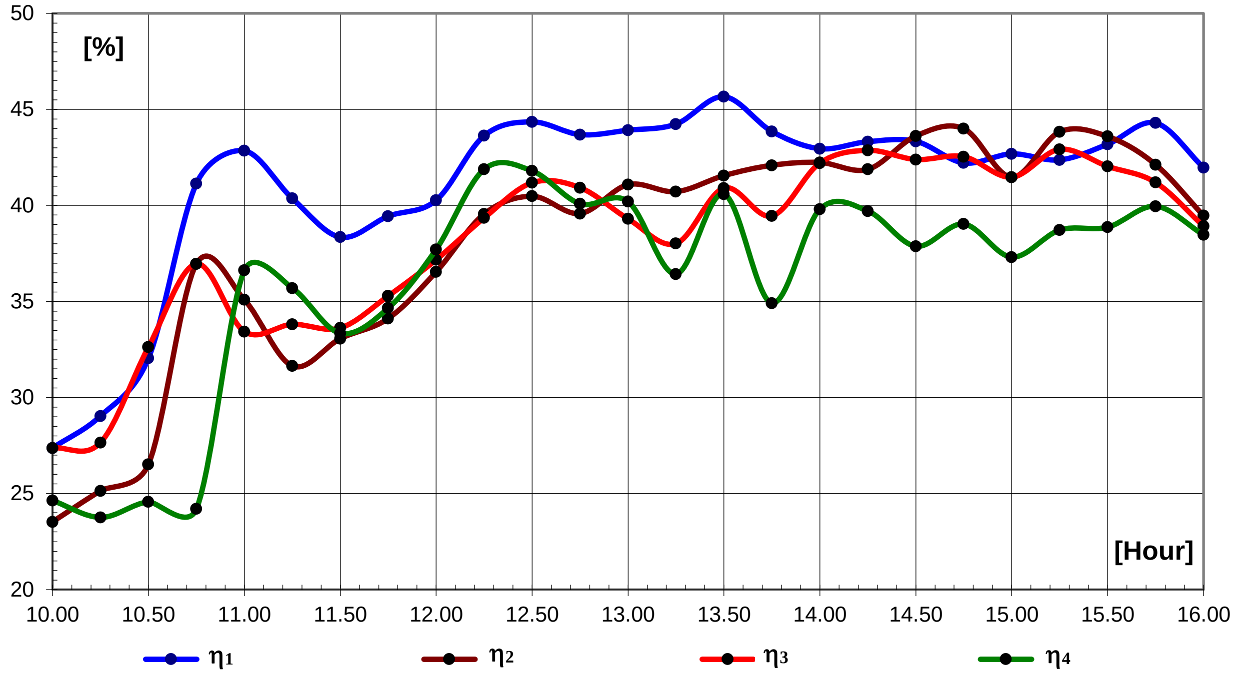

Fig. 7 - The variation of the efficiency of the panels for tilting in the vertical plane at 60° from the horizontal
η_1 - yield at panel 1; η_2 - yield at panel 2;
η_3 - yield at panel 3; η_4 - yield at panel 4

Experiments with tilting the receivers in the vertical plane at fixed angles of 30°, 45°, and 60° simultaneously with their rotation in the horizontal plane at 30°, 45° and 60°

From the integral flow of radiant energy that comes continuously from the Sun to the Earth, and which has the value of the solar constant $E_0 \pm 3\%$, (according to paper 2 E_0 =1353 W/m^2), outside the terrestrial atmosphere, a quantity reaches the earth that has a lower value (0.8-0.9 kW/m^2). This size is no longer constant but depends on the following geophysical and meteorological factors: latitude, altitude, season, day, hour, the amount of dust and water vapor in the atmosphere, as well as the angle at which the Sun's rays fall on the Earth.

At angles lower than 90° (relative to the horizontal of the place) the Sun's rays cross a larger amount of atmospheric air, so that the absorption and dispersion of radiation through the atmosphere is more pronounced than at 12 o'clock, when the thickness of the air layer is minimal.

Compared to those shown previously, the measurements presented in this chapter were made to highlight the influence of the angle of incidence of the solar rays on the surface of the collectors.

Table 2 shows the values of the angles of incidence of the solar rays with the surface of the collectors, results for fixed positions of their inclination in the vertical plane (respectively 30°, 45° and 60°), while they were rotated in the horizontal plane.

The measurements were made starting from -30° (to the East), passing through 0° (South) and continued up to +30° (to the West), from 15 degrees to 15 degrees.

It can be observed that throughout the rotation in the horizontal plane, the collector with a fixed inclination at 30° achieved angles of incidence of the sun's rays, higher than at the other inclinations. Even between 13-14 hours when the most advantageous angle is achieved, it was a maximum of 73 degrees, a fact that recommends tilting the collector at 30° as the best for the area where the experiments were carried out.

Table 3 and figure 8 show the temperature values recorded at the exit of the collectors both for fixed positions (respectively 30°, 45° and 60°) and in the case of their rotation following the position of the sun between 10-14 hours.

From the analysis of the diagram, the temperature difference recorded between the fixed collectors (T_{f1}, T_{f2}, T_{f3}, T_{f4}) and the mobile ones (T_{m1}, T_{m2}, T_{m3},T_{m4}), can be observed, highlighting also in this case the constructive variant "A", where the evolution temperature curve is the best.

Table 2

Den. no.	Hour	The angle of incidence of the sun's rays with the surface of the inclined panels in the vertical plane at:		
		30°	45°	60°
1	10	44	37	31
2	11	51	44	36
3	12	64	54	43.5
4	13	73	61	50
5	14	73	61	51

Table 3

Den. no.	Hour	Environment temperature (T_0)	Temperature at panels adjusted in vertical plane at fixed positions of:			Temperature at panels rotated in horizontal plane (from –30° to +30°) having in vertical plane fixed positions of:		
			30° (T_{f1})	45° (T_{f2})	60° (T_{f3})	30° (T_{m1})	45° (T_{m2})	60° (T_{m3})
1	10	26	40	38	44	36	46	47
2	11	27	45	42	43	54	54	48
3	12	27.5	54	50	48	62	54,5	54
4	13	28.5	60	53	55	65	55	56
5	14	27.5	66	65.4	58	67	68	60

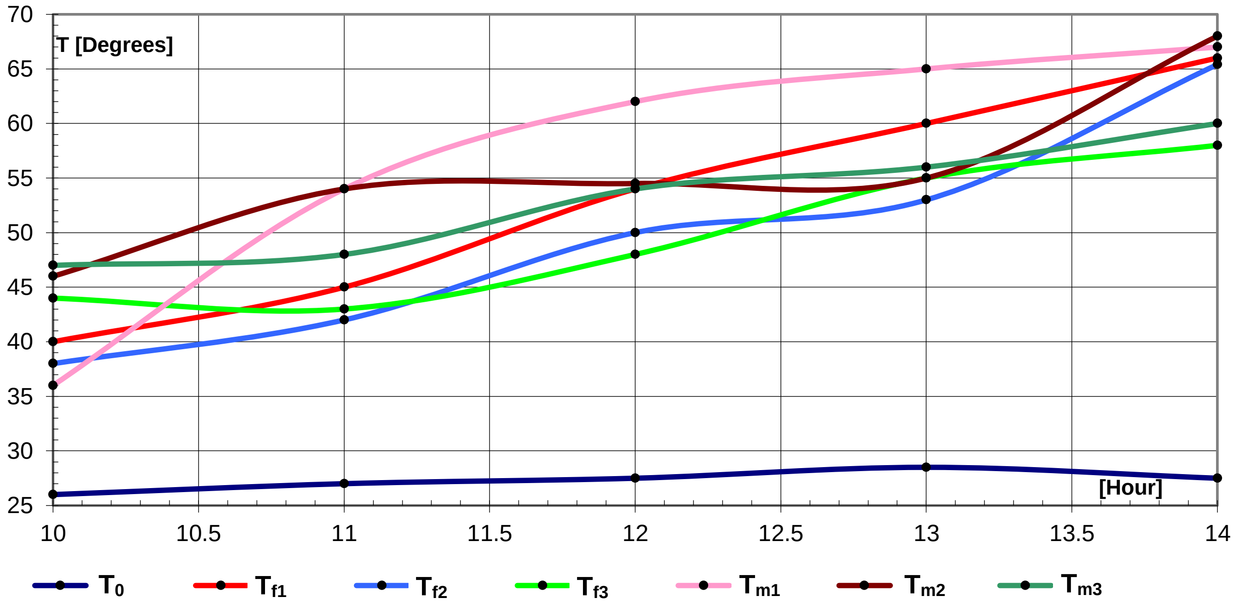

Fig. 8 - The variation of temperatures recorded at sensors with fixed positions (in the vertical plane), compared to those recorded by rotating them in the horizontal plane (respectively 30°, 45° and 60°)

CONCLUSIONS

The experiments highlighted the fact that in the months of May - June in the Bucharest-Ilfov area, at the angle of inclination of the solar collectors in the vertical plane of *60°* good yields (of converting solar energy into thermal energy) were obtained, but still lower than those obtained at the *45°* angle (presented in part I of the article).

And in this case, among the four options initially tested, option A was the most efficient in terms of heat transfer.

It is recommended that when using solar panels in the Bucharest-Ilfov area, the inclination angle of the collectors in the vertical plane should be *45°* and in the vertical plane between *30°* and 45°.

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