RECOVERY OF SOLAR THERMAL ENERGY AND ENERGY FROM THE COMPOSTING PROCESS
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RECUPERAREA ENERGIEI TERMICE SOLARĂ ȘI A ENERGIEI TERMICE DIN PROCESUL DE COMPOSTARE

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ABSTRACT

The use of energies from renewable sources, as an alternative to those obtained from fossil fuels, represents a sustained concern in the world scientific environment, this action being a particularly important objective at present, especially in the context of increasingly acute manifestations of the effects of climate change. The recovery and use of thermal energy developed in the composting process of biodegradable and solar waste is a current concern of the research environment in the field. In this paper we want to present some research on the recovery of thermal energy from the two renewable energy sources mentioned in order to use thermal energy for the production of the agent that can be used in the current activity of individual agricultural and livestock farms as well as in households, for the preparation of domestic hot water and heating of living spaces, greenhouses, and solariums. The paper presents the current state of research, some theoretical considerations regarding the thermodynamic phenomena that occur in the thermal energy recovery process, a modulated system for the recovery of thermal energy from the composting process and solar energy, experimentation in real operating conditions, the results and their interpretation and related conclusions.

REZUMAT

Utilizarea energiilor din surse regenerabile, ca alternativă la cele obținute din combustibili fosili, reprezintă una din preocupările susținute ale mediului științific mondial, această acțiune fiind un obiectiv deosebit de important la ora actuală, mai ales în contextul manifestării tot mai acute a efectelor schimbărilor climatice. Recuperarea și utilizarea energiei termice dezvoltată în procesul de compostare a deșeurilor biodegradabile și a celei solare, reprezintă una din preocupările actuale ale mediului de cercetare din domeniu. În această lucrare se prezintă rezultatele cercetărilor obţinute privind recuperarea energiei termice din cele două surse de energie regenerabila menționate, în vederea utilizării acesteia pentru producerea de agent termic care poate fi utilizat în activitatea curentă a fermelor agricole şi zootehnice precum și în gospodăriile individuale, pentru prepararea apei calde menajere și a încălzirii spațiilor de locuit, sere, solarii. În lucrare se prezintă stadiul actual al cercetărilor, câteva considerente teoretice privind fenomenele termodinamice ce se manifesta în procesul recuperării energiei termice, un sistem modulat de recuperare a energiilor termice din procesul de compostare și a celei solare, experimentarea acesteia în condiții reale de funcționare, înregistrarea rezultatelor, interpretarea acestora și concluziile aferente.

INTRODUCTION

This paper discusses the perspective of renewable energy (solar, biomass) in the making of strategies for sustainable development. Such strategies typically involve three major technological changes: energy savings on the demand side, efficiency improvements in energy production, and replacement of fossil fuels by various sources of renewable energy. Consequently, large-scale renewable energy implementation plans must include strategies for integrating renewable sources in coherent energy systems influenced by energy savings and efficiency measures *(Lund H., 2007).*

An important reason for replacing fossil fuels with RE (renewable energy) is to promote ecological sustainability - in particular to minimize further climate change. Nature provides many ecosystem services, such as food provision, fresh water, and climate regulation, but land-intensive RE systems, particularly hydroelectricity and bioenergy, inevitably reduce such service provision *(Moriarty P. et al 2016).*

Although agriculture is responsible for providing people with food, it is one of the sectors that are heavily dependent on fossil fuels, which not only jeopardizes food security but also poses significant risks to its sustainability and production. Most agricultural practices are generally carried out by burning fossil fuels, which increases the risk of greenhouse gas emissions into the environment. The Consultative Group on International Agricultural Research (CGIAR) notes that agricultural and food chains alone consume about 30% of the world's total energy, and because of the high consumption, this accounts for about one-third (19–29%) of annual greenhouse gas (GHG) emissions. Given concerns about climate change and the damaging impact of fossil fuel prices on production costs, increasing fossil fuel use in the agricultural sector will not be affordable or sustainable. This provides an incentive for the development of renewable energy sources that can supplement and replace fossil fuels *(Gorjian S. et al, 2022).*

Composting is an effective process for treating organic solid waste (OSW). There is a growing interest in recovering and reusing heat from composting, in the context of climate change and fossil fuel depletion. Several literature reviews have been conducted to address the composting process; however, several engineering aspects, including heat estimation, recovery, and utilization, are inadequately addressed in current reviews *(Fan S. et al, 2021).*

Aerobic biodegradation of biomass can release considerable heat, reaching temperatures of up to 65 °C. This heat can be recovered and used for domestic purposes through the implementation of a Compost Heat Recovery System (CHRS) *(Malesani R. et al, 2021).*

According to the blue economy model proposed by *(Pauli G.A., 2010)*, it is necessary to find ways of utilizing physics, chemistry, and biology with renewable materials and sustainable practices just like ecosystems do. In this context, the technologies that mimic processes naturally occurring in ecosystems aim for sustainable economic growth while avoiding the use of non-renewable natural resources and preserving ecosystems by implementing the blue economy model. Green technologies are an example of applying artificial processes for the same purposes. Compost Heat Recovery Systems (CHRS) could be considered a technology that meets the blue economy principles, according to its characteristics (*Malesani R. et al, 2021)*.

A limited number of previous studies have investigated the potential energy content of compost. A recent study reports that during high-temperature phases (~6) of municipal waste composting, on average 1136 kJ kg^{-1} of heat was released. Similar values (961 kJ kg^{-1}) have been reported earlier with an average compost moisture content of 52.7% *(Irvine G. et al, 2010).*

The recovery of solar thermal energy (solar radiation) means the capture of this energy with the help of a technical system and the partial transfer to a solar thermal agent that circulates inside an installation and is generally used for heating, and the difference is ceded to the environment through optical, conductive and convective dispersions. In the renewable energy sector, solar power is the best alternative energy source because it has no harmful effect on the surrounding environment. Solar energy has the potential to meet energy demands in terms of sustainability and quality. The solar energy that falls on Earth's continents is more than 200 times greater than the annual total commercial power currently consumed by humans.

In Europe, the energy of the incident solar rays is 200...1000 W/m2, depending on the latitude, the period of the calendar year, and the climatic conditions. Solar collectors are used to capture this radiant energy of the sun to heat closed spaces, produce hot water, or use it as an energy source in a refrigeration system. Also, the heat obtained can be used to indirectly generate electricity by producing steam and using turbine-generator type systems, or by supplying hot air to Stirling engine-generator type systems. These latter aspects will be discussed in a later chapter *(Maican, 2015).*

Nowadays, the energy originating from photovoltaic sources is used for powerful generators on or off-grid, but it is also used to power small-scale applications such as for isolated embedded systems. Considering all these applications, photovoltaic energy is an interesting source of energy as it is renewable, inexhaustible, pure, and clean to be used in several applications meeting the cost constraints *(Fares M.A et. al, 2017).*

In the published documentation written by *(Shaikh M.R et al, 2017)* it is stated that the previous 10 years are more significant for the per-watt cost of solar energy equipment due to the diminishing availability of renewable energy sources. In the coming years, it will undoubtedly become more affordable and advance as a superior technology in terms of both price and applicability. Earth receives sunshine every day from above (1366 W approx.). This energy source can be used endlessly and is totally free. The primary advantage of solar energy over other conventional power sources is that it can be produced using the tiniest photovoltaic (PV) solar cells, which allow sunlight to be directly transformed into solar energy. In comparison to the cost of various fossil fuels and oils during the past ten years, the most advantageous aspect of solar energy is that it is readily available and free to the general public.

Agriculture and horticulture seek to optimize the capture of solar energy in order to optimize the productivity of plants. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows, and mixing plant varieties can improve crop yields.

Recovery systems and solar thermal energy have been developed in various types, both from a technical standpoint and the calorific installed power, many of which are equipped with automated monitoring and control of their operation.

The objective of this paper is to present the development and performance evaluation of a pilot-scale compost equipment and the method used for energy recovery.

MATERIALS AND METHODS

The research was carried out on an integrated system, fig.1, which has three component installations, as follows:

- the installation for the recovery and transfer of solar thermal energy, symbolized IRTS - realizes the recovery of solar thermal energy and transfers it to a circuit connected to the public cold water network for heating it for use as domestic hot water.
- the thermal energy recovery facility from the compost symbolized IRTC - carries out the taking over of the hot air from the compost by a fan and its passage through a heat exchanger inside which the transfer of heat from the hot air to the cold water takes place, a phenomenon that leads to its heating for further use, the air used in the exchanger being then introduced back into the composting container;
- the monitoring and automation module, symbolized MMA - performs the control, monitoring, and automation of the modulated system, ordering the use of one or the other of the two thermal energy recovery installations, IRTS or IRTC.

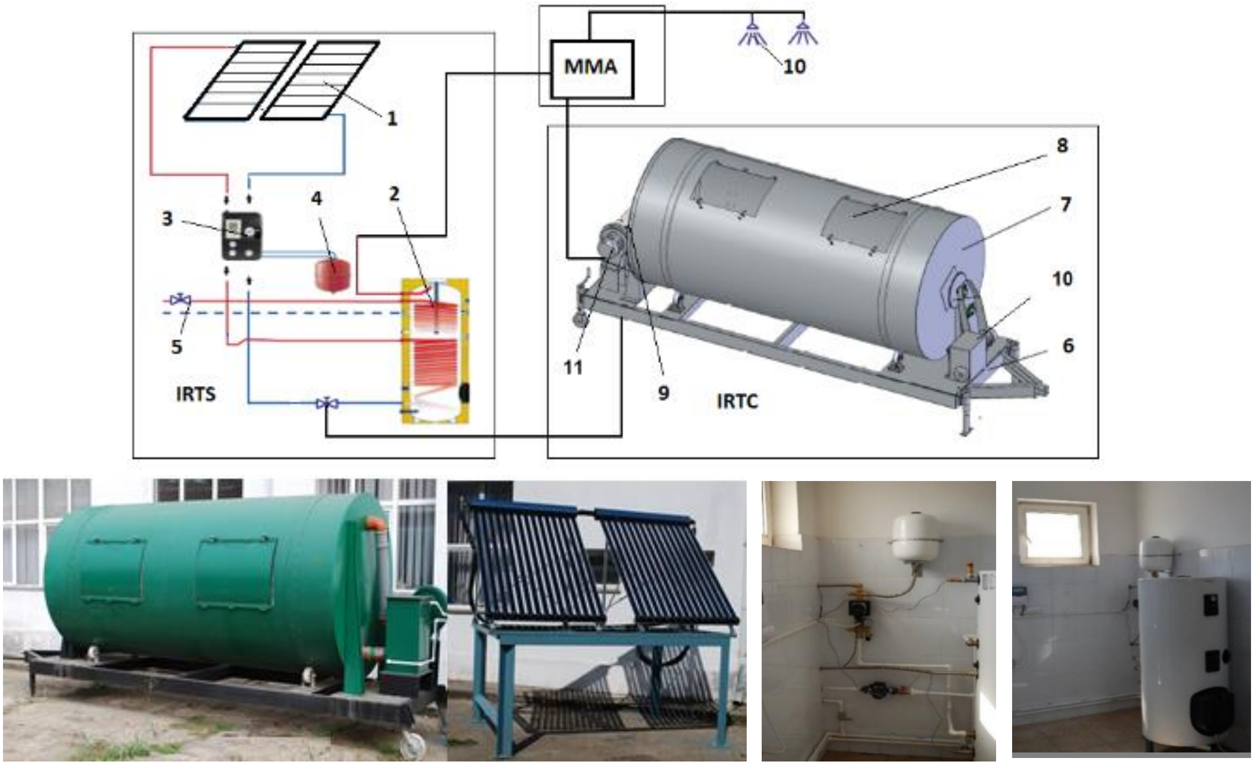


Fig. 1 - Integrated system for recovering solar thermal energy and thermal energy from the composting process

The solar thermal energy recovery installation symbolized IRTS, is mainly composed of two solar collectors (1), a storage tank (boiler) (2), the hydraulic equipment (3), the expansion vessel (4), water circuits (5).

The thermal energy recovery facility resulting from the composting process symbolized IRTC, consists of a frame (6), provided with four rollers on which the composting cylinder (7) rests, two doors (8) for loading-unloading waste /compost, a rear cover (9) equipped with vapor air suction/rejection holes mounted by screws on the frame, a transmission with a gear motor and chain wheels (10) for rotating the composting cylinder in the process of mixing, aeration and discharge of compost, a thermal energy recovery and transfer installation for the production of domestic hot water (11), consisting of a metal tank, a fan equipped with a frequency converter to regulate the airflow, a copper heating coil.

Technical and functional characteristics of IRTS and IRTC equipment:

- **IRTS**
  - Heating capacity of 650 W/ m^2 (A1 1000 W/ m^2)
  - Ideal flow rate: 2.5 l/min
  - Maximum flow: 18 l/min
  - Maximum power: 1290 W / 4420 Btu
  - Daily heating capacity (Δ40°C): 140-200 l
  - Absorption area: 1.98 m^2
  - Heat-pipe stagnation temperature: 180°C
  - Vacuum tube stagnation temperature: 280°C
  - Required boiler volume: 250 l.
- **IRTC**
  - The volume of the composting cylinder: 10 m^3;
  - Engine power: 3.5 kW;
  - Speed of the composting cylinder: 1.2 min^{-1};
  - Air flow of the fan, adjustable: max. 1790 m^3/h;
  - Fan motor power: 1.5 kW.

1. The recovery process in the installation for the recovery and transfer of solar thermal energy – IRTS

Romania is located in a geographical area with good solar coverage, having 210 sunny days per year and an annual flow of solar energy between 1000 kWh/m^2/year and 1300 kWh/m^2/year. Between 600 and 800 kWh/m^2/year can be captured from this amount of energy.

The potential of using solar energy in Romania is relatively important. There are areas where the annual solar energy flow reaches 1450-1600kWh/m^2/year, in the area of the Black Sea Coast and Dobrogea, as in most southern areas.

The use of solar thermal energy represents the transformation of direct and indirect solar rays into heat or hot water. This heat is produced by capturing the sun's rays by the solar collector, which, through a heat exchanger, heats the water in a boiler. Heated water is used in the kitchen, bathroom or to help heat the home. Thus, by investing in solar energy, the environment can be protected both for our comfort and safety and for future generations *(Solar panels Constanţa).*

Heating load calculation for domestic hot water heating for a solar system

The thermal load required for heating domestic hot water, Q_{acm} can be calculated with equation (1) (*Lund, 2007*):

$$\dot{Q}_{acm} = \frac{m \cdot c_w \cdot (t_b - t_r)}{\pi \cdot 3600} \text{ [kW]} \tag{1}$$

where:

m - the amount of hot water is considered as a daily intake, [kg];

c_w - the specific heat of the water quantity which varies with temperature, [kJ/kg K];

t_b - the temperature of water from the boiler [°C];

t_r - the temperature of the cold water at the inlet, [°C]

π - the length of the hot water heating period considered, [h].

For heating domestic hot water, manufacturing companies recommend the use of solar collectors in different areas depending on the type of collectors and the percentage of annual heat to be provided by those.

For the proposed system we choose solar collectors with vacuum heat tubes, they have the highest capture efficiency. The calculation of the absorbing area S, of the solar collectors for solar sizing is accomplished by the relation (2):

$$S = \frac{\dot{Q}_{acm}}{\dot{Q}_{acm1}} \text{ [m}^2\text{]} \tag{2}$$

where:

Q_{acm1} - average unit thermal load of the solar collectors, [W/m^2].

The number of solar collectors still needed, n_c, is calculated with relation (3).

$$n_c = \frac{S}{s_c} \tag{3}$$

where:

s_c - absorber surface of a solar collector, declared by producer, [m^2] *(Ciupercă R. et al., 2019).*

2. The process of heat transfer from the composting process

The transfer of thermal energy from the composting process consists of the transfer of heat from the air mixed with steams, sucked from inside the composted material by the fan of the plant and introduced into the premises of a heat transfer system which, in turn, transfers the heat to the cold water which pass through a copper pipe, in the form of a serpentine, which crosses diagonally the transfer tank.

The heat transfer system (fig. 2), which is the subject of research in this work, is a regenerative heat exchanger and the calculation of the transmitted heat is based on a thermal balance relation.

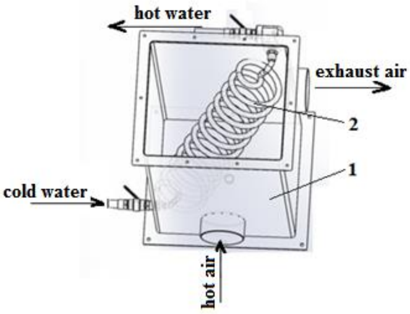


Fig. 2 – Heat transfer system
1-tank; 2- serpentine

Since the installation is thermally insulated and the losses are very small, it is considered that the thermal energy in the form of heat, given by the warm fluid (boiled air from the compost) is equal to the thermal energy transmitted to the cold fluid (cold water from the coil of the installation).

The calculation method for heat transfer in the installation is the classic "LMTD Method" (Log Mean Temperature Difference), which is based on the logarithmic average temperature difference Δt_m *(Fullarton J. W., 1993).*

The heat flow yielded by the warm fluid (air) conforms to the relation (4):

$$Q_1 = m_1 \cdot c_1 \left(t_{f_1} - t_{p_1}\right) \text{ [W]} \tag{4}$$

where:

m_1 – mass flow rate of hot air, [kg/s];
c_1 – thermal mass capacity of hot air, [J/kg °C];
t_{f1} – temperature of the 1st fluid (warm air from compost), [°C];
t_{p1} – temperature of the outer wall of the pipe, [°C];

The thermal flow received by the cold fluid (cold water) is calculated by the relation (5):

$$Q_2 = m_2 \cdot c_2 \left(t_{f_2} - t_{p_2}\right) \text{ [W]} \tag{5}$$

where:

m_2 – mass flow rate of cold water, [kg/s];
c_2 - thermal mass capacity of cold water, [J/kg °C];
t_{f2} – temperature of the 2nd fluid (cold water from the pipe), [°C];
t_{p2} – temperature of the inner wall of the pipe, [°C];

The transmitted thermal flow complies equation (6):

$$Q_{tr} = K \cdot A \cdot \Delta t_m \text{ [W]} \tag{6}$$

where:

K – global heat transfer coefficient, [W/m °C];
Δt_m – mean logarithmic temperature difference, [°C].
A – transfer surface, [m^2].

Product $K\,A$ is determined with the relation (7):

$$\frac{1}{K \cdot A} = \frac{1}{\alpha_1 \cdot A_1} + R_p + \frac{1}{\alpha_2 \cdot A_2} \tag{7}$$

where:

α_1 – convection coefficient between the outer wall of the pipe and hot air, [W/ m^2 °C];

α_2 - convection coefficient between the inner wall of the pipe and the cold water in the pipe, [W/ m^2 °C];

A_1; A_2 – the unfolded transfer area of the outside or the inside of the pipe, [m^2]. At small thicknesses of the pipe wall, the two surfaces are considered equal and denoted by A.

R_p – the thermal resistance of the heat exchanger wall is according to the relation (8).

$$R_p = \frac{\delta_p}{\lambda \cdot A_m} \tag{8}$$

where:

δ_p – thickness of the pipe wall, [m];

λ – thermal conductivity of the pipe material, [W/m °C];

A_m – transfer surface deployed on the median thickness of the pipe wall, [m^2];

Thus, the relationship (7) becomes (9):

$$\frac{1}{K} = \frac{1}{\alpha_1} + \frac{\delta_p}{\lambda} + \frac{1}{\alpha_2} \tag{9}$$

Since the two fluids flow in the same direction (equidirection), the average algorithmic temperature difference is calculated with the relation (10):

$$\Delta t_m = \frac{\Delta t_a - \Delta t_b}{\ln \dfrac{\Delta t_a}{\Delta t_b}} \tag{10}$$

where:

Δt_a; Δt_b – the temperature differences between hot and cold fluids at the ends of the pipe (11).

$$\Delta t_a = t_{f1} - t_{p1}$$
$$\Delta t_b = t_{f2} - t_{p2} \tag{11}$$

To explain the temperatures of the process, the recovery system was considered as a homogeneous cylinder surrounded by two fluids with known temperatures, boundary conditions of the III-rd type *(Coman G. 2000; Leca A., 2000; Miron V. et al, 2006).*

The process consists of three stages of transfer, as follows:

- stage 1, such *as forced thermal convection*, consists of the transfer of heat from the hot air sucked from the composted material to the outer wall of the copper coil that is mounted in the transfer rail;
- stage 2, of the type *of thermal conduction in the variable regime*, consists of the transfer of heat from the outer wall of the coil to its inner wall;
- stage 3, such *as forced thermal convection*, consists in transferring heat from the inner wall of the coil to the cold water circulating inside it.

In these conditions, the relations of the unitary heat flow are written for the three stages, according to the relations (12):

$$Q_1 = \alpha_1 \cdot \pi \cdot d_1 \left(t_{f1} - t_{p1}\right)$$
$$Q_p = \frac{t_{p1} - t_{p2}}{\dfrac{1}{2 \cdot \pi \cdot \lambda} \cdot \ln \dfrac{d_2}{d_1}} \ \text{[W/m]} \tag{12}$$
$$Q_2 = \alpha_2 \cdot \pi \cdot d_2 \left(t_{p2} - t_{f2}\right)$$

Putting the condition of the unidirectionality of the thermal flux, according to the relation (13):

$$Q_1 = Q_p = Q_2 = Q \tag{13}$$

It follows, the relation (14) for the thermal flux:

$$Q = \frac{t_{f1} - t_{f2}}{\frac{1}{\pi \cdot d_1 \cdot \alpha_1} + \frac{1}{2 \cdot \pi \cdot \lambda} \cdot \ln \frac{d_2}{d_1} + \frac{1}{\pi \cdot d_2 \cdot \alpha_2}} = K\left(t_{f1} - t_{f2}\right) \quad \text{[W/m]} \tag{14}$$

in which K has the expression (15):

$$K = \frac{1}{\frac{1}{\pi \cdot d_1 \cdot \alpha_1} + \frac{1}{2 \cdot \pi \cdot \lambda} \cdot \ln \frac{d_2}{d_1} + \frac{1}{\pi \cdot d_2 \cdot \alpha_2}} \quad [\frac{\mathrm{W}}{\mathrm{m} \cdot {}^{\mathrm{o}}\mathrm{C}}] \tag{15}$$

where: d_1 – external diameter of the pipe, [m];

d_2 - the inner diameter of the pipe, [m];

The temperatures on the outer and inner walls of the pipe are according to the relations (16):

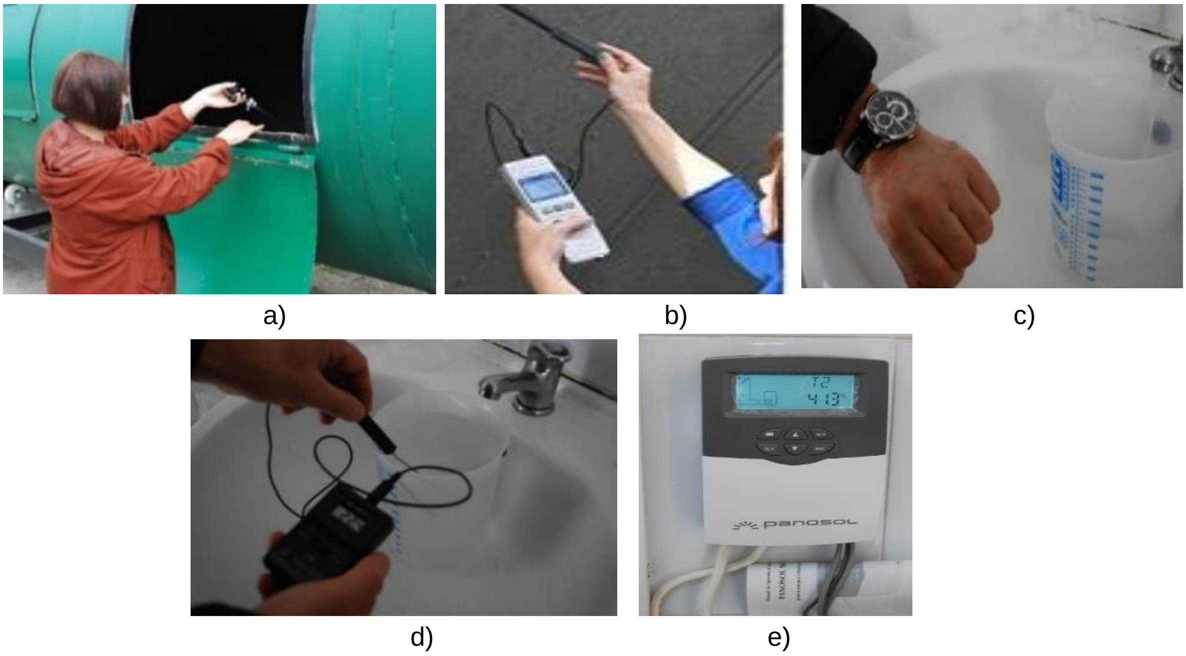
$$t_{p1} = t_{f1} - \frac{Q}{\pi \cdot d_1 \cdot \alpha_1} \quad [{}^{\mathrm{o}}\mathrm{C}]$$
$$t_{p2} = t_{f2} + \frac{Q}{\pi \cdot d_2 \cdot \alpha_2} \quad [{}^{\mathrm{o}}\mathrm{C}] \tag{16}$$

Previously written expressions are valid for heat exchange in a second. If fluid 2 (water from the coil) circulates in the transfer medium for a longer time, then the value, according to written relationships, will be amplified with the circulation time. These values, obtained through detailed experimental data, must be amplified with a coefficient because in any moment, following the first second, the temperature of the water in the coil increases with a certain value, the phenomenon being one of the type convections + conduction + forced convection.

In order to determine the water flow circulated in the thermal energy recovery installation, a 2-liter graduated vessel and a wristwatch were used, and for the speed of the air current of the fan a Testovent 4000 type anemometer with a measuring range of 0.4-40 m/s, with the help of which the air current flow was calculated.

The speed of the fan air current was measured on the air return circuit (after exiting the recovery plant and back into the composting container).

Details from the experiments with the plant for the recovery and transfer of thermal energy resulting from the composting process (IRTC) are presented in fig. 3.



a) b) c)

d) e)

Fig. 3 - Details from the time of the measurements

a-Compost, temperature; b-Airspeed; c-Water flow in the plant; d-Temperature of cold and hot water; e-Temperature in hydraulic circuits for IRTS

RESULTS

➢ Results obtained using the IRTS solar energy recovery system

The measurements were carried out on 4 days, in the time interval 9.30-18.00, hour by hour, the measured parameters being the temperatures of the heating agent and water in various essential points of the installation as well as of domestic hot water to the user.

The graph in fig.4 shows the air temperature and solar radiation recorded during the measurement period.

Input data:

- m - the hot water requirement is 250 l/day or 250 kg/day.
- the average thermal energy required to heat a litre of water is approx. 35W/h;
- $t_b = 45$ °C - recommended value for the temperature of the hot water in the boiler;
- $t_r = 15$°C - the average value of the cold water in the public network, at the date of the measurements;
- $\pi = 8$h - a value roughly coincides with the average duration in which the solar radiation manifests itself, so with the average duration it can be captured.
- $c_w = 4.186$ kJ/kg K;
- $Q_{acm} = 1290$ W.

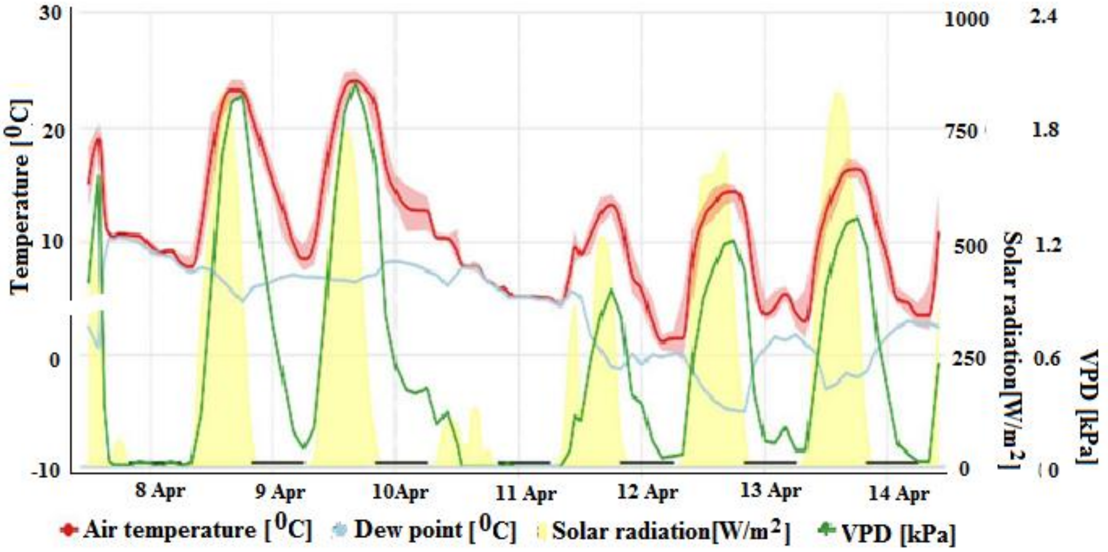


Fig. 4 - Graphic representation of air temperature and solar radiation

VPD - Vapour pressure deficit

Using relation (1), the average temperature in the boiler that the installation can achieve during the experiments, according to the graph in fig. 2, was $t_b = 50.5^oC$.

This temperature is lower than that measured by the thermometer placed on the boiler, in its upper spot, which indicates the maximum. The average temperature in the boiler was close to the one that results in the user, the one presented in Table 4 which is close to the one obtained from the theoretical calculations.

The measured values of the temperatures in the Installation for the recovery and transfer of solar thermal energy - IRTS, corresponding to the mentioned period, are presented in Tables 1-4.

Table 1

Water temperature at the entrance to the storage tank (lower part), T2

Date / Time range of measuring	Temperature, C°									
	9h 30min	10h 30min	11h 30min	12h 30min	13h 30min	14h 30min	15h 30min	16h	17h	18h
*04/08/2022	14.2	16.6	18.2	23.3	31.5	35	38.3	43.6	45.8	46.5
11.04.2022	18.7	20.5	25.3	25.4	26.4	26.9	30.2	32.1	31.4	30.5
12.04.2022	23.5	26.7	30.2	34.7	39.1	41.3	43.7	45.3	45.6	47.3
13.04.2022	29.7	32.7	33.6	35.7	38.1	42.3	44.3	47.6	50.3	50.8

* *Loading the installation with a heating agent and cold water from the public network*

Table 2

The temperature of the heating agent, at the exit from the storage tank (return), T1

Date / Time range of measuring	Temperature, C°									
	9h 30min	10h 30min	11h 30min	12h 30min	13h 30min	14h 30min	15h 30min	16h	17h	18h
*04/08/2022	19.4	25.4	30.6	36	41.5	46.5	47.3	48.4	47.5	46.1
11.04.2022	26.5	28.1	33.3	32.6	33.4	35.9	40.3	43.4	45.5	45.1
12.04.2022	31.3	37.9	42.2	45.4	49.0	51.6	54.6	55.3	55.7	53.2
13.04.2022	37.1	45.2	46.3	52.0	56.2	58.4	60.4	58.9	57.8	54.5

Table 3

The temperature of the water in the storage tank at the top of it

Date / Time range of measuring	Temperature, C°									
	9h 30min	10h 30min	11h 30min	12h 30min	13h 30min	14h 30min	15h 30min	16h	17h	18h
*04/08/2022	19.5	22.5	26.0	34.0	48.0	51.5	53.0	55.0	55.0	55.0
11.04.2022	52.0	52.0	53.0	54.0	54.5	55.0	57.0	57.5	57.5	57.5
12.04.2022	55.0	56.0	56.5	59.0	62.0	64.0	68.5	69.0	69.0	69.0
13.04.2022	67.0	67.0	67.5	69.0	70.0	74.0	76.5	77.0	77.0	77.0

The temperatures measured at the user, for domestic hot water, compared to the temperature in the storage tank (boiler), were measured on 13.04.2022 when the installation reached a normal operating regime.

Table 4

Domestic hot water temperature at the user

Date / Maximum temperature in the storage tank, at the top of it C°	Domestic hot water temperature at the user, C°			
	67.0	69.0	74.0	77.0
13.04.2022	45	46	52	53

➢ **Results for the IRTC composting process energy recovery system**

- **Preparation of experiments for IRTC**

To carry out the experiments with the installation for the recovery and transfer of the thermal energy resulted in the composting process (IRTC), the following steps have been taken:

- the material for composting was prepared, which consists of manure mixed with fragments of chopped twigs, straw, and dry leaves;
- the composting material was permanently mixed and moistened so that the humidity was adequate, this being checked with the "fist" method;
- the material, prepared according to the previous point, was loaded into the composting container through the two side doors with which it is provided. The amount of material loaded in the quota was about 7m^3;
- the mixing plant was started to homogenize the material, by turning the loaded container. This operation was repeated 5 times a day, 10 min. for each mixing to speed up the composting process.
- measurements of the temperature in the compost were made until it reached values between 55-65^{o}C when the composting process is at its peak. At this moment, the experiments for the recovery of the thermal energy released in the composting process have effectively started;
- the fan of the thermal energy recovery installation and the rotation of the container was put into operation. The fan absorbs hot air from the compost and transfers it to the tank with the transfer coil through which the cold water passes from the public network.
- during the experiments, measurements were made of the temperature from the compost, the hot air from the compost, the cold water from the network, and the resulting domestic hot water.

Using the known data of the transfer system in relations (4-6) and (10-16), in which:

m_1 =0.51 kg/s; c_1 = 1005 J/kg °C; t_{f1} = 62.5 °C; m_2 = 0.039 kg/s; c_2 = 4218 J/kg °C; t_{f2} = 22.5 °C;
δ_p = 0.0005 m; λ_{air} =0.0234 W/m °C; λ_{water} =0.6 W/m °C; λ_{Cu} =397 W/m ^{o}C; d_1 = 0.015 m; d_2 = 0.014 m;
$\alpha_1 = \lambda_{air} / \delta_{air}$ = 0.1872 W/m^2 °C; $\alpha_2 = \lambda_{water} / \delta_{water}$ = 42.86 W/m^2 ^{o}C; δ_{air} = 0.125 m; δ_{water} = 0.014 m;
A = 0.258 m^2

δ_{air} = the thickness of the warm air layer; δ_{water} = the thickness of the water layer.
t_{f2} – average domestic hot water temperature for 4 samples/water flow, according to the values in table 6.

For the recovery and transfer of thermal energy resulting in the composting process (IRTC), the determined values are presented in Table 5-6.

Table 5

Determination of operating parameters

Parameter	Measurement unit	Sample number			
		1	2	3	4
Compost temperature	°C	62	63.5	63	65.5
Fan air flow speed	m/s	35	33.5	34	33.8
Fan airflow	m^3/h	1566	1499	1522	1513

Table 6

Domestic hot water temperature

Parameter	Measurement unit	Water flow in the installation, l/min			
		2.67	3.23	3.65	4.2
Cold water temperature	°C	22.4	22.6	22.5	22.6
Average domestic hot water temperature for 4 samples / water flow	°C	45.5	38.0	33.8	29.2

CONCLUSIONS

Following the experiments of the Installation for the recovery and transfer of thermal energy resulting from the solar installation, IRTS, and from the composting process (IRTC), the following conclusions were drawn:

- When sizing the radiant surface of the panels and the capacity of the boiler, of a thermal energy recovery installation, the estimated amount of water used in a day and its temperature must be taken into account;
- The temperature variations measured in the IRTS facility depend directly on the values of air temperatures and solar radiation and indirectly on the degree of cloud cover and precipitation;
- The values of the hot water temperature at the user are in percentage of approx. 69% of the maximum temperature values in the storage tank, at first use. These values decrease to the extent that the installation is used continuously for a longer time;
- In the IRTS installation, the temperature variations measured for domestic hot water produced by the user depend, in the main, indirectly on the flow rate of the water circulating in the installation and on the temperature of the cold water from the public water network and directly on the temperature of the air in the compost.

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