SOLAR ENERGY BASED INDUSTRIAL APPLICATIONS AT THE "POLITEHNICA" UNIVERSITY OF TIMISOARA

by

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A short overview of a more than 30 years long activity in industrial and home applications of solar energy at the "Politehnica" University of Timisoara, Romania, is presented. A built "Solar House", an industrial system for preheating bitumen, a solution for waste water cleaning, and an industrial hall for drying ceramic products are described. Some recent studies on solar concentrators are reported.

Key words: *bitumen fluidization, thermal applications, waste water cleaning, concentrators*

Introduction

At the Department of Physics from the "Politehnica" University of Timisoara, Romania, (45°46' N, 21°25' E), research in solar energy has been started in 1976, motivated by the classical resources exhaustion, rise of the price of classical fuel, and ecological problems. An outdoor laboratory has been built from scratch and, as a consequence of local and international conditions of the period, a part of the equipment has been designed, built, and calibrated locally [1]. Measurements demonstrated that solar radiation and climate conditions were favorable for implementing solar energy based solutions in the area. One of these activities will be described below, namely the study of bitumen fluidization, due to its direct connection to its industrial counterpart.

Based on results obtained in laboratory, industrial and home applications have been developed in the region of Timisoara. Some of these applications had a pioneering character and still present interest. We describe industrial solutions for air heating in view of drying ceramic products, preheating of bitumen to be used in road construction, ecological waste water cleaning for an industrial swine farm, and a "solar house" built for study and optimization of home thermal applications of solar energy. The recently approached problem of solar concentrators is also tackled.

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Industrial hall for drying ceramic products at Jimbolia, Department of Timis [2, 3]

The first industrial application of solar energy technology approached by the research group has ended in a hall for drying ceramic products, where the circulated air was heated by solar means. The co-operation between the "Politehnica" University of Timisoara and the Plant for Ceramic Products from Jimbolia started back in 1976. It has been a pioneering research joint action in the field of solar energy in Romania that ended with a functional industrial hall. The industrial partner's wish to use an existing building raised many problems that had to be solved, and sometimes led to technical compromises.

The hall was a rectangular, metallic construction, with sides of 8 m and 10 m. The height of the walls was 4 m. A protecting brick wall has been raised to the north, which served later as a support for automation, measuring and control devices. The roof, in two slants, had the axis oriented on the north-south direction, with a slope of 30 deg. This orientation, imposed by the existing construction, reduced the insolation period, each half of the roof being illuminated for half of the time. The eastern and western walls have been equipped with glass spinning panels, in order to provide ventilation during drying of the ceramic products-hollow bricks (figs. 1 and 2).

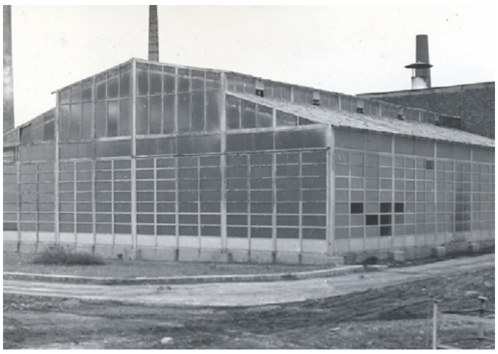

Figure 1. Plant for drying ceramic products – exterior (1978)

Figure 2. Plant for drying ceramic products – interior (1978)

Brick drying imposes a well defined process of elimination of water from the ceramic material, depending on ambient temperature and necessitating a large quantity of heat. The drying speed influences the quality of the ceramic blocks that are introduced in the ovens.

The purpose of using solar energy in the process was to reduce the quantity of classical fuel for drying air heating, to shorten the drying time and to provide controllability by automation.

The hall was built and its performances have been observed for several years, allowing for a good understanding of the involved phenomena. A number of practical conclusions could be drawn, such as:

– the hall walls and the roof give the best results in the capture and conversion of solar energy when they are made of clear window glass, with a thickness of 4-5 mm,

– the spinning panels with controllable orientation are essential for an appropriate evacuation of water vapors by air current, without energy consumption,
– an air circulating system must exist that absorbs the air from the upper side of the hall (under the roof), conducts it to the lower side and blows it over the bricks,
– on the 45 deg. northern parallel, where Jimbolia is situated, the meteorological, insolation, and temperature conditions allow for the use of solar energy in such purposes for six contiguous months per year and in some sunny periods during autumn and winter; however the drying plants must be equipped with classical heating solutions for night and periods with overcast sky,
– automation improves efficiency, and
– solar energy is competitive as long as prices of classical fuel increase and also as an ecological counterpart.

Solar equipment for bitumen preheating in view of melting [4-10]

A second potential industrial application has been identified: the melting of bitumen, as the local representatives of the road construction industry were interested in this problem. However, as the involved phenomena were more complex then in the case of drying ceramic products, a preliminary laboratory study had to be performed.

An experimental equipment has been built in the outdoors laboratory, whose structure is presented in fig. 3. The elements are: (1) – brick walls, (2) – metallic bitumen tank painted in black, (3) – glass plate, tilted at 30 deg. with respect to the horizontal plane, (4) – mirror tilted at 70 deg. with respect to the horizontal plane, (5) – vertical mirror on the northern wall, (6) – vertical glass plate posed on the black painted southern wall, (7) – glass plate incorporated in the southern wall, and (8) – thermometers. Solaris 1 is a pyranometer built and calibrated within the department [1]. The cylindrical tank had a mass *m* = 10 kg and it contained *M* = 25.15 kg of bitumen.

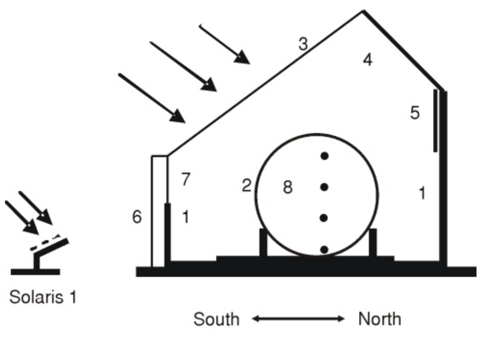

Figure 3. Installation for bitumen

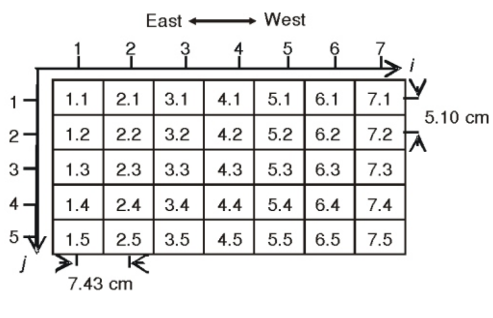

Figure 4. Numbering of the probes (*i, j*)

The probes of the thermometer were placed in the bitumen as shown in fig. 4. The axis of the tank was oriented in the east – west direction. The origin of the axes for probe numbering, (*i, j*), was at the eastern superior end of the tank. The temperature distribution in the tank at 3 p. m. in a summer day is presented in tab. 1.

Table 1. Temperatures $t_{i,j}$ ± 0.1 [°C]

*i**j*	1	2	3	4	5	6	7
1	57.0	60.5	62.4	63.3	62.9	62.3	59.0
2	49.7	50.5	51.0	51,6	50.2	48.7	47.1
3	45.0	44.5	44.2	44.1	44.2	44.4	45.5
4	43.9	43.6	43.4	43.4	43.8	44.4	45.0
5	43.5	43.4	43.0	43.0	43.0	44.2	44.8

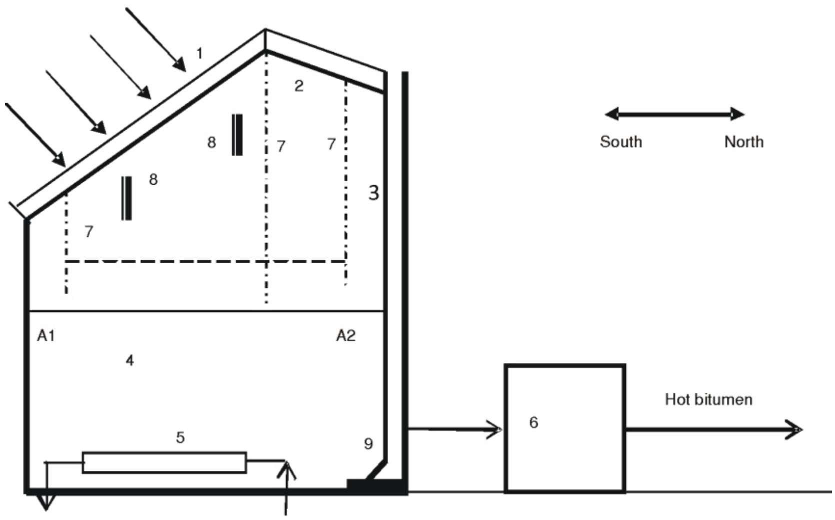

Figure 5. Diagram of the classical and solar installation for bitumen preheating)

The results of experiments performed in real conditions have shown that the bitumen can be heated up to 50-65 °C by means of solar energy. The obtained average efficiency of solar to heat conversion was between 7.1 and 9.1%. The thermal field in the bitumen mass is influenced by the solar radiation, the geometry of the installation and the ambient. It turned out that the existing installations within the Department Sections of Roads and Bridges could be rearranged in an inexpensive way for use with solar energy.

The installation for bitumen melting contain several compartments that perform the following tasks: heating of the upper layer of bitumen until by melting; leak of fluid bitumen in another compartment where additional heating is realized by conventional means, and storage of heat for use in periods of time without insolation.

As laboratory results have been encouraging, a solar system for bitumen preheating has been realized at Sacalaz, department of Timis [10]. The system has been installed on an existing construction. Insufficient funding allowed only for preliminary measurements: only the temperature of the air volume comprised between the bitumen surface and the roof (the solar trap) has been measured. A plate made of steel, with a thickness of 0.75 mm has been posed between the bitumen surface and the glass plate.

The principle of the installation is represented in fig. 5. The elements are: (1) – solar collector with an area of 300 m^2, (2) – metallic roof, (3) – pipes immersed in bitumen, (4) – compartment with bitumen preheated at 90-100 °C, (5) – heat exchanger with mineral oil, (6) – tank for heating bitumen at 100-150 °C, (7) – metallic meshes distanced by 0.5 m, (8) – thermometers, (9) – fire place. The free surface of the bitumen is A1A2.

Bitumen is usually heated in two steps. It is preheated by the heat exchangers with mineral oil (5) and by burning diesel oil or fuel oil in the vertical pipes (3) in a first step, until it reaches 90-100 °C. In a second step, the bitumen is heated in the tank (6) to 150-170 °C.

Figure 6. The "Solar House" (present view)

The solar installation attempts to preheat the bitumen to 50-55 °C by means of solar energy in order to achieve an economy of conventional fuel. The averaged daily measurement results on the temperatures in the solar trap $\langle t_h \rangle$ and ambient $\langle t_a \rangle$, obtained in summer, are presented in tab. 2. A maximum value of 54-56 °C of the average temperature is reached at 2.30 p. m. The average maximum temperature in the solar trap was by 27 °C higher than the ambient temperature.

Table 2. Average temperatures in the solar trap

Time	9h30min.	10h30min.	12h30min.	14h30min.	16h30min.	18h30min.
$\langle t_a \rangle$ [°C]	27.5	28.5	34.0	35.0	33.5	31.0
$\langle t_h \rangle$ [°C]	38.0	47.5	55.5	56.5	55.0	52.5

The "Solar House" pilot station [11-16]

Successful experience of solar applications in Europe (*e. g.* [17]), local expertise in building thermal installations [18, 19], and international experience in solar design [20, 21] encouraged the research group to approach applications of solar energy to heating of buildings.

A small residence has been built using materials and local possibilities of the eighties, in order to perform real life experiments on the home applications of solar energy, in Timisoara, inside the University campus, fig. 6. The walls were built in brick, insulated with mineral wool. The roof was made in concrete and insulated with bitumen; a terrace has been built on the top. The building (still existing) has two floors with a room on each floor, an entrance room and a corridor. The main target for design, experiments, and measurement was the so called "minimum thermal loss room", situated at the first floor, provided with a double-layered door and three double-layered windows. The dimensions of the room are 3.5 × 3.5 × 2.8 m, giving a total volume of 34.3 m^3 and surface for thermal exchange with the ambient A_r = 63.7 m^2. The room at the ground floor was used for technical activities. In order to perform experiments on heat storage, a bedrock thermal accumulator has been built beneath the ground floor, having the shape of

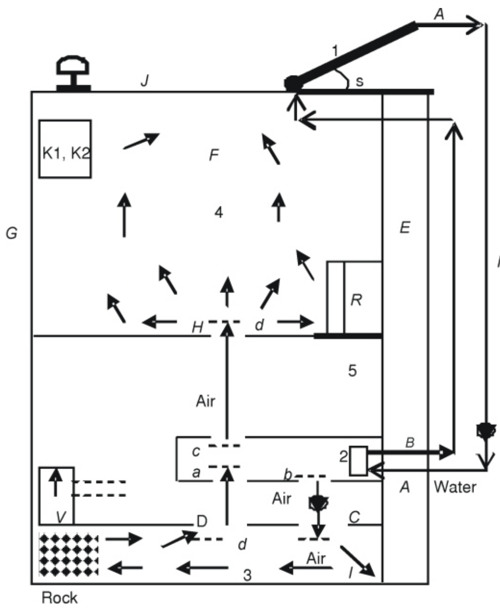

Figure 7. Diagram of the energetic chain

a parallelopiped of sides 1.5 × 1.5 × 4 m. The rock had m = 17,291.6 kg and a calorific capacity of C = 16.6 MJ/K. The walls were built in concrete with a width of 40 cm, insulated with mineral wool.

The energy chain is presented in fig. 7, including: (1) – flat-plate solar collectors, (2) – heat exchanger, (3) – thermal accumulator, (4) – heated room, and (5) – room for technical activities.

The collecting field comprised 12 locally made panels, of dimensions 2.0 × 1.0 × 0.12 m, connected in parallel, giving a total collecting area of 24 m^2. The main aluminum pipe in the collector branched in smaller pipes with a diameter of 20 mm and distanced by 150 mm. The tilt angle of the collecting surface was 45 deg. The greenhouse effect was created by a glass plate having a width of 4 mm. The mineral wool layer had a width of 50 mm. The box was made of steel with a width of 0.8 mm. The heat carrying fluid (water) was moved by a 40 W pump with a mass flow rate m_w = 300 kg/h. A thermal loss coefficient U = 3.7 W/m^{2}K and an absorption – transmission product $(\tau\alpha)_{ef}$ = 0.81 have been measured. The heat exchanger was of water-air type, with a sinuous copper pipe and a fan having a power P = 60 W. The mass air flow rate was m_a = = 1154 kg/h. The water, air and ambient temperatures have been measured at points A, B, C, D, E, F, G, H, and I (fig. 7). The solar radiation has been measured at point J. The diaphragms that determined the sense of air flow are denoted by a, b, c and d. On fig. 7, R is a radiator, K1 and K2 are electric counters and V is the measuring instrument that displays the temperature at the points indicated above.

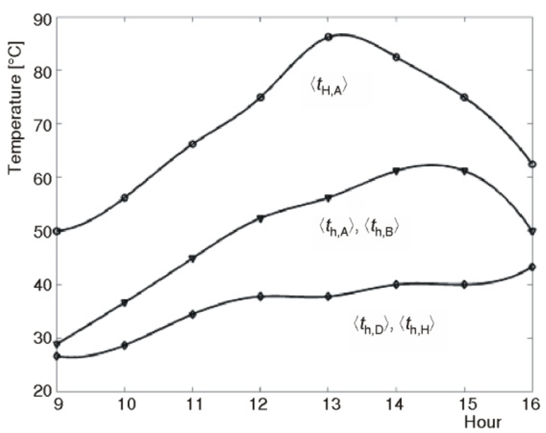

Figure 8. Average temperature at points A, B, C, D, and H *vs.* hour

The warm air penetrated the thermal accumulator and warmed up the rock. In periods of overcast weather, the room heating was achieved by means of the air circulated by a low power pump through the rock.

The measured hourly average temperatures at points A, B, C, D, and H are shown in fig. 8. The average temperature at noon, at point A was 83 °C. The largest value has been 87 °C, obtained in June and September. The lowest value, 61 °C has been obtained in March and November.

The maximum temperature in spring and autumn in the heat exchanger has been 52 °C. The daylight raise of the temperature in the tank has been of 11 °C per day. The natural decrease of the temperature in the tank has been measured as 0.3 °C per day. When heat was extracted from the tank, its temperature decreased by 4.5 °C per day. The average temperature in the climatized room was 20 ± 1 °C for an outside variation from 4 to 15 °C. For the period of time during which measurements have been performed (March-April and October-November), the temperature inside the tank did not drop below 30 °C.

The following parameters have been obtained: average efficiency of the collector $\overline{\eta}_1$ 0.75, average efficiency of the heat exchanger $\overline{\eta}_2$ 0.82; efficiency of the thermal charging of the accumulator $\overline{\eta}_{3,\mathrm{ld}}$ 0.77, efficiency of heat extraction from the tank $\overline{\eta}_{3,\mathrm{ds}}$ 0.63, and global efficiency of the system $\overline{\eta}_{\mathrm{syst}}$ 0.30.

Studies on concentrators [22-32]

All three applications presented above have shown the necessity of improved solar collectors. A known solution is the concentration of solar radiation, which determines, for example, an increase of more than 30% in the efficiency of the photovoltaic cells. In order to keep the price of solar installation within reasonable limits, non-image, static concentrators are preferred. In Tenerife Islands, 480 kW solar concentrators have been built in the framework of the Euclides Project. The cost of energy will reach 13 cents per kW for a production volume of 15 MW per year [22].

A non-image, static concentrator for thermal applications has been designed and built [23]. It contains 22 polyester lamellas, with a length of 40 cm each, covered with electrolysis aluminum deposited in vacuum. The deposition has been performed at S. C. ELBA SA, a Timisoara based plant. The reflectance of aluminum is $\rho = 0.91$. The area of the reflecting surface is $A_R = 2968$ cm^2, and the area of the input aperture is $A_p = 1225$ cm^2. The multi-lamellar mirror forms two focal bands, of $A_F = 113$ cm^2 each. The concentration factor is $C = 5.4$.

Studies on static concentrators for photovoltaic applications have been performed with the Ray-Tracer method [27-32]. This method is used for obtaining information on the behavior of solar installations in conditions that mimic the natural ones [24-26], which are used in the design of solar installations relying on concentrated solar radiation [27, 28].

As an example, results obtained by numerical simulation on the behavior of static, parabolic concentrators, for the day of 22$^{\mathrm{nd}}$ August, at Timisoara, are presented below [29-32]. Conditions of clear sky are supposed, such that the contribution of diffuse radiation to the photovoltaic effect is negligible.

The following quantities are input: radius of input aperture $R = 50$ mm, radius of output aperture $r = 20$ mm, position of the photovoltaic cell $H_0 = 10$ mm, and the distance between the directrix and the focus of the parabola $p = 20$ mm. In these conditions, the geometric concentration factor is $C_{\mathrm{geom}} = 6.25$, and the height of the paraboloid is $h = 62.5$ mm. The calculated quantities are: direct solar radiation intensity B, angle of incidence of solar radiation on the input aperture θ, direct solar radiation intensity on the input aperture B_{conc}, radiant flux density

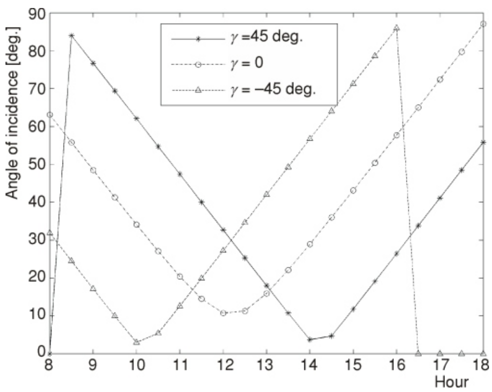

Figure 9. Angle of incidence of solar radiation on the input aperture *vs.* hour

on the cell B_{rec}, the optical concentration factor C_{optic}, the quantity of energy that penetrates the input aperture during simulation Q_{conc}, the quantity of energy received by the cell Q_{rec}, mean daily optical efficiency of the concentrator $\langle\eta_{optic}\rangle = Q_{rec}/Q_{conc}$.

Examples of calculated time variation of some quantities are presented in figs. 9-11. The concentrator is supposed to stand on a roof tilted by an angle s = 45 deg., and oriented to

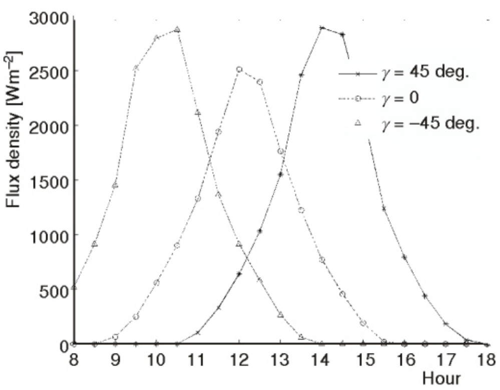

Figure 10. Radiant flux density on the photovoltaic cell *vs.* hour

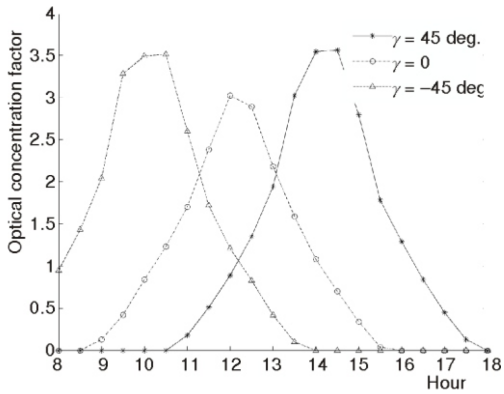

Figure 11. Optical concentration efficiency *vs.* hour

Table 3. Calculated quantities relative to the concentrator on a tilted roof

	γ = 0 deg	γ = 45 deg	γ = –45 deg
Interval of illumination	9 a. m.-3.30 p. m.	11 a. m.-15.30 p.m.	8 a. m.-13.30 p. m.
Time when B_{rec} is maximum/ maximum value of B_{rec} [W/m^2]	12 a. m./2512.5	2 p. m./2892.0	10.30 a. m./2876.6
Time when C_{optic} is maximum/maximum value of C_{optic}	12 a.m./3.02	2.30 p.m./3.56	10.30 a. m./3.51
Interval when C_{optic} > 1	10 a. m.-16 p. m.	12.30 p. m.-4 p. m.	8.30 a. m.-12 a. m.

Table 4. Quantity of energy that penetrates the input aperture during measurements Q_{conc}, quantity of energy received by the cell Q_{rec}, and mean optical efficiency of the concentrator $\langle\eta_{optic}\rangle$

Orientation / Quantity	γ = 45 deg	γ = 0	γ = –45 deg
Q_{conc} [kJ]	149.5	156.7	133.6
Q_{rec} [kJ]	37.6	32.5	36.4
$\langle h_{optic}\rangle$ [%]	25.1	20.5	27.2

south (azimuth angle γ = 0), south-west (γ = 45 deg.), or south-east (γ = –45 deg.). Conclusions are synthesized in tab. 3. In tab. 4, the values for the quantities Q_{conc}, Q_{rec}, and $\langle\eta_{optic}\rangle$ for the simulated situation are reported. It can be seen that the average daily optical efficiency of the concentrators located on roofs with azimuth angles of ±45 deg is by 5-7% higher than the efficiency of the concentrators located on the south oriented roof.

Waste water cleaning [33-35]

In the eighth decade of the past century, the development of industrial swine farms in the region of Timisoara (Banat) produced a heavy pollution of surface water that was approaching the deep water too. An ecological solution was looked for, in co-operation with the Chemical Laboratory of the Town Water Plant of Oradea.

Our idea has been to use plants that can develop in water contaminated by swine farms, such as water cabbage (*pistia stratiotes*) and water hyacinth (*eichornia crassipes*), which were known to have an important cleaning capacity. The problem with these tropical plants was they could not withstand the local winter temperatures, when water freezes.

An experimental installation has been built near the small swine farm the University possessed at that time. The farm had a capacity of 100 pigs per cycle and a cycle was lasting 6 months. A land surface of 2.4 ha was also available. The experimental installation consisted of two pools having a surface of 9 m^2 and a depth of 3 m each. Waste water was flowing gravitationally from the stables in one of the pools, and then in the next. The surface of the pools was free most of the time, but a plastic cover could be used when thermal protection of the tropical plants was necessary.

Seeds of the two plants have been posed in the first pool at the beginning of spring. The plants developed due to the contents of the water from the stables and the increasing quantity of incident solar radiation. After the first pool became full, water and plants flowed into the second one, where the cleaning process continued. In May, both pools were fully covered with plants. The water of the second pool had a low turbidity, had lost its characteristic, unpleasant smell and could be used for irrigation of the fields cultivated with swine food. Chemical analyses have shown that the plants did not contain particles of heavy metals or other toxic elements, so that they could be used as green mass swine food on a daily basis. The purification efficiencies after two months are presented in tab. 5.

Table 5. Purification efficiencies [%] after two months

COD	55.50
BOD_5	96.25
TSS	80
NH_4	73.33

The pools had to be covered with plastic sheets in mid October, and plants continued to develop and clean water, at a reduced pace, until mid November. During winter, the pools have been cleaned, and the plants needed for the next year have been kept in small pools in the flowers greenhouse owned by the University.

The tested method had some advantages, such as: cleaning water without classical energy consumption, covering of badly smelling pools by green plants, deposition of a reduced quantity of solid polluting substances at the bottom of the pools, and impossibility of a random ecological aggression as the used plants do not withstand the negative temperatures that occur in Romania during winter. The main drawback was that the method could not cover the whole year, corresponding to the two swine cycles.

Tropical plants can be used at 45° N for cleaning still waters without important investments since there is no danger of aggressive proliferation, due to the winter conditions. In 1988, an ecological cleaning of a 6000 m^2, 1 m deep pond at Sacalaz has been initiated. The pond had never been cleaned before, so it contained many kinds of suspensions, including home waste. A few plants of water cabbage and water hyacinth have been disseminated and their proliferation and the water cleaning have been observed. Although the summer has been hot, local plants, insects, and frogs have not been aggressed. Unfortunately, for external reasons, the experiment had to be stopped before the completion of a full cycle and before performing chemical analyses.

Conclusions

We have presented industrial applications of solar energy devised at the Physics Department of the "Politehnica" University of Timisoara, Romania. A pioneering one has been the hall for ceramic products drying at Jimbolia.

A research direction started in laboratory has ended in the application of solar energy to bitumen preheating for road construction within a plant in Sacalaz. This approach was considered as novel at that time.

Solar concentrators have been simulated, designed, and built.

A "solar house" has been built for an experimental study of home thermal applications of solar energy. The house accomplished successfully its role that consisted of demonstrating the viability of partially covering the energetic needs from solar sources and of providing an appropriate infrastructure for experiments. The house still exists and it is currently refurbished using present day's materials and equipped, in view of research, with state-of-the-art thermal installations, sensors and measuring instruments.

An ecological method for cleaning waste water from an industrial swine farm has been successfully experimented.

Nomenclature

A – surface area, [m^2]
B – irradiance, [Wm^{-2}]
BOD_5 – biochemical oxygen demand (5 days), [mg/l]
C – calorific capacity [MJK^{-1}]; concentration factor, [–]
COD – chemical oxygen demand, [mgl^{-1}]
h, H – height, [mm]
m, M – mass [kg]; flow rate, [kgh^{-1}]
p – distance between the directrix and the focus of the parabola, [mm]
P – power, [W]
Q – energy, [J]
r, R – radius, [mm]
s – tilt angle, [deg.]
U – thermal loss coefficient, [Wm^{-2}K^{-1}]
t – temperature, [°C]
TSS- – total suspended solids, [mgl^{-1}]

Greek symbols

γ – angle, [deg.]
η – efficiency
ρ – reflectance
θ – angle, [deg.]
$\tau\alpha$ – absorption – transmission product, [–]

Subscripts

a – ambient; air
ds – tank
F – focal band
h – solar trap
ld – accumulator
p – input aperture
r – heat exchange
R – reflector
w – water

Mathematical operator

$\langle\ \rangle$, $^{-}$ – average

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