RESEARCH IN SOLAR ENERGY AT THE "POLITEHNICA" UNIVERSITY OF TIMISOARA: STUDIES ON SOLAR RADIATION AND SOLAR COLLECTORS

by

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A short overview of a more than 30 years long history and results of research and thermal applications of solar energy at the "Politehnica" University of Timisoara, Romania, are presented. The main directions approached are: actinometry, studies on materials and greenhouse effect, thermal collectors, industrial and home thermal applications, computer simulation of physical phenomena, and concentrators. This paper focuses on the conception and building of a dedicated laboratory and on the experimental results that allowed the development of industrial and home applications.

Key words: *absorbance, actinometry, exergy, thermal collectors, passive wall, transmittance*

Introduction

A historical account of research in solar energy at the "Politehnica" University of Timisoara is motivated by its relatively long duration, the large quantity of work and enthusiasm involved, and mainly by its results.

The activities related to solar energy have been performed within the Department of Physics fig. 1 [1-4]. A drop of the interest in solar energy occurred after the historical events of 1989, but this attitude has been reconsidered after 2000. The activity is presently revigorated, and, following winning of public national grant competitions, important investments are being made.

Figure 1. The building were the Department of Physics was situated until 2007

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Research in solar energy has been approached back in 1976, motivated by the raise in the price of classical fuels and resources exhaustion, pollution and local meteorological and climate conditions. Access to international market was difficult or sometimes impossible in those days, so that many instruments and laboratory equipment had to be designed and built locally.

The objectives in this newly approached research area were: (1) construction of a database with meteorological and climate conditions in the western part of Romania, (2) theoretical and experimental research on capture, storage, and use of solar energy for warm water and warm air flow production in industrial applications, (3) drying of ceramic and wood products and bitumen, (4) radiation concentration, (5) obtaining and use of biomass, and (6) simulation of physical phenomena involved in the thermal conversion of solar energy. The experimental work has been finalized with industrial and home thermal applications.

Research laboratory in natural conditions

A research laboratory has been equipped and placed outdoors on a south oriented terrace in the courtyard of the building (fig. 2). This newly created laboratory was used by the team for performing several activities, as outlined below.

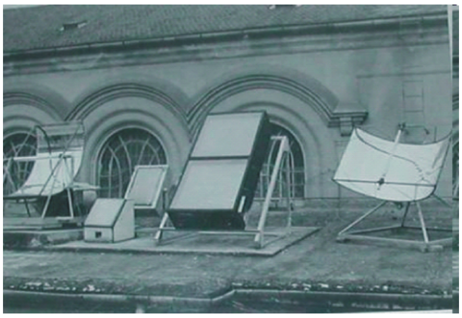

Figure 2. Terrace with the solar laboratory

Actinometry

For measurements of solar radiation intensity, two measuring devices have been designed and realized.

Solaris 1 is a compensation wattmeter intended for individual solar energy users [5]. The sensor of the device consists of two thermally conductive plates, painted in black. One of the plates is active, while the other is the reference. The solar radiation falls on and heats the active plate until thermal equilibrium is reached, while the reference plate is protected from the radiation by a silver plated mirror. An electronic circuit heats the reference plate until it reaches the temperature of the active plate and measures the electrical energy consumed for this purpose. The radiation intensity is then calculated from this energy, the time needed for warming up the reference plate and the area of the capture surface. The sensor mount is represented in fig. 3. The sensor orientation can be made identical to the orientation of the solar collector whose efficiency is studied.

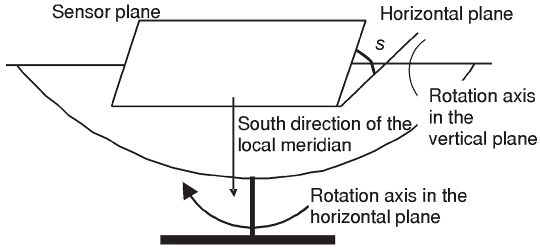

Figure 3. Mount of *Solaris* 1

Solaris 1 has been compared to a calibrated albedometer from the local meteorological station. Results are presented in fig. 4. Processing of experimental data led to the following standard function for *Solaris* 1 [5]:

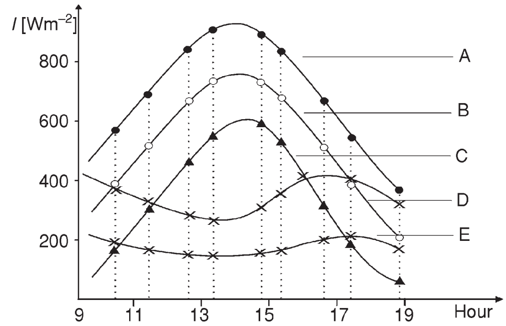

Figure 4. Comparison between *Solaris* 1 and an albedometer
Radiation intensity vs. hour: global radiation measured with the albedometer (A) and Solaris 1 (B), direct radiation (C), diffuse radiation measured with the albedometer (D), and Solaris 1 (E)

$$G = aG_{Solaris} + b \tag{1}$$

where $G_{Solaris}$ is the global radiation flux density measured by *Solaris* 1, G – the true value of the radiation flux density, and a and b are the constants to be determined by calibration for the geographical place where measurements are performed.

Solaris 2 is a pyranometer that measures the intensity of the global radiation in the horizontal plane (fig. 5) [6-10]. The radiation sensor (A in fig. 5) comprises 8 copper circular sectors, of 0.1 mm thickness, painted alternately in white and black that constitute cold and warm contacts of thermocouples mounted on their back sides and connected in series. The sensor is covered with a dome made of soda-lime glass for windows, having a refraction index of 1.6, and a transmittance of 94% in the domain 0.4-1.1 μm. This type of glass has been specially designed and fabricated for this application within a chemical plant from the region. An electronic unit controls thermally the device against environmental temperature variations, amplifies the signal provided by the thermocouples and displays the result of measurements. The intensity of the output current is:

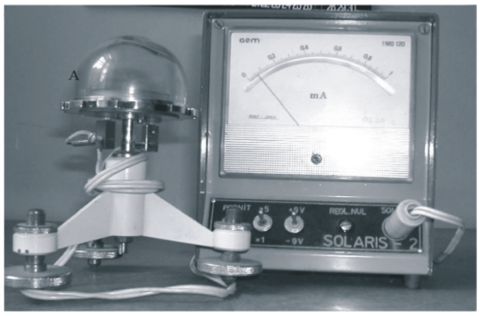

Figure 5. The pyranometer *Solaris* 2

$$i \quad G \quad \frac{\alpha_1}{\lambda_1} \quad \frac{\alpha_2}{\lambda_2} \quad C \tag{2}$$

where: $\alpha_{1,2}$ are the absorption coefficients and $\lambda_{1,2}$ – the heat transfer coefficients.

A calibration curve has been obtained by using comparative measurements with a reference pyranometer from the National Meteorology and Hydrology Institute of Bucharest, taken at a frequency of 1 per minute, fig. 6. The results, expressed in W/m^2, reveal a remarkable linearity, at a slope of 45 deg.

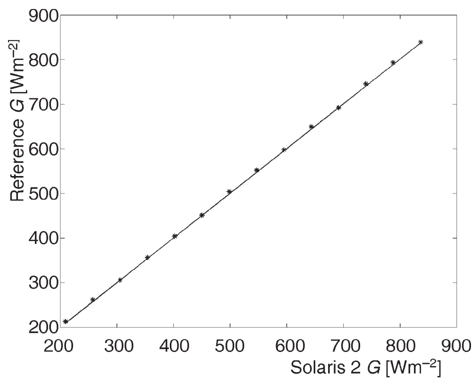

Figure 6. Calibration curve for *Solaris* 2

By using devices such those described above, measurements on solar radiation have been performed for several years in Timisoara, (45°46' N, 21°25' E). Averaged results are presented in tab. 1, where G_i is the hourly average for the mean day of the month, and G is the monthly average [11].

It is reasonable to connect thermal solar installations when the intensity of the solar radiation is larger than the threshold of 300 W/m^2. Table 1 shows that thermal solar installations are efficient in the period April – September for the place where measurements have been performed. Furthermore, it can be concluded from tab. 1 that the thermal solar potential of Romania is similar to other countries from the European Union, where solar applications are developed.

Table 1. Solar radiation in Timisoara G_i and G

Hour / Month	G_i [Wm^{-2}]								G [Wm^{-2}]
	9	10	11	12	13	14	15	16	
Jan.	73	102	154	188	190	174	104	36	128
Feb.	106	169	247	291	282	210	165	84	194
Mar.	190	286	336	384	380	345	293	214	304
Apr.	330	374	508	512	470	412	352	280	405
May	480	580	610	615	605	590	512	384	547
June	590	704	745	807	810	720	629	431	680
July	475	681	771	801	778	693	602	504	663
Aug.	416	612	691	704	701	646	538	426	592
Sept.	312	414	478	538	543	476	413	279	433
Oct.	183	276	334	364	367	315	273	127	280
Nov.	97	163	231	261	252	182	116	44	168
Dec.	46	94	137	158	146	107	82	14	998
Annual average [Wm^{-2}]									374

The diffuse radiation is converted into heat when incident on a solar collector. In cloudy (overcast) days, the flux density of diffuse radiation can reach 418 W/m^2, rendering functional the thermal collectors. A measuring device for diffuse radiation, sketched in fig. 7, has been designed constructed at the Department of physics and calibrated against a similar instrument from the National Meteorology and Hydrology Institute of Bucharest [12]. The represented elements are: (1) and (2) – the thermal collectors, (3) – the magnetic needle for indication of the south direction, (4) – the alidade providing the complement of the angle between the panels and the vertical, (5) – the rod, (6) – the device for modifying the angles between the panels and the vertical, (7) – the device for rotating the system with respect to the horizontal plane, (8) – the goniometer for reading the rotation angle in the horizontal plane, (9) – the mechanical mount, (10) – the lead thread, (11) – the lens for positioning one of the panels towards the Sun, and (12) – the black plate where the image of the Sun is observed. The thermal collectors contain a brass plate each, with dimensions of 13.5 and 7 cm and a mass m = 235 g.

The contribution of the diffuse radiation to the heat collected by a solar collector is relatively low (7.4%), but it becomes significant when the collecting surfaces are large [13]. The above presented instruments are cheaper than standard, commercial ones, of comparable accuracy when calibrated and may be constructed locally by solar energy users.

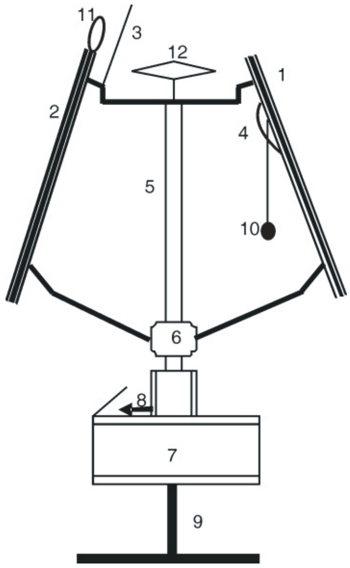

Figure 7. Mount with two thermal collectors

(1, 2) – thermal collectors, (3) – magnetic needle, (4) – alidade, (5) – rod, (6) – device for modifying the angles, (7) – device for rotating the system, (8) – goniometer, (9) – mechanical mount, (10) – lead thread, (11) – lens, (12) – block plate

Studies on materials

Experimental work has been performed for measuring physical properties of materials relevant for various solar energy applications. Then, the results were used in the design of installations and solar energy applications setups [13].

For example, results of experimental studies on the transmittances of various materials in the range of wavelengths of 0.65-1.10 m are synthetized in the spectrograms of fig. 8. It can be seen that glass windows with thicknesses in the domain of 2-5 mm have transmittances greater than 70%, and a red plastic has the largest transmittance [13]. The transmittance of the glass used for the dome of *Solaris* 2 was measured to 94% in a domain of wavelengths between 0.4 and 1.1 μm [14].

A polyester sheet coated with a thin aluminum plate was found to have a maximum transmittance of 25% around the wavelength of 0.5 μm. The transmission maximum of a glass window plated with such a sheet is situated in the blue region of the spectrum, so that the transmitted light creates a pleasant sensation, as red and orange radiations contents are poor [15-17]. This material has been used in climatization applications.

In an attempt to devise cheap solar collectors, the capability of heat capture in water has been tested in two circumstances: (a) by using a recipient covered with a 3 mm thick glass plate exposed to solar radiation, and (b) by using the same setup with an additional thin oil sheet on the surface of the water. It has been found that 63% of the incident energy has been captured in the second situation, with an optimum oil sheet thickness of 1 mm, as compared to 54% in the first situation (water only) [18, 19].

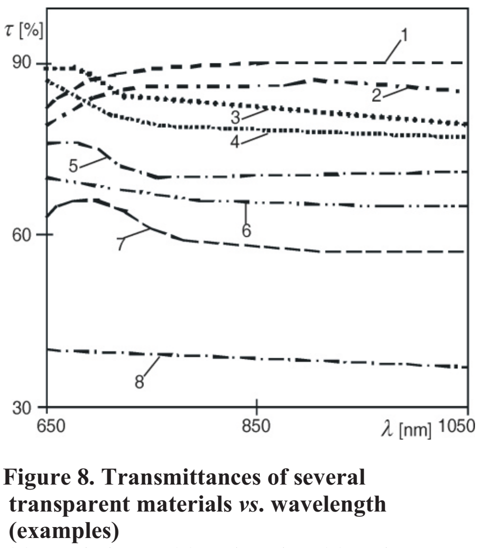

Figure 8. Transmittances of several transparent materials *vs.* wavelength (examples)

(1) – red plastic, (2) – plexiglas, (3) – glass-2 mm (4) – glass-3 mm, (5) glass-5 mm, (6) – patterned glass-3 mm, (7) – ornament 2, (8) – ornament 1

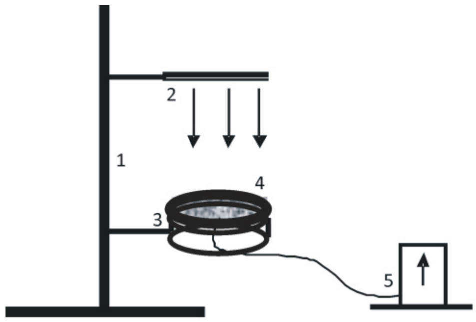

Figure 9. Setup with irradiated iron plates
(1) – support, (2) – radiation source, (3) – circular support, (4) – iron plate, (5) – thermometer

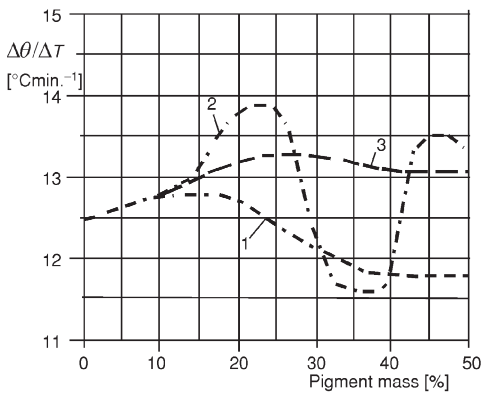

Figure 10. The slope at the origin of the heating curves
(1) – pigment X, (2) – pigment Y, (3) – pigment Z

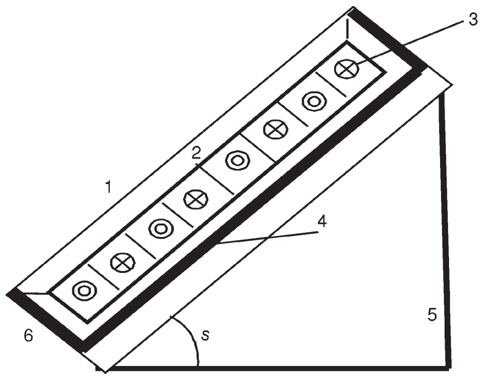

Figure 11. Flat-plate solar collector
(1) –transparent plate, (2) – absorber, (3) – pipe for air flow, (4) – insulating flame, (5) – support, (6) – mount wall

The liquids that contain black pigments with an optimal concentration of 0.08% produce greenhouse effect, and the slope of the heating curve at the origin is of 0.37 °C/min. for a width of 2 cm of the layer of water with black ink [20].

The composition of a material with superior absorbing properties has been established using the experimental setup presented in fig. 9 [21]. The iron plates had a thickness of 0.5 mm, and the irradiated surface was of 25 cm^2.

The optimal composition of the irradiated material has been established by raising the heating curves of the iron plates covered with paints of various compositions.

The compositions have been varied by mixing an absorbing, supporting material, whose mass is denoted by V, with pigments. The slopes at the origin of the heating curves *vs*. the pigment masses are represented in fig. 10 for three pigments; we denote by X, Y, and Z [%] the ratios between the pigment masses and V (curves 1, 2, and 3). Figure 10 reveals that the fittest materials are $Y = 20\%$ and $Z = 20\%$. The slope is large also for $Y = 50\%$ and $Y = 60\%$, but these high proportions of pigments raise economical problems and technological ones, as uniform spraying of the absorbing surface becomes difficult.

Thermal collectors

Flat-plate solar collector

A solar collector was built, whose structure is presented in fig. 11 [22-29]. The angle between the normal to the collector surface and the vertical is denoted as usual by s. The absorbing plate plays also the role of wall for the air flow pipe. Two neighbour corridors share a common wall, so the transport factor is unity $F_t = 1$. The air flow rate takes values in the interval of 25-135 m^3/h. The collecting surface is $A = 3.8$ m^2 and the length of the pipe is $L_{cd} = 15.2$ m. The air enters and leaves through square shaped holes, of side $a = 0.25$ m so that $A = a\,L_{cd}$. The air is circulated by a low power fan.

The hourly variation of the average efficiency, measured at Timisoara, is presented in fig. 12, for s = 45 deg. The air flow rates are: 135, 108, 81, and 54 m^3/h. The solar radiation data presented in tab. 1 allow for the estimation of the energy produced by a collector with a given surface. The results presented in fig. 12 reveal that high efficiencies are obtained around noon, when the angle of incidence is small, and the absorbance-transmittance product is high. The increase of the angle of incidence determines a lower absorbance-transmittance product during the rest of the day, so that the efficiency diminishes. The curves are not symmetric around noon, the magnitude of the slope in the afternoon being smaller than the corresponding value before noon, as the fluid is heated by the metallic pipe in the afternoon. At high air flow rates (135 m^3/h) the efficiency approaches 40%.

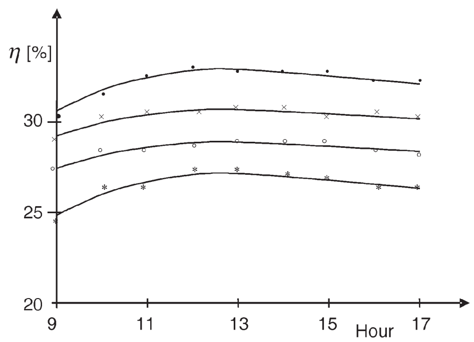

Figure 12. Mean efficiency *vs.* hour

These results in the simplicity of the construction recommend the air flow collector for home and industrial drying applications. A capacity of 800 W may be obtained at a price of about 1200 EURO.

Passive wall

The passive (Trombe) wall is used for accumulation and storage of solar produced heat, for short periods of time, in order to climatize adjacent rooms [30-37].

A passive wall was built, having an area of 8.8 m^2, and it has been installed on the southern wall of a building having a classic heating system. During experiments, the room adjacent to the passive wall has been disconnected from the heating system. The construction of the passive wall is presented in fig. 13. The wall is heated by greenhouse effect, which determines the heating of the air and the variation of its density. The warm air penetrates the room via the upper hole, cools down heating the air in the room, and then enters the solar trap through the lower hole, where it is heated again.

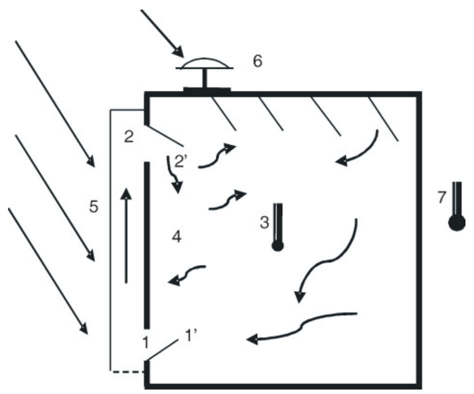

Figure 13. Passive wall
(1, 2) – admission holes, (1', 2') – flaps, (3, 7) – thermometers, (4) – wall, (5) – transparent plate, (6) – solarimeter

The following physical quantities have been measured: flux density of solar radiation, air temperature inside and outside, and temperatures of the walls at their centers. Some of the results are presented in fig. 14. The passive wall must be thermally insulated at night; otherwise important heat losses occur.

The power to the presented wall is:

$$\dot{Q} = 237.9\left(1 - \frac{546}{546 + t_1 + t_2}\right)(t_1 - t_2) \tag{3}$$

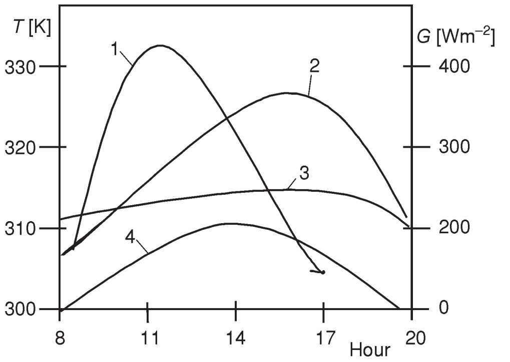

Figure 14. Solar radiation and temperatures of the elements of the passive wall
(1) – solar radiation, (2) – temperature at the upper hole, (3) – temperature at the lower hole, (4) – ambient temperature

where t_1, t_2, and t_3 are the temperatures at points 1, 2, and 3, respectively, in fig. 13.

Measurements have been performed during daylight and 3-4 hours after sunset and revealed that the power varied between 82 W and 260 W. The average energy the wall provided to the room in the period October-November was Q_u = = 6.4 MJ per day. The power incident on the glass plate varied between 2000 W in the morning and 4800 W at noon. The average energy incident on the plate was Q_i = 91 MJ per day. The average daily efficiency of use of solar energy resulted:

$$\langle \eta_{day} \rangle = \frac{Q_u}{Q_i}, \quad \langle \eta_{day} \rangle = 10.4\% \tag{4}$$

Computer simulation of physical phenomena involved in the thermal conversion of solar energy

The energy efficiency of a solar collector varies monotonically with the flow rate of the working agent and with the collecting surface and it does not have extremum points that would allow the definition of optimal working conditions.

The exergy efficiency varies with the flow rate and collecting area in such a way that local extremum points and a global extremum point are present. These extremum points allow to define optimal working conditions of the collector with respect to flow rate and collecting area [38-42].

Determination of optimal regime for a solar collector in open circuit

It has been shown in [41, 42] that the exergy efficiency of a solar collector using water as working fluid, in open circuit is given by:

$$\eta_{ex} = \frac{\dot{m}C_P}{A_C}\frac{\tau\alpha}{U}\left[1 - \exp\left(-\frac{UF'A_C}{\dot{m}C_P}\right)\right] - \frac{\dot{m}C_P T_a}{A_C G_C}\ln\left\{1 + \frac{\tau\alpha G_C}{UT_a}\left[1 - \exp\left(-\frac{UF'A_C}{\dot{m}C_P}\right)\right]\right\} \tag{5}$$

where the following symbols are used: η_{ex} – exergy efficiency, A_C – solar radiation collecting area, C_p – isobar specific heat of the circulating agent, G_C – solar radiation, $\tau\alpha$ – absorption-transmission equivalent product, U – coefficient of thermal losses; F' – efficiency factor, T_a – ambient temperature, and $\dot{m}$ – mass flow rate of the working fluid.

The calculated exergy efficiency in function of the collecting surface area and the flow rate, obtained by means of a specially written computer program, is presented in fig. 15.

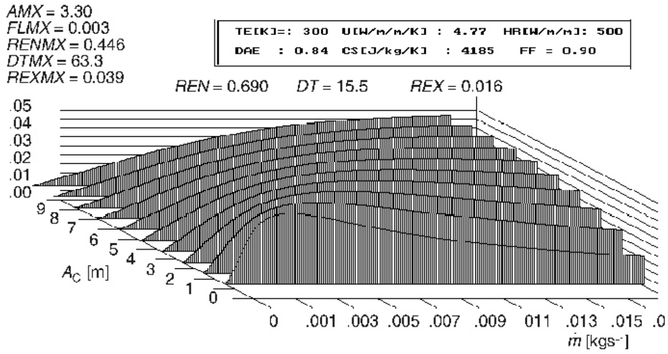

Figure 15. The exergy efficiency $\eta_{ex} = f(A_C, \dot{m})$

Three kinds of quantities appear in fig. 15: keyboard input quantities, those corresponding to the current position of the cursor and co-ordinates of the global maximum of the exergy efficiency.

Input (keyboard) quantities are: *TE* = 300 K (ambient temperature), *U* = 4.77 W/m^{2}K (thermal losses coefficient), *HR* = 500 W/m^2 (solar irradiance), *CS* = 4185 J/kg/K (specific heat of the working agent), and *FF* = 0.90 (collector's efficiency factor). Calculated quantities, corresponding to the current position of the cursor are: *REN* = 0.690 (energy efficiency), *DT* = 15.5 (temperature rise), *REX* = 0.016 (exergetic efficiency), *AREA* = 1.30 m^2 (area of the collecting surface), *FLOW* = 0.0076 kg/s (mass flow of the working agent). The coordinates of the global maximum (typical values for Romania) are: *AMX* = 3.30 (surface of the collecting area), *FLMX* = 0.003 (mass flow of the working agent), *RENMX* = 0.446 (energy efficiency), *DTMX* = 63.3 (temperature rise), and *REXMX* = 0.039 (exergetic efficiency).

Solar radiation

Several computer programs running on personal computers of the eighties have been written and used for the dissemination of information on solar radiation [43-47] and for educational purposes, using commercial software such as Turbo Pascal. Geographical position, season and time of the day were input data, and solar quantities such as irradiance were calculated and plotted by means of the graphical tools provided by the packages, using simple models [48-50].

Conclusions

Research in solar energy at the "Politehnica" University of Timisoara started in 1976, motivated by the raise of the price of classical fuels, resource exhaustion and pollution. Initially, it has been performed within the Department of Physics. Cooperation with other departments of the university followed.

Besides standard Physics laboratories, an outdoors research laboratory has been created and equipped. Many instruments had to be designed and constructed ("home made"), as access to international market was difficult or sometimes impossible.

In the field of actinometry, design, construction and calibration of a compensation wattmeter and a pyranometer allowed for extended solar radiation measurements.

Experimental setups for measurement of transmittance and absorbance of materials have been devised; results of experiments have been used in greenhouse effect and climatization applications.

Several types of thermal collectors have been studied, such as flat-plate solar collectors and Trombe walls.

Computer simulation of physical phenomena was applied to solar radiation prediction for educational and engineering design purposes and to finding the optimal regime of solar collectors in open circuit.

The experience gained and data gathered in laboratory work proved to be fruitful for the development of home and industrial applications, such as a pioneering functional application in Romania – an industrial hall for drying ceramic products and the first functional, solar energy based industrial installation for bitumen melting, which has been considered an international novelty in the roads and highways building industry in the eighties. An overview of these applications is the subject of another work.

After the drop in interest and financing occurred in 1990, the activity has been resumed. The research in solar energy (and in renewable energies in general) is now coordinated at the University level. An important national grant in solar energy has been won in 2006. The funding was intended for the creation of five new laboratories, renovation of older assets, creation of a new master direction in solar energy education, research, and international cooperation *etc*. This year, based on the research tradition in solar energy and other renewable energies applications, such as in windmills and microhydro plants [51], funding has been attracted for building a new Research institute in renewable energies, which will function within the structure of the University.

Nomenclature

A – surface area, [m^2]
a – length, [m]
a – constant for the geographical place, [–]
b – constant for the geographical place, [Wm^{-2}]
C – specific heat, [$Jkg^{-1}K^{-1}$]
C – device constant, [AK^{-1}]
F – transport factor, [–]
F' – efficiency factor, [–]
G – solar radiation, [Wm^{-2}]
i – intensity of the current, [A]
L – lenght, [m]
$\dot{m}$ – mass flow rate, [kgs^{-1}]
Q – heat quantity, [J]
$\dot{Q}$ – power, [W]
T – temperature [K]
t – temperature, [°C]
U – coefficient of thermal losses, [$Wm^{-2}K^{-1}$]
X, Y, Z – pigment mass in $V = 1$, [m^3]

Greek letters

α – absorption coefficients, [–]
η – efficiency, [–]
λ – thermal transfer coefficients, [$Wm^{-2}K^{-1}$]
τa – absorption-transmission equivalent product, [–]

Subscripts

a – ambient
C – collector
ex – exergy
i – incident
p – isobar
t – transport
u – useful

Mathematical operator

– average

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