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Solar Air Collectors for Space Heating and Ventilation Applications – Performance and Case Studies in Romania Climatic Conditions

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Abstract: Solar air collectors have various applications: on one side, they can be used for air heating in cold seasons; on the other side they can be used in summer to evacuate the warm and polluted air from residential, offices, industrial and commercial buildings. The paper presents experimental results of a solar collector air, in climatic conditions from South Eastern Europe. The relationships between the direct solar irradiation, the heat flow resulted, the air velocity at the outlet, the air flow rate, the time of input in nominal regime of the collector and efficiency of conversion of solar energy into thermal energy are highlighted. Thus, it was shown that after maximum 50 minutes, solar air collectors, with baffles and double pass of air can reach 50 % efficiency for solar irradiation of 900-1000 W/m^2. The article also presents a mathematical model and the results of a computational program that allows sizing solar collectors for the transfer of the air, for their purpose to improve the natural ventilation of buildings. The article is completed with a case study, sizing the area to be covered with solar collectors to ensure ventilation of a house with two floors or for an office building. Also, the *ACH* coefficient was calculated and compared.

Keywords: solar air collector; performances; space heating; cooling; case studies.

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1. Introduction

In the context that solar energy is the cheapest source of renewable energy and it is used in very small proportion (only 2%), research of the specialists must focus on improving the operating efficiency of solar heat collector and extending their domains of applications.

This paper analyses the conversion efficiency of a solar air collector, whose performances depend on the collector's materials [1-2] and the technology used in manufacturing of the collector (form of flow channels with baffles, roughness, turbulence induced of air movement) [3-6]. The solar collector performance depends on operating parameters, the global solar irradiance, air flow velocity and air flow rate discharged through the solar collector. The improvement in energy performances of solar heat collectors is important both for their usage in space heating, also in natural ventilation systems integrated in building technology of passive houses [7-8]. Thus, there are two technologies to mount a solar air collector: in closed loop system, when the air is circulated from the house to the collector and back to the house - for heating; in open loop system, when the air is taken from the outside, flows through the panel, is circulated into the building and comes back to the outside- for ventilation, to improve indoor air quality [9].

In this regard, the article shows on one hand the performance of the solar air collector used in the climatic conditions of Romania (Bucharest) during the cold season to establish the performances in the heating process, on the other hand, during the warm season to establish the efficiency in improving the ventilation process.

In experimental analyze, the heat flow - the heat provided by solar collector SH 1500G and performances variation with solar radiation depending on time were followed. Thus, conclusions about the optimal working point of this solar collector were shown, both in heating process, also in cooling process. Experimental researches demonstrated that an efficiency of about 50% can be achieved for radiation of 900-1000 W/m^2. Optimum operating regime is reached after about 50-55 minutes. It was determined the relationship between air velocity at the outlet of the solar collector, the incident radiation and air temperature variation between entering and leaving the collector. As the temperature difference is greater, the conversion efficiency is greater, as shown also in [10-11].

The article presents a computational model for living space ventilation with solar panels in order to determine the surface to be covered with solar air collectors, in different assumptions of solar radiation, correlated with air velocity in panel and temperature variation supposed to be achieved. This model was applied in two case studies: for a house with about 200 m^3 living space and for an office building with about 1000 m^3 ambient space. Numerical application can easily be used for sizing solar panels for ventilation residential, commercial or industrial area.

2. Experimental research

2.1. Characteristics of the solar air collector

In experimental research it was used a commercial solar collector SH 1500G, glazed, to reduce the losses by radiation and convection, insulated to avoid heat dissipation. This type of collector is double pass with baffles to create flow turbulence and to increase the absorber surface, technology used also in [12-13]. The casing and the absorber material are in extruded aluminium. The collector has at the upper side a photovoltaic panel of 14 W to deliver energy for the small axial fan with variable speed, placed on the back upper side, to hasten the warm air to exit. The air collector's surface is 1,9 m^2 and 0,5 m^2 for photovoltaic panel. The air enters at the bottom of the panel and exits to the upper side by ducts with diameter of 127 mm. The unit is controlled by a thermostat.

The operation of a solar collector can be done with optimal control of parameters, in order to maximize the energy and ensure thermal comfort by stopping the system to avoid overheating.

2.2. Test setup

Romania's geographical location, taking as reference Bucharest town, located at $44^0$25 'North latitude and $25^0$6' East longitude were taken into account in establishing the incident solar global radiation, at an angle of 50^0 for the winter months and 35^0 for the summer months. Firstly, a own application was used to set I_g based on time and atmospheric temperature, T_a. Temperature and radiation are variable in time and they were obtained from measured values every 10 minutes, for January and July. Values are pictured in Figures 1a and 2a, and they were compared with the values determined by application JRC PVGIS [21], like in Figures 1b si 2b. I_g' and T'_a values are interpolated values with sixth degree polynomials.

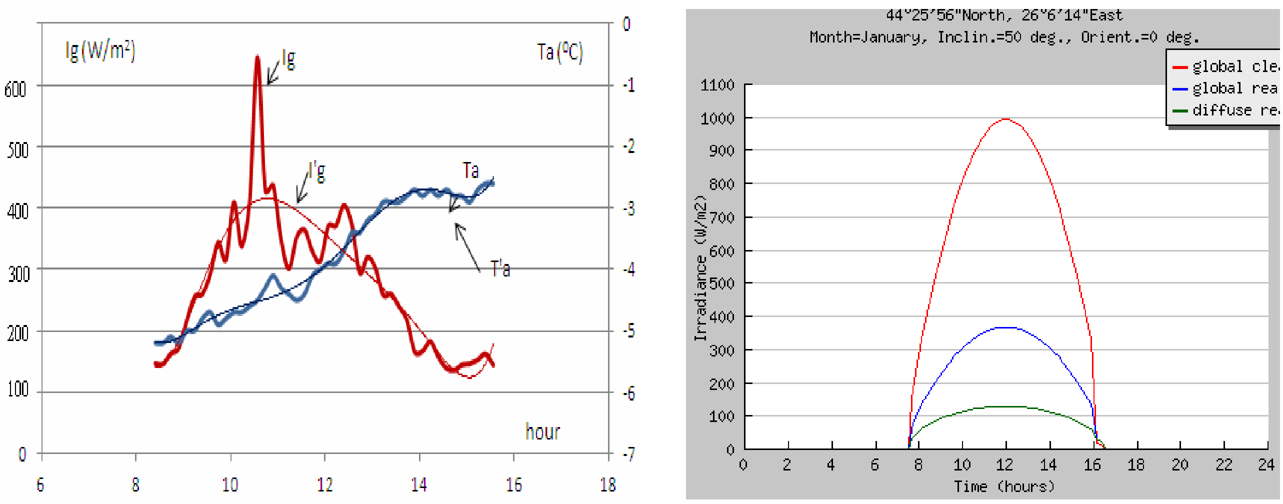
The solar collector SH 1500G, see Figure 3a, was tested in Polytechnic University, in the outside courtyard of the Hydraulic Laboratory. The experimental stand has the possibility to modify the inclination angle of the panel, taking account of the chart from Figure 3b.

We measured the ambient temperature - inlet air temperature, the outlet temperature, the solar radiation, outlet air velocity and the intervals of time.

Figure 1. Global solar irradiance on a tilted plane for a clean sky day from January 2009

(a) Own application, T' and I'g are interpolated values with sixth degree polynomials.

(b) JRC PVGIS application

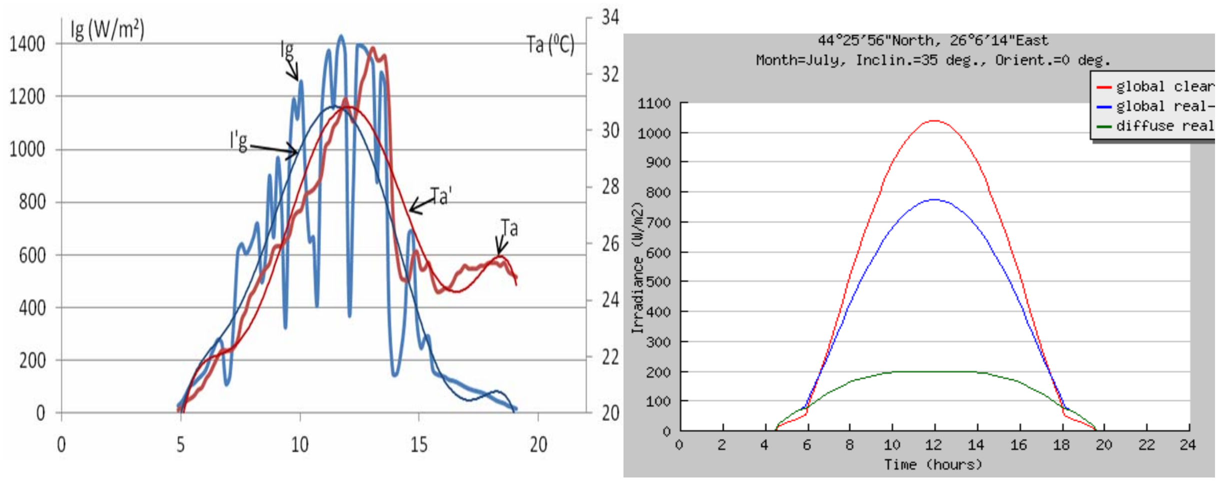


(a) (b)

Figure 2. Global solar irradiance on a tilted plane for a parly cloudy sky day from July, 2009

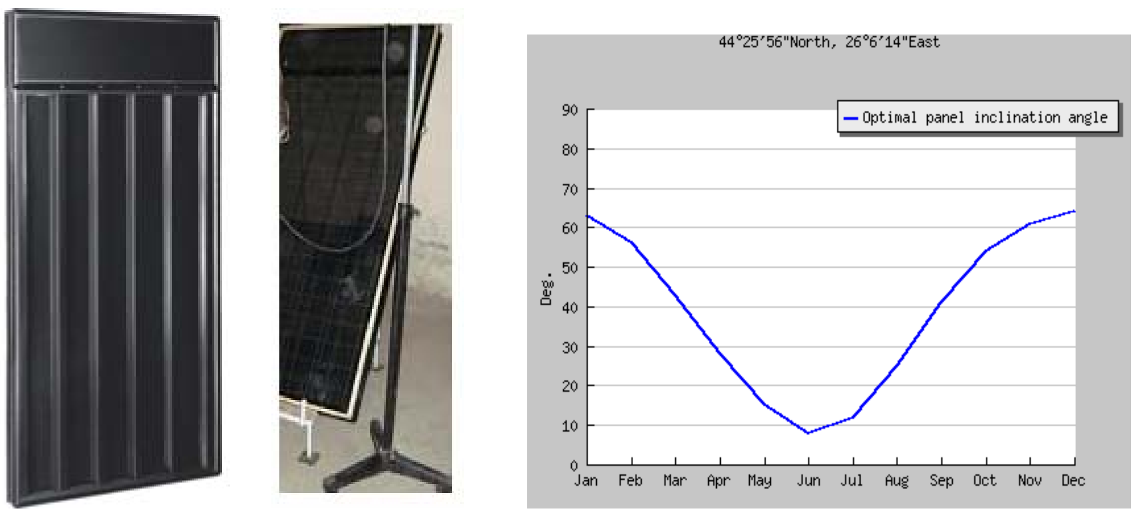
a) Own application, T' and I'g are interpolated values with sixth degree polynomials.

b) JRC PVGIS application



(a) (b)

Figure 3. a) solar collector SH1500 and system to modify the angle of inclination b) Optimal inclination angle for Bucharest [21]



(a) (b)

The solar radiation was measured with a portable pyranometer PL 110SM, with accuracy ±10 W/m^2, the temperature was measured with a laser thermometer Fluke 576 (accuracy ±0,5^{0}C) and the air speed leaving the collector was measured with an anemometer (accuracy ±3%).

2.3. Mathematical modelling

In order to estimate the heat flux delivered by the solar air collector was applied following formula:

$$\left[Q = c_p \cdot m \cdot \Delta T = c_p \cdot m \cdot (T_{fout} - T_{fin})\right] \quad (1)$$

C_p is the specific heat of air at constant pressure: $c_p = 1{,}008 \frac{kJ}{kgK}$

In equation (1) m is the mass flow rate in *(kg/s),* given by equation (2):

$$m = \rho \cdot \dot{V} = \rho \cdot \frac{\pi \cdot d^2}{4} \cdot v \qquad (2)$$

$\dot{V}$ is the volume of the air leaving the collector by the duct with diameter d, v is the air speed in *(m/s)* and ρ is the density of air in *(kg/m^3^)*.

ΔT is the difference of temperature between collector outlet and inlet.

The efficiency of the solar collector was calculated with the following formula:

$$\eta = \frac{Q}{I_{av} \cdot A_c} \qquad (3)$$

I_{av} is the average of intensity of solar radiations, measured with the pyranometer *(W/m²)*.

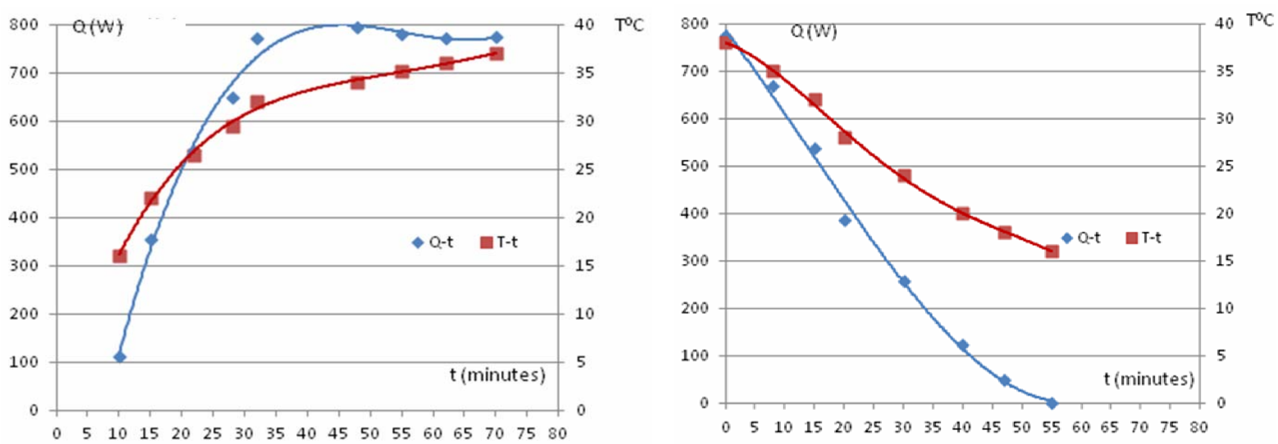
A_c is the area of the solar air collector *(m²)*.

After measuring the ambient temperature that is equal with inlet air temperature, the outlet temperatures, solar radiation, outlet air velocity and timing the intervals, the heating characteristic of the collector, the air flow rate, the heat flux and finally the conversion efficiency of solar energy in thermal energy were calculated. For cooling process the steps were the same.

2.4. Results and analysis

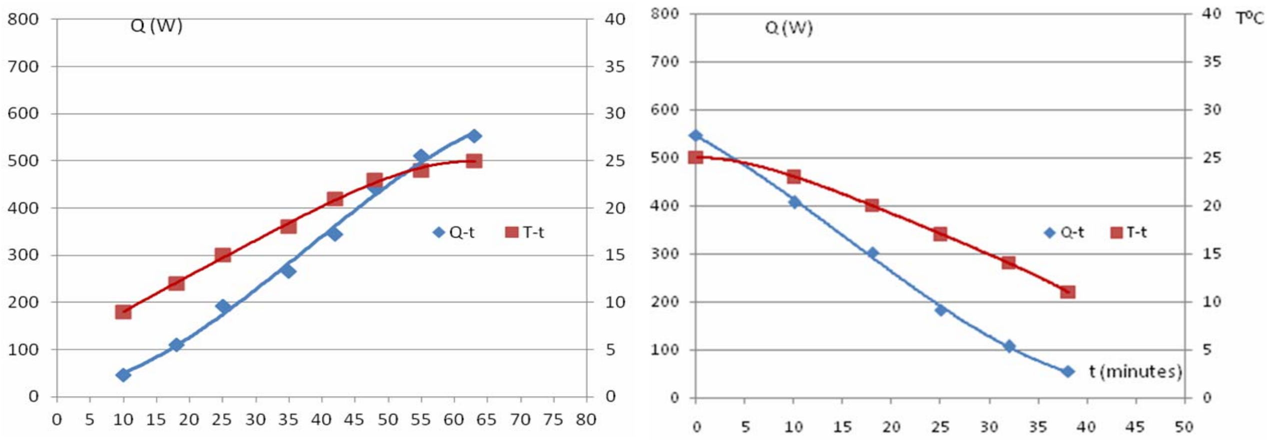
The results were centralized in Figure 4 and 5: heat fluxes and outlet temperatures in heating process (a) and in cooling process (b) in July and the same features in a day in January Figure 5 a) and b). Also, relationships were established between the solar global irradiation, the variation of temperatures and outlet air velocity, as in Figure 6.

Figure 4. Heat fluxes and air outlet temperatures variation in times, in July
a) heating process b) cooling process



In the heating process, a stable functioning was found, representing the optimal operating point of the solar air collector after about 50 minutes in summer and after about 70 minutes in winter. In terms of cooling, it was done in longer time in summer and in shorter time in winter.

Figure 5. Heat fluxes and air outlet temperatures variation in times, in a sunny day in January
a) heating process b) cooling process



Increasing of the speed of warm air to the exit from the collector simultaneously with increasing of the difference of air's temperature and with density variation are due to the solar radiation and are illustrated in Figure 6.

Figure 6. Solar global irradiance and variation of temperature with the air velocity

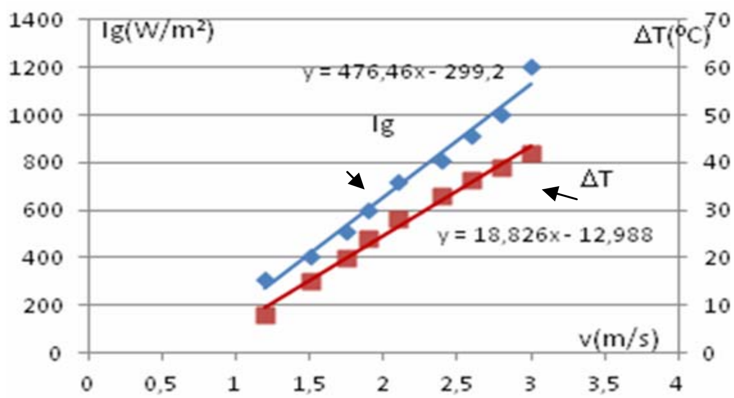
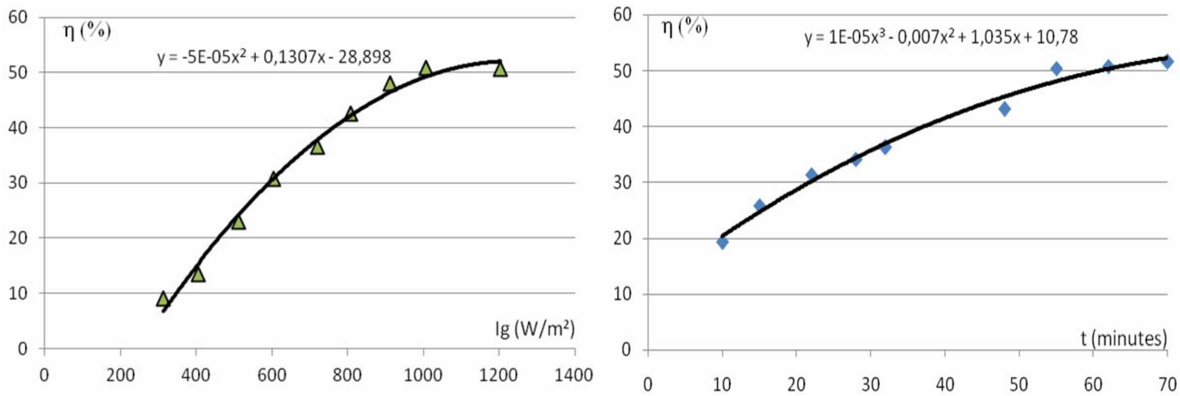


Figure7. Efficiency of solar air collector versus solar radiation *Ig* (W/m^2) and time *t* (minutes)



Similar results regarding the efficiency were found by Ian Morson [10]. The results are better than those presented by K. Visagavel [14] with 10-12% due to the type of collector used in these experiments – double pass with baffles in galvanized aluminium. In K.Visagavel experiments [14] a galvanized iron and single pass collector with maximal efficiency of about 38% was used. In our experiments the collector eficiency is about 50% in optimal operating point.

3. Applications of solar collectors in ventilation of spaces

Studies regarding the building ventilation have important experimental components, both by combined chimney effect also using solar air collectors [15-20].

3.1 Computation models for natural ventilation

In summer, to evacuate the warm and polluted air from the industrial or residential buildings, three computational models can be used to calculate natural ventilation: first taking into account the internal thermal pressure, second with the influence of external air currents and third taking account of the heat transfer inside of solar collectors located on the roof of the building.

Using the solar air collectors is an efficient solution to induce supplementary natural ventilation. In this case the mathematical model estimates the airflow rate through the solar inclined collector with a heat-absorbed material.

The main parameters are: the absorbed material and the glass surface temperature, the inlet and outlet air temperatures, the environment temperature, the flow rate, the collector's surface and openings surfaces.

The mathematical model consist in thermal balance equations at the passing of the solar radiation through the glass cover, heat transfer for the air between the glass cover and the absorbed material and for the absorbed material, in following assumptions: laminar flow in the air channel; one dimensional processes; the air inlet temperature is equal with the environment temperature; heat losses are neglected.

The mass flow rate of air for the natural ventilation can be obtained from equation (1):

$$[\ m = \frac{Q}{c_p (t_{fout} - t_{fin})}\ ] \tag{5}$$

To calculate the dimensions of the flat solar collector the equation (8) can be used, where the solar collector efficiency and air velocities values are known from experiments presented in paragraph 2.2; then the geometric values are introduced in relation (7) where the new mass airflow rate value and velocity are calculated. A new iteration is performed and the final dimensions of the collector are obtained.

The equation for the energetic balance is:

$$[Q = \eta \cdot I_g \cdot A_c] \tag{6}$$

with:

$$[Q = A_o \cdot v \cdot \rho \cdot (t_{fout} - t_{fin}) \cdot c_p] \tag{7}$$

A_o is area of inlet section (m^2).

From the equations (6) and (7) the surface of the solar air collector results:

$$[A_c = \frac{A_o \cdot v \cdot \rho \cdot (t_{fout} - t_{fin}) \cdot c_p}{\eta \cdot I_g} = l \cdot L] \tag{8}$$

η - is the efficiency of the solar collector, according with paragraph *2.2*
I_g – the solar global irradiation (W/m^2),
A_c – surface of the collectors (m^2),
v – the air velocity (m/s), according to I_g, as can see in Figure 6 .

3.2 Case studies

As it can be seen in previous paragraph, for different global solar radiations I_g, air velocities v and efficiency values are different. For a family residence of about 200 m^3 ambient space, the surface of the solar air collector results as in table 1.

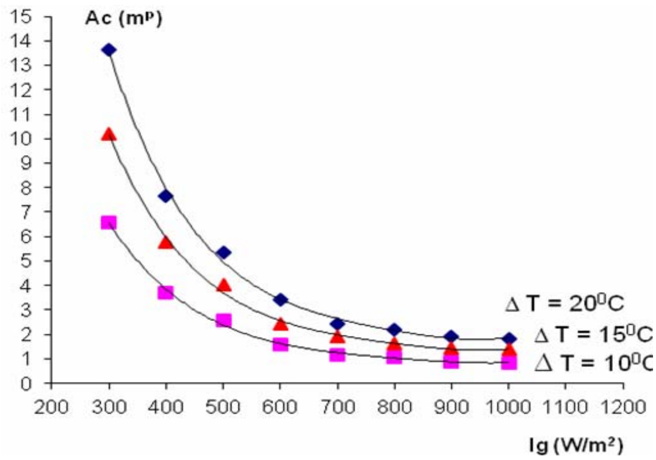
Table 1 Area of solar air collector for three gradient of temperature, for a family house

I_g (W/m^2)	v (m/s)	η (-)	ΔT (°C)	A_c (m^2)	ΔT (°C)	A_c (m^2)	ΔT (°C)	A_c (m^2)
300	1,2	0,09	10	6.59	15	10.22	20	13.62
400	1,5	0,15	10	3.7	15	5.75	20	7.66
500	1,75	0,2	10	2.59	15	4.02	20	5.36
600	1,85	0,28	10	1.56	15	2.43	20	3.41
700	2	0,36	10	1.18	15	1.93	20	2.43
800	2,4	0,42	10	1.06	15	1.64	20	2.19
900	2,6	0,46	10	0.89	15	1.44	20	1.93
1000	3	0,5	10	0.83	15	1.38	20	1.84

Application of optimization strategies in solar operation involves the limitation of the exhaust air velocity at about 2.5 m / s. Limitation is imposed by the axial fan that works with photovoltaic energy. The graph in Figure 8 shows the variation of useful area for solar collectors used in improving the ventilation of the building, depending on solar radiation. It was considered the temperature variation $\Delta T = (t_{fout}-t_{fin})$ in three cases: 10°C, 15°C and 20°C.

The numerical results are summarized in Figure 8. As it can be seen from this figure, for an average solar radiation of 500 W/m^2, ventilation of a house of 200 m^3 can be provided with two solar panels of the studied model. For rradiation of 700 W/m^2 or better, is sufficient a single air collector.

Figure 8. Area of solar air colectors vs solar radiation for three fileds of temperature, for a family house



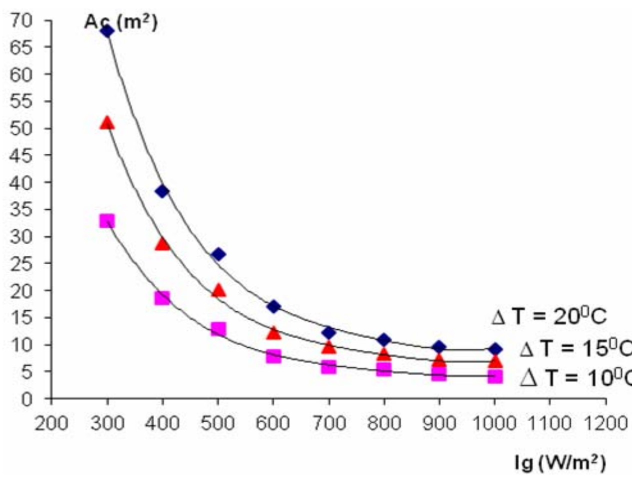
In table 2, the same analyse and results are made for an office building with about 1000 m^3 inside space.

Table 2 Area of solar air collector for three gradient of temperature for an office building

I_g (W/m^2)	v (m/s)	η (-)	ΔT (°C)	A_c (m^2)	ΔT (°C)	A_c (m^2)	ΔT (°C)	A_c (m^2)
300	1,2	0,09	10	32.95	15	51.1	20	68.1
400	1,5	0,15	10	18.5	15	28.75	20	38.3
500	1,75	0,2	10	12.95	15	20.1	20	26.8
600	1,85	0,28	10	7.8	15	12.15	20	17.05
700	2	0,36	10	5.9	15	9.65	20	12.15
800	2,4	0,42	10	5.3	15	8.2	20	10.95
900	2,6	0,46	10	4.45	15	7.2	20	9.65
1000	3	0,5	10	4.15	15	6.9	20	9.2

As it can be seen in Figure 9, for radiation of 500 W/m^2, to achieve a difference of temperature of 10° C, a surface of 12 m^2 is required, which means 6 solar collectors. For a variation of temperature of 20° C, 26 m^2 are required, which means 13 solar air collectors to improve natural ventilation.

Figure 9. Area of solar air colectors vs solar radiation for three fields of temperature for an office building



By introducing the concept of air change per hour *ACH*, like in Visagavel [14], given by the equation (9):

$$[\, ACH = \frac{\dot{V} \cdot 3600}{V_r} \,] \tag{9}$$

with V_r (m^3) the volume of the room / ventilated space, values for *ACH* were found like in table 3, compared to the values indicated by Mathur[19], Bassioiny and NaderSA Koura [20] and Visagavel [14].

Table 3 *ACH* air change per hour

Solar radiation W/m^2	Mathur (2006)	Bassiouny (2007)	Visagavel (2010)	Present study
300	2	2.5	2.4	2.02
500	2.2	3.2	2.6	2.9
700	3	3.5	2.9	3.3

Conclusion

The study of energetic performances of solar heat collectors is important both for their use in space heating and also for natural ventilation systems integrated in building technology. The energetic building efficiency requires on one side a better sealing and exhaust of the polluted air, on the other side heating with solar energy, which is cheaper. Ventilation can be made by forced ventilation using fans and air cleaning equipment, by natural ventilation where possible or by mixed methods using solar air collectors.

Present paper offers experimental results and performances for a solar air collector SH 1500G in Romania climatic conditions and a computation method to improve the natural ventilation with this air collector. There were determined the heating and cooling characteristics of the collector, the air mass flow rate, the heat flux and the efficiency of conversion of solar energy in thermal energy. Relations between solar radiations, air velocity and variation of temperature were established. The efficiency of the solar air collector was about 50%.

The external wind velocity is difficult to transpose into a technical model due to its random variation. This paper proposed a simplified method to dimension a solar collector that induces a flow air rate and performs natural ventilation inside the building. It was established that two computation relations for the ventilation could be considered (thermal pressure and heat transfer in a solar collector) in order to obtain geometrical dimensions, with an iterative method. Two case studies were realised to improve the ventilation with solar air collectors in a family residence of about 200 m^3 ambient spaces and for an office building with 1000 m^3, by calculating the required area of solar collectors for three gradient of temperature - 10° C, 15° C and 20° C.

Finally, *ACH* coefficient was determined and compared with the values of similar papers.

Conflicts of Interest

State any potential conflicts of interest here or “The authors declare no conflict of interest”.

References and Notes

1. Chiou J.P., El-Wakil M.M., Duke J.A.- A slit-and-expanded aluminium-foil matrix solar collectors, *Solar Energy* , Volume 9 (2), 1965; pp. 73-80.
2. Hachemi A. - Technical note comparative study on the thermal performances of solar air heater collectors with selective absorber plate, *Renewable Energy,* Volume 17 (1), 1999; pp. 103-112.
3. Biondi, P., Cicala, L., Farina, G., Performance analysis of solar air heaters of conventional design. *Solar Energy* Volume 41**,** 1988; pp. 101–107.
4. Gupta D.,. Solanki S.C,. Saini J.S.- Heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plates, *Solar Energy,* Volume 51 (1), 1993; pp. 31-37.
5. El-Sawi A.M., Wifi A.S., Younan M.Y.,. Elsayed E.A, Basily B.B..- Application of folded sheet metal in flat bed solar air collectors- *Applied Thermal Engineering* , Volume 30, 2010; pp. 864–871.
6. Lanjewar A. , Bhagoria J.L., Sarviya R.M..- Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness, *Experimental Thermal and Fluid Science* SCI 01/2011; Volume 35(6), 2011,;pp. 986-995.
7. Krzaczek, Kowalczuk M.Z.,- Thermal Barrier as a technique of indirect heating and cooling for residential buildings, *Energy and Buildings* Volume 43, 2011; pp. 823–837.
8. Chan H.Y., Riffat S.B., Zhu J.- Review of passive solar heating and cooling technologies, *Renewable and Sustainable Energy Reviews,* Volume 14, 2010; pp. 781–789.
9. Active solar air heating systems, *Education of Architects in Sol ar Energy and Environment*; pp. 1-22. www-ceneg.ensmp.fr/ease/active_overheads.pdf .
10. Morson I.- Performance Review of the SH 1500G Solar Air Heater, Ryerson University, 2007, http://www.yoursolarhome.com.
11. A.Ciocănea, A.Dragomirescu, Sanda Budea - Experimental Research on Transient Regimes of Solar Air Heat Collectors, Environmental Engineering and Management Journal, 10, 8, 2011, pp. 1097-1103.
12. Ben Slama Romdhane, - The air solar collectors: Comparative study, introduction of baffles to favor the heat transfer, *Solar Energy* , Volume 81, 2007; pp. 139–149.
13. Ramani B.M., Akhilesh Gupta, Ravi Kumar -Performance of a double pass solar air collector, *Solar Energy* , Volume 84, 2010; pp. 1929–1937.
14. Visagavel,K., Srinivasan, P.S.S. – Experimental investigation on solar air heater assited natural ventilation in single side ventilated room, *Indian Journal of Science and Technology*, Volume 3(7), 2010; pp. 802-806
15. Fraisse G., Johannes K., Trillat-Berdal V., Achard G.- The use of a heavy internal wall with a ventilated air gap to store solar energy and improve summer comfort in timber frame houses, *Energy and Buildings,* Volume 38, 2006; pp. 293–302.
16. Zhai X.Q., Dai Y.J., Wang R.Z. - Comparison of heating and natural ventilation in a solar house induced by two roof solar collectors, *Applied Thermal Engineering*, Volume 25, 2005; pp. 741–757.
17. Hirunlabh J., Wachirapuwadon S., Pratinthong N., Khedari J.- New configurations of a roof solar collector maximizing natural ventilation, *Building and Environment*, Volume 36, 2001; pp. 383–391.
18. Sandberg M., Moshfegh B.-Ventilated-solar roof airflow and heat transfer investigation, *Renewable Energy*, Volume 15 (1–4), 1998; pp. 287–292.

19. Mathur J., BansalNK, et.al.-Experimental investigations on solar chimney for room ventilation, *Solar Energy*, Volume 80, 2006; pp. 927-935.
20. Bassiouny R., Nader SA – An analytical and numerical study of solar chimney use for room natural ventilation, *Energy and buildings*, Volume 39(2), 2007; pp. 128-135.
21. JRC PVGIS, http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe