The contribution of a solar air heater collector to the cooling load in a Building

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ABSTRACT

Over the last few decades, there is a clear target for reducing energy needs in the building sector. The above objective can be achieved both by renovating the existing building stock and/or by constructing new buildings that will meet the characteristics of zero or nearly zero energy buildings. In order to construct or renovate a building into a zero or almost zero energy building, different passive, active and hybrid systems can be used. One such system is a solar air heater collector. The above system was installed in the south facade of the outdoor test cell (ZED-KIM (Zero Energy Demand – Kimmeria)), located at the Campus of the Environmental Engineering School, DUTH at Xanthi (Greece). In the present study, the monitoring results of the solar air heater collector and its contribution to cover the cooling load of a building will be presented. The system was monitored under real weather conditions for the period June 2017 to August 2017. This period was separated in two sub-periods. In the first one, the system operated as a solar air heater and with the appropriate modifications air from inside the test cell was passed through solar collector and hot air was rejected out. In the second sub-period, a ventilation inlet was added in the north facade of the test cell, and the system operated as a solar chimney. The heating load that rejected out in the first sub-period was 12 KWh and in the second sub-period was 58.5 KWh. In other terms the cooling load of the test cell was reduced by 70.5 KWh for the whole period of measurements. In addition the cooling load for the specific climate zone of Greece and for 20m^2 cooling space was 488 KWh so there was a reduction of 15 percent. Furthermore, it was noticed that the thermal efficiency of the system increased above 50 percent between 1st and 2nd sub period, with values being 16% and 34% respectively. Based on the above results, it is concluded that even in hot weather conditions prevailing in northern Greece, the use of a solar air heater collector with the appropriate modifications can cover, in a significant degree, the cooling load of a building and in conjunction with other passive and active systems it can lead at a nearly zero energy building.

KEYWORDS

Hybrid Systems, Solar Air Heater Collector, Thermal Efficiency, Solar Chimney

1 INTRODUCTION

In the building sector, different active, passive and hybrid systems can be used in order to reduce energy needs and achieved thermal comfort. Several studies have been carried out on solar systems in order to improve their performance and to integrate on buildings. For instance, the International Energy Agency (IEA) has launched in 1977 a program on solar heating and cooling (SHC) which aims, among others, to provide guidelines for the use of such systems. In addition, both in the world and in the Mediterranean countries due to the prevailing weather conditions, the study of solar thermal systems is quite well developed. However, solar air collectors have not been adequately studied as solar water collectors are predominant. The study of solar air collector systems focuses mainly on improving their performance with the researchers studying both experimentally and theoretically a range of parameters such as the effect of the use of baffles and fins on the absorber surface ((Bayraka et al (2013), Chabane et al (2011), El-Sebaii et al (2011), Yeh (2012)), the effect of roughness on the ducts or the absorber surface ((Akpinar and Koçyiğit (2010), Bopche and Tandale (2009)),different coatings of the absorber surface ((El-Sebaii and Al-Snani (2010)), and using heat storage media (Aboul-Enein et al., 2000). In contrast, the bibliography is limited to the application of solar air collector systems in the building sector ((Oikonomidis G., Davliakos N. and Botsios-Valaskakis A. (2014), Toumpoulidis et al., 2018)) and referred mainly on covering of the heating loads of a building. Additionally, the already limited literature is old enough with no access to relevant studies. Instead, as shown above, solar collector systems have been studied in depth only in terms of improving their performance through various techniques, and combining the use of such systems with other passive and active systems, emphasizing only the energy benefits that have emerged. Therefore one of the main objectives of the present study is to study solely a solar air collector system as far it concerns the energy performance in conjunction with the weather conditions prevailing in the study area. Finally, an additional objective which will be also presented in this study is to study the use of the solar collector as a mean of reducing the cooling load of a building in cooling period.

2 METHODOLOGY

2.1 Description of ZED-KIM (Zero Energy Demands–Kimmeria)

The prefabricated test cell ZED-KIM (Zero Energy Demand - Kimmeria), located at the Campus of the Engineering School, DUTH, 4 km east of the city of Xanthi, in Greece. The ZED-KIM consists of an imitation of an average household on a scale of 1:5, has been constructed in such a way so as to conform to bioclimatic design principles (Kosmopoulos and Galanos. (2006)).The ground plan is rectangular and 20 m^2 in total, the house faces south with an azimuth angle of 0^o. It has two windows, one on the south and one on the east side, which allow sun light to enter, thus increasing thermal energy. It is worth mentioning that this pilot house is very well insulated, its roof provides additional thermal insulation and sound proofing (Papadopoulos 2000). The roof is tilted at 42^o which is considered the most appropriate slant for the latitude of the city of Xanthi, in order to exploit the greatest levels and intensity of solar radiation during the sunny months (Hussein et al. 2004). Two photovoltaic arrays, one with 2 axis tracker, with a total power of 2120 Watt have been installed on the roof and near the test cell. On the west side of the house a wind generator of 900Watt has been installed, in order to function alongside the hybrid system in connection with the photovoltaic modules and to help considerably in the production of energy during seasonal fluctuations. With all the above-mentioned active systems, the total power of installed RES exceeds 3 kW. At this point it is worth noting that in the ZED-KIM a complete system has been installed to follow and record meteorological conditions, this system consists of a wind cup anemometer, rain gauge, temperature and humidity gauge, barometer, and one pyranometer to measure the intensity of total solar radiation. The general image of ZED-KIM is presented in figure 1.

Figure 1: The test cell ZED-KIM

Finally on the south façade of the test cell, as shown in figure 2, a solar air collector system have been installed in which carried out the present study.

Figure 2: Solar air collector

2.2 Description of the solar air collector system

2.2.1 Technical specification of solar air collector

The solar air collector used is a single-flow hybrid solar collector. Its total surface area is 1.08m^2, of which 0.97m^2 is the absorbing surface. The absorbent surface of the collector is made of 0.4mm thick aluminum and has a titanium (TiO_2) oxide coating that is blue in color, which contributes substantially to improving collector performance. The cover of the collector is made of cast 3mm thick acrylic sheet with 92% permeability coefficient. The frame is made of aluminum, resulting in a weight of 20kg, with special attention being paid both to the sealing of the individual materials and to the insulation of the system using 20mm rock wool on the back side and 20mm glass wool on the side panels. Finally at the bottom of the system there is a small 10-watt photovoltaic panel, in which a small low-power fan is installed. At this point it is worth noting that for maximum solar radiation of 1000W / m^2 the maximum calculated power is 700W with a maximum air flow of 100m^3 / h and a maximum surface temperature of 155 ° C (Sole, 2017).

2.2.2 Solar air collector system function

The solar collector system is driven through adjustable air ducts, with 10 cm diameter, inside the house as shown in figure 3.

Figure 3: Installed solar air collector

In winter, with the air ducts open the system takes off the cool air, through the intake duct, and driven to the absorbing surface of the collector. After that, the heated air is reintroduced by the upper duct into the test cell at a higher temperature. Thus, both space heating and dehumidification are achieved. On the other hand, in summer air ducts are closed and they do not let the system to function. In transition periods, like spring, if both fresh air and heating is needed, the ducts can be adjusted from 0 to 100%. Also, the air ducts are insulated with fiber glass with 5cm width, this insulation diminishes thermal losses during the procedure of transition of the air from the collector to the inside of test cell. Finally, there is a small solar panel at the bottom of the system with maximum power equal to 10W, in which a small power fan is installed. So in sunny hours the system will be more efficient due to faster air exchange. In the reference system, sensors of air temperature and relative humidity have been installed at the center of the two ducts and at a height of a sitting person at the center of the test cell. The sensors are connected with a data logger, which also records weather data from the meteorological station. Finally, the recording system is connected with a computer from both the recording and saving the measurements. The whole experimental scheme is illustrated in figures 4a and 4b.

Figure 4a: Measurements points at the air duct

Figure 4b: Measurements point at the center of area

The experimental set up during cooling period is not differed from that of heating as it concerns the procedures of measuring and storing data. The difference, though, in system operation lies in the fact that the air is being rejected out, instead of reintroduced after being heated from the absorbing surface. Thus, instead of placing sensors of air temperature, humidity and air velocity in the upper duct, the sensor were placed at a modified air outlet of the collector, well insulated with fiberglass, shown presented in figures 5a and 5b.

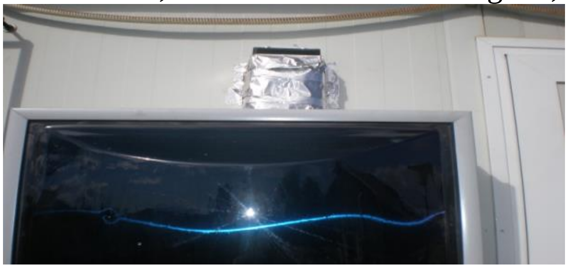

Figure 5a: Modified air outlet

Figure 5b: Measurements point at the modified air outlet

The sensors were placed in a special structure. At the same time, the upper duct remained closed, preventing in that way the entry of hot air. The cooling period is divided into two time intervals. Those time intervals are different each other only in the way the air inlet from the outdoor environment to indoor one. Therefore, a rectangular ventilation inlet was created at a height of 30cm. This inlet is 7.5 times bigger than ducts, with 30cm long and 20cm height, as shown in figure 6a. An instrument that measures and records air temperature, humidity and air velocity inlet in the indoor area was placed at the center of the ventilation inlet as shown in figure 6b.

Figure 6a: Ventilation inlet

Figure 6b: Measurements point at ventilation inlet

2.3 Measurements period

Greece is divided in four climatic zones, A,B,C and D, in order to specify the time periods round the year for heating and cooling. The study area belongs in climatic Zone C and the cooling period is from 1st of June to 31st of August. As already mentioned, the cooling period is divided into two sub-periods. The first sub-period concerns the operation of the system as a solar collector system and the second as a solar chimney system. The first sub-period was from 1st of June to 28th of July 28, 2017 and the second from 29th of July to 31st of August, 2017. At this point need to mentioned that was absent from measurements taken from 11th of June to 13th of June, 2017 and from 10th of August to 15th of August, 2017 as the data logger was not recording during technical problem.

2.4

The useful thermal power delivered by a solar air collector according to can be calculated from the equation 1.

$$Q_u = \dot{m} C_p (T_o - T_i) \tag{1}$$

Where Q_u the useful heat output of the collector in kW, $\dot{m}$ the air flow in kg / s, C_p the specific heat capacity in kJ / Kg * K, while T_i and T_o the temperature in K at the system inlet and outlet respectively. At this point, it is worth to mention the assumptions that had made. The collector operated in a permanent state, the air flow was one dimensional and there is mass preservation. Also, regarding the collector's losses to the environment was assumed that they were included in the equation as the temperatures measured were experimental. On the above basis and knowing the inlet and outlet temperatures of the collector, the useful thermal power can be calculated by taking a coefficient of specific heat capacity equal to 1,005 kJ / Kg * K and calculating the air flow from the equation 2.

$$\dot{m} = \rho V D \tag{2}$$

Where $\dot{m}$ the air flow in kg / s, ρ the air density in kg / m^3, V the average fluid velocity is perpendicular to the duct inlet cross section in m / s and D the cross sectional area of the duct inlet in m^2. The calculation of the output of thermal energy in the space derived by multiplying the thermal power by the time it takes. Finally, the equation 3 is proposed by authors to calculate the efficiency of a solar collector system.

$$n = \frac{E}{\mathrm{H}_\tau \mathrm{A}_c} \tag{3}$$

Where n the collector efficiency, E the mean daily energy output of solar collector in kWh, H_τ the mean daily solar radiation incident to collector surface in kWh / m^2 and A_c the active surface or the absorbing surface of the collector in m^2.

3 RESULTS

The results which presented in this study referred to the energy that system reject out of the test cell and also the energy efficiency of the system regarding the whole period of measurements and the two sub-periods separately. Daily average values of solar radiation, incident to collector surface, thermal energy and energy efficiency presented in Table 3.1.

Table 3.1 Mean value of solar radiation, thermal energy and energy efficiency of the solar air collector-June 2017

Day	**Solar Radiation* (kWh/m^2)**	**Thermal Energy (kWh/ m^2)**	**Energy Efficiency (%)**
1/6	3.0	0.4	15
2/6	2.7	0.5	18
3/6	2.9	0.6	21
4/6	2.4	0.4	16
5/6	2.9	0.6	22
6/6	2.9	0.4	15
7/6	2.9	0.5	18
8/6	1.9	0.2	11
9/6	2.8	0.4	14
10/6	2.8	0.4	14
14/6	2.8	0.5	17
15/6	2.3	0.2	9
16/6	2.9	0.5	19
17/6	1.9	0.0	0
18/6	2.4	0.2	6
19/6	2.7	0.5	19
20/6	2.7	0.3	11
21/6	2.9	0.5	16
22/6	2.8	0.6	20
23/6	2.9	0.6	20
24/6	2.6	0.3	13
25/6	2.9	0.7	24
26/6	2.9	0.6	20
27/6	2.9	0.5	19
28/6	2.9	0.6	21
29/6	2.9	0.6	21
30/6	2.9	0.7	22

*Solar radiation incident to collector surface

Based on the above table the maximum thermal energy which is 0.7 kWh/ m^2, and energy efficiency which is 24%, observed to the 25th June in which the solar radiation, equal to 2.9 kWh/ m^2 approach the maximum value of 3 kWh/ m^2. The minimum thermal energy which is 0 kWh/ m^2 and energy efficiency which is 0 kWh/ m^2 noticed on the 17th June in which the solar radiation incident to collector surface has the minimum value of that period which is 1.9 kWh/ m^2. In addition, the daily mean thermal energy and energy efficiency values were 0.5

kWh/ m^2 and 16% respectively, while solar radiation was equal to 2.7 kWh/ m^2. Also, the total thermal energy for June 2017 was about 12.0 kWh. Finally, both the daily mean thermal energy values and the energy efficiency values presented in figure 3.1 and 3.2 respectively.

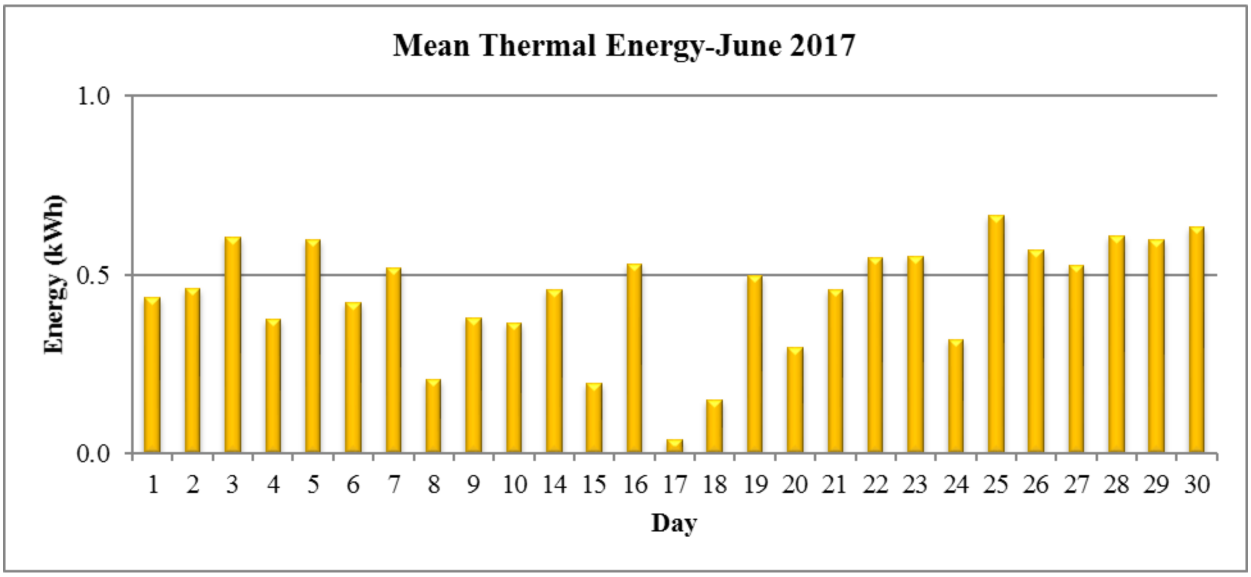

Figure 3.1: Mean Thermal Energy-June 2017

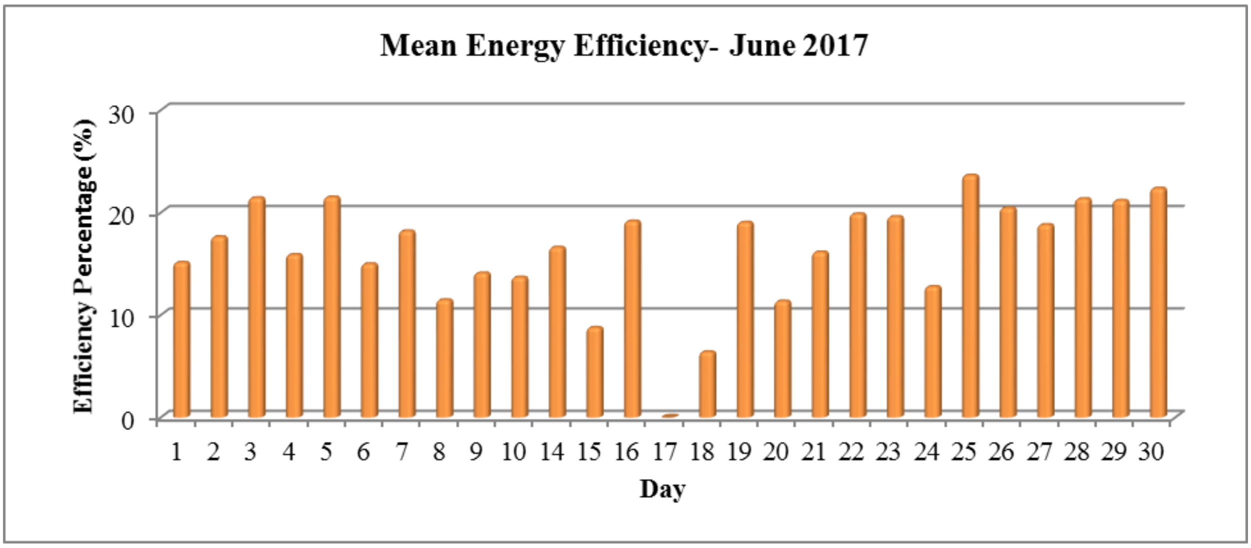

Figure 3.2: Mean Energy Efficiency -June 2017

Similar results observed both July and August 2017. Both thermal energy and energy efficiency daily mean values, depends on solar radiation incident to collector surface, showed in Table 3.2.

Table 3.2 Mean value of solar radiation, thermal energy and energy efficiency of the solar air collector

Month	**Solar Radiation* (kWh/m2)**	**Thermal Energy (kWh/ m2)**	**Energy Efficiency (%)**
June	2.7	0.5	16
July	2.8	0.9	32
August	3.3	1.2	36

*Solar radiation incident to collector surface

From the above table, noticed that the maximum energy efficiency observed at August, equal to 36%, while the minimum value 16% noticed in June. Also, the average energy efficiency during measurements was equal to 28%. These results were expected while the contribution of ventilation inlet lowering the temperature on the test cell and therefore at the inlet duct of the system. Based on the above the air flow as well as the difference between inlet and outlet of the system, was maximized. In addition, in August there was better angle of incidence solar radiation at the collector, with daily average 3.3 kWh/ m^2, which guide to increase the performance of the solar air collector. On the other hand, in June the lack of the external air supply in conjunction to the low levels of the incidence of the solar radiation at the collector, equal to 2.7 kWh/ m2, lead to significantly reduce of system performance almost 50 %. Furthermore, it has to be mentioned that the thermal energy is strongly depends on thermal energy performance of the system and therefore cannot be excluded. The 25 days measurements during August showed that the results of thermal energy was quite closed to those of July, with 30.1 kWh total energy and 1.2 kWh/ m^2 daily average and, 28.4 kWh total energy and 0.9 kWh/ m^2 average respectively. On the other hand the 27 day measurements during June showed that the thermal energy was equal to 12 kWh total energy and 0.5 kW daily average. As it can be concluded, the thermal energy produced during June was generally low, almost the half production among period measurements. The total thermal energy rejected out from the test cell during cooling period was 70.5 kWh. Also the aforementioned heat load rejected out at the first sub-period was 12 kWh and at the second sub-period was 58.5 kWh. Finally according to Droutsa et al (2016), for climate zone where the study area belongs, the average consumption, regarding the cooling load, of a typical household is equal to 2440kWh/year. According to reference, the cooling load for the total area of $20m^2$ was 488 KWh. We conclude that there is a reduction of 15% of cooling load, while the solar collector's energy production was equal to 70.5kWh. Based on this the cooling load for $20m^2$ calculated at 488 KWh, so there was a reduction of 15 percent while the solar air collector thermal energy as previously referred was in total 70.5kWh.

4 CONCLUSIONS

As part of this study, it has been shown that the solar air collector system has an important role about the thermal loads that rejected out of the test cell in cooling period. Taking into account the fact that was the only cooling systems that function on the test cell a significant reduced in cooling loads had been achieved. The results obtained from the pilot house lead to the conclusion that in conjunction with other interventions both on building shell and using other passive and active systems, even in climatic conditions such as those that prevailed during the measurement period, it can be lead at a nearly zero energy building Finally, the simplicity of the construction of the system makes its installation as a mild intervention in the building shell, while the maintenance cost is zero, resulting in a quick economic damping.

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