APPLICATION ASPECTS OF HYBRID PV/T SOLAR SYSTEMS

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Abstract – PV modules show temperature increase during their operation due to the absorption of solar radiation, as most of it is converted into heat and not into electricity. Hybrid Photovoltaic/Thermal (PV/T) solar systems combine a simultaneous conversion of solar radiation in electricity and heat. These devices consist of PV modules and heat extraction units mounted together, by which a circulating fluid of lower temperature than that of PV modules is heated by cooling them. An extensive study on water and air cooled PV/T solar systems has been conducted at the University of Patras, where hybrid prototypes have been experimentally studied. The water cooled PV/T systems consist of metallic heat exchanger placed at PV module rear surface, by which water circulating through pipes is heated. The methodology of Life Cycle Assessment (LCA) has been used to do an energetic and environmental assessment of the heat recovery system. The goal of this study, carried out at the University of Rome " La Sapienza", was to verify the benefits of heat recovery, implemented by a specific software for LCA, SimaPro 5.0. In this work we present the design, performance and aspects of improved PV/T systems based on the LCA results, giving guidelines for their application.

1. INTRODUCTION

The electrical efficiency reduction of PV modules due to their temperature increase can be partially avoided by water or air heat extraction. PV heating is mainly the result of the absorbed solar radiation that is not converted into electricity and PV cooling is considered necessary to keep electrical efficiency at a satisfactory level. Natural or forced air circulation is a simple and low cost method to remove heat from PV modules, but it is less effective if ambient air temperature is over 20^{o}C, as it is usual for many months in low latitude countries.

The water heat extraction is more expensive than air heat extraction, but it is considered practical for the above case, as the water temperature from mains is under 20^{o}C almost all year. The usual mode of PV cooling by water is the circulation of it through a heat exchanger in thermal contact with the PV module rear surface, to avoid pressure and electrical problems.

If the heat extraction fluid is used not only for PV cooling but also for other practical applications, these devices constitute the hybrid Photovoltaic/Thermal (PV/T) solar systems. In these devices PV modules and thermal units are mounted together and the systems can simultaneously convert solar radiation to electricity and heat. PV/T systems provide a higher energy output than standard PV modules and could be cost effective if the additional cost of the thermal unit is low.

Air type PV/T systems are recently used in building PV applications, but water PV/T systems are less applied systems as they are not improved enough for commercial applications.

The literature on hybrid PV/T systems include several works and among the first, there are the papers of Kern and Russel (1978), Florschuetz (1979) and Raghuraman (1981). Following them, Lalovic (1987) proposes novel transparent type cell as a low cost PV/T improvement, Garg and Agarwal (1995) present same aspects of a water type PV/T system and Bergene and Lovvik (1995) give results for liquid type PV/T systems.

Last years, Hausler and Rogash (2000) study a latent heat storage PV/T system, Huang et al (2001) an integrated PV/T system with hot water storage and Zondag et al (2002) present dynamic 3D and steady 3D, 2D and 1D models for PV/T prototypes with water heat extraction. The electrical and thermal output of hybrid PV/T systems can be increased by using flat or curved reflectors, as presented by Sharan et al (1985), Al-Baali (1986), Brogren et al (2000), Karlsson et al (2001) and Brogren et al (2002).

Design concepts, prototype construction and test results for water and air cooled PV/T systems are included in the work of Tripanagnostopoulos et al (2002). In this paper PV/T systems with and without glazing cover are presented, suggesting also the concept of using stationary diffuse reflector, instead of specular reflector, to increase the total energy output. The study of the dual type PV/T system based on the water or air heat extraction (Tripanagnostopoulos et al, 2001) and the results of an economic analysis comparing water cooled PV/T systems with standard PV and thermal systems (Tselepis and Tripanagnostopoulos, 2002) are also two works, that are referring to the improved by University of Patras water cooled PV/T solar systems.

The electrical output of PV/T systems is of priority, as the cost of PV modules is some times higher than the thermal unit. The different performance of these two subsystems regarding operating temperature affects system cost effectiveness and optimised modifications for both electrical and thermal efficient operation must be considered. Aspects and cost analysis results for standard PV modules are presented by Evtuhov (1979), Hynes et al (1995), Alsema et al (1998) and for PV/T systems by Leeders et al (2000).

The consideration of the environmental impact of PV modules by using Life Cycle Assessment (LCA) methodology has been presented by Hynes et al (1994), Keoleian and Lewis (1997), Kato et al (1998), Dones and Frischknecht (1998), Alsema (2000) and regarding comparison of concentrating and non concentrating PV systems by Wheldon et al (2000).

The LCA method has been extensively used at University of Rome " La Sapienza" through the works of Frankl (1996), Frankl et al (1998) and Frankl (2002). Additionally, Frankl et al (2000) give figures of a simplified LCA method comparing PV/T systems to standard PV and thermal systems.

In the present work we give test results and energy output of PV/T systems with water heat extraction, that have been investigated at University of Patras. We also include aspects on system environmental impact, based on LCA results from a specific software, SimaPro 5.0, performed at University of Rome. These results are considered useful as guidelines for the application of the modified PV/T systems.

2. DESCRIPTION OF PV/T SYSTEMS

2.1 Design concepts

In PV/T systems the thermal unit for water heat extraction, the necessary pump and the external pipes for fluid circulation constitute the complete system that extracts the heat from PV module and brings it to the final use. The cost of the thermal unit is the same either the PV module is c-Si, pc-Si or a-Si, but the ratio of the additional cost of the mounted thermal unit per PV module area cost is different and is almost double in using a-Si than c-Si or pc-Si PV modules.

The hybrid PV/T systems consisting of PV modules without thermal protection of their illuminated surface to the ambient, have high top thermal losses and therefore the achieved operating temperature is not high. To increase the system operating temperature, an additional glazing cover is necessary (like that of the usual solar thermal collectors), but it has as result the decrease of the PV module electrical output from the additional absorption of the solar radiation.

In Fig.1 we show the cross section of the two basic PV/T module designs, one without (PV/T UNGLAZED)and a second with the additional glazing (PV/T GLAZED). These systems use flat heat exchanger with pipes for the circulation of water and have also thermal insulation to avoid thermal losses from the non illuminated system side.

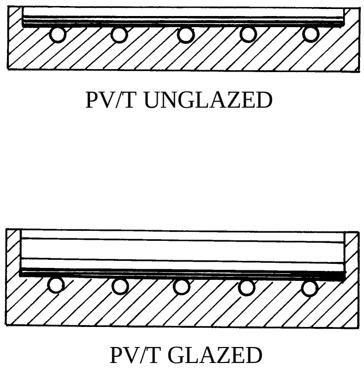

Figure 1 Cross section of the PV/T experimental models

Considering PV/T solar systems installed on horizontal building roof they are usually placed in parallel rows, keeping a distance from one row to the other in order to avoid PV module shading. We suggest to place stationary flat diffuse reflectors, as shown in Fig. 2, from the higher part of the modules of one row to the lower part of the modules of next row (Tripanagnostopoulos et al, 2002). This installation increases solar input on PV modules almost all year resulting to an increase of electrical and thermal output of the PV/T systems. The suggested diffuse reflectors don't contribute to electrical efficiency drop, as they provide an almost uniform distribution of reflected solar radiation on PV module surface.

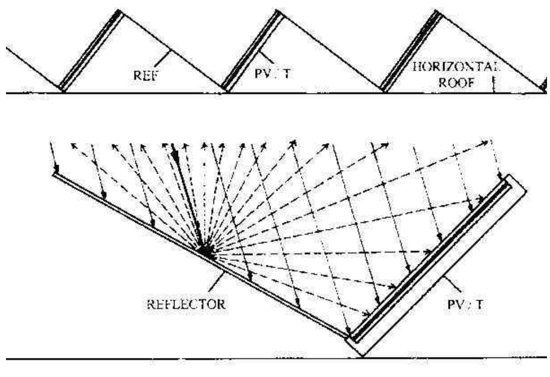

Figure 2: PV/T systems with diffuse reflectors installed between collector rows.

2.2 PV/T experimental models

The study of the hybrid PV/T water systems includes outdoor tests for the determination of the steady state thermal efficiency η_{th} and electrical efficiency η_{el} . The PV/T systems were constructed in University of Patras and the experimental models consisted of pc-Si PV modules in combination with water heat extraction. The two PV/T model types are the PVT/UNGLAZED and

PVT/GLAZED, regarding the use of additional glazing. For the systems that combine PV/T modules with diffuse reflector we have PVT/UNGL+REF and PVT/GL+REF.

The heat exchanger for the water heating was consisted of 10 mm in diameter copper pipes in thermal contact with a copper sheet, which was mounted on PV rear surface. The thermal unit of all models was thermally protected by 5 cm thermal insulation.

The systems were tested with slope equal to the latitude of Patras (38.25^o). In the experiments with the diffuse reflector, the PV/T system was tested for variable additional solar radiation to get data for different angles between system and sun.

3. EXPERIMENTAL RESULTS

The thermal efficiency of the experimental PV/T models is determined as function of the incoming solar radiation (G), the input fluid temperature (T_{in}) and the ambient temperature (T_a). The electrical efficiency of the PV/T systems is determined for the two PV module types as function of the operating temperature (T_{PV}) of them.

During tests for the determination of system thermal efficiency the PV modules were connected with load to simulate real system operation and to avoid PV module overheating by the solar radiation that is converted into heat instead of electricity.

The steady state efficiency is calculated by the relation $\bullet_{th} = \dot{m} C_p(T_o-T_i)/GA_a$, where $\dot{m}$ is the fluid mass flow rate, C_p the fluid specific heat, T_i and T_o the input and output fluid temperature and A_a the PV/T system aperture area (A_a =0.4 m^2). The thermal efficiency $\bullet_{th}$ is function of the ratio $\bullet$ T/G where $\bullet T= T_i-T_a$, and T_a the ambient temperature.

The electrical efficiency $\bullet_{el}$ depends mainly on the incoming solar radiation and the PV temperature (T_{PV}) and is calculated by the relation $\bullet_{el}=I_mV_m/GA_a$, where I_m and V_m the current and the voltage of PV module operating at maximum power.

In the case of using diffuse reflector, the calculation of thermal and electrical efficiency of the system is based on the net solar radiation on the PV module surface (not included the radiation from the reflector).

This result could be considered as system performance rather than system efficiency and it is done in order to get a clear idea about the achieved effect from the additional solar input by the diffuse reflector.

The results from the performed tests regarding thermal efficiency are the following:

PVT/UNGLAZED: $\bullet_{th} = 0.55 – 11.99 (\bullet T/G)$

PVT/GLAZED: $\bullet_{th} = 0.71 – 09.04 (\bullet T/G)$

The results regarding the electrical efficiency for the two PVT types are the following:

PVT/UNGLAZED: $\bullet_{el} = 0.1659 - 0.00094 (T_{PV})_{eff}$

PVT/GLAZED: $\bullet_{el} = 0.1457 - 0.00094 (T_{PV})_{eff}$

The calculation of $\bullet_{el}$ is function of $(T_{PV})_{eff}$, which is the PV temperature for the operating conditions of the PV/T systems. The formula that can be used for the calculation of the temperature of the photovoltaics, as function of the ambient temperature and the incoming solar radiation, is: T_{PV}=30+0.0175(G-300)+1.14(T_a-25) (Lasnier and Ang, 1990).

This relation is used for standard PV modules, but in PV/T systems the PV temperature depends also on the system operating condition, which is function of the heat extraction fluid mean temperature. Therefore we can use an effective value of T_{PV} , $(T_{PV})_{eff}$, including the difference of the fluid operating temperature to the ambient temperature.

The results for thermal and electrical efficiencies from the addition of the diffuse reflector to the PVT systems achieve a concentration ratio from CR=1.00 in December up to CR=1.30 in June. These values are considered in the calculation of the thermal and electrical efficiencies of the PV/T systems and also in the calculation of the PV temperature, regarding the incoming solar radiation by using: T_{PV}=30+0.0175(G*CR-300)+1.14(T_a-25).

4. CALCULATED ENERGY OUTPUT

The experimentally extracted thermal and electrical efficiencies of the above mentioned PV/T systems were used to calculate the monthly and also the annual energy output. In the calculations we used the weather conditions of Patras, considering only the positive energy output.

We estimated interesting to compare the electrical performance of the PV/T systems with that of standard PV modules of the same type in a typical installation and also with diffuse reflectors. In the following Tables we present the monthly energy output for the PV modules, the PVT/UNGLAZED and PVT/GLAZED systems and also their performance with the diffuse reflector.

In Table 1 we give the calculated values of the standard pc-Si PV modules regarding the electrical output per m^2 for each month and the annual sum. In this Table we include the solar radiation G in kWh/m^2mo, on the plane of the PV modules (slope 38.25^o), the mean monthly ambient temperature (during sunshine), T_a, the mean concentration ratio CR for each month of the considered diffuse reflector and the calculated values of the electrical energy of the plain PV modules (PV-ELECTRIC) as well as with the diffuse reflector (PV+REF-ELECTRIC).

In the next Tables 2-5 we consider the same values of the monthly incoming solar radiation on the PV/T system plane, the same mean monthly ambient temperature and the mean monthly concentrating ratio CR.

TABLE 1 Monthly PV and PV+REF system electrical output in kWh/m^2 mo

Month	Solar Radiation kWh/m^{2}mo	Amb. Temp. ^{o}C	CR	PV-EL kWh per m^2 and mo	PV+REF-EL kWh per m^2 and mo
Jan	96.766	12	1.05	12.91	13.92
Feb	97.932	13	1.10	12.96	14.61
Mar	127.621	14	1.15	16.73	19.67
Apr	133.654	18	1.20	17.01	20.83
May	165.379	21	1.25	20.49	26.05
Jun	169.704	27	1.30	20.08	26.47
Jul	182.644	29	1.25	21.15	26.83
Aug	186.561	29	1.20	21.49	26.21
Sep	161.763	25	1.15	19.27	22.61
Oct	134.810	21	1.10	16.68	18.78
Nov	103.377	17	1.05	13.25	14.29
Dec	84.506	14	1.00	11.13	11.44
Total	**1644.717**			**203.15**	**241.70**

In Table 2 we give the calculated values for the system PVT/UNGLAZED, in Table 3 for the corresponding system PVT/UNGLAZED+REF and in Tables 4 and 5 the calculated values for systems PVT/GLAZED and PVT/GLAZED+REF. These amounts are referred to system operation at 25 ^{o}C, 35 ^{o}C and 45 ^{o}C, and only to the systems that are installed on a horizontal building roof (not to systems that include controllers, inverters, pipes, heat exchangers and storage). The complete systems include the necessary additional components and therefore the final energy output is reduced due to the electrical and thermal losses from one part to the other.

TABLE 2 Monthly PVT/UNGLAZED energy output in kWh /m^2 mo

Month	PVT/UNGL 25 ^{o}C kWh/m^{2}mo		PVT/UNGL 35 ^{o}C kWh/m^2		PVT/UNGL 45 ^{o}C kWh/m^{2}mo	
	Thermal	Electric	Thermal	Electric	Thermal	Electric
Jan	4.32	11.87	-	11.07	-	10.27
Feb	8.41	11.99	-	11.18	-	10.37
Mar	18.61	15.57	-	14.51	-	13.45
Apr	35.92	16.24	-	15.13	-	14.07
May	61.80	19.94	15.95	18.58	-	17.21
Jun	91.74	20.36	44.20	18.95	-	17.55
Jul	106.84	21.75	60.99	20.24	15.15	18.73
Aug	107.43	22.11	64.86	20.56	22.29	19.02
Sep	78.38	19.27	40.36	17.93	2.33	16.59
Oct	50.91	16.23	14.89	15.11	-	14.00
Nov	24.74	12.57	-	11.71	-	10.86
Dec	8.53	10.36	-	9.66	-	8.96
Total	**597.63**	**198.26**	**241.25**	**184.66**	**39.76**	**179.10**

TABLE 3: Monthly PVT/UNGLAZED+REF energy output in kWh/m^2 mo

Month	PVT/UNGL +REF 25 ^{o}C kWh/m^{2}mo		PVT/UNGL +REF 35 ^{o}C kWh/m^{2}mo		PVT/UNGL +REF 45 ^{o}C kWh/m^{2}mo	
	Thermal	Electric	Thermal	Electric	Thermal	Electric
Jan	5.76	12.60	-	11.68	-	10.85
Feb	11.32	12.93	-	12.09	-	11.26
Mar	24.35	17.16	-	16.08	-	14.99
Apr	44.21	18.31	1.84	17.17	-	16.03
May	74.79	23.00	27.64	21.59	-	20.18
Jun	108.18	24.00	59.28	22.55	10.41	21.11
Jul	122.28	25.17	75.13	23.56	27.99	22.01
Aug	118.93	24.98	75.15	23.39	31.37	21.80
Sep	87.20	21.29	48.09	19.91	8.99	18.53
Oct	56.03	17.51	18.98	16.36	-	15.21
Nov	26.85	13.25	-	12.36	-	11.48
Dec	8.77	10.66	-	9.94	-	9.22
Total	**688.64**	**220.69**	**306.14**	**206.69**	**78.76**	**192.68**

Estimating that a minimum energy reduction of about 10% for the converted solar radiation in electricity and heat, we can take the 90% of the calculated energy output of the PV and PV/T systems and to consider these new values as the final use energies.

In Table 6 we present the final use annual amounts of all systems, including also the efficiency (%) of each system for the annually solar input on the PV plane for Patras (1644.717 kWh/m^{2}y). These results give an idea about the limits of practical use, as the operation of PV/T systems in moderate (35^{o}C) or high (45^{o}C) temperatures results to a considerable electrical and thermal reduction.

TABLE 4 Monthly PVT/GLAZED energy output in kWh /m^2 mo

Month	PVT/GL 25 ^{o}C kWh/m^{2}mo		PVT/GL 35 ^{o}C kWh/m^{2}mo		PVT/GL 45 ^{o}C kWh/m^{2}mo	
	Thermal	Electric	Thermal	Electric	Thermal	Electric
Jan	27.92	9.96	3.67	9.19	-	8.38
Feb	31.24	10.06	7.16	9.28	-	8.47
Mar	46.38	13.05	17.29	12.04	-	10.98
Apr	60.74	13.61	30,24	12.55	-	11.44
May	87.99	16.69	54.06	15.38	20.12	14.00
Jun	111.26	17.02	76.07	15.67	40.89	14.26
Jul	125.75	18.17	91.81	16.71	57.87	15.20
Aug	127.18	18.44	95.67	16.96	64.16	15.41
Sep	99.35	16.10	71.20	14.81	43.05	13.47
Oct	72.13	13.58	45.46	12.51	18.80	11.39
Nov	44.72	10.54	21.26	9.71	-	8.85
Dec	27.90	8.69	6.08	8.02	-	7.32
Total	**862.55**	**165.92**	**519.98**	**152.83**	**244.87**	**139.17**

TABLE 5: Monthly PVT/GLAZED+REF energy output in kWh/m^2 mo

Month	PVT/GL+REF 25 °C kWh/m^2mo		PVT/GL+REF 35 °C kWh/m^2mo		PVT/GL+REF 45 °C kWh/m^2mo	
	Thermal	Electric	Thermal	Electric	Thermal	Electric
Jan	28.73	10.68	4.15	9.88	-	9.08
Feb	32.71	11.00	8.29	10.19	-	9.39
Mar	49.49	14.55	19.99	13.50	-	12.45
Apr	65.92	15.47	35.00	14.37	4.08	13.27
May	97.48	19.36	63.07	18.00	28.66	16.63
Jun	125.75	20.13	90.08	18.73	54.40	17.33
Jul	136.62	21.11	102.21	19.60	67.80	18.10
Aug	135.00	21.04	104.05	19.50	71.10	17.96
Sep	103.85	17.99	75.30	16.66	46.76	15.33
Oct	74.55	14.87	47.51	13.76	20.48	12.65
Nov	45.80	11.30	22.01	10.45	-	9.59
Dec	28.29	9.13	6.17	8.43	-	7.74
Total	**924.17**	**186.64**	**576.84**	**173.08**	**293.29**	**159.52**

TABLE 6 Annual system energy output in kWh/m^2y

SYSTEM	Annual electrical energy kWh/m^2y	% of input energy	Annual Thermal energy kWh/m^2y	% of input energy
PV MODULES	182.84	11.12		
PV+REF MODULES	217.53	13.23		
PVT/UNGL 25 °C	178.43	10.85	537.87	32.70
PVT/UNGL 35 °C	166.17	10.10	217.13	13.20
PVT/UNGL 45 °C	161.19	9.80	35.79	2.18
PVT/UNGL +REF 25 °C	198.62	12.08	619.77	37.68
PVT/UNGL +REF 35 °C	186.02	11.31	275.53	16.75
PVT/UNGL +REF 45 °C	143.57	8.73	263.96	16.05
PVT/GL 25 °C	149.33	9.08	776.30	47.20
PVT/GL 35 °C	137.55	8.36	467.98	28.45
PVT/GL 45 °C	125.25	7.62	220.39	13.40
PVT/GL+REF25 °C	167.98	10.21	831.75	50.57
PVT/GL+REF35 °C	155.77	9.47	519.15	31.56
PVT/GL+REF45 °C	143.57	8.73	263.96	16.05

5. LCA PV AND PVT SYSTEM CALCULATIONS

A Life Cycle Assessment study has been carried out at the Department of Mechanics and Aeronautics of the University of Rome "La Sapienza", using SimaPro 5.0 software and an updated version of Ecoindicator '95 as characterisation methodology.

Since each modification of the system (glazed covering, reflectors, heat recovery) on one side leads to a higher energy output, but, on the other side, it requires new components and materials with their energy content, the main aim of the LCA study has been to investigate the effectiveness of these modifications.

The results have been calculated using two pay back time parameters: the Energy Pay Back Time (EPBT) and the CO_2 Pay Back Time (CO_2 PBT). Actually, producing clean energy during their operation, the systems analysed avoid the Cumulative Energy Demand (CED) and the CO_{2eq} emissions related to traditional energy sources; those PBT parameters represent the periods required by the systems outputs to avoid the same amounts of CED and CO_2 emissions produced by the systems themselves during their whole life cycle. Only after those periods the real environmental benefit starts.

We focused our attention on these values because of their relevance and importance in environmental and energy saving strategies. We did not take into consideration other pollutants (whose emission participates, for example, to the eutrophization or acidification of air), because of the poor quality of some environmental data strictly related with this kind of impacts.

The main hypotheses of the LCA study are:

- PV module materials:
  - pc-Si
  - glazing (glass)
  - aluminium frame
  - other lamination materials (EVA, etc.)

- PV support structures: we considered only horizontal flat roofs installations because the use of reflectors is possible only in that case; for the installations galvanized iron rods have been considered.

- reflector materials:
  - aluminium (reflectors)
  - galvanized iron (installation material)

- heat recovery unit materials:
  - copper (sheet + pipes)
  - PUR (insulation)
  - aluminium (collector back cover)
  - glazing (glass, only for glazed PVT systems)

– aluminium (additional collector frame, only for glazed PVT systems)

- amount of secondary aluminium in the aluminium parts: 30%

- PVT operating temperatures considered: 25 °C, 35°C, 45°C

In Table 7 and Table 8 we give the EPBT and CO_2 PBT values for the analysed systems, considering the final use energy output in electricity for standard PV modules and in electricity and heat for the suggested hybrid PVT systems (annual system energy output, shown in Table 6).

TABLE 7 Energy Pay Back Time values for the analysed systems

SYSTEM	EPBT (years)
PV MODULES	4.43
PV+REF MODULES	3.97
PVT/UNGL 25 ^oC	1.61
PVT/UNGL 35 ^oC	2.82
PVT/UNGL 45 ^oC	4.93
PVT/UNGL+REF 25 ^oC	1.49
PVT/UNGL+REF 35 ^oC	2.51
PVT/UNGL+REF 45 ^oC	4.31
PVT/GL 25 ^oC	1.34
PVT/GL 35 ^oC	2.00
PVT/GL 45 ^oC	3.36
PVT/GL+REF 25 ^oC	1.31
PVT/GL+REF 35 ^oC	1.89
PVT/GL+REF 45 ^oC	3.02

TABLE 8 CO_2 Pay Back Time values for the analysed systems

SYSTEM	CO_2 PBT (years)
PV MODULES	4.35
PV+REF MODULES	3.87
PVT/UNGL 25 ^oC	1.99
PVT/UNGL 35 ^oC	3.25
PVT/UNGL 45 ^oC	4.97
PVT/UNGL+REF 25 ^oC	1.84
PVT/UNGL+REF 35 ^oC	2.90
PVT/UNGL+REF 45 ^oC	4.49
PVT/GL 25 ^oC	1.73
PVT/GL 35 ^oC	2.50
PVT/GL 45 ^oC	3.94
PVT/GL+REF 25 ^oC	1.67
PVT/GL+REF 35 ^oC	2.36
PVT/GL+REF 45 ^oC	3.55

The main conclusions that could be drawn from the values shown are:

- the effect of reflectors is positive in any case, the electricity surplus (from 8% to 19%) gives benefits that are higher than the corresponding costs due to the additional materials required (aluminium and galvanized iron);

- heat recovery with an unglazed PVT system operating in higher than 35^{o}C is not good up to now, because the higher energy demand due to the materials of the heat recovery unit is actually higher than the avoided CED thanks to thermal energy recovered;

- the use of a glazed covering lowers the electrical output, because of the reflection by the covering; but, on the other side, thanks to the greenhouse effect inside the collector, the amount of heat recovered is widely increased; the result of this two effects is positive: lower PBTs

We must underline that material choice is very important to optimise the energy and environmental profiles of these systems. For example, aluminium is a material with a high energy content and we should focus on the chance to increase the recycled aluminium amounts for frames and reflectors.

Another possibility to improve the environmental performances of the systems analysed is to use lighter components for the reflectors, in order to have less aluminium per m^2 of system.

5. CONCLUSIONS

Hybrid Photovoltaic/Thermal solar systems with water heat extraction were developed by University of Patras, aiming to the increase of electrical and thermal output. The system performance depends on the PV operating temperature and for lower values of it, higher levels of electricity and heat can be obtained.

We calculated the energy output for operation of all PV/T systems in 25^{o}C, 35^{o}C and 45^{o}C and the results showed that it decreases with temperature rise, although higher temperature values are more effective in practical applications. The PV/T systems with additional glazing are of lower electrical output, but of sufficiently higher thermal output.

The use of a diffuse reflector between parallel rows of PV/T systems increases both electrical and thermal output and can be considered an effective system modification.

The Energy Pay Back Time (EPBT) and CO_2 Pay Back Time (CO_2 PBT) of all studied systems were calculated, also considering the corresponding materials of horizontal building roof installation of systems, by University of Rome, using the LCA methodology.

The best results have been pointed out for system operating with a temperature of 25°C, while the performance is satisfactory for 45°C, except of the system PVT/UNGLAZED. Regarding the contribution of the stationary diffuse reflector, the solar input increase effect is positive in all cases. Finally, it becomes clear that the use of less aluminium in the frames and the reflectors could lead to a further environmental improvement.

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