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Study and Design of PV/Thermal Solar Collector and Their Potential in IRAQ

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Abstract: The increasing of the population and development of the different countries converts the energy topic in one of the most important aspects of our times. The main target due to the limited life of conventional energy sources is the achievement of a sustainable energy mix where thermo solar energy plays an important role. One of the disadvantages of this renewable energy is the fact that energy is not available all the time: the need of heat storage systems appear. In this research, a review on the work done until the moment in the frame of latent heat and thermo-chemical storage systems is presented in the temperature range from 200 to 700 ºC. Finally a design and the first calculations for the modeling of a latent heat storage system for a laboratory device are shown. The potential of the PV/thermal solar collector is studied to be used in Iraqi houses.

الخلاصة:

يعتبر موضوع الطاقة واحدة من اهم الجوانب فى عصرنا الحديث. وتلعب الطاقة الشمسية الحرارية دورا هاما كمصدر من مصادر الطاقة التقليدية فى تحقيق مزيج من الطاقة المستدامة. وحيث ان هذه الطاقة المتجددة ليست متاحة فى كل وقت.

وتظهر الحاجة لتخزين الحرارة فى هذه النظم فى وسائل هى موضوع هذا البحث وامكانية استخدامها على نطاق واحد فى العراق.

ويقدم هذا البحث استعراضا للعمل المنجز حتى هذا الوقت فى اطار انظمة الحرارة والتخزين الحرارية والكيميائية الكامنة فى نطاق درجة حرارة 200-700 درجة مئوية واخيرا تم عرض تصميم وحسابات لنمذجة تخزين الحرارة الكامنة للاجهزة المختبرية. كما تم دراسة امكانية تعميم هذه التقنية على المنازل العراقية.

1. INTRODUCTION

The increasing on the prices of the conventional energy sources and the environmental awareness have leaded to increase the use of renewable energies and the energy efficiency. In this scene, storing thermal energy plays a really important role as it allows to improve the dispatch ability and the efficiency of different applications such as thermo-solar power plants, greenhouses and buildings heating systems. [1]

There are three methods used and still being investigated in order to store thermal energy. One is the sensible heat storage (SHS), the other one is the latent heat storage (LHS) and the last one is the thermo-chemical storage. In the present work the last two ones will be presented in the following sections focusing on the high temperature storage between 200 and 700 C^{o}. The first method (SHS) is based on raising the temperature of a solid or liquid to store heat and releasing it with the decrease of temperature when it is necessary. The volumes needed to store energy in the scale that world needs are extremely large. That is why the other two methods are being developed. The LHS method is a medium term method and the thermo-chemical storage is a long term method as there have not been so many research work and experiments as with the other two methods. [2,3]

1.1 Classification of the PCM(Phase Change Materials):

The different materials which have the properties mentioned before are classified in different groups. One possible classification is the one shown in figure 1. There are three main groups: organic materials, inorganic materials and eutectics. It must be mentioned that generally the materials do not respect all the properties listed in the previous section and it 3has to be compensated with the system design and different enhancement methods such the use of fins or composite materials in the form of matrixes. [4]

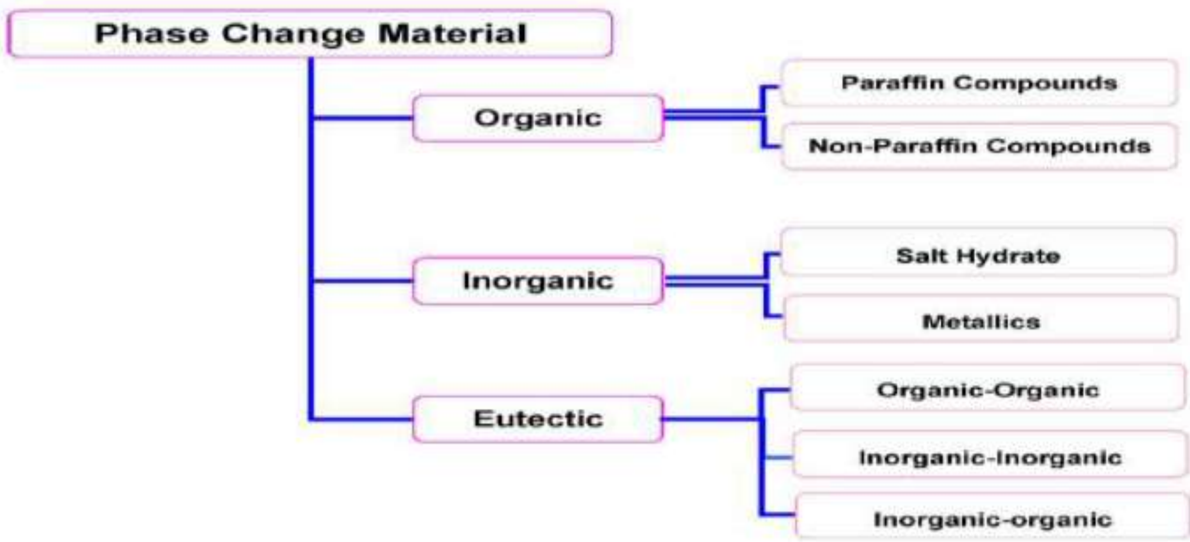

Fig.(1): Classification of PCM(Phase change materials)

1.2 Latent heat storage systems:

In the temperature range of interest (200-700C^O) the concepts used for the power solar plants can be generalized to use them for the rest of applications. The concepts here presented can be also applied to sensible heat storage systems. As told in [8] there are two main concepts: the active and the passive systems. In the active systems the storage medium itself circulates

1.2.1. Active direct systems

Proposed Project

Solar thermal power plants using parabolic trough collectors are the most economic systems to generate electricity from solar insulation in the MW range. DISS project demonstrated the feasibility of high temperature direct steam generation (DSG) in absorber pipes of parabolic trough which resulted in a cost reduction of the thermal fluid as it is water and also a higher working temperature which improves the efficiency of the plant. The project, based on the know-how achieved in the DISS project, performed the design of the first pre-commercial DSG solar power plant (5 MWe). [9]

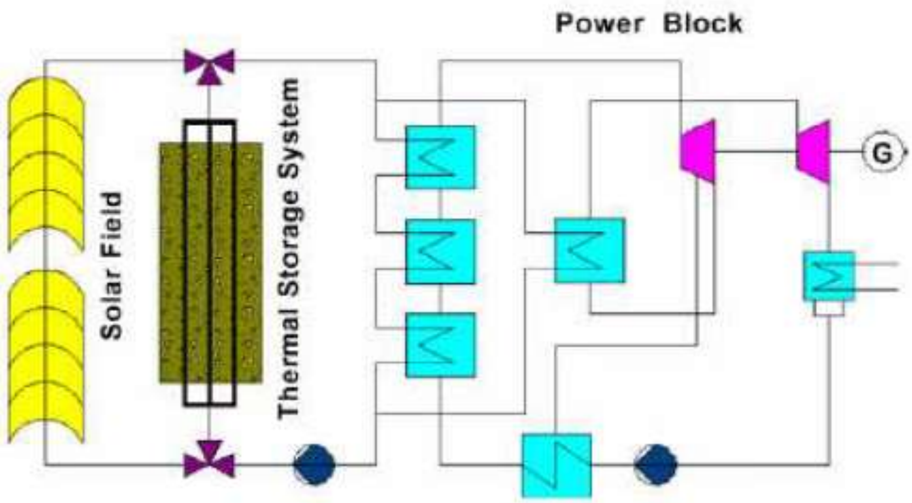

Fig.(2) Basic concept for integration of thermal energy storage into solar thermal parabolic trough power plants using DSG technology [9]

1.3 Definition of PV/T collector designs:

PV/T collectors being considered in this report are collectors, which can provide both electrical and thermal energy. These hybrid collectors are divided in two groups:

Water PV/T collectors. One example is a conventional flat plate solar heat collector with integrated PV cells on the absorber, to produce both thermal and electrical energy. [10]

1.3.1 Air PV/T collectors:

These can be façade or roof integrated PV cells with ventilation air passed behind or in front of the PV cells. These collectors are very useful to be used on the roofs of Iraqi houses and other buildings to collect heat directly from the sun. Furthermore, water PV/T collectors can be divided into groups according to temperature levels of the heat transfer fluid. This range from low-temperature applications for e.g. swimming pool and heat pump applications to medium-temperature applications around 55°C for e.g. domestic hot water applications. In the researchers [21-22] , further information can be found regarding the benefits and potential markets for low-temperature applications.[22] present study focus has been on the medium-temperature applications.

1.4 Water PV/T collectors:

For these systems, water is used as heat transfer fluid. The PV cells are pasted either directly on the absorber or interior on a cover plate with a dielectric material. This means that the only contact between the PV cells and the absorber or the cover plate is a high thermal contact. The heat transfer fluid runs inside the ducts on the absorber and collects heat from the absorber. If the PV cells are pasted to the absorber, heat is also extracted from the PV cells resulting in a higher electrical efficiency of the PV cells.

Useful thermal energy is extracted to one end of the ducts where it can be utilised. The ducts can be coupled either in series or in parallel, which effects the efficiency of the system. The heat transfer fluid can be circulated by either a pump (a pumped system) or by the difference in specific gravity of the heat transfer fluid (a gravity system). [23]

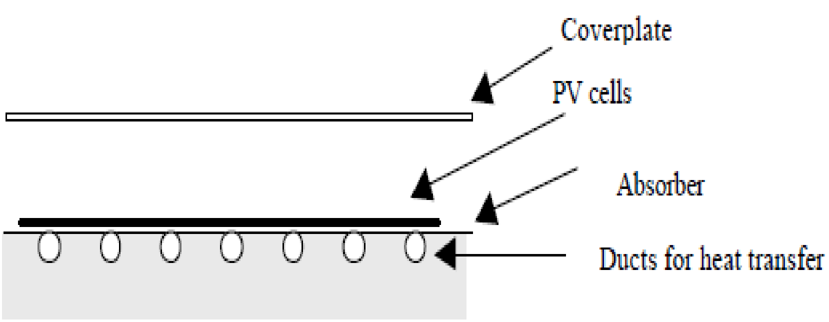

Fig.(3): A Typical water PV/T collector

1.4.1 Air PV/T collectors:

The other type of PV/T collector is an air-based system. Instead of water, air is used as heat transfer fluid. The PV cells are either pasted to the interior of the cover plate or to an absorber or the PV cells are acting as an absorber or cover plate itself. The air can be circulated by either natural ventilation or forced ventilation. [24]

3. Commercial PV/T Collectors:

3.1 Water PV/T collectors:

PV/T collectors have been developed by the company since 1991. The commercially available PV/T collector is a flat plate solar heat collector with PV cells integrated on the absorber. The producer first tested their PV/T collector in several locations , finding that the PV/T collector could supply apartment's electricity and hot water demand. The system was developed in such a way that additional generated electricity could be sold to the main Electricity network. The average cost for the PV/T collector, named "Multi Solar System", are about I.D. 500,000/m2 collector. The system can be grid-connected or standalone. [25]

Fig.(4:) Multi Solar System

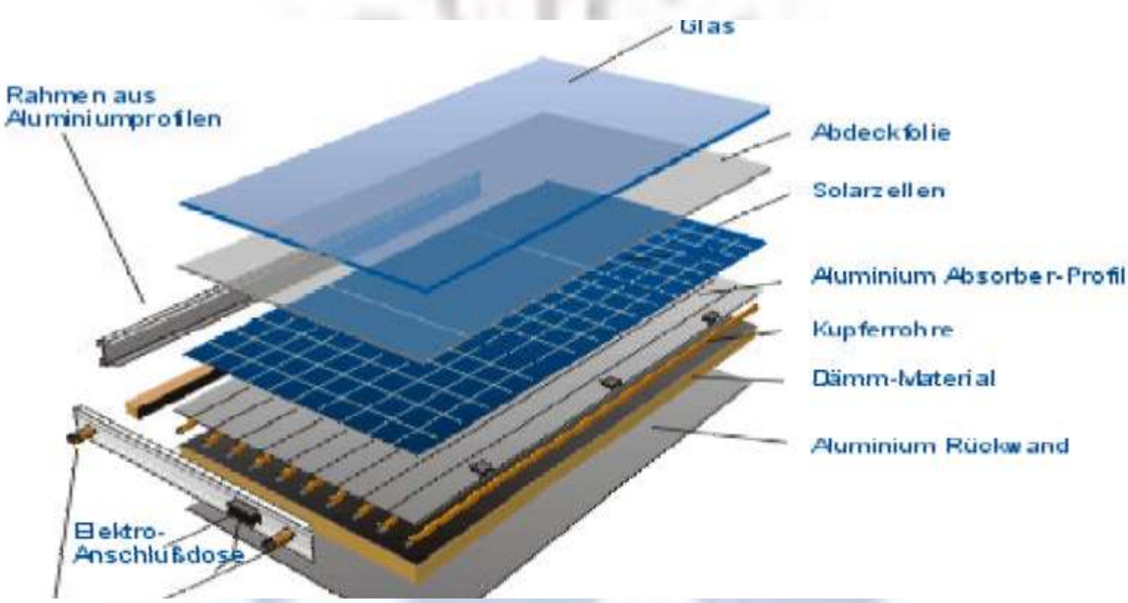

Fig.(5): Solar "Spectrum"

The other The company developed a product which is also a flat plate solar heat collector with PV cells integrated on the absorber, [13]. Both companies have however problems maintaining long time stability of the PV cells as they are integrated on an absorber. This seems to be a common problem for companies interested in commercializing PV/T systems where the PV cells are integrated on the absorber. [26]

Fig.(6): installed on a cabin

The manufactures have developed a PV solar wall product where PV panels can be mounted onto a perforated absorber. This building integrated PV/T Collector can be used as a facade or roof element and is named "PV Solar Wall". The PV panels are mounted in such way that cool ambient air is allowed to pass behind the PV panels in a uniform way. Heat generated from the PV cells will be transferred to the air, which can then be used for heating ventilation air. The PV Solar Wall is a variation of their standard Solar Wall, which collects thermal energy using the same perforated absorber plate without the PV panels. [27]

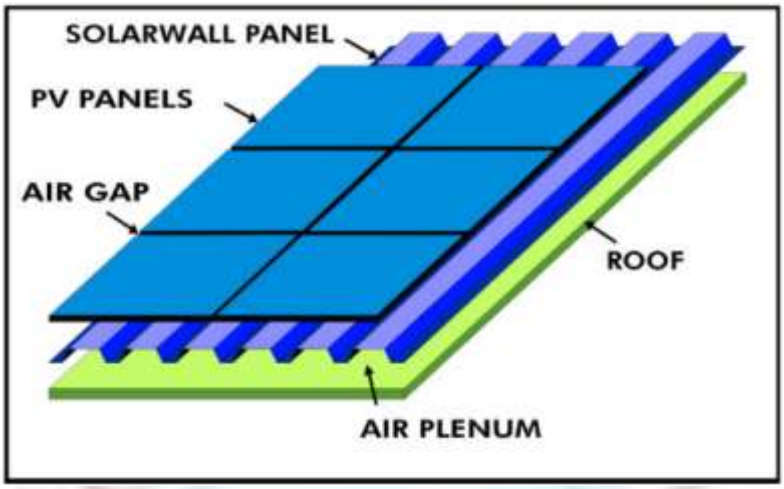

Fig.(7): PV Solar Wall

Another manufactures currently have a commercial available PV/T product where the PV panel is cooled by air for preheating ventilation air. The product is made available in 4 different module sizes ranging from 50 kWp to 250 kWp per module as shown in Figure (8). [28]

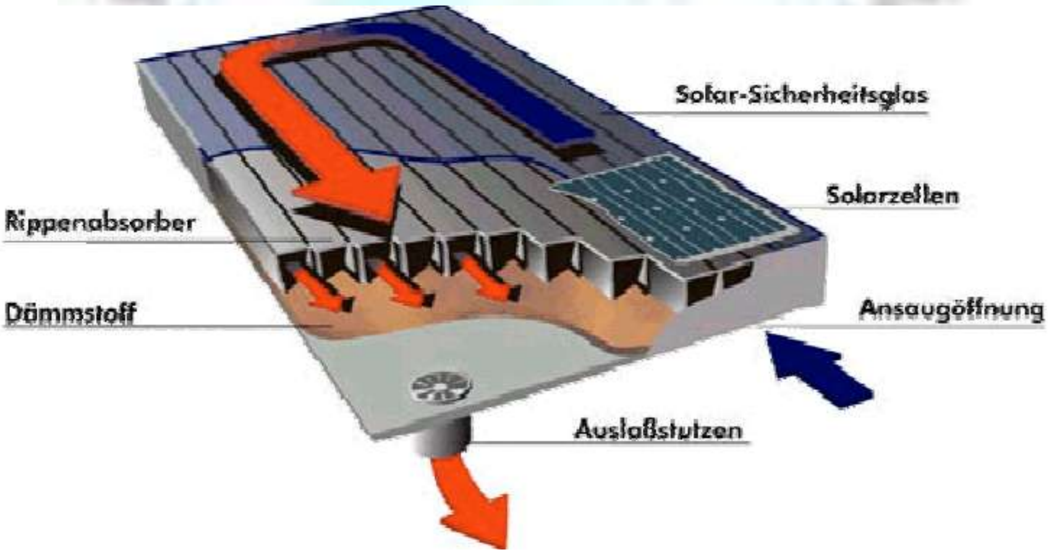

Fig. (8): The internal construction of the solar wall

4. Design Considerations:

The following paragraph summarizes the specifications regarding recommendations for designing BIPV solutions with PV/Thermal solar collectors. The recommendations are provided by researchers and other external companies and scientists working in the field of designing solar thermal systems and PV systems.[29]

4.1 General recommendations:

In choosing what type of PV/T system is most suitable for a particular project, the project demands need to be considered, e.g.:

1. Temperature and characteristics of thermal load
2. Thermal load (kW)
3. Electrical load (kW)
4. Suitable mounting locations
5. Building constraints, e.g. weight bearing capacity, aesthetics

The current technical level of the commercial PV/T systems still need to be verified tested and monitored. Still many issues regarding the combination of materials, the dependency on temperature level on the overall yield and the optimum combination of heat and electricity production for various climates and applications needs to be determined.[29]

5. Initial calculations and Results:

Whether a PV/T collector is better than a separate PV module and a solar collector or not, depends on several factors:

- Is space a problem, or is the total collector area unimportant?
- Does the load profile fit to the combined production of heat and electricity?
- Does the installation become simpler or more difficult than in separate systems?
- Does the production costs increase due to a more complex construction?

In order to get a first estimate of the characteristics of PV/T the traditional and well-documented set of equations for solar thermal collectors are used. The only difference to a PV/T collector is that a part of the collected energy is extracted as electricity instead of heat. If the formulas are corrected for this and secondary effects such as radiation heat transfer inside the solar cells are neglected, they are valid for the PV/T collector.

5.1 Performance in terms of energy and energy:

When the various types of PV/T collectors are to be evaluated, a principal question arises – what is the value of the electricity versus the heat form the collector? The consumer's rate of electricity and heat is to a large extent a politically determined value, and if those rates were used the results would not be universally valid. We have therefore chosen to present two key figures for each collector:

1) The total energy yield per year for the researchers. The results are calculated from the 1st. law of thermodynamics, known as the **energy efficiency**.

2) The total energy per year, which is the part of the energy that could theoretically be converted to work in an ideal Carnot process. The results are calculated from the 2nd. law of thermodynamics, known as the **energy efficiency**.

The **energy efficiency** is calculated as:

$$\eta_{thermal} = \frac{Q_{thermal}}{G}$$

$$\eta_{power} = \frac{Q_{power}}{G}$$

$$\eta_{total} = \frac{Q_{thermal} + Q_{power}}{G}$$

While the **energy efficiency** is calculated as

$$\varepsilon_{thermal} = \frac{Q_{thermal} \cdot (1 - 293K/(293K + (T - T_a))}{G}$$

$$\varepsilon_{power} = \eta_{power} = \frac{Q_{power}}{G}$$

$$\varepsilon_{total} = \frac{Q_{thermal} \cdot (1 - 293K/(293K + (T - T_a))}{G} + \frac{Q_{power}}{G}$$

Where

$$Q_{power} = \eta_{el,ref} \cdot (1 - \beta_{ref} \cdot (T - T_a)) \cdot G$$

$$Q_{thermal} = (\eta_0 - U_L \cdot \frac{(T - T_a)}{G}) \cdot G$$

The constants and the calculated variables for use in the above expressions are found in table 1.

Table 1. Constants and variables for use in efficiency expressions

	No coverplate	15 mm acrylic coverplate directly on PV cells	15 mm acrylic coverplate with an airgab between coverplate and PV cells
G	800 W/m^2	800 W/m^2	800 W/m^2
η_0	0,6101	0,6236	0,6100
U_L	14,8192	8,3618	7,2165
$\eta_{el,ref}$	12,5 %	12,5 %	12,5 %
β_{ref}	0,005	0,005	0,005
T	293 K	293 K	293 K

5.2 Results:

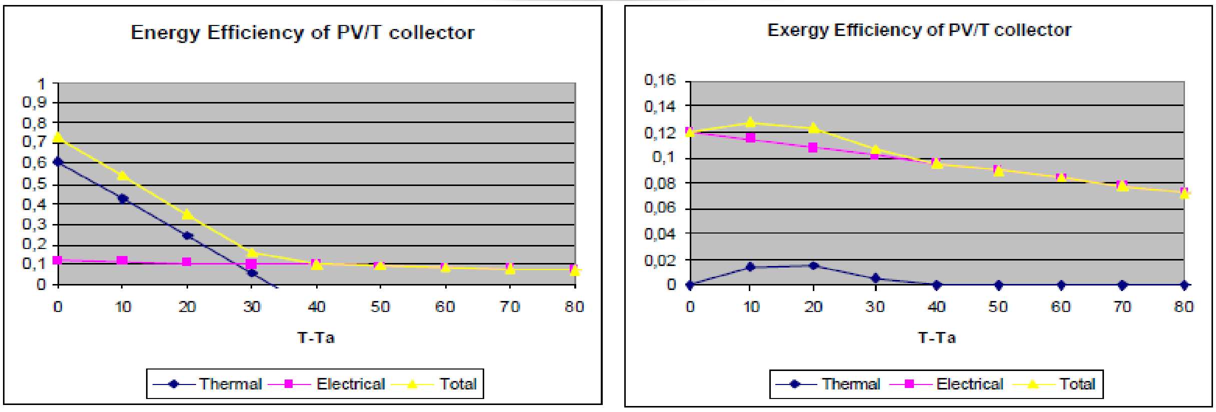

Figure 9: Efficiency of PV/T collector without coverplate

Table .1 and the curves in Figure (9) show that the high heat loss coefficient due to the low thermal resistance of glass results in a low thermal performance at temperature above 20K over ambient temperature.

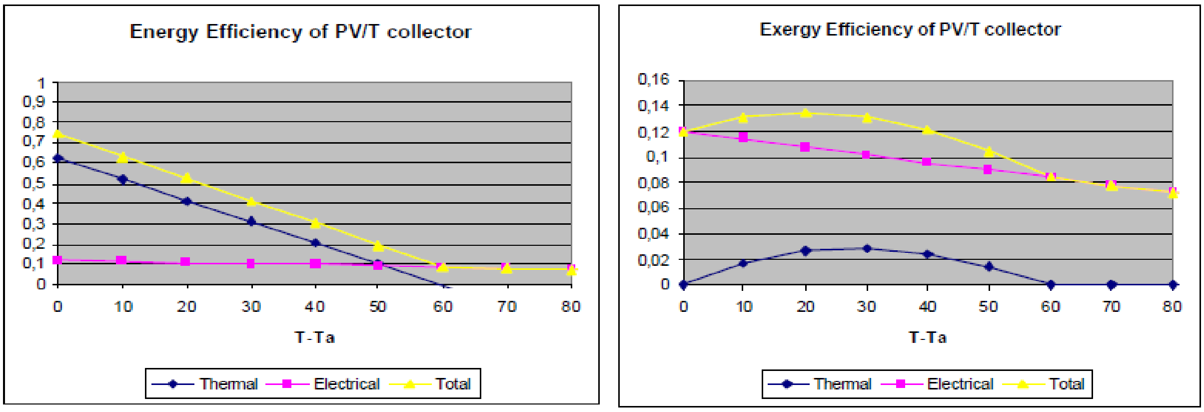

Fig.(10) : Energy Efficiency of the PV/T collector with temp.

In case b) the thermal performance is improved for temperatures above 10K over ambient temperature. The electrical output is almost the same for the two, because acrylic has very good optical transmission properties so the thickness is not a serious drawback.

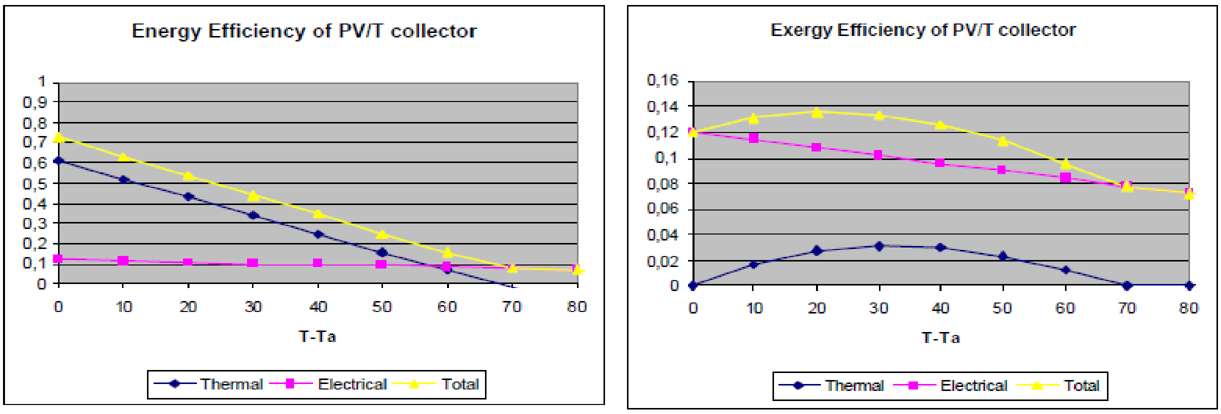

Fig.(11): Energy Efficiency of PV/T collector

Efficiency of PV/T collector with 15 mm acrylic coverplate and air-gab between coverplate and PV cells f an air gap is introduced between absorber/PV cells and the coverplate, the thermal performance is slightly improved, but not to the level of modern solar collectors with a selective coating. All simulations were made with a back insulation of 30 mm mineral wool and an ideal heat transfer from solar cells to the collector fluid. It is clear that the practical performance depends on the system the collectors are a part of. Assuming that the PV part is grid connected, and all produced power therefore is useful, it is mainly the temperature level and thermal storage size that determines the actual yield.

6. Conclusions:

The status of commercial PV modules is that only 10-15% of the incident solar energy is transformed to electricity. The potential heat production from a given surface is thus much higher than the electrical performance, but it is an open question whether this heat can be used in a sensible way. Combining PV and a solar thermal collector for tap water heating ends up with a temperature compromise. PV needs to have a low temperature to maintain a high efficiency, whereas a solar thermal collector requires a high temperature. With the current technologies, the PV/T combination has a lower efficiency than two separate systems and, due to the initial development stage, the PV/T combination is also more expensive. However, advantages are foreseen in aesthetics, future (production & installation) cost reductions and market / consumer.

Air-cooled PV panels for electrical and thermal gain is currently the most commonly used PV/T system. It is most suitable for façade type applications. These BIPV systems add a little thermal to the PV. Otherwise, thermal systems are available that adds a little PV to their thermal gains e.g. PV powered thermal collectors produced by manufactures.

In between are products being developed , that both optimise the use of PV and the thermal system. These systems have PV cells integrated on the absorber in a conventional solar thermal collector. There are a number of companies working in developing commercial liquid PV/T collectors but currently only three companies **AG** have succeeded. There seems to be a problem in maintaining the long time stability of the solar cells as they are integrated on the absorber. These systems need to be developed further to serve the large consumer market of solar powered energy (heat and electricity).

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