Utilization of Heat from PV-Air Collectors in Residential Buildings

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Abstract: ***The purpose of this project is to find and evaluate suitable models of a PV air collector for building integrated applications. Especially the focus is based on the models developed by TRNSYS and POLYSUN simulation tools. In this report, two types of PV air collectors are explained. One is normal PV air collector and the second is building integrated type collector. As PV air collector is a niche area in solar thermal, very little amount of research has been done so far in this very area. This project has done in two stages. In the first stage, literature survey was done and in the second stage, simulation was done on the available models. The collectors found were categorised based on their type (Flat plate, concentrated), parameters and inputs. One can choose a collector among the available models based on their need. This project can be used as a starting point for those who want to work with PV air collectors.***

Keywords: Solar enrgy, PV-air collectors, Residential buildings, TRNSYS.

1. Introduction

There are two possible ways so far to directly utilize the energy from sun beams and convert into different forms of energy. One way is to use photovoltaics to produce electrical energy and the second way is to use solar thermal collectors to produce heat and this heat can be transferred to a medium (air, water or fluid) and can be further used to heat water, heat air or even to heat swimming pools.

Currently the efficiency of photovoltaic cells is around 14 to 19% and the efficiency of solar collectors is around 30% annually. These efficiencies are looking quite low but these are the best achievable efficiencies for dominant solar technologies in the current market. Though the recorded efficiencies in research laboratories are quite higher than the ones mentioned above, they are restricted to laboratory level.

In order to improve these low efficiency issues, PV/T systems came into picture. This system is a combination of solar photo voltaic and solar thermal system, which can produce both electrical energy and thermal energy from the solar irradiation. In this system, the solar cells convert light from the sun into electricity and the solar thermal collector does the work of absorbing remaining waste heat from the PV module. In this way by capturing the waste heat from the PV module, it is indirectly increasing overall energy efficiency of the system than compared with solar thermal or photovoltaic system alone.

PV-Air Collectors:

A PV-air collector is similar to PV-water collector. In a PV-air collector (Fig.1), air is circulated through the collector instead of water circulation. This type of collector is used when there is a demand of hot air.

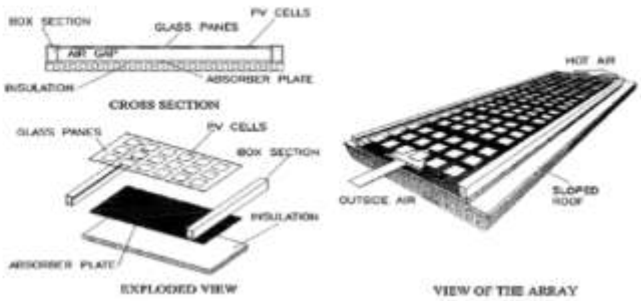

Figure 1: PV-Air collector

These collectors are cheaper, light weighted and comparatively less complex than PVT water collectors. In a PV air collector, leakage and corrosion are less of a concern and high pressure protection is not required.

In PV/T collectors, PV cells are integral part of the absorber surface and air flows through the passage attached with the absorber plate. As this air removes the heat from the back of the PV, it increases the efficiency of the panels. This heated air can be used for following applications,

- Space heating applications using this heated air, space heating for residential and commercial buildings can be done.
- Process heat applications

This heated air can be used in process application like drying of laundry, fruits, crops and other drying applications in which removal of moisture from the material is required

2. Previous Research

Transient system simulation analysis is a software which is used to simulate the behavior of transient systems. It is quite useful to analyze the practicability of a system

The table1 shows the history of different kind of models on PV/T-air collectors. Majority of these models were developed by IEA (International Energy Agency) as a part the programme called SHC, (Solar Heating and Cooling) which was established in 1977 to promote solar thermal energy.

Table 1: Practical models

Type	*Observations*	*Sourse*
Type 50	Floating point error	Basic model in Trnsys
Type 555 and Type 56	More specific in their applicability	A report of IEA SHC [1]
Type 201	Consideration of panel geometry on shading of the cell	A report of IEA SHC
Type 250	Correction of floating error and error in temperature coefficient	A report of IEA SHC
Type 251	Reorganization of model inputs, outputs and parameters	A report of IEA SHC

Type 50 model is the base for all other models. The usability of type 50 is limited because of the errors in it. Therefore new models were developed by doing modifications to type 50 model. As listed in the table, every other model has their own purpose behind it. As these models have different purposes and consists of complexity in using them, they are not used in this project.

Table 2: Theoretical models

Type	*Purpose*	*Source*
Type 560, Type 563	Modified model of Type 50 to compare the performance	A study of PV/T hybrid system with mathematical modelling [2][3]
Type 850	Developed using analytical solution to calculate cover temperature in flat plate collectors	Analysis of flat plate PV/T models [4]
Type 223	Mathematical model with radiation heat loss	Modelling of glazed liquid PV/T collector [5]

These models are limited to theory. In order to implement these models we need to solve these equations and create a new component using the solution. These models are also having the same problems like the models in the table1. So these models are not used in this project.

3. Available models

As per the aim of the project, research has been done on available models of PV-air collector in TRNSYS and POLYSUN simulation tools. After doing a rigorous research, we concluded that there was no previous research of PV-air collectors in POLYSUN but we were able to find some models on TRNSYS. Though there are more sub models under type50, only one of those models showed in Fig.2. However, the rest of the models are listed in the table 4.

Figure 2: Available Trnsys models[8]

The models Type 566 and Type Type569 can couple to a simple building model and the models Type 567 and Type Type568- Can couple to a more detailed building model (type- 56).[7]

Type 50: This is the basic PV/T model in TRNSYS. It lies under photovoltaic panels which is a component under "Electrical" library. There are sub models in this component namely 50a, 50b, 50c, 50d, 50e, 50f, 50g and 50h. The models type 50a, 50b, 50c and 50d are flat-plate collectors and the rest of the models are concentrating collectors. Table 3 shows some common parameters of these models.

Table 3: Common parameters of Type 50 models

	Parameters	Units
1	Collector area	m2
2	Ratio of aperture to absorber area	-
3	Fluid thermal capacitance	kJ/kg.K
4	Heat transfer coefficient	kJ/hr.m2.K
5	Plate absorptance	-

Table 4: Characteristics of Type 50 models

Model	Type	Losses	Remarks
Type50g	Concentrating collector	Constant losses	Cell operating voltage is input
Type50e	Concentrating collector	Constant losses	No cell operating voltage
Type50h	Concentrating collector	Top loss is f (wind, temperature)	Cell operating voltage is input
Type50f	Concentrating collector	Top loss is f (wind, temperature)	No cell operating voltage
Type50c	Flat plate collector	-	Angular dependence of transmittance
Type50a	Flat plate collector	Constant losses	-
Type50d	Flat plate collector	Loss is f (T, WS, G)	-
Type50b	Flat plate collector Constant losses	Loss is f (T, W, G)	-

There is no picture of construction or heat transfer of the model is available for this type. As "fluid thermal capacitance" is one of the parameters, this model is considered in. Because there is a possibility of changing fluid thermal capacitance.

Type566: Glazed-Building integrated PV System (Interacts with zone-air temperature): This component refers to a glazed PV/T air collector model. It has two purposes. The first purpose is to generate power from the photovoltaic cells and the second purpose is to provide the waste heat from the back side of panel to an air stream passing behind the PV panel. This component or model can be coupled with simple building models. A simple building model can provide the zone air temperature behind the collector. Fig.3 shows the structure of 566 Model.

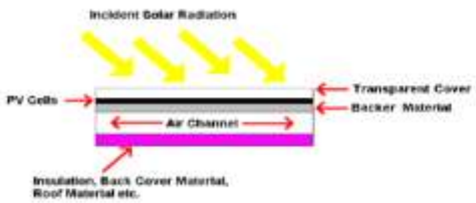

Figure 3: Construction of Type 566 Model (Glazed)

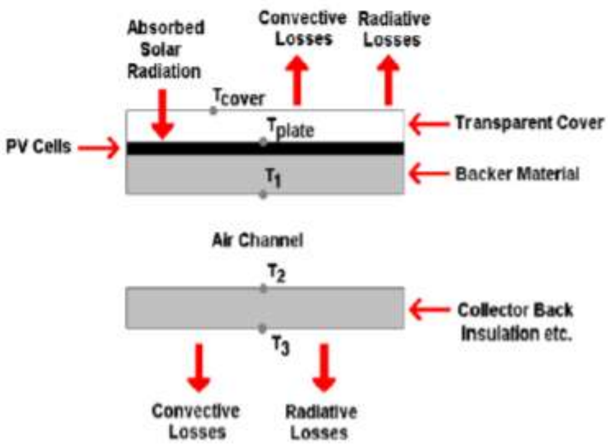

Figure 4: Heat transfer in the Type 566 Model [8]

Fig. 4 shows the heat transfer in the model. As solar radiation falls on cover surface, it gets absorbed by the absorbing surface while some of it gets wasted as convective and radiative losses. From this absorbing surface heat is transferred to upper-air channel through conduction. This heat is then transferred through the air to the required application. Some part of this heat gets transferred to the back of the collector through conduction.

Type567: Glazed-Building integrated PV System (Interacts with Type 56 Building Model): This component refers to a glazed PV/T air collector model. It has two purposes. The first purpose is to generate power from the photovoltaic cells and the second purpose is to provide the waste heat from the back side of panel to an air stream passing behind the PV panel. This component or model can be coupled with detailed building models. In a detailed building model user has the freedom to define various parameters refers to the building. Type 56 component in TRNSYS is an example of detailed building model.

Type569: Unglazed-building integrated PV system (Interacts with zone-air temperature): This component is similar to type566 but it does not have any glazing. It refers to an unglazed PV/T air collector model. It has two purposes. The first purpose is to generate power from the photovoltaic cells and the second purpose is to provide the waste heat from the back side of panel to an air stream passing behind the PV panel. This component or model can be coupled with simple building models. A simple building model can provide the zone air temperature behind the collector. Fig.5 shows the structure of Type 569.

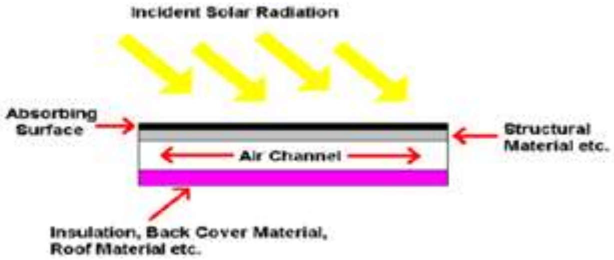

Figure 5: Construction of Type 569 model (Unglazed)[8]

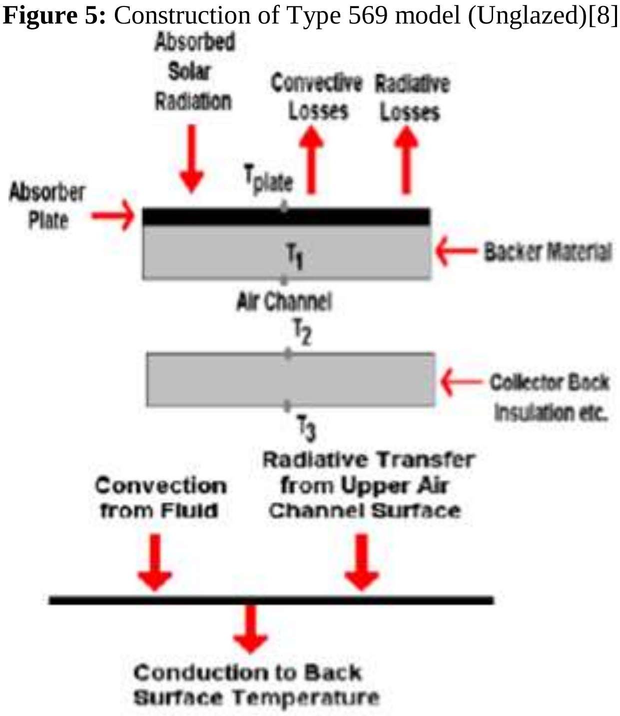

Figure 6: Heat transfer in Type 569 Model[8]

Fig.6 shows heat transfer in the unglazed building integrated PV system. As this model does not have a cover surface, solar radiation falls directly on the absorber plate. This absorbed heat gets transferred to upper-air channel surface through convection and some heat gets lost as convective and radiative losses. Rest of the heat transfer is same as glazed building integrated PV model.

Type568: Unglazed-Building integrated PV System (Interacts with Type 56 Building Model):
This component is similar to type567 but it does not have any glazing. It refers to an unglazed PV/T air collector model. It has two purposes. The first purpose is to generate power from the photovoltaic cells and the second purpose is to provide the waste heat from the back side of panel to an air stream passing behind the PV panel. This component or model can be coupled with detailed building models. In a detailed building model user has the freedom to define various parameters refers to the building. Type 56 component in TRNSYS is an example of detailed building model.

4. Comparison between the models

Comparison between available models has done by simulation in TRNSYS for simulation time of 2880 hours to 2904 hours. Table 5 shows inputs and parameters which have given to the models.

Table 5: Common inputs for models

Inputs	Value	Units
Collector area	1	M2
Collector slope	21	Degree
Location	Nagpur, India	
Emissivity	0.9	
Absorptance	0.9	
Fluid flow rate	50	Kg/hr
PV efficiency	0.12	
Solar irradiation	5.38	kWh/m2/day

Models of type 566-1, 567-1, type 568-1 and type 569-1 and all sub models in type 50 simulated as a part of the project. Building integrated models were compared among each other and type 50 models were compared among each other. Models were simulated by giving the same values for various parameters which are listed in the below tables.

Table 6: Parameters for Type 566-1, type 567-1, type 568-1 and type 569-1(building integrated) models

Parameter	Value	Units
Cover conductivity	5.04	kJ/hr.m.K
Cover thickness	0.00635	m
Top heat loss coefficient	25	kJ/hr.m^2.K
Bottom heat loss coefficient	11	kJ/hr.m^2.K

Table 7: Parameters for Type 50 g, type e, type h and type f (concentrated) models

Parameter	Value	Units
Back loss coefficient for no-flow condition	10	kJ/hr.m^2.K
Heat transfer coefficient	5	kJ/hr.m^2.K

Table 8: Parameters for Type 50 c, type a, type d and type b (flat plate) models

Parameter	Value	Units
Collector loss coefficient	5	kJ/hr.m^2.K
Temperature coefficient of pv cell efficiency	-0.0003	1/K

5. Results

The table 9 and table 10 show the results from TRNSYS simulation of various PV air collectors. Type 566-1 and type 569-1 are glazed and unglazed collectors respectively. Both of them can be coupled with a simple building model. Type 50 is a glazed collector with different variables as inputs.

Table 9: Results of simulations

Type	Useful energy gain (kJ/day)	Power production (kJ/day)	Total loss (kJ/day)
566-1	1.74 E+04	1.25 E+04	7.38 E+04
567-1	1.77 E+04	1.25 E+04	7.37 E+04
568-1	1.64 E+04	1.25 E+04	7.55 E+04
569-1	1.96 E+04	1.41 E+04	8.35 E+04

Type	Useful energy gain (kJ/day)	Power production (kJ/day)	Total loss (kJ/day)
50h	2.25 E+04	0.00 E+00	3.12 E+03
50f	1.84 E+04	3.47 E+03	1.78 E+03
50g	7.82 E+04	0.00 E+00	4.59 E+02
50e	7.86 E+04	6.97 E+02	2.29 E+02
50d	4.78 E+04	1.06 E+04	5.56 E+03
50b	6.44 E+04	1.00 E+04	5.58 E+03
50c	5.65 E+04	1.07 E+04	2.45 E+03
50a	7.99 E+04	9.88 E+03	2.41 E+03

It is evident from the results that type 566-1 is producing more power and has more useful energy than the other available building integrated PV air collectors. Type 50 c is producing more power (kJ/hr) than any other type50 concentrated models. Type 50 f and type e models generating the power among flat plate type 50 models

6. Discussion

The models simulated in this project falls into two categories. One is type50 collectors and the other is building integrated collectors. All of these collector models divided based on their inputs. Each type of collector has a purpose. For example, if top losses are important in a project then they can go for type50 h or type50 f. If there is no importance for losses then they can go for constant losses type models. If PV efficiency is of importance then it is better to consider type 566. Like these examples, each model carries a purpose. There is enough amount of data available for building integrated models. Therefore, it was easier to analyze them. However, the data available for type50 models is not enough to understand (construction and heat transfer) them. Based on the parameters of type50 models they were considered as PV air collector models. As building integrated models have the access to couple them with a simple or detailed building model in TRNSYS, they are the best option for those who wants to analyze the performance of a PV air collector in building integrated system applications.

7. Conclusion

PV-hybrid or PV/T collectors can be classified into four types. They are, PV/T liquid collector, PV/T air collector, PV/T liquid and air collector, PV/T concentrator. Water based models are very common amongPV/T collectors. There had not been much focus on PV air models. These kind of models developed only for research purposes. Majority of households use various heating methods to heat houses and these methods consumes lot of electricity. An air collector can be used as a substitute for heaters in the households. It has the potential to replace traditional heating methods (district heating, heat from wood and coal,etc.) in the households. Households are not the only beneficiaries from this type of collectors. Their exist lot of sectors which need hot air.

As the PV/T air collector model is available in TRNSYS, one can easily model a collector based on their requirement (household, industrial, etc.).

This report will be starting point for those who wants to study the performance of PV air collectors in building applications and the performance of PV (efficiency) cells with air collector(hybrid model).

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