Operation of Solar Photovoltaic-Thermal (PVT) Hybrid System in KIER

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Absract: The details of the Photovoltaic Thermal (PVT) hybrid air heating system, UTC air heating sys tem and its effect on the performance of photovoltaic (PV) module and room temperature in KIER are expl ained in this paper. Two identical test rooms were co nstructed such that one had unglazed transpired colle ctor on its south facing wall while other had no solar wall. The temperature inside the room with UTC was 10-20°C higher than the temperature inside the room wit hout UTC on a typical winter day. In second set of ex periments, 75W PV modules were installed on the so uth facing walls of each test rooms. The temperature of the PV module with UTC was 5-9 ℃ lower than the PV module without UTC resulting in a 6% recovery of output electrical power under the for ced ventilation. PVT hybrid system may alleviate bur den on conventional energy consumption in Korea fo r heating the buildings and electricity generation.

1. INTRODUCTION

South Korea is a conventional energy resources deficient country and over 95% of energy requirements are met through imported energy. It is estimated that the primary energy use will increase by 23.61% in 2011 (KEEI, 2005). Therefore, it is imperative to utilize renewable energy sources to gain more energy independence, and meet ever increasing conventional energy prices and obligations of climatic change conventions. More than fifty percent of the total energy consumption is in the industrial sector whereas 25% is used in the buildings. Due to extreme cold climatic conditions in winter, half of the energy consumed in buildings is for heating. Thus, using alternative heating source other than the conventional energy sources is expected to reduce the burden on the national exchequer used for importing energy sources. The yearly averaged daily solar radiation on horizontal surfaces in South Korea is 3.56kWh/m^2/day (Jo et al, 2002) and it can play an important load in reducing the building heating load as well as generate electricity using PV modules.

Unglazed Transpired solar Collector (UTC) air heating system utilizes solar energy for building ventilating and heating in winter. It uses air instead of water as heat transfer medium therefore it is free from any risk which may arise due to possible water freezing during winter in the water heating systems. UTC system is easy to install and less costly as compared to glazed solar thermal collectors (Hollick, 1994). Photovoltaic Thermal (PVT) hybrid systems can generate electricity using photovoltaic modules and thermal energy using the solar thermal collector at the same time (Hegazy, 2000). The energy yield per square meter is improved and the system requires less area for installation as compared to its individual components. It is more important in the urban areas where the availability of land or space for the installation of solar collectors (photovoltaic or thermal) is a problem. In this paper the operation of PVT hybrid air heating system in Korea Institute of Energy Research (KIER) is described and characterized under transient conditions. The effect of the photovoltaic module on the thermal performance of UTC and effect of UTC on the electrical performance of PV are studied by using three different configurations. First configuration consists of UTC air heating system. Second configuration uses PV module with UTC air heating system and third configuration utilizes PV without UTC. The thermal and electrical performances of UTC and PVT hybrid system are monitored and results are presented.

2. UTC AIR HEATING SYSTEM

Fig. 1. Identical test rooms for monitoring UTC performance

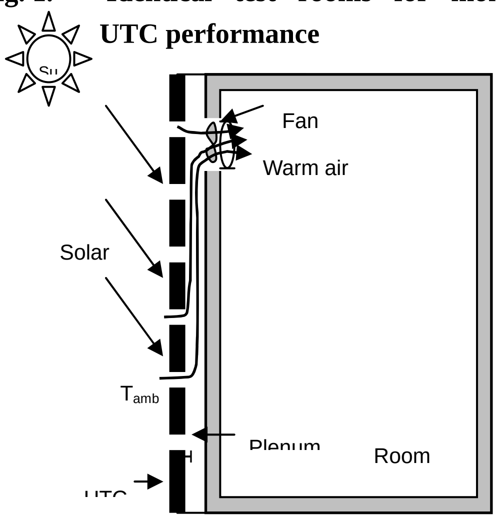

Fig. 2. Schematic of UTC air heating system in KIER

Two identical rooms have been chosen for the performance monitoring and verification UTC performance. The twin test rooms used in the experiment are shown in figure 1. Each test room is 2.7m wide, 2.8m high and 2.4m deep. The thermal and physical characteristics of the room are given in Table 1. Unglazed transpired solar collector made of corrugated steel absorber sheet with perforations covering 1% of its surface area was fixed to the south-facing wall of the room. The area of the UTC was 6.48m^2 with a 0.1m plenum connected by a fan inside the room for heated air circulation or ventilation purposes. The gap between the UTC and wall was covered on all sides. An opening was made in the center near the ceiling to draw the outside air into the room using a fan (Figures 1 and 2).

The schematic of operating principle of the UTC air heating system is shown in figure 2. Selective solar paint is coated on the surface of the UTC to absorb the incident solar radiation. The temperature of air entering the plenum is increased by heat transfer through conduction and convection from the UTC front, back surfaces and through the holes. The UTC has a large number of small holes so that when the fan is operated the outer air inflows into the air gap through the holes, it absorbs heat by convection before it enters the room. The heat losses to the surrounding by convection are negligible for large area UTC and air flow rate or approach velocity higher than 0.02m/s (Dymond and Kutscher, 1997).

Tab. 1.Characteristics and Dimensions of the two Test rooms

Building	Dimension	2.7m × 2.8m × 2.4m	
	Volume	18.14 m^3	
	Wall area	41.52 m^2	
	Floor area	7.56 m^2	
Wall Material	Steel module	Conductivity (W/m-k)	194
		Thickness (m)	0.02
	Urethane foam	Conductivity (W/m-k)	0.047
		Thickness (m)	0.075
Thermal properties	U	1.65 kJ/hr ^{o}C	
	UA	68.51 kJ/hr m^2 ^{o}C	
	CAP	17039.18 kJ/ ^{o}C	
	Dimensions	2.7 x 2.4 m^2	
	Area	6.48m^2	
	Pitch	20mm	
	Hole diameter	1.65mm	
	Plenum depth	0.1m	
	Absorptivity	0.93	
	Emissivity	0.89	
	Porosity	1%	

$$\eta_{th} = \frac{\rho \dot{m} c_p \left(T_{plen} - T_{amb}\right)}{A G_T} \qquad (1)$$

The energy conversion efficiency η_{th} is defined as the heat transferred to the air volume over the solar radiated heat added to the UTC and it can be expressed as (Summers 1995):

Where G_T is the total global solar radiation incident in the plane of the UTC. the density (ρ) and specific heat of air (C_p) was given as 1.15 kg/m^3 and 1,007 J/kg^{o}C respectively for each temperature. The mass flow rate ($\dot{m}$) can be written as:

$$\dot{m} = VA \quad (2)$$

Where approach velocity (V) is defined as a specific air flow rates per unit area, which is simply fan air flow rate divided by collector area 'A'.

The measurement of solar radiation was made by Eplab's PSP (Precision Spectral Pyranometer) installed at the south wall of the experimental building so that it could measure the total global solar radiation incident on the UTC surface. The outer building temperature and UTC air heating system plenum temperature and the inner building temperature were measured by T-type thermocouple (Omega, USA). The fan was operated at a flow rate of 110CFM to draw the warm air into the room.

3. PVT HYBRID AIR HEATING SYSTEM

Two PV modules of 75W output power each manufactured by S-Energy Co. Ltd have been used in two different configurations. The first one is a typical PV without UTC configuration in which PV module is mounted directly on the south facing wall of a room as shown in figure 3. The characteristics of the PV modules are given in Table 2.

Fig. 3. Twin test rooms for PVT hybrid air heating system performance monitoring.

Tab.2. Electrical Parameters of 75W PV Module Used in the PVT Hybrid Air Heating System at 25°C and 1000W/m^2.

Maximum Power (P_{max})	75W
Voltage at P_{max} (V_{mp})	17.3V
Current at P_{max} (I_{mp})	4.35A
Short circuit current (I_{sc})	4.75A
Open circuit voltage (V_{oc})	21.8V
Temperature coefficient of Power	0.5±0.0.5%/°C
Total number of solar cells	36
Number of cells in series	36

In the second configuration, PV module without the frame was mounted on the UTC. The junction box behind the PV modules might have caused some air flow disturbances and make the ventilating airflow at the gap turbulent in nature. The PVT hybrid air heating system setup is shown in figure 3 and figure 4.

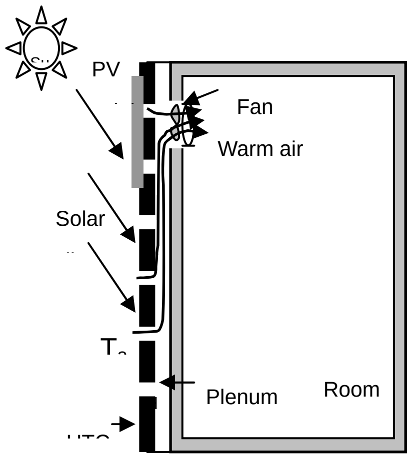

Fig. 4. Schematic of PVT hybrid air heating system in KIER

The electrical conversion efficiency (η_{elec}) of the PV module is given by:

$$\eta_{elec} = \frac{I_{mp} \; V_{mp}}{A_{PV} G_T} \quad (3)$$

where I_{mp} and V_{mp} are the current and voltages of the PV module at the maximum power point. A_{pv} is the area of the PV module. The combined effeiciney of the PVT system can be written as:

$$\eta = \eta_{th} + \eta_{elec} \quad (4)$$

The dimensions and characteristics of both the south facing walls and the rooms are the same as listed in Table 1. The electric output power of the PV was recorded for both systems using a data logging system under the same measurement conditions such as solar radiation and ambient temperatures. For the present experimental work, the airflow rate was fixed at 160 CFM. The temperature conditions were measured with a Type 'T' thermocouple (Omega Co USA). Global irradiance was recorded using a calibrated pyranometer model M11 Kipp and Zonen (Holland) connected with a high–precision millivolt meter and installed on the south facing wall of the PV without UTC . The fan in the PVT hybrid system was turned on between 12:00noon and 5:00pm to study the effect of the forced air ventilation on the PV module temperature.

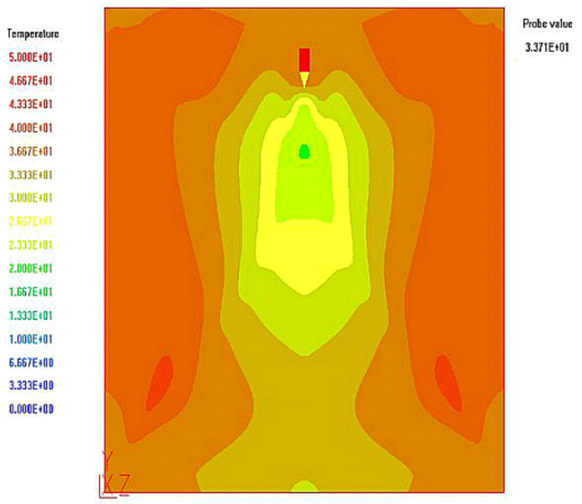

Fig. 5. Temperature variation across the UTC under forced ventilation

The effectiveness of heat extraction from the back of the PV module will depend on the position of the PV module on the SW. It is desired to place the PV module at a position where the temperature is the lowest so that maximum heat could be removed from the PV module. The UTC air heating system without the PV module was simulated using Phoenix simulation software to find out the temperature distribution over the area of the UTC. The simulation results are shown in figure 5. The temperature is higher on the right and left edges of the UTC but it is lower in the central region. The temperature is lowest at the position of the ventilation fan. These simulations provided the basis for the most suitable position of the PV module on the UTC to achieve the maximum cooling of the PV module.

4. RESULTS

4.1 Thermal Output Of UTC Air Heating System.

The time dependent transient of solar radiation, ambient temperature, plenum temperatures without and with UTC air heating system are shown in figure 6. Room 1 is the room with UTC air heating system and room 2 is without the UTC. The plenum temperature of the UTC air heating system was as high as 50°C when the incident total global solar radiation on the UTC surface was about 750Wm^{-2}. During this period the temperature inside the room with UTC was as high as 35°C. On the other hand the maximum temperature in the room without UTC was only 10°C. By using a temperature controller, the room temperature can be maintained at a desired temperature level. The backup heater can be used for heating when the sufficient solar radiation is not available and the indoor temperature is lower than the desired comfort level.

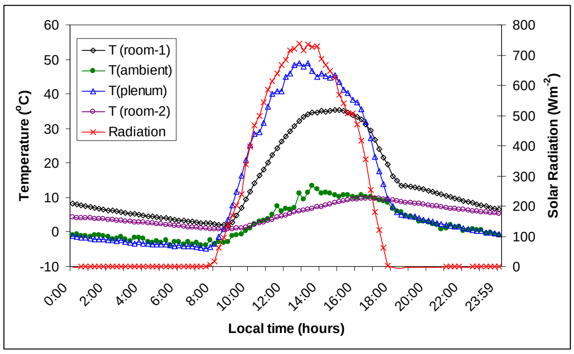

Fig.6. Variation of room and ambient temperatures and solar radiation with UTC and without UTC.

4.2 Thermal Output Of PVT Hybrid System.

The temperature variations inside the two test rooms along with the ambient temperature and solar radiation measured on a typical winter day are shown in figure 7. Room 1 represents the room with PVT and room 2 is with PV only. The ventilation fan was turned on at 12:00noon was turned off at 17:30 hours. The temperature of the PVT hybrid system room is in the range of 15-20°C from 13:00 to 17:00 hours. After turning off the fan and sunset time, the temperature inside the PVT room is reduced. The air duct drawing the plenum air into the room is not closed although the fan was turned off at 17:30 hour which caused the reduction in the room temperature and it was nearly similar to the ambient temperature outside the room. The maximum temperature inside the room without UTC was 10°C around 14:00 hour and then the room gradually cooled down. The room temperature is lower in case of PVT hybrid system when compared to the UTC air heating system is due to the reasons that the outside ambient temperature on the day of measurement is zero or below zero degrees Celsius. On the other had, the outside temperature was 0-10°C during the measurements in case of the UTC air heating system.

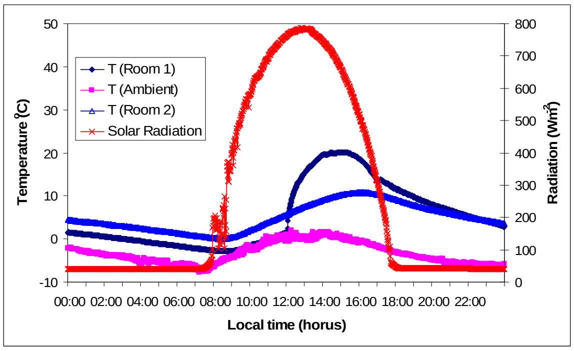

Fig. 7. Variation of room temperatures, ambient temperatures and solar radiation in PVT hybrid air heating system and without UTC.

4.3 Electrical Output Of PV Module.

The measured electrical power output and the simulated power along with the total solar radiation in the plane of the collector are plotted in figure 8. The experiment was carried out on a typical winter day. The sky was clear during the measurements except few clouds in the early part of the day as is evident from the solar radiation data (Figure 7 and 8). The measured electrical outputs of the PVT hybrid system and PV without UTC are shown in figure 8 along with the total global solar irradiance in the plane of the PV module. The electrical outputs of both the PV module were similar before turning on the ventilation fan. However, once the fan was turned on at 12:00noon, the electrical output power of the PVT was increased and it is higher than the electrical power of the PV module without UTC before turning off the fan at 17:30 hours. The PVT electrical output power between 12:30 and 14:00 hours was 57W for PVT case which is about 6% higher as compared to the PV without UTC. The continuous flow of warm air in plenum acts like a cooling source of the PV module resulting in increased output power of the module. The advantages of the PVT option are more obvious during the forced ventilation period as electrical as well as thermal output of the system is higher during this period.

5. CONCLUSIONS

The details of UTC air heating system, the PVT hybrid air heating system, and its effect on the performance of PV module and room temperature in KIER are explained in this paper. Two sets of experiments were conducted. In first set of experiments, the thermal performance of the UTC air heating system was monitored using two identical test rooms. The room temperature of the test room with UTC air heating system reached as high as 35^{o}C during the typical day of winter in Korea (figure 6). The averaged outside ambient temperature was 10^{o}C during the day. The maximum temperature inside room without UTC air heating system was 9^{o}C during the day.

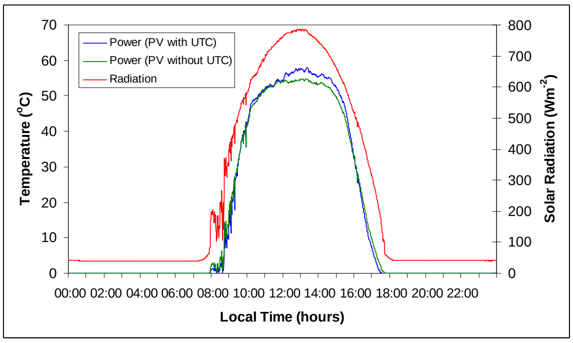

Fig. 8. The electrical power outputs of PVT hybrid system and PV without UTC along with the incident global solar radiation in the plane of the PV modules.

In the second set of experiments, PV module was installed on the south facing walls of identical rooms used in the first experiment. One PV module was installed on the UTC air heating system whereas the second PV module was installed without UTC. Under the forced ventilation conditions, the maximum temperature inside the room with PVT hybrid system was 20^{o}C as compared to 10^{o}C inside the room without UTC (Figure 7). However, the averaged ambient temperature was below 0^{o}C during the day. The temperature of the PV module with UTC was 5-10^{o}C lower than the PV module without UTC resulting in a 6% recovery of output electrical power under the forced ventilation (Figure 8). Thus, it is possible to combine PV and UTC to generate electricity and warm air for building heating at the same time. The heating of buildings in Korea by renewable energy technologies such as PVT may help to reduce the conventional energy consumption for heating in winter and generate electricity simultaneously.

6. ACKNOWLEDGMENTS

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