Combined PV-air collector as heat pump air preheater.

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Abstract – A PV laminate converts roughly 15% of the incoming radiation into electricity, but a far larger part of roughly 65% of the incoming radiation is converted into heat. In order to test if this heat can be collected and used as a source for a heat pump, a system of 20 m^2 PV has been installed on the roof of one of the test houses at the complex of ECN. The monitoring of the system has started in February this year. This paper shows the results of preliminary measurements as well as the the first simulations.

1. INTRODUCTION

A PV-panel not only produces electricity, but it gets hot in the sun as well. Of the incoming radiation, roughly 20% is reflected and 15% is converted to electricity, which implies that 65% goes to heat production in the PV laminate. The hot PV panels can be cooled by an air flow. In this way, both the PV temperature is lowered, which increases PV performance, and the hot air can be used as a source of heat for a heat pump.

2. THE SYSTEM CONFIGURATION

On the complex of ECN, the Dutch Energy Research Foundation, 4 test houses have been constructed as shown in Figure 1. The leftmost of these houses has 20 m^2 PV-panels integrated in its South roof.

Figure 1: The 4 test houses at ECN, labelled 'A' (at the left) to 'D' (at the right). PV is integrated in the roof of the leftmost house (the 'A-house').

Air is drawn through rectangular channels underneath the PV and is then guided to the evaporator of a heat pump boiler. This heat pump boiler supplies heat for space heating and hot tap water preparation.

The heat pump boiler not only withdraws heat from the channels underneath the PV, but also from the emitted ventilation air. In the present experimental configuration, the airflow from underneath the PV is controlled by adjusting the valves manually. In a non-experimental configuration, the heat pump would draw heat from the continuous stream of hot ventilation air that is emitted from the house. Only if the ventilation heat is insufficient, additional hot air is drawn from the channels underneath the PV.

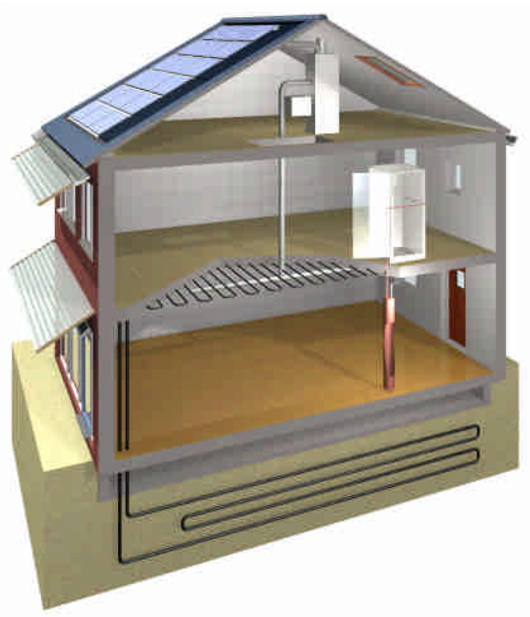

Figure 2: The system configuration in the A-house. The heat pump boiler is located in the attic.

3. MEASUREMENTS

The air gap underneath the PV-roof consists of 3 parallel channels that are connected to a header at the top of the roof. The height of the air gap is 8 cm and the laminate area is 5 meters long and 4 metres wide. The header is connected to the heat pump boiler, and the ventilator of the heat pump boiler withdraws air from the PV-roof if the valves between header and heat pump are open. A shutter is used to open or close the air gap underneath the

PV. In addition, various valves can be set to direct the airflow, as shown in Figure 3. This allows various options:

1. Recirculation of air in the PV-roof/heat pump circuit.
2. Intake of fresh air and exhaust of used air through the chimney.
3. Intake of ambient air through the chimney and exhaust of used air under the PV-roof.
4. No intake of air from the PV-roof but only from the building ventilation system.

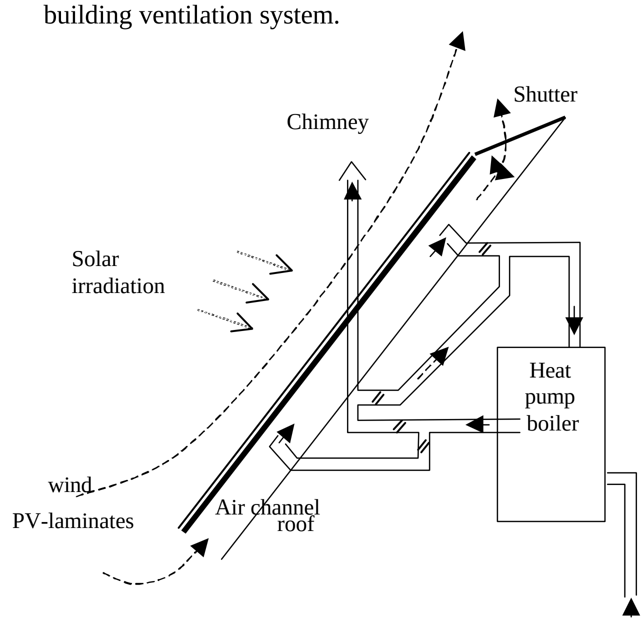

Figure 3: The roof configuration (side view). Note the adjustable shutter on top of the air gap.

The PV temperature is measured with Pt-100 sensors, which are located as shown in Figure 4. Calculations indicated that the volume flow in the three channels can be expected to be equal within 5%. The airflow between PV-roof and heat pump boiler is measured by a flow meter. The ambient conditions are monitored by a meteorological station next to the row of test houses. Several types of measurements have been planned.

1. Natural convection measurements in which the effect of the natural air flow on the PV temperature is established. In these measurements the valves between heat pump and PV are closed.
2. Forced convection measurements in which the heat pump is drawing air from under the PV, possibly in combination with the ventilation air from the house. The effect of the airflow on the PV temperature is established, as well as the efficiency of the roof in preheating the air for the heat pump.

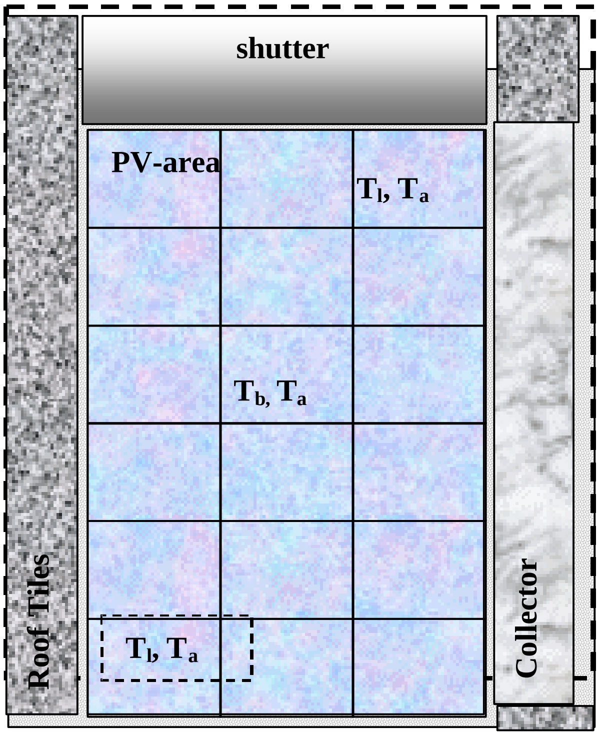

Figure 4: The PV-roof lay-out (top view), consisting of 3´6 PV-laminates. Each vertical row (6 laminates) corresponds to an air channel. The Pt-100's are Ta (rear PV), Tb (top PV) and Tl (airflow).

3. Bypass experiments, in which the PV panel is bypassed, so that heat is extracted from air at ambient temperature directly through the chimney.

The measurements started in February 2001. The main focus has been up till now on the natural convection experiments. Figure 3 shows the rear temperature of the PV as a function of irradiance for the case in which no air was drawn of by the heat pump.

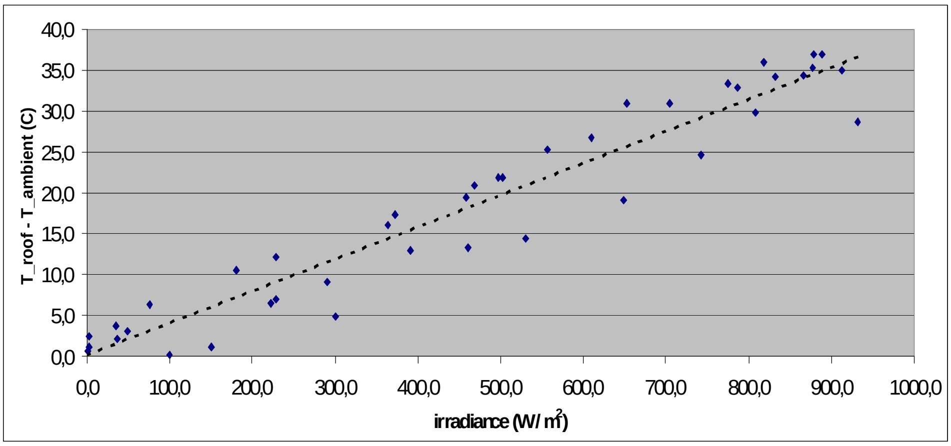

Figure 5: Preliminary measurements of the effect of irradiance on the temperature difference between roof and ambient.

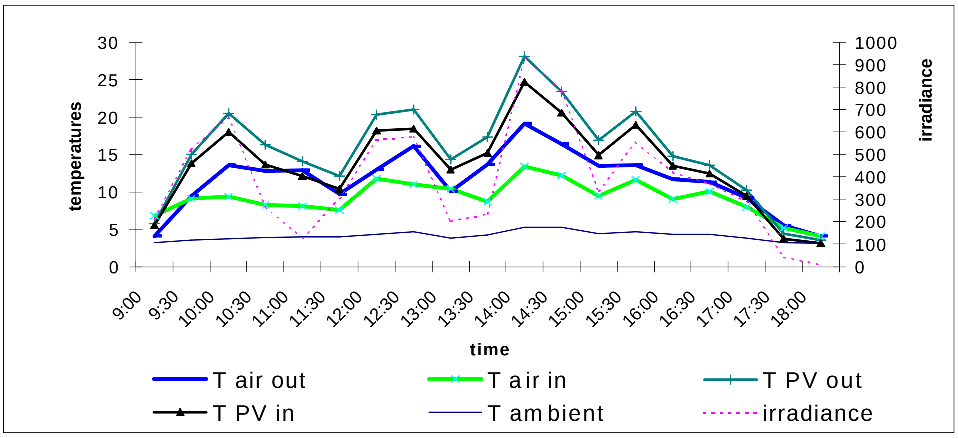

Figure 6: Ambient conditions and temperatures of PV and airflow at 26-2-2001.

Obviously, a substantial heating of the PV roof takes place due to the absorbed irradiation. In Figure 5 data were included only if the wind speed was below 3 m/s. Since the wind speed has an important effect on the heat loss of the PV, increasing the range of wind velocities would strongly increase the scatter in Figure 5.

Figure 6 shows the temperatures of the roof and the airflow for a sunny day in February. Again, the figure indicates a substantial heating of the air by the PV. In addition, the figure shows a substantial temperature rise in the airflow, as indicated by the difference between $T_{ambient}$, $T_{air,in}$ and $T_{air,out}$. This heat will contribute to the energy demand of the heat pump.

4. SIMULATIONS

Initial calculations on the PV-roof were carried out. First the temperature difference was calculated as a function of irradiance. The results are shown in Figure 7 and Figure 8 for two cases

1. An air flow due to natural convection is present in the channel at the rear of the PV.
2. The rear side of the PV is insulated.

For both cases, the wind velocity is taken to be 2 m/s.

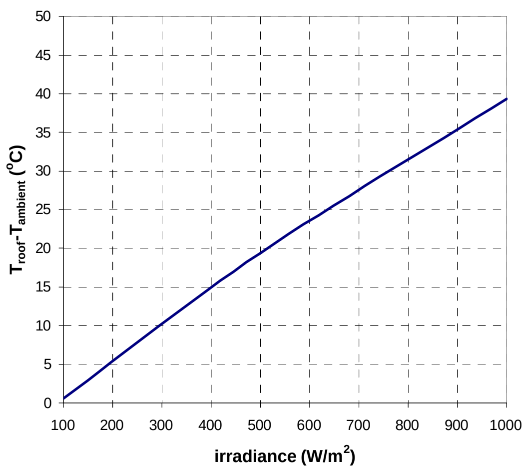

Figure 7: Simulations of the effect of irradiance on the temperature difference between roof and ambient for natural convection at the rear.

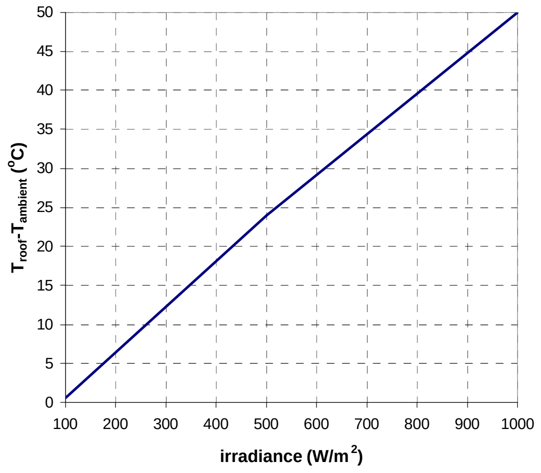

Figure 8: Simulations of the effect of irradiance on the temperature difference between roof and ambient for the case of no airflow at the rear.

Figure 7 shows a fairly good correspondence between the measurements and the simulations for the case of natural convection at the rear side. Measurements indicate that the temperature difference of 10 °C between insulated and non-insulated rear for an irradiation of 1000 W/m^2 is a realistic value.
Next, the thermal efficiency was calculated as a function of the irradiance, as shown in Figure 9. Obviously, the thermal efficiency is rather low for a natural convection system, and decreases even further for low irradiance. For forced convection a higher efficiency is expected. This will be examined in a later stage of the research.

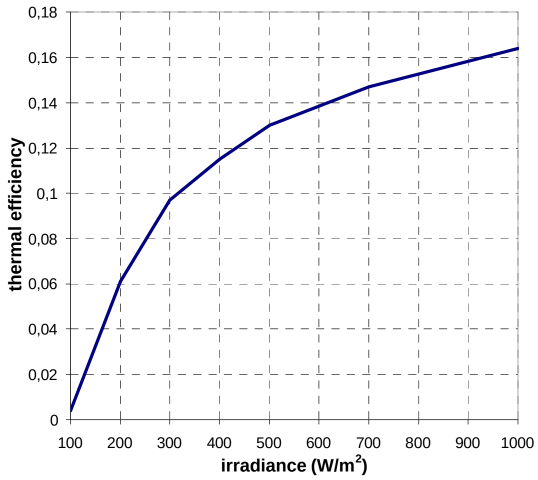

Figure 9: Simulations of the effect of irradiance on thermal efficiency for natural convection at the rear.

5. CONCLUSIONS

Heating of the PV roof of up to 40 °C above the ambient temperature is observed in both measurements and simulations. This heat can be drained off and will contribute to the energy demand of a heat pump.

6. FUTURE PLANS

The measurement program will be continued. The measurements will be used for further validation of the simulation program. This simulation program will then be used for the determination of the seasonal performance factor of the system as well as for optimisation of the system design.