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SYSTEM STUDIES ON COMBINED PV THERMAL PANELS

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Abstract – PV/Thermal panels transform sunlight into electricity and heat. Combining PV panels and thermal panels into one panel results in lower direct electric as well as thermal efficiencies per unit area, but the advantages are a potential cost saving in production and installation and a saving of roof area.

In this study, three different systems with PV/T panels are studied numerically to examine the best way to use these kinds of panels. These systems are:

- PV/T panels for domestic hot water and electricity production. With 6 m^2 PV/T area and a storage tank of 200 liter, thermal and electrical efficiencies of 22.1 and 6.8 % are achievable. The solar fraction is 50.5 % of the total energy demand for hot water.
- PV/T panels for electricity production and preheating ventilation air for a boarding house. With 183 m^2 PV/T area and a storage tank of 150 m^3, the thermal and electrical efficiencies of 27.0 and 6.9 % are possible. The solar fraction is 55.3 % of the total ventilation air heating demand.
- PV/T panels for electricity production and a low temperature heating system for a house with a heat pump. Thermal and electrical efficiencies of 28.2 and 2.5 % are possible with a PV/T area of 5 m^2 and a storage tank of 20 m^3. The solar fraction is 95.8 % of the total heating demand of the house.

1. GENERAL INTRODUCTION

PV/Thermal panels transform sunlight into electricity and heat. Combining PV panels and thermal panels into one panel results in lower direct electric as well as thermal efficiencies per unit area, but the advantages are a potential cost saving in production and installation and a saving of roof area. To examine the best way to use these kind of panels, 3 different systems with PV/T panels are studied numerically. These systems use the PV/T panels for electricity and a domestic hot water system, for preheating ventilation air for a boarding school and for a low temperature heating system for a house.

The thermal efficiency of the PV/T panel that is used in this study is shown in the formula below.

$$\eta_{th} = 0.67 - 5T^*$$

$$T^* = \frac{T_{col\,in} - T_{amb}}{I_{tot}}$$

With:

$T_{col\,in}$ = Collector inlet temperature [°C]
T_{amb} = Outside temperature [°C]
I_{tot} = Total solar radiation on PV/T panel [W/m^2]

The electrical efficiency of the PV/T panel that is used in this study is shown in the formula below.

$$\eta_{el} = 0.086 * \left(1 - 0.0045 * \left(T_{surf\,col} - 25\right)\right)$$

With:

$T_{surf\,col}$ =Surface temperature PV cell [°C]

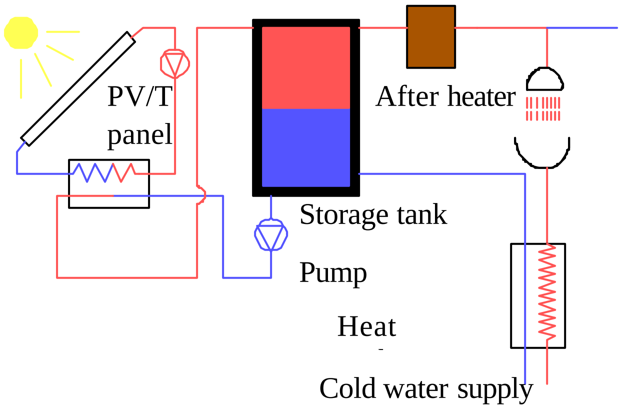
The flow that runs through the collector is in every system 50 liter/hour per square meter PV/T panel area. The flow will be controlled with an on/off controller. There will only run a flow through the panel in the case of a positive thermal efficiency.

The aim of the study is to find an optimum for the panel area in relation to the size and insulation of the storage tank and to compare the three systems with each other in terms of annual electric and thermal efficiencies. All systems are simulated numerically with TRNSYS, a transient systems simulation program with a modular structure.

2. SYSTEM 1: HOT WATER SYSTEM

2.1 Introduction

A schedule of this system is shown below.



Normally, natural gas or electricity is used for making domestic hot water. To make hot water with renewable energy, a PV/T panel is an option. In this system, the PV/T panel is south located, on the roof of a house (tilt 37 °). The hot water system is provided with a storage tank, located in the attic of the house. In the case of enough sunshine, the water will be pumped through the panel, with the result that the water will be heated. This heat will be transferred with a heat exchanger to the water in the storage tank.

If there is a hot water demand, the water will be tapped from the top of the storage tank. Between the storage tank and the tap, there is an after heater for the cases that the temperature of the water is below 60 °C. At the tap, the hot water will be mixed with cold water (approximately 10 °C) to get the right temperature. At the moment there will be a water tap, the storage tank will be supplied with cold water (also approximately 10 °C). This cold water will be preheated with the heat of the used hot water for the shower, with the help of a heat exchanger.

2.2 Starting points for the simulation

The simulations are executed with the starting points as shown below.

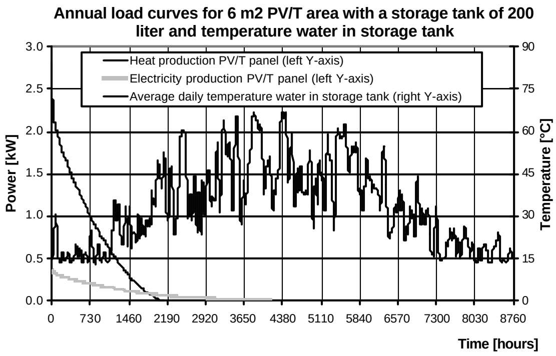
Climate data:	Test Reference Year (TRY) De Bilt, The Netherlands
PV/T area:	6 m^2
Volume of the storage tank:	200 liter
Thickness of insulation around the storage tank:	10 cm
Daily hot water demand:	175 liter

2.3 Results of the simulations

The simulations are executed for a period of a year. In the table below, the final results of the simulations are shown in numerical values.

	Energy [GJ/year]
Total solar radiation on PV/T panel	22.7
Heat production PV/T panel	5.8
Electricity production PV/T panel	1.5
Total system losses	0.8
Heating demand after heater	4.9
Heating demand for domestic hot water (without PV/T panel)	9.9

In the graph below, the annual load curves of the heat and electricity production of the PV/T panel and the average daily temperature of the water in the storage tank are shown.

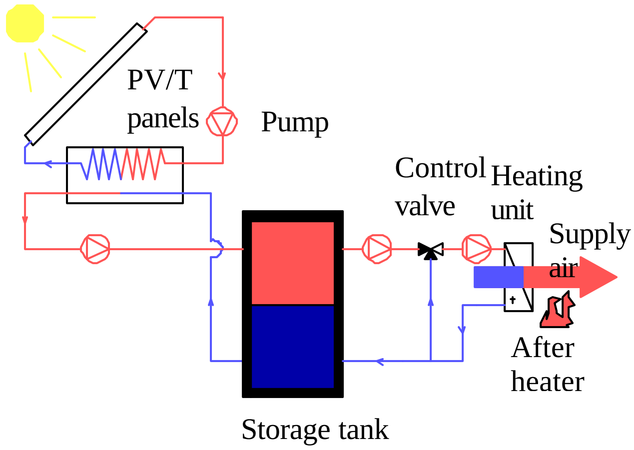


With this system, the thermal and electrical efficiencies are 22.1 and 6.8 %, with a solar fraction of 50.5 % of the total heating demand for hot water.

3. SYSTEM 2: PREHEATING VENTILATION AIR FOR A BOARDING HOUSE

3.1 Introduction

Below, a schedule of the heating system is shown.



A boarding school in the United Kingdom, located near London, will expand their boarding houses. The new boarding house will be provided with PV/T panels on the roof. These panels will supply electricity and heat for the boarding house. The electricity will be for own use. The boarding house is connected to the grid, so during periods of little electricity production the boarding house will have enough electrical power.

The supplied heat from the PV/T panels will be stored in a big seasonal storage tank. Because of the size of the tank, the tank will be buried in the ground. With the help of the stored heat in the tank, the ventilation air for the boarding house will be preheated with a heating unit in the air handling unit. In the air handling unit, there is also an after heater. This heater will only be used if there is not enough heat in the tank to preheat the ventilation air to the desired temperature.

3.2 General building description and starting points

The boarding house consists of a West and East wing. Every wing has bedrooms on the North and South part. Totally, 60 people can sleep in the boarding house. Beside bedrooms, the boarding house is provided with stairwells, relax rooms and sanitary facilities.

The boarding houses will be ventilated with a ventilation rate of 1. This results in a supply air quantity of 3600 m^3/hr. The temperature of the supply air is 21 °C (by day) or 18 °C (at night). The PV/T area is 183 m^2, the volume of the storage tank is 150 m^3 with 50 cm insulation.

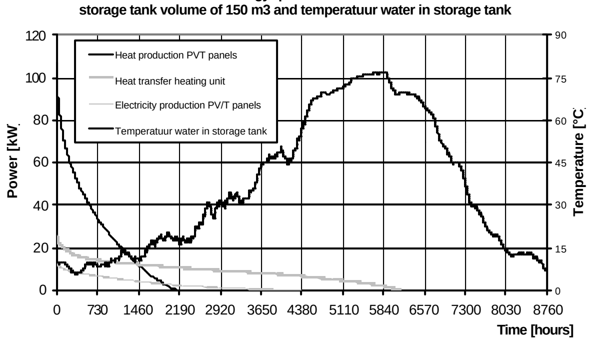
3.3 Results of the simulations

The simulations are executed for a period of a year.

In the table below, the results of the simulations are shown in numerical values.

	Energy [GJ/year]
Total solar radiation on PV/T panels	757.9
Heat production PV/T panels	212.7
Electricity production PV/T panels	52.0
Heat transfer in heating unit	203.5
Heating demand after heater	164.3
Heat loss of the water in storage tank	12.2

In the graph below, the annual load curves for the heat and electricity production of the PV/T panels, the heat transfer in the heating unit and the average temperature of the water in the storage tank are shown.

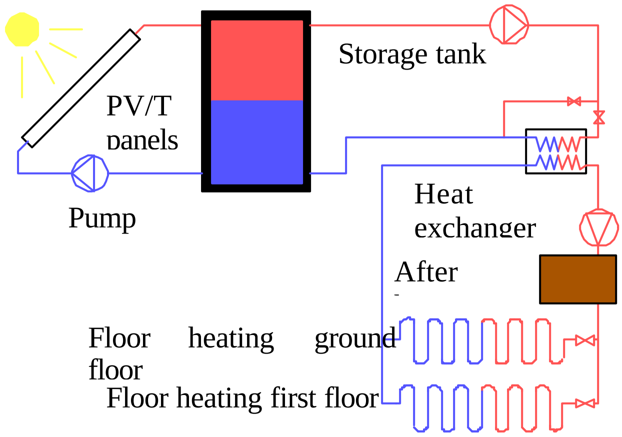


With this system, the thermal and electrical efficiencies are 27.0 and 6.9 %, with a solar fraction of 55.3 % of the ventilation air heating demand.

4. SYSTEM 3: LOW TEMPERATURE HEATING SYSTEM

4.1 Introduction for a system without a heat pump

A schedule of the system is shown below.



As well as using the PV/T panels for making domestic hot water and preheating the ventilation air, the panel can also be used for a low temperature heating system for a house. The problem is that a house has the largest heating demand during wintertime. The winter is the period with the minimum quantity of sunshine. This implies that you have to store the heat in the summertime so that you can use it in wintertime. This will be realized by using a big seasonal storage tank filled with water.

This system will be the most attractive if it supplies a big part of the total heating demand of a house. Because the stored energy is finite, this system will operate the best in low-energy houses provided with a low temperature heating system (floor heating system).

During periods of high temperatures (> 35 °C) of the water in the storage tank (and heating demand), the heat from the storage tank will be transferred to the floorheating system with the help of the heat exchanger. During periods of low temperatures (<35 °C) of the water in the storage tank (and heating demand), the after heater will be used to get the right supply temperature for the water of the floorheating system.

4.2 Starting points for the simulation

The simulations are executed with the starting points as shown below.

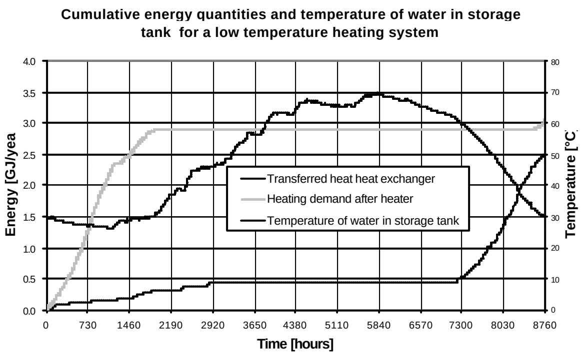
Climate data:	TRY De Bilt, The Netherlands
PV/T area:	10 m^2
Volume of the storage tank:	20 m^3
Thickness of the insulation around the storage tank:	50 cm
Insulation value of the walls and roofs of the house:	3.8 m^2 K/W
Insulation value of the floor of the house:	6 m^2 K/W
Total heating demand of the house:	5.5 GJ/year
Minimum supply temperature floorheating system:	35 °C

4.3 Results of the simulation
The simulations are executed for a period of a year.

In the table below, the results of the simulations are shown in numerical values.

	Energy [GJ/year]
Total solar radiation on PV/T panel	37.4
Heat production PV/T panel	7.5
Electricity production PV/T panel	2.8
Transferred heat in heat exchanger	2.5
Energy demand after heater	3.0
Energy losses	4.9

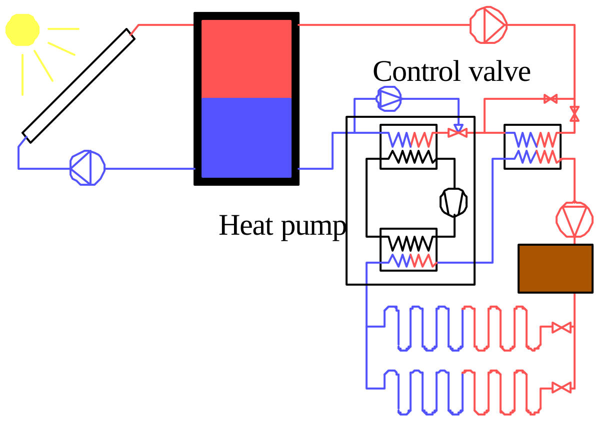
In the graph below, some of these energy quantities are shown cumulatively. In the same graph the course of the temperature of the water in the storage tank is shown.



With this system, the thermal and electrical efficiencies are 6.7 and 7.6 %. This system can supply 45.4 % of the total heating demand of the house.

The thermal efficiency of this system is, in comparison with the two other systems, the lowest. To increase the thermal efficiency, a heat pump can be used. For this reason, a system study for a low temperature heating system with a heat pump is done.

4.4 Introduction for a system with a heat pump
A schedule of the system is shown below.



With the system without the heat pump, the after heater will be used if the temperature of the water in the storage tank is lower than the supply temperature of the floorheating system (=35 °C). By introducing a heat pump in the system, the heat of the water in the storage tank can be used in cases that the temperature of the water is lower than the supply temperature for the floorheating system.

If the temperature of the water in the storage tank is below 35 °C and there is heating demand, the heat pump will be switched on. The heat pump will cool the water in the storage tank and heat the water for the floor heating system.

For constructional reasons, the heat pump will only operate with source temperatures that not exceed 25 °C. If the temperature of the water in the storage tank is between 25 – 35 °C, the water that leaves the evaporator of the heat pump will be mixed (with the help of the control valve) with the supply water to the heat pump. The supply temperature of the water that enters the evaporator of the heat pump will be controlled on 25 °C.

If the temperature of the water in the storage tank is below 25 °C, this water will not be mixed and enters direct the evaporator of the heat pump.

4.5 Starting points for the simulation

The simulations are executed with the starting points as shown below.

Climate data:	TRY De Bilt, The Netherlands
PV/Thermal area:	5 m^2
Volume of the storage tank:	20 m^3
Thickness of the insulation around the storage tank:	50 cm
Insulation value of the walls and roofs of the house:	3.8 m^2 K/W
Insulation value of the floor of the house:	6 m^2 K/W
Total heating demand of the house:	5.5 GJ/year
Minimum supply temperature floorheating system:	35 °C

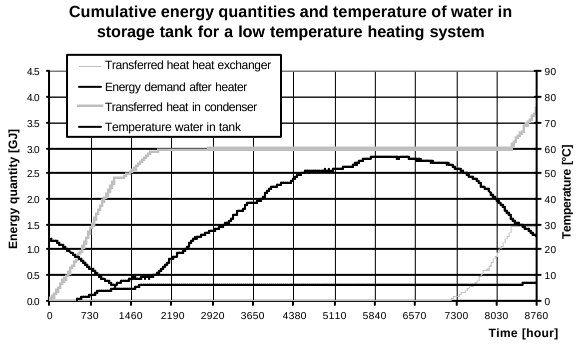
4.6 Results of the simulation

The simulations are executed for a period of a year.

In the table below, the results of the simulations are shown in numerical values.

	Energy [GJ/year]
Total solar radiation on PV/T panel	18.7
Heat production PV/T panel	6.6
Electricity production PV/T panel	1.5
Transferred heat in heat exchanger	1.4
Transferred heat in condenser heat pump	3.8
Electrical energy compressor heat pump	1.0
Energy demand after heater	0.4
Energy losses	2.4

In the graph below, some of these energy quantities are shown cumulatively. In the same graph the course of the temperature of the water in the storage tank is shown.



With this system, the thermal and electrical efficiencies are 28.0 and 2.7 %. This system can supply 95.8 % of the total heat demand of the house.

The electrical efficiency is rather low in comparison with the other systems. In this system, a part of the electricity production will be used for the compressor of the heat pump. This part is not included to calculate the electrical efficiency.

5. CONCLUSION

Below, there is an overview of the results of the different systems of this study.

System	1	2	3 without heat pump	3 with heat pump
PV/T area [m^2]	6	183	10	5
Volume tank [m^3]	0.2	150	20	20
Insulation [cm]	10	50	50	50
Thermal eff. [%]	22.1	27.0	6.7	28
Elec. eff [%]	6.8	6.9	7.6	2.7
Solar fraction [%]	50.5	55.3	45.4	95.8

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