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Decentralized Hot and Cold Water Production with Peltier Elements

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Abstract

Due to the increasing building standard in the last years the specific heat energy demand for new buildings but also for refurbished buildings decreases. Due to this fact the percentage of end energy use for hot water production rises. But small scale devices, which can be used for decentralized applications, are hardly available.

The focus of this paper is the decentralized production of hot and cold water with Peltier elements. Therefore two prototypes with a hot and cold water storage were measured. Between the hot and cold water storage Peltier elements were placed.

The measurements showed, that the best COPs could be reached when the Peltier elements were operated in the part load range, which was 5 Volts this case (the maximum applicable voltage was 29,5 V according to the manufacturer). The maximum COP as a mean value over the first hour was reached with 5 Volts with an initial temperature of both storage tanks of 15 °C. This COP was 1.6. The temperature at the highest measurement point of the hot storage water tank was 17 °C. Compared with a high voltage application of 15 V the mean COP for one hour was 1.0 with a hot water temperature of 24 °C.

The results are interesting for future research in the building sector. In multi storey buildings e.g. the hot water production could be covered by such a decentralized system with a hot and cold water storage.

Keywords – heat pump, Peltier elements, hot water production, decentralized systems

1. Introduction

Due to the increasing building standard in the last years the specific heat energy demand for new buildings but also for refurbished buildings

decreases. Due to this fact the percentage of end energy use for hot water production rises. But small scale devices, which can be used for decentralized applications, are hardly available. Usually devices with a high nominal power, short operation times and small capacity utilization are used. Therefore there is a lack on devices for heating and cooling for small scale applications ($< 2 \text{ kW}_{\text{thermal}}$), which do not have moving parts and therefore need low-maintenance, which have no noise emissions and therefore can be used for decentralized applications and which do not use climate-relevant refrigerants.

The focus of this paper is the decentralized production of hot and cold water with Peltier elements. This thermoelectric device is characterized through long operation times, through operation without climate-relevant refrigerants, through operation without noise emissions, through operation without maintenance and through the fact that it can be connected to PV without DC/AC conversion losses. Thermoelectric devices can be applied for heating, cooling and hot water production.

2. State of the Art

The literature describes research activities in the field of using thermoelectric elements as heat pumps. Table 1 shows some references which show the potential of Peltier elements for heating and cooling in buildings. As an example [2] shows, that a thermoelectric heat pump could reach a coefficient of performance (COP) for heating of up to 2.6. Also Peltier elements are driven by DC, therefore a direct coupling with PV is possible without inverter-losses. A combination with PV is reported in [5] for example. Other literature references are shown in Table 1.

Table 1. Literature (abbreviations: TE...thermoelectric, c...cooling, h...heating, η ...efficiency)

Reference	Focus / Method	Results
[1]	TE cooling device, experimental research, combination with PV, test duration 180 minutes	COP_c 0.35 mean value with DC source COP_c from 0.55 to 1.05 when coupled with PV – mean value 0.74
[2]	TE heat pump, experimental research, forced convection (water)	COP_h 1.6 to 2.6 at different mass flow rates
[3]	TE heat pump, simulation, forced convection (air), number of elements was varied	COP_h to 2.5
[4]	TE heat pump, but integration into a 2-stage chiller cycle	1 kW additional heating power together with a 9% reduction of the COP_h

Table 1. *Continued* - Literature (abbreviations: TE...thermoelectric, c...cooling, h...heating, η ...efficiency)

Reference	Focus / Method	Results
[5]	TE cooling box, experimental research, forced convection (air), combination with PV	COP _c 0.1
[6]	TE generator + solar thermal energy, experimental research, forced convection (water)	Up to 3 W per module at ΔT of 100 K
[7]	Determination of the Peltier coefficient, experimental + analytic	COP _c 0.1 to 2,2 (calculated)
[8]	TE generator in combination with water heating (Cogeneration), experimental research	η_{system} up to 80 % (power + heat)

3. Method

Two prototypes with a hot and cold water storage were measured, with an approximate volume of 16 liters and 51 liters, respectively. Between the hot and cold water storage Peltier elements were placed (Fig. 1).



Fig. 1 Prototype 1 with cold water storage (left side) and hot water storage (right side) [9], [10]

Prototype 1 had three separate aluminium blocks between the cold water storage and the hot water storage in order to enforce heat conduction. On the hot water side of the blocks the Peltier elements were placed, so that the hot side of the elements were in direct contact with the hot water storage surface. Instead of the three separate aluminium blocks prototype 2 had three extruded blocks, but only at the cold water storage (Fig. 2). The inside of the blocks were hollow and therefore in contact with the water of the cold water storage.

The gap between the cold and hot water storage, and also the total test apparatus were insulated. The thermal conductivity of the insulation was less than 0.04 W/(m.K) . The temperatures were measured with calibrated PT100 temperature sensors. The measurement scheme of the surface temperatures and water temperatures inside of the hot and cold water storage can be seen in Fig. 3.



Fig. 2 Prototype 2 with cold water storage, the three extruded blocks, temperature measurement and the Peltier elements

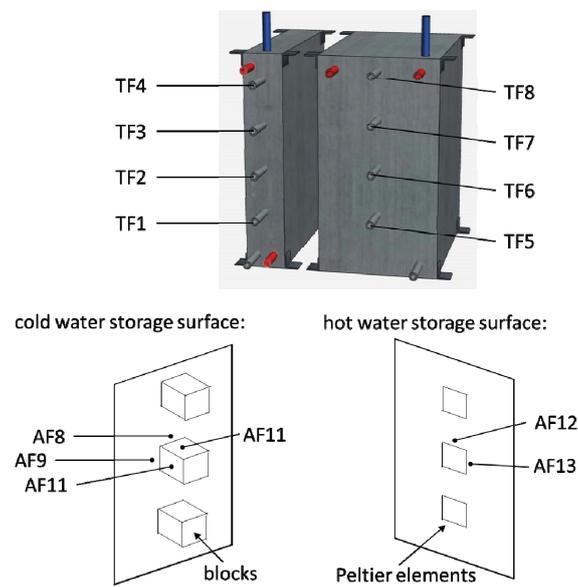


Fig. 3 Measurement scheme of the surface and water temperatures of prototype 2, TF...sensors in contact with water, AF...surface sensors

The electrical power consumption of the Peltier elements was measured with a calibrated power analyzer. Available one-stage Peltier elements were used for this experiment. The Peltier elements had a maximal cooling power of 270 W according to the manufacturer. Different voltages were applied to the Peltier elements and the coefficient of performance (COP) as the heating power related to the electrical power consumption was evaluated in each case, as written in (1).

$$\text{COP} = \frac{Q_{\text{dot_heating}}}{P_{\text{electric_elements}}} \quad (1)$$

$Q_{\text{dot_heating}}$ heating power added to the hot water storage, [W_{thermal}]
 $P_{\text{electric_elements}}$ electric power which is supplied to the Peltier elements, [W_{electric}]

The measurement protocol for both prototypes can be seen in Table 2 and Table 3.

Table 2. Measurement protocol of prototype 1

ID	Start		Conditions		Power off		End	
	Date	Time	Initial Temp.	Voltage	Date	Time	Date	Time
M1	21.08.2013	4:54 PM	15°C	25V	21.08.2013	11:15 PM	22.08.2013	8:20 AM
M2	22.08.2013	9:56 AM	15°C	15V	22.08.2013	5:00 PM	23.08.2013	7:45 AM
M3	23.08.2013	9:15 AM	15°C	5V	24.08.2013	7:30 AM	26.08.2013	7:39 AM
M4	26.08.2013	10:19 AM	15°C	10V	27.08.2013	7:51 AM	28.08.2013	10:30 AM
M5	30.08.2013	7:47 AM	15°C	20V	30.08.2013	4:45 PM	03.09.2013	7:42 AM
M6	04.09.2013	3:08 PM	10°C	5V	05.09.2013	5:26 PM	06.09.2013	8:02 AM
M7	09.09.2013	10:29 AM	10°C	10V	10.09.2013	7:37 AM	10.09.2013	5:38 PM

Table 3. Measurement protocol of prototype 2

ID	Start		Conditions		Power off		End	
	Date	Time	Initial Temp.	Voltage	Date	Time	Date	Time
M9	21.11.2013	4:41 PM	15°C	5V	22.11.2013	2:56 PM	25.11.2013	7:50 AM
M10	25.11.2013	9:52 AM	15°C	15V	25.11.2013	4:56 PM	26.11.2013	7:46 AM
M11	05.12.2013	11:32 AM	15°C	5V	06.12.2013	9:47 AM	09.12.2013	8:45 AM
M12	09.12.2013	10:50 AM	15°C	15V	09.12.2013	5:54 PM	10.12.2013	8:02 AM

4. Results

In all measurements different voltages were applied to the Peltier elements and the temperatures and the electrical power consumption were measured in each case. Each measurement can be divided into two phases. During the first phase a defined voltage was applied to the Peltier elements, while in the second phase the power was shut off. In Fig. 4 the temperatures inside the cold and hot water storage of measurement M3 are shown. The figure shows the temperatures of the cold water storage, where TF1 is the lowermost and TF4 is the topmost sensor, and the temperatures of the hot water storage, where TF5 is at the bottom and TF8 is at the top of the hot

water storage. The initial temperature of this measurement was 15 °C. During the phase 1, where power was supplied to the Peltier elements, all temperature sensors of the cold water storage had lower temperatures than the initial temperature. Although a continuous cooling effect could only be observed the first 10.5 hours. At this time the lowest temperature was 11.0 °C. After that the temperatures of the cold water storage began to rise until the end of the phase 1. The highest temperature of the hot water storage (TF8) was 27.7 °C at the end of phase 1. After that the power supply to the Peltier elements were shut off and the warming of the cold water storage and the cooling of the hot water storage could be measured. The mean room temperature during the measurement M3 was 21.5 °C.

The COP during the measurement M3, which was calculated based on the temperature and electric power measurement, is depicted in Fig. 5. For the calculation of the COP minutes values and a moving average filter with a span of 5 values was used. Fig. 5 displays only the phase 1 of the measurement, where the Peltier elements were supplied by electrical power. The mean COP during this phase was 1.0 (n=1334 minute values, equivalent to 22.2 hours), while the maximum value was 1.9. After 501 minutes the COP fell below 1 for the first time. This means that the COP was above 1 for more than 8 hours.

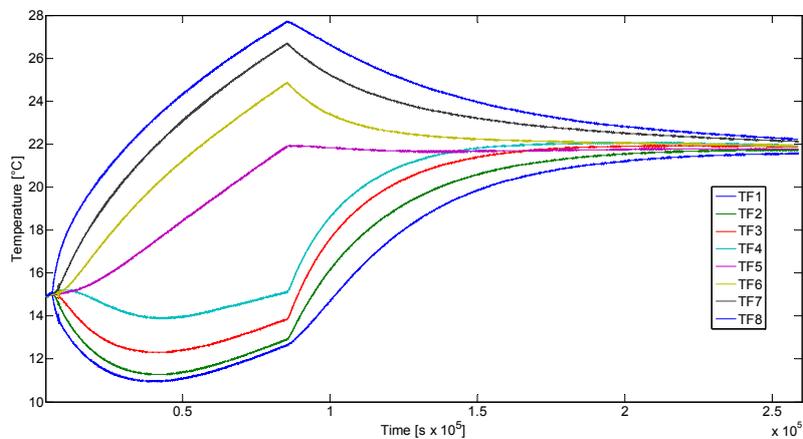


Fig. 4 Temperatures of the cold water storage (TF1 to TF4) and temperatures of the hot water storage (TF5 to TF 8), prototype 1, measurement M3, applied voltage: 5V, mean room temperature: 21.5 °C

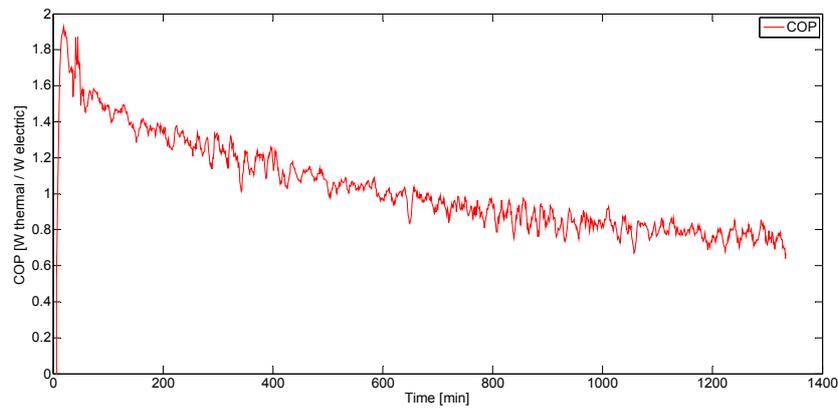


Fig. 5 calculated COP based on the temperature and electrical power measurement, prototype 1, measurement M3, applied voltage: 5V, mean room temperature: 21.5 °C

Fig. 6 shows the temperatures on the surfaces of the extrude blocks of the cold water storage and nearby (compare Fig. 3). The Peltier elements were placed between the blocks of the cold water storage and the surface of the hot water storage. The zoom of this figure (Fig. 7) shows only the two surface temperatures AF9 and AF11. In this figure a positive temperature difference between AF9 and AF11 (= cooling effect) can be observed for the first 9.6 hours. Afterwards the temperature difference turned into a positive difference, which is equal to a heat transfer into the cold water storage.

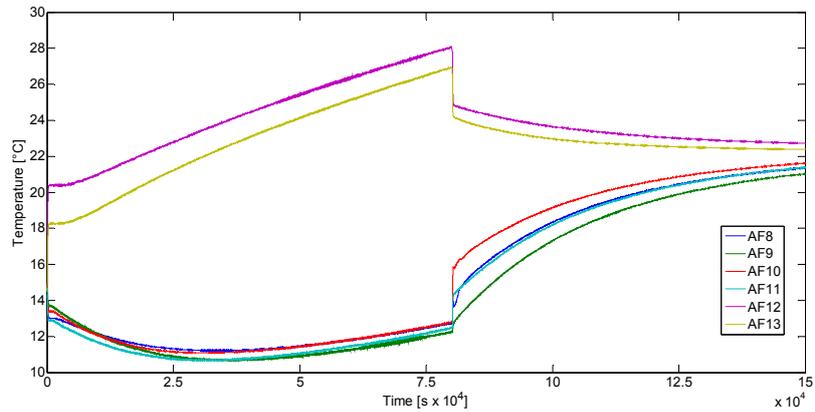


Fig. 6 Temperatures of the extruded blocks, prototype 2, measurement M11, applied voltage: 5V, mean room temperature: 23.0 °C

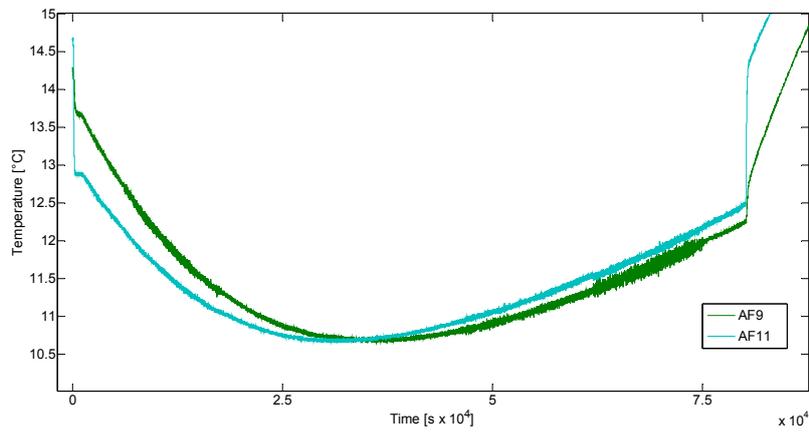


Fig. 7 ZOOM Temperatures of the extruded blocks, prototype 2, measurement M11, applied voltage: 5V, mean room temperature: 23.0 °C

In order to compare the results from all measurements, the COP-values were compared to each other. Therefore the mean COP over the first hour of the measurement and the mean COP over the first six hours of the experiment were calculated. The results can be seen in Fig. 8.

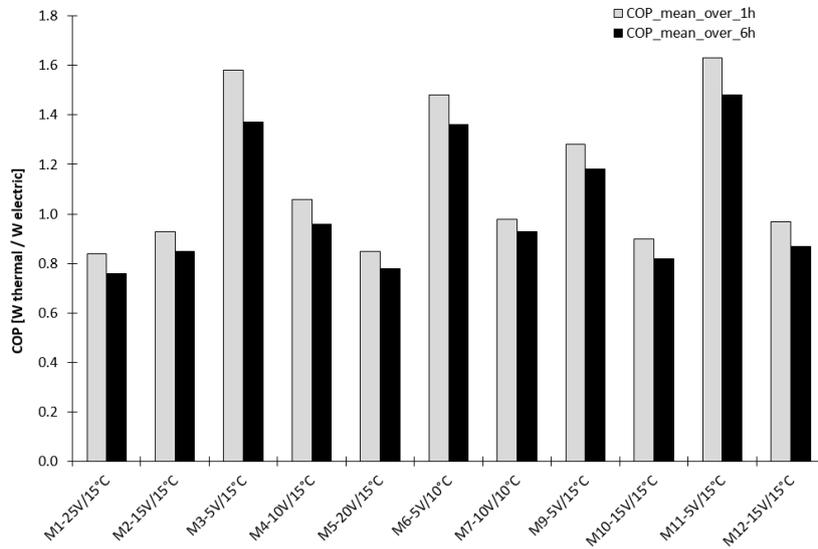


Fig. 8 Comparison of the COP of all measurements, prototype 1 (M1 to M7), prototype 2 (M9 to M12)

5. Discussion

The measurements with two different prototypes showed interesting results. However, it has to be stated that these results were achieved without forced convection of the cold and hot side of the Peltier elements. Therefore it can be assumed, that better results will be possible, if a forced convection on the cold and hot side will be applied. The forced convection will enable lower temperature differences on the Peltier elements and therefore will reduce the losses due to higher temperature differences.

6. Conclusion

The use of Peltier elements for the production of hot and cold water showed, that a maximum mean COP of 1.6 over 1 hour and a maximum COP of 1.5 over 6 hours could be reached only by natural convection on the hot and cold sides of the Peltier elements. The results are interesting for future research in the building sector. In multi storey buildings e.g. the hot water production could be covered by such a decentralized system with a hot and cold water storage.

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