HEAT PUMP SYSTEMS WITH UNCOVERED AND FREE VENTILATED COVERED COLLECTORS AS ONLY HEAT SOURCE

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ABSTRACT

In the past years the research and development activities for heat pumps in combination with solar thermal collectors for preparation of domestic hot water and space heating were increasing. In most of these systems the collectors are used as a direct heat source for the load-side storage and thus only if the irradiation is high enough to reach the temperature level that is needed to increase the temperature of this storage. In this work it was analysed how low irradiation and the ambient can be used also as heat source. Therefore, three different systems were modelled and simulated in TRNSYS. One of the systems is a basic solar-heat pump (air source) combination which is sold today on the market. The other two systems use solar collectors in combination with an ice-storage as the only heat source of the heat pump. One of these variants uses unglazed selective coated absorbers and the other variant uses covered collectors with controlled natural ventilation behind and in front of the absorber. All systems have been sized to have the same costs for the end consumer. A single family house with boundary conditions according to the IEA SHC/HPP Task44/Annex38 was simulated with four different climates. The simulation results show that unglazed collectors and a brine heat pump in combination with a 400 litre ice storage can work reasonable and even reach a better performance than the reference. The free ventilated collector shows a benefit compared to the unglazed and standard glazed collector only for very warm climates and low energy demand.

Keywords: Selective Unglazed Collectors, Heat Pump, Natural Convection, Ice Storage

INTRODUCTION

Heat pumps are a favoured choice for providing heat for new buildings or for the replacement of old heating systems. However, their application is restricted: At some places, for example, it is forbidden to drill boreholes, and an air-source system may be unfavourable because of noise or aesthetic reasons. Alternatively, a heat pump system which uses uncovered selective collectors in combination with an ice storage as the only heat source might be used. The use of uncovered collectors instead of covered collectors gives the advantage that the ambient heat can be used additionally to the solar irradiation. The disadvantage is that uncovered collectors have higher heat losses at elevated temperature levels which mean that the direct contribution of these collectors at the temperature level of the heat demand is significantly lower than for covered collectors. In this work, a collector-design is investigated which is expected to combine the advantages of uncovered and covered collectors. This can be reached with a new type of covered collector with controllable free ventilation. It allows ventilation by natural convection between the glazing and the absorber as well as between absorber and insulation by additional openings that are passively controlled to open and only when needed (see Figure 3). In this article a reference solar and heat pump system was compared with two alternative heat pump systems that involve an ice storage and different collector concepts:

One with unglazed selective absorbers and the other one with passive controlled free ventilation collectors.

METHOD

TRNSYS 17 was used for all simulations. The boundary conditions were based on the IEA SHC/HPP Task44/Annex38 (T44A38) [1], but slightly adapted in order to include different climates and a more realistic DHW profile which was calculated according to Jordan & Vajen [2], detailed information can be found in Mojic et al. [3]. Table 1 summarizes the climates and the corresponding heat loads.

Location, Country Code	Heating Demand [kWh/(m²a)]	Domestic Hot Water Demand [kWh/a]	Mean ambient Temperature [°C]
Zurich, CH	56.4	3038	9.1
Carcassonne, F	23.2	2691	13.2
Davos, CH	79.6	3571	2.8
Helsinki, FIN	93.3	3343	5.5

Table 1: Climates and heat demand for four different locations.

Reference System

In this simulation study a reference system was chosen that represents a state of the art system which is sold many times on the market according to its manufacturer. Figure 1 shows the hydraulic design of the reference. The collector area is 10 m^2 of standard glazed flat plate collectors (a_1 = 3.95 W/(m^2K), a_2 = 0.0122 W/(m^2K^2), η_0 = 0.793) with 45° inclination and south orientation. The heat storage has a volume of 750 litres with an internal coiled heat exchanger for the solar input (U = 1125 kJ/(hm^2K)). For the domestic hot water supply an external heat exchanger is used which is simulated without heat losses (UA = 19200 kJ/(hK)). The reference system includes an air-source heat pump with a power of 8 kW and a COP of 3.5 at A2W35. The heating distribution (floor heating) was simulated with a flow temperature of 35 °C and return temperature of 30 °C (Davos and Helsinki 40/35).

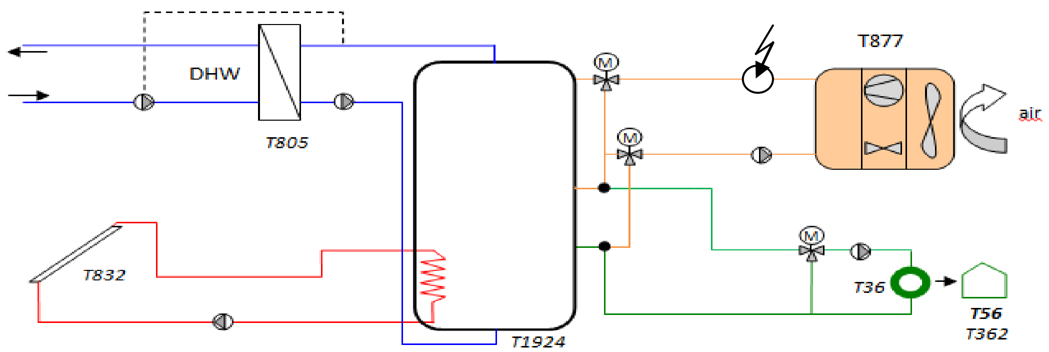

Figure 1: Hydraulic scheme of the reference system; Txy = TRNSYS Type number xy

Alternative Systems

The ***alternative systems*** (unglazed and ventilated) have different collectors, a different heat pump (brine source) and an additional ice storage. The hydraulic scheme can be seen in Figure 2. The heat pump was replaced by a brine-source heat pump with a power of 8 kW and a COP of 4.65 at B0W35 that is optimized for very low brine temperatures (minimal inlet temperature is -18 °C). The ice storage has a volume of 400 litres and is equipped with a coiled pipe heat exchanger (diameter 20 mm, 30 mm distance between the pipes).

For the ***unglazed system*** the collector field was replaced by selective unglazed absorbers with a total area of 18 m^2 (a_1 = 9 W/(m^{2}K), a_2 = 0 W/(m^{2}K^2), η_0 = 0.954) inclined at 45° and orientated south.

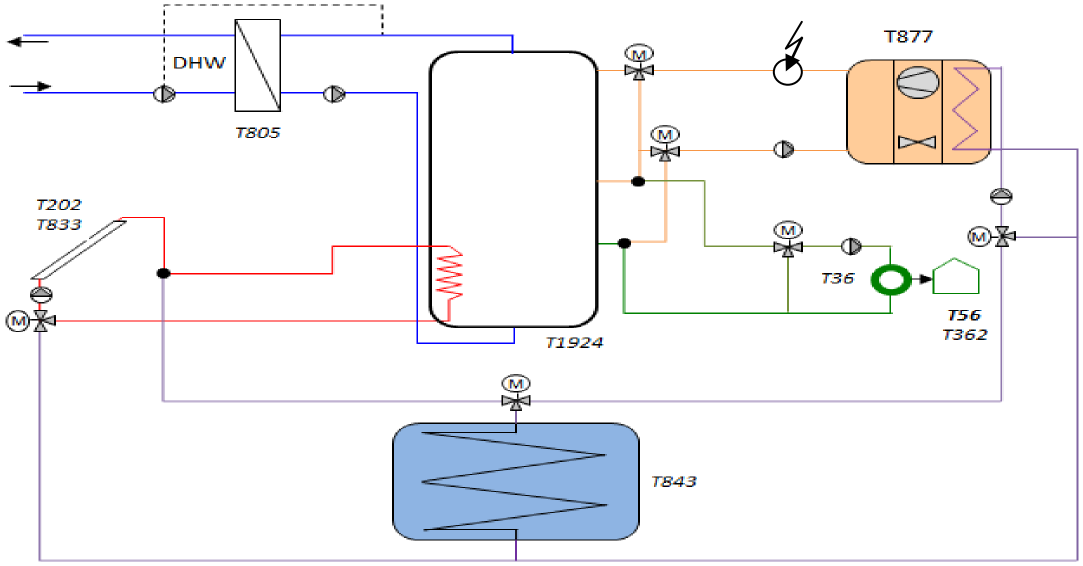

Figure 2: Hydraulic schema of the both alternative systems; Txy = TRNSYS Type number xy

The heat pump uses primarily the collectors as a heat source. If the collector outlet temperature gets too low, the heat pump switches to use the ice storage as a source. The main priority of the collectors is to charge the heat storage directly. Only if the required temperature cannot be reached, the collectors are heating the ice storage up to a maximum of 20 °C. In the case that the heat pump power output is too low an electric backup heater switches on which is placed downstream of the heat pump outlet.

The ***ventilated system*** has the same hydraulic scheme as shown in Figure 2. The only difference to the unglazed system is that another collector design is used as shown in Figure 3. This is basically a standard flat plate collector with the option to open channels which allow a natural convection between the absorber and the glazing as well as between the absorber and the insulation. The idea behind this concept is to additionally use ambient air as a heat source for the heat pump at low irradiations where direct collector heat use for the load-side storage would be inefficient or impossible.

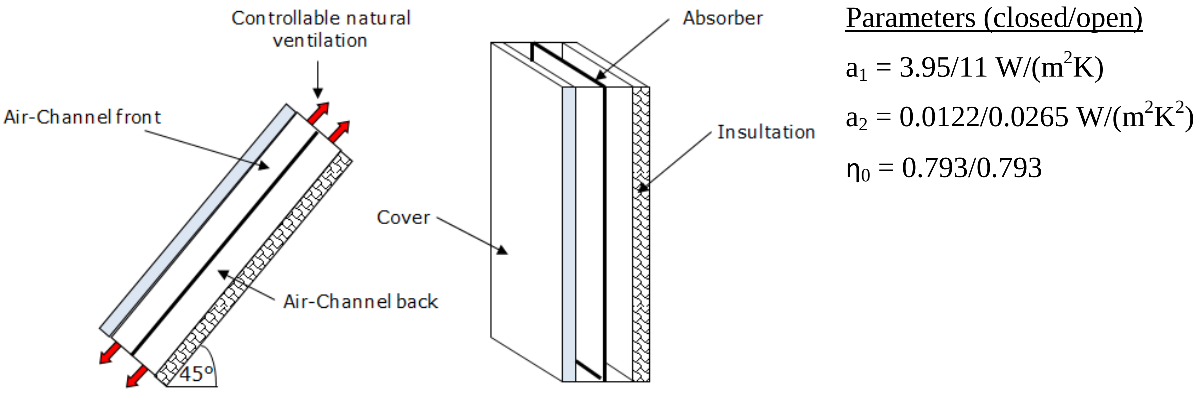

Figure 3: Design of the natural ventilated collector

The TRNSYS collector model (Type 832) [4] was modified to enable the ventilation feature. The collector parameters for the open air channels were calculated in EES (Engineering Equation Solver) based on equations from the Kolektor 2.2 software [5]. The free convection heat transfer was based on the theory of Klan [6]. A possible influence of wind on the air flow in the channels was not taken into account. For this first potential study the development of a mechanism for passively opening and closing the ventilation channels has not been developed yet. In these simulations it was assumed that this mechanism works perfect.

A fair comparison of the performance of the three different collector and system concepts can only be done if the investment cost for all three systems are equal. Therefore, the collector areas of the alternative systems have been sized in order to reach the same estimated investment cost as for the reference. Thus, the unglazed and the ventilated system have collector areas of 18 m^2 and 14 m^2 instead of 10 m^2 for the reference.

RESULTS

Table 2 shows the parameters which were used for the comparison of the three systems.

Parameter	Unit	Description	Boundaries
$SPF_{SHP+,pen}$	-	seasonal performance factor	complete system (T44A38) [3]
$Q_{solar,tot}$	MWh	collector gains	collector field without heat losses of the pipes
$W_{el.tot}$	MWh	electric demand of the total system	complete system, with space heating pump
$W_{el.Backup}$	MWh	electric demand of the backup heating	only backup heating device

Table 2: Overview of the comparison criteria for the simulation study

The SPF factor is the quotient of all energy gains contributed to the system divided by the total electricity consumption of all system components including the space heating pump and penalties for comfort losses because of not reaching the needed temperatures for space heating and domestic hot water, according to the definitions in T44A38 [3].

Figure 4 shows the results for the four different climates, all energies are in MWh.

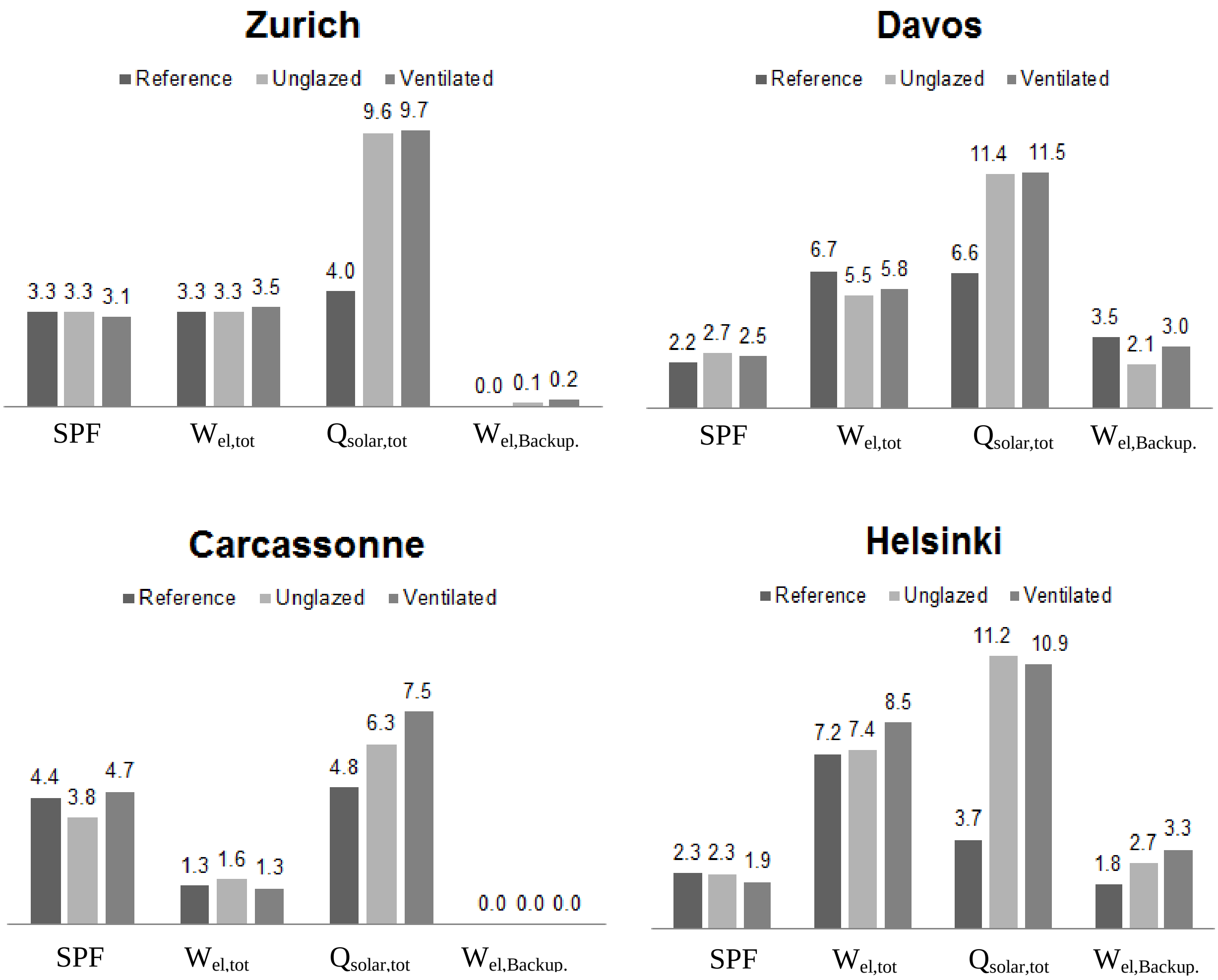

Figure 4: Result summary of the comparison of all three systems, all energies in MWh

The simulation results show that for Zurich the unglazed system can perform as good as the reference system, also for the very cold climate Helsinki the unglazed system has the same SPF as the reference. High differences between these two systems can be found for the climates Davos and Carcassonne, here the comparison shows that the unglazed system performs about 23% better in Davos and 14% worse in Carcassonne.

Compared to the reference, the ventilated system performs +14 % better for Davos and 7% better for Carcassonne, but only for Carcassonne the results are better than those of the unglazed system. Naturally, the heat delivered from the collectors is much higher (2-3 times) for the unglazed and the ventilated system then for the reference. However, only for Carcassonne the heat output of the ventilated collectors is significantly higher than for the uncovered collectors.

The electric backup heater contributes a lot to the total electric demand for the cold climates of Davos and Helsinki. This is an indication that the chosen heat pump is not suitable for these cold climates.

DISCUSSION AND CONCLUSION

The comparison of the simulated systems shows that their performance depends a lot on the climate. For none of the systems it can be claimed that it is the best for all cases. The ventilated system outperforms the others only for the climate of Carcassonne.

There is a possibility that the performance of this concept is underestimated because of the very basic simulation model of the collector that does e.g. not take into account the influence of wind on the air flow in the channels when they are open. On the other hand, the unglazed system leads to a good performance compared with the reference for many cases which makes it a good alternative. Only for Carcassonne the performance is significantly worse. The reason for this is the lower amount of heat that can be loaded directly to the load-side storage. A second one can be the low heating demand for this building and climate that leads to a high DHW share of the total heat load. It has to be mentioned also that for the unglazed collectors not all effects are taken in account, for example the loss of selectivity when the collector is covered by water droplets from condensation of moisture from the air [7] or the ice formation that may occur when the circulating fluid is at temperatures below 0 °C.

To conclude it can be said that selective unglazed collectors in combination with a small ice storage can lead to a good and reasonable SPF, which is in the same range or even better than a state of the art air source heat pump combined with standard glazed collectors. Additional benefits of the unglazed system compared to the reference air source heat pump are that noise emissions and outdoor ventilated air heat exchanger units can be avoided.

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