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Combining heat pumps with solar energy for domestic hot water production

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Abstract

In a simulation study two combinations of air-to-water heat pumps with either solar thermal collectors or photovoltaics have been scrutinized. Other heating systems have been included in the comparison. All system components applied are field proven and available on the market. Although all heat generators were sized to cover space heating and domestic hot water demand, the focus lays on domestic hot water preparation. As required by local regulations, all systems cover 50 % of the final energy demand from solar insolation. The results show that both air-to-water heat pump combinations are nearly equivalent regarding economic feasibility and environmental impact.

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Keywords: Heat pump; solar heat, photovoltaics; domestic hot water; ecological assessment; life cycle analysis; economics

1. Introduction

The knowledge about the reduction of heating energy consumption in dwellings has reached a sophisticated level, especially regarding the nowadays highly insulated building envelopes. The next step are net zero energy buildings, where the total amount of yearly energy demand has to be covered by building integrated generation of energy from renewable sources. The most promising technologies are solar thermal collectors, photovoltaics and heat pumps. These technologies can be randomly combined. But it is not yet obvious which combination is best, both from an ecological and economical point of view. This study shall contribute to the answer of this question, focusing on air-to-water heat pumps combined with solar thermal collectors or photovoltaics for domestic hot water preparation.

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Nomenclature

UBP	environmental impact points
GWP	global warming potential
CO ₂ -eq	carbon dioxide equivalents
CHF	Swiss currency (Swiss franc)
A/W-HP	air-to-water heat pump
B/W-HP	brine-to-water heat pump
ST	solar thermal collectors
PV	photovoltaics

1.1. Background

In a simulation study combinations of air-to-water heat pumps with either solar thermal or photovoltaic collectors have been scrutinized. The systems were designed to supply heat to a typical single-family house in Switzerland (5.1 kW design heat load). All system components applied are field proven and readily available on the market. Although the heat pump was sized to cover both space heating and domestic hot water demand, the focus lays on the domestic hot water preparation. Thereby, no additional direct electric heater has been applied, meaning that the heat pump alone should reach the required temperature levels. Background of the study is a local legal requirement of 50% renewable coverage for domestic hot water heating. Besides air-to-water heat pumps other systems fulfilling this requirement have been evaluated for comparison reasons. All solar systems cover 50 % of the final energy demand for domestic hot water from solar irradiation, as required by local regulations. For solar electricity this means that 50 % of the electricity consumed by the heat pump has to be generated over the year. As typical hot water demand is around 2'800 kWh/a, the electricity consumption of the heat pump reaches values of approximately 1'200 kWh/a if storage losses are considered as well. Thus, the minimal required solar collector area is about 5 m². In combination with a solar thermal system, 50 % of the heat has to be delivered from the collector field to the storage tank. This leads to a minimum area of nearly 3 m² for flat-plate collectors, albeit typical installations will be larger as usually two collectors of about 2.5 m² each are needed to fulfill this minimum requirement.

2. Ecological impact

The ecological impact has been evaluated by applying a life cycle analysis (LCA) methodology, summing up all environmental impacts during the whole life of a system, its manufacturing process, emissions during operation and disposal at the end of life. Fundamental ecological data for the evaluation originates from the Swiss life cycle inventory database 'ecoinvent' v2.01 and v2.2 [1]. Two different evaluation paths were followed: The assessment following an ecological scarcity methodology sums up all ecological aspects in a single number while the evaluation of the global warming potential considers one specific impact only, namely the impact on the greenhouse effect.

Summarizing all effects on the environment in a single number results in a value which is expressed in 'environmental impact points' per annum (UBP/a) [2]. The applied methodology compares actual

emissions and resource flows with legal goals (distance to target principle) for a specific region, specifically Switzerland in this study. The bigger this difference is, the higher the impact on the environment. This assumes political decisions to be reasonably based on scientific knowledge. It has to be pointed out that this methodology regards individual effects only if there are given targets to reach for. Apart from this overall evaluation, the global warming potential (IPCC GWP 100a [3]) of each system has been calculated separately. Fig. 1 shows the results of both evaluations. The air-to-water heat pump combinations are shown on the left side, followed by the other systems included in the study. As there is

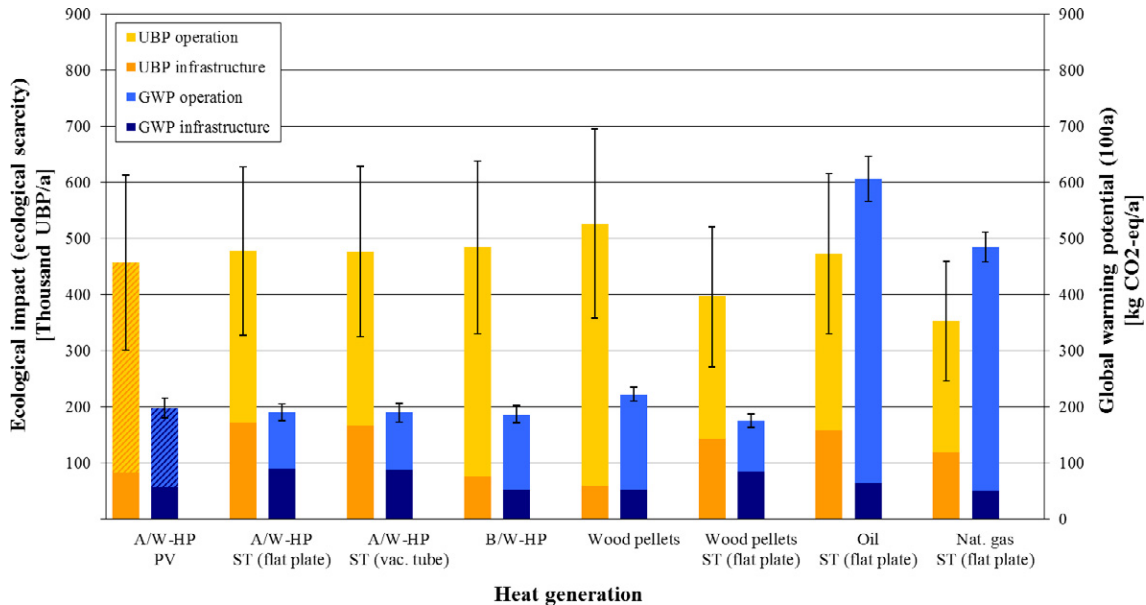


Fig. 1. Annual ecological impact of all compared systems. There is no legal requirement for brine-to-water heat pumps (B/W-HP) and wood pellet boilers to be combined with a solar installation

no legal requirement for brine-to-water heat pumps and wood pellet furnaces to be combined with a solar installation, these heat generators have been evaluated without solar support. All data is separated into two categories: ‘infrastructure’ and ‘operation’. ‘Infrastructure’ means all parts of the on-site equipment for domestic hot water generation, including the storage tank. ‘Operation’ covers direct on-site emissions as well as maintenance expenses (e.g. ash disposal of wood pellet furnaces) and the provision of the consumed end energy (fuel, electricity, its transport to the customer). This includes required off-site infrastructure such as power plants. Photovoltaic energy production is evaluated by drawing solar electricity from the grid rather than evaluating a specific installation on-site. This is why the solar generator (PV) shows up under the ‘infrastructure’ category in the figure, marked by the hatched filling of the bars. It is important to note that the ecological impact of any good is burdened to its consumer. So in this case the origin of the solar electricity –be it from an on-site installation or from a remote plant via the grid– for the operation of the heat pump has no greater ecological influence as long as conventionally produced electricity with higher ecological impact can be substituted. By contrast, the ecological benefit of an on-site installation is lost if the ecological added-value of the produced solar electricity is sold to someone else, for example on a green electricity market, and the heat pump is operated from conventionally produced electricity only.

The results in Fig. 1 show that environmental impacts during operation outweigh effects resulting from the provision of the infrastructure. This is the reason why photovoltaics can be assessed by drawing solar

electricity from the grid rather than considering particular installations on site without losing too much accuracy. But this also means that the orientation –and as a consequence its size– of the solar area is of minor importance from an ecological point of view. For the same reason there are no differences in the ecological impact between systems with flat plate collectors and systems with vacuum tube collectors, as long as the energy output is the same. Concerning the global warming potential, the impact of fossil fuels is clearly higher than for all other systems, even those without solar support. CO₂ emissions from wood pellet furnaces are assumed to be captured during the growth of the originating trees and therefore do not contribute to additional greenhouse gases in the atmosphere. Consequently, these emissions do not account for global warming potential. On the other hand, the processing of wood pellets needs some energy itself which leads to a not negligible amount of global warming potential for wood pellet boilers in operation. As Swiss electricity mix mainly consists of hydro and nuclear production, carbon-dioxide emissions originating from electricity supplies are held low for heat pump operation too. Looking at the global warming impact of air-to-water heat pump combinations one can see that there is no significant advantage for any of the systems.

Regarding environmental impact points, summarizing all environmental impacts in one single value leads to relatively high uncertainties. Thus, comparing the results of this ‘overall’ assessment leads to non-decisive differences between the regarded systems. In fact, differences between individual installations of the same system type are greater than differences between various types of systems.

3. Financial evaluation

For the economical evaluation (see Fig. 2) yearly costs have been calculated, based on actual prices at the time the study has been worked out. The lifetime of solar systems was assumed to be 30 (photovoltaics) and 25 years (solar thermal) respectively, while heat pumps as well as other heat generators and storages have an average lifetime of 20 years. All costs were calculated for the smallest possible systems satisfying the legal 50% requirement, assuming an ideal orientation of the solar

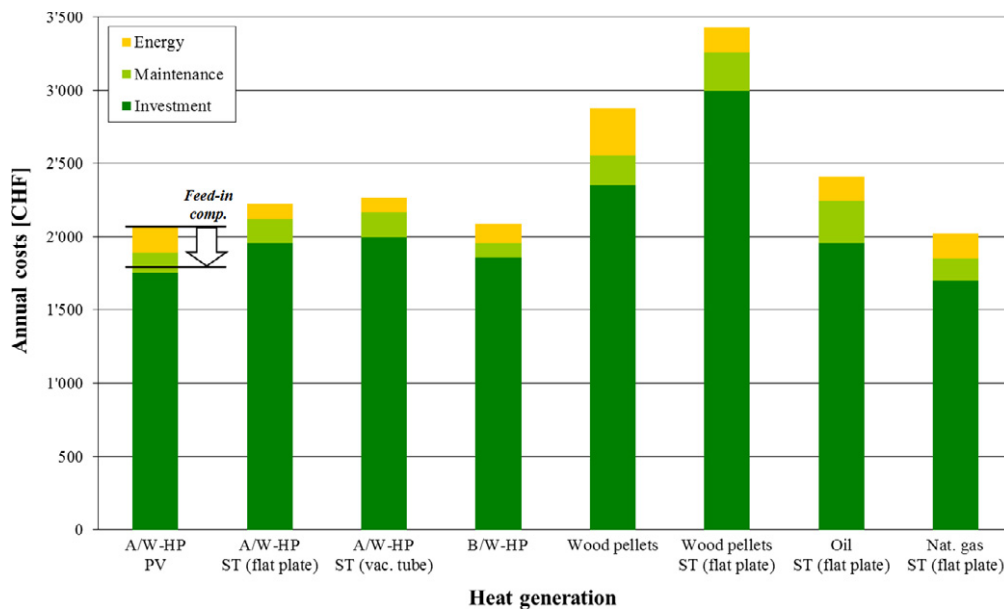


Fig. 2. Yearly costs of all compared systems. Feed-in compensation for photovoltaics would make the A/W-HP / PV combination favourable, but at the cost of the ecological benefit

collector area. Clearly, the investment costs show the biggest contribution to annual expenses. They cover the heat generator, solar systems where present and the domestic hot water storage, all with installation costs, but without tap water and space heating distribution and emission system since they are equal in all variants. Not considered are costs for anything provided by the customer (e.g. chimney). If no feed-in compensation is considered, both air-to-water heat pump/solar combinations end up with almost equal annual costs. From an economical point of view it would be favorable to sell the solar electricity and operate the heat-pump with conventionally produced electricity, as indicated in Fig. 2. But this would be at the cost of the ecological benefit. As prices for photovoltaic installations rapidly dropped over the last year, the further evolution may change the picture. Yet it has to be pointed out that for small photovoltaic installations as regarded here, material costs make up half of the investment costs. While these costs may decrease further in the future, labor costs are subject to smaller changes only.

4. Conclusions

This study shows for the assumption of a 50% renewable coverage of the domestic hot water preparation that there is no decisive difference between air-to-water heat pump systems combined with either solar heat or photovoltaic systems. This conclusion is based on an evaluation of ecological and economical aspects. It is valid as long as no direct electric backup-heater is applied. Also the solar heat storage is realized and financed in the building, whereas the solar electricity storage is assumed to be covered by the grid. The ecological evaluation of the solar generated electricity is based on the assumption that its ecological added-value is not sold to someone else, but is used by the owner of the installation to replace conventionally produced electricity. The ongoing decline of prices for photovoltaics may change the outcome of the financial evaluation in the near future. Electricity from bigger photovoltaic systems is already considerably cheaper than from small systems in the range below 1 kW_{peak} as applied in this study.

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