Dishwasher with Integrated Heat Pump

Stefan Flück, Mirko Kleingries, Ernst Dober, Beat Wellig - Switzerland

Everyday appliances such as refrigerators, dryers, washing machines or dishwashers add to a household's electricity demand considerably. To reduce their consumption of electricity, these appliances can be equipped with heat pumps to provide the necessary heating and cooling. This article describes a domestic dishwashing machine with an integrated heat pump that reduces the energy consumption by up to 50 % compared to conventional dishwashers with electrical resistance heating.

Introduction

The use of heat pumps for the heating of buildings has rapidly grown over the last decades. In Switzerland, for instance, the market share of newly built single and multi-family houses that include a heat pump reached over 80 % in the last few years (FWS, Heat Pump Association in Switzerland, www.fws.ch). This trend towards an increasing adoption of heat pumps can be seen in other household applications as well. Table 1 gives an overview of household appliances containing heat pumps that are currently available on the market. The table shows the typical ranges of electrical energy consumption for conventional appliances and those with an integrated heat pump for the respective standard process.

In Switzerland, sales information and statistics are recorded for household appliances [1]. Most significantly, the energy label given to each appliance shows that they are becoming increasingly more energy efficient. This fact is due, on the one hand, to incremental efficiency increases as a result of continuous development and improvement of the units, e.g. through process optimization or installation of more efficient electric motors. On the other hand, it is due to the implementation of new technology. Both aspects result in the energy demand being substantially reduced. As an example, the energy requirement for a dishwasher can be reduced by up to 50 % by the integration of a heat pump [2]. This dishwasher, which has been available on the market since 2014, is described in this article.

Dishwasher with integrated heat pump

Several requirements apply to household dishwashers with a monovalent heat pump program and an open drying process. In this context, the dishwasher's door is physically opened during the drying process (i.e. open drying process) as opposed to conventional dishwashers where the door remains closed (i.e. closed drying process). The term monovalent means that only one heating system is employed for the respective program. However, the dishwasher with the monovalent heat pump program is also equipped with electrical resistance heaters which are used in further washing programs additionally to the heat pump.

The following list provides the specifications for the dishwasher:

a. Duration of 130 min (excluding drying process) for dishwashing program.
b. Compliance with the standard test: The period of time between the start of two dishwashing programs is 24 h [3].
c. Installation limited to a "Standard Euro Niche" covering a ground area of 60 cm by 60 cm.
d. Common, competitive costs of manufacturing for the additional components.

Figure 1 illustrates the design of the household dishwasher with a monovalent heat pump program. As the figure shows, a latent heat storage filled with water is employed as the heat source for the heat

Table 1. Comparison of the energy requirements of different household appliances. A distinction is made between conventional appliances and those with an integrated heat pump. The electrical energy consumption refers to the respective standard process for one wash load or dish load.

	CONVENTIONAL TECHNOLOGY	WITH HEAT PUMP
Tumble dryer (7 kg dry clothes)	ca 4 900 Wh	1 400 Wh - 2 250 Wh
Washing machine (7 kg dry clothes)	ca 950 Wh	ca 560 Wh
Dishwasher	ca 1 000 Wh	490 Wh

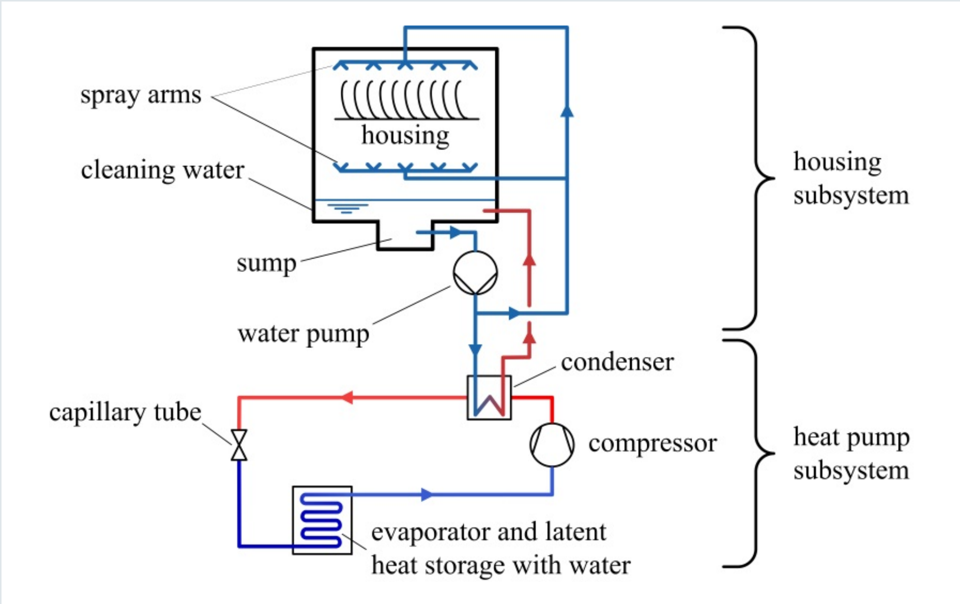

Figure 1. Simplified scheme of the household dishwasher's design with a monovalent heat pump program.

pump [4]. This storage offers a high energy storage density due to the phase change between liquid water and ice. Using this approach, the heat pump can provide the entire required process heat monovalently. After the washing program has finished and the storage tank has been discharged, the heat storage is recharged, i.e. heated, passively via the heat from the surroundings. According to the specifications, see previous page, the storage must return to its initial state after 24 h.

The water pump draws the cleaning water out of the sump of the dishwasher into the water circuit whereby it is split into two different lines. In the first line, the water is pumped to the spray arms in the housing and distributed by means of washing jets, so the dirty dishes are cleaned and heated up. In the second line, the cleaning water is pumped through the condenser and heated by the condensing refrigerant before flowing back to the sump. The condenser used is a horizontally arranged tube-in-tube heat exchanger, whereby the outer tube is made from flexible plastic tubing and the inner tube is made from stainless steel. The cleaning water flows in the annular gap and the refrigerant R-134a inside the inner tube. The materials were selected due to the corrosive nature (acidic or basic) of the cleaning water.

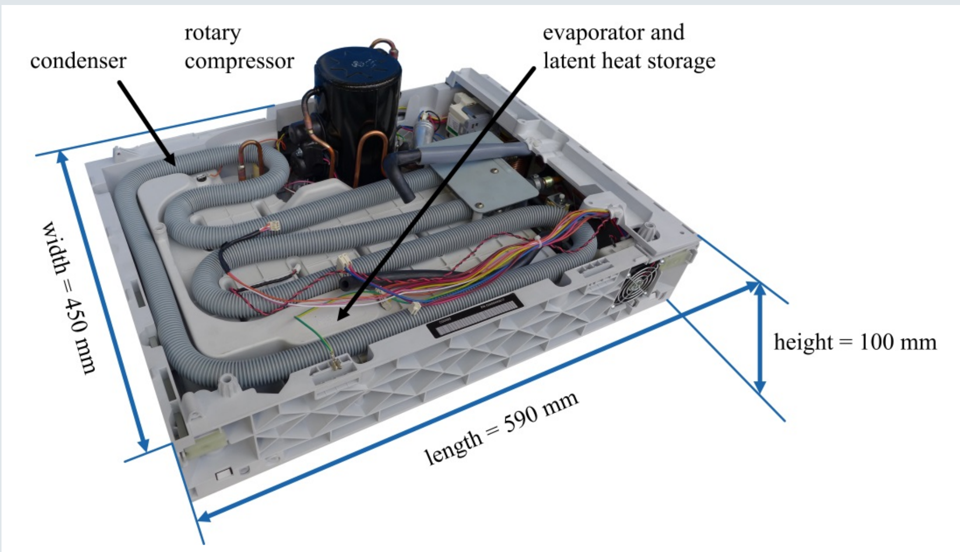

Figure 2. Assembled heat pump unit of the serial dishwasher.

At the start of the dishwashing process, the evaporator coil in the latent heat storage is immersed in liquid water. The water then cools and partially freezes as the evaporating refrigerant extracts energy from the water. Next, the evaporated refrigerant passes through a rotary compressor before going to the condenser. Following the condenser, the pressure level of the refrigerant is lowered to the evaporation pressure using a capillary tube.

The entire heat pump unit with latent heat storage (i.e. heat pump subsystem) is placed underneath the housing. With this arrangement, the dishwasher can still fit into a Standard Euro Niche. Moreover, the latent heat storage is thermally separated from the housing and no heat is transferred between the housing subsystem and the heat pump subsystem.

Figure 2 shows the assembled heat pump unit of the serial dishwasher. The components are labeled and the outer dimensions are given.

Dishwashing process

Figure 3 presents the dishwashing process for the dishwasher featuring the monovalent heat pump program with an open drying process. For the various cleaning steps, it is necessary to identify the curve of the cleaning water temperature over time, which approximately corresponds to the temperature of the dishes, the housing, and the water masses involved in the different dishwashing baths. At the beginning of the dishwashing process, 4.4 kg of water are filled into the sump and the heat pump warms the housing subsystem (i.e. housing, dishes, and washing water, see Figure 1, from 20 °C to 50 °C. Then the water is circulated and the dishes are cleaned. The temperature in the dishwasher steadily decreases during this period because of heat losses through the housing and the transient heat absorption of the dishes. When washing is completed, the dirty water is pumped out at a temperature of about 42 °C, and the sump is filled with 3.4 kg of fresh water at a temperature of 15 °C. The mixing temperature is approximately 36 °C. During this intermediate washing step, the dishes are cleaned again to remove any remaining residues. At the end of this cleaning step, the cleaning water is again pumped out.

In the final rinse cleaning step, 3.5 kg of fresh water are added, resulting in a mixing temperature of around 30 °C. Then the housing subsystem is heated by the heat pump to 45 °C for drying. At the end of this cleaning step, the water is pumped out. During the subsequent drying process, the water remaining on the dishes evaporates and part of the water condenses on the cooler housing walls. The energy necessary for evaporation comes from the dishes. After a defined waiting period, the dishwasher door opens automatically and room air flows in to help complete the drying of the dishes. The rinse temperature is lower for the open drying process than for closed drying process (45 °C instead of 65 °C) resulting in a smaller temperature lift and thus greater efficiency.

Regeneration of the latent heat storage

After the end of the dishwashing process, the ice in the latent heat storage must be thawed and heated up for the next dishwashing process. This regeneration process is accomplished using the surrounding room air and takes around 20 h assuming standard conditions (22 °C, 55 % RH) [3]. If a new washing program is initiated before the regeneration process is finalized, the heat pump operates at lower efficiencies because of lower

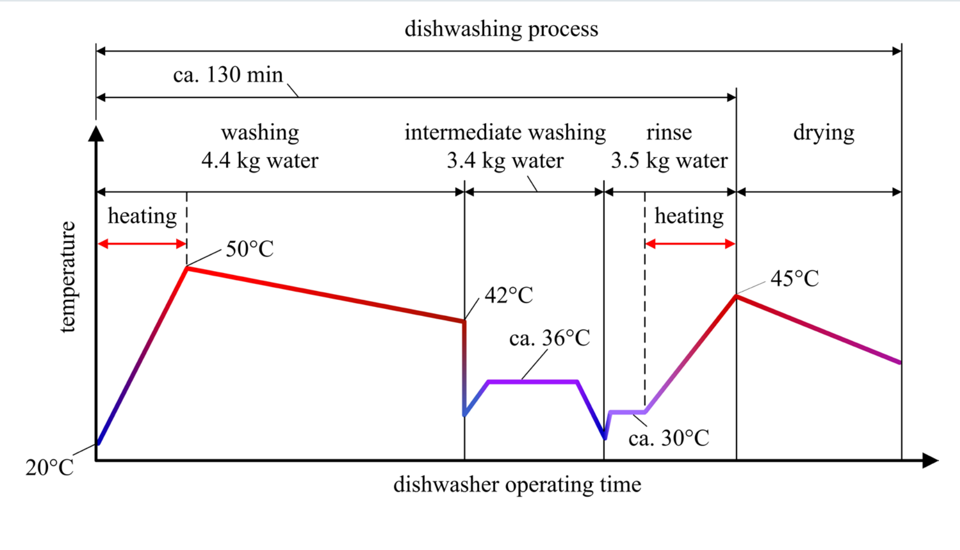

Figure 3. Dishwashing process for a dishwasher with a monovalent heat pump program and open drying process (not to scale).

Table 2. Comparison of the electrical energy needs of different dishwashers.

DISHWASHERS	SOURCE	ELECTRICAL ENERGY NEED [WH]	ENERGY REDUCTION* [%]
Standard dishwasher with electrical resistance heating and closed drying process (Adora N)	V-ZUG Ltd.	930	47.3
Dishwasher with open adsorption system	[5]	800	38.8
Dishwasher with bivalent heat pump system	[6]	910	46.2
Standard dishwasher with electrical resistance heating and open drying process (Adora SL)	V-ZUG Ltd.	750	34.7
Serial dishwasher with monovalent heat pump program and open drying process (Adora SL WP)	V-ZUG Ltd.	490	0

* The energy reduction expresses how much lower in percent the energy needs are for the dishwasher with monovalent heat pump program and open drying process compared to other dishwashers

average evaporation temperatures. The air cools off in the process due to the melting of ice. However, as the warm dishwasher itself cools to room temperature, it releases thermal energy into the air and warms the surrounding room air. Owing to the supplied electrical compressor energy, the air is supplied with more energy than is extracted by regeneration of the latent heat storage resulting in a net energy input to the room. However, compared to a conventional dishwasher the internal heat load of the room is reduced.

Electrical energy need

Table 2 compares the electrical energy needs for different dishwashers. The results show that the use of a monovalent heat pump program in a dishwasher with an open drying process can reduce the electrical energy needs by up to 50 % compared to dishwashers with electrical resistance heating and a closed drying process. The reduction is 38.8 % compared to dishwashers with an open adsorption system [5] and 46.2 % compared to a dishwasher with a bivalent heat pump system [6]. Compared to structurally similar dishwashers (Adora SL from V-ZUG Ltd.) with electrical resistance heating and open drying process, the reduction is 34.7 %.

The heat pump is not exclusively used for the "energy saving program", but is also used for other washing programs to provide additional heating utility. For example, in the so called "sprint program", the program duration can be reduced by 10 %, since the additionally installed resistance heaters are operated simultaneously with the heat pump resulting in an increase in the overall heating power. Besides the shorter program duration, the energy consumption of this program can also be reduced in comparison to purely electrical heating.

The installation of a heat pump increases the energy required for production, transport and disposal ("grey energy") of the dishwasher. An internal investigation has shown that after around 20 % of the overall number of dishwashing processes (according to the design specifications) the break-even in terms of grey energy is reached. The prerequisite is that the energy saving program is selected consistently and the dishwasher is equipped with the maximum possible load.

Conclusion

The integration of a heat pump in a dishwasher is an illustrative and positive example for a new application of the heat pump technology. The dishwasher with the monovalent heat pump program presented in this article clearly shows that the energy consumption can be reduced by up to 50 %. In addition to the benefit of employing the energy saving program where only the heat pump is used, other washing programs will also be improved with the heat pump. In particular, the total heating powers can be increased by the parallel use of the heat pump and electrical resistance heaters leading to shorter program durations. Also, compared to pure electrical resistance heating, the energy consumption of these programs is reduced as well. The increasing proliferation of energy-efficient household appliances can significantly reduce the energy demand of private households. Therefore, it is useful to incorporate this technology in other applications. For example washing machines with heat pumps have been already available on the market since 2013.

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BSc STEFAN FLÜCK
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
stefan.flueck@hslu.ch

Prof Dr MIRKO KLEINGRIES
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
mirko.kleingries@hslu.ch

Mechanical Engineer ERNST DOBER
V-ZUG Ltd
Switzerland
ernst.dober@vzug.com

Prof Dr BEAT WELLIG
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
beat.wellig@hslu.ch