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A household dishwasher heated by a heat pump system using an energy storage unit with water as the heat source

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ABSTRACT

Electricity usage by a household dishwasher can be reduced by using a heat pump system to heat the dishwasher cabinet, dishware and washing water. The evaporator obtains the energy from an energy storage unit which consists of a container filled with water which freezes to ice. The majority of the heat transfer from the energy storage to the evaporator occurs when ice is created in the energy storage unit. A transient simulation model of a dishwasher with a heat pump system was developed and compared to an experimental setup with good agreement. A simulation study of the compressor cylinder volume and the compressor operating time was performed. The results showed a 24% reduction in total electricity use compared to a dishwasher cycle using a traditional electric element.

Lave-vaisselle domestique chauffé grâce à un système de pompe à chaleur utilisant un accumulateur d'énergie comme source de chaleur

Mots clés : Appareils domestiques ; Utilisation d'énergie ; Transfert de chaleur ; Congélation ; Simulation transitoire

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Nomenclature

A	Area (m^2)
C	Correction coefficient (–)
COP	Coefficient of performance (–)
cp	Specific heat (J kg^{-1} $°C^{-1}$)
E	Electricity energy (Wh)
Gr	Grashof number (–)
h	Specific enthalpy (J kg^{-1})
H	Height (m)
k	Thermal conductivity (W m^{-1} $°C^{-1}$)
m	Mass (kg)
$\dot{m}$	Mass flow rate (kg s^{-1})
n	Speed of the compressor (rpm)
Nu	Nusselt number (–)
p	Pressure (Pa)
Pr	Prandtl number (–)
Q	Heat transfer (Wh)
$\dot{Q}$	Heat transfer (W)
RH	Relative humidity ratio of air (%)
S	Latent heat for freezing pure water (J kg^{-1})
t	Time (s)
T	Temperature (°C)
U	Heat transfer coefficient (W m^{-2} $°C^{-1}$)
$\dot{V}_s$	Theoretical swept volume flow of the compressor (m^3 s^{-1})
V_s	Compressor cylinder volume (m^3)
$\dot{W}$	Electricity power (W)

Greek symbols

δ	Thickness (m)
ε	Emissivity factor for surface (–)
ηis	Isentropic efficiency of the compressor (–)
ηv	Volumetric efficiency of the compressor (–)
λ	Thermal conductivity (W m^{-1} $°C^{-1}$)
ν	Specific volume (m^3 kg^{-1})
σ	Stefan-Boltzman constant (W m^{-2} K^{-4})

Subscript

am	Ambient
cond	Condenser
dw	Dishwasher
dw_loss	Energy loss from the dishwashing cabinet to the ambient
es	Energy storage
evap	Evaporator
in	Inner isolation *out* Outer isolation
ph_tra	Phase transition of water
pump	Water circulation pump
r	Refrigerant

1. Introduction

The purpose of a dishwasher is to wash dishware. The four main factors affecting the washing results are chemical action, mechanical action, heat and time. Different combinations of these yield different washing results and use different amounts of electricity, water and detergent.

In the past, the main method of decreasing the electricity use in a dishwasher (without affecting the washing result) was to reduce the water use while increasing the washing time. In Europe the biggest drop in electricity and water use by dishwashers occurred when the European dishwashing standard (EN50242, 2008) was introduced at the end of the 20th century. For example, between 1977 and 2003 one manufacturer reduced the total electricity use from 3.7 to 1.1 kWh, and water usage from 60 to 9.9 dm^3 (Höjer, 2013). The rate of improvements slowed down in the following years mainly because of the difficulty of further reducing water use.

To reduce electricity use still more, new technology is required. One option is to use the heat of the wastewater exhausted from the dishwasher to heat fresh water entering the dishwasher (De Paepe et al., 2003). Calculations and performance results showed a 25% relative reduction in electricity use. By using an additional absorption cycle during the drying process, the electricity use was reduced by 25% (Hauer, 2011). By using a hot water circulation loop to heat the dishwasher, the energy was transferred to the dishwasher via a heat exchanger (Persson, 2007). Experimental results showed it was possible to replace up to 90% of the electricity used for hot water heating (Persson, 2007). In that study energy use was not reduced; only a change of heating source occurred, from electricity to hot water.

The concept introduced in this article is to reduce the electricity use by adding a heat pump system to the dishwasher. The dishwasher cabinet including dishware and the dishwater are the heat sink, and an energy storage unit is the heat source. The energy storage unit is a container filled with water that will freeze to ice. An alternative heat source is the ambient air in the kitchen. A fan would be required to move this air, but this has the drawback of creating a stream of cool air in the kitchen. An energy storage unit inside the cabinet will not affect the climate in the kitchen.

It is common to simulate heat pump systems in cooling applications in order to find ways to reduce electricity use. Ablanque et al. (2011) performed a numerical and experimental study of the transient response of a vapour compression refrigerating system with less than 1 kW compressor power. Their model allows the simulation of both steady-state and transient conditions. It was validated against a domestic refrigerator, with good agreement (discrepancies lower than 10%). Fardoun et al. (2011) present a quasi-steady state simulation model used to predict the performance of an air source heat pump water heater. The model was used to predict system parameters such as electricity power input and the coefficient of performance (COP). Wang et al. (2010) developed a simulation model of