HOW TO REDUCE ENERGY CONSUMPTION OF BUILT-IN REFRIGERATORS?

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Abstract:

Due to new technical developments and improvements, energy consumption of domestic refrigerators and freezers has decreased by about 60 % in recent decades. These reductions are mainly traceable to more efficient and lower dimensioned compressors as well as to improved insulations. Despite a high market share of 59 % for built-in refrigerators and freezers in Germany, their energy efficiency could not be improved in the same way. Because of standardized niche measures for built-in appliances, insulation is limited to a certain extent and additional insulation material would decrease the refrigerators' net volume. For this reason, built-in refrigerators and freezers are seldom graded into the highest energy efficiency classes. Moreover, energy consumption of a built-in appliance not only depends on its technical components, but rather on the way it is installed in private kitchens. Simple calculations show that even minor modifications of air vents may have a significant impact on the ventilation of the appliances. Accordingly, an insufficient air vent will cause heat, which is emitted by the condenser coils on the back wall of the refrigerator, to accumulate inside the refrigerator cabinet. Consequently, conduction through the refrigerator walls will increase and will lead to an increase in energy consumption. On the other hand, oversized air vents waste space, which otherwise could be used for additional insulation. To the best of our knowledge, these factors were neglected in previous investigations and optimizing measures.

The objective of this project is to investigate to what extent the energy consumption of built-in refrigerators and freezers can be reduced by modifying installation conditions (e.g. air vents, air flow velocity) or by additional features (e.g. drawers). In particular, the focus here is on reducing conduction through refrigerator walls as well as on accelerating heat removal from the condenser. The results of both, experimental and numerical (CFD) approaches will be presented.

Introduction

With a share of 26 %, private households are the second largest consumer in terms of electrical energy in Germany and in most developed countries (BDEW, 2011). Most of this electrical energy (29 %) is used to operate domestic refrigerators and freezers because these appliances are common in nearly every household. Moreover, refrigerators and freezers are the only devices in private homes which are permanently connected to the power supply. This is the reason why they have attracted considerable attention in view of energy efficiency improvements during the last decades. As a result of the implementation of the European Energy Label, new technical developments and improvements could be achieved and the energy consumption has decreased by about 60 %. These reductions are mainly traceable to more efficient and lower dimensioned compressors as well as to improved insulations (for example vacuum panels).

However, the energy efficiency of built-in refrigerators and freezers could not be improved in the same way. Because of standardized niche measures, insulation here is limited to a certain extent and additional insulation material would decrease the refrigerator net volume (Rüdenauer, 2006). However, the thickness of the layer of insulation is directly related to the heat load by conduction through cabinet walls, which accounts for 60-70 % of refrigerators' heat load (ASHRAE, 2002). For this reason, built-in refrigerators and freezers are seldom graded into the highest energy efficiency classes. Moreover, energy consumption of a built-in appliance not only depends on its technical components, but rather on the way it is installed in private kitchens. Simple calculations suggest that even minor modifications of air vents may impair ventilation of the appliances. Accordingly, an insufficient air vent will cause heat, which is emitted by the condenser coils on the back wall of the refrigerator, to accumulate inside the refrigerator cabinet. Consequently, conduction through the refrigerator walls will increase and will lead to an increase in energy consumption. On the other hand, oversized air vents waste space, which otherwise could be used for additional insulation.

Melo et al. (2004) carried out an experimental study on the performance of wire and tube condensers as a function of its geometry and its position to the adjacent (back, side and bottom) walls. This kind of condensers is widely applied for household refrigerators and freezers all over the world and consists of a steel tube, which is bent into a snake like shape, and wires, which are vertically attached on both sides of the tube (Melo and Hermes, 2008). Instead of a refrigerator, a special experimental apparatus, mainly consisting of hot water circulating through a heat exchanger, was used. Heat transfer rate was calculated from the water mass flow rate and the temperature difference between the inlet and outlet of the water. Melo et al. (2004) found that the performance of these wire and tube condensers is mainly influenced by the gap between the refrigerator and the rear wall. The heat transfer rate increased with an increasing gap until reaching a maximum value. After this maximum point, heat transfer rate decreased due to a reduction in buoyancy. The optimal position of the condenser was found to be half the distance between the refrigerator and the rear wall.

Despite the high market share of built-in refrigerators and freezers (59 % in Germany; Gruber, 2006), no further studies were published on optimizing the interaction between refrigerators and the cabinets they are built-in.

In this study, the emphasis will be put on this interaction. The objective is to evaluate to what extent the energy consumption of built-in refrigerators and freezers can be reduced by modifying installation conditions (e.g. air vents, air flow velocity) or by additional features (e.g. drawers). In particular, the focus here is on accelerating heat removal from the condenser and, by implication, on reducing the condenser's temperature, which is the most crucial factor for refrigerators' energy consumption (Geppert, 2011; Geppert and Stamminger, 2013). Experimental as well as numerical (CFD) approaches are applied in this study.

Materials and methods

Experimental setup

The experiments were carried out with a commercially available domestic built-in refrigerator under temperature-controlled conditions in a climatic chamber (accuracy ± 1.5 °C). A detailed description of the appliance is given in Table 1. All tests were conducted at an ambient temperature of 21 °C. The internal compartment temperature of the refrigerator was set to 5 °C. The refrigerator was installed into a dull black-painted test enclosure made of 20 mm thick plywood. This enclosure allows the position of the rear and side walls as well as the area of the air vents (inlet at the socket and outlet at the top) to be varied.

Table 1: Specification of test appliance

Type	Built-in refrigerator
Energy efficiency class	A^+
Cooling	Dynamic
Total net capacity	0.308 m^3
Net freezer capacity	-
Climate class	SN-ST
Power rating	90 W
Voltage	220-240 V
Frequency	50 Hz
Distance refrigerator back wall-condenser	10 mm

Energy consumption tests were largely conducted following the European standard for household refrigerating appliances EN ISO 15502:2005. Experimental data like internal compartment temperatures (°C), ambient temperature (°C), ambien t humidity (% RH), refrigerator's energy consumption (Wh), power (W), voltage (V) and current (A) were recorded using a computer-based data-acquisition system. All data were recorded at 60-second intervals for at least 24 h. Compartment temperatures were measured in accordance with standard EN ISO 15502:2005 using three type T (copper-constantan) thermocouples with a measurement uncertainty of ± 0.2 °C inserted in a brass cylinder. The air velocity and air temperature inside the flow passage near the inlet and outlet of the air was measured using two thermoanemometers (measuring range: 0,08-2,00 m/s, accuracy: ±(0,04 m/s + 1 % of measured value)). Temperatures of the condenser coils were measured by nine thermocouples type T equally distributed along the height and width of the condenser.

To study the effect of different wall positions and areas of air vents, a reference point was used which corresponds to the measures recommended by the manufacturer (gap between refrigerator and side walls: 11 mm, gap between condenser and rear wall: 50 mm, area of air vents: 200 cm^2).

Numerical simulation (Computational Fluid Dynamics (CFD))

CFD is a simulation method widely used in engineering to analyse and predict heat transfer and fluid flow by numerically solving the Navier–Stokes equations. The geometry of the entire system (refrigerator and cabinet) was meshed into discrete cells. The software program Fluent was used to solve the equations 3-dimensionally. This program uses the finite volume method of discretisation. The geometry of the condenser was simplified by dividing its surface into nine parts of equal size as shown in Figure 1. Each part was assigned a constant surface temperature, which was deduced from IR thermography during operation. In order to limit computational effort, heat transfer and airflow were examined at a discrete and representative point of time.

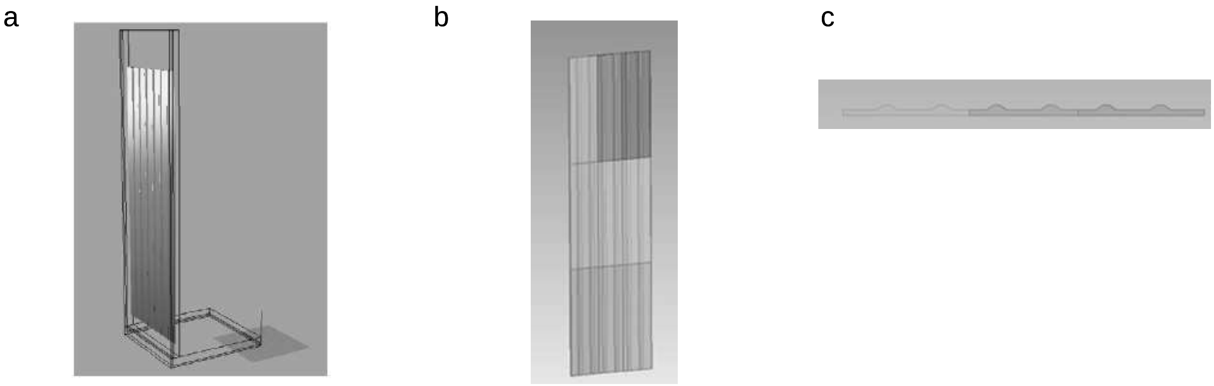

Figure 1: Geometry of condenser,(a) geometry model, (b) front view, (c) top view (source: Transsolar Energietechnik GmbH)

For the simulation, the walls were assumed to be adiabatic meaning that heat is exclusively supplied and dissipated by the wires and tube of the condenser and the air vents. Since modifications in geometry mainly influence convective heat transfer, radiation was neglected during simulation.

Besides the reference, three different variants were simulated (Table 2). CFD simulations were carried out by the climate engineering firm Transsolar (Stuttgart, Germany).

Table 2: Variants of simulation

	Reference	**Variant 1 (V1)**	**Variant 2 (V2)**	**Variant 3 (V3)**
Power	90 W	90 W	90 W	90 W
Distance refrigerator back wall-condenser	10 mm	25 mm	10 mm	10 mm
Air vents (inlet/ outlet)	200 cm^2	200 cm^2	400 cm^2	200 cm^2
Gap refrigerator-rear wall	50 mm	50 mm	71 mm	71 mm

Results and discussion

The first results indicate that there is a high potential for reducing energy consumption of built-in refrigerators by modifying installation conditions. In accordance to the results of Melo et al. (2004), CFD simulations reveal that the optimal position of the condenser is half the distance between the refrigerator and the rear wall (Figure 2, V1). Compared to reference, heat dissipation is increased by about 17 % as a result of an increased air velocity (Figure 3 and 4, V1).

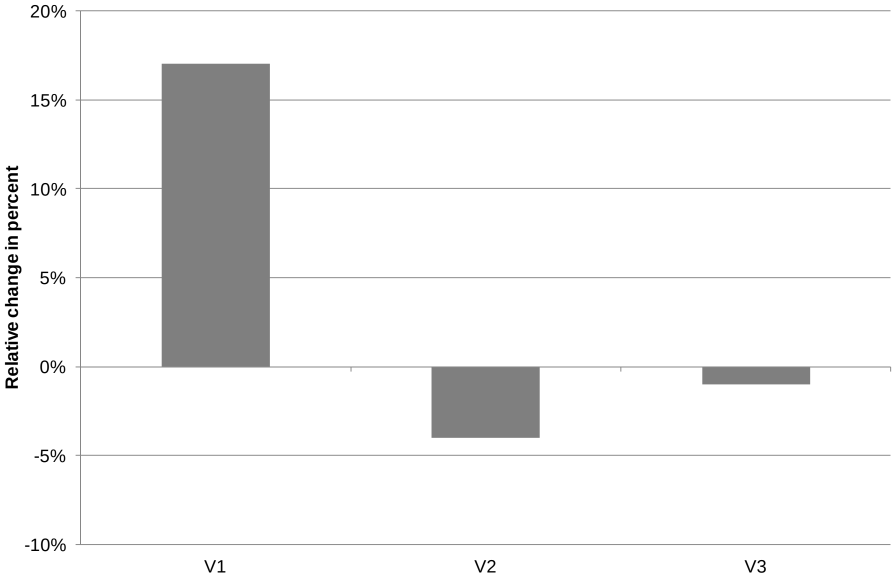

Figure 2: Changes in convective heat dissipation compared to reference obtained by numerical simulation (Transsolar Energietechnik GmbH)

However, it seems to be not promising to enhance the gap between the refrigerator and the rear wall of the cabinet. Regardless of the cross sectional area of the air vents, air velocity and heat dissipation slightly decreases compared to reference (Figure 2 and 4, V2, V3).

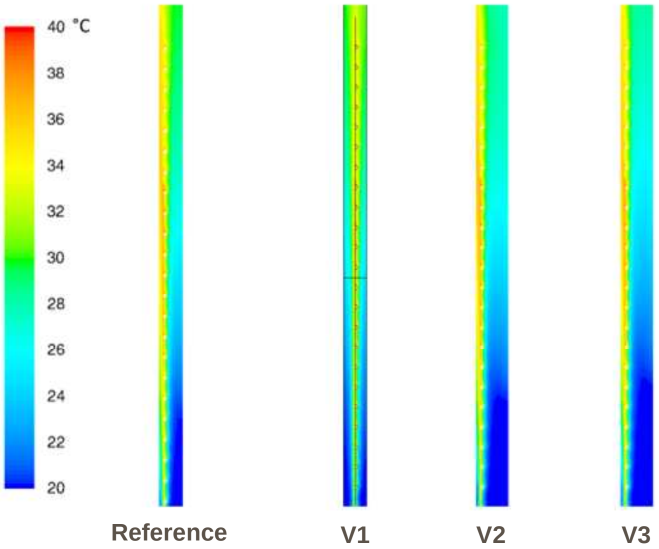

Figure 3: Air temperatures inside the gap between refrigerator's back wall and rear wall obtained by numerical simulation (Transsolar Energietechnik GmbH)

The aforementioned results could be confirmed to a high extent by experiments. Figure 5 illustrates changes in energy consumption as a function of the gap between the refrigerator and the rear wall of the cabinet. In accordance to the results of Melo et al. (2004), it can be noted that energy consumption increases significantly if the gap decreases, which is mainly caused by a reduction in circulating air flow. Energy consumption decreases with increasing gap between refrigerator and rear wall, reaching a minimum at 30 mm. Between 30 and 110 mm, energy consumption remains constant, meaning that the gap between refrigerator and rear wall can be reduced by 20 mm compared to actual recommendations (50 mm) without negative effects for energy consumption. So, the insulation layer of the refrigerator may be extended by using this additional space, in spite of standardized niche measures.

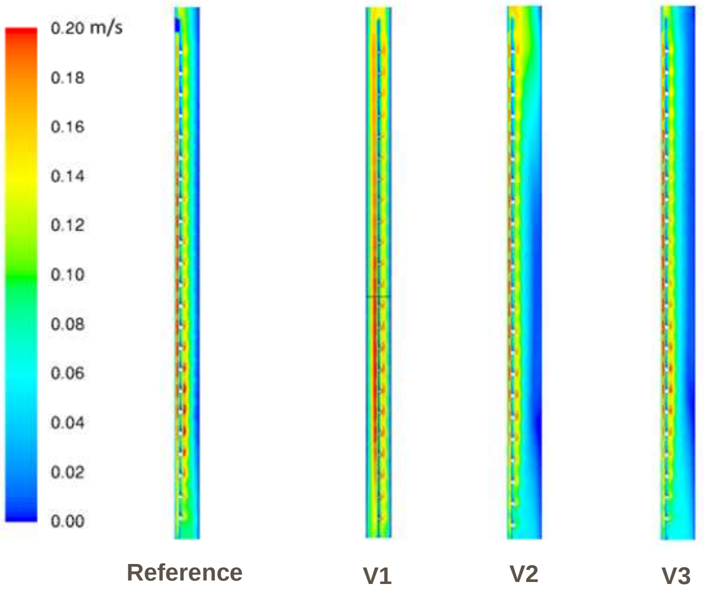

Figure 4: Air velocities inside the gap between refrigerator's back wall and rear wall obtained by numerical simulation (Transsolar Energietechnik GmbH)

Unfortunately, it is not possible to test gaps greater than 110 mm because of limitations in test cabinet. Such experiments could show whether or not a reduction in buoyancy leads to an increase in energy consumption if the gap is further increased, as shown by Melo et al. (2004).

Experiments carried out with different air vents (50 – 400 cm^2) while other parameters remained fixed have shown that there is almost no effect on energy consumption.

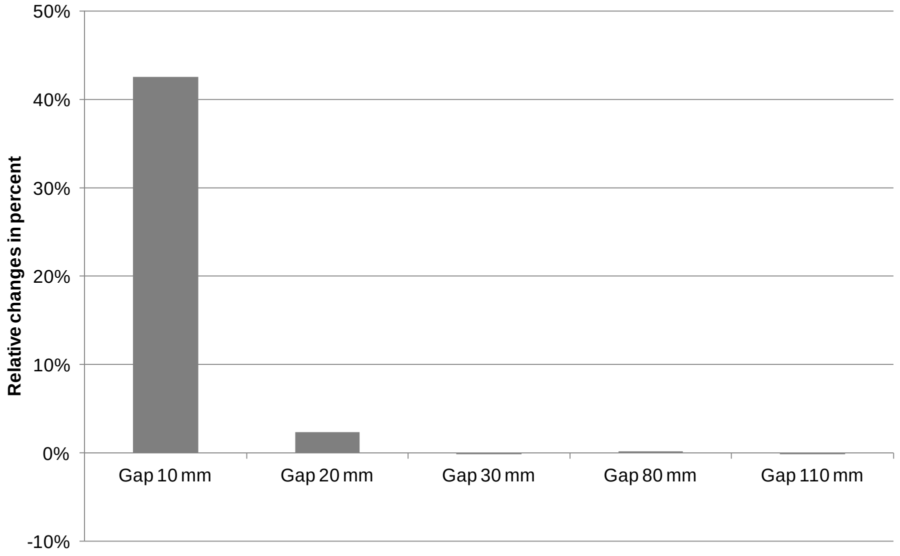

Figure 5: Changes in energy consumption compared to reference, obtained by experiments

Conclusion

Numerical simulations as well as experiments were carried out to evaluate if the energy consumption of built-in refrigerators and freezers can be reduced by modifying installation conditions (e.g. air vents, air flow velocity). It was shown that the gap between the refrigerator and the rear wall of the cabinet has the highest impact on heat dissipation and, related with this, on energy consumption. Experimental results portend energy savings if the gap is reduced by 20 mm compared to actual recommendations and if this space is used for extending refrigerator's insulation layer.

CFD simulations revealed that the optimal position of the condenser is half the distance between the refrigerator and the rear wall. The effect of other parameters tested was vanishingly low.

In future, additional experiments and simulations have to show whether or not energy consumption of built-in refrigerators can further be reduced by changing material of the rear wall (increased thermal conductivity) or by using additional features. Furthermore, the applicability of the results to other refrigerators and freezers has to be tested.

Acknowledgement

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