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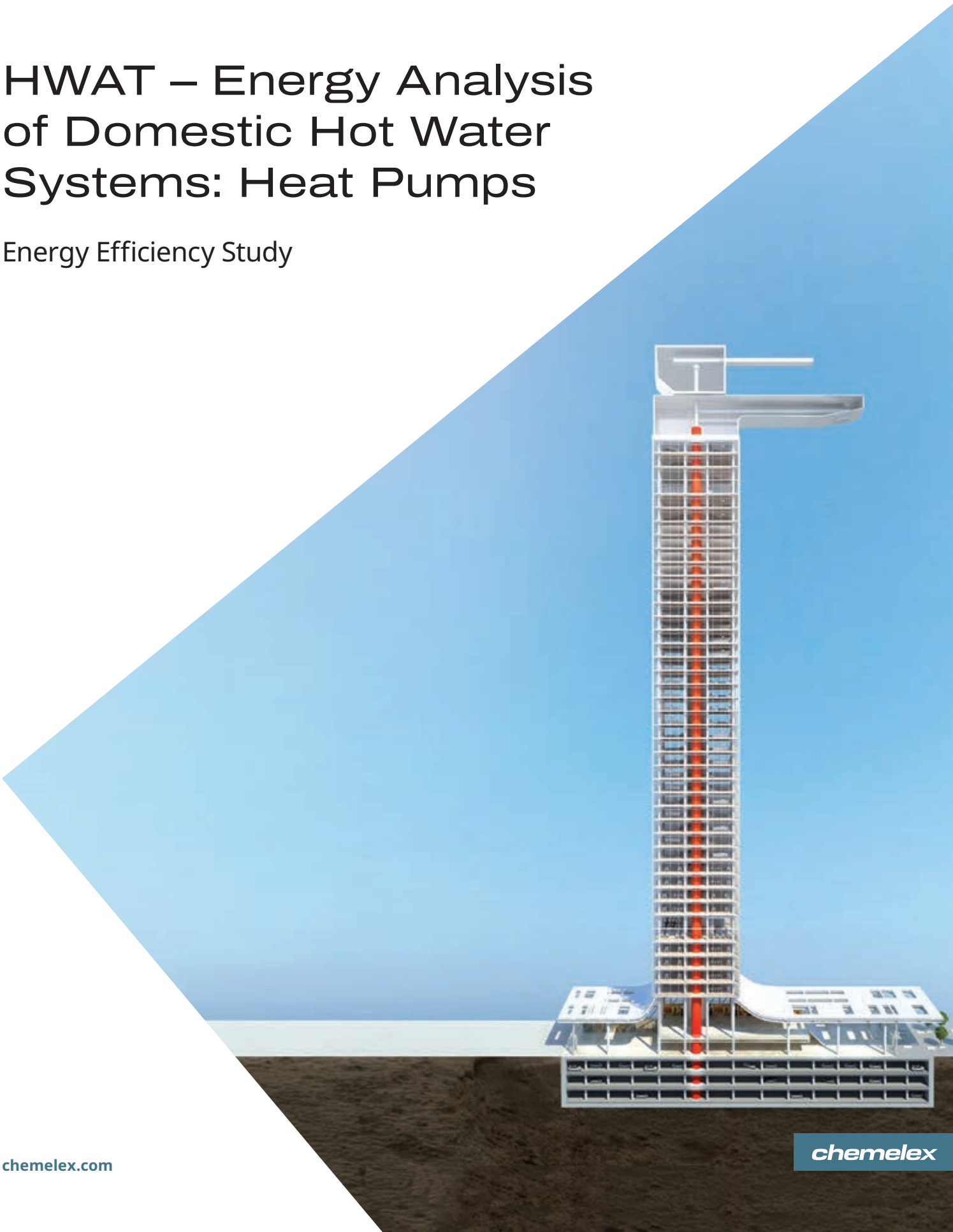
HWAT – Energy Analysis of Domestic Hot Water Systems: Heat Pumps

Energy Efficiency Study



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Technical information

Total energy analysis of domestic hot water generation and distribution systems. Hot water generator: Heat pump

There are two options to compensate for the heat loss in hot water distribution pipes: using a temperature maintenance heating tape or using a recirculation pipe. What is more sensible from an energy point of view when using a heat pump for hot water generation? What happens to primary and final energy consumption with the different distribution systems depending on the heat generator used? The results presented show that a single-pipe hot water distribution system with an electrical temperature-maintenance tape compensating for heat-loss compares favourably to a conventional recirculation system as a better supplement for systems served by a heat pump, both in terms of energy efficiency and economy. A single-pipe hot water system (without recirculating pipework) has inherently lower heat-loss due to the smaller quantity of pipework, and this is a key factor in such a system achieving a significantly higher COP value from the heat pump.

INTRODUCTION

The measures decided at EU level to reduce CO2 emissions to a large extent relate also to buildings. Country-specific energy guidelines for new-build and renovated properties were introduced in EU member states as part of the EU Energy Performance of Buildings Directive. These are reflected in Germany in the EnEV (Energy Saving Regulations) and the subsequent standards and directives (e.g. DIN V 18599). In addition to space-heating the energy expended for providing domestic hot water is particularly significant. With increasing construction and energy standards more and more attention is being paid to the energy required for domestic water heating, to comply with the EnEV. The method of heating domestic hot water must also be co-ordinated with the hot water distribution system in order to guarantee optimisation of the lowest possible primary energy consumption.

The primary energy factor for the power-mix will reduce further in view of the increasing proportion of renewable energy involved in power generation. From a primary energy point of view therefore, compensating for heat loss using a temperature maintenance tape on hot water pipes has increasingly significant impact.

This Technical information provides up-to-date results on the comparable primary and final energy performance of a heat pump when used in both single pipe trace-heated and recirculated distribution systems. These results were determined based on a scientific investigation by the Institute for Energy Technology at the Technical University of Dresden using a digital building simulation program (TRNSYS-TUD). These results have been incorporated into a TU Dresden research report and are shown in detail in that report.

THE PROBLEM

In the last few years an increasing trend for using heat pumps for domestic water heating has been noted. When operating with lower flow temperatures of no more than 40°C a heat pump is ideal for space heating, but it must exert maximum effort when generating domestic hot water at temperatures of 55-60°C. When the required flow temperature level increases (e.g. above 40°C) the COP value of the heat pump reduces. To counteract this adverse effect, often the water is pre-heated to 50°C by the heat pump and then heated further by an electrical heating element to the 60°C required to satisfy the regulations related to legionella prevention.

Here the hot water cylinder should have a lower water volume but also keep the hot water temperature constantly at 60°C and cover variable peak times for hot water consumption. Even more important is the use of a proper downstream distribution system in order to use and not lose the energy benefits of the heat pump in the whole system too.

THE SOLUTION

A heat pump with a 66Kw connected load and a 500 litre hot water storage unit were selected by TU Dresden to provide domestic hot water for a building model of an apartment block with 12 living units in accordance with energy standard EnEV 2009. In order to meet the hygiene requirements of DVGW (German Technical and Scientific Association for Gas and Water) work sheet W551 an electrical temperature maintenance tape was fitted to the hot water distribution system.

This temperature maintenance tape is fitted under the thermal insulation and only compensates for the static heat losses from the hot water pipes thus maintaining temperatures above 55°C.

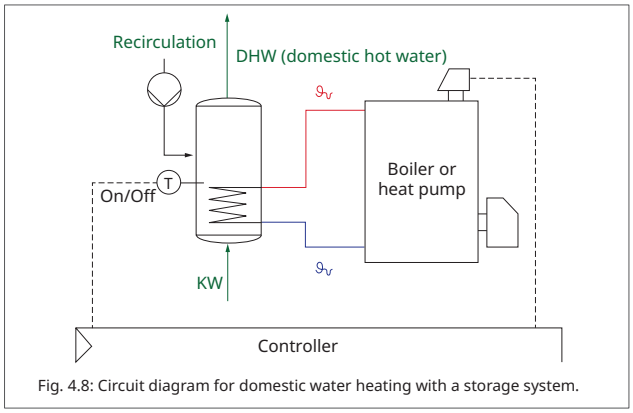


Fig. 4.8: Circuit diagram for domestic water heating with a storage system.

Source: TU Dresden

The benefit of the self-regulating effect of the temperature maintenance tape is that its power output adjusts naturally in each area of the pipe - this results in accurate temperature maintenance throughout the whole distribution system.

The recirculation system used as an alternative compensates for the heat loss by continual reheating and recirculating of the water. The recirculation system is designed in accordance with DVGW work sheet W553.

DIN 4708-2 was used for the design of the hot water cylinder and reproduced in the TRNSYS-TUD simulation program.

A heat pump system that can provide a sufficiently high flow temperature to heat domestic hot water was selected as a heat generator.

User behaviour plays an important role in achieving effective use of the hot water provided. Tapping times and the volumes of water drawn were taken into consideration here.

When defining the tapping profile reference was made to the international standard for European Countries in ANNEX 42. This tapping profile is also reflected in the Raychem HWAT-ECO control unit for the temperature maintenance tape.

The temperature maintenance tape is operated by a control unit that enables the draw-down and switch-off times as well as other functions to be specified depending on the time. The holding temperature is reduced to 50°C at night. Statistical analyses showed higher tapping mass flow times depending on usage. The temperature maintenance tape was switched off for these times because hot water at 60°C was flowing through the hot water pipe anyway.

With recirculation systems 'hygienically perfect' systems may be switched off for no more than 8 hours a day in accordance with DVGW work-sheet W551. It is possible to switch the system off during the night when there will be less water drawn off but the whole distribution system begins cool down to lower temperatures, with greater requirement for reheating later.

RESULTS

The seasonal performance factor is used to analyse the energy efficiency results. This seasonal performance factor looks at the whole heat pump heating system over a period of a year under variable temperatures. It is the ratio of heat energy delivered versus the electrical energy converted (including the energy for auxiliary drives etc). Normally the seasonal performance factor is theoretically in the range of 3.0 to 4.5. The COP (Coefficient of Performance) value is a separate standardised current value under laboratory conditions that is specified by the heat pump manufacturer. Depending on the heat pump used this value is normally in the range 3.0 to 5.0.

With these results for the sample project it is clear for the heat pump that the seasonal performance factor covers a wide range of 1.5 - 2.6 depending on the system design and management and thus falls significantly below the range of the stationary performance figure (COP) of 2.8 - 4.7. The reason for this difference is the combined effect of the increased power consumption of the heat pump to achieve the hot water flow temperatures and the impact of dynamic system behavior (frequent switching cycles). The implementation of the recirculation system in particular tends to lead to shorter switching phases and low seasonal performance factors as the build-up of heat stratification layers in the storage unit is adversely affected by the recirculation back-flow at low re-circulation temperatures.

Thus more primary energy must be used to compensate for recirculation heat losses than to maintain the heat with a temperature maintenance tape.

The difference in performance factors has an effect on both the power consumption of the heat pump system *and* the primary energy expenditure.

In all there is **an additional primary energy expenditure of up to 40%** for the heat pump in combination with a recirculation system.

The heat delivered from the recirculation system can be reduced by operating

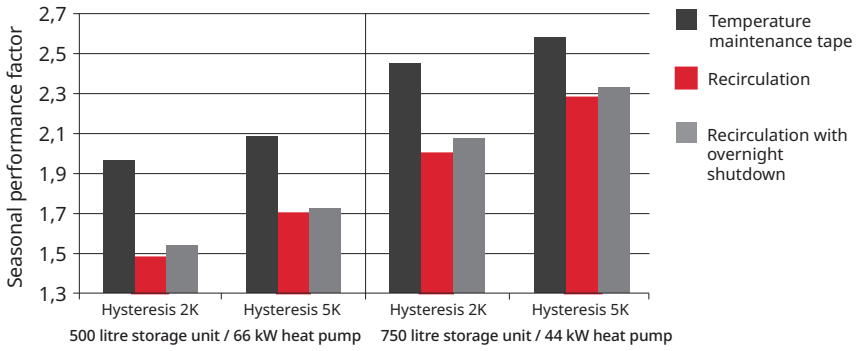


Fig. 1: Heat pump seasonal performance factor
Source: TU Dresden

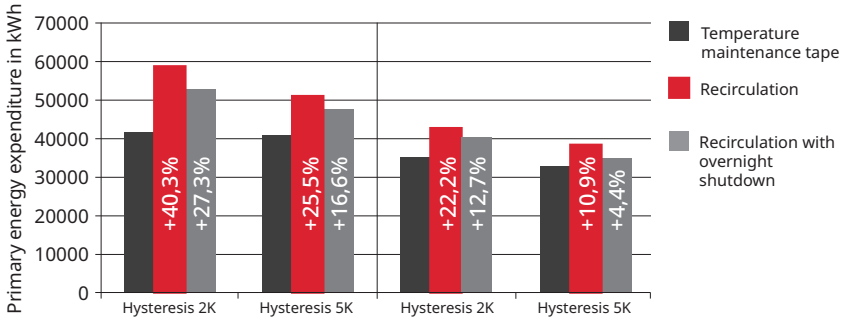


Fig. 2: Primary energy comparison between the temperature maintenance tape <-> Recirculation system
Source: TU Dresden

the recirculation pump and turning it off by night. The additional primary energy expenditure is reduced to 27% compared with the temperature maintenance tape.

It is interesting to look at the primary energy trend in the next few years. An analysis of the primary energy expenditure with lower primary energy factors demonstrates that assessment values of recirculation compared with temperature maintenance tape change in quality in a similar way.

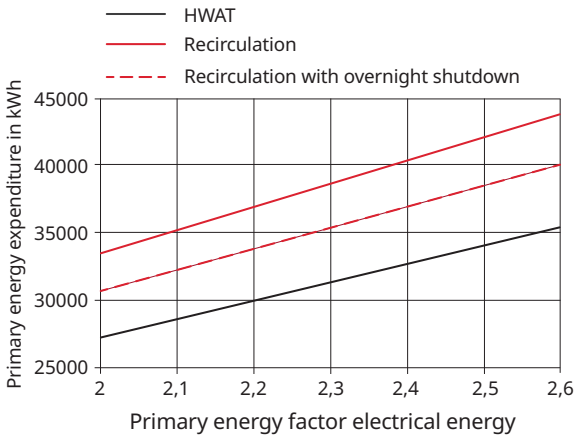


Fig. 3: Primary energy expenditure for the whole system when varying the primary energy factor for electrical energy, a 44 Kw heat pump and 2K hysteresis.

Source: TU Dresden

ECONOMIC COMPARISON

The actual useful energy converted is crucial for the economic analysis of the sample project tested. First of all it has been demonstrated that when using the temperature maintenance tape the useful energy requirement can be almost halved because there is no recirculation pipe. The tests show that to cover the heat losses from recirculation the effectiveness of the heat generation may not be disregarded. It is also shown that the temperature maintenance tape produces heat exactly where it is needed, under the insulation directly on the hot water pipe. The flow temperature from the water storage unit is actively monitored in combination with the temperature maintenance tape thus ensuring in operation that the temperature maintenance tape only compensates for heat losses and never bears the duty of raising the temperature of the water. Using preconfigured programs the temperature maintenance tape can also be switched off at peak draw-down times when hot water flows directly from the heat generator to the withdrawal points. During the night, when normally no water is drawn off, a setback temperature may also be selected.

Apartment block: Electrical energy - amount consumed in kWh

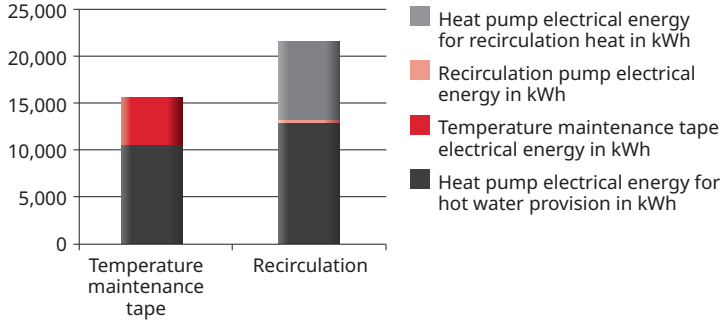
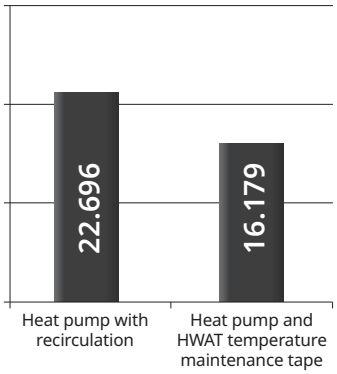


Fig. 4: Electrical power consumption of the heat pump for hot water generation and heat loss compensation of the pipes with temperature maintenance tape or recirculation pipe.

Final power in kWh



Annual energy costs with energy price CHF 0,29/kWh (Switzerland 2025)

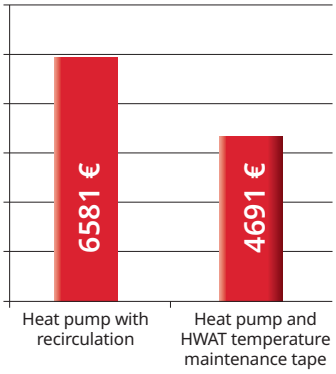


Fig. 5: Useful energy total and annual operating costs comparison of the two distribution systems; electricity price CHF 0,29/kWh (Switzerland 2025)

Fig. 5 shows that when using a temperature maintenance tape the necessary useful energy for the apartment block examined is up to 30% lower compared with a recirculation pipe both for hot water generation and temperature maintenance. This difference is reflected in the costs too because the energy source used - electrical energy - is the same in both versions.

SUMMARY

By extending the assessment limits to include the whole system [i.e. hot water generator (heat pump), hot water storage and hot water distribution system] the interaction between these system components is correctly incorporated into the energy assessment.

It is demonstrated that higher seasonal performance factors are achieved for heat pumps when used in combination with temperature maintenance tapes - due to the lower temperatures required within the heat pump and from the longer associated switching cycles.

This effect therefore shows that it is crucially important for systems incorporating heat pumps to be designed to include other components or techniques which reduce heat pump power requirement; **the use of a single pipe distribution with temperature maintenance tape is the prime example of such a technique.**

For the basic conditions examined it is shown that the temperature maintenance tape enjoys primary energy savings of up to 40% compared with the recirculation system. The conclusion is that when using a heat pump for hot water generation a single pipe distribution system with a temperature maintenance tape is the most effective and efficient energy solution. It must also be mentioned that the fact that the heat pump system does not have to be turned on so frequently leads to a longer service life and thus has a positive effect on the durability of the system.

Contacts

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