Water and Energy recycling in a Residential Passive House

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Summary

Before producing new energy, whether fossil or renewable, or pumping freshwater from groundwater resources, one should look first on how to avoid energy and water consumption and how to optimise the total resource efficiency for both the energy as well as the water sector.

Greywater recycling is one effective tool to improve the efficiency of water use in buildings. Advanced greywater systems have been developed and tested which produce high quality non-potable water (service water) for indoor (toilet flushing, laundry) and outdoor use (gardening, cleaning).

In this paper the treatment of greywater from showers and bathtubs in combination with heat recovery from greywater is presented. Greywater undergoes an advanced mechanical-biological treatment and a final UV disinfection without the use of chemicals, at the same time the heat recovered from greywater is used to pre-heat the drinking water for the building's combined heat and power plant (CHP).

Well planned greywater recycling systems can contribute considerably to water and energy savings in buildings and should therefore be marketed in future urban context as sustainable, environmentally friendly and safe technologies.

Keywords
Greywater recycling, water and energy efficiency, heat recovery, passive house, non-potable water, service water.

Introduction

Water and energy are very much closely linked as water is often needed to generate energy, and vice versa. In order to produce 1 kWh of electrical energy from fossil or nuclear fuel, about 2.7 – 3.2 litres of water will be needed for cooling.

On the other hand, the water supply and wastewater disposal sectors are the largest municipal energy consumers. A city like Berlin with 3.5 million inhabitants and modern conventional water technologies requires for its water sector as much electrical energy as the household electrical energy demand for a city with 280,000 inhabitants [1].

Low-energy houses and passive buildings are milestones when it comes down to reducing the heating demand in a building. What remains ignored is that most of the energy released today into the environment is through wastewater rather than through the building’s facade.

In contrast to material recycling of household wastes, which had been reinvented 30 years ago und put into praxis, the value of wastewater had been also long recognised but its realisation compared to waste management lags more than 30 years behind.

Although the first large greywater recycling plant for a 400 bed, four-star hotel is successfully in operation since 1996 [2], many investors and home engineering planners have not yet realised that today water costs in many buildings are significantly higher than the costs for space heating or electrical power and that there exists in buildings a high saving potential, not only for water but also for energy.

Therefore, wastewater should be regarded as a resource and segregating wastewater into its different streams, e.g. blackwater and greywater, can contribute towards a holistic water management strategy. Greywater is the wastewater sourced from bathtubs, showers, washbasins, kitchen and laundry. Greywater is different from blackwater in its composition, and constitutes the largest proportion of wastewater by volume produced in an average household.

Although early efforts to recover heat energy from greywater largely failed mainly due to high maintenance expenditure, low energy yield, low energy prices as well as the lack of legal requirements, there are very promising approaches today that are able to considerably improve sustainable energy and water efficiency in buildings through decentralised systems.

1. Greywater recycling

Greywater is generally classified as low load and high load. Low load greywater usually originates from showers, bathtubs and sometimes hand washbasins, while high load greywater also includes greywater from kitchens and washing machines. Figure 1 shows the average partial water flows in private households in Germany. With greywater recycling, the total drinking water demand can be easily reduced to 45 l/p/d [3].

Greywater recycling in buildings is a sustainable water management approach offering several benefits including economical, environmental and social. Once appropriately treated, greywater is considered suitable for non-potable uses such as toilet flushing, irrigation, laundry and cooling.
In general, greywater recycling systems should fulfil four criteria: hygienic safety, no loss of comfort to the users, environmental tolerance and economic feasibility [4]. The choice of a greywater management strategy is highly dependent on the end use of the effluent produced and should therefore be adapted to a specific application such as for outdoor agricultural reuse (gardening, irrigation), indoor reuse (toilet flushing, laundry) or for safe discharge into surface waters.

In an urban context, the potential for greywater recycling is mainly new-build residential developments, where dual piping can be included during the construction phase. However, greywater recycling is also feasible for already existing buildings within the scope of rehabilitation measures.

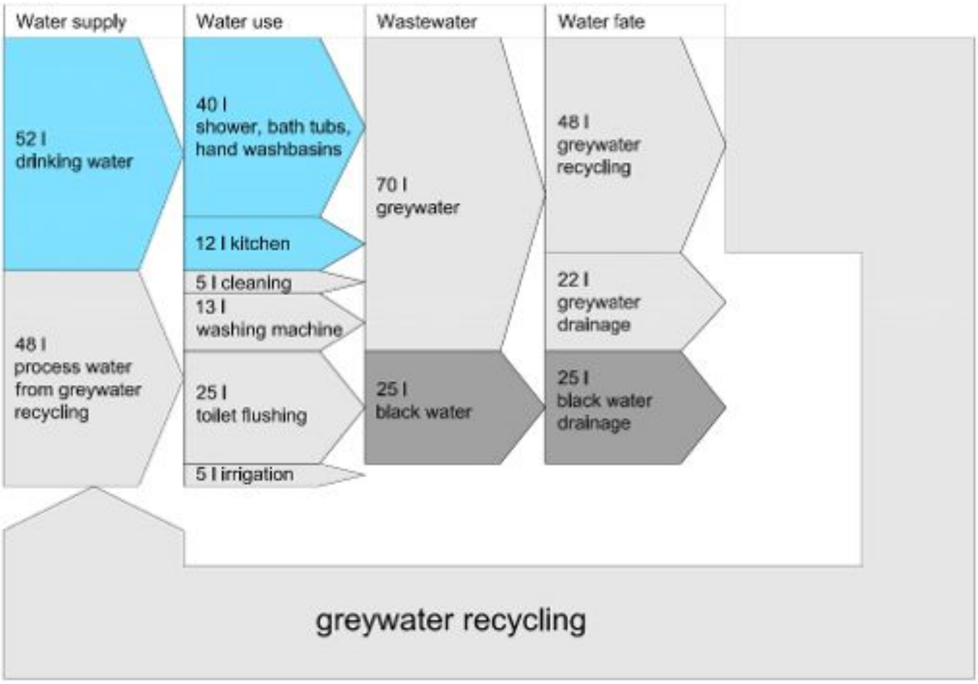

Figure 1: Average partial water flows (litres per inhabitant and day) for private households in new and rehabilitated buildings [Mehlhart, 2001].

Since fresh greywater exhibits relatively high temperatures, the feasibility of energy recovery from greywater is also high, as can be demonstrated in this project. Such an integrated approach would also considerably increase the efficiency of the entire system.

Taking as an example the passive house at Arnimplatz it has been shown that during the winter months heat recovery by means of very low-maintenance heat exchangers can achieve a coefficient of performance (COP) of ≥ 10, producing at the same time high-quality service water (non-potable water). Service water can be used in the building for applications which do not mandatorily require a drinking water quality, whereby further savings can be achieved.

2. Project Arnimplatz

Greywater recycling and heat recovery from greywater can be viewed as an ideal system combination to increase the total efficiency of the system. Fresh greywater has relatively high temperatures (up to 35°C) and therefore a potential for heat recovery already exists in the system.

A greywater recycling plant combined with heat recovery was launched in March 2012 in a multi-storey passive house in Berlin, Germany. For a standard passive house, which has a heat demand for space heating of <15 kWh/m^2/a, about 1.5-fold more energy is needed for hot water generation than for space heating. A total of 41 flats with 123 tenants occupying an area of 4,600 m² and 4 commercial units (600 m²) are connected to the greywater/heat recovery system. About 3,000 litres of low load greywater from showers and bathtubs are treated daily to produce high quality service water which is reused for toilet flushing.

The greywater system including heat recovery is placed in the cellar where the building's heating system is also found, occupying an area of 9 m^2 (ca. 0.1 m^2 per person) (Photo 1).

Photo 1: Greywater recycling combined with heat recovery in a multi-storey passive house in Berlin, Germany (Photos: E. Nolde).

The filtered greywater from showers and bathtubs enters the heat exchanger, where heat is withdrawn by means of a 20-watt circulating pump (Figure 2).

A self-cleaning sieve provides for a very low-maintenance operation of the heat exchanger and the greywater recycling system.

The cooled greywater exiting the heat exchanger enters two aerated buffer tanks acting as a biological pre-treatment stage. Subsequently greywater enters a secondary treatment stage (also a moving bed biofilm reactor (MBBR)) with an integrated particulate removal setup, before it finally passes a UV disinfection unit to enter the service water tank.

The biologically treated greywater (BOD_7 < 3 mg/l; turbidity < 1-2 NTU) is then fed into the service water network by means of a booster pump to serve as non-potable water for toilet flushing. The total electrical demand for heat recovery, greywater treatment and service water distribution is less than 1.5 kWh/m³. Treatment is achieved without the addition of chemicals and at very low maintenance.

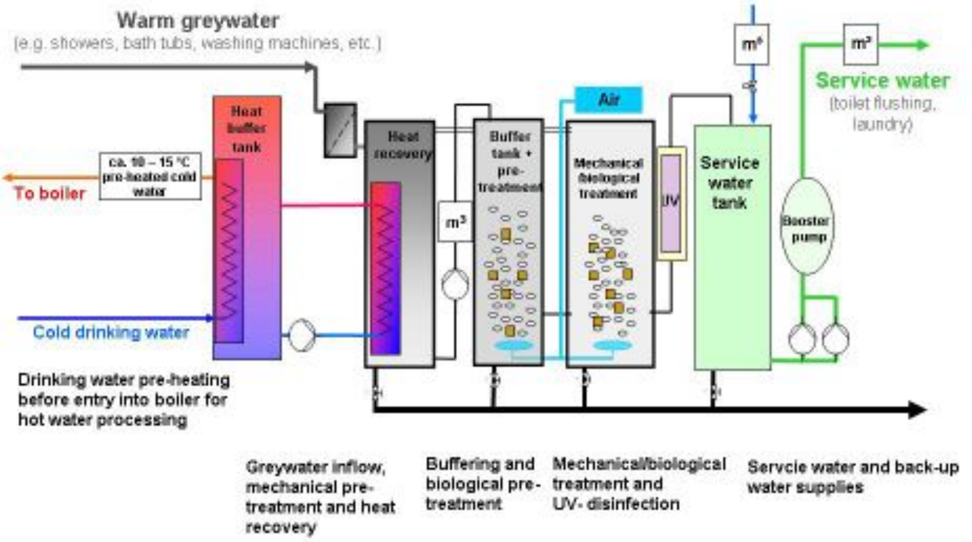

Figure 2: A schematic diagram of the greywater recycling system coupled to heat recovery in a passive residential house in Berlin, Germany.

3. Results and discussion

One essential technical aspect is that the generated greywater is not cooled down strongly before entering the recycling system. For this reason, the use of modern plastic pipes which also possess a good noise insulation is advantageous over conventional cast iron pipes. Even in winter, the mean temperatures of the influent greywater did not drop below 30 °C.

During winter when drinking water temperatures are relatively low (ca. 8.5 °C), it was possible to withdraw over 15 KWh of thermal energy per cubic metre of greywater with the combined system without the use of a heat pump. This energy was used to pre-heat the cold drinking water before it entered the decentralised combined heat and power plant (CHP) to be heated to 60 °C end temperature. During the first summer of operation when higher drinking water temperatures were measured, the recovery potential was only about 10 kWh/m³.

A monitoring study also showed an optimisation potential that would increase the future heat recovery performance of the system.

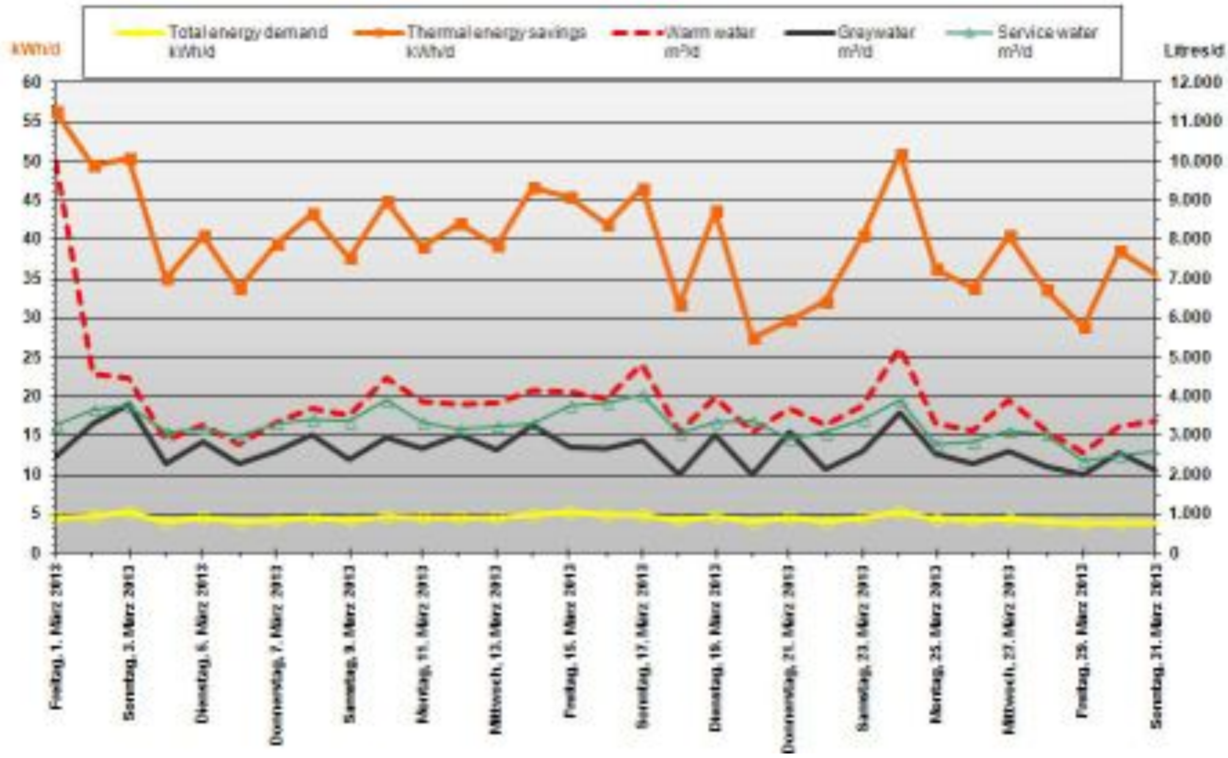

Figure 3: Monitoring results of the water and energy input and output during March 2013 in the greywater recycling plant at Arnimplatz.

Figure 3 shows that dependent on the amount of inflow greywater and freshwater demand more than 40 kWh/d of thermal energy can be often recovered from the system (orange line), compared to the electric energy demand for the entire system which lies constantly around 4 kWh/d (yellow line). Comparing the primary energy gains, this decentralised approach achieves a relatively higher degree of efficiency than centralised systems, where only about 1.5 °C can be withdrawn from municipal wastewater using heat pumps.

The results also show that the amount of greywater (black line), originating in this case only from showers and bathtubs, is not sufficient to cover the demand for toilet flushing (green line). It is therefore recommended to utilise additional greywater sources in buildings, for example, from handwash basins and laundry and even the high load greywater from kitchens (including fats and solids) to increase the availability of greywater and in turn the system’s efficiency

Figure 4 shows the measurable benefits of greywater recycling coupled to heat recovery exemplified by the project “Arnimplatz”. It is clear from the above results that the benefits of greywater recycling coupled to heat recovery are multiplied exerting eventually a significant positive impact on the greenhouse emissions.

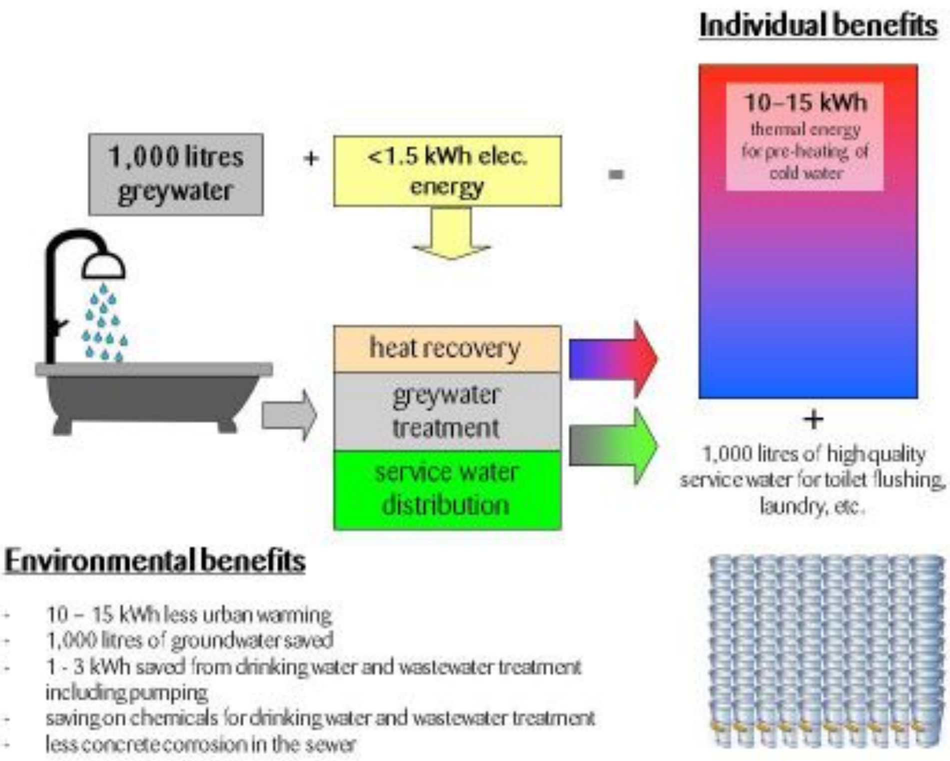

Figure 4: Individual and environmental benefits of greywater recycling combined with heat recovery based on an inflow of 1,000 Litres of raw greywater.

4. Conclusions and recommendations

Greywater recycling and heat recovery from greywater can be viewed as an ideal system combination to increase the total efficiency of the system. Fresh greywater has relatively high temperatures (up to 35°C) and therefore a potential for heat recovery already exists in the system.

Compared to outdoor installation, compact indoor installation systems using the warm heating room has several advantages since no additional insulation of all pipes and the recycling system is necessary and the plant is also more easy to maintain. An advanced monitoring system with access to the internet is very helpful to optimise the system and save operation and maintenance costs.

The additional costs for greywater recycling schemes of 10 €/m² of floor space (excluding second pipe system), compared to the real estate costs (3,500 - 4,000 €/m²), are very low (< 0.3%) and these costs will further decrease if individual plant design and engineering moves on to industrial and modular production. The inclusion of high load greywater, which can be also successfully recycled as had been already shown in a preceding project [6], should be practised at a larger scale in order to increase the efficiency of the system.

Also the increased use of service water for cooling purposes, such as in adiabatic cooling, would result in significant energy savings; about 630 kWh of cooling capacity can be generated from one cubic metre of water [7].

Especially for the area of Berlin the introduced greywater recycling system in combination with heat recovery saves as much energy which is equivalent to a thermal solar energy system of about 35 m² and even exhibiting best performance during the cold winter months.

The separation of blackwater and greywater in buildings should become a standard. Well planned greywater recycling systems can contribute considerably to water and energy savings in buildings and should therefore be marketed in future urban context as sustainable, environmentally friendly and safe technologies.

Therefore, it is essential to establish mandatory guidelines and standards for water and energy efficient systems especially for new buildings. Certification and rating schemes for buildings (e.g. LEED, BREEAM, DGNB, etc.) are only one step in the right direction.

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Further Reading

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