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Combined greywater reuse and rainwater harvesting in an office building in Austria: analyses of practical operation

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Abstract

The combined system of greywater treatment and reuse in a multi storey office building has been investigated over one year of operation. The system consists of an indoor constructed wetland, rainwater harvesting and water saving measures. The analyses covered quantitative and qualitative aspects like the water saving potential and physico-chemical and microbiological parameters. The existing system has been compared to three other water use scenarios by the calculation of capital cost (investments, re-investments) and operating costs (materials, labour and energy). The results showed that the system was capable to fulfil the physico-chemical requirements suggest by different guidelines but could not ensure the hygienic quality for all operating conditions. In comparison to a conventional system the combined system was capable to reduce the fresh water demand by more than 60%. The economic comparison revealed that the installed system is more expensive than rainwater harvesting only but cheaper than greywater treatment only. The difference to the conventional system was mainly due to the additional labour costs for maintenance and operation. Non-monetary benefits like the positive effect of indoor water treatment on the climate of the building have to be considered within the overall evaluation of such systems.

Figure 1: Rainwater storage canal (left) and indoor greywater treatment (right).

Introduction

Modern water use concepts for buildings aim on saving natural resources ensuring minimum emissions like carbon dioxide and wastewater. Beside the ecological benefits, economic but also additional benefits arise: using the internal water cycle as a visible design element and improving the climate within the building at the same time. In contrast to easily accountable benefits like reduced freshwater consumption the former are more difficult to account for. Nevertheless, they have to be considered to allow a broader application of so called 'green technologies'. A broad application of such technologies would be an important contribution to freshwater conservation. Before looking for alternative water sources, the first thing to consider is water saving measures. Nowadays, a variety of sanitary equipment to reduce the daily water consumption is available. Low flush toilettes and dry urinals have become common in many public and commercial buildings. Alternatives for fresh water sources are rainwater harvesting and reuse of separated and treated wastewater streams like greywater (wastewater of non-toilet origin). Rainwater harvesting is dependent on the availability of sufficient precipitation. Collection and storage of rainwater is more or less common for single households. The use of treated greywater for applications with lower water quality requirements like irrigation and toilette flushing is not new. Water reuse via greywater has been integrated as component of innovative building concepts since decades (Nolde, 1999). Although, the composition of greywater is different to domestic wastewater in terms of organics, nutrients and microbiological contamination, the treatment concepts applied mainly originate from wastewater treatment (Eriksson et al., 2009; Li et al., 2009). The applied systems vary from extensive biological treatment such as constructed wetlands (CWs) to more sophisticated methods (Knerr et al., 2008). Within the planning process, the three options of water saving, rainwater harvesting and greywater reuse can be applied as single solutions or in combination. The users expect safe and clean water use at the same standard as with conventional systems. The question is how the applied alternative concepts reach these requirements (Reinoso et al., 2008). This paper attempts to describe the results of the analyses of one year operation of a combined system of water saving, rainwater harvesting and greywater reuse in a multi storey office building in Austria. According to the requirements for treated greywater stated by Nolde (1999), the aspects of hygienic safety, aesthetics, environmental impact and economic feasibility have been investigated.

Materials and methods

The investigated building is a three story office building with a total floor space of 2090 m^2 and roof area of 460 m^2. The building is workplace for nine fulltime and five half-time employees. Water is also used for the affiliated car wash and garage. Beside the normal operation, the building serves also as venue for conferences and meetings. The building has been constructed under the Austrian standards for green housing with energy consumption below 10 kWh per square meter and year. Construction was finished in 2003. It is connected to the public water supply and sewer system. The integrated water concept of the building comprises the following components:

- Water saving measures: Low flush toilets and dry urinals
- Rainwater harvesting: Roof collection and outdoor storage in an open canal (Figure 1, left)
- Greywater treatment: In-door CW treatment (Figure 1, right)

Quantitative and qualitative measurements

Treated greywater and rainwater is mixed in the water storage tank for non-potable use (16 m^3) and partly circulated over the indoor-CW to avoid odour. Also the rainwater stored out-door was circulated via a separate line. The scheme of the combined treatment system is shown in Figure 2. Water flow was measured continuously at the sampling points Q1-07 over a period of one year. Additionally, the following parameters were analysed at the sampling points Q5, Q7 and Q8 (Figure 2):

- Organics: BOD_5, COD, TOC.
- Nutrients: Total Nitrogen, Ammonium, Nitrite, Nitrate, Total phosphorus.
- Microbiological parameters: Total coliforms, E.coli, Enterococci.
- Suspended matter: Total suspended solids.
- On-site parameters: Dissolved oxygen (DO), Electrical conductivity, Redox potential, pH and Temperature.

The lab analyses were carried out during three different sampling periods with monthly grab sampling (during one year), daily grab sampling (for one week) and 2h mixed samples (for two days).

The applied indoor- greywater treatment is a vertical flow sub surface CW with a surface area of 3 m^2. The configuration of the CW was 10 cm top layer of coarse gravel, 60 cm main layer (1 -4 mm) and 20 cm drainage layer. The inflow was intermitted at a flow rate of 15 L/min for one minute every eight minutes (100 L/h). The system was sparesly planted with *Philodendron sp.* and *Spathiphyllun sp*.

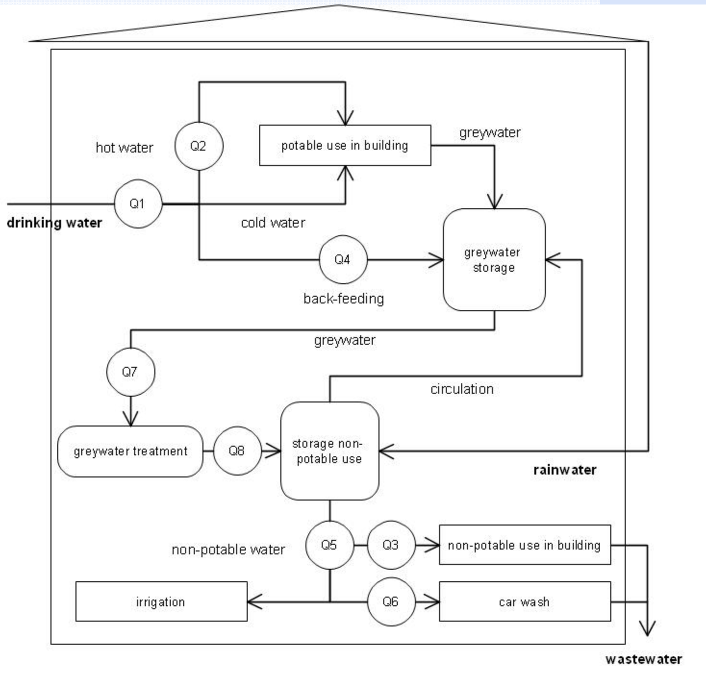

Figure 2: Scheme of the combined greywater and rainwater system. Quantitative measurements have been carried out at points Q1 to Q7, qualitative sampling at points Q5, Q7 and Q8, respectively.

Economic analyses

The economic analyses are based on a dynamic cost calculation using an overall interest rate of three percent for a life span of the system of 25 years and 12 years for mechanical and electrical equipment, respectively (LAWA, 2005). The analyses comprised investment costs, re-investment costs and operation and maintenance costs. The latter cover energy costs, labour and material costs. Data was collected by interviews with the responsible operator. To compare the existing system with other possible options, the estimated costs of the system components reported at the planning stage have been used. The following planning scenarios were investigated:

- Conventional system
- Greywater treatment and reuse only
- Rainwater harvesting only
- Combined system (existing)

It is important to mention that the water saving measures have been considered as option for every planning scenario since the water consumption patterns directly influence the economics of the different variants. The economic benefit of water saving was calculates based on the local tariffs for public drinking water supply and wastewater disposal. For the calculation of labour costs, standard costs for technicians in Austria have been used.

Results and Discussion

Greywater treatment

The median influent nutrient ratio of COD: N: P= 5:1:1 was unfavourable for the biological community compared to the optimum value of 100:20:1 (Metcalf and Eddy, 1991) due to the high dilution rate by the circulation (average 1:10). Also, the organics and nutrient concentrations were very low in comparison to usually reported values for greywater in central Europe (FBR, 2005). Average load conditions and removal rates are shown in Table 1.

The 60% load reduction was obtained from measurements - considering the mentioned dilution rate one can estimate a maximum BOD removal of 85% from incoming raw and undiluted greywater. The nutrient content remained more or less unchanged. Having in mind that CWs may easily reach more than 95 % of BOD removal in wastewater treatment (Haberl and Pressl, 2005) these results are unsatisfying. The phosphorus load was observed to be exceptionally high compared to literature values (Li et al., 2009) – the reason could be the use of industrial cleaning agents containing phosphates. The high hydraulic loading resulted in periodic blocking of the filter media and very low nitrification (median of ammonium elimination was zero) due to limited oxygen transfer. Besides that, circulation of the mixed greywater and rainwater resulted in a substantial additional energy demand.

Table 1: Average load conditions and removal rates of organics and nutrients over one year.

Parameter	Daily		Reduction	
Organic load (BOD)	22 g/d	7,3 g/(m^2.d)	60 %	4,4 g/(m^2.d)
Nitrogen load	12 g/d	4,0 g/(m^2.d)	0 %	0 g/(m^2.d)
Phosphorous load	34 g/d	11,3 g/(m^2.d)	0 %	0 g/(m^2.d)
Hydraulic load	3 m^3/d	1 m^3/(m^2.d)	-	

An important aspect for non-potable water use in buildings is the hygienic quality. Quality standards for greywater recycling are given by FBR (2005). The given suggestions are a combination of the microbiological standards of the German drinking water regulation and the European guidelines for the quality of bathing water (Directive 2006/7/EC). The requirements of the different regulations, standards and guidelines available in Germany and Austria are shown in Table 2.

n.a.…not available; n.d…not detectable

1) EU bathing water directive (Directive 2006/7/EC)
2) German guidelines for greywater recycling.
3) Austrian guidelines for irrigation water quality.
4) German standards for irrigation water quality.

40 % of the analysed CW effluent samples reached the quality standards of the EU bathing water quality directive and the half reached standards suggested by FBR (2005). Comparable results for other CWs have been reported and the need for subsequent disinfection was stated elsewhere (Li et al., 2009; Reinoso et al. 2008). The standards for irrigation water quality given by OEWAV A011 and DIN 19650 were reached by 50% and 80% of the monthly samples, respectively. The quality requirements for other than microbiological parameters like organic load and oxygen conditions suggested by FBR (2005) and suspended solids (Asano, 2007) were fulfilled by the system.

Beside the maintenance efforts for cleaning the screening and pre-treatment of the indoor CW, the operator is satisfied with the systems operation so far. Additional efforts arise occasionally by the algae bloom in the outdoor water canal and due to blocking of the indoor constructed wetland.

Rainwater harvesting

The quantitative measurements showed that about 25% of the yearly non-potable water consumption was covered by rainwater. Due to the cold weather conditions during December and January, the rainwater collection was put out of

Table 2: Summary of microbiological parameters suggested for different applications.

Parameter	Bathing water	Non-potable water	Irrigation water	
	1) EU-Dir.	2) FBR	3) OEWAV A011	4) DIN 19650
E. Coli /100ml	<1,000	<1,000	<2,000	<2,000
Enterococci/100ml	<400	n.a.	<1,000	-
Salmonella /100ml	n.a.	n.a.	n.a.	n.d.
Coliforms /100ml	n.a.	<10,000	n.a.	n.a.
Pseudomonas Aeruginosa /100ml	n.a.	<100	n.a.	n.a.

service during those two months. During this time period potable water was added to the storage tank for non potable use by back feeding (Figure 2). The circulation of rainwater in the out-door canal resulted in additional energy consumption.

Water saving potential

The water balance resulted in total water consumption of 145 m^3 per year and a drinking water consumption of 83 m^3 per year. The average water consumption was about 20 L per employee and day which is 20 % below the standard amount of 25 L given by the German guidelines for office buildings (VDI 3807). The combined greywater and rainwater use leads to an overall reduction of potable water demand of more than 60%. Since the wastewater discharge tariffs are linked to the drinking water consumption, this reduction also reduces the wastewater fees significantly. The daily drinking water consumption was 240 L/d (median) and the daily non-potable water consumption was 320 L/d (median). During conferences and meetings, the drinking water consumption and hence the greywater production was increased up to 2300 L/d. The monthly averages of the daily water consumption are shown in Figure 3.

The results confirm the assumptions of the system design (300 l/d estimated for non-potable use). The non-potable use showed no significant yearly variation (Figure 4). This was not unexpected since no non-potable water has been used for irrigation during the observations.

Economics

Three additional system scenarios have been calculated to compare the costs and benefits of the existing system to other technical options. The scenarios can be described as follows:

- Scenario 0 (a/b): Conventional system.
- Scenario 1 (a/b): Combined rainwater harvesting - greywater reuse system (existing).
- Scenario 2 (a/b): Greywater reuse system.
- Scenario 3 (a/b): Rainwater harvesting system.

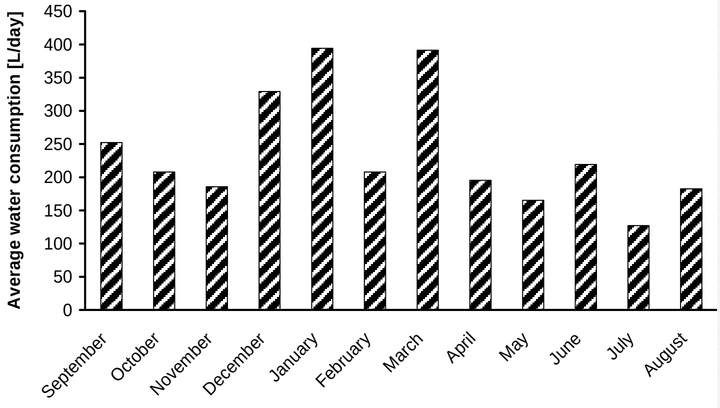

Figure 3: Average daily potable water consumption over one year.

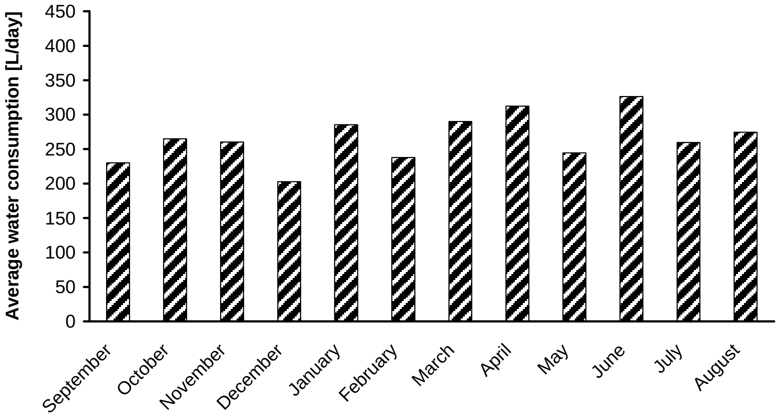

Figure 4: Average daily non-potable water consumption over one year.

As mentioned above, water saving measures have been considered for every technical option (sub scenarios (a) with and scenarios (b) without water saving measures). The capital value represents the total project costs at the start of operation. Savings due to lower water supply and disposal fees have been considered separately using an interest rate of 2.5%. The results in Table 3 show that the conventional solution is not the cheapest. The difference between the conventional scenario and the existing system lies with the relatively high personal costs for operation and maintenance. The low operating costs and medium investment costs lead to the good result for rainwater harvesting. Energy costs for pumping are relatively high when circulation of rainwater or treated greywater is necessary but low in comparison to labour costs for maintenance. Nevertheless, energy demands should be reduced as far as possible to foster the sustainable character of non-potable water use systems.

Table 3: Comparison of the costs and the water saving potentials of the different water use scenarios (life span 25 years, re-investment period 12 years, interest rate 3% p.a.).

Scenarios	Investments €	Re-Investments €	Operating costs €/a	Drinking water demand m^3/a	Capital value €
0 a- Conventional	9,100	1,500	1,500	145	36,900
0 b- Conventional	8,400	900	1,700	170	38,000
1 a- Combined	17,300	3,100	2,200	62	47,400
1 b- Combined	16,600	2,500	2,200	62	43,400
2 a- Greywater	16,740	3,100	2,300	73	49,100
2 b- Greywater	16,000	2,500	2,400	104	52,000
3 a- Rainwater	13,750	2,500	1,200	83	28,800
3 b- Rainwater	13,000	1,920	1,200	88	25,900

Further, the results indicate that greywater reuse only or rainwater harvesting only result in a higher drinking water demand and lower water saving potential. The influence of the water saving measures is evident for the scenarios 0 and 2. The influence on scenario 3 is relatively low, because the water saving measured impact the drinking water demand only in months without sufficient rainfall (winter months in Austria). The existing system showed the highest potential for water saving. Only about one third of the conventional scenario was consumed. The capital value of the installed system is more than 20,000 € higher than the cheapest scenario (rainwater harvesting). For the comparison of scenarios for decision making it is necessary to include non-monetary aspects into the evaluation. The positive effect of indoor treatment plants of the buildings climate and the company’s reputation as green player may change the results above.

Conclusions

Summarizing the main results from above, the following conclusions can be given:

- The removal performance of the indoor greywater treatment system in terms of organic matter and nutrients was below the reported performance of other comparable systems, but the required quality of the mixed non-potable water for the physico-chemical parameters was sufficient according to various guidelines. The required reduction of microbiological parameters could not be ensured for all operating conditions.
- The aesthetics of the non-potable water was sufficient for all operating conditions, the use of mixed greywater and rainwater did not lead to any disorders over five years of operation.
- It was shown that the combined system of water saving, greywater reuse and rainwater harvesting leads to the highest fresh water savings. The existing combination allows a freshwater consumption of only one third of a conventional system.
- A comparison of the capital costs of the existing combined system to three additional water use scenarios shows that the existing system is more expensive than rainwater harvesting but cheaper than greywater reuse only. The difference to a conventional concept is rather low and the additional costs are mainly due to the high labour costs for operation and maintenance. Non-monetary benefits like the positive climatic effect for the building can be also accounted for the installed system.

Within five years of practical experience, the system fulfilled the expectations of the operator of this multi storey office building. Drawbacks are the high energy demand of the greywater treatment system due to the circulation and the related adverse influence on the treatment performance and filter permeability. Dilution and intensive circulation over the constructed wetland should be avoided.

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