Developments in the quality of treated greywater supplies for buildings, and associated user perception and acceptance

Article

Published Version

Hyde, K., Smith, M. J. and Adeyeye, K. (2017) Developments in the quality of treated greywater supplies for buildings, and associated user perception and acceptance. International Journal for Low Carbon Technologies, 12 (1). pp. 136-140. ISSN 1748-1325 doi: https://doi.org/10.1093/ijlct/ctw006 Available at http://centaur.reading.ac.uk/56704/

To link to this article DOI: http://dx.doi.org/10.1093/ijlct/ctw006

Publisher: Oxford University Press

International Journal of Low-Carbon Technologies Advance Access published April 3, 2016

Developments in the quality of treated greywater supplies for buildings, and associated user perception and acceptance

K. Hyde[1]*, M.J. Smith[1] and K. Adeyeye[2]
[1]The University of Reading, Reading RG6 6AW, UK; [2]The University of Bath, Bath, UK

Abstract

A manufactured aeration and nanofiltration MBR greywater system was tested during continuous operation at the University of Reading, to demonstrate reliability in delivery of high-quality treated greywater. Its treatment performance was evaluated against British Standard criteria [BSI (*Greywater Systems—Part 1 Code of Practice: BS8525-1:2010*. BS Press, 2010); (*Greywater Systems—Part 2 Domestic Greywater Treatment, Requirements and Methods: BS 8525-2:2011*. BS Press, 2011)]. The low carbon greywater recycling technology produced excellent analytical results as well as consistency in performance. User acceptance of such reliably treated greywater was then evaluated through user perception studies. The results inform the potential supply of treated greywater to student accommodation. Out of 135 questionnaire replies, 95% demonstrated a lack of aversion in one or more attributes, to using treated, recycled greywater.

Keywords: greywater treatment; low carbon greywater recycling; domestic water reuse; social acceptance and aversion

*Corresponding author.
k.hyde@reading.ac.uk

Received 1 February 2016; revised 15 February 2016; accepted 29 February 2016

1 INTRODUCTION

Subsequent to greywater research conducted at the University of Reading in 2012 and 2013 [1], two separate research questions were presented: first, whether the operation of a greywater system at the University of Reading would be competent to provide a continuous stream of suitably treated greywater, for potential reuse for flushing toilets; secondly, if well-treated greywater supplies were then available, what consumer expectations about greywater supplies might be evident among users and students. The low carbon greywater technology provides treatment and recycling close to the point of use of domestic water. It demonstrates carbon efficiency, imposing a lower energy demand upon water use derived from large-scale water treatment and wastewater treatment infrastructure.

The first research question concerned the quality of greywater that could be produced by aeration and nanofiltration greywater units, supplied by Aqua-Lity UK. The treatment process was installed in the Engineering Laboratories at the University. The flows of untreated and treated greywater were analysed to establish whether the treatment process is competent to deliver acceptable greywater quality that meets the quality conditions of the British Standard [2, 3].

In order to address the second research question, a greywater questionnaire survey was conducted among students in University Halls of Residence to which 135 replies were received. Some greywater reuse schemes have failed due to an underestimation, by decision makers and implementers, of the impact and importance of social, sociotechnical and economic factors [4]. Given that background, it would seem important to learn as much as possible from past schemes, and to understand the influencing factors that encourage or discourage people from using greywater systems. The questionnaire was designed to avoid pre-warning or pre-disposing the respondents by the provision of accompanying information. Hence to an experienced practitioner, a few of the questions presented could appear to be lacking in advanced knowledge.

Po *et al.* [5] describe a user reaction of distaste that has been recognized in the literature since the 1970s, as a significant barrier to greywater reuse. Furthermore, Kaercher *et al.* [6] identified that while communities may have recognized the rationale for recycling domestic greywater, they felt that they could not follow such a scheme through, in order to use the greywater

doi:10.1093/ijlct/ctw006

themselves. If consumers are able to initially recognize the rationale for and, the benefits of reuse, for which reasons could discouragement then subsequently prevail; also, what missing factors or missing reassurances may have given rise to adverse reactions or discouragement?

A number of adverse factors have been identified by Po *et al.* [5] and include: health risks associated with greywater reuse, restricted uses for recycled greywater, unavailable or inadequate information about greywater recycling, unknown or unexplained benefits to the environment, the costs involved and socio-demographic factors. Low carbon benefits to the environment that may not be widely appreciated include the overall reduction to the carbon footprint realized by locally re-treating water that was originally treated elsewhere, and reducing the volumes of wastewater returned to that same location for treatment and disposal. Other public misconceptions of greywater may be based on assumptions that greywater means sewage ('black water'). It has therefore been recognized that achieving realistic and fair perceptions will be a key element in the future success of greywater reuse schemes. Ilemobade *et al.* [7] suggested that people often perceive the use of greywater to be risky because (i) it is not a pristine, natural source of water, (ii) it maybe perceived as potentially harmful to people, (iii) the decision to use greywater may be irreversible and (iv) the safety and quality of the greywater is not within personal control. It is likely that the perceived quality of greywater can be associated with a number of easily detectable factors, including smell, colour and particulate matter. Ilemobade *et al.* [7] also found that smell was the most important qualitative judgement applied by greywater users, followed by colour.

The risk perception barrier concerning the reuse of greywater operates in either or both the conscious and subconscious domains within individuals. In order to achieve realistic and fair perceptions, at least two elements must work together; that is first, the amelioration of perceived negative risks and barriers; secondly, the promotion of the positive effects and benefits. Improving perception and education about the efficiency of greywater recycling, should, as a minimum, explain how greywater systems function and can be operated safely; how human health is safeguarded; the benefits of greywater recycling for environmental protection and for sustainability of resources. Knowledge transfer must be delivered in a strategic and organized way in order to reach the widest communities possible.

Misconceptions about the smell and colour of recycled greywater can often be addressed in practical ways; it may be possible to provide a physical proof to users by using an in-line monitor, for example, to show that the installed systems are working safely. Furthermore, it is possible to reduce perceived or actual risks by reducing the possibility of human contact, such as through specific types of flushing toilets and irrigation systems [7]. Making financial incentives available may encourage more greywater recycling and reuse, particularly when offered alongside education and a better understanding of any potential risks or absence of risks.

2 GREYWATER TREATMENT AND PROCESS CONTROL

The study design consisted of:

(i) establishing a treatment process and proving its design to produce a consistent stream of high-quality greywater for buildings at the university campus;
(ii) proving that the treatment efficiency could meet accepted Greywater Quality Standards, as in BS8525-2 [3];
(iii) undertaking a questionnaire study to elucidate social and sociotechnical acceptance of the treated greywater.

An aerated membrane bioreactor (MBR) was installed at the University of Reading during summer 2013. The equipment applies aeration and ultrafiltration to lightly loaded domestic greywater. Aeration is intermittently delivered by a small compressor according to process cycles. Analytical determinations for monitoring the greywater quality have been conducted continuously during and since treatment stabilization. The types of greywater studied have included synthetic greywater, mixed in general accordance with BS8525 [3], and that includes a small amount of treated final sewage effluent to provide a source of human bacteria; secondly, domestic greywater collected from sources such as hand basins. The treatment process in the main tank ('Tank 1') aerates the greywater bacteria at a rate of almost 30 000 l of air per day. The ultrafiltration membrane has a pore size of 38 nm which provides structure for the growth of healthy aerobic bacteria, consuming nutrients in the greywater.

Once the greywater has passed through the membrane filter, it is transferred to the treated greywater storage tank ('Tank 2') for short-term storage.

The laboratory measurements consisted of analytical determinations of greywater parameters, including applying standard chemical methods in electrochemistry, light detection methods, auto-analysis and flame photometry. The parameters monitored on a daily/weekly basis included pH, electrical conductivity (EC, $\mu S\ cm^{-1}$), dissolved oxygen (DO, $mg\ l^{-1}$), turbidity (NTU, nephelometric turbidity units) and 5-day biochemical oxygen demand (BOD_5, $mg\ l^{-1}$). Other parameters measured were sodium (Na, $mg\ l^{-1}$), ammonia (NH_3, $mg\ l^{-1}$), nitrate (NO_3, $mg\ l^{-1}$), total organic nitrogen (TON, $mg\ l^{-1}$), phosphate (PO_4, $mg\ l^{-1}$), and total solids (TS, $mg\ l^{-1}$). The parameters were monitored in accordance with the British Standards [2, 3] and are cited in literary sources [8–10]. Validation was achieved through routine quality control in the laboratory, through peer review by external university teams and industry, and through the publication of results.

Figure 1 shows the greywater analytical results obtained over 1 year from June 2014 to June 2015. All the tests conducted since January 2014 indicated that the greywater quality met the quality requirements of BS8525 and other published greywater standards [1]. Independently of the degree of organic loading applied that was increased in December 2014, the indication of consistent baselines in pH in both tanks and in Turbidity in Tank 2 demonstrated very good treatment efficiencies, in addition to other parameters that are not discussed in this article.

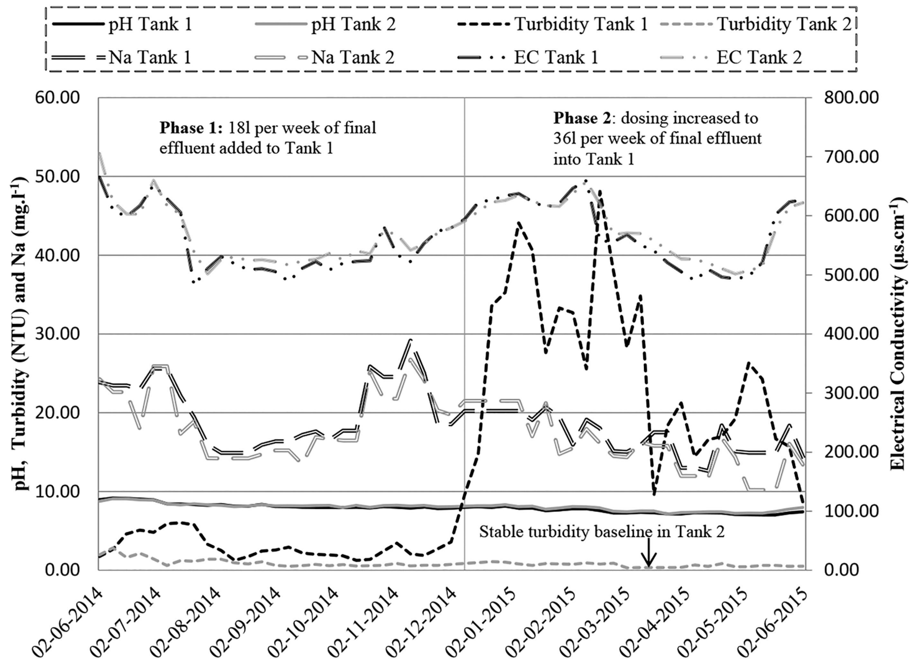

Figure 1. *Results in Tank 1 (reaction tank) and in Tank 2 (treated greywater tank).*

The concentration results for pH, EC and sodium in the treated water, Tank 2, generally followed the profile of those in the process tank, Tank 1. The Turbidity in Tank 1 from December 2014 onwards began to show a marked change in water quality due to the increase in added final effluent that introduced additional numbers of bacteria, and increased concentrations in TS and Organics. However, the Turbidity results from the treated greywater in Tank 2 maintained a stable performance from December 2014 onwards, despite the increase in final effluent added from 18 l per week in Phase 1, to 36 l per week in Phase 2. This interesting and excellent performance in the reduction in Turbidity demonstrated the efficiency and stability of the process in reducing such concentrations of contaminants.

Table 1. *Results from question: 'Which of the following best describes your opinion of recycled greywater?'*

Opinions about the uses to which recycled water may be put	Number of responses
I am in support of it for all uses	20
I am in support of it for most uses	26
I am in support of it for non-drinking uses only	50
I am in support of it if it is safe to use	48
I do not support it because of the health risks	2
I am not aware that there are any health risks in using recycled water, but I do not like to take chances	3
I do not support it (please explain below)	2

3 QUESTIONNAIRE SURVEY 2014: OBSERVATIONS AND DISCUSSION

The second research question was evaluated using a questionnaire study to assess what consumer expectations about greywater supplies might be evident among users and students should reliable, well-treated greywater supplies be available. The questionnaire survey produced 135 responses that were analysed. Underlying analytical data are likely to be made available in 2018. Questionnaire results cannot be made available since research participants did not give consent for these to be shared.

3.1 Public opinions about recycling and reusing greywater

Participants were able to select more than one statement if they felt it was necessary or appropriate (Table 1). The results indicated that the largest proportion of the respondents would use greywater, although under a variety of different criteria and assumptions. Most respondents indicated that they would be happy to use the greywater, provided it was not for drinking purposes, and was safe to use. Evidence of different levels of conceptual awareness among participants was apparent, and a lack of knowledge about greywater may have led some participants to assume that the treated greywater quality had been improved to the highest standards of drinking water quality. In other research, participants not willing to use greywater have attributed that to religious reasons, or to health or safety concerns. Since various potential uses for the recycled greywater were not specified to the respondents, ill-informed choices were not excluded.

3.2 Factors encouraging greywater reuse

Table 2 reports the factors that would encourage participants to use recycled water. The response rate in this questionnaire study was good. What was expected and seen in other studies, for example, Ilemobade *et al.* [7], was that the colour and odour of the greywater was of high importance to users when considering reuse. The complementary interpretation might be that a significant proportion of participants might not be affected by the colour and/or odour of the greywater in their choice about whether to use the recycled water. In order to encourage the reuse of greywater, it is clear that people require easy access to the greywater resource, whether this is for flushing toilets or for irrigation. If the resource were difficult to access, or if it were difficult to include within conventional facilities and behavioural norms, then it would be hard to encourage people to use the treated greywater. Evidence also suggests that people require the water-saving activity to be presented within its environmental perspective, and reporting on the water saved may be a way of communicating this. Only a small number of participants seemed to regard peer pressure as a dynamic influence for encouraging the greater use of recycled greywater. In contrast, previous work has shown that the recycling of goods has often been associated with peer encouragement [5, 11], whereby the action of one encourages another to follow.

Table 2. *Results from question: 'Which of the following will encourage you to use recycled water?'*

Opinions about using recycled water	Number of responses
If it is colourless	40
If it is odourless	52
Easy to access, e.g. simply turning on the tap	62
Being sustainable; helping to conserve the environment	60
Positive image with peers and friends	12
Other	10
Total votes	236

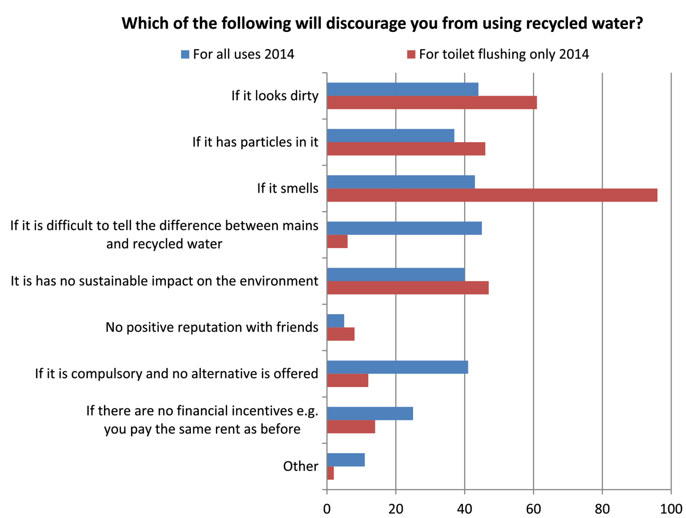

Figure 2. *Results from question: 'Actions and properties that would discourage greywater reuse'.*

3.3 Factors discouraging greywater reuse

It is evident from the results in Figure 2 that, for all uses specified in the survey, a large number of participants would be discouraged from using the greywater if: (i) it was compulsory and if no alternative was offered; (ii) there was no sustainable impact on the environment; (iii) it were difficult to tell the difference between mains water and recycled greywater and (iv) the greywater smells; if it has particles in it and/or if it looks dirty.

While financial incentives have been required in other sectors to encourage the take-up of initiatives, the greywater survey results showed that only a small proportion of participants would be discouraged from using recycled greywater if there were no financial incentive. Similarly, only a few participants responded that any lack of peer reputation associated with the use of recycled greywater would discourage them from using it. Thus, it was concluded that the participants did not think that peer pressure or interaction was particularly influential in encouraging or discouraging greywater reuse.

It was observed that the environmental benefits arising from the recycling of greywater require effective and clearly articulated dissemination. Only six people in the survey felt discouraged from using greywater for toilet flushing. In the case of other respondents, as long as the greywater met the criteria about looking clean, the absence of smell and the absence of particulate matter, then its use for toilet flushing would appear to have a reasonable chance of being accepted. The results support the conclusion that the smell and aesthetics of greywater are very important factors that influence reuse. In addition to several unexpected attitudes reported by the survey, it is perhaps most surprising that the control of the quality of water for flushing toilets is widely regarded as being of particular importance.

3.4 Summary observations

The results indicated that a large majority of respondents would use recycled and treated greywater, under a variety of different circumstances and criteria. Thirty-five per cent of respondents indicated the importance of good practice in terms of requirements for proof of safety, and 34% indicated the specific exclusion of drinking applications. The small number of participants (1.4%) who did not support any domestic uses for recycled greywater did not provide reasons for that. In the case of toilet flushing, a significant number (69%) of respondents would not wish toilets to use recycled greywater should the greywater smell. That suggests that good greywater aesthetics is one of the principal factors affecting willingness to use and the acceptability of greywater. In other research, the causes of participants not wishing to use greywater have been variously attributable to factors such as religious, health or safety concerns [7].

The respondents were not pre-warned or pre-disposed in their questionnaire responses by the provision of accompanying information nor, within the context of the survey, regarding questioning about the purposes for which they would be permitted to use the recycled greywater such as watering gardens, washing cars and certain types of cleaning. This is likely to have generated a range of respondent interpretations concerning the circumstances and purposes for which greywater might be used. The absence of prior information was intended to avoid influencing participants by providing systematic information about the chemical and microbiological quality of different sources of water supply. An objective for a future survey will include giving more information to potential users about the constituents of the greywater, together with advice about appropriate uses. Therefore, it was not intended, at the time of conducting the survey, that the data would be used to estimate the degree of participant understanding of the issues upon which they were being asked to comment. The scope of future research could explore whether the survey participants were well informed, moderately well informed, poorly informed or not at all informed.

The respondent engagement approach ensured anonymous participation by residents living in University accommodation. The respondents' e-mail addresses were provided under Data Protection rules. Based on the experience of previous surveys concerning personal water use, it was decided that a good response rate would be more likely if overt questions were omitted relating to the respondent's age and other personal details.

Knowledge of undergraduate intake statistics has indicated that a large majority of residents in University accommodation would be likely to have ages between 18 and 30 years, including mature students. However, the authors had no grounds upon which to make related quantitative assumptions, and thus consideration of age-related variances was excluded from any analysis of the results. The respondents sampled in this research were assumed to have alignment with a random cohort of students, probably having an age profile reflecting the general student population, including undergraduate and masters students. Also, it was broadly assumed that students in University accommodation might have a similar range of residential preferences to each other. These limitations of the research should be recognized when comparing the results with other populations. Nevertheless, the beneficial attributes of such a questionnaire study mean that comparably defined studies can be repeated in subsequent years, reflecting views towards water efficiency of people in younger age groups. Furthermore, the benefits of water-efficient low carbon technologies are thereby disseminated to respondents living within a frame of reference of climate change, and for whom such knowledge transfer is more likely to produce more efficient water-carbon using behaviours in future.

4 CONCLUSIONS

The greywater treatment system at the University of Reading produces a consistent stream of high-quality greywater, suitable for meeting the British Standards Institution Greywater Quality Standard, as in BS8525 Parts 1 and 2 [2, 3]. The treated greywater quality also meets aesthetic standards on odour and clarity.

The results of the questionnaire survey gave an overview of the sociotechnical acceptance of treated greywater drawn from a population of university students living on campus and some of whom might be mature students. Of these, 95% of respondents fell into four groups: (i) those in support of greywater for all uses, (ii) those in support of greywater for most uses, (iii) those in support of greywater for non-drinking uses only; (iv) those in support of it if it is safe to use. This respondent population of 135 adults has demonstrated a number of important features, including an overriding willingness to reuse domestic greywater treated by a low carbon technology. This result perhaps provides some contrast to earlier research work, for example, that of Burn [11]. Nevertheless, the observations of Kaercher will require testing in a population that has access to the use of treated domestic greywater supplies, in order to confirm whether or not a lack of preconceived aversion could then be identified in daily use. Future research will also be directed to perceptions of risk and safety.

ACKNOWLEDGEMENTS

We thank EU Climate-KIC funding programme, Aquality Trading & Consulting Ltd and British Standards Institution.

REFERENCES

[1] Hyde K, Yearley T, Ahktar Q. Greywater characterisation before and after filtration at the University of Reading Halls of Residence; early observations on the potential feasibility for greywater collection at the campus. In: *Water Efficiency in Buildings Network, Proceedings of Water Efficiency Conference*. Oxford. 25–27 March 2013, 170–83.

[2] BSI. *Greywater Systems—Part 1 Code of Practice: BS8525-1:2010*. BS Press, 2010.

[3] BSI. *Greywater Systems—Part 2 Domestic Greywater Treatment, Requirements and Methods: BS 8525-2:2011*. BS Press, 2011.

[4] May-Le NG. Household greywater reuse for garden irrigation in Perth: Environmental Engineering Project 640.406. Centre for Water Research, University of Western Australia, 2004.

[5] Po M, Kaercher JD, Nancarrow NB. Literature review of factors influencing public perceptions of water reuse. CSIRO Land and Water, Technical Report 54/03, 2003. http://www.clw.csiro.au/publications/technical2003/tr54-03.pdf.

[6] Kaercher JD, Po M, Nancarrow BE. Water recycling community discussion meeting I (unpublished M). Australian Research Centre for Water in Society (ARCWIS), 2003.

[7] Ilemobade AA, Olanrewaju OO, Griffioen ML. Greywater reuse for toilet flushing at a university academic and residential building. *Water SA* 2013;**39**:351–60.

[8] Christova-boal D, Eden RE, Mcfarlane S. An investigation in to greywater reuse for urban residential properties. *Desalination* 1996;**106**:391–7.

[9] Eriksson E, Auffarth K, Henze M, *et al*. Characteristics of grey wastewater. *Urban Water* 2002;**4**:85–104.

[10] Li F, Wichmann K, Otterpohl R. Review of the technological approaches for grey water treatment and reuses. *Sci Total Environ* 2009;**407**:3439–49.

[11] Burn SM. Social psychology and the stimulation of recycling behaviours: the block leader approach. *J Appl Soc Psychol* 1991;**21**:611–29.