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by

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WATER CONSERVATION WITH INNOVATIVE TOILET SYSTEMS

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ABSTRACT

A demonstration study was performed at the University of Wisconsin to evaluate under field conditions, the performance of residential water conservation systems including commercially available extreme low-flush toilets and washwater recycle units. The objectives of the study were to delineate the water use and waste flow characteristics and assess the impacts of the system use on them, identify installation operation, and maintenance needs, determine user acceptance, and estimate system costs. The low-flush toilets studied included the Microphor, Monogram and Ifö with flush volumes of 1.9 to 5.3 L. A total of nine fixtures were installed in five Wisconsin homes and monitored over a total of 1926 days. Three washwater recycle systems were initially identified but only one, the Aquasaver, was available for study. This system utilized the unit process of sedimentation, pressure cartridge filtration (20 μ) and chlorination to purify bathing and laundry washwaters for reuse in toilet flushing and turf irrigation. Two of these units were installed in two homes and monitored over a total of 559 days.

INTRODUCTION

In residential dwellings throughout the United States various in-house water-using activities contribute to a yearly per capita consumption of potable water in excess of 69,000 L. Of this, over 75% results from toilet usage, bathing and clotheswashing with over one-third due to toilet usage alone. For the average American, yearly toilet flushing results in the contamination of nearly 23000 L of fresh potable water to transport a mere 490 L of body waste. With growing concerns over U.S. water resources, serious questions have been raised regarding the use of large quantities of potable water for domestic functions, and an increasing number of innovative systems that use little or no fresh water are reaching the U.S. marketplace. To enhance the limited data base available regarding the performance of these products, a field demonstration project was performed at the University of Wisconsin. This study evaluated the performance of extreme low-volume toilet fixtures and washwater recycle systems with the objectives being to investigate the impacts of these units on water use and waste flow characteristics, to delineate the installation operation and maintenance requirements, to determine user acceptance, and to estimate system costs. The methods and results of this investigation have been documented elsewhere (1) and only a brief synopsis is presented herein.

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METHODS

At the onset a search was made to identify commercially available low-flush toilet systems and washwater recycle systems. Three toilet fixtures were selected for study, including the Microphor (2), Monogram (3), and Ifo (4). All were similar in appearance to a conventional U.S. water closet, but required flush volumes of only 1.9 to 5.3 L. To enable flushing with such small volumes, the Microphor employed a burst of compressed air, the Monogram utilized a small macerator pump and the Ifo possessed a blowout action. A total of nine fixtures were installed in five typical American homes and monitoring of their performance occurred over a total of 1926 days. Usage data were collected automatically for interior water use, fixture use and toilet water use with specially altered water meters and flow indicating switches interfaced with ocurrence counters and continuous strip-chart recorders. Data were collected at each home over many multi-day periods and analyzed on an hourly and daily basis. System operations were monitored with separate power meters and elapsed time indicators, and maintenance requirements were delineated in a log. User acceptance was assessed through recordings in a user log and responses to a final questionaire.

Three commercially manufactured home recycle systems that purified bathing and laundry washwaters for reuse in toilet flushing were initially selected for study, but only the Aquasaver system (5) proved to be truly available. This system employed the unit processes of sedimentation, pressure cartridge filtration (20 μ) and chlorine disinfection in a small inhouse module. Two recycle units were installed in two homes and monitoring of their performance occurred over a total of 559 days. Monitoring during this period was similar to that for the low-flush systems but also included other flow streams associated with the recycle systems. Qualitative characterization was also accomplished through collection of grab and 24-hour flow composited samples with analyses for various parameters performed according to Standard Methods (6).

RESULTS

Water Use and Wastewater Flow - The inhouse water use and waste flow characteristics measured in this study are tabulated in Table 1. Due to a limited water use data base, the results for home VE were excluded. At the four homes with the extreme low-flush toilets, the average daily flow ranged from 42.4 to 123.0 Lpcd, of which 6.0 to 19.6 % was due to toilet flushing. At the three homes that exhibited the low per capita consumption, conventional water-saving faucets and showerheads (8 - 12 lpm approx.) were also present. Day-to-day variations about the mean day at each home were similar, with the lower and upper limits of the 95% confidence interval for total daily flow varying from 78 to 88% and 112 to 123% of the respective mean daily flows. The maximum daily flow experienced at the homes ranged from 170 to 350 Lpcd, or from 285 to 402% of the respective mean daily flows. Hourly flow data indicated wide fluctuations with minimum flows of zero and maximum flows ranging from 44.2 to 94.6 Lpch (Table 1). Increases in water use above the mean day and hour were found to be closely correlated with increases in the non-toilet use component of the flow.

At the two homes with the washwater recycle systems, the average daily freshwater flow varied from 78 Lpcd to 127 Lpcd (Table 1). Day to day variation, shown by the limits of the 95% confidence interval for daily flow expressed as a percent of the mean day, were 75 and 125% to 89 and 111%. Since toilet water use was recycled washwater, freshwater use for flushing was essentially eliminated as long as washwater production and storage met toilet flushing demands. At home NE no additional freshwater was needed for flushing, while at home VAR an average of 2.3 Lpcd was required. This was due to occasional unfavorable balances between available washwater and required flushwater, as well as to a slight difference in recycle system design requiring freshwater for chlorine feed with each use. The maximum daily freshwater flow at the two homes was 280 Lpcd and 364 Lpcd (Table 1). Hourly water use data again indicated wide fluctuations with minimum flows of zero and maximum flows of 68.1 and 113.6 Lpch. Maximum day and hour flows were due almost entirely to non-toilet water use at these sites.

The recycle water quality varied widely and was generally of a much lower quality than a typical freshwater toilet supply (Table 2). Compared to the raw washwater characteristics, the recycle water showed only limited pollutant removals by the various unit processes. Coliform bacteria concentrations in the recycle water varied widely, corresponding closely to variations in residual chlorine levels. As long as a measurable chlorine residual was present, total and fecal coliform values were <10 org./100 mL.

The quality of the recycled water is important for health, safety and operational considerations as well as from an aesthetic viewpoint. While no regulatory standards exist regarding recycle water quality for home toilet flushing and lawn irrigation, the National Sanitation Foundation (NSF) has set standards associated with testing and certification of home recycle systems (7,8). According to NSF Criteria C-9, recycle water must possess Tot. Coliforms $\leq$ 1/100 mL, turb. $\leq$ 100 TU, $BOD_5 \leq$ influent, and TSS $\leq$ 90 mg/L. An Aquasaver was tested under lab conditions by NSF and approved per these criteria. Subsequently, Standard 41 was developed requiring Tot. Coliforms $\leq$ 240/100 mL, turb. $\leq$ 90 TU, $BOD_5 \leq$ 45 mg/L, TSS $\leq$ 45 mg/L, and a nonoffensive odor (8). Under field conditions in this study, the Aquasaver recycle water met NSF Standard 41 limits, except BOD_5 at both homes and TSS at home VAR.

Impacts of System Use on Water Use Characteristics - Assessing the impacts of water saving technologies on the water use characteristics at a given home can be a complex task. At first glance, the most direct method would appear to be a comparison of data obtained prior to installation of the water-saving technologies to post-installation data. However, this approach suffers from potentially serious shortcomings. For new homes this comparison is impossible. At existing homes, changes in water demand and fixture usage totally unrelated to the water-saving technologies employed, can yield inaccurate results. These changes in water use can be due to rapidly changing lifestyles of growing children, changing work schedules and lifestyles of adult residents, and changes in the physical characteristics of the dwelling including water-using fixtures, water supply pressure, and so forth. At the three homes where background data was collected, changes in water demand and fixture use with time were exhibited that were apparently unrelated to the innovative toilets. An alternative strategy utilizes actual measured fixture usage data. For the innovative toilet systems, the measured toilet usage data with these systems was utilized to determine the water use characteristics that would have occurred if conventional toilets had been used instead. This water use data was then compared to the measured data to assess the impacts of the innovative toilets. The results of this analysis follow.

The use of low-flush toilets rather than conventional fixtures provided major reductions in daily water use.(Table 3). Compared to a 13.2 L toilet, reductions of 12 to 68 Lpcd, or 17 to 36% were calculated, while compared to an 18.9 L toilet, reductions of 21 to 102 Lpcd, or 26 to 45% were calculated. The use of the low-flush toilets did not significantly affect routine day-to-day flow variations and the maximum day was reduced by 5 to 22%. The maximum hour was decreased by less than 12%.

The use of the washwater recycle systems in place of conventional toilet systems also resulted in significant reductions in daily water use with reductions of 24 and 35 Lpcd relative to a 13.2 L toilet, and 36 and 50 Lpcd relative to an 18.9 L toilet (Table 3). These reductions represented 24 and 22%, and 31 and 28% reductions in total daily freshwater flow, respectively. Day-to-day variations in freshwater use were not significantly altered. The maximum days were reduced by 7 to 16% while the maximum hours were not changed.

The water conservation potentially achievable at typical American households is outlined in Table 4. Daily flow reductions near 30% can be expected with these innovative systems.

System Installation - Installation of all three low-flush fixtures can be readily accomplished in a new dwelling. Retrofitting the Microphor toilet may pose minor difficulties in running the required air supply line from the compressed air source to each fixture. Retrofitting the Monogram fixture is readily accomplished. Retrofitting the Ifö fixtures for a conventional U.S. water closet results in a separation of 15 to 23 cm from the rear of the toilet tank to the finished wall, which may be physically or aesthetically unacceptable. Alteration of the drainage system to remedy this situation may be feasible however.

Installation of the Aquasaver recycle system can be readily accomplished in a new dwelling. Additional plumbing requirements over a conventionally plumbed house include separate toilet supply lines, washwater drain lines, and recycle system vents and connections. Retrofitting such a system is very site specific, and can pose substantial difficulties due to venting requirements, and the need for separate toilet supply lines, especially in two-story homes with second floor bathroom facilities.

Operation and Maintenance - The operation and maintenance requirements of the low-flush systems were relatively minor, varying from none at all with the Ifö fixtures, to quarterly servicing of the air compressor for the Microphors, and replacement of a broken cutter blade on the Monogram unit with a new improved blade. Power consumption was found to be negligible, varying from 0 with the Ifö units to 0.0016 kwh/use with the Microphors.

The only major operational problem encountered with the recycle system was in maintaining a proper chlorine residual in the recycle water. Residual chlorine values fluctuated widely (0 to 25 mg/L) due to fluctuations in raw washwater quality as well as system design, and caused infrequent odor problems at both homes. Operation at a desired constant residual chlorine level would require considerable monitoring and adjustment. Chlorine use by the system was approx. 0.20 gm/L at home NE and 0.30 gm/L at home VAR in the form of calcium hypochlorite tablets of 70% available chlorine content. Power use by the recycle system was 0.021 and 0.013 kilowatt-hours/cycle at homes NE and VAR, respectively. Scheduled maintenance was performed quarterly in approx. 3 man-hours and consisted of cleaning an influent screen, washing cartridge filters, replenishing chlorine tablets, and removing sludge from the washwater storage tank. Results of this study indicated that the maintenance required for the washwater recycle system may vary from home to home due to differences in water use and raw washwater quality. At home NE, quarterly maintenance as described was readily accomplished and sufficient to maintain the system. In contrast, at home VAR, the influent screen and cartridge filters clogged more severely and made cleaning much more difficult. At this home more frequent maintenance with annual replacement of the cartridge filters appeared necessary. Sludge accumulations were noted at both homes and consisted of a wispy, black layer occupying the bottom 2 to 10 cm of the storage tank. Analyses of several grab samples of this material revealed high concentrations of organic materials and suspended solids. Sludge disposal via the house sewer system was felt to be the most practical scheme.

User Acceptance - The overall participant assessment of the low-flush fixtures was very positive. The flushing capability of the toilets proved to be satisfactory. For the most part, double flushing was not necessary to clear the bowl and typical cleaning frequencies were sufficient to keep the bowl stain-free. In all study homes, the adult residents indicated they would recommend their type of low-flush toilet to others.

Participant assessment of the recycle systems was both positive and negative. Although the systems provided an adequate water supply for flushing purposes and the use of the recycled water was not generally objectionable for toilet flushing, additional fixture cleaning requirements and occasional septic and chlorine odors reduced the potential for long term user acceptance of these systems.

Economic Analysis - The costs of the innovative toilet systems as well as two types of conventional toilets are outlined in Table 5. An abbreviated economic analysis was performed for several common residential applications in the U.S. (Table 6). While the data presented are only estimates and subject to considerable variability due to site specific factors, for all of the applications considered the use of the extreme low-flush toilet systems offered potentially significant savings in water supply and sewage disposal costs. Due to the high capital cost of the recycle system, only the holding tank application showed potential cost effectiveness.

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TABLE 1 - Water Use and Wasteflow Characteristics*

Parameter		Extreme Low-Flush Toilets				Washwater Recycle	
		Microphor [VA]	Monogram [MI]	Ifo [GA]	Ifo [GL]	Aquasaver [NE]	Aquasaver [VAR]
Interior Water Use	Mean	75.2	123.0	78.6	42.4	126.7	78.0
	S.D.	52.8	84.0	46.3	33.5	58.1	68.1
	95%-	66.2	103.9	63.9	32.8	112.7	58.8
	C.I.	84.3	142.1	93.0	52.0	140.6	97.2
	Min.	14.2	28.4	25.2	6.3	47.3	15.1
	Max.	298.1	350.1	239.7	170.3	364.3	280.1
	Max hr.	75.6	94.6	63.1	44.2	113.6	68.1
Toilet Water Use	Mean	4.5	11.6	9.8	8.3	33.1**	24.7**
	S.D.	2.2	2.5	6.0	3.0	18.2	10.7
	Min.	1.0	4.4	1.0	2.6	9.4	7.3
	Max.	15.6	18.7	28.3	16.8	106.2	49.8
	Max hr.	4.2	3.3	7.1	4.4	22.0	22.3
Non-Toilet Water Use	Mean	70.7	111.4	68.9	34.2	126.7	75.7
	S.D.	52.5	84.0	45.1	32.8	58.1	67.6
	Min.	9.6	18.5	18.9	1.9	47.3	14.2
	Max.	293.8	336.9	230.6	157.1	364.3	274.2
	Max Hr.	75.2	93.0	63.1	43.3	113.6	68.1
Fixture	Mean	2.54	6.02	1.95	1.56	2.65	2.00
	S.D.	1.23	1.35	1.22	0.57	1.46	0.86
	Volume	1.9	1.9	3.0/5.3	5.3	12.5	12.3
Data Pts.	Total	133	77	41	49	69	51
Residents	No.†	4(3,5)	4(5,8)	3(1)	6(1,2, 9,10)	4(17,19)	5(4,6, 14)

*Results presented in Lpcd except max hr flow (Lpch), fixture usage (npcd), max hr fixture usage (npch), and flush volume (L)
**Toilet water use is recycled washwater, not freshwater
†Total residents with childrens' ages (yr.) in parentheses.