The Millennium Dome "Watercycle" experiment: to evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors

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Abstract Thames Water's "Watercycle" project at the Millennium Dome was one of the largest in-building recycling schemes in Europe, designed to supply up to 500 m^3/d of reclaimed water for WC and urinal flushing. It catered for over 6 million visitors in the year 2000. Overall, 55% of the water demand at the Dome was met by reclaimed water. The site was also one of the most comprehensive studies ever carried out of water conservation in a public environment, evaluating a range of water efficient appliances and researching visitor perceptions of reclaimed water.

Within the Dome there were six identical core buildings housing the washrooms, which were equipped with a variety of different water-efficient devices for comparison. Water usage by the different appliances was monitored using a sophisticated metering and telemetry system. The importance of correct installation and maintenance of "high tech" water efficient devices was highlighted during the research programme, as some water wastage occurred due to poor installation. The results prove that metering should complement any large-scale water efficient system, so that any faults with the appliances can be quickly identified. The visitor survey showed very positive attitudes to the use of reclaimed water for non-potable uses.
Keywords Greywater; recycling; water conservation; water efficiency

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Introduction

As part of its water resources strategy, Thames Water is investigating a number of water resource and demand management options including additional reservoirs, metering, aquifer storage and other novel solutions. The drivers for this being the implications of changing lifestyle patterns, increasing customer expectations, the requirement for an extra 4 million new homes in Britain and the influence of climate change, meaning that water resources will be ever more stretched. For Thames Water in the South East of England, which, with an average 613 mm/year receives less rain than some Mediterranean regions, a twin track water resources strategy is being adopted. This involves the development of new resources and demand management, the latter including the investigation of water recycling and water efficiency options.

In accordance with this strategy Thames Water agreed to work with the New Millennium Experience Company (NMEC), in implementing the first major in-building recycling scheme in the UK at the Millennium Dome (see Figure 1). The project was christened "Watercycle" and was designed to supply up to 500 m^3 a day of reclaimed water from a combination of greywater, rainwater and groundwater treated on site, for WC and urinal flushing (Hills *et al.*, 1999). During the year 2000, it was the venue of one of the largest studies of water conservation in a public environment, involving the comprehensive evaluation of water-efficient appliances as well as research into user perceptions of reclaimed water.

Figure 1 The Millennium Dome, Greenwich, England

Method

Within the Dome there were six identical core buildings housing the washrooms. These were equipped with a variety of different water-efficient appliances for comparison, ranging from the "super efficient" core, housing waterless urinals and infra-red taps, to more conventional technology in the "control" cores. Figure 2 shows a schematic of the washroom layout within the Dome and lists the appliances that were evaluated.

At the Dome site, there were 646 WCs and 191 urinals being flushed with reclaimed water and 361 washbasins providing greywater to be reclaimed for toilet flushing. For the comparative research in the core buildings 337, 165 and 361 WCs, urinals and washbasins were monitored respectively.

Water use by the different appliances in the various cores was monitored via 150 discrete meters, which recorded the use of hot, cold and reclaimed water by visitors to the washrooms. Each washroom was also equipped with an infra-red detector at the entrance, which recorded the specific number of visitors to each particular washroom. The meter and entrant readings were logged every 5 minutes, stored in data loggers and telemetered back to the central control room of the recycling plant. The data received from the loggers were read by "Radcom" software and analysed over the year as a whole and comprehensively on a weekly, daily and, in some cases, hourly basis, to gain the most realistic picture of patterns and variations in water usage throughout the year. Using this data, combined with a correction coefficient, it was possible to calculate the water consumption of each visitor to the

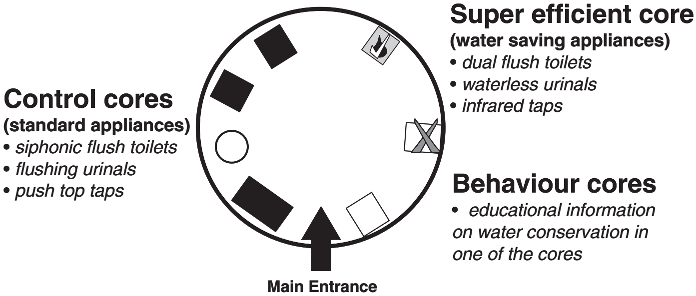


Figure 2 Layout of the core buildings housing the washrooms within the Dome

washroom for each particular appliance. The correction coefficient was applied to take account of the fact that not all visitors to the washrooms used all of the appliances (e.g. some visitors have just been accompanying children or may not have washed their hands). The correction coefficient was calculated via a series of visual surveys, where Thames Water researchers undertook detailed observations in the male and female washrooms over several hours. Observation of users in a washroom environment required a sensitive approach, therefore experts in this area of study were consulted so that the survey was carried out in an ethical manner. The observers logged the proportion of visitors who, for example, washed their hands, used the WCs or urinals or used the mirror. The correction coefficient was of particular importance in the male washrooms, where visitors would be unlikely to use both the WC and the urinal.

The other aspect of the study was to ascertain visitor attitudes to the use of recycled water for toilet flushing and the water conservation initiatives. The majority of this work was undertaken using market research techniques, interviewing 1,055 visitors to the Dome. Each interview took approximately 10 minutes, carried out by a professional market researcher, and was structured into 24 questions. The visitor was asked their opinions on a range of topics from their attitudes to reuse in general to their specific opinion on each of the washroom appliances that they had just used. A control group who had not yet used any of the washrooms was also surveyed.

Results and discussion

Reclaimed water volumes

During the year, on average, reclaimed water made up 55% of the 131,000 m^3 water used at the Dome. The major source of reclaimed water was from groundwater at 71% of the source water volume, with rainwater contributing 19% and greywater (from washbasins) contributing 10%. The contribution of rainwater to the scheme was limited by storage constraints on site, which meant that a maximum of 100 m^3 a day of rain could be collected. This is a typical problem with rainwater systems where storage facilities to cope with dry periods must be considered and can be particularly difficult in space-constrained urban environments. The volume of greywater produced at the Dome was less than had been predicted, with the 6 million visitors using only 10,000 m^3 of water for hand washing throughout the year, equating to 13% of the overall water demand at the Dome (see Figure 3a). This is less than half the demand in a typical office washroom environment (Shouler *et al.*, 1998 – see Figure 3b).

This highlights the water deficit that occurs when greywater only is recycled in this type of public venue. At the Dome site the contribution of groundwater (68,000 m^3 was

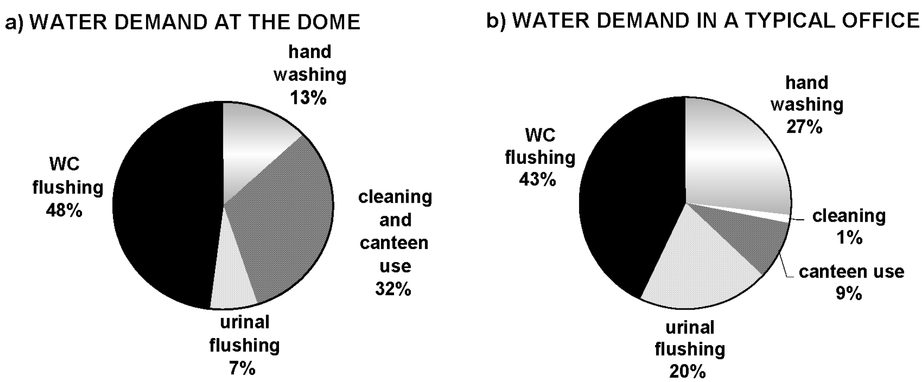


Figure 3 Water demand in a) the public areas of the Millennium Dome in the Year 2000; b) a typical office (from Shouler *et al.*, 1998)

abstracted from the borehole over the year 2000) was essential to make up the required flushing volumes.

Comparison of water efficient devices

Correction factors based on washroom usage. In order to accurately assess the water usage for different water efficient devices it was necessary to calculate correction factors from observation surveys to account for the fact that not all washroom entrants used all of the appliances. The observation surveys also provided data that proved that there was no statistical difference in user behaviour between any of the cores and, consequently, meaningful inter-core comparisons of water usage could be made.

These data also provided valuable information on activity in public washrooms. As Figure 4a and b show, more females washed their hands after using the WCs (83%) than males (73% – when they were using either the WCs or urinals). More females (6%) used the washrooms just for "preening" (i.e. using the mirror and none of the actual washroom appliances, or, in some cases, accompanying children) than males (2%).

WCs. Dual flush (3 and 6 litre) cistern WCs (177 in total) were compared with standard 6 litre siphonic cisterns over the year (160 in total). Due to the comprehensive metering system it quickly became apparent that the dual flush toilets were exhibiting problems due to continual flushing, a problem that has previously been documented with dual flush toilets on a number of occasions (Pennell, 1997; Griggs *et al.*, 1997). The sophisticated nature of the Radcom software, which read the water usage data from the loggers, meant that malfunctions with any of the washroom appliances was quickly and easily identified, so that they could be rectified as soon as possible to minimise the disruption to the comparative research. Unfortunately the original installation of the WCs, as with all of the water-efficient appliances, was undertaken outside of the scope of the Watercycle project, so Thames Water did not identify the installation problems until the project was underway.

Figure 5 demonstrates a typical Radcom trace showing a continuous flush occurring intermittently over a seven day period in a male washroom, compared with a normal flushing regime

Over the course of the year, Thames Water and the manufacturers of the dual flush WCs carried out a thorough investigation into the problems occurring with the dual flush toilets and several major retrofits were undertaken by the manufacturers to try and remedy them. Discrepancies in the individual flushing volumes of both dual flush and siphonic toilets were also discovered, all of which were re-calibrated precisely to enable a true comparison of the devices to be undertaken.

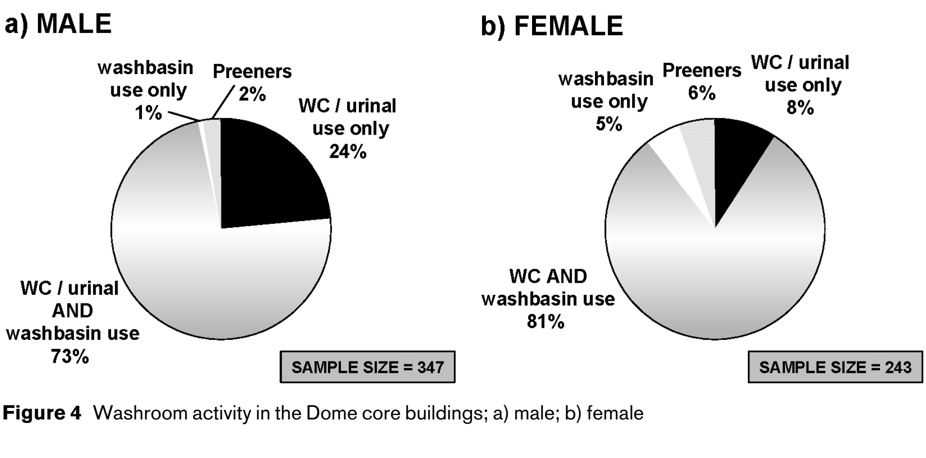
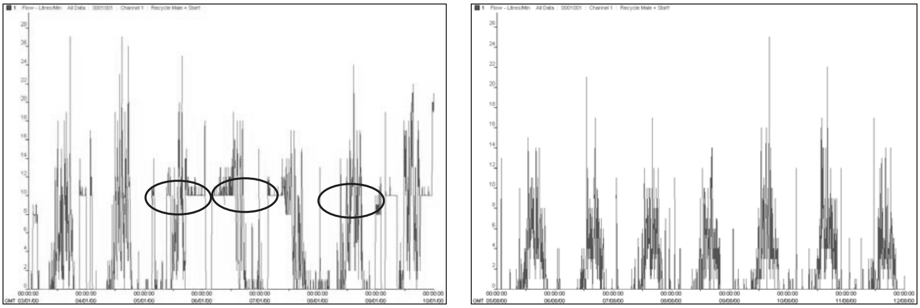


Figure 4 Washroom activity in the Dome core buildings; a) male; b) female



(a) (b)

Figure 5 Radcom trace showing; a) continuous flushing (circled) occurring intermittently in a washroom over a 7 day period; b) an example of a normal flushing regime

Table 1 shows a comparison of the mean water usage by the dual flush and syphonic toilets prior to, and following, all of the required retrofits (shown in values of litres of water used per flush). Table 1 shows that before any retrofits the dual flush toilets were actually using significantly more water than the standard siphonic toilets (e.g. in the male washrooms, on average, each user used 8.6 litres of water for WC flushing in the dual flush toilets compared to only 6.2 litres with the siphonic toilets). Following all of the retrofits, water usage in the female washrooms was significantly less in those installed with dual flush toilets compared to those installed with siphonic toilets (each female user used, on average, 5.1 litres of water for WC flushing with the dual flush toilets compared to 5.5 litres with the siphonic toilets). However, the difference in water usage between dual and siphonic flush was not apparent in the male washrooms. This is because the males would be more likely to use the urinals rather than the dual flush half flush (i.e. 3 litres) in most instances.

Therefore, in busy public male washrooms where urinals are also available there is no water saving advantage of installing dual flush WCs. Overall the results show the importance of the correct installation and maintenance of more sophisticated water-efficient devices if savings are to be realized.

Urinals. All of the flushing urinals (136 in total) at the Dome were equipped with a passive infra-red (PIR) automated flushing system, to regulate the flushing so that it was not constant if the washrooms were not in use (i.e. overnight and during quiet periods of the day). The "super efficient" core was installed with waterless urinals as a comparison. However, as with the WCs, installation problems with the flushing urinals became apparent during the monitoring period. Many of the PIR flushing regulation systems were malfunctioning and were flushing and refilling even when the washrooms were empty. In addition to this, the urinal cisterns filling rates had not been standardized during installation, which led to water wastage. Attempts were made to repair and standardize the systems where possible to enable a valid comparison to be undertaken.

Table 1 Mean water usage for WC flushing by males and females prior to, and following, all retrofits

Appliances	Mean WC water usage (litres per flush)				Water saving from retrofits	
	Prior to any retrofits		Following all retrofits			
	M	F	M	F	M	F
Dual flush	8.6	6.5	5.4	5.1	37%	15%
Siphonic	6.2	5.2	5.5	5.5	11%	0*

* as the majority of these WCs were under flushing

The total volume of reclaimed water supplied for urinal flushing throughout the year 2000 was 6,218 m^3, which amounted to 13% of the total reclaimed water supplied to the Dome washrooms (and 7% of the overall water demand of the Dome – see Figure 3). By comparison of two of the core buildings it was estimated that on average the malfunctioning urinals used 42% more water than the correctly installed urinals. The importance of the correct positioning of PIR sensors was also highlighted by the study, as the location of some of the sensors meant that visitors to the WCs or hand basins often activated unnecessary urinal flushing.

Water and cost savings as a result of the installation or retrofit of waterless urinals is well documented (BSRIA, 1999; Lillicrap *et al*., 1999). It was estimated that the waterless urinals in the "super efficient" core (29 in total) saved over 1,000 m^3 of flushing water over the year, and if waterless urinals had been installed throughout all of the washrooms in the Dome, over 8,000 m^3 of water could have been saved. The waterless urinals, in addition to saving water, also required considerably less maintenance and fine-tuning than the flushing types but did need the proprietary cartridges changing after approximately 8000 uses, which was costly.

Taps. Three types of tap were evaluated during the research, infra-red activated (48 in total), push-top (96 in total) and conventional swivel top (96 in total). Surprisingly over the year the conventional swivel top taps used significantly less water than the purported more efficient types (see Figure 6), with each user of the swivel top taps using, on average, just less than 1 litre of water.

Assuming that users could deliver the optimal amount for their hand-washing needs from the manually operated swivel top taps the optimal value for a single hand wash would appear to be approximately 0.9 litre per use (see Figure 6).

During the course of the year, as with the WCs and urinals, problems with the functioning of the infra-red and push top taps were identified from the metering data. These were again traced to problems of poor installation and set-up. A retrofit of the push top taps, so they flowed for 7 seconds rather than 15 seconds after activation, resulted in a significant reduction in water usage.

Attitudes to water recycling

The Dome attitude survey revealed the opinions and perceptions of 1,055 visitors in relation to the water recycling and conservation initiatives undertaken as part of the

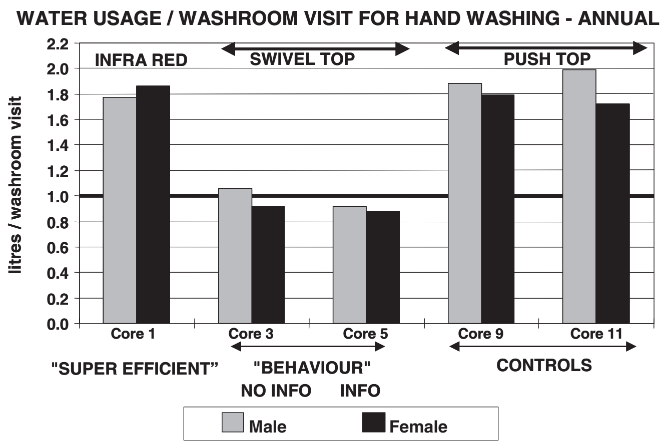


Figure 6 Mean volume of potable water used for hand washing (litres per washroom visit) by males and females

"Watercycle" project. It also assisted with the analysis of the effectiveness of information on water conservation in influencing water usage. It was found that visitors' levels of acceptance for uses of dual water supply were high, with 95% of respondents agreeing that dual water supply was acceptable for use in public areas as a method of conserving limited resources. There was no significant difference between male and female responses but the higher socio-economic groups (ABC1 social classes) were more accepting. There were lower levels of acceptance for use of reclaimed water in people's own homes. Regarding accepted uses for reclaimed water, results followed the trends of similar surveys (e.g. a Thames Water telephone survey carried out in 1999 and WROCS, 2000) indicating high positive acceptance in general but declining as the uses became "more personal" e.g. watering vegetables, but still 61% of respondents were strongly positive (see Figure 7).

The level of signage in the washrooms explaining the use of reclaimed water and the Watercycle exhibit at the recycling treatment plant, were both integral parts of the experiment. The results of the attitude survey revealed very positive results. The acceptability of reclaimed water systems was significantly enhanced in the individuals who had seen the signage in the washrooms or the Watercycle exhibit, compared with a control group who had not yet been exposed to them.

Users in the one experimental washroom that had additional signage appeared to be more aware of water conservation issues than those in the control. A particular effect was noted for male washbasin users in this washroom who significantly reduced their use of handwash water, presumably as a result of the additional signage.

Conclusion

The recycling system operated effectively for the year 2000 and provided, on average, 55% of the water used at the Dome site. Over 6 million visitors were introduced, in many cases for the first time, to reclaimed water and water-saving devices.

The importance of correct installation and maintenance of "high tech" water-efficient devices was highlighted by the work. Water savings are not realized without this attention to detail, in fact water wastage is more likely to occur. A comprehensive metering system, or other method of tracking actual consumption and highlighting wastage problems is vital to realize savings.

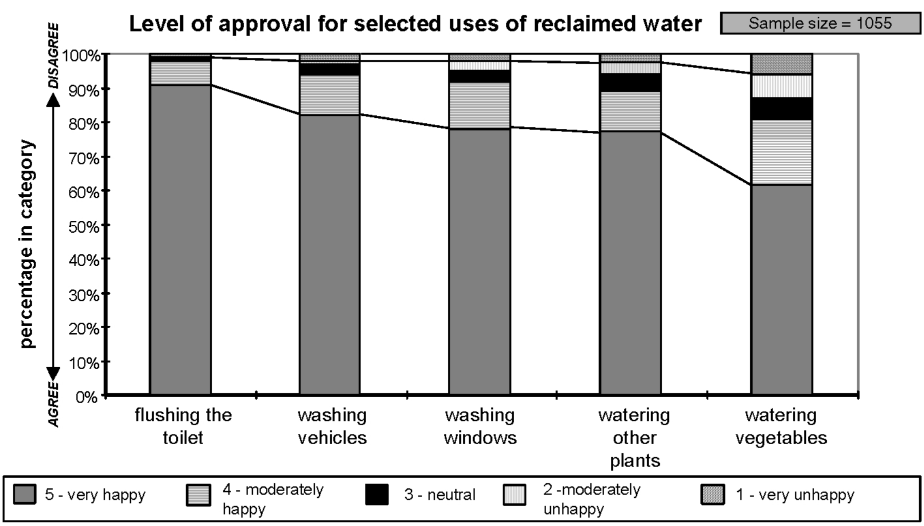


Figure 7 Levels of approval for selected uses of reclaimed water – Dome survey 2000

Acceptance of the use of reclaimed water and dual supply was very high amongst the Dome visitors surveyed. Encouragingly, it appears that education, information and exposure to reclaimed water systems further increases user's acceptance of the concepts.

In summary, the Watercycle project provided, via a unique public participation research experiment, the opportunity to gather important information for consideration when implementing future water efficiency programmes.

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