# Performance Assessment of Low Volume Flush Toilets

**St Leonards Middle School, Hastings**

**Final project report**

September 2004

**Report prepared by**

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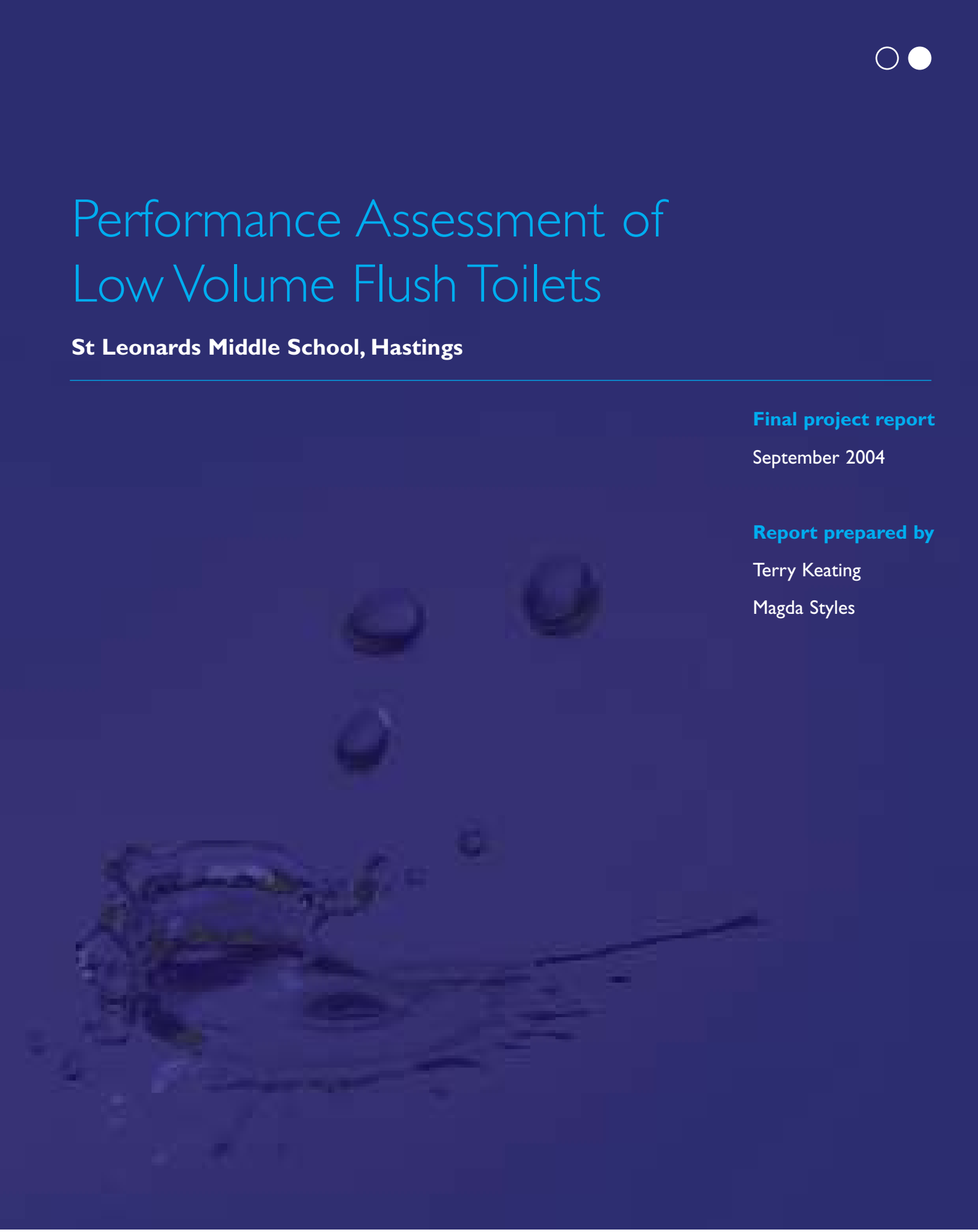

East Sussex County Council

Environment Agency

Southern Water

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# Executive summary

Toilet flushing accounts for up to a third of the total domestic water consumption and has therefore been a focus for water efficiency campaigns and promotions by water companies. Ongoing debate about robust ways of reducing flush volumes prompted Southern Water to trial 4.5 litre, single flush ES4 toilets in a practical school setting, to verify their water saving potential and performance.

Seven existing 9 litres toilets in St Leonards School in Hastings were replaced by low flush (4.5 litre) units and the water use in each unit recorded over a period of several months.

Measurements indicate an estimated reduction of some 38% in the volume of water used for flushing in those units replaced during the trial. In addition, user feedback to date has indicated no performance problems.

The results obtained from the study also suggest that ES4 toilets could contribute to significant reductions in water use if promoted and installed on a wider scale. Specifically, the volume of water saved through the installation of these low flush (rather than conventional 6 litre) units in new build domestic properties could amount to around 5% of total domestic consumption. Alternatively, the savings could be as high as 16% if ES4 toilets were used as a replacement for existing 7.5 and 9 litre toilets.

This project was jointly sponsored by Southern Water, the Environment Agency and East Sussex County Council, who obtained European Union (EU) funding for the installation of the equipment.

*Pupils from St Leonards School demonstrate how much water is being saved from the new low flush toilets*

# Introduction

## Background

Toilet flushing accounts for up to a third of the total domestic water consumption and has therefore been a focus for water efficiency campaigns and promotions by water companies.

The Water Supply (Water Fittings) Regulations 1999 lowered the maximum flush volume for toilets from 7.5 litres to 6 litres. The regulations also allow dual flush and valve flush mechanisms, which were prohibited under the previous Byelaws. While 6 litres may be considered the base case for new purchases, the manufacturers claim that about 75 to 80% of current sales are now dual flush toilets.[1]

Although the regulations stipulate the maximum flush volumes, there has been very little interest from manufacturers in driving innovation towards reducing the volume further. Indeed, except for dual flush of 6/4 and 6/3 litres, the only lower volume toilets available for purchase in the UK are Scandinavian 4/2 litre drop valve-operated dual flush, and ES4 single flush siphon based toilets.

Dual flush toilets were initially viewed as one of the better options for water efficiency promotion. However, concerns are now being raised about valve mechanisms' potential for leakage. While the siphon (until recently the only flushing mechanism allowed in the UK) was developed to prevent leakage, valves, by their very nature, will eventually leak. How soon this would occur depends on many factors but the following should be considered:

- Not all valves on the market are appropriately tested;
- Random failure may occur at any time due to non-laboratory conditions;
- A significant proportion of households in the UK are not on water meters and therefore have no financial incentive to repair small leaks;
- Leaks of up to 2.5 l/hour are difficult to spot and may not register on water meters. Such flow equates to around 22m$^3$/year from each toilet.[2]

Few toilets currently on the UK market have their performance independently verified and some nominal 6 litre flush units (or 6/4 litres for the majority of dual flush) may fail to clear the pan effectively, thereby necessitating further flushing.[2]

Furthermore, dual flush toilets may not be suitable for all circumstances, for example public buildings. In addition, the design of some dual flush toilets on the market leaves doubt about which is the short and which is the long flush.

In view of the often marginal balance between supply and demand in the South of England, Southern Water is keen to adopt and promote robust water efficient products, which would help to slow down or even reduce the ever increasing demand for water.

The company is of the view that the promotion of dual flush as the most suitable water efficient option for new build and the refurbishment market may not be wholly justified given the reasons listed above. As an alternative, the water use reduction afforded by siphon-operated, single flush low water use toilets is now being investigated in some detail. Only one such toilet, the ES4, is currently available on the UK market.

## ES4 toilets

According to supplier information, ES4 is a siphon operated low flush toilet (4.5 litre) with an integral delayed action valve and an independently assessed flushing performance (WRAS approval). It combines Swedish design with British water saving technology developed by Elemental Solutions. The cistern contains a Thomas Dudley Turbo siphon and a virtually silent Opella Ecofill delayed action valve, which prevents the cistern from starting to re-fill until the flush is completed, therefore limiting the flush to the nominal 4.5 litres. The pan, produced by Ifö Sanitär, is engineered to work effectively with the low flush volumes ensuring good flush performance.

In addition, the off-the-floor or back-to-wall pan make washroom cleaning easier and the concealed cistern makes the toilet suitable for a variety of situations where vandalism could be a problem.

The retail price is in the region of £260, which is comparable to other models with similar specifications, but considerably more than some commonly available toilets.

Although ES4 toilets have been installed in a variety of buildings, no detailed assessment of their in- situ performance has previously been reported.

The opportunity for Southern Water to test the water savings predicted for ES4 toilets in a tough, practical setting, arose during early 2003 when St Leonards School was identified during a water audit as planning to replace a number of old toilet cisterns. This study presented the school with the opportunity to obtain

[1] *National Water Conservation Group, minutes of meeting, October 2002*

[2] *The Economics of Water Efficient Products in the Household, Grant, 2003*

*Introduction continued...*

entirely new equipment rather than just replacing the existing cisterns as originally planned.

## The school

St Leonards CE School, St Leonards on Sea, East Sussex, is a mixed primary school with some 430 pupils on the register. Over the past four years consumption in the School has averaged around 1000 $m^3$ per year, which equates to 2.4 $m^3$/pupil/year. The 'best practice' benchmark for primary schools recently published by Watermark,[3] the Government sponsored initiative, is 2.7 $m^3$/pupil/year. Consumption in the school is currently below this benchmark figure, which has been defined as the lower 25% of measured usage from a sample of over 11,000 schools. Nevertheless, this study demonstrates that significant reductions in consumption can still be made through changes of equipment.

The Year 5 washrooms are the most heavily used in the school. All cisterns originally had a nominal 9 litre flush, with actual volumes varying considerably between toilets due to poor adjustment of the ball valves. The refill rates also varied, with the longest refill time noted at over 10 minutes. These two factors meant the toilets generally flushed below their design volume, resulting in poor flush performance often leading to unpleasant smells and unflushed deposits. The washrooms were due for refurbishment because of the age and the general bad state of the toilets. This project has provided the opportunity for the refurbishment.

## Project sponsors

The project was jointly sponsored by Southern Water, the Environment Agency and East Sussex County Council, who obtained EU funding for the installation of the equipment.

[3] *Final Benchmark Report on Schools, Watermark, May 2003. Office of Government Commerce*

# Objectives and scope of the project

The objectives of the project were:

- To assess the water savings resulting from replacing existing toilets with low flush models in St Leonards School;
- To assess financial savings achievable from the replacement
- To assess performance of ES4 toilets in terms of flush efficiency, flush volume repeatability, and the suitability of the toilet for commercial as well as domestic environments.
- To develop water savings estimates for replacement of a typical 9-litre and 7.5 litre toilet with ES4, to enable other users to make appropriate decisions.
- To make a comparison between fitting ES4 toilets and a typical 6 litre toilet.

The project involved toilet replacement in the Year 5 washrooms, which were due for refurbishment. Seven units were replaced (two in the boys' and five in the girls' washrooms) out of the total of 26 toilets in the school.

# Methodology

V100 water meters and Technolog DCM flow loggers were installed on the water supply pipes to each of seven cisterns in May 2003. The loggers were configured to record each flow event of 0.5 litres to allow subsequent analysis of flows and numbers of flushes from each toilet.

The logging equipment was in place throughout the trial, and regular data downloads were made. Analysis of the logged data enabled an assessment of the volume of water used in each cistern, both pre- and post-refurbishment to be made.

In addition to the logger data, flush volumes were also recorded at each visit, based on direct meter readings.

In August 2003 the new toilets were installed and data monitoring then continued until January 2004. Regular communication was also established with the School's Building Manager and feedback was obtained from him on the toilet performance.

# Analysis of the results

Each logger was set up to record the flow through the inlet pipe as a series of 0.5 litre pulses. This mode of logger operation allows each flush to be delineated individually as a series of closely occurring pulses. Figure A and B demonstrate this schematically.

As the water level in a conventional float operated valve cistern rises, the rate of inflow of water to the cistern decreases, and the time interval between successive 0.5 litre pulses progressively increases Figure A. Thus relatively long refill periods may ensue. In contrast, the inflow valve on the new equipment remains fully open until the cistern is full, resulting in a more regular pulse pattern Figure B with an enhanced inflow rate and a correspondingly much reduced refill time.

In low use situations the arbitrary choice of time interval between consecutive pulses deemed to be contributing to separate flushes doesn't present analysis difficulties because the flush separation time is likely to be well in excess of the refill time. But in high use situations, the flush separation time may be comparable to the refill time, leading to uncertainty in delineating individual flushes from double/multiple flushing.

For the analysis of the data from the original toilets (before replacement), pulses separated by more than 60 seconds were deemed to belong to separate flushes. But the rapidity and regularity of refilling the ES4 units enabled this minimum separation time to be reduced to 15 seconds.

Thus, for the original systems, individual flush volumes were determined as the sum of the 0.5 litre pulses occurring within 60 seconds of each other, while dual/multiple flushes were identified as extended series of pulses. But for the ES4 units flush volumes were determined as the sum of pulses occurring within 15 seconds of each other.

Data recovery during the pre-refurbishment phase was relatively poor due to staff changes and problems with data recording. Nevertheless, sufficient data was obtained to characterise the average flush volumes in six out of the seven toilets; the seventh unit was vandalised after the project commencement.

The six toilets from which useful data was obtained, two in the boys', and four in the girls' washrooms, are denoted as B1 and B2, and G3, G5, G6 and G7 respectively in the tables below.

Table 1 (page 7) gives the results for each toilet during the pre- refurbishment phase, which lasted from May through to

Figure A: Flow pulse pattern from conventional float operated ball valve cistern

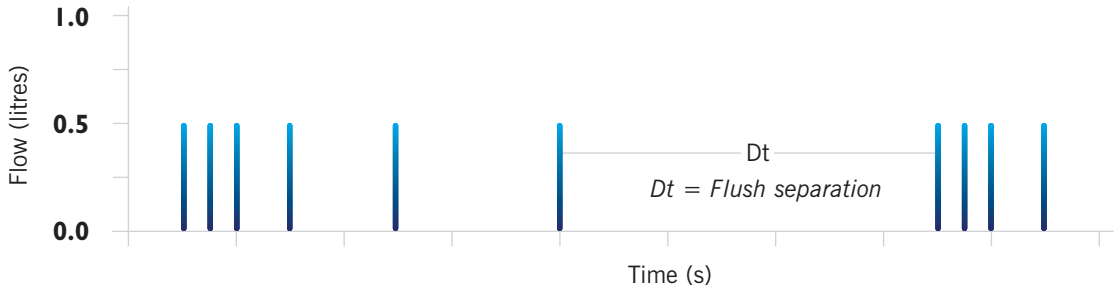
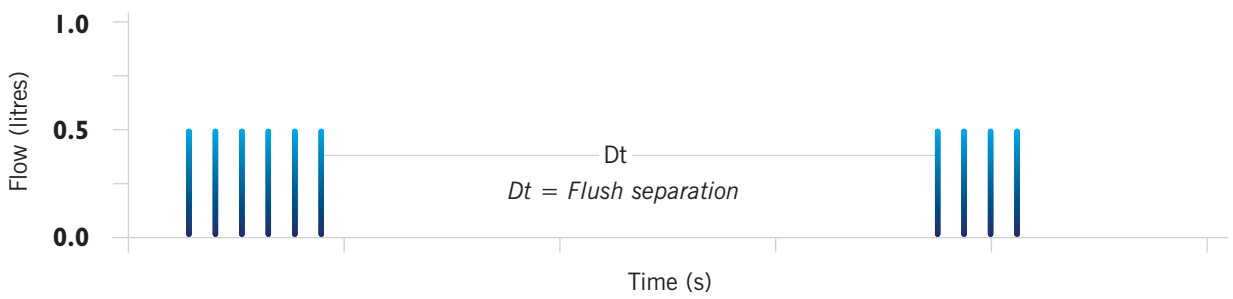



Figure B: Flow pulse pattern from the ES4 Units



*Analysis of the results continued...*

the end of the summer term. Average flush volumes ranged from 4.1 litres to 9.6 litres for the nominal 9 litres cisterns, albeit on a small sample. This range reflects the variability in float level setting within each cistern and partial flush due to slow refill. The table also lists the modal, or most common, flush volume, as delineated by the number of pulses recorded by each logger. The modal flush volumes are less than the average flush volumes, reflecting the impact of multiple flushing.

Table 2 (below) gives the corresponding post- refurbishment results, which covered the period from September 2003 to January 2004. During this period data recovery was considerably better than during the pre-refurbishment phase. Average measured flush volumes ranged from 4.0 litres to 4.7 litres, for nominal 4.5 litre flush cisterns. This relatively wide range is now considered to be due to the top water levels in the cisterns not being consistently adjusted during installation.

By way of validation of the logger data analysis process, the volumes of typical flushes were also measured directly at each meter on a number of occasions. These measurements are given in Table 3 (below), and compare well with the modal values as determined from the logger analysis.

## Table 1: Pre-installation monitoring

| | B1 | B2 | G3 | G5 | G6 | G7 |
|---|---|---|---|---|---|---|
| Number of flushes recorded | 11 | 10 | 110 | 64 | 24 | 8 |
| Average flush volume (litres) | 8.7 | 4.1 | 6.1 | 6.3 | 9.6 | 8.0 |
| Modal flush volume (litres) | 7.5 | 4.0 | 5.5 | 6.0 | 8.5 | 8.0 |

## Table 2: Post-installation monitoring

| | B1 | B2 | G3 | G5 | G6 | G7 |
|---|---|---|---|---|---|---|
| Number of flushes recorded | 408 | 235 | 1,528 | 944 | 799 | 462 |
| Average flush volume (litres) | 4.0 | 4.2 | 4.7 | 4.5 | 4.0 | 4.2 |
| Modal flush volume (litres) | 4.0 | 4.0 | 4.5 | 4.5 | 4.0 | 4.0 |

## Table 3: Measured flush volumes

| | | B1 | B2 | G3 | G5 | G6 | G7 |
|---|---|---|---|---|---|---|---|
| Pre | 24 July | 7.4 | 3.4 | 5.3 | 5.6 | 8.2 | 8.0 |
| | 11 September | 3.9 | 4.0 | 4.4 | 4.3 | 3.9 | 3.9 |
| Post | 20 November | 3.9 | 3.8 | 4.4 | 4.3 | 4.0 | 3.9 |
| | 10 December | 4.0 | 4.2 | 4.0 | 4.3 | 3.9 | 3.8 |
| | 12 January | 4.1 | 4.4 | 4.5 | 4.2 | 3.9 | 3.8 |

*Analysis of the results continued...*

## System performance

Figure C (below) illustrates the distribution of flush volumes measured in G5 during the trial, as determined by the number of recorded 0.5 litre pulses. The modal volume in this unit was nine pulses (4.5 litres) which accounts for 54% of all measured flushes.

In addition, a further 38% of flushes are indicated as comprising of eight pulses (4 litres). Together, eight and nine pulse flushes account for 92% of all identified flushes with the majority of the remaining 8% accounted for by larger volume flushes.

These larger flushes, comprising of more than nine pulses tend to peak around 17 pulses, suggesting "double flushing". But this could encompass instances where the toilet is used consecutively in a very short space of time – not uncommon during school breaks.

The other five units produced flush distributions similar to that shown above with the larger volumes attributed to rapid re-occupancy typically comprising between 8% and 12% of all recorded flushes.

## Feedback from the school on the performance of the new toilets

The school management has been very enthusiastic about this project and full of praise for the equipment. Despite the much-reduced volumes required for flushing, the performance has been very satisfactory, with (according to the Premises Manager) no need for double flushing ever noted. The problems of bad smells and blockages associated with the old toilets have disappeared.

Before the refurbishment the school has to deal with unblocking of the drains due to poor flushing twice a month on average (at a cost of £75 per incident).

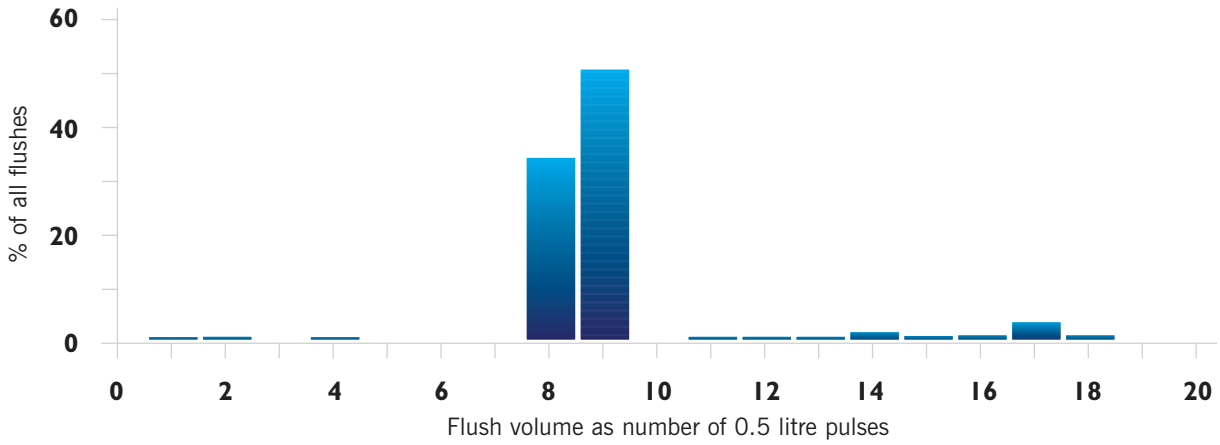
Since the refurbishment this occurred only once, and that was due to a pair of underpants being deliberately pushed down the toilet.

The Premises Manager claims that the toilets are almost maintenance free thanks to their robust design (the toilets have very sturdy Presalit seats and concealed cisterns).

Before the refurbishment incidents of cisterns blocked with crisps packets and other items were frequent, and seats had to be replaced regularly. Between August 2003 (installation) and August 2004 (when this report was written) there were no incidents of vandalism recorded.

Overall, according to the Premises Manager, the school's annual maintenance expenditure has been considerably reduced as a result of the refurbishment.

## Figure C: Flush volume distribution from G5



# Assessment of potential water savings

## Water savings in St Leonards School

Table 1 (page 7) shows the average volume per flush before installation of the ES4 units, whilst Table 2 (page 7) gives the corresponding figure post-installation for each toilet. An estimate of the volume of water saved through changing the units may be calculated using these two average flush volumes, which takes account of "double flushing", and the post- installation flush frequency (flushes/toilet/day),

The volume of water used during the post-refurbishment phase was calculated as 19.2 $m^3$. This compares to 31.2 $m^3$, which would have been used in the same period had the units not been changed, and the flush frequency remained the same. This represents a reduction of around 38% used in the six toilets during the monitoring period. It seems reasonable to assume that, if the cisterns of the original toilets had been filling quickly, the volumes flushed would have been larger and the savings from replacement would have been even greater.

The data can be extrapolated to illustrate the volumetric savings, which would accrue during the course of a 200- day school year. Table 4 (page 9) lists the flush frequency for each toilet, derived as the average daily number of flushes recorded during the post- refurbishment period; the average flush volumes and the total volume of water saved.

Based on the measured flush frequencies, the estimated volumetric savings over a 200-day school year from the equipment installed would be some 33$m^3$. This would result in a reduction of around 3% in the annual consumption, and based on Southern Water's 2004-2005 water and sewerage charges, would generate a financial gain of approximately £53 per year. This estimate is based on only replacing the 6 out of the existing 26 toilets in the school.

It is not possible to accurately quantify the saving which would result from the installation of low volume flush (4.5 litre) toilets throughout the school because the proportion of water used in each washroom was not measured.

However, based on data from a previous study,[4] it can be assumed that the volume of water used in the washrooms accounts for around 75% of overall school usage, and that toilet usage accounts for some 40% of washroom usage. On this basis, the proportion of the school water supply used for flushing toilets is estimated to be approximately 30%. For a school supply of 1000 $m^3$/yr, this equates to 300 $m^3$/yr. A reduction of 38% due to the installation of low flush toilets would give a volumetric saving of 114 $m^3$/year, which at 2004-2005 prices would cost around £180. This is over 10% of the annual total volumetric charge, and is not insignificant.

However, it has to be acknowledged that the washrooms refurbished are the most heavily used of all washroom facilities in the school and direct extrapolation of the results to other washroom facilities within the school may be overstating the total savings.

### Table 4: Predicted water savings over 200-day school year from the replaced units

| | | B1 | B2 | G3 | G5 | G6 | G7 | Total ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| Flush frequency (number of flushes/day) | | 5.6 | 3.9 | 20.6 | 13.9 | 10.9 | 6.3 | |
| Average flush volume (litres/flush) | Pre | 8.7 | 4.1 | 6.1 | 6.3 | 9.6 | 8.0 | |
| | Post | 4.0 | 4.2 | 4.7 | 4.5 | 4.0 | 4.2 | |
| Volume used ($m^3$) in 200 days | Pre | 9.7 | 3.2 | 25.3 | 17.4 | 21.1 | 10.1 | 86.8 |
| | Post | 4.5 | 3.3 | 19.2 | 12.6 | 8.8 | 5.3 | 53.7 |
| Difference over 200 days ($m^3$) | | 5.2 | -0.1 | 6.0 | 4.8 | 12.3 | 4.9 | 33.1 |

[4] *Worthing High School: Water Efficiency Project, (1999) Southern Water report 90001/TR/99/014*

*Assessment of potential water savings continued...*

## Estimated water and cost savings from the replacement of typical 9 litre toilets by ES4s in schools

Based on the above assumptions and using the latest water consumption data,[5] it is possible to estimate the savings that could accrue from the installation of 4.5 litre flush toilets as standard fittings during refurbishment in a typical school.

Assuming that 30% of school water consumption is used for toilet flushing, and given that the median annual water consumption per pupil in English schools during 2002-2003 was 4m$^3$, the volume used per pupil for flushing amounts to 1.2m$^3$ /yr. Further, assuming that the original on-site facilities have a nominal 9 litre flush and have not been modified in any way, then the average flush volume[6] will be around 9.6 litres.

If all the existing units are replaced by the new nominal 4.5 litre models, which the present study suggests could produce an average flush volume of around 4.7 litres, the reduction in water used for flushing would amount to approximately 50%, or 0.6 m$^3$ /yr. Overall this would represent a saving of 15% on the school water use. The recent Department for Education and Skills (DfES) paper also quotes the median annual expenditure on water consumption per pupil as £6.1. Assuming this charge is volumetrically based, a reduction of 15% in consumption equates to around £0.9/pupil/year.

## Estimated water and cost savings from the replacement of typical 7.5 litre toilets in schools

If the original toilets have a nominal flush of 7.5 litres, then the average flush volume, based on the performance of the 4.5 litre and 9 litre systems described above, will be around 8 litres. On the same basis as above, the replacement of these with ES4 units would lead to a reduction in consumption of around 12% on the average school water use, equivalent to £0.7/pupil/year.

## Estimated water and cost savings from using ES4 as a standard specification for new domestic installations

As an addendum to this study, the savings that could accrue from the installation of ES4 units in new domestic properties, rather than using the standard 6 litre systems currently allowed under the Water Fittings (Water Supply) Regulations 1999, can be estimated.

Assuming that the average flush volume for a nominal 6 litre is 6.3 litres, the reduction in water use per flush would be (6.3 - 4.7) litres, which equals 1.6 litres/flush. Previous studies,[6,7] have shown that the average domestic flush frequency is of the order of 5 flushes/head/day, giving a total saving of around 8 litres/head/day, or some 5% of average daily personal consumption.[8]

There are approximately 25,000 new dwellings constructed each year in the South East.[9] With an occupancy ratio of 2.4 per property and a per capita consumption of 150 litres/head/day, an extra 9 million litres of water is required each day to satisfy the increased demand from these homes. A saving of 5%, around 0.5 million litres per day, would have a significant impact on the supply/demand balances of the water companies who have to provide this additional water. Such a saving will ultimately be of benefit to the water user, through reduced water charges.

## Estimated water and cost savings from using ES4 as a replacement for existing domestic installations

Assuming that the average flush volume for a nominal 9 litre cistern is 9.6 litres, the reduction in water use per flush would be 4.9 litres/flush. With the average domestic flush frequency of 5 flushes/head/day this gives a total saving of 24 litres/head/day, or some 16% of daily personal consumption.

Replacement of a nominal 7.5 litre cistern (with an average flush of 8 litres) would give a saving of 3.3 litres/flush and would equate to 16 litres/head/day, or 11% of the average per capita consumption.

[5] *Energy and Water Benchmarks for Maintained Schools in England: 2002-03; (2004), DfES Report Bweb02/2004*

[6] *The water efficiency of retrofit dual-flush toilets: Experience from Southern England, (2003); Keating T & Howarth D., CIWEM, 17(3), 135-139*

[7] *Microcomponent analysis and peak demand, (2002), WRC Report UC3992 for Southern Water*

[8] *Security of supply, leakage and the efficient use of water :2002-03 Report, Ofwat (2003)*

[9] *Office of the Deputy Prime Minister: Housing Statistics*

# Conclusions

ES4 toilets deliver good, reliable performance with much reduced flush volumes. The toilet design makes it suitable for a variety of applications, from domestic to heavily used commercial washroom situations.
The toilet cost, at £260 in 2005, makes it expensive in comparison to other commonly available toilets, but is comparable to other models with similar specification. ES4 is listed on the Water Technology List and as such attracts the Enhanced Capital Allowance available to tax-paying businesses. Unfortunately, no similar incentives exist for non-tax-paying users like schools, which may find it difficult to justify this additional expenditure.

If installed as standards in all new homes ES4 toilets could reduce future domestic water demands by at least 5%, while having a negligible effect on the total house cost. Their impact on the retrofit market could be even more significant if sufficient incentive was given to householders to choose ES4 instead of other models.

# Appendix

## Pictures from before and after washroom refurbishment

*Old toilets before replacement*

*Downloading the pre-installation data*

*Meter and logging equipment installed on downpipes in each cubicle*

*Delivery of the new toilets in July 2003*

*New toilets in situ*

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