Impact of Low-Flush Toilets on Drainage Design: A Belgian Case Study

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Abstract

Numerous studies have analysed the impact of low-flush volume toilets on the performance of drainage systems. Key parameters affecting system efficiency—such as pipe length, slope, flush volume, and the number of bends—are well documented. However, since each country has its own guidelines, a specific analysis is essential to assess their impact on national practices.

In Belgium, toilets with a low flush volume of 4 l or 4,5 l are commonly available on the market. Local guidelines, however, do not consider flush volumes lower than 6 l. Rather than changing these guidelines, which is a long-term endeavour, we decided to provide additional recommendations concerning the key parameters that affect system efficiency. As an additional safety measure, we recommend that the flush systems can be adjusted at a minimal volume of 6l at any time, if necessary.

To make these recommendations, Buildwise carried out a series of experiments to evaluate the transport capacity of a drainage system. Tests were performed using adjustable flush volumes, varying pipe slopes (0,5% to 2%), and pipe diameters (75 mm to 110 mm). The experimental setup included a transparent pipe network to visualize flow behaviour. Toilet paper and faecal simulators were used, along with a mix of full and reduced flushes. Based on these results, recommendations are provided in terms of maximum pipe length and maximum number of bends, as a function of the slope.

Our approach allows water-saving sanitation technologies to be implemented effectively in Belgium without compromising system performance and without a full revision of the local guidelines TV265/NIT265 [1].

Keywords

Drainage; sizing methods; low-flush volume toilets; low-flush volume water closet.

1 Introduction

Despite annual precipitation levels of around 900 mm in the central part of the country, Belgium—particularly the northern region of Flanders—is notably subject to water stress mainly because of its high population density and insufficiently permeable ground surfaces. Since buildings are major water consumers, alongside industry and agriculture, efforts must be made to control water usage. Installing water-efficient sanitary appliances is one of the main levers for reducing consumption, along with rainwater harvesting, greywater reuse for non-potable applications, and improved monitoring and leak detection.

This paper focuses specifically on low-flush toilets and their impact on drainage systems. These toilets typically use around 4,5 l for a full flush and around 2 l for a reduced flush. While their contribution to water savings is clear, there are currently no guidelines in Belgium for designing drainage systems compatible with such appliances: national recommendations still refer only to toilets with flush volumes of 6 l or more, in line with the European standard EN 12056-2 [2]. This standard defines four drainage system types, each corresponding to different codes of good practice in European countries. For example, Belgium and Germany follow the guidelines of system I, while some northern European countries follow those of system II. System I prohibits the use of toilets with flush volumes below 6 l[1], whereas system II permits them under alternative design requirements.

Switching from one system to another, and changing the associated design and sizing practices, is a long-term endeavour. It is therefore necessary to develop guidelines that allow the integration of low-flush toilets while remaining compatible with current practices. Germany has faced a similar challenge: their standard DIN 1986-100 [3] only allows toilets with adjustable flush volumes, ensuring that the flush volume can be increased if drainage performance proves insufficient. We will discuss this approach later in the paper.

The key question this study aims to answer is: *How can we guarantee the reliable integration of low-flush toilets in Belgium with minimal changes to existing drainage design guidelines?*

The structure of this paper reflects the approach adopted in this study. We start by identifying the key parameters influencing drainage performance, based on a review of the scientific literature. Then, informed by these findings and the current the Belgian design standards, we present the development of a test setup to evaluate drainage systems equipped with low-flush toilets, allowing controlled variation of critical design parameters. The following section details the testing protocol, and the performance indicators selected for assessment. Finally, we report and discuss the experimental results and conclude with insights and recommendations for future research.

2 Literature review and selection of the experimental parameters

[1] The EN 12056-2 standard provides guidelines for flush-volumes ranging from 6l to 9l for System I and flush volumes ranging from 4l to 9l for System II.

A simulation study commissioned by the Scottish Government [4] employed the DRAINET software to estimate the distance solid waste could be transported at flush volumes of 6 l and 4 l. Simulations were run for pipe slopes ranging from 1% to 2.5% and diameters of 75 mm and 100 mm. The solid used in the simulation was a cylinder (38 mm diameter, 80 mm length). Considering the widespread use of dual-flush systems, the authors took the approach of a cycle combining one full flush followed by four reduced flushes. The solid was initially moved by the full flush and then pushed further by the subsequent reduced flushes. The highest transport distances were recorded for steeper slopes and narrower pipes. However, under a 1% slope and 100 mm diameter, solids in a 4 l/2.6 l system travelled just over 10 meters. The authors warned that a 10-meter horizontal run is common in practice and could pose a risk if bends are included. While they concluded that the overall blockage risk was low, they recommended avoiding long distances at shallow slopes unless additional sanitary fixtures are connected to the same pipe, supplying extra flushing water. As the recommended pipe slope in Belgium is also 1%, the identified risk is directly relevant in that context.

The same software was used in a Dutch study published by TVVL [5]. This research evaluated the distance solids travelled after a single flush of 6 l or 4 l. Unlike the previous study, which simulated multiple consecutive flushes, this one pursued immediate removal. At a 1% slope and an internal diameter of 84 mm, a 4-l flush moved the solid only 5 meters. Based on these findings, installing 4-liter flush toilets under current Dutch sizing methods, is not permitted. This view is reinforced by additional TVVL publications [6], [7].

In a 2005 Canadian laboratory study [8], researchers evaluated the effects of several parameters on nine different types of toilets: flush volume, drop height at the connection (150 or 900 mm), slope, pipe diameter, solid mass, and the presence of a second flush. They used extruded soy paste (4 sausages of 50 g) and toilet paper to simulate waste. Results showed that greater slope and flush volume, reduced mass, and smaller diameter all contributed to longer transport distances. A 4-liter flush reached 10 meters only when slope was 2% and diameter was reduced to 75 mm, with total mass below 300 g. Drop height had little effect. As expected, a second water-only flush helped to move solids further.

Another study [9] investigated flush volumes of 6 l, 4 l, and even lower using a Propelair toilet, which features an airtight, lockable lid to generate overpressure. This model works differently from vacuum toilets. Though not available in Belgium, the study's methodology—measuring transport distance along a long straight pipe under repeated flushes—is noteworthy. Even though such frequent flushing does not reflect typical use, the results demonstrated a critical distance beyond which solids could no longer be transported, regardless of the number of additional flushes.

A Japanese study [10] tested toilets, including both washdown type WC-s but also siphonic types, with flush volumes between 10 l and 4 l using two types of solids: 6 meters of tightly rolled toilet paper (single or double-ply) and 6 meters of stacked sheets. The system included an 18-meter pipe with a 1% slope and 75 mm diameter, tested with and without bends. Researchers recorded maximum and average flow rates and solid transport distances. As the wave of wastewater decreased over distance, its ability to carry solids declined, confirming the concept of a maximum transport distance. The presence of bends significantly worsened performance for low-flush systems. Transport distances were sometimes less than 10 meters, although the amount of paper used makes these results somewhat unrealistic.

A second Japanese study [11] examined a pipe branch connecting five toilets, simulating an office environment. Only toilet paper was used. The study found that reducing the pipe slope from 1% to 0.5% reduced the transport distance by 30–35%. The presence of multiple toilets allowed an assessment of how repeated flushing by different users could assist solid transport.

In a Portuguese study, researchers conducted a series of controlled tests [12] to investigate the effect of diameter, flush volume, and slope. They used faecal simulants and crumpled paper, flushed in intervals along a straight pipe. Distances were measured after each flush, and the procedure was repeated until full clearance was achieved. As in previous studies, slope had the greatest impact. A 1% slope was found acceptable for 6 liter flushes, but insufficient for 4-liter systems. A 2% slope was recommended. Based on these findings, the authors recommended a 90 mm diameter with a 2% slope for low-flush toilets and a 110 mm diameter with a 1% slope for standard systems.

A study in the United States [13] addressed a gap in previous research: the absence of thorough analysis on obstruction risks despite widespread reductions in flush volume. In addition to slope, flow rate, and volume, the study evaluated toilet paper type. Surprisingly, the wet tensile strength of paper was found to be the second most influential factor on transport performance – just behind slope – and ahead of volume. Stronger paper significantly reduced the transport distance of solids.

Some field studies have assessed the performance of water-saving toilets in real-world buildings. One such study [14] monitored ultra-low-flush Propelair toilets installed in a public facility. A notable observation was the accumulation of toilet paper in the inspection chamber serving the women's facilities. This was resolved with an automatic rinse mechanism.

A similar field study was conducted in Brazil [15], where low slopes and 100 mm diameters were identified as problematic for low-flush systems (4,8 l per flush). Over eight months, ten households switched from 6,8 l to 4,8 l toilets. Water consumption varied—decreasing in some homes, increasing in others—with no clear explanation. One sewer blockage was reported, possibly linked to the lower flush volume, though the evidence remained unclear.

3 Presentation of the experimental setup

The design of our test setup is based on both the findings of the literature review and the relevant standards in Belgium and neighbouring countries. It consists of a single toilet connected to a discharge stack via a branch discharge pipe.

According to the Belgian guidelines, to the standard DIN 1986-100 and to the EN 12056-2, the length of the branch discharge pipe upstream of the stack must not exceed 10 m under any circumstances. Additionally, studies cited in the previous section, such as [4] or [10], identify 10 m as a critical length for low-flush toilets, particularly when combined with a slope of 1%—a common value in Belgium. Therefore, a test configuration with a total length of 10 m appears to be an appropriate starting point. It is worth noting that, under the above-mentioned standards, branch lengths exceeding 4 m are permitted only if the pipe is ventilated. Belgian guidelines also allow unventilated branches, provided that a larger pipe diameter is used.

Both EN 12056-2 and the Belgian guidelines impose no restriction on the number of 90° bends in ventilated discharge branches (or in larger-diameter unventilated branches, in the Belgian case). This may seem surprising, given the negative effect of bends on flow observed in studies such as [10]. The German DIN 1986-100 standard however explicitly limits the number of 90° bends to three, even for ventilated branches. Our test setup follows this German restriction. The final layout of the test rig is shown in figure 1. Our setup is not ventilated.

The next step is to determine which design parameters should be varied during the experiments. The studies discussed earlier consistently highlight the influence of the following parameters on drainage performance: pipe slope, diameter, and flush volume. Accordingly, the slope of the test pipes can be adjusted between 0.5% and 2%, and three pipe diameters are considered: 75 mm, 90 mm, and 110 mm. Finally, the toilet used in the setup is equipped with an adjustable flush volume system.

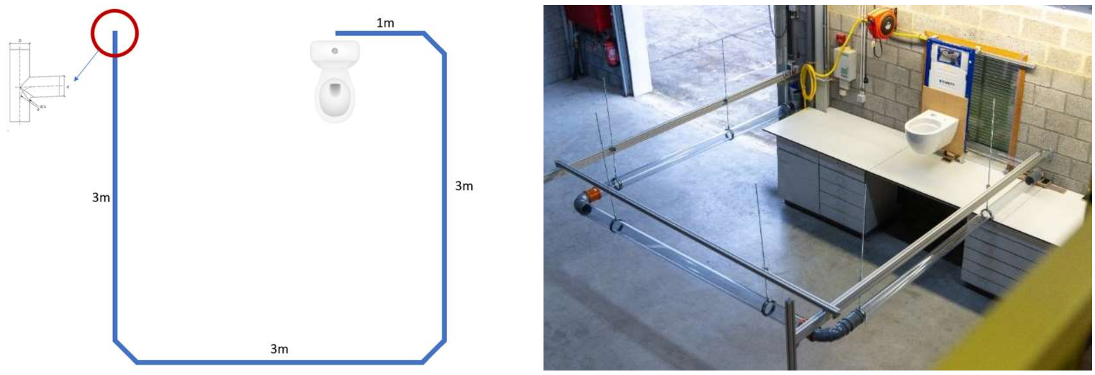

Figure 1Test rig used for the experimental study, made of transparent pipes.

4 Tests protocol and performance indicators

During the experiments, solid materials are introduced into the toilet and flushed. The distance travelled by these solids is measured using transparent pipes. Consequently, both the type of solids and the flush sequence must be clearly defined.

For the flush sequence, a combination of small and full flushes is used, reflecting real-life usage. During the experiments, each full flush is followed by three small flushes. This sequence aligns with the average flush volume definition used by the Unified Water Label[2].

As shown in the literature review, a wide range of solid simulants has been used in previous studies, but no universally accepted approach could be identified. In our study, we chose to use faecal simulators manufactured in accordance with the EN 997 standard. Although this standard is designed to evaluate toilet performance rather than drainage systems, the use of these faecal simulators is considered relevant here, as toilets are

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[2] https://uwla.eu/

specifically engineered to evacuate them. Unlike the EN 997 protocol, which requires the evacuation of four faecal simulators, we replaced one of them with toilet paper. Before each full flush, we introduce three faecal simulators along with two sets of three sheets of toilet paper, folded as shown in figure 2. Before each small flush, only toilet paper is introduced.

This latter choice reflects a common misuse of flushing systems as small flushes are intended for liquid waste only.

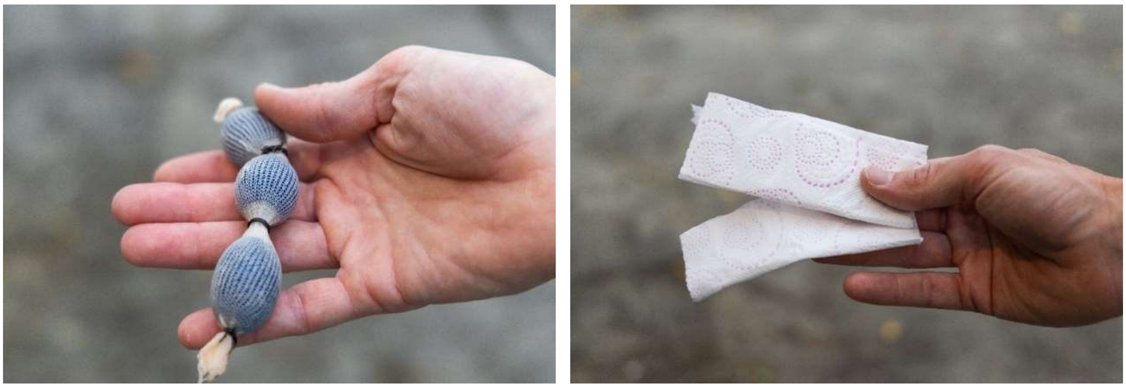

Figure 2 Faecal simulators (left) and toilet paper (right) used during the experiments.

Two types of flush cycles are considered in this study, as summarized in the table below. Each cycle consists of three full flushes and nine reduced flushes. The first cycle (NOMINAL) represents the use of a conventional toilet, while the second (ECO) corresponds to a low-flush toilet.

Nominal flush cycle (total 45 l/cycle)	**ECO flush cycle (total 31,5 l/cycle)**
1 flush of 6 l – paper+ faecal simulators 3 flushes of 3 l – paper only 1 flush of 6 l – paper+ faecal simulators 3 flushes of 3 l – paper only 1 flush of 6 l – paper+ faecal simulators 3 flushes of 3 l – paper only	1 flush of 4,5 l – paper+ faecal simulators 3 flushes of 2 l – paper only 1 flush of 4,5 l – paper+ faecal simulators 3 flushes of 2 l – paper only 1 flush of 4,5 l – paper+ faecal simulators 3 flushes of 2 l – paper only

The primary indicator used to assess flow performance is defined as the *acceptable length* (in meters), referred to as [ID1]. Depending on the configuration, solids introduced into the system may be evacuated immediately or removed after several successive flushes. In practice, it is preferable to minimize the number of static loads—i.e., waste remaining in the system between two flushes under stabilized conditions. In our study, we define the acceptable length as the distance measured in downstream direction in which not more than 1 load of faecal matter remains present directly after a full flush. This indicator offers designers a direct and practical measure of a system's ability to consistently evacuate waste. It should be noted that this assumption is specific to our testing protocol; other studies or institutions may apply different criteria. As highlighted in the literature review, the Dutch reference body TVVL doesn't allow solid parts to remain in the drainage systems upstream of the stack between two flushes [5].

Two additional indicators are introduced, primarily to distinguish between configurations that yield similar values for [ID1]. These indicators provide further insight into the potential for solid stagnation within the system:

- [ID2] Number of faecal simulators evacuated immediately upon introduction: This represents the number of faecal simulators that are flushed out of the system directly during their respective flush, across the flush cycle, from a total of nine introduced faecal simulators.
- [ID3] Total number of faecal simulators evacuated during the flush cycle: This indicates the total number of faecal simulators successfully evacuated at any point during the test cycles, again out of nine introduced faecal simulators.

5 Experimental results and discussion

A total amount of 16 different configurations has been tested as presented in the table below. They are identified by pipe diameter, slope and flush type.

Pipes of 75 mm are not allowed for toilets according to the different standards that have been examined They are not even allowed for installations designed according to the prescriptions of system II of the EN 12056-2 standard, which prescribes a diameter of 80 mm[3]. However, since some references in our literature study used them, we considered them in our study as well. The 90/110 mm configuration refers to a branch discharge pipe where a 90 mm pipe is used for the first 4 meters, followed by a 110 mm pipe.

90 mm - 0,5% - ECO	90 mm - 0,5% NOMINAL	75 mm - 1,5% - ECO	90/110 mm - 0,5% ECO
90 mm - 1% - ECO	90 mm - 1% NOMINAL	75 mm - 2% - ECO	90/110 mm - 1% ECO
90 mm - 1,5% - ECO	90 mm - 1,5% NOMINAL	75 mm - 1,5% NOMINAL	90/110 mm - 1,5% ECO
90 mm - 2% - ECO	90 mm - 2% NOMINAL	75 mm - 2% NOMINAL	90/110 mm - 2% ECO

For each configuration, the flush cycle is performed three times and the result with the poorest ID1 value is selected. The results for the configurations involving a NOMINAL flush cycle are presented in the table below. All configurations exhibit an acceptable length (ID1) of at least 10m, excepted with a diameter of 90 mm and a slope of 0,5%. When the slope increases, as expected, we notice that an increasing number of solids are evacuated during the first flush after their introduction [ID2] and that stagnation decreases. From a slope of 1,5%, all solids have been flushed out after finishing the flushing cycle of 12 flushes [ID3]. The system performs well under nominal conditions, although we observed some issues with the 75 mm pipes. This could be due to the absence of ventilation. A 6 litre flush into a 75 mm drain may create suction pressures that can cause

[3] 80 mm diameter synthetic pipes are not available in Belgium. The closest bigger available diameter is 90 mm.

siphonage in traps of other fixtures. Including ventilation piping is generally considered to improve system performance.

Diameter [mm]	Slope [%]	ID1 [m]	ID2 [-]	ID3 [-]
90	0,5	8	0	5
90	1	10	0	8
90	1,5	10	5	9
75	1,5	10	6	9
75	2	10	7	9
90	2	10	9	9

As expected, the performance decreases when switching to the ECO flush cycle as it can be seen from the results displayed in the table below. As highlighted in previous research works, the travelled distance is significantly reduced with reduced flush volumes. It starts at 4 m with a slope of 0,5% and the largest diameter and reaches 10 m for only 3 configurations, combing high slopes and low diameters. Fewer faecal simulators are flushed out immediately after their introduction and at least one simulator stays present in the system avec completion of the flushing cycle.

Diameter [mm]	Slope [%]	ID1 [m]	ID2 [-]	ID3 [-]
90/110	0,5	4	0	0
90	0,5	4,5	0	0
90	1	5,5	0	3
90/110	1	6	0	0
90/110	1,5	6	0	5
90	1,5	8	1	6
90/110	2	8,5	1	6
75	1,5	10	1	7
75	2	10	3	6
90	2	10	5	8

6 Recommendations

These initial results have already been integrated into installation recommendations in Belgium. Reducing the flush volume of toilets for a given diameter and gradient lowers the capacity for solid transport, thereby increasing the risk of blockages. This risk can be reduced by installing toilets with adjustable flush volumes, which can be increased to at least 6 l when necessary. This is also advised by the standard DIN 1986-100. To ensure consistent drainage performance, the system should be dimensioned based on a 6 l flush volume.

To avoid having to rely on this backup rule too easily, some precautionary measures can be taken: limiting the number of bends and the total length of the discharge pipe compared to what is currently allowed by the Belgian guidelines. In the specific case of a single toilet connected to a vertical discharge stack via a 90 mm diameter pipe, we suggest limiting both the pipe length and the number of bends according to the values presented in the table below.

Slope	Acceptable length (m)	Amount of 90° (i.e. 2 x 45°) bends (without taking the 90° connection bend into account)
0,5%	4,5	1
1%	5.5	2
1,5%	8	3
2%	10	3

It is important to recall that the drainage system must meet TV265/NIT265 requirements to switch to a 6 l flush if necessary [1]. These include providing ventilated branches in certain cases, such as when the slope is only 0.5% or when the pipe length exceeds 4 m.

7 Conclusions and perspectives

The results of this study demonstrate that the integration of low-flush toilets in Belgian buildings is technically feasible, provided that certain design parameters are adjusted. Experimental tests confirm that reducing the flush volume compromises solid transport capacity—especially at low slopes and with larger pipe diameters. Nevertheless, acceptable performance could be achieved through a combination of measures: limiting the number of bends, reducing the length of horizontal pipes, and complying with current venting requirements. The use of adjustable-flush toilets is proposed on top of previous measures to increase the flush volume if performances would not be found acceptable. The latter is directly inspired by the DIN 1986-100 standard. These recommendations have already been presented to installers and represent a step towards incorporating water-saving goals into Belgian drainage design practices.

However, the scope of this study is limited to relatively simple layouts. Further research should focus on expanding the methodology to more complex drainage networks, including multiple sanitary appliances and branching configurations. In the longer term, this work could support the evolution of Belgian guidelines for drainage design and dimensioning.

8 Acknowledgements

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