Case Study

A Case Study of Delayed Action PIR Urinal-Controls in a University Setting and Their Impact Before, During and After Covid-19

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Abstract:
This study looks at the application of delayed action Passive InfraRed (PIR) sensors in the control of water use for urinal flushing. In this we briefly review the literature on urinal controls before reviewing four different approaches to PIR urinal controls. Exisiting literature discusses some of the pros and cons of different types of urinal control. However, the literature doesn't consider the marked differences that can occur within individual approachs, based on the way controls operate. This study was initiated at the University of Surrey during 2019 following a water saving audit, in an attempt to bring down what had been identified as one of the largest users of water. This paper therefore aims to identify the most effective way to reduce water consumption of urinal systems, through retro-fitting PIR control systems within the variety of settings found across university campuses. This paper also reviews the different reductions achieved over periods of different levels of use, linked to term time, holidays, Covid-19 related lockdowns, and the 'new normal'. It found that grouped delayed action flushing was the most effective form of urinal control for reducing water use. The delayed action, grouped PIR sensors, achieved between, a 59-64% adjusted reduction against the control group during non-Covid19 periods, and a 35% reduction against the control group during lockdowns.

Keywords: Urinal; Passive Infrared (PIR); Water Conservation; Water efficiency; Campus;

1. Introduction

In many parts of the world, water is an increasingly scarce or unreliable resource [1]. However, in many countries water is still an undervalued and relatively 'cheap' commodity [2]. To help protect supplies, simple yet effective measures need to be taken to reduce consumption. However, the existing literature is split on how to do this, with a divide on the impacts and significance of behavioural interventions compared with infrastructure changes. There is literature to support the idea that long-term cultural change can lead to habit development, leading to lower water consumption [3] especially in subjects with existing positive environmental awareness [4]. However, other literature such as [5]and [6] found there was no link between water use and environmental values or individuals' willingness to adopt water saving initiatives. This is despite [6] showing that households

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that consumed the least water exhibited higher levels of awareness of water conservation issues. Although [7] found that there was a correlation between water use and the presence of technological utilization (dishwashers, washing machines etc.) in rural China, [5] and [8] state that in more developed regions, levels of domestic water use are more highly linked to the efficiency of the appliances installed as opposed to attempts to save water or concern for the environment. This is reinforced by regulations and standards which consider building water use a technological aspect, rather than occupant consideration [9].

In commercial and business settings, the impact of technology over behaviour, as the most powerful conservation factor, becomes clearer, with the majority of water consumption being linked to automated processes such as urinal flushing, heating/cooling, landscaping (where applicable) and also fixed volume uses where the end user has no control such as toilet flushing [10] [11] [12]. The amount of water use due to urinals varies dramatically between buildings, with controlled urinal use attributing on average 20% of consumption to urinals, while in uncontrolled buildings the literature indicates this can be as much as 68% of total [13] [14] [15]. As such this makes urinal flushing an obvious target for water efficiency measures.

There are a multitude of different ways to reduce consumption linked to urinal use. The four most common are the use of waterless urinals, timer controls, manual flushing and Passive InfraRed (PIR) sensors. The greatest in-situ saving is through waterless urinals, with the benefits, disadvantages and challenges reviewed in detail by Bristow et al. (2006). Some of the benefits that Bristow et al. (2006) set out are; water saving; 'low maintenance' (although this is more skilled than conventional urinals); hygienic- in that the surface dries out between uses, making them unconducive to bacteria and viruses; energy saving- due to a reduced need to pump and treat water. However, there are various reasons why retro-fitting waterless urinals is also not always the best option, primary amongst them can be the need for remodeling. This can be simply to remove the newly created dead legs in supply, or to implement the more substantial realignment of the waste pipes required to ensure sufficient drainage, or to work with the new urinal bases. There are also challenges linked to regional legislation, user acceptance and the need for non-water-based cleaning and the creation of a captive market for purchasing replacement cartridges [16].

Timer based flush controls, although simple, do not account for use, risking under flushing during high use periods or significant overuse of water during quite periods. Although simple, manual flush controls require user activation, and this can result in a lack of flushing when needed, or can potentially result in excess water use and add unnecessary touch points. Therefore, due to the factors discussed above, the University of Surrey (UoS) decided to test PIR controls, and their impact on water consumption for both individual buildings and the overall site .

During 2019 and early 2020 the UoS conducted a pilot study reviewing the impact of PIR urinal controls on their operational water consumption, comparing individual and group action PIR controls as well as instant and delayed action flushes. This was designed to look at the impact over different levels of site use and occupancy. However, the outbreak of Coivd-19 within the UK and the subsequent series of lockdown(s) which followed, allowed for an analysis of the impact that these devices had during both the lockdowns themselves and also the 'New Normal' which followed. This paper aims to identify the most effective way to reduce water consumption of urinal systems, through retro-fitting PIR control systems within the variety of settings found across university campuses. It also aims to provide a longitudinal demonstration of the effectiveness of these controls over different use periods.

2. Materials and Methods

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In 2018 the UoS ranked as the 7th largest educational user of water in the UK, despite its Gross Internal Areas ranking 28th amongst UK universities, 43rd for the size of its estate and 66th for its number of students [17] [18]. All of this highlighted the water inefficiency of the institution at that time. In recognition of this, in the summer of 2018 the UoS's Estates Facilities and Commercial Services (EFCS) Sustainability Team, engaged a team of Masters students from the UoS Civil and Environmental Engineering (CEE) department to analyse UoS's water use and identify inefficiencies. Following their analysis, urinal flushing was identified as the single largest potential source for reducing water use [19].

During early 2020 the Covid-19 pandemic reached the UK, quickly becoming endemic within the UK. This led to rapid changes in behaviour, followed by the closure of most business and educational institutions. This resulted in the suspension of the final phase of the roll out of this PIR implementation, but provided a unique opportunity to compare the change in water consumption between buildings with PIR devices and those without, showing the impact of these devices during 'normal' closure periods and their impact during periods of greater disruption.

In this paper we look at the impact of PIR urinal controls on a University Campus, during four periods;

Table 1. Time Periods.

Period A	Pre-Covid-19 term-time
Period B	Pre-Covid-19 holidays
Period C	Full lockdowns during Covid-19
Period D	The post-Covid-19 'new normal' term time

We compare the following four approaches, along with a control group;

Table 2. Experimental Groups.

Group 1	Delayed action, grouped flush, roof-mounted PIR urinal controls, with a 20-minute delay
Group 2	Delayed action, grouped flush, roof-mounted PIR urinal controls, with a 5/10-minute delay
Group 3	Instant action, grouped flush, roof-mounted PIR urinal controls, with a 25-minute reset
Group 4	Instant action, individual flush, PIR urinal controls, with a 25-minute reset
Group 5	The Control Group, existing continuous fill and flush cisterns with flush times varying based on the inlet flow rate and volume of cistern, with times varying from as low as every 5-minutes and as long as 30 minutes

These combined Periods (Table 1) and Groups (Table 2) result in a matrix of 20 distinct conditions laid out in Table 3

Table 3. Conditions.

	Period A	Period B	Period C	Period D
Group 1	Pre-Covid-19 term time. Grouped PIR with a 20-minute delay	Pre-Covid-19 holidays. Grouped PIR with a 20-minute delay	Full lockdowns during Covid-19. Grouped PIR with a 20-minute delay	The post-Covid-19 'new normal'. Grouped PIR

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				with a 20-minute delay
Group 2	Pre-Covid-19 term time. Grouped PIR with a 5/10-minute delay	Pre-Covid-19 holidays. Grouped PIR with a 5/10-minute delay	Full lockdowns during Covid-19. Grouped PIR with a 5/10-minute delay	The post-Covid-19 'new normal'. Grouped PIR with a 5/10-minute delay
Group 3	Pre-Covid-19 term time. Instant action, individual PIR with a 25-minute reset	Pre-Covid-19 holidays. Instant action, individual PIR with a 25-minute reset	Full lockdowns during Covid-19. Instant action, individual PIR with a 25-minute reset	The post-Covid-19 'new normal'. Instant action, individual PIR with a 25-minute reset
Group 4	Pre-Covid-19 term time. Instant action, individual PIR with a 25-minute reset	Pre-Covid-19 holidays. Instant action, individual PIR with a 25-minute reset	Full lockdowns during Covid-19. Instant action, individual PIR with a 25-minute reset	The post-Covid-19 'new normal'. Instant action, individual PIR with a 25-minute reset
Group 5	Pre-Covid-19 term time. Control	Pre-Covid-19 holidays. Control	Full lockdowns during Covid-19. Control	The post-Covid-19 'new normal'. Control

The baseline for this study is the averaged consumption during the same months from three previous years, (or five years if there were any significant gaps in the data), while a control group was maintained for comparison and to account for other factors.

This study comprises of five parts. Part 1 is the baseline data from all buildings across the estate. Part 2 is the focused pilot study conducted in 2019 targeting high consumption areas, and comparing the change from the 20-minute delayed PIR devices against both the baseline and changes within other buildings. Part 3 assesses the wider rollout to the majority of buildings in the estate, and the temporary installation of battery powered grouped instant action PIR devices. Part 4 assesses the impact of the PIR devices during the periods of prolonged building closure during the Covid-19 pandemic, and Part 5 assesses the subsequent new normal during term time.

Part 1

Data was accessed from UoS utility management platform operated by TeamSigma. This data was used for establishing the baselines for each building, and selecting the highest consumption buildings for part 2 of the study.

Part 2

Data was collected from across 38 sub-meters, covering 32 out of the 33 buildings at UoS with urinals fitted. From these, nine buildings which were covered by 10 meters and contained 124 urinals were selected for the initial roll-out. This covered both the majority of the highest use buildings at UoS and also provided a mix of building types including office space, lecture/teaching space, multi-use space and the students' union. Thirty-six

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WRAS approved PIR devices[1] were installed, with a hard-wired electricity supply to control the flow to 124 urinals in total. These devices were set to trigger one flush 20 minutes after a user had broken the PIR beam from the sensor, regardless of the number of other users during this period. The device would then reset. If a flush was not triggered for a 12-hour period a hygiene flush would occur to prevent the urinal traps drying out and smell escaping from the pipes into the washroom areas.

Part 3

Thirty-three additional devices were fitted in a further 12 buildings, covering 92 urinals, in a mix of building types. Alongside this, seven battery-powered, instant action, PIR devices were provided and installed by Thames Water across four buildings. These devices would trigger a 25-minute fill and flush of the cistern immediately after being triggered. If not activated for a 12-hour period a 30-minute period of filling to allow for hygiene flush(es) is activated.

Around the same time, it was established that two of the newer buildings, which had been outside of this phase of the study, already had a different form of PIR control in place. These were then used to form Group 2 of this study. Following these installations, a short period of data was collected covering December (2019), January (2020), February and early March, prior to the start of the UK's first Covid-19 lockdown.

Part 4

Due to difficulties in accurately establishing occupancy levels during inter-lockdown periods, it was decided to only compare consumption during periods designated as full lockdowns by the UK government. A comparison was run of each of the different sample groups against the existing control groups and original baseline. Data was aggregated from across the three full lockdowns implemented in England during 2020 and 2021.

Part 5

The UK government lifted the final Covid-19 related restrictions on the 24th February 2022 [20]. As such it was decided that sampling for the new normal would run for 3 months from the 1st of March, as this correlated with the resumption of greater levels of teaching and working on site. However, many staff and students choose to spend a greater amount of time working remotely under hybrid working patterns.

Control and Comparisons

During Part 2 of the study three conditions existed. The first consisted of, the one block from Group 4- consisting of 10 urinals, spread across four washrooms, with each urinal operating on individual instant action PIR devices responding to each individual user. The second group consisted of 36 Group 1 devices. The third consisted of the remainder of the buildings across both sites which did not have PIR installed, and excluding buildings that experienced other water conservation measures during this time, forming Group 5.

During Part 3, there was an expansion in the number of Group 1 devices, bringing the number of sensors up to 69. The study was also expanded with the addition of Group 2, considering other designs with different trigger times. This took place alongside the installation of group action, battery powered PIR devices installed in three buildings by Thames Water as part of their Smarter Business Visits scheme, representing Group 3.

3. Results

[1] Devices were supplied by Robert Pearson & Company Ltd. from Dart Valley as a combination of Product number UC01-024 (if a suspended ceiling was present) and UC01-006 (if not)

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3.1. Pilot

The six buildings with a 'viable' data set from the initial pilot study (as outlined above) saw water consumption savings ranging from 32-65% with a mean of 49%, median of 47%, and total saving of 50% against each building's consumption over the baseline period (as shown in Figure 1). while a clear cumulative benefit can be seen in real terms in Figure 2, where the clear shift in the baseline can be seen through the step change in water consumption at the start of the pilot period.

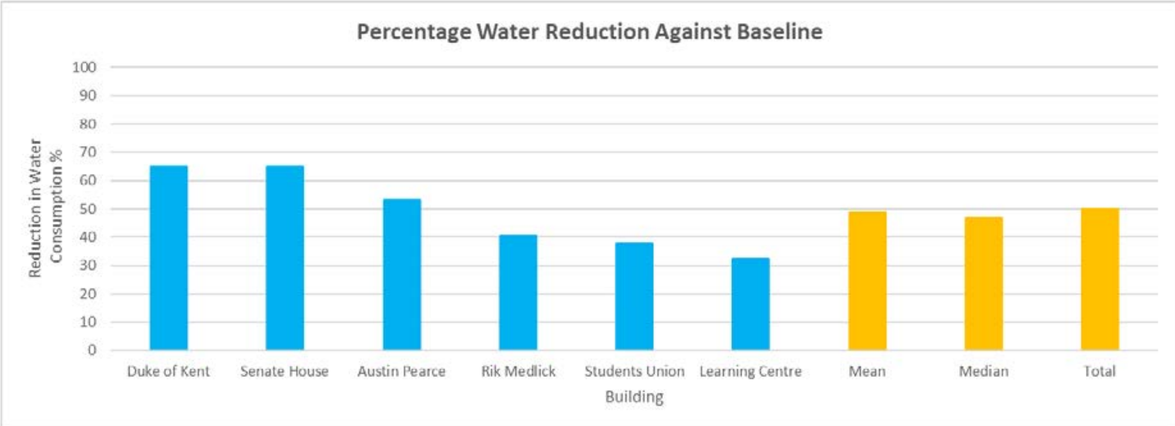

Figure 1- Graph of percentage water reductions across 6 pilot study buildings, during the 6-month pilot study

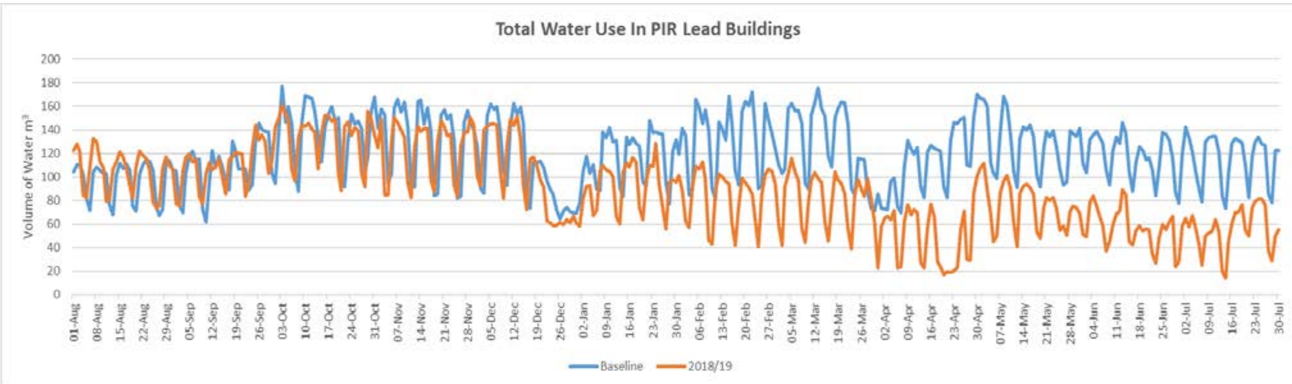

Figure 2- Graph of the volume of water used during the baseline period, and academic year of the pilot scheme

3.2. Overall

Five 'conditions' were in place during the time frame of this study where each were assessed over time periods A-D (as set out Table 3) (as shown in Figure 3). The greatest reduction in consumption was during the full lockdowns. However, this also represents the period with the smallest additional saving against the control group, with an additional 35% reduction, compared to reductions between 51-64% for the other 4 groupings, while the greatest saving at 64% compared to the control group is present during the new normal term time period.

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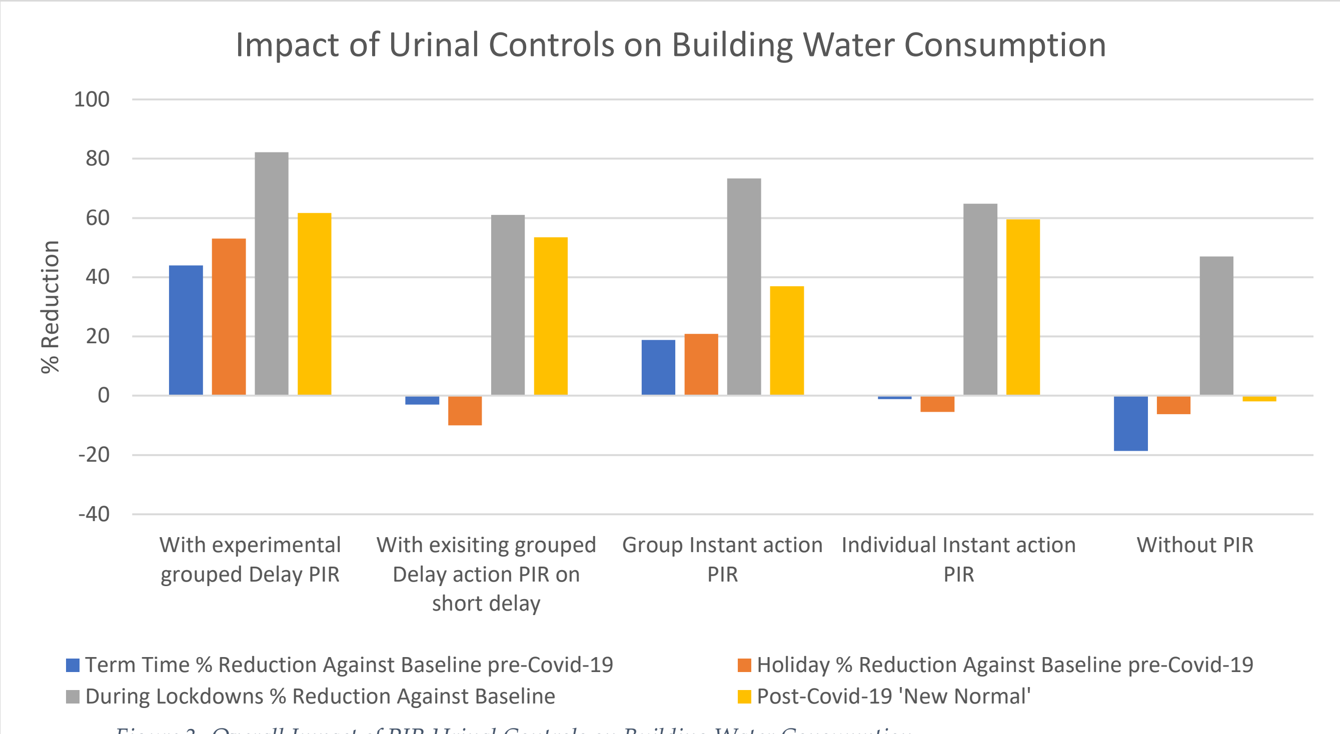

Figure 3- Overall Impact of PIR Urinal Controls on Building Water Consumption

4. Discussion

4.1. Suitability

Different water efficiency devices and approaches will be suitable for different locations. Therefore, a range of different options were considered prior to the initiation of this study. Waterless urinals were considered, however, despite saving the greatest volume of potable water, they were deemed to have too many drawbacks, such as the cost of converting existing systems, these systems' maintenance requirements both in terms of cleaning and issues with waste pipes, and also there was a reluctance to introduce additional chemicals into the waste stream. Individual PIRs for each urinal were also considered, but a member of the estates project team had previously seen increased water consumption from these in high footfall areas. These also had a significantly higher initial cost. Manual urinal flushes were considered. However, papers by [21] and [22] have shown that there can be issues around user engagement. This is in addition to greater maintenance requirements, a higher upfront cost and hygiene concerns. As such, group sensors were selected because these appeared to provide both the lowest installation costs and the lowest expected operational costs. There was also a desire to have flexibility in the duration of the delay in flushing, allowing them to be set initially to the desired 20-minutes but being able to be adjusted without being replaced as necessary later.

4.2. Challenges

A significant issue during this study was the incorrect installation of multiple devices by the external contractors during both Part 1 and Part 2. For example, devices were attached to only one out of two cisterns, another not calibrated correctly for the 20-minute delay, and a third with power coming off lights meaning devices defaulted open if and when lights turned off (either manually or through their own PIR devices, with both controls present). These issues were often only picked up through individual inspection by the PI due to investigations as a result of certain areas not experiencing the savings seen in other parts of the estate.

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4.3. Staff and Student Feedback

Following the initial pilot, one device in the Learning Resource Centre had the time reduced from 20 to 10 minutes due to a particularly high footfall and a small number of complaints about the smell in that area, coupled with an increase in maintenance requests. In one building (the Duke of Kent building) the devices had their hygiene flush period reduced to once every six hours and then once every three hours due to concern from cleaning staff within the building. However, this concern was not supported by any increase in complaints from users, or noticeable smell in these areas.

One concern, prior to the installation of the pilot, was that there would be an increase in complaints, blockages and maintenance work. However, what was found is that in both the first and second full years following the installation of the pilot, there was a statistically significant (at the 99% confidence level) decrease in work requests relating to urinals/toilets/blockages/minor leaks raised in all buildings across the pilot for 2019. This was repeated in 2020 (although 2020's result will have been significantly impacted by Covid19 restrictions and the associated reduced use). This was unexpected as the expectation was for no significant change and it was probably due to other unaccounted for factors.

4.4. Positioning

One thing that appeared to make a notable difference to the effectiveness of PIR devices was their positioning within the space. Devices were installed based on proximity to electrical supplies and the water feed to the urinal cistern. However, those placed in areas where all washroom users triggered sensors were subject to higher consumption than those placed to only detect people who actually used the urinals. This was assessed through visual inspection, and correlated with buildings which saw marginally smaller reductions in water use. However, this has not been quantified, and is a key consideration that should be addressed in any future projects or study in this area.

5. Implications and Conclusions

The implications of this study can be measured in four distinct metrics, the first being the conservation of water, with the University seeing adjusted reductions within the Group 1 study buildings of 64% (with direct reductions of 62%), accounting for approximately 98,000L per day within this study during the new normal term time. The second, directly linked to this, is the energy savings associated with the pumping of this water around the network and associated reduction in heat loss from cold water passing through the buildings. The third factor is the carbon savings, with there being an estimated 41 Kg CO_2e per day from water supply and treatment, with an additional 6 Kg CO_2e per day from the energy needed from onsite pumping (BEIS & DEFRA, 2021). The fourth distinct metric is the financial case and while there was a combined financial saving from the water and energy savings, the water savings alone saw a return on investment in less than 200 days.

While each of these four metrics are important in building the case for facility management teams to take steps to control urinal water use, the overall reductions seen by each of the different forms of PIR urinal control show the wastefulness of uncontrolled flushing.

The findings from this study strongly imply that (at least initially) the greatest possible water savings in office and campus settings, are likely to be though mechanical changes, rather than behavioural change. This is due to the significant volumes of water involved, within this study, showing that the majority of water use within these buildings was due to the automated and uncontrolled use of water in urinal flushing. This study shows that it would be impossible for behavioural changes to have an equal or similar effect. This

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supports the findings of [10] [11] [12], highlighting that the significant majority of the water used pre-study, was from automated mechanical processes.

Overall, this study has shown, that in the context of both high use and low use conditions in a university campus, grouped delayed action PIR urinal controls are more effective at reducing and controlling water consumption than the other forms of PIR controls considered. This study has also shown the importance of having occupancy-based controls for conserving resources during closures and lockdowns, and has shown continued benefits during the new normal which followed these lockdowns.

6. Future Research

Future research should look at the implications of the positioning of these PIR devices within the washroom to minimise 'accidental' flushing, triggered by other washroom users. Research should also look at the effect of combining the results of this study with that of other washroom controls and the ability to control cistern flow rate, and a study of the perceptions of end users. Studies could also be done into the length of the delay in flush action across different building types and with different levels and type of use.

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