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The Bathroom of the Future

- Prospects for Information and Control

PREPARED FOR: GWA Bathrooms and Kitchens
Group, October 2018

About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures.

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Research team

Dr Rachel Watson

Jay Falletta

A/Prof Pierre Mukheibir

A/Prof Simon Fane

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Institute for Sustainable Futures

University of Technology Sydney

PO Box 123 Broadway, NSW, 2007

www.isf.edu.au

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Executive Summary

Across sectors, innovative data collection at a device level and command and control appliances, are providing an opportunity for improved resource efficiencies, facilities management and user experiences. The applications of intelligent technologies and localised networks are growing rapidly. Based on this review of the potential benefits of digital bathroom fixtures, the information collected at the fixture point and its subsequent analysis could reveal useful insights into fixture operations and user behaviour. This information has possibilities to inform planning and operations at multiple scales, from the actual fixture and bathroom, through to buildings, precincts and whole cities.



Water efficiency in Australia advanced rapidly during the Millennium drought in the 2000's, and was further supported with the introduction of mandatory appliance efficiency labelling in 2006. More recently, data from digital metering has been used to evaluate the savings of demand management programs and alternative supply programs. The use of intelligent metering (IM) for end use analysis purposes reflects a growing interest in improving water efficiency at the level of each water using product or technology.

In the short term, key benefits to be realised from bathroom fixture information would include water efficiencies through the faster detection and repair of problems and improved facilities management. This may include, water loss and breakages, usage patterns to inform cleaning, pressure management, and energy savings through hot water optimisation. Due to the direct link between water and energy consumption, in particular hot water use, the ability to adapt and control temperatures and change behaviour in relation to hot water provides considerable potential to improve both environmental outcomes and financial savings.

Projecting into the future, the collection of data and the control of appliances could provide benefits well beyond water efficiency or improved facilities management at a building scale. The ability to monitor and influence behaviour (through feedback mechanisms) could provide benefits in a range of specialist applications, such as the health sector, peak demand for bathroom facilities, and behaviour change towards to improve general hygiene. Nudge applications to influence hand-washing behaviour for example, or toilet occupancy linked with signage in event venues have significant potential.

In relation to planning at a precinct scale, the collection of real-time end-use data for the non-residential sector and mixed-use buildings will allow for better planning outcomes at precinct and wider city scales.

For the full potential of digital fixtures to be realised will require protocols and resources to manage the way data is collected, stored, transmitted, analysed and integrated with other applications and data sets through the internet of things (IoT).

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1 Introduction

Since the development of the original dual flush toilet in the early 1980s, rapid advancements in water metering, efficient fixtures and fittings, in conjunction with regulation and education, have revolutionised the way water is used within buildings in Australia. In Sydney for example, we saw the average demand for water per capita fall from 500 L/p/d in the 1990 to 425 L/p/d in 2003 (Sydney Water 2017). Increased focus on water demand driven by the Millennium drought resulted in a step change reduction in water demand in most urban centres across Australia. Changes in standards and regulations, including the Water Efficiency Labelling and Standards (WELS) scheme, during the drought and a broad range of incentivised demand management and education programs accelerated the uptake of efficient fixtures. In Sydney there was a 20% reduction in total demand in 2008 from its peak in 2002. In the decade since, water demand has held steady at around this level despite the increase in population. This was achieved through a combination of behaviour change, efficient appliance purchases, higher prices for water, recycled water usage, and improved leakage management (Sydney Water 2017). Through voluntary rating schemes such as the Green Building Council of Australia's Green Star, water efficiency in the commercial sector has also seen substantial gains (<https://new.gbca.org.au>).

While these savings enable existing urban water networks to support larger populations, the ongoing challenges of climate change and increasing climate variability, rapid urban growth and sustainability drive the need for continual advancement. Future strategies to reduce water demand will require accurate and reliable data that can be meaningfully interpreted to enable utilities and building operators improve customer services, reduce water losses and manage demand (Fane *et al* 2018). The collection of relevant data, its timely and comprehensible interpretation and communication to end-users, operators and planners have become key focus areas in recent times.

It is this history of plumbing product innovation and a familiarity with digital metering, together with the push for sustainable urban water management, which primes Australia for the next generation of fixture-driven water efficiency. Technology providing more frequent, higher resolution and remotely accessible data generation allows both data-driven change and intelligent control. This paper discusses recent trends in water efficiency and metering and considers this in the context of developments in other sectors, particularly with the rise of the digital era.

The Institute for Sustainable Futures (ISF) at the University of Technology Sydney has developed this discussion paper to demonstrate the value and potential applications of smart water management technologies specifically focused on commercial bathroom products. The work was commissioned by the GWA Bathrooms and Kitchens Group. The paper has been developed using available knowledge, with a literature scan of fixture driven innovations, innovations in collecting and using data from fixtures and other monitoring devices. Preliminary data provided by GWA from digital fixtures installed in a commercial application were reviewed by ISF to reveal trends and insights, and to envisage the way future bathrooms could leverage data and thereby control functions to create efficiencies well beyond that of water savings.

2 The drive for efficiency: efficient fixtures and behaviour change

Government and utility driven water efficiency initiatives in Australia advanced rapidly during the Millennium drought of the 2000s, both in terms of the breadth of end uses and sectors and the scale of programs. Across Australia, many of the key end uses in the residential sector (i.e. showers, toilets, and clothes washers), a significant proportion of non-residential sectors (i.e. commercial, institutional and industrial), as well as particular sub-sectors (i.e. schools) have all been targeted for the water efficiency programs (Liu *et al* 2017). As a result, large-scale roll out of low cost efficiency programs focused on hardware modifications for demand management (such as showerhead exchange programs) now have limited impact due to saturation of the market.



The focus of these Government and utility programs has been on efficient products and technologies (which is critical to reducing water consumption); several studies have pointed out that as the increasing efficiency of fixtures and appliances approaches maximum limits. Traditional, large-scale hardware-focused demand management programs are seen to have limited further potential. A focus on behaviour and duration of use is therefore likely to yield greater efficiencies than a focus on hardware alone (Kenway *et al* 2016). In concert, highly targeted programs designed for specific customer groups are seen as the 'next generation' for demand programs (Fane *et al* 2018). Fixtures that are efficient and can also provide both data and control to help manage and drive efficient behaviour (i.e. the duration of use) will lead to further efficient water usage (Liu & Mukheibir 2018). Likewise, usage data collection enables precise targeting of programs.

Examples of the efficiency potential gained from combinations of fixture modifications and behaviour change has been demonstrated in smart lighting and smart irrigation. Sensor driven lights can be programmed to provide light only to areas that are being used, or dim lights based on ambient light levels. This can save energy in the range of 17-60% over conventional lighting systems (Chew *et al* 2017). Similarly, smart irrigation practices, integrating other weather data such as soil moisture and evapotranspiration, have increased the efficiency and effectiveness of irrigation in a variety of different climate and irrigation contexts (Haley and Dukes 2012, Vick *et al* 2016).

In the private sector, Green Star certification by the Green Buildings Council of Australia in 2002 helped to drive improvements in resource efficiency for commercial building owners, including for water. Green star buildings reportedly use 51% less potable water than minimum industry standards (<https://new.gbca.org.au/green-star>). This was soon followed by the expansion of the Australian Building Greenhouse Rating (ABGR) to NABERS in 2004 to include energy, water, waste and indoor environment quality, which further motivated building owners and operators to install innovative and efficient appliances. Improved monitoring and data would allow building owners and operators to make informed decisions on how to maintain or improve their NABERS rating. Such data would also potentially support the proof required for the rating.

2.1 Development of efficient fixtures

The Commonwealth WELS Act was introduced in 2005 to drive the uptake of water efficient fixtures and appliances in Australia. The WELS scheme provides information to purchasers on water use of products using a system of mandatory labelling; all products cover by the scheme must display their water use and a star rating to indicate their level of water efficiency. The scheme requires all WELS products to be registered and labelled before they are sold in Australia (source: www.waterrating.gov.au). WELS also mandates minimum standards for toilet and clothes-washing machines. This scheme has led to a high penetration of efficient toilets and showers in residential and non-residential buildings. Figure 1 shows the modelled water savings in Australia due to WELS (Fyfe *et al* 2015) growing to over 200 GL (billion litres) per year in 2030.

Table 1: Timeline of efficiency events

Date	Details
1981	Caroma released first dual flush system released 11 litres / 5.5 litres on half flush.
1988	National Water Conservation Rating and Labelling Scheme - voluntary scheme was established and administered by Melbourne Metropolitan Board of Works before being taken over by Sydney Water.
1993	AS 3500 which specified the maximum allowable water use per flush for toilets. Caroma redesigned their toilet to 6 and 3 litres.
1998	Launch of Australian Building Greenhouse Rating (ABGR) focused on energy
1999	National Water Conservation Rating and Labelling Scheme taken over by Water Services Association of Australia (WSAA).
2002	Green Building Council of Australia (GBCA) established
2003	Green Star certification launched by GBCA
2004	ABGR renamed as the National Australian Built Environment Rating System (NABERS) to expand its reach beyond energy, to water, waste and indoor environment quality.
2005	Water Efficiency Labelling and Standards Act 2005 Caroma 4.5 litre full flush / 3 litre half flush toilets enter the market
2006	On 1 July 2006 it became mandatory for urinals taps toilets and washing machines to carry WELS rating label.
2007	The first 5 star WELS rated toilets and urinals are registered
2008	The first 5 star WELS rated dishwashers are registered
2011	Setting of minimum standard for clothes washing machines in WELS 6 star urinals become available.
2013	6 star dishwashers become available.
2016	New 4-star ratings for showers (lower flow rates than 3-star showers but need to pass spray force and coverage tests) in WELS. 0.5 L flow rate reduction for 5-star urinals in WELS 6 star toilets become available

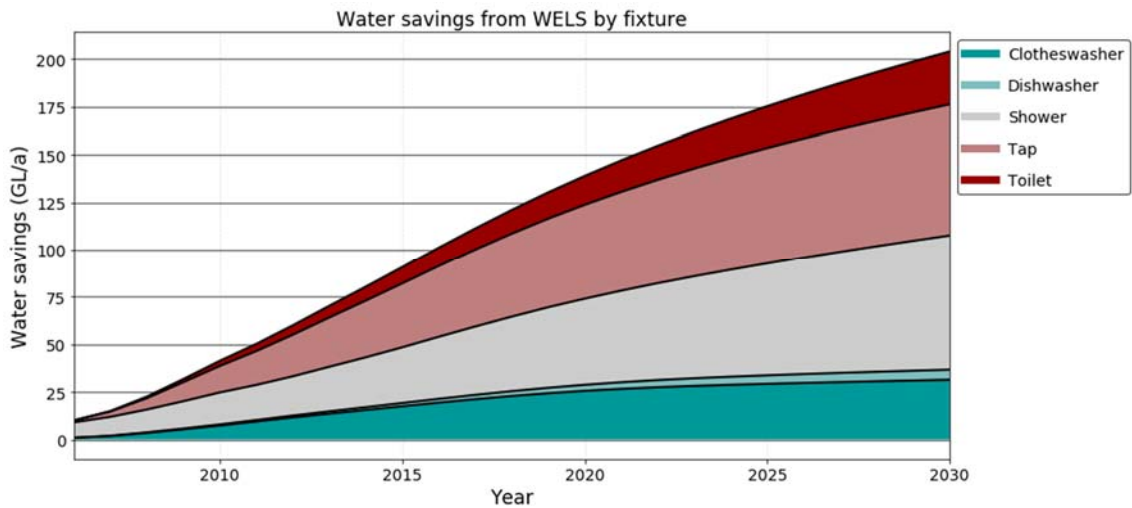


Figure 1: Water savings due to WELS rated fixtures and appliances (Fyfe et al 2015)

Efficient toilets:

The first dual flush toilets were introduced by Caroma in 1981. Replacing 12 litre single flush, these initial dual flush models were 11 litres, with 5.5 litres on the half flush. Since then improved dual flush toilet classes have been introduced over time (see Figure 2), with Caroma's 4.5 litre full flush / 3 litre half flush toilets entering the market in 2005. Efficient four WELS star toilets are now becoming the dominant stock in Australian houses and buildings.

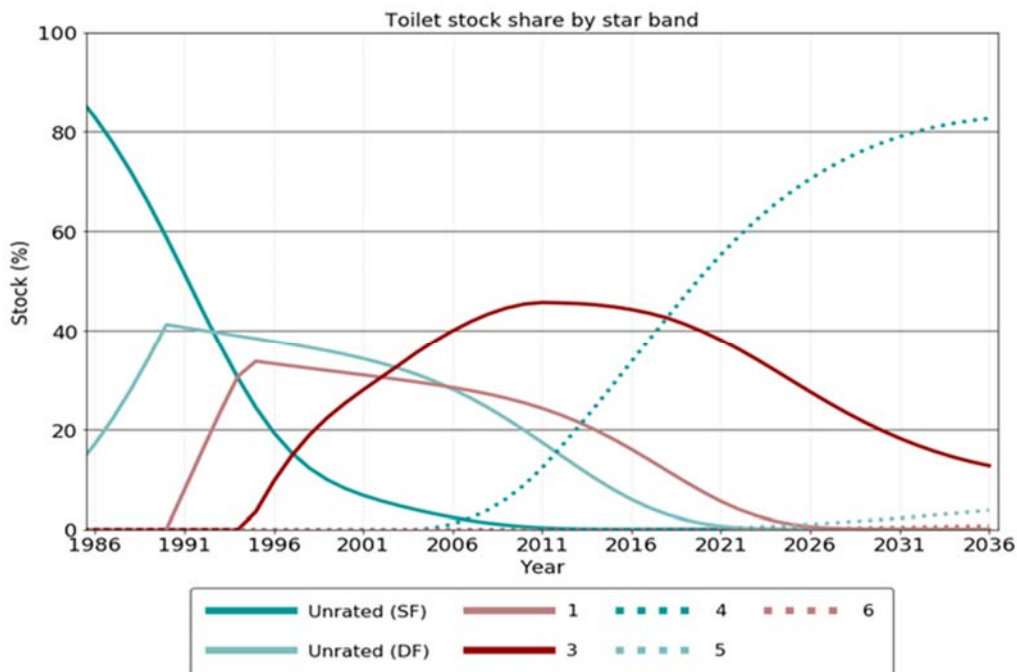


Figure 2: Stock of toilets models in Australia by star WELS band (ISF iSDP model)

Since the 1980s dual flush toilets have seen the demand for water due to flushing reduce substantially. Figure 3 shows that over time the total demand due to toilet flushing in Australia has declined despite a significant increase in population. After a peak in the early 1990's, total water use dropped to current level and then gradually increased with the projected population

growth trend (ISF iSDP model). The current savings across Australia are estimated at 270 billion litres per year, the equivalent of three times the capacity of the Sydney desalination plant.

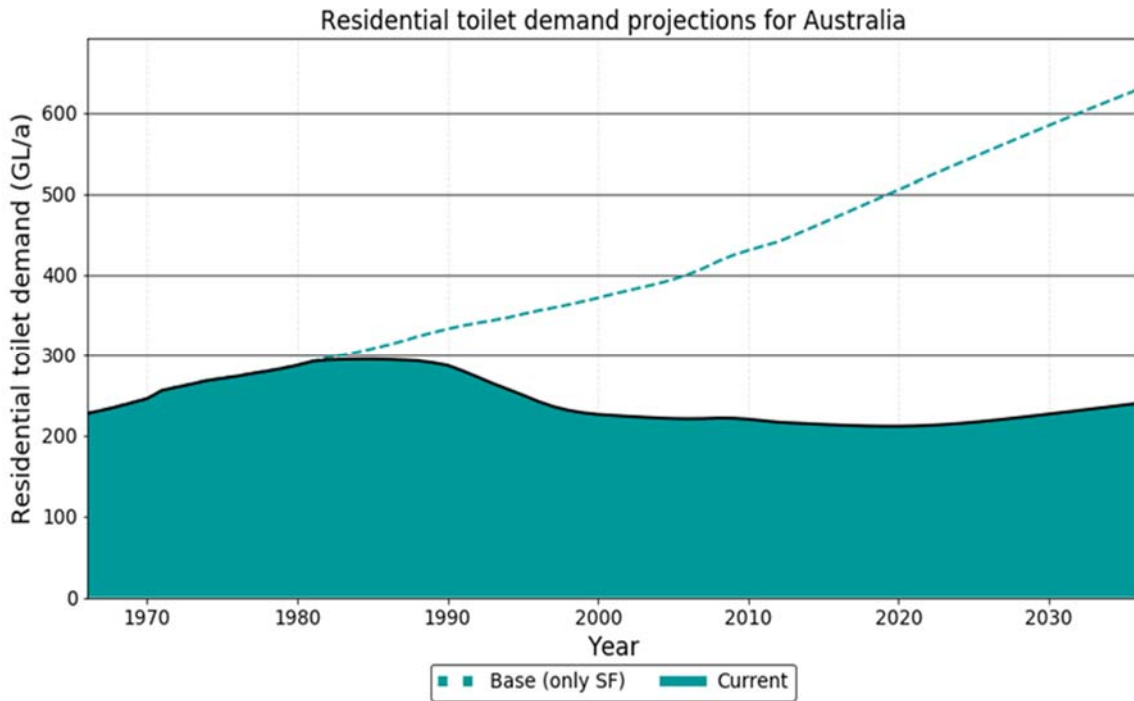


Figure 3: Water consumption in toilets in Australia with and without dual flush (ISF iSDP model)

Efficient showerheads:

Similarly, the introduction of more efficient showerheads into homes, coupled with water conservation information on shower durations, led to reduced volumes of water being used per shower in studied examples – as illustrated in Figure 4 by the results of the Willis *et al* (2010) study of retrofits in South East Queensland.

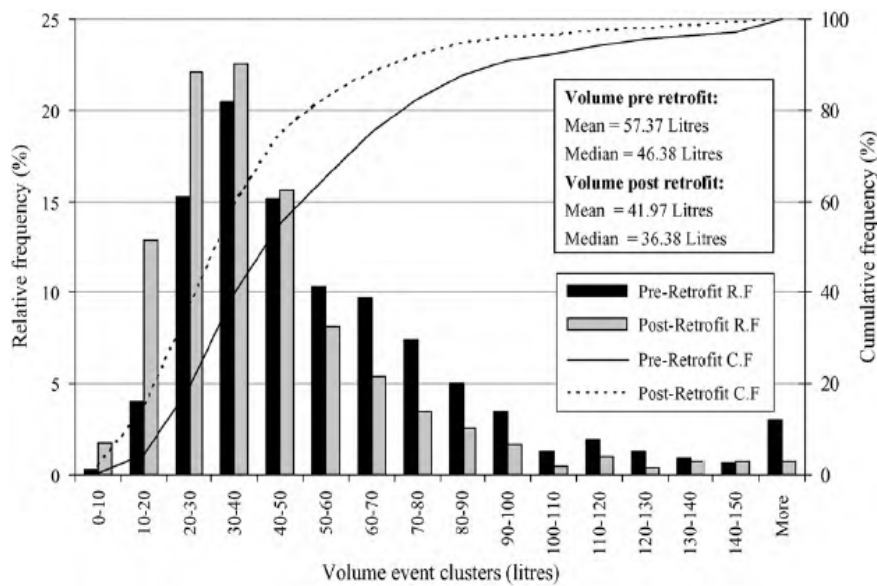


Figure 4: Shift in shower volumes (Willis et al 2010)

2.2 The evolution of digital era and intelligent water metering

Developments in intelligent water metering technology have evolved to a large extent from the energy sector, where smart electricity and gas meters and communications infrastructure have been more widely introduced. From an operational and planning perspective, water utilities have used Supervisory Control and Data Acquisition (SCADA) systems to monitor network flow and pressure, record and analyse the data, remotely control pumps and valves, schedule maintenance and plan future infrastructure augmentations (Boyle *et al* 2013).

Water utilities are increasingly considering intelligent metering (IM) as a way to enhance water supply security, minimise waste and control costs (e.g., through reduced labour costs for meter reading) as well as transform the customer-utility relationship (Liu & Mukheibir 2018). Within the distribution network, flow and pressure data acquired from IM can be used to balance high demands (and the resultant low pressures) across the network. This data is useful both operationally and for longer term planning to identify areas in the network where there are higher flows, or where there are low pressures during peak demand.

The above advancements have not involved the end user in any way, except for gradual development in the deployment and use of customer flow registration meters. The main drivers for introducing IM were the need to recover costs directly from the customer, to cut out an intermediary body and to ring-fence the financial operations from other local government activities. In Australia, multi-residential blocks generally have a single water meter which captures aggregate usage across all apartments. Sub-metering for individual units/apartments is on the rise however, bolstered by the recent introduction of legislative requirements in some Australian states. For example, sub-metering is now compulsory for all new residential multi-unit developments in Queensland (DIP 2008), and in New South Wales, the *Residential Tenancies Act 2010* allows landlords to charge tenants for water usage on sub-metered units.

Since the 2000s, utilities have become interested in demand side management and water efficiency in an attempt to delay expensive capital investments for supply options and to suppress demand during drought periods (White & Fane 2002). Mirroring the electricity industry, where “least cost planning” and “integrated resource planning” were developed to compare energy conservation to increased supply, so too have these principles been emerging as priorities and are now widely applied to planning for urban water supplies (Turner *et al* 2010).

The current drivers for IM in the water sector are illustrated in Figure 5, and include:

1. Improve end-use analysis and end-use efficiency
2. Improve feedback and/or customer service and stimulate behaviour change
3. Implement pricing reform to manage peak demand (and associated behavioural response)
4. Improve network efficiency (leaks, pressure, illegal use and non-revenue water)
5. Enable remote accessibility

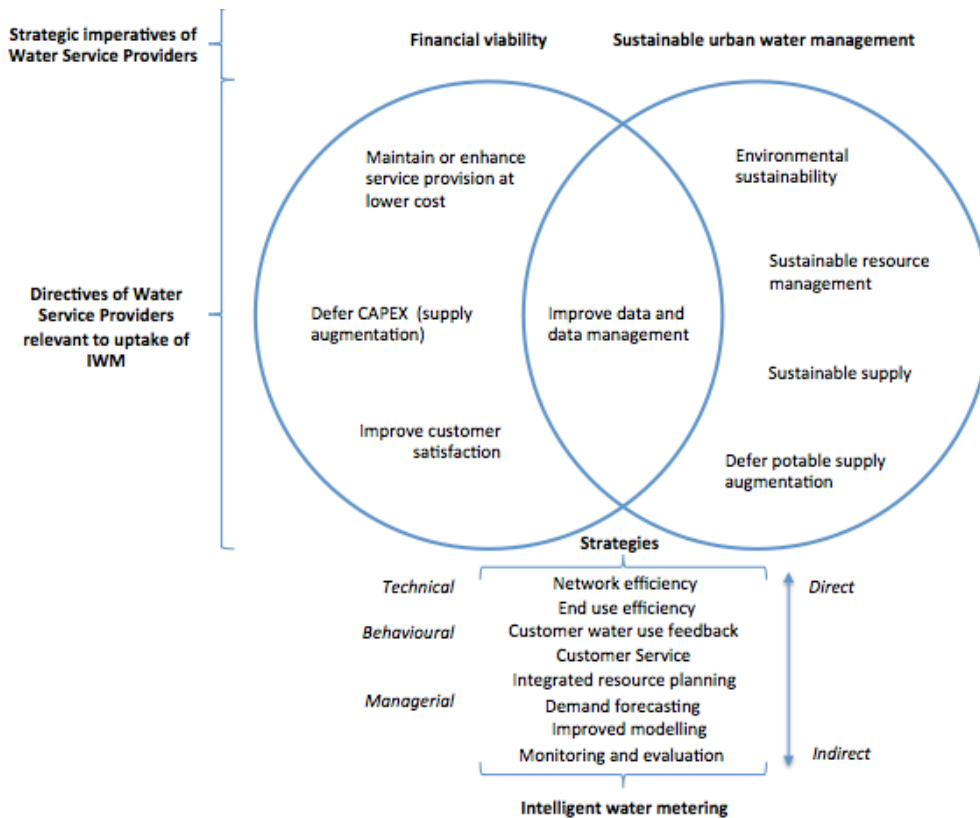


Figure 5: Drivers for intelligent metering (Boyle *et al* 2013)

2.3 End-Use Analysis and Efficiency

Use of IM for end use analysis purposes reflects a growing interest in improving water efficiency at the level of each water using product or technology. Over the last decade, IM data has been used to evaluate the savings of demand management programs (Giurco *et al* 2008) and alternative supply programs such as the performance of rainwater tanks (Umapathi *et al* 2012). Studying fixture and appliance efficiencies and “water use behaviours” is core to the end use based demand forecasting used by most Australian water utilities (Turner *et al* 2010). It is also critical for evaluation of water savings as water use patterns change over time with demographic shifts and the introduction of new technologies. By capturing high resolution data from individually metered households and network zone meters, utilities have gained an understanding of daily and seasonal residential consumption patterns that are necessary for planning their supply systems.

As is the case in the energy sector, residential consumption patterns have historically garnered most interest (McKenna *et al* 2014), and little research has been done to understand the water end-use patterns in commercial buildings. The absence of this data signifies a real gap in the knowledge required for optimising operational processes and planning for network improvements (Beal *et al* 2014). The data is also critical for integrated resource planning of urban water supply systems, which benefits from end-use modelling for demand forecasting and the design, implementation and refinement of demand management programs. In addition to strategy planning purposes, this data also provides the opportunity for a utility to reduce its operational costs through asset management efficiency and upgrade deferrals.

2.4 Customer and user feedback

Empowering customers and users with information about their consumption patterns and uses will allow them to make informed decisions about how they use water in future. By providing more information about water use, which can then be converted into more *meaningful* information for the user/customer, IM presents an opportunity to improve water literacy within the community. It also empowers users to develop a greater understanding of their consumption (Liu & Mukheibir 2018). For instance, rather than estimated (average) daily use based on historical consumption data, IM can potentially offer real-time monitoring of consumption and anything in between.

The provision of more detailed water use information to customers is gaining traction, drawing on successes in the energy sector (Hallinan *et al* 2012). Research into electricity use feedback, for example, suggests a 5%–15% reduction in demand is achievable (Darby 2006). A review of 25 published detailed customer water-use information feedback studies revealed mean savings across all the studies of 5.5%, within the 10th–90th-percentile envelope of 3.0%–8.0% savings (excluding the extreme outliers) (Liu & Mukheibir 2018).

Advancements in mobile applications are facilitating fast and simple management of personal and household activities, but the success of these applications depends on access to relevant and useful information while also acknowledging the sensitivity of such information. The increased availability of this data in conjunction with the emergence of the “internet of things” (IoT) and Long Range Wide Area Network (LoRaWAN) networks is shifting cultural expectations of the convenience, detail and accessibility of consumption information (Boyle *et al* 2013).

2.5 Pricing Reform

While the elastic *range* of various end-uses remains the subject of ongoing deliberation (Nataraj 2007), the *role* of water pricing in regulating water consumption behaviours is well established. Australian electricity retailers already employ time-of-use tariffs (TOUTs) in their pricing structures to help regulate peak demand. IM offers this same potential for the water sector—by shifting consumption from peak periods to non-peak periods through information access and peak usage pricing. Through a TOUTs approach, based on hourly consumption data, infrastructure constraints might be avoided and infrastructure upgrades could be postponed, saving money for utilities and customers (Cole 2012).

Real time price signalling presents another option for scenarios where balancing the supply and demand of recycled water is required; i.e. lower prices or free water in times of abundant supply and vice versa in times of constrained supply. Two-way communication between customer onsite storage and the service provider could allow such a transaction to take place seamlessly. This option becomes particularly relevant under a zero discharge to the environment scenario where at times the utility may require the use of recycled water, but at other times experiences peak demands that exceed capacity.

2.6 Network Efficiency: Leak Management, Illegal Use and Asset Management

Improved leak management in the residential, commercial and industrial sectors, municipal buildings (particularly schools) and within the water supply network is at the core of improving network efficiency, to which IM for mitigating and reducing losses is essential (Beal *et al* 2014, Britton *et al* 2008). Network water losses may vary between 5% and 55% of total supply, depending on factors such as number of connections, geography of the water supply network, asset condition and climate (Mukheibir 2010). In a study of leakage in 52 Australian schools equipped with IM, the top ten highest consuming schools were found to account for 77% of total leakage (Turner *et al* 2012).

Work commissioned by Sydney Water in 2011 showed the potential for water savings in high rise residential buildings could be made in the following areas (Jones and Jha, 2011):

- Irrigation – through reduced irrigation frequency
- Cooling towers – through appropriate settings
- Taps – flow regulators to match pressure
- Showers – flow regulators to match pressure
- Toilets – lower flush volumes
- Urinals – flow regulators to match pressure
- Leak detection – faulty taps and toilet cisterns.

The largest areas for savings were identified for leak repairs, flow regulators for taps and lower flow shower fittings. Many of these potential areas for savings would apply to commercial buildings. A related aspect of leak management is pressure management. Water pressure can fluctuate with reservoir levels and when high, the risk of leakage may increase. IM can be employed to understand and manage network pressure and mitigate leakage through pressure reduction during low flow periods.

Beyond leak management, a number of other elements to network efficiency have been identified, such as efforts to improve response times to issues of non-compliance (illegal use), particularly during times of water shortage (Little & Flynn 2012). Monitoring asset condition is also integral to network efficiency, and IM can provide data on meter performance and failure and broader network operations.

With improved technologies and new digital fixtures and fittings, building owners and operators may soon be able to draw inspiration from these large utility network applications of digital technologies and apply them on the smaller scale of building systems.

2.7 Precinct planning and management

Data acquired from digital fixtures will refine planning estimates at precinct and more regional levels and provide insights into end use behaviours not previously available, particularly for the non-residential sector. Information on daily and peak demands for water, wastewater and non-potable water will inform a range of design and planning criteria, allowing for the optimisation of resourcing and service networks. Smart fixtures may be able to receive signals about peak demands and shut off non-critical appliances in return for bill savings, as has been done to some extent in the energy sector.

3 Going beyond water efficiency

There are significant opportunities for leveraging the data and control features of smart devices to capture benefits beyond water savings, with potential for improvements in building management and security, intelligent monitoring control across multiple applications, energy savings and efficiency, and health and wellbeing.

3.1 Building management

Previous innovations in smart lighting and ventilation have demonstrated that, in addition to monetary and environmental savings from energy efficiency, there are a number of additional benefits for building management optimisation and ultimately for the end-user (van de Werff *et al* 2018). Monitoring of lighting patterns gives building managers additional information including verification of security walkthroughs, alerts to unauthorised occupancy and mechanisms to minimise building maintenance while maximising occupant satisfaction (Chew *et al* 2017). Smart bathroom fixtures could be utilised in a similar manner to optimise building management practices as well as save water and energy. For example, data on traffic through bathrooms could allow facilities managers to direct cleaning staff to the most-used bathrooms and optimise the cleaning and maintenance schedules accordingly. Further, automated control of public access to the bathroom could be linked to a type of fault identified through the data, restricting access if required.

For street lighting, automatic outage detection and remote monitoring allows operating and maintenance costs to be reduced by reporting exactly where faulty lights are, while also improving safety for pedestrians and vehicular traffic (Mahoor *et al* 2017). For building managers, knowing exactly the type of fault would allow for correct maintenance reporting and more efficient repairs, saving money and providing a better customer experience.

Developments in smart urinals and toilets allow external isolation of faulty fixtures, improving efficiency and cost savings by allowing facilities managers to identify the specific fault allowing the correct technician to be called. For example, a leak due to a faulty solenoid would need to be repaired by an electrician rather than a plumber. For facilities managers with geographically dispersed facilities, for example councils, being promptly alerted of changes in usage patterns and faults would assist in maintenance and cleaning regime scheduling.

As is the case in most water supply networks, pressure management in the parts of the network that have high pressures helps to reduce leaks, reduce the volume of water used, and (in the case of booster pumps) can increase pressure during times of peak demand. These practices can be extended to building networks where the lower floors may experience higher pressures than the top floors. Pressure can also fluctuate between the floors of buildings and throughout the day depending on the demands on the network. By monitoring the flows and pressures across the building, pressures can be reduced in some parts, and boosted in other parts.

Reducing hydraulic pressures can substantially reduce leaks and also extend the useful life of water related appliances (Liu *et al* 2017). A lack of pressure can create flushing issues; conversely, too much pressure can cause undue strain on tapware, causing maintenance issues. Detecting and controlling for pressure at a fixture level can prolong the life of fixtures and provide water savings through reduced leaks. If higher pressure is detected in a urinal for example, the volume of the flush could be reduced while still achieving adequate cleaning flows.

3.2 Intelligent buildings and the internet of things

The “internet of things” (IoT) is the concept that describes merging information from a diverse range of sources and devices through a common language for devices and apps. By connecting all these devices, data is both shared and transmitted between devices, providing a deeper understanding of how these operate individually as well as synergistically. In a building setting, this could mean that appliances communicate with each other cooperatively as everything is interconnected wirelessly.

The introduction of localised networks such as LoRaWAN that enable low power, wide area communication between remote sensors and gateways connected to the internet network are initial steps towards IoT network functionality. The rise of LoRaWAN technology has driven an explosion of interconnected electronic devices that both send and receive data signals.

The automation of electronic devices based on instantaneous data inputs has led to concepts such as the ‘intelligent home’. The intelligent home learns the behaviours and preferences of people in the home. It uses data gathered from a selection of devices and sensors around the home and anticipates the needs of the users and responds accordingly, such as controlling the airflow, lighting and temperature based on parameters such as occupancy density or movement. The key components of an intelligent home are the analytics engine, the artificial intelligence underpinning the application, and most importantly, a high level of user trust and data transparency.

3.3 Health and wellbeing

The ability to vary lighting levels in response to ambient light not only saves energy, but also has proven health and wellness benefits for inhabitants (Chew *et al* 2017). Similar benefits have been shown from smart ventilation systems which adjust the airflow across the building based on CO₂ levels, humidity, occupancy and outdoor temperature. Although still an emerging technology, an analysis of 38 smart ventilation studies revealed that up to 60% energy savings can be achieved through this practice, as well as improved health benefits (Guyot *et al* 2018). Similarly, being able to regulate the temperature of taps through the mixing of hot and cold water based on the ambient temperature or the demographic of the users would save hot water heating costs, reduce scalding risk, and ensure adequate temperatures for cleaning or healthcare requirements.

Remotely monitoring fixtures and fittings to ensure they are being used may provide an additional level of surveillance of the infirm or aged to ensure their wellbeing in a nursing home, or allowing them to remain in their own unsupervised environment for longer. There are however, potential ethical and privacy issues related with such an approach.

Developments in car park design has allowed for signalling of free parking spaces, and redirection of traffic when capacity has been reached (Vera- Gómez 2016, Pranav *et al* 2016), a feature facilitated through sensor data capture and transmission from individual parking spots. In a similar manner information from fixtures in bathrooms could be used to detect high rates of occupancy (during breaks in play at sporting stadiums) and redirect patrons to bathrooms of lower usage through appropriate signage informed by real time data, thereby enhancing the user experience.

Behavioural economics suggests that most human decisions are made ‘fast’ and are intuitive, automatic, experience-based, involve relatively unconscious judgements and ‘rules of thumb’. Such decision-making is based on cognitive shortcuts or impressions and is prone to unconscious bias. This means information or education and rational choices alone do not drive behaviours. Instead, many unconscious cues have a strong impact on actual behaviour. There is potential for digital fixtures to also influence behavior in the future. For example, the HYDRAO shower (Liu et al 2017) in Europe lights up with different colours for different volumes of water use with the aim of encouraging users to have shorter showers – especially during peak usage periods at a gym for example. A tap with similar properties could be used to elicit different handwashing behaviours in high risk areas such as childcare, hospitals, schools, food preparation areas (for example red: ‘too short’, orange: ‘nearly there’, green: ‘you are done’). Another ‘nudge’ application could be the lighting up of a tap after the toilet has been flushed as a prompt to encourage handwashing.

3.4 Energy Savings

There is a strong link between water efficiency and energy efficiency. A small study in Melbourne by Binks et al (2017) demonstrated that, on average, the energy saved from reduced shower water use (and therefore hot water use) was in the order of 0.034 kWh per litre of total water saved – this is usually more energy than is used to provide a litre of potable water and sewage services. As discussed earlier, changing water temperatures in fixtures to reflect seasons and daily temperatures could result in major energy savings.

There is very little information about the end-uses of water in the commercial sector. While hot water from tap use makes up 25-30% of residential consumption (Figure 6), tap use is likely to be predominant hot water consumption point within a commercial building, along with some brands of industrial dishwashers.

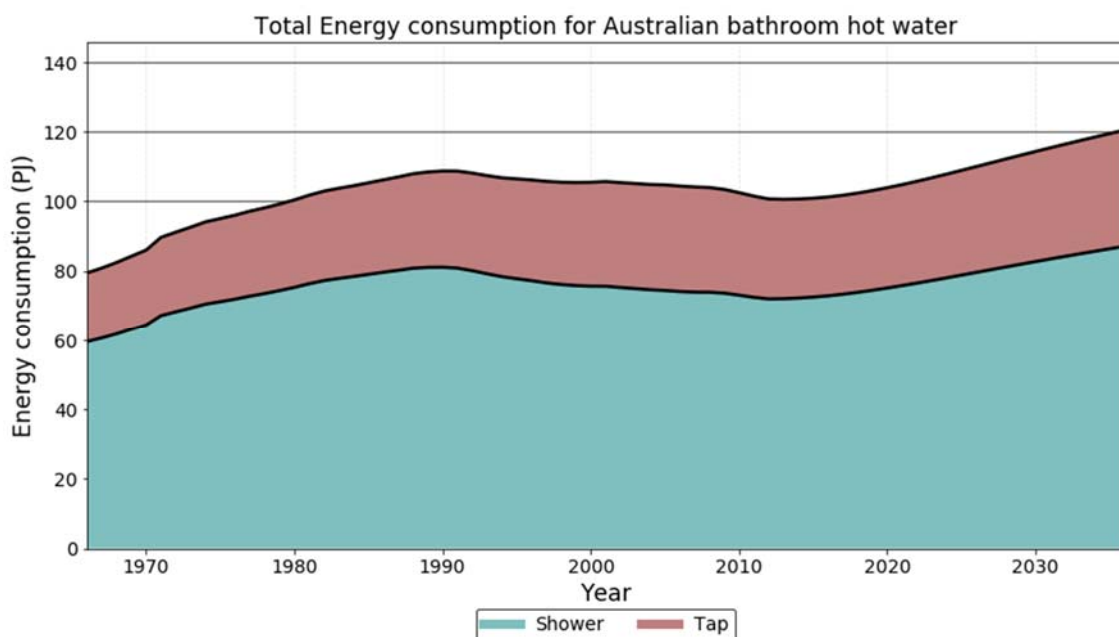


Figure 6: Residential use of hot water (ISF iSDP model)

4 What bathroom data could reveal

There is the potential for digital fixtures to revolutionise both the management of fixtures and collection of valuable data to change a range of behaviours. Data collected from fixtures in bathrooms installed in a commercial application, as part of initial trials by GWA, have provided preliminary insights to the type of information that could be analysed, as well as the controls that could provide value at bathroom, building and city planning scales – as shown in Figure 7.



Figure 7: GWA smart control bathroom fixtures and data collection

At a bathroom level, data collected from individual fixtures has provided a number of insights that have assisted with building management and have the potential to influence future bathroom design. The observations based on the limited data collected thus far are revealing and highlight that understanding patterns of use for particular fixtures within bathrooms can allow more focused cleaning cycles. As shown in Figure 8, there is clearly a higher average use over the weekend when compared to the week days, and a clear peak of toilet flushing around midday. This diurnal profile is distinctly different to that of a residential complex and the overall trends for the city (which exhibit peaks in the morning and early evening). If the high rise building is mixed use (residential and commercial), then pressure management across the building over the day might be advantageous.

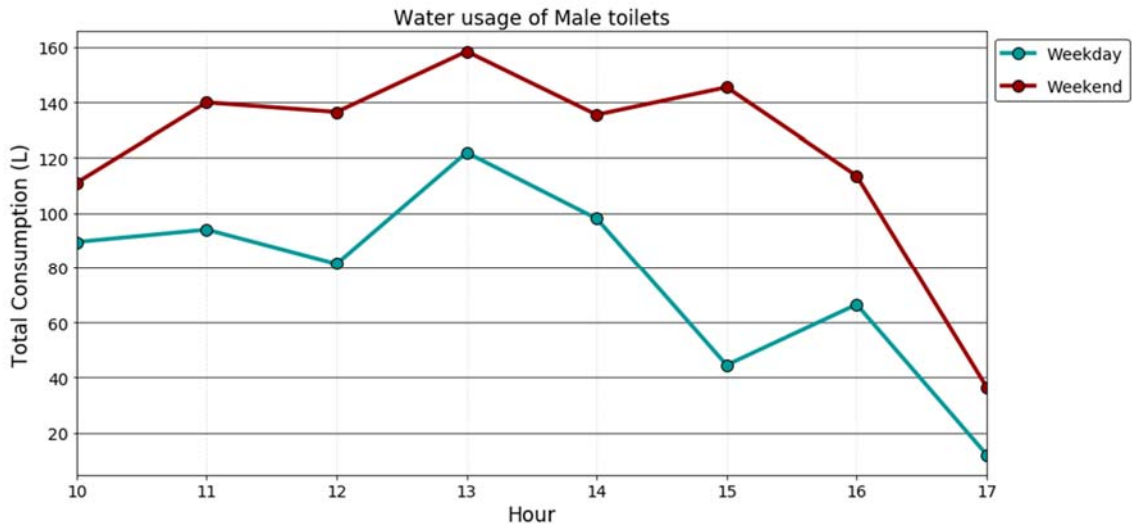


Figure 8: Diurnal pattern of toilet flushing

Sudden changes in patterns of use, such as those highlighted in Figures 9 and 10, can indicate faults. The rapid increase in flow from the tap in Position 2 might signify a leak or running tap. In the second image, the toilet in Position 1 remains unused for 20 days, signifying a potential fault with the fixture, or some other problem that has led to users avoiding that cubicle. With increased digital control of fixtures building managers could remotely isolate faulty fixtures to stop leaks and further problems and trigger service calls in a timely manner.

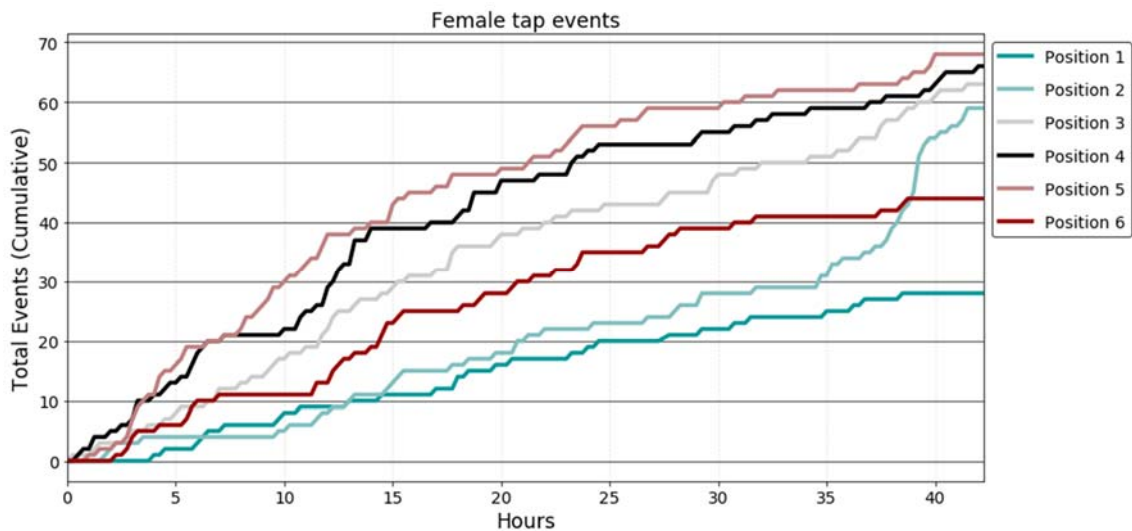


Figure 9: Tap (Position 2) with sudden increase in use, indicating a leak

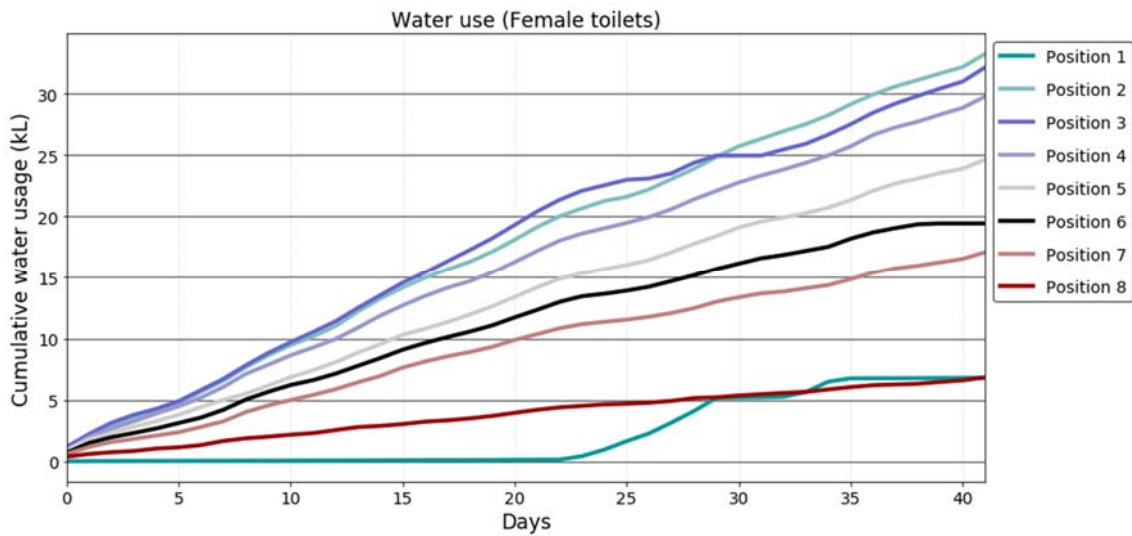


Figure 10: Toilet (Position 1) with unexplained usage pattern (no usage for 20 days) indicating fault

Further diagnostics could indicate user preferences for particular facilities. As can be observed in the previous two graphs, not all toilets and taps are used equally. This could be due to their location or state of cleanliness. Being able to monitor the level of usage of a particular bathroom or fixture could allow more efficient allocation and scheduling of cleaning and maintenance staff.

Data could also be used to identify the need for behavioural change programs. For example Figure 11, which shows the percentage of water used by appliance type in 15 minute periods in one bathroom, highlights a potential disconnect in some of the periods between toilet and urinal usage and tap usage (the grey portion of the graph). Drawing on behavioural insights research, a flashing tap after a toilet flush or urinal use to encourage handwashing, or changing the lighting colour or brightness on the tap to indicate sufficient handwashing time are some of the possible ways of using the data collected to promote positive behaviour change.

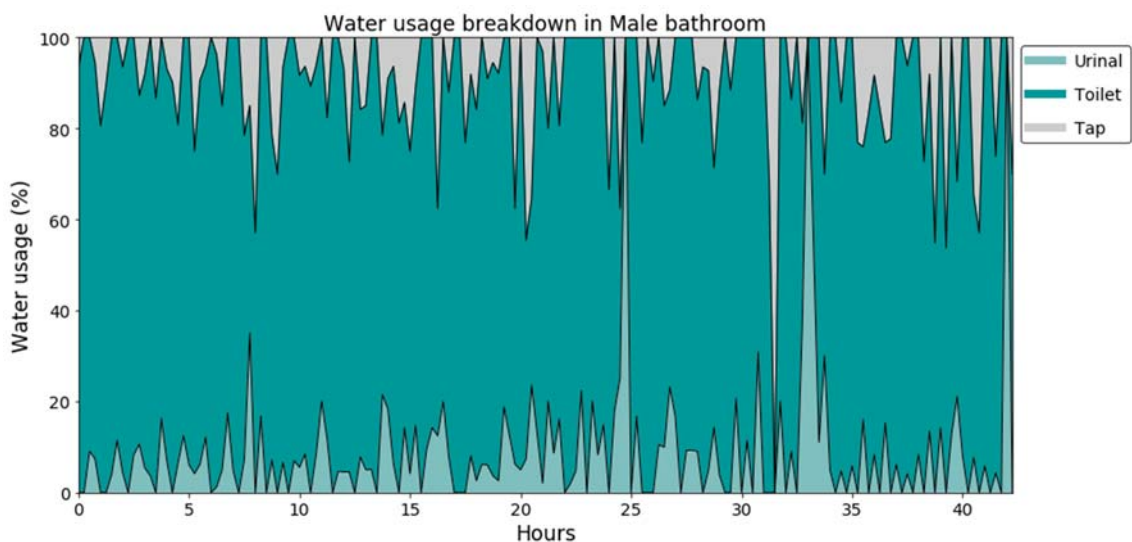


Figure 11: Toilet and urinal use within a bathroom with limited hand washing

5 Information collection and appliance control across scales

It is evident that the collection of data from smart appliances and fixtures is not limited to the fixture or bathroom alone, and can provide insights at broader scales, including for increasing efficiency, detection of faults, determining cleaning requirements, and broader public health considerations such as hand-washing behaviour. Figure 12 illustrates how information can be collected at outwardly cascading scales – from the fixture itself, the bathroom and the building more broadly, and at the precinct and city scales. Utilities and planners may find commercial building consumption patterns useful when planning new or upgrade infrastructure, especially in densifying precincts.

This information then provides the opportunity for controls by various actors, including building managers as well as external stakeholders such as public health practitioners. Examples of controls include changed user behaviour, improved user experience, optimised operational activities (such as cleaning and repairs), improved resource efficiency (water and energy), and better-informed building designs. Water and energy utilities may also have interest in controlling appliance use during peak demand periods.

However, as Freeman (2015) points out, taking advantage of smart appliances (be they lighting, ventilation or taps), five key strategic components are required: (1) the smart appliance, (2) sensors and controls, (3) connectivity, (4) analytics and (5) intelligence (This is further described in Appendix 1). By incorporating the last two components, building operators would be able to monitor and compare multiple buildings, and the “smarts” in the system would perform predictive and learned responses to specific end-uses and occupancies.

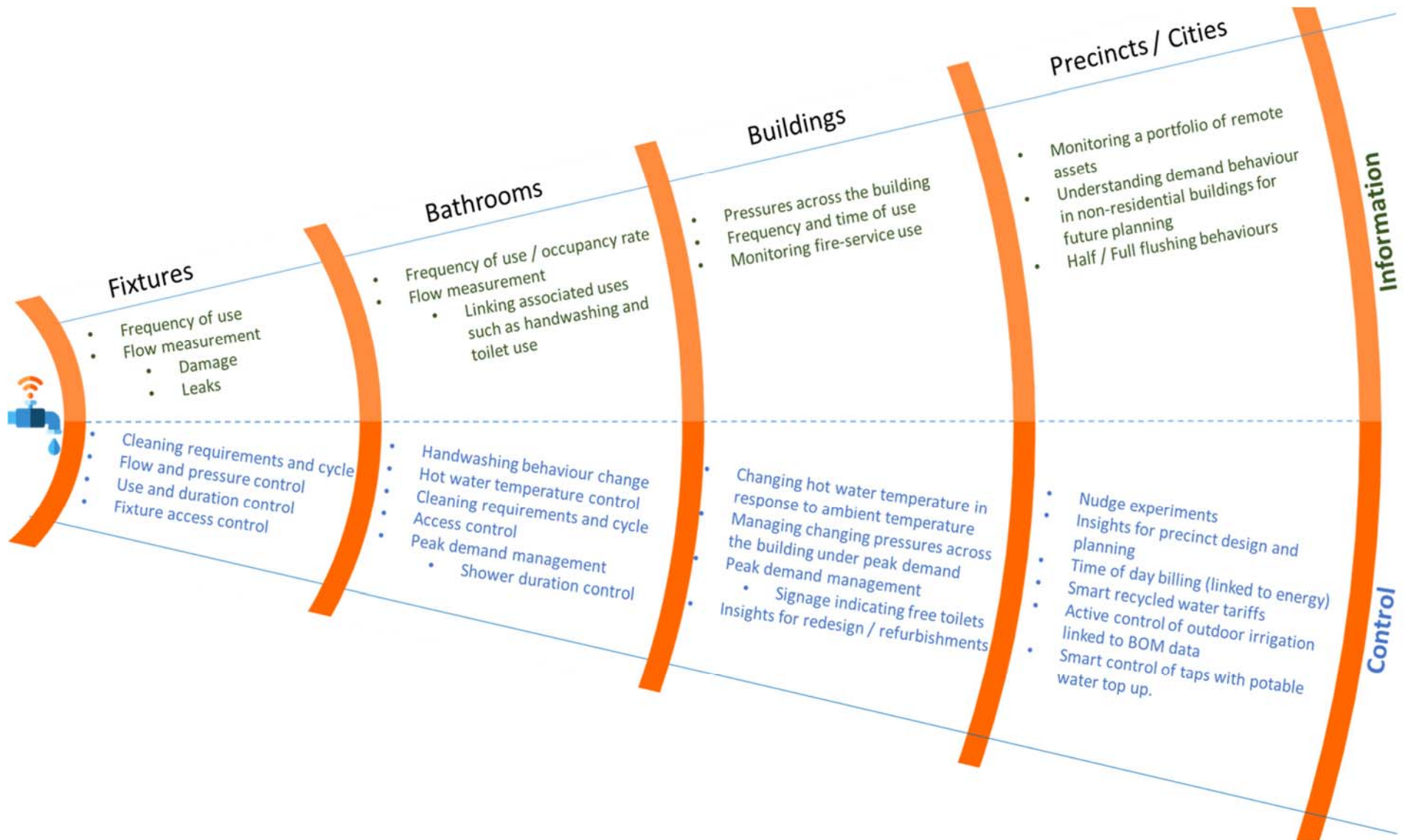


Figure 12: Bathroom data - Information and Control

6 Conclusions

The increasing use of data and control across fixtures and fittings has led to widespread efficiencies and advancements in facilities management and user experience. However, there has been limited adoption and integration in intelligent water using fixtures to date. Based on this review, it is clear that in the short-term digital fixtures in the bathroom could help provide water efficiencies through the faster detection and repair of problems and improved facilities management.

Drawing parallels with the lighting industry, it appears unlikely that water efficiency savings alone will justify broad-scale adoption. Due to the direct link between energy consumption and particularly hot water use, the ability to adapt and control temperatures and change behaviour in relation to hot water use provides consideration for further adaptations, to improve both user and environmental outcomes as well as financial savings.

Projecting into the future, collection of data and control of fixtures could provide benefits well beyond water efficiency of single fixtures and appliance or improved facilities management at a building scale. The ability to monitor and influence behaviour could provide benefits in a range of specialist applications, such as the health sector, peak demand for bathroom facilities, and general health behaviour change. In relation to planning at a city scale the collection of real-time end-use data for the non-residential sector and mixed-use buildings will allow for better planning outcomes at precinct and wider city scales.

To allow the full potential of digital fixtures to be realised, protocols and resources should be developed in order to manage the way data is collected, stored, transmitted, managed, analysed and integrated with other applications and data sets through the internet of things (IoT).

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Appendix 1. Processes of an intelligent monitoring system (modified from Boyle et al 2013)

Parameter	Measurement	Transfer	Processing/Analysis	Feedback
<i>Mode</i>	Water flow, pressure and data logger technology combinations used to capture information about water consumption and pressure in a network.	Means by which data is transferred from and from meters and loggers. Data is transferred via broadband, cable or wireless (e.g., radio, GSM, CDMA*). May be fully remote or require near range collection (e.g., via LoRaWAN network).	Means by which the data is stored (e.g., data servers) and analysed (e.g., end-use analysis software package).	Method by which data is provided to user/customers for interpretation, e.g., postal bill, email, web interface, smart phone application. Behaviour change may/may not ensue.
<i>Frequency</i>	The specified time intervals or number of pulses at which (i) activity is recorded by the meter; and (ii) data from the meter is collected by the data logger, e.g., 15 min intervals.	How often data is sent or collected e.g., daily, half hourly, “real-time”. This will vary depending on the type of meter, e.g., pulse versus interval.	The frequency at which this information is used to update u operations (e.g., for pressure management).	The frequency at which information is communicated to the user/customer (e.g., quarterly, monthly, daily, real-time, etc.).
<i>Resolution</i>	The granularity of the information (e.g., L/pulse) is determined by the purpose, capabilities and settings of the meter. The resolution of the recorded data will depend on the data logger, e.g., L/15 min (<i>i.e.</i> , frequency of measurement, above).	Resolution of data remains unchanged, though quality of data (<i>i.e.</i> , complete/partial) may suffer from disruptions to transmission process.	Data may be aggregated or manipulated to analyse trends (e.g., leak assessment; end-use analysis).	The level of detail of information provided to the user/customer, such as usage per unit of time and/or end use breakdown. Comparative framing and benchmarking may aid legibility and comprehension. Content and framing should be informed by behaviour change theory, information about target audience and tailored to the mode in question.

* N.B. CDMA = Code Division Multiple Access; GSM = Global System for Mobile communications—both are technology platforms for mobile/cellular telephones.