ISS-EWATUS

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ICT - Information and Communication Technologies

D3.2 Decision Support System at Household Level

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1.0	Kim Perren et al	30th Jan 2016	Initial Draft
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EXECUTIVE SUMMARY

This report is a deliverable of the Integrated Support System for Efficient Water Usage and Resources Management (ISS-EWATUS) Project funded through the 7th European Union Framework Programme for Research and Technological Development. It details the design and implementation of a Decision Support System (DSS) at household level. The DSS is an information system for monitoring household water consumption disaggregated by end use. On the basis of data retrieved, feedback and recommendations can be presented to households via a mobile application (app). By increasing awareness and promoting behaviour change, the implementation of the DSS is conceptualised as a water demand reduction intervention measure.

A previous deliverable (D3.1 'Data and practice models of water consumption at household level') detailed the construction of models of domestic water-related practice based on spatio-temporal and social scientific data. Chapter 2 of the current report outlines how these models informed the design of a behavioural intervention model for the DSS. By applying this behavioural intervention model, a suite of intervention strategies was compiled for inclusion in the DSS. Figure 3 (Section 2.2) links individual behaviour change strategies with the correspondent DSS function.

As illustrated in Figure 4 (Section 3.1.1) the DSS system consists of: a wireless water consumption measuring system; a local DSS; a DSS server; and external applications. This provides three water consumption feedback loops. In the first of these, the local DSS uses real-time and short-term spatio-temporal water consumption data to present instant feedback. In addition, the DSS server processes long-term spatio-temporal water consumption data as well as historic data from household water bills. Finally, external applications have the potential to harness social network power.

The tips service analyses the users' water use and provides water-related tips relevant to their situation (Section 3.2). These are predefined in the database and involve multiple behaviours. The display language of the generated tips is dynamically chosen.

Chapter 4 offers a user's view of the DSS and its functions. These include feedback on water consumption associated with individual appliances across various time frames. Users can set goals for reducing water consumption compared with their long term (baseline) average and monitor their progress. The WaterDiary function allows households to engage with the DSS by identifying usage associated with individual members. The Water User Classification Survey function presents consumers with a water user identity based on their self-reported behaviours, household appliances and concern for the environment.

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Chapter 1 Introduction

Work Package 3 (WP3) is tasked with developing and testing the effectiveness of a Decision Support System (DSS) for the efficient use of water at household level. The household DSS is conceptualized as a novel application (app) suitable for mobile devices. It will support residential consumers in modifying their water usage by providing near real time, fine grained feedback on their household consumption as well as information and tailored advice on water conservation. The developed application will be applied to encourage consumers to engage in 'low effort' behaviour modification in order to use water more efficiently. The ISS-EWATUS project involves the development of the household DSS and its subsequent trial in a real world setting.

As specified in the DoW, attainment of the first WP3 objective required a "detailed analysis of current domestic water related practice, identifying opportunities for reducing water consumption to ascertain how the use of ICT can be developed to support user-led water demand reduction". This forms the basis for the deliverable D3.1 - 'Data and practice models of water consumption at household level' submitted in 2015. The current deliverable addresses the second WP3 objective of designing a water demand reduction intervention approach that offers maximum impact potential. Table 1 identifies the task components associated with this objective. In addition, for each component, the table identifies: the scheduled end month; whether it is currently completed and the relevant section(s) of the current report.

Task	Description	End	Completed	Chapter/Section
3.3	Design of the intervention strategy	24		
	• Identify water intervention strategies from the data and practice models		Yes	S2.1
	• Generate a design behaviour intervention model			S2.2
3.4	Household DSS implementation and maintenance	36		
	• specify the functionality of the DSS		Yes	Chapters 4 & 5
	• design architecture based on hardware platform		Yes	S3.1-S3.3
	• implement the DSS on a mobile devices platform with a central database at the remote server		Yes	S3.1-S3.3
	• Lab testing of the DSS		Yes	3.4
	• Field trial of the DSS		No	-
	• Deploy the DSS in all the pilot households		No	-

Table 1. DoW requirements for attainment of WP3, second objective

Chapter 2 of the current report presents an account of the construction of a behavioural intervention model and the specification of a suite of intervention strategies selected for implementation in the DSS. Chapter 3 explains the DSS's design and architecture and Chapter 4 gives an account of its functions. Chapter 5 provides a summary.

Chapter 2 Design of the intervention strategy

In this chapter, we describe the results of the Task 3.3 related to the design of the intervention strategies. In designing an intervention, the specific user context needs to be addressed to identify empirical evidence of causal processes involved in water consumption and behaviour change. For the ISS-EWATUS project, data models were extracted from baseline spatio-temporal data. To complement this exercise, findings from social scientific fieldwork in the Polish and Greek intervention areas and were used to construct a practice model.

2.1 Practice model

A schematic diagram illustrating the practice model is given in Figure 1. The practice and data models are the subject of a previous deliverable (D3.1 'Data and practice models of water consumption at household level') and allied publications (Shan et al. 2015; Perren and Yang 2015; Yang et al. 2015).

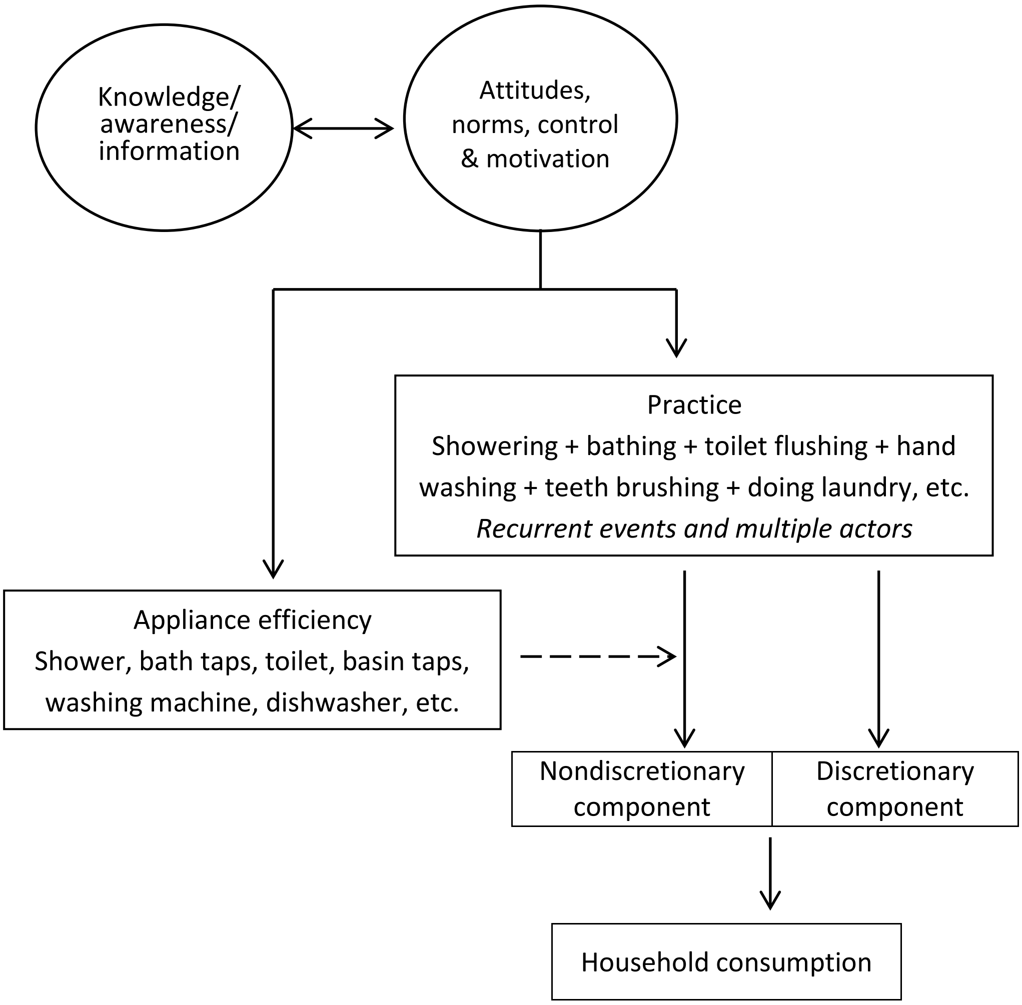


Figure 1 Framework for Practice model

At the base of the practice model is the outcome of ultimate concern for the intervention, i.e. household consumption; a reduction in this measure is a key performance indicator for the project. Household consumption is the sum of consumption from each end use site. For any given site, consumption derives from practice, i.e. recurrent events (e.g. flushing a toilet) performed by multiple actors. The target for the intervention thus becomes each water-related event performed by each household member.

Nondiscretionary consumption is conceptualized as the amount of water required by the household to function adequately while discretionary consumption is anything in excess of this. In any water conservation intervention, the discretionary component is a key concept as this is the share of water that has the potential to be saved. Household technology influences the nondiscretionary component of any water use event. Some homes are fitted with water efficient domestic appliances while others have older inefficient appliances; this will affect the amount of water required to carry out the same essential functions. This consideration is encapsulated in the 'technology efficiency' box in Figure 1 which is depicted as mediating the association between practice and the nondiscretionary component of consumption.

An intervention that takes no account of consumers' attitudes and social norms may demotivate them. For example, consumers may be encouraged to restrict themselves to a five minute shower once a day. Some may reject this proposition because, for them, showering is not just about 'getting clean' but has a multitude of other meanings. In addition, they may be concerned about how others would view them if they lowered their standards of personal care. Attitudes and social norms are, however, malleable. Educational campaigns that highlight problems of overconsumption may change perceptions of acceptable and desirable behaviour. In addition, practical information about ways to save water (for example how to source and fit tap aerators) may increase consumers' perception of control and therefore increase their motivation to save water. These considerations highlight the key role of the practice model in the construction of a behaviour intervention model.

2.2 Behavioural intervention model

The intervention design stage harnesses expertise from the domains of intervention design, software engineering and social psychology. The ISS-EWATUS intervention design team integrated findings from three major research components: 1) a review of behaviour modification theories and previous studies; 2) the user practice model and; 3) user data models. These three components required varied levels of research resources. The review of behaviour theories and previous research demanded the lowest level of resources while the development of data models demanded the highest. Resource levels impact upon the granularity that can be achieved by an intervention. Potential strategies were identified and brainstorming sessions were carried out to identify the technical feasibility of each strategy. Technically infeasible intervention elements were discounted. On the basis of these generating processes, a behavioural intervention model was proposed, as illustrated in Figure 2.

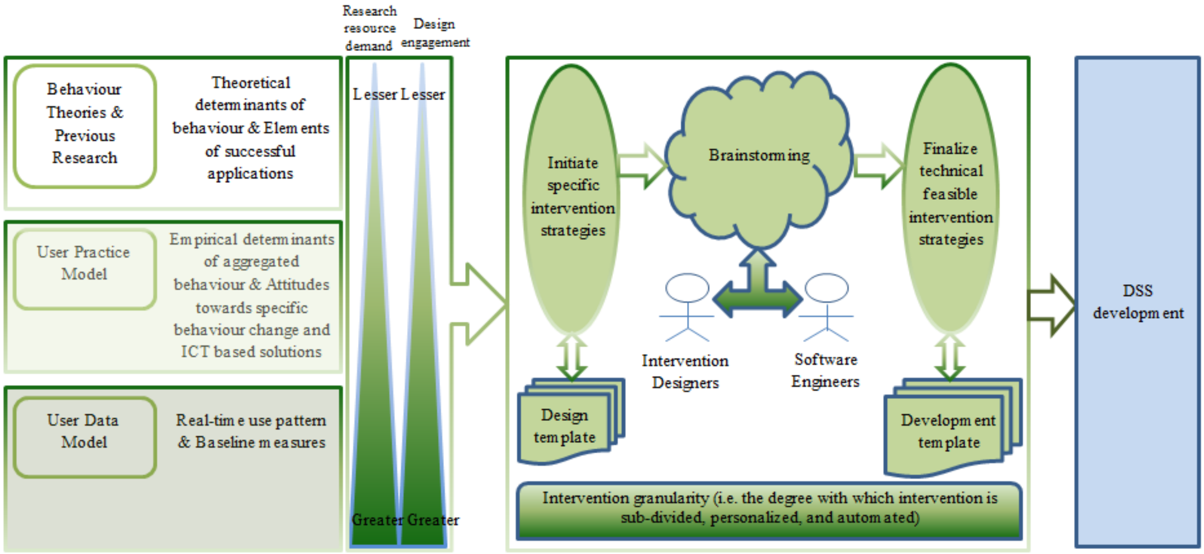


Figure 2 Behavioural Intervention Model for the DSS

For each of the retained intervention strategies, descriptions of correspondent functionality in the DSS were specified so that the development process could seamlessly transition from intervention designers to software engineers. Figure 3 identifies how the retained strategies informed the design of individual DSS functions. Each of the boxes on the left represents a retained strategy utilized within the DSS. These are linked to the specific DSS function (DSS screen) presented on the right.

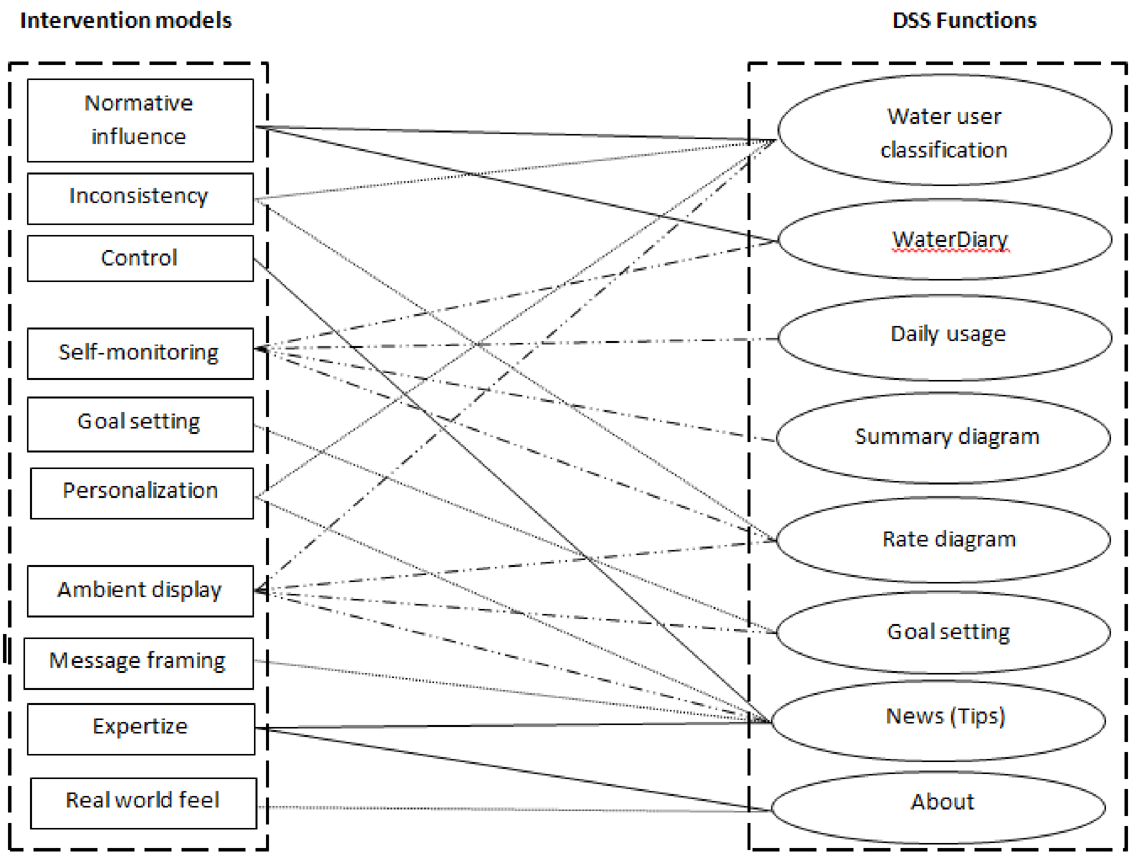


Figure 3 Implementation of Intervention model into the household DSS

2.2.1 Design templates

A design template served as a standard container for the intervention designer to synthesize findings and produce a solid, systematic and meaningful specification of the intervention strategy. Five dimensions of information were required for each strategy utilised, namely;

1. A unique **strategy name**;
2. An easy to understand **general description**;
3. **References** for the theoretical foundation of the strategy. These may derive from cases that have been successfully applied in other previous studies as well as the data and practice models from the ISS-EWATUS field studies;
4. A **functional description**, which outlines how the intervention strategy will be implemented in the DSS; and
5. A '**use case name'** which identifies the DSS feedback and advice functions associated with the strategy (as depicted in Figure 3). As The WaterDiary does not conclude with feedback or advice, the process is not defined for this function.

Strategy name: Normative influence
General description: Leverage normative influence or peer pressure to increase the likelihood that a person will adopt a target behaviour.
Reference from literature: Perceived social pressure to conform (subjective norm) is theorized to be a major driver of people's intention to perform a target behaviour. It is underpinned by beliefs about what different social groups would think of the individual if they engaged (or failed to engage) in the behaviour and the extent to which the individual cares about the perceptions of each group. Where individuals perceive that an important reference group wants them to behave in a certain way they feel pressure to conform. **Reference from practice model:** As part of our practice model, personal accounts obtained from our home interviews suggested that most interviewees cared about the opinions of their partner and parents.
Functional description: 1 The WaterDiary function allows household members to quantify their own consumption for each end use and to compare the consumption of different household members. **2** The water user classification function gives individuals feedback on what type of water consumer they are. Where a user perceives that their water user identity transgresses social norms they may be motivated to modify their behaviour.
Use case name: WaterDiary (see Section 3.1.6)
Use case name: Water user classification **This Use Case begins** when a consumer wants to find out what type of water consumer they are. **It performs the function of** classifying the user on the basis of their survey responses. **It concludes** when the water user classification is displayed.

Strategy name: Inconsistency
General description: Individuals experience psychological dissonance when they recognize an inconsistency between their attitudes and behaviours. This motivates them to reduce or eliminate the dissonance.
Reference from literature: Cognitive Dissonance Theory asserts that an individual who experiences inconsistency (dissonance) tends to become psychologically uncomfortable. This motivates them to try to

reduce this dissonance and to actively avoid situations and information likely to increase it. In particular, diaries have been used to trigger this psychological effect for the purpose of behaviour change (e.g., Hopko et al., 2003; Michie et al., 2008). **Reference from practice model:** As incorporated into our practice model, our field work found a gap between people's articulated behavioural beliefs and actual consumption behaviour. **Reference from data model:** Our data model is able to provide measures of a household's disaggregated water consumption.
Functional description: 1 Where current/recent consumption is greater than the benchmark, this may highlight an increase in discretionary consumption 2 Users who believe they have 'green' credentials may get feedback via the water user classification function that contradicts this, causing cognitive dissonance.
Use Case name: Rate Diagram display
This Use Case begins when a member wants to check his/her household's consumption level in comparison with its benchmark. **It performs the function of** showing the consumption eco-level of the last 7 days. **It concludes** when the consumption eco-levels are displayed.
Use case name: Water user classification (see Normative influence strategy)

Strategy name: Control
General description: Reducing the perceived difficulty of a task increases the likelihood that it will be performed.
Reference from literature: Theorists propose that perceived behavioural control (PBC) is positively correlated with an actor's intention to act in a certain way as well as their likelihood of actually doing so. PBC is underpinned by control beliefs, which relate to an assessment of specific barriers to, or facilitators of, an action; the likelihood that each will be present; and the extent to which each would affect performance of the action. Intervention strategies could influence water usage intentions and behaviours by reducing the difficulty of a task or by modifying people's perception of its difficulty. **Reference from practice model:** Our field studies suggested that PBC was positively associated with intention to engage in water saving behaviour as well as actual engagement in such actions in Greece. The lack of effect in the Polish context may be associated with the overall high level of control reported by Polish respondents compared with their Greek counterparts. This implies that the level of awareness of ways to save water may have an impact on whether PBC was significantly associated with intention and actual engagement in water saving actions. Accordingly, suggested water saving actions should be delivered with information on how the practice could be implemented.
Functional description: A database of water saving tips is embedded in the system. This offers information on actions that can save water.
Use case name: News display
This Use Case begins when a member want to check the tips list. **It performs the function of** showing the tips list. **It concludes** when the tips list is displayed.
Use case name: Tip display (within News display)
This Use Case begins when a member want to check a detailed tip from the tips list. **It performs the action of** showing the tip selected. **It concludes** when the tip is displayed.

Strategy name: Self-monitoring
General description: A system that keeps track of one's own performance or status supports the user in achieving his/her predetermined goals.
Reference from literature: Self-monitoring makes it easier for people to know how well they are performing the target behaviour, increasing the likelihood that they will continue (Fogg 2002; Oinas-Kukkonen and Harjumaa 2009). This is particularly important for promoting pro-environmental behaviour as, in this context, infrequently making a poor or arbitrary decision on behaviour is seldom a disaster; rather it is a pattern of such decisions that typically prevents the achievement of long-term lifestyle change (Consolvo et al., 2009). **Reference from data model:** Our data provide measures of a household's water consumption. Data models also confirm the existence of water use routines.
Functional description: 1 Users can check their household's total and end use water consumption whenever they want. 2 Users can check their personal consumption using the WaterDiary.
Use case name: Daily Usage display
This Use Case begins when a member wants to check his/her household's water consumption for each monitored fixture across the last 23 hours. **It performs the function of** showing household water consumption for each monitored fixture across the last 23 hours. **This use case concludes** when the requested information is displayed.
Use case name: Summary Diagram display
Summary **This Use Case begins** when a member wants to check his/her household's water consumption broken down by individual fixtures across a longer period of time. **This Use Case performs the function of** showing water consumption for individual monitored fixtures. There are three modes of this display: daily across the last week; weekly across the last four weeks; and monthly across the last three months. **This Use Case concludes** when the requested information is displayed.
Use case name: Rate diagram display (see Normative influence strategy).
Use case name: WaterDiary (see Section 3.1.6)

Strategy name: Goal setting
General description: Goals encourage behaviour change by acting as a reference point for a future desirable state.
Reference from literature: Goal-setting theory asserts that conscious goals affect action (Locke and Latham, 2002). The more specific the goal, the more precisely performance is regulated. Where there is a high level of commitment, goals that are both specific and difficult lead to the highest performance. High commitment occurs when the individual believes that the goal is important and attainable (or that, at least, progress can be made toward it); these factors also influence goal choice. Self-set goals can be highly effective, although they may not be as ambitious as those assigned by another person. Feedback acts as a moderator of the goal-performance relationship. Goal setting is most effective when there is feedback showing progress in relation to the goal.
Functional description: The DSS allows users to specify a goal for reducing their household's total water consumption compared with its benchmark (e.g. 20% less). The benchmark reflects mean baseline consumption (i.e. for the period when sensors monitored consumption but prior to the ICT intervention). DSS

translates this goal into consumption goals (in litres) for a week and month. Alongside these goals, feedback is presented on household total water consumption across the previous 7 and 30 days.
Use Case name: Goal setting display
This Use Case begins when a member decides to set a water consumption reduction goal. **It performs the function of** allowing a household member to set up a weekly and monthly goal by choosing a pre-set level of consumption reduction. **Actions performed by the system** 1 The system provides average daily consumption options for the member to select in setting his/her goal. These are produced on the basis of the calculated consumption benchmark. 2 The system updates the visualization of the household's weekly and monthly goal once a new daily consumption goal is set. **This Use Case concludes** when a different consumption goal is selected by a household member.

Strategy name: Personalization
General description: A system that has personalized content is more persuasive.
Reference from literature: Oinas-Kukkonen and Harjumaa (2009) argue that personalized services can make people think the system understands their situations and is working to help them achieve their goals. Users offered personalized content are more likely to perceive the system, and the people behind it, to be trustworthy. In addition, when a system has the capability to tailor content, people will view the system as smarter, boosting expertise perceptions. **Reference from data model:** Our data model is able to provide near real-time measure of household's water consumption. This makes possible the implementation of personalized advice (in the form of tips) to users.
Functional description: 1 The DSS provides personalized tips to users regarding their water consumption patterns (e.g., the user whose water habits are non-optimal is identified and reported) 2 The water user classification function offers feedback that is personalized for the user.
Use case name: Tip display (see Control strategy).
Use case name: Tips list display (see Control strategy).
Use case name: Water user classification (see Normative influence strategy).

Strategy name: Ambient display
General description: Information provided ambiently can subliminally influence use.
Reference from literature: The appropriate use of ambient display can make consumption visible and thereby prompt awareness of use (DiSalvo et al. 2010). Strengers (2011) used a green, red and orange traffic light display to indicate electricity consumption. It was found that the display could serve as a normative benchmark for acceptable and unacceptable electricity consumption for the household, and was the most effective form of in-home display feedback. Ham and Midden (2010) also found that a light colour change (where more green = lower energy consumption, and more red = higher) led to greater conservation than numeric feedback.
Functional description: 1 In the Rate diagram display a household's daily water consumption is categorized into 7 levels on the basis of its benchmark. Levels are visualized with changing colours from deep green (at least 30% lower than benchmark) to deep red (at least 30% higher than benchmark). This visualization is more meaningful and intuitively understandable than numeric feedback (e.g. litres), which increases the persuasiveness. 2 In the goal setting display the comparison between the household's weekly/monthly water

consumption and its weekly/ monthly goal is visualized through red/green background colours, with red indicating that current consumption exceeds the goal, and green indicating the opposite. 3 In the water user classification feedback, high water consumption positions are coloured red and low consumption is coloured green; intermediate is coloured yellow. 4 News tips are colour coded with red and green backgrounds.
Use Cases
Use case name: Rate diagram display (see Normative influence strategy).
Use case name: Goal setting display (see Goal setting strategy).
Use case name: Water user classification (see Normative influence strategy).
Use case name: Tips list display (see Control strategy).

Strategy name : Message framing
General description: The way a message is framed affects the amount of persuasion it elicits.
Reference from literature: Rothman and Salovey (1997) proposed that whether a gain- or loss- framed message will be more effective depends upon whether the behaviour described is perceived to involve risk, threat, or uncertainty. A gain-framed message emphasizes the benefits of engaging in the behaviour. It should be most effective in promoting behaviours associated with safety and certainty, as people tend to avoid risks in the face of potential gains. In contrast, a loss-framed message emphasizes the costs of not engaging in the behaviour. It would be most effective in promoting behaviours when involving potential risk or uncertainty, because people are relatively open to taking risks when faced with potential losses. Colour can communicate specific information, the meaning of which depending on the situation or context (Elliot et al., 2007). Red primes the threat of a failure due to learned associations with warning labels, traffic signals and threat advisory systems (Wogalter, Conzola, and Smith-Jackson, 2002). We hypothesize that these effects will hold in sustainable HCI context. In addition, we further hypothesize that green colour primes the safety of a status, and the combined effects of gain-framed message and green colour would boost the effectiveness of persuasion.
Functional description: The tips provided by the DSS are divided into two categories (i.e. gain-framed and loss-framed). Gain-framed message are presented with green background colour, while loss-framed message are presented with red background colour.
Use case name: Tip display (see Control strategy).

Strategy name: Expertise
General description: A system that is viewed as incorporating expertise will have increased powers of persuasion.
Reference from literature: The strategy of embodying expertise cues into an information system has been identified as a key principle for system credibility support Oinas-Kukkonen and Harjumaa 2009). **Reference from practice model:** Interviewees in Poland reported that they would value the opinion of experts with regard to conserving water and energy around the home.
Functional description: A database of education tips is embedded in the system to educate users on the environmental impact of water usage. Many tips demonstrate expertise (e.g., the cost of producing potable water).
Use case name: Tips list display (see Control strategy).
Use case name: Tip display (see Control strategy).

Strategy name: Real-world feel

General description: A system that highlights the people or the organization behind its content or services will have more credibility than one that does not.
Reference from literature: Oinas-Kukkonen and Harjumaa (2009) claim this is a key principle for information system credibility support. The Stanford Web credibility surveys found that elements which allow people to contact a Web site source increase perceptions of web credibility; the more direct the contact, the better. This openness shows users that real people are behind the Web site – people who can be reached for questions, comments, or complaints.
Functional description: The DSS provides information on the organizations which funded and conducted the relevant research and system development.
Use case name: About display
This Use Case begins when a member wants to check background information of the system **It performs the function of** showing the background information of the system (e.g. the research institutes that developed the system, organizations that funded the project). **It concludes** when the background information is displayed.

Chapter 3 DSS design and architecture

An overview of the DSS design is presented in Section 3.1. Section 3.2 expands upon the architecture of the Tips Service and Section 3.3 outlines the design of the WaterDiary. Details of the verification of the DSS are provided in Section 3.4.

3.1 DSS structure

The Decision Support System (DSS) at household level is a data gathering and information system designed to promote efficient water usage among residential consumers. At the current pilot stage of the project, sensors have been attached to water appliances (such as kitchen taps and washing machines) in volunteer homes. The home WiFi system sends data collected by these sensors to a remote server which records the water flow rate and water temperature associated with each appliance. A tablet computer has been deployed in each home. This tablet, or other mobile devices, will provide access to a novel app which offers feedback on the household's water use. The app allows users to view their household's water consumption, broken down by appliance, across the past 24 hours or at a daily, weekly or monthly level. Users can set themselves a target for reducing their overall water consumption and the app will give them feedback on their progress towards this goal. A key component of the DSS is a news function which provides personalised information on saving water around the home. Bespoke tips are generated in response to the household's recent, as well as predicted, water consumption. The graphical format of the DSS display has been designed to appeal to children as well as adults. To complement the automated feedback, a water diary function is provided to encourage households to come together and identify the water consumption associated with individual household members. An additional function uses information on a user's showering and laundry habits, and household appliance efficiency, to highlight where a consumer's water use practices do not align with their level of environmental concern.

3.1.1 DSS Architecture

The overall DSS system components are illustrated in 0. It consists of four parts: a wireless water consumption measuring system; a local DSS; a (remote back-end) DSS server; and external applications (third-party add-on services such as social network functions). This architecture provides three water consumption feedback loops:

- The local DSS uses real-time and short-term spatio-temporal water consumption data to present instant feedback.
- The DSS server processes long-term spatio-temporal water consumption data as well as historic data from household water bills. A water consumption benchmark is constructed using spatio-temporal water consumption data.
- External applications will harness social network and community power.

A content aggregator pattern is employed to simplify implementation and increase flexibility. The local DSS, DSS server and third-party applications are designated as content sources. The local DSS also performs an aggregator function by aggregating content from these sources and interacting with end users. A dedicated tablet is designated as the primary device for hosting the local DSS for pilot households. However other devices are not ruled out and household members could access the local DSS via a PC, laptop or smart phone.

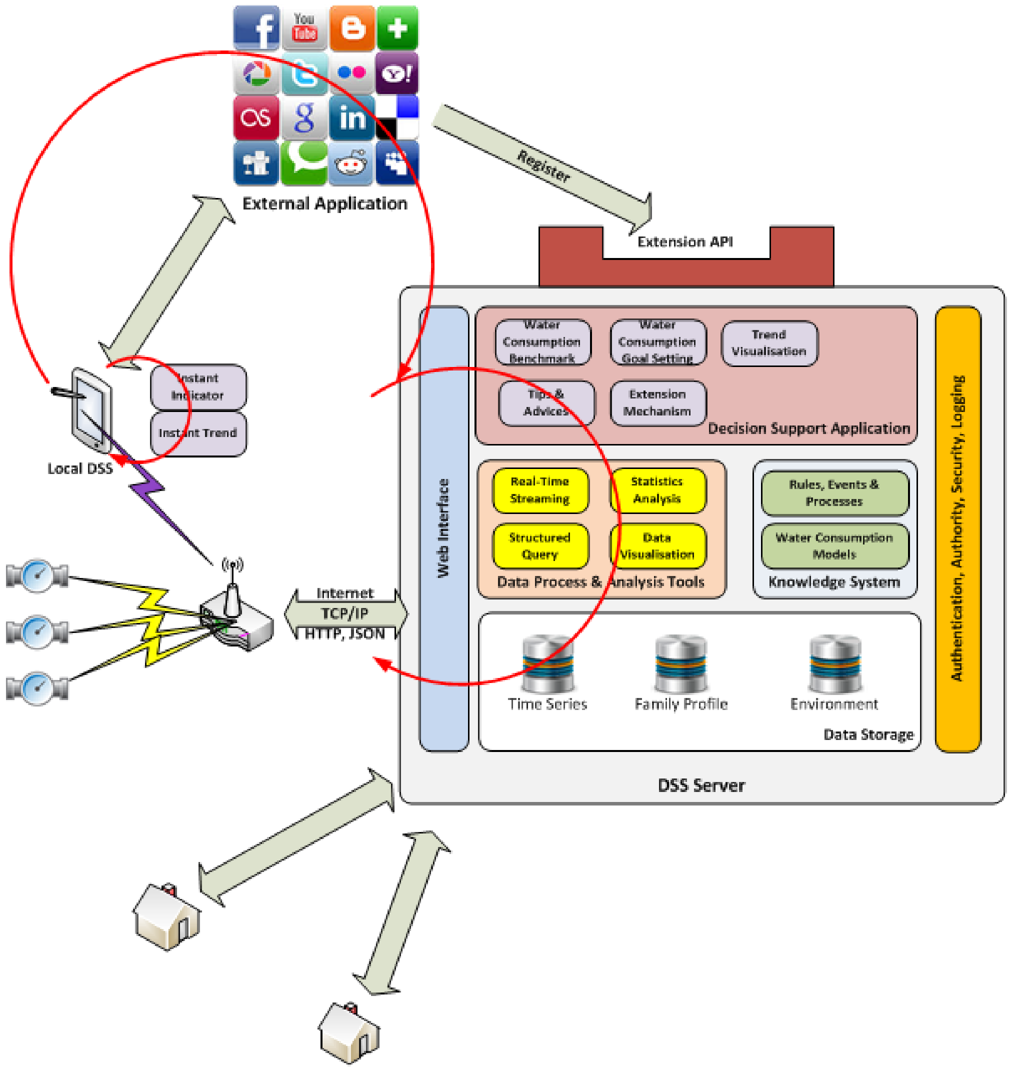


Figure 4 DSS System Architecture

3.1.2 Local DSS Navigation Model

0 illustrates the local DSS content pages which comprise the front end for end users. The configuration page can be used to customise the local DSS for the individual household; currently, this function is not utilised. The real time graph is generated locally while other pages are retrieved from remote content sources. The local DSS can be extended dynamically with the construction of new pages.

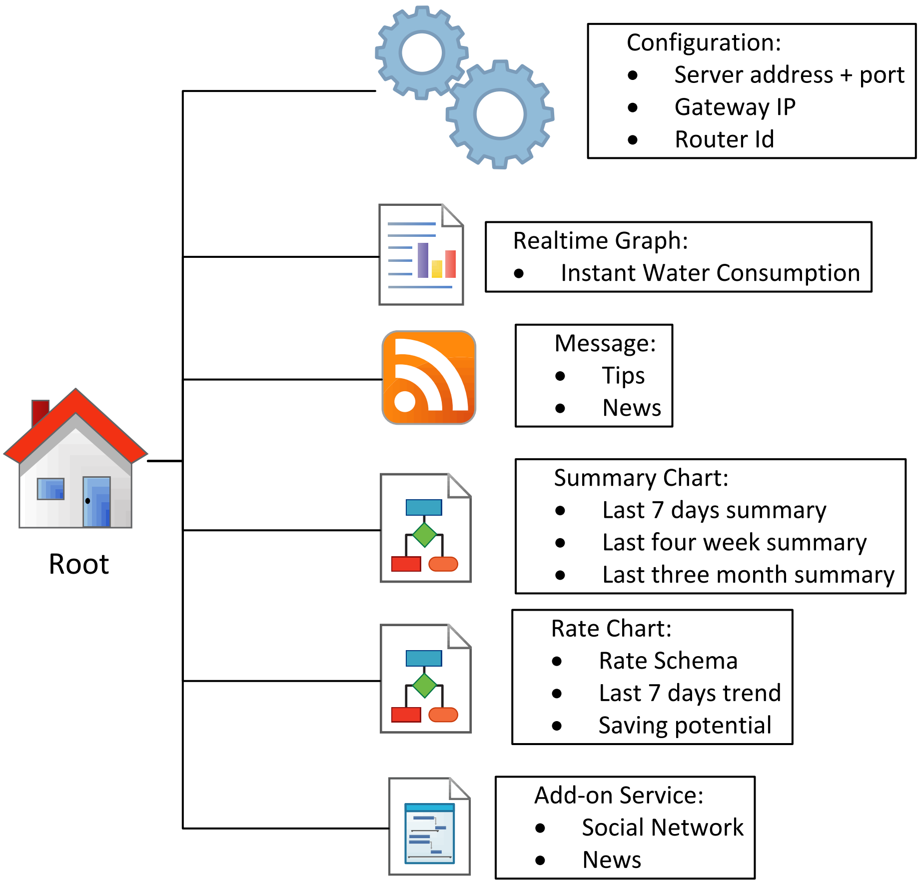
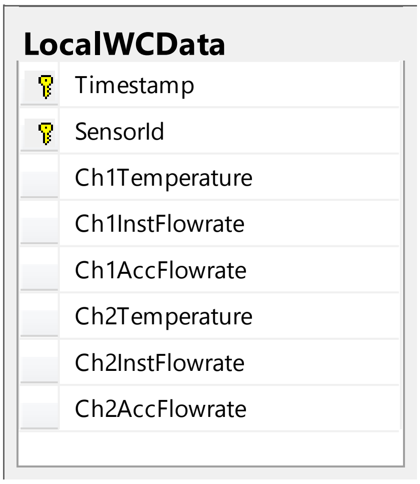


Figure 5 Local DSS navigation model

3.1.3 Data Model

The screenshot below illustrates the data schema for the local DSS to store the last 24 hours' data. Local storage is used to provide the data for the local DSS content generation.



3.1.4 Local DSS Server Implementation

The local DSS has been implemented on the designated tablet.

3.1.5 DSS Server

The (remote back-end) DSS server stores, processes and analyses data. On the basis of this analysis, its knowledge system and decision support applications produce content for the local DSS and support DSS functionalities.

3.1.6 Data Storage

Data storage tables can be classified as relating to household profile, water consumption or technical features (Figure 6). A profile of the household is stored in *Family Profile*. *WCData* stores time-series water consumption data disaggregated by sensor while *WCMeasureType* identifies the associated end use. Household DSS parameters are described in *DSS_Param* while *WCRouters* records the current status of each router. Tables are linked via a unique *RouterId* key.

These data are stored on a (remote back-end) server. In order to demonstrate that the DSS is flexible in terms of data sources, two types of water consumption monitoring system were installed as part of Work Package 2 (Data acquisition and structuring). The first is based on devices designed and provided by Loughborough University as part of the ISS-EWATUS (LU monitoring system) and the second is based on smart water meters provided by the Apator Company (Apator system). Both monitoring systems transmit data in near real time to the ISS-EWATUS spatio-temporal database to make them available for further processing and use in the household DSS. The purpose of using two different systems was to ensure that the DSS is capable of using different data providers, i.e. it is not limited to one type of water consumption monitoring system.

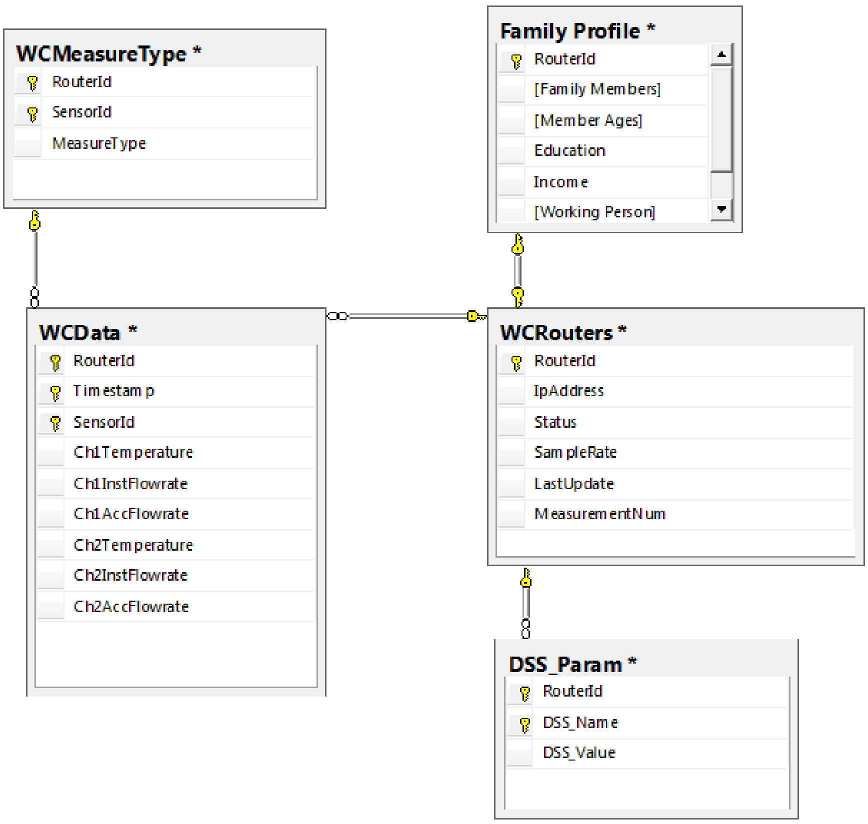


Figure 6 Data Schema of DSS Server

3.1.7 Process Model

07 illustrates the process model which describes the interaction between the local DSS and the network gateway to the DSS server. The local DSS will initiate the interaction by registering with the gateway. This will initialise the local content on the basis of long-term data. Initially, short-term and instant feedback (e.g. the real-time chart) will be based on long-term data. However, as soon as the local DSS receives local data, the local content and short-term and instant feedback will be updated. Periodic receipt of local data will trigger an update of the short-term and instant feedback.

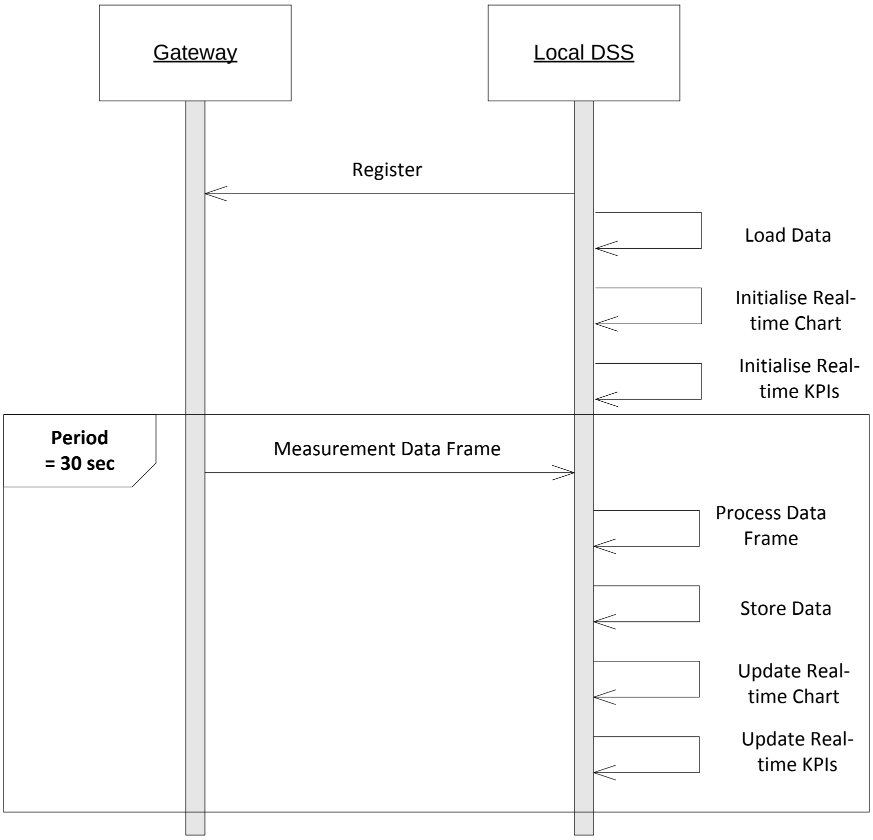


Figure 7 Real time data process diagram

3.1.8 Data Flow and Processing

Figure 8 illustrates the data flow of the DSS among the classes that implement the data stream processing. *DataServer* is the main implementation class. It utilises *DataProcessor* to process the incoming data frame and *DataSaver* to save the processed data item. The whole process is illustrated in Figure 9.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [619228]

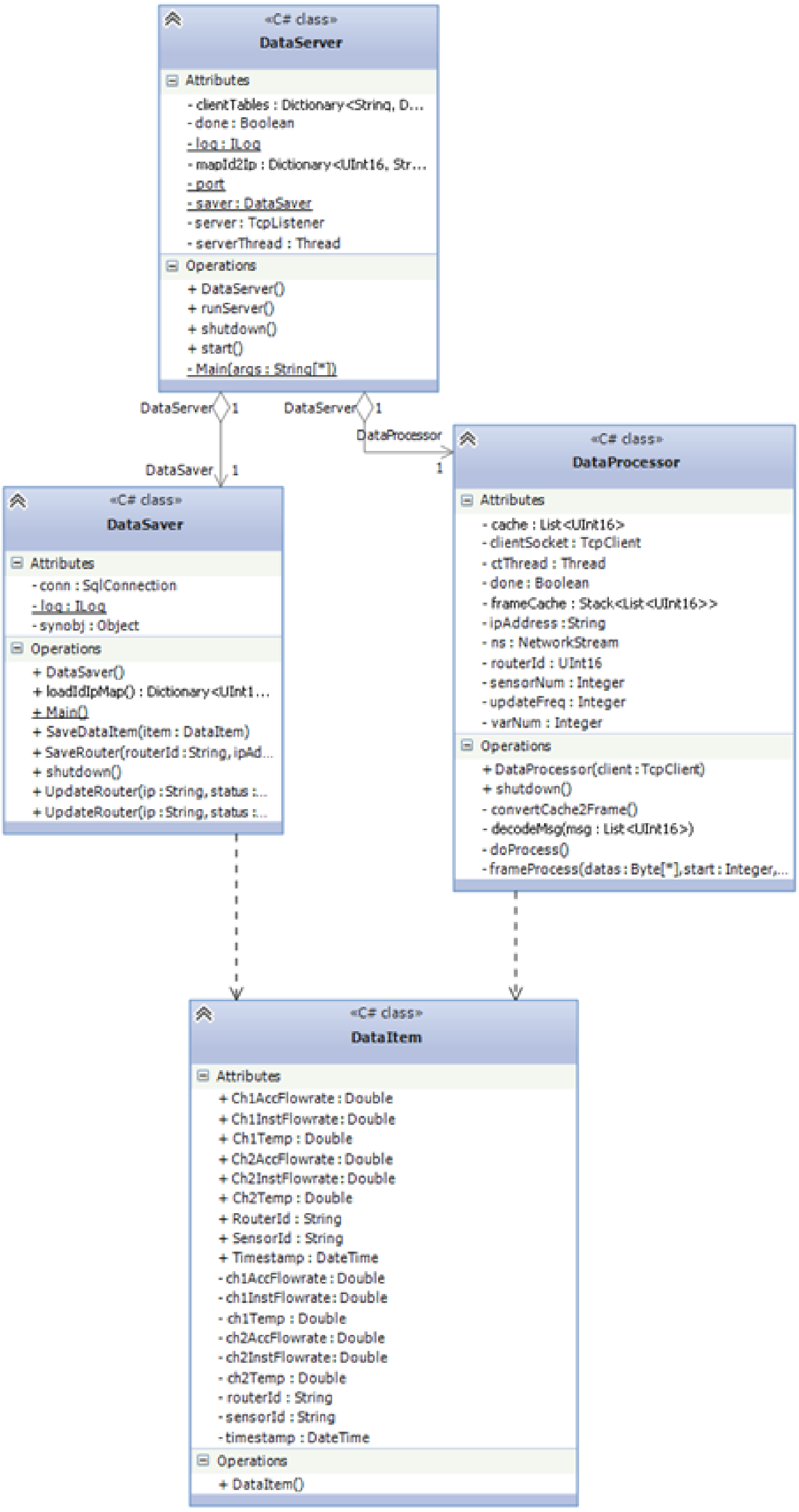


Figure 8 Class Diagram of Data Server

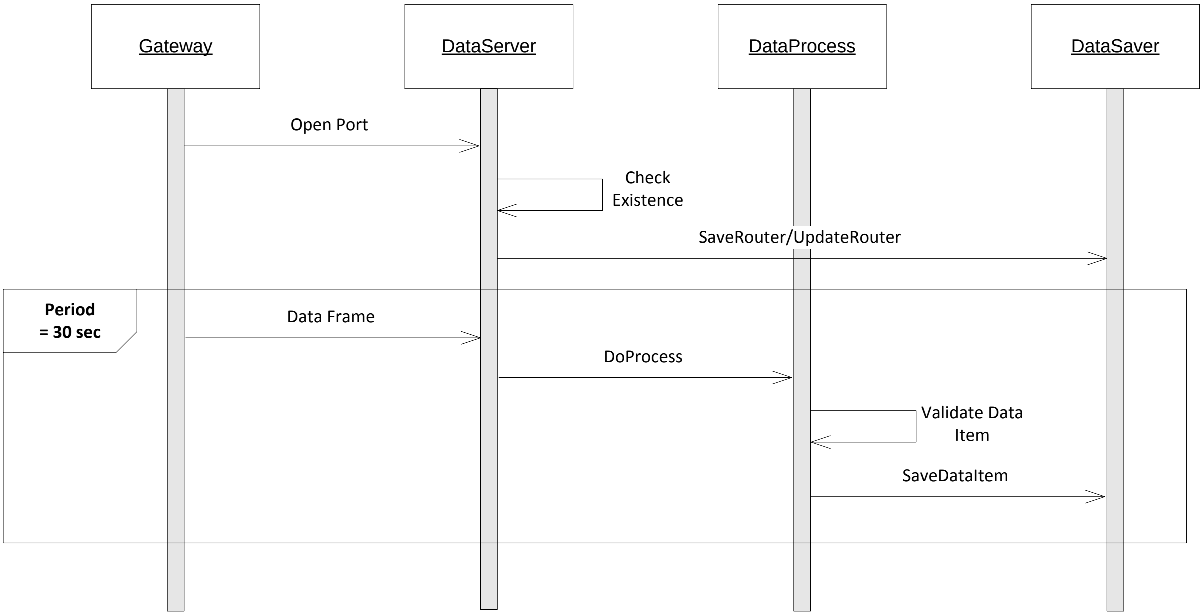


Figure 9 Process Diagram of Data Streaming

3.1.9 DSS User Interface Component Generator

The DSS user interface component generator has adopted a Model-View-Controller (MVC) implementation pattern (Figure 10) where user interface components are "View", logic algorithms are "Controller", and data storage is "Model". View transfers instructions to the controller, the controller requires the model to change the state after completion of the logic, the model sends the new data to the view and finally the users receive a dynamic interface. This separates the development into interconnected parts reflecting the logic concerns.

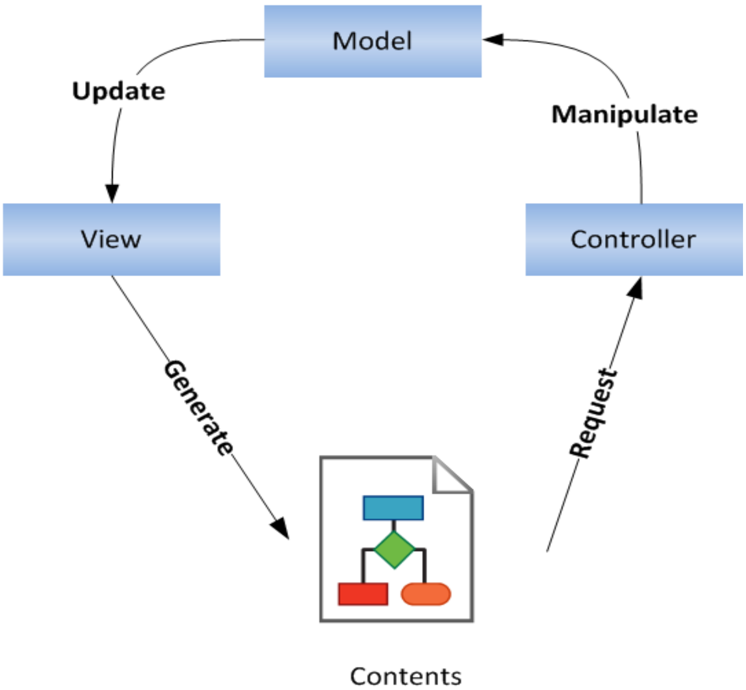


Figure 10 Model-View-Controller Pattern

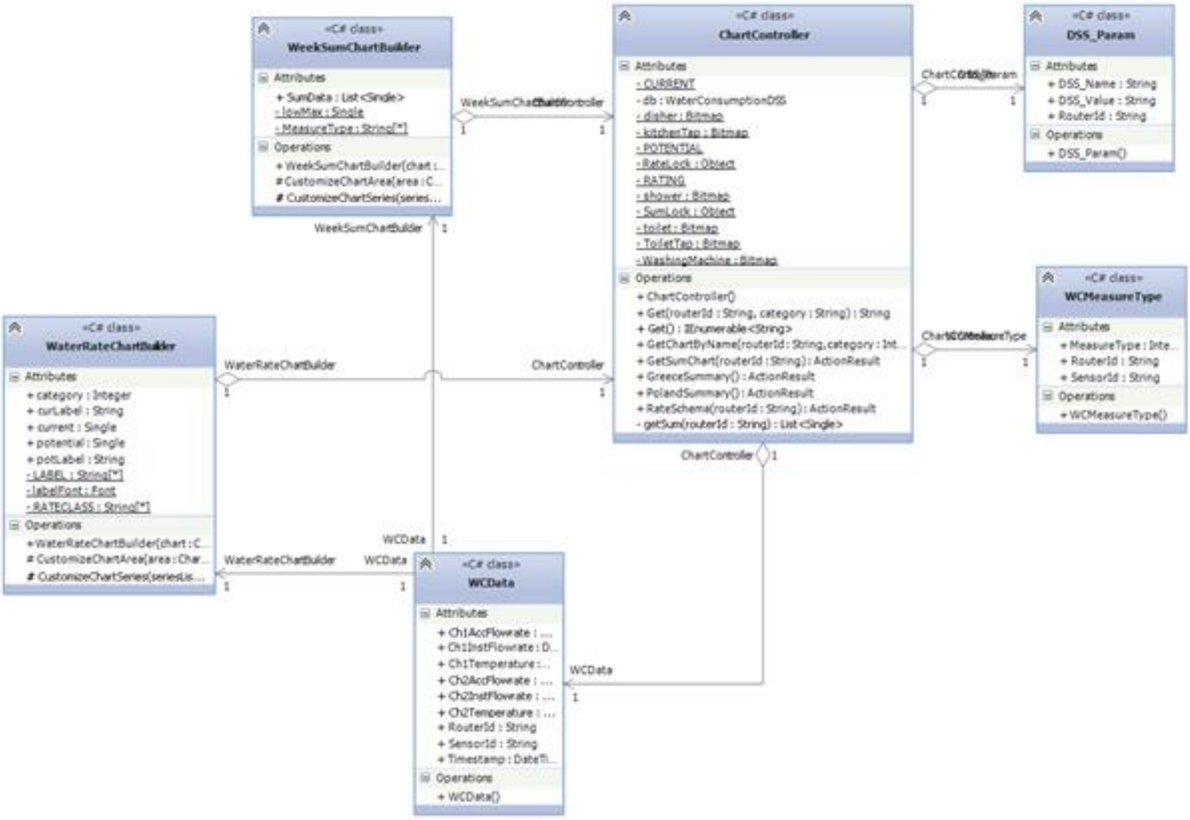


Figure 11 Class Diagram of DSS Applications

The implementation of the DSS user interface component generator is illustrated in 11. The DSS user interface component generator mainly provides charts, which demand substantial processing resources in terms of storage capacity, memory and computing power. The design utilises the server's potential without compromising the local DSS response. The communication protocol is based on standard web protocols. Table 2 presents a summary of interval implemented items on the basis of the MVC pattern.

Controller	Action	View	Model	Function Description
Chart Controller	Multi Summary Get Sum Chart	MultiSummary.cshtml	WC Data WC Measure Type	Providing the daily, weekly and monthly summary charts of water consumption
	Rate Schema Get Chart By Name	RateSchema.aspx	WC Data DSS_Params	Rating individual home daily water consumption
	Self Goal Set Goal	SelfGoal.aspx	DSS_Params	Allowing the householder to set their own water conservation target
DSS Params Controller	Get	N/A	DSS_Params	Providing the customisation parameters for the individual home (e.g. additional tabs) and messages. This is not currently functional.

Table 2. Summary of Model-View-Controller items

3.2 Tips service

The tips service is a component of the Household DSS providing the ability to generate water-related tips. These tips are predefined in the Database and involve multiple behaviours of the users. The whole Tips generation service consists of:

1. Additional tables for the DSS
2. Java-based application serving the purpose of a scheduler and tips generator
3. R-project scripts implementing sophisticated water-usage models

The tips service as the name suggests, works as a service which at specified periods of time analyses the water usage from the users and provides them with tips. The tips are generated using:

1. SQL queries analysing the water usage directly using the Database
2. R-project scripts which compute the ARIMA models
3. Java based Linear Regression

The display language of the generated tips is dynamically chosen for each user. The end-user is presented only with tips which are relevant to their situation (e.g. if someone uses too much water during a shower, they will be presented with shower-related tips).

3.2.1 Tips service model

The tips service class diagram is presented in 0 and 0. Basically, the Tip class serves as a part of Object-Relation-Mapping (ORM). It directly reflects the Tip table in the database. The Tip class is also provided with methods to conveniently manipulate the contents of the database from the Java source files. The JobAbstract class represents the different types of Tips Jobs (that is, different ways to generate tips). The LinearRegressionJob, LogicalRegressionJob, RscriptJob and SqlScriptJob classes provide specific methods and ways to generate tips from which methods their name derives. The PurgeJob is the special case of a job which purges the assignment of tips to users daily (in order to provide new tips every day).

3.2.2 Tips service database structure

The Tips Service additional tables include:

1. WCTips table, which stores the tips itself. The tip is translated into three languages. Each tip has a title and a description. Additionally, each tip belongs to one of the predefined categories. A future plan is to use data mining techniques (e.g. clustering) in order to identify users who are then shown tips from a particular category.
2. WCData which is a common table for all the household sensor data.
3. RouterAssignTip is a table which stores the connection between Tips and Households. Every record stored in here corresponds to one tip displayed on the tablet application in a particular household.

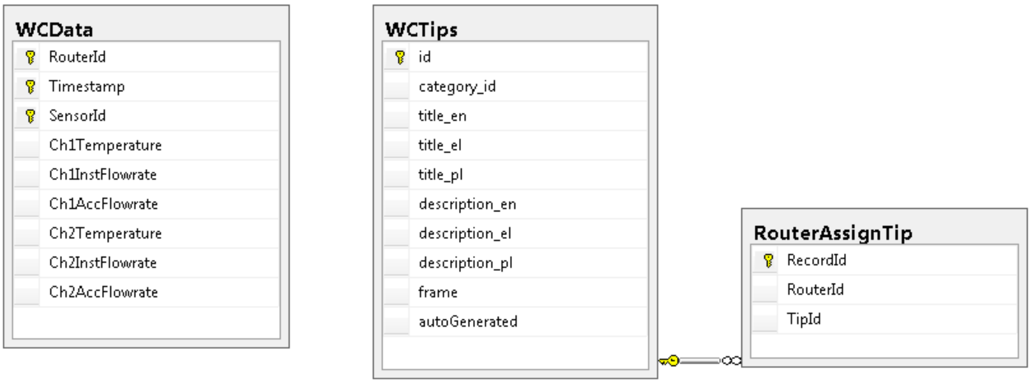


Figure 12 Tips service database tables

3.2.3 *Tips service processing*

The tips service uses the existing Database to get current and historical water usage data for each and every household. These data are then analysed using methods described previously (R-scripts, Java-based regression models, SQL-based queries) in order to assign different tips to different household users. Because of the complexity of some of the computations, the R statistical language was used. 0 shows the sequence diagram for this part of the DSS.

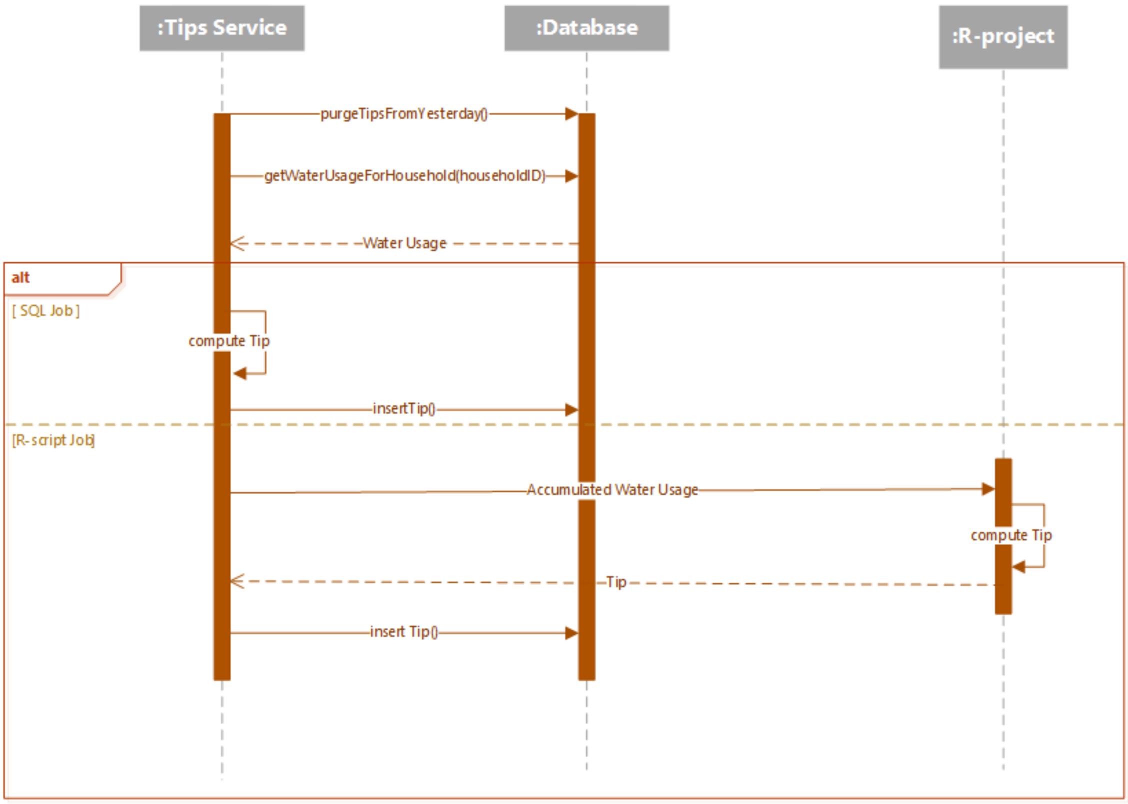


Figure 13 Sequence diagram for Tips Service

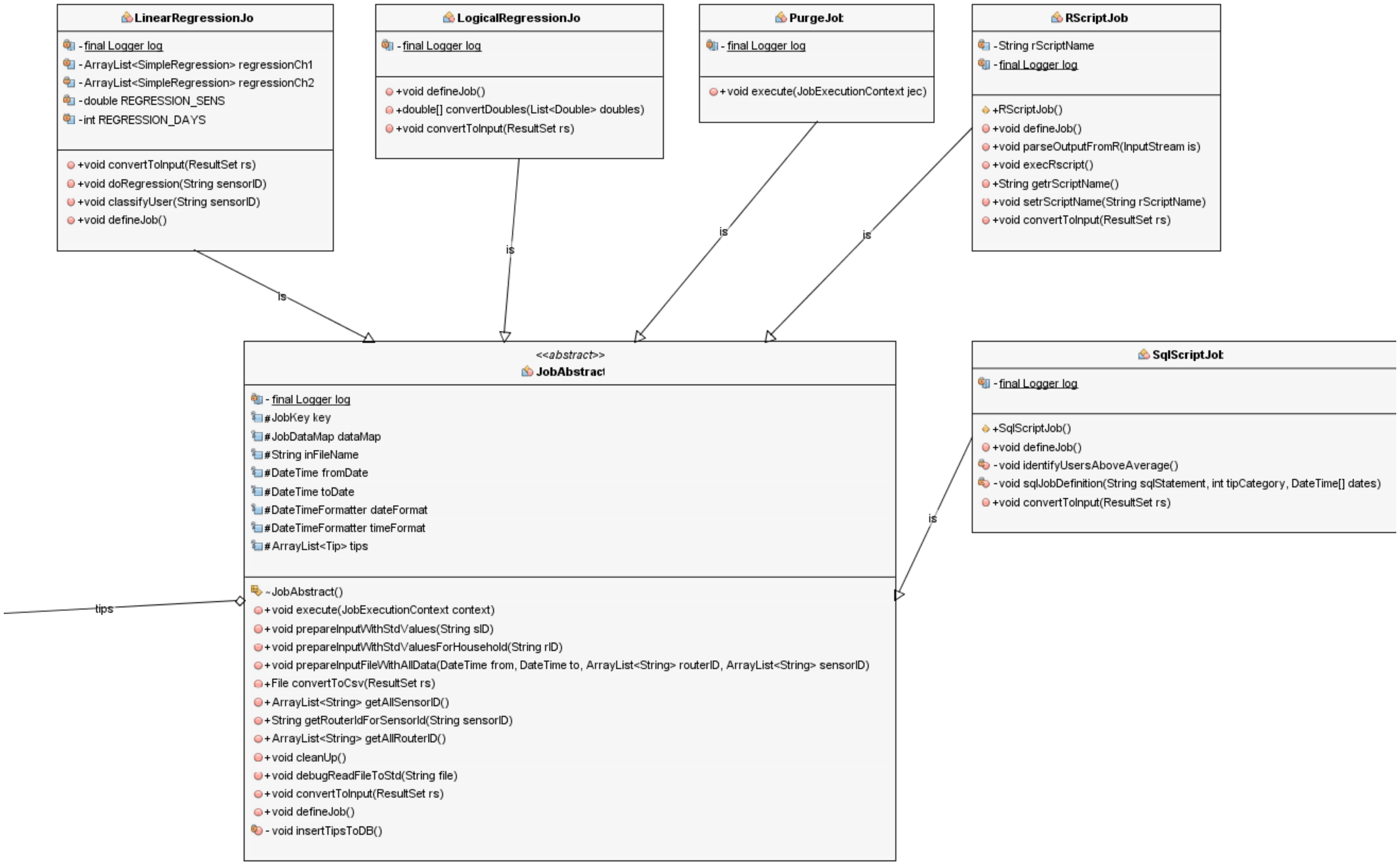


Figure 14 The class diagram for Tips Service (part 1 of 2)

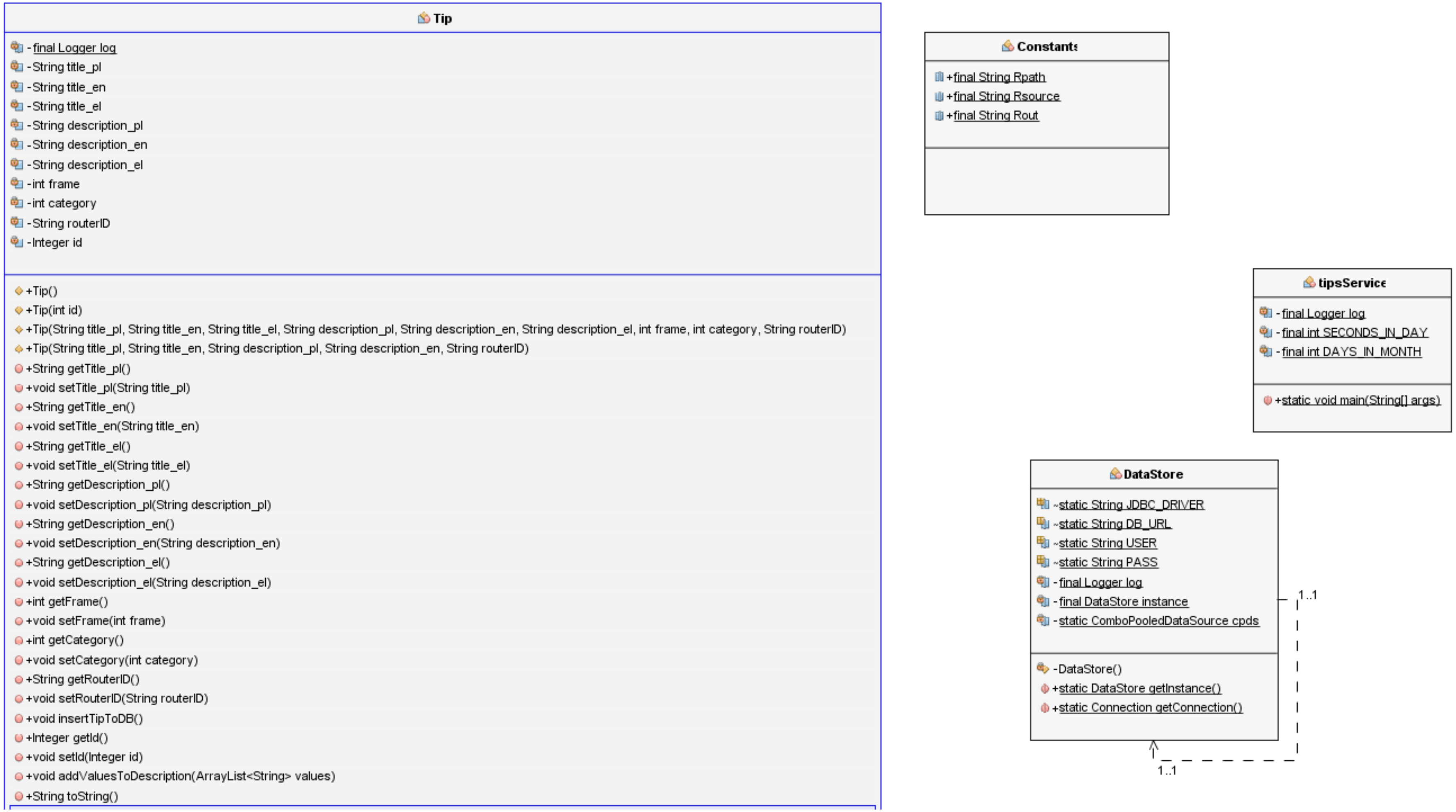


Figure 15 The class diagram for Tips Service (part 2 of 2)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [619228]

3.2.4 Technical description

The tips service framework utilizes the self-made job Scheduler based on Quartz Scheduler[1]. First, the tips mapping for users is erased to ensure that old tips are not shown to the user every day. The service then looks for all methods of tips generation previously mentioned:

```
public class PurgeJob implements Job {

    private static final Logger log = LogManager.getLogger("PurgeJob");

    @Override
    public void execute(JobExecutionContext jec) throws JobExecutionException {
        String sql = "DELETE FROM  WaterConsumption2.dbo.RouterAssignTip";
        try (
                Connection connection = DataStore.getConnection();
                Statement statement = connection.createStatement()) {
            statement.executeUpdate(sql);
        } catch (SQLException ex) {
            log.error("Error purging tips assignment table");
        }
        sql = "DELETE FROM  WaterConsumption2.dbo.WCTips WHERE autoGenerated=1";
        try (
                Connection connection = DataStore.getConnection();
                Statement statement = connection.createStatement()) {
            statement.executeUpdate(sql);
        } catch (SQLException ex) {
            log.error("Error purging tips table");
        }

    }
}
```

After successfully purging the mapping of the tips, the service itself starts the job. Every job (understood later as the method of tips generation) is started in a similar way:

```

JobDetail job1 = newJob(SqlScriptJob.class)
                    .withIdentity("sqlScriptJob", "SqlTipsGroup")
                    .usingJobData("period", SECONDS_IN_DAY * 30)
                    .build();

```

The respective options which are passed to the constructor of the class include:

1. Identity, which allows the constructor to properly identify the jobs later on.
2. JobData, which is a map of parameters necessary to properly run the scripts. These include:
    a. Period of the input data. Because of the need to improve the effectiveness of the service, the generation of tips is usually computed using only part of the household data. This assumption is valid because the tips should be based upon the most recent user behaviour rather than a historical one.
    b. RScript name, which is the full path to the R-script

Each job is then passed to the Trigger class which is responsible for the scheduling part of the tips generation:

[1] https://quartz-scheduler.org/

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [619228]

```
Trigger tipsSqlTrigger = newTrigger()
        .withIdentity("tipsy1", "SqlTipsGroup")
        .startNow()
        .withSchedule(simpleSchedule()
                .withIntervalInSeconds(120)
                .repeatForever())
        .build();

```

The mapping of the tips commences. By using all the available methods (see the class diagram description) the WCTips and RouterAssignTip tables are populated. For example, the SQLScriptJob definition is as follows:

```
private void sqlJobDefinition(String sqlStatement, int tipCategory, DateTime[] dates) throws SQLException {
        try (
                Connection connection = DataStore.getConnection();
                PreparedStatement statement = connection.prepareStatement(sqlStatement)) {
            for (int i = 0; i < dates.length; i++) {
                statement.setString(i + 1, dates[i].toString(dateFormat));
            }
            try (ResultSet rs = statement.executeQuery()) {
                while (rs.next()) {
                    Tip t = new Tip(tipCategory); //TIP ID associated with above average water usage
                    t.setRouterID(rs.getString("RouterID"));
                    tips.add(t);
                    log.debug(t.toString());

                }
            }
        }
    }
```

As we can see, the definition involves the SQL statement itself which returns the ResultSet with "RouterID" of household identificators which is presented with a particular tip (denoted by tipCategory). The last parameter denotes the dates for the beginning and end of the relevant period. Some tips are computed using only data from the previous day while some are based on monthly data.

The other way to produce tips is to use R programming language. There are currently two models implemented:

1. Using Autoregressive Integrated Moving Average (ARIMA) model
2. Using Linear Regression model

In the future, we are going to provide additional models, such as Bayes network and Logical Regression.

The R-script starts by parsing the data from SQL database and converting it to a format specified by R programming language:

```
    @Override
    public void convertToInput(ResultSet rs) throws IOException, SQLException {
        File temp = File.createTempFile("Rdata", ".tmp");
        inFileName = temp.getAbsolutePath();
        try (PrintWriter RfileWriter = new PrintWriter(temp)) {
            //headings
            RfileWriter.println("Nr RouterId SensorId Date Time Month Day Hour Min Sec LTS Flow1Acc Flow1Inst Temp1 Flow2Acc Flow2Inst Temp2 TotalFlow");
            //data
            StringBuilder line;
            int lineNo = 1;
            while (rs.next()) {
                line = new StringBuilder();
                line.append(lineNo++);
                line.append(" ").append(rs.getString("RouterId"));
                line.append(" ").append(rs.getString("SensorId"));

                DateTime dateTime = new DateTime(rs.getTimestamp("Timestamp"));
                line.append(" ").append(dateFormat.print(dateTime));
                line.append(" ").append(timeFormat.print(dateTime));
                line.append(" ").append(dateTime.getMonthOfYear());
                line.append(" ").append(dateTime.getDayOfWeek());
                line.append(" ").append(dateTime.getHourOfDay());
                line.append(" ").append(dateTime.getMinuteOfHour());
                line.append(" ").append(dateTime.getSecondOfMinute());
```

After creating the temporary R input file, the Rscript.exe file is called. As stated previously, it uses different data models to compute tips. For example, the ARIMA model is computed as:

```
library(forecast)
args <- commandArgs(trailingOnly = TRUE)
dane <- read.csv(args[1], header = TRUE, sep = " ")
dl_danych <-length(dane$Nr)
ARIMAmodel <- function(){
current_day <- as.character(dane$Date[dl_danych])
# kumulacja danych
i<-1
daner <-c()
while(i <= dl_danych) {
  suma_dnia <- 0
  dzien <- as.character(dane$Date[i])
  if (dzien != current_day){
    while ((i <= dl_danych) && as.character(dane$Date[i]) == dzien){
      suma_dnia <- suma_dnia + as.numeric(dane$TotalFlow[i])
      i<-i+1
    }
   # print(paste(dzien,suma_dnia))
    daner <- c(suma_dnia,daner)
  }
  else
      i<-i+1
}
i<-1
suma_dnia <- 0
while(i <= dl_danych ) {
  if (as.character(dane$Date[i]) == current_day){
    suma_dnia <- suma_dnia + as.numeric(dane$TotalFlow[i])
  }
  i<-i+1
}

danem <- matrix(daner,ncol = 1)
m <- auto.arima(danem)
pred <- forecast(m,h =1)

#tip <- paste(dane$SensorId[1],";Expected water usage for today ",as.numeric(round(pred$mean,2)), ". Currently consumed ",suma_dnia,sep = "")
tip <- paste(dane$SensorId[1],as.numeric(round(pred$mean,2)),suma_dnia,sep = ";")
cat(tip)

}

ARIMAmodel()
```

As an output, the pairs of RouterID and different values which substitute the placeholders inside the tips description, are produced. If the Rscript produces the output as a three-part value, eg. [212;101;67], this is converted to the tip for RouterID 212 with the description:

*Your expected water usage for today is **101**. You have currently consumed **67**.*

The WCTips data are prefilled with tips written in three project languages. The mapping of the tips is stored in RouterAssignTip database:

WaterConsumption2.RouterAssignTip: 6 Razem wierszy

RecordId	RouterId	TipId
1 206	312	371
1 207	305	371
1 208	213	371
1 209	210	371
1 210	102	371
1 211	210	372

As it can be clearly seen in the above screen shot, the RouterID 312 should be presented with Tip 371 (which can be found in the WCTips table). In order for any visualising software (especially the DSS tablet application) to show the tip, the simple SQL query is made:

select TipId from WaterConsumption2.dbo.RouterAssignTip
where RouterId=?

3.3 WaterDiary

WaterDiary is a mobile application created for family members to identify their water readings. It enables the user to declare who used the water and for what purpose. This application allows users to analyze which family member, and which activities, consume the largest volume of water. An additional feature of this application is a notification system which supports users in keeping their water diary.

3.3.1 Data Storage

Data are retrieved from remote database where information about water usage readings is stored. Database stores information about water usage readings (dbo.HouseholdConsumption), families and family members (dbo.tblFamilies, dbo.tblFamiliesMembers) and information about what the water was used for (dbo.tblBehaviours).

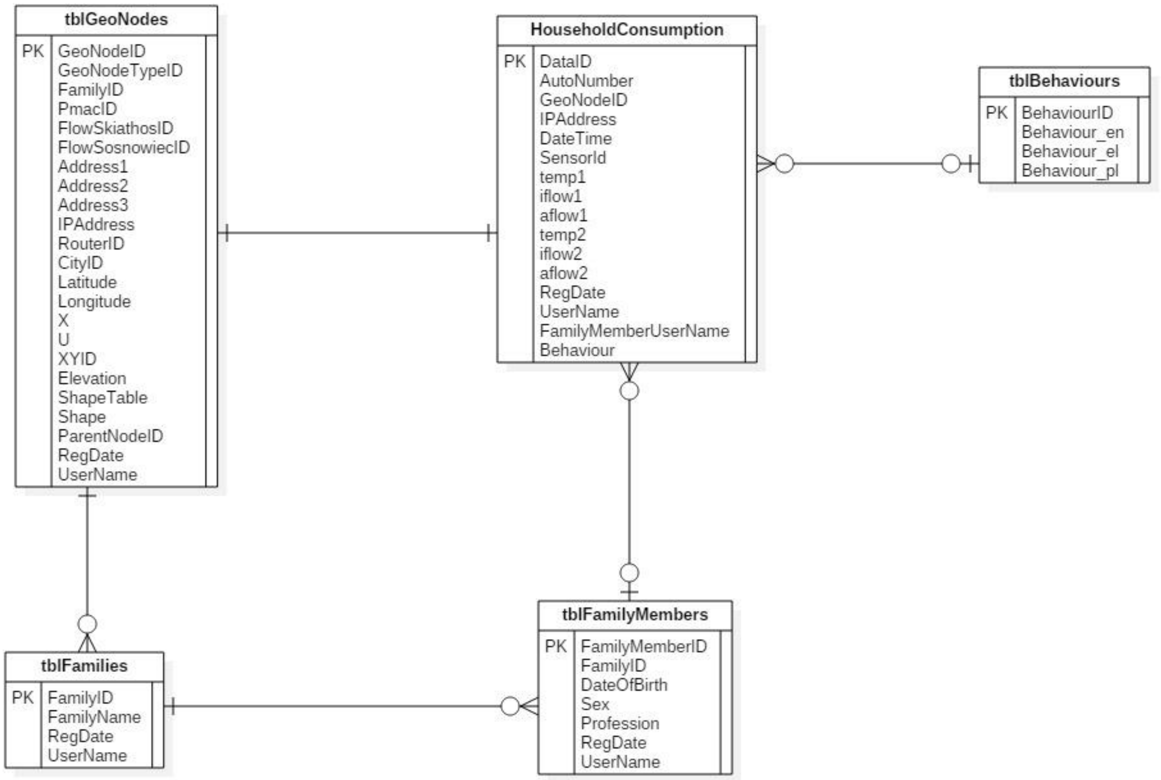


Figure 16 Data schema of Water Diary

3.4 Verification

The two testing tools currently integrated into android SDK are Monkey and Monkeyrunner. The Monkey tool is mainly used for stress and reliability testing as it can be used to generate random simulated keyboard event streams which are sent to the target programme. By specifying the number of transmissions, the developer can observe the stability and reliability of the test application. Monkeyrunner is a more powerful and more flexible tool for function and regression testing. As the current project requires reliability testing, Monkey was used.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [619228]

Commands are executed in the form of "adb shell monkey [options] <event-count>". In the above example, "abd shell monkey –p com.hello.mytemp –v 500" means start the specified application and send 500 pseudo-random events to the application. During the operation, the Application program will constantly switch screen on emulator and show different levels of feedback. Implementation reports and events generated can also be seen in Monkey, for example:

```
:Sending Trackball (ACTION_MOVE): 0:(-3.0,2.0)
:Sending Touch (ACTION_DOWN): 0:(314.0,727.0)
:Sending Touch (ACTION_UP): 0:(384.2978,774.4703)
:Switch: #Intent;action=android.intent.action.MAIN;category=android.intent.categ
ory.LAUNCHER;launchFlags=0x10200000;component=com.hello.mytemp/.MainActivity;end

    // Allowing start of Intent { act=android.intent.action.MAIN cat=[android.in
tent.category.LAUNCHER] cmp=com.hello.mytemp/.MainActivity } in package com.hell
o.mytemp
:Sending Touch (ACTION_DOWN): 0:(22.0,696.0)
:Sending Touch (ACTION_UP): 0:(7.507246,700.1871)
:Sending Trackball (ACTION_MOVE): 0:(-2.0,3.0)
:Sending Trackball (ACTION_MOVE): 0:(2.0,-2.0)
:Sending Touch (ACTION_DOWN): 0:(275.0,307.0)
:Sending Touch (ACTION_UP): 0:(238.05406,377.08936)
:Sending Touch (ACTION_DOWN): 0:(9.0,582.0)
:Sending Touch (ACTION_UP): 0:(0.0,587.4636)
:Sending Trackball (ACTION_MOVE): 0:(3.0,2.0)
:Sending Trackball (ACTION_MOVE): 0:(0.0,-3.0)
Events injected: 500
:Sending rotation degree=0, persist=false
:Dropped: keys=0 pointers=8 trackballs=0 flips=0 rotations=0
## Network stats: elapsed time=32810ms (0ms mobile, 0ms wifi, 32810ms not connec
ted)
// Monkey finished
```

If the application crashes or receives any uncontrolled abnormal result, Monkey will stop and display an error log. Ten rounds of testing yielded no errors so the application was deemed to be stable and reliable.

During the alpha test for this application a number of bugs were identified:

1) TimerTask issue: TimerTask appeared to have been either cancelled or already scheduled.

```
AndroidRuntime    FATAL EXCEPTION: main
AndroidRuntime    java.lang.IllegalStateException: TimerTask is scheduled already
AndroidRuntime    at java.util.Timer.scheduleImpl(Timer.java:572)
AndroidRuntime    at java.util.Timer.schedule(Timer.java:481)
```

2) Null pointer issue: the system will crash when there is a pointer pointing uncertainly.

```
AndroidRuntime    FATAL EXCEPTION: main
AndroidRuntime    java.lang.NullPointerException
AndroidRuntime    at com.hello.mytemp.fragment.ShopTabFragment$MyOnPageChangeListener.onPageSelected(ShopTabFragmen
```

3),Fragment issue: The fragment with the View Pager works properly the first time but the application will subsequently crash when it is navigated to that fragment.

```
AndroidRuntime          FATAL EXCEPTION: main
AndroidRuntime          java.lang.IllegalStateException: No activity
AndroidRuntime          at android.support.v4.app.FragmentManagerImpl.moveToState(FragmentManager.java:1091)
AndroidRuntime          at android.support.v4.app.FragmentManagerImpl.moveToState(FragmentManager.java:1086)
AndroidRuntime          at android.support.v4.app.FragmentManagerImpl.dispatchActivityCreated(FragmentManager.java:1884
```

Resolution of these issues is presented in Table 3.

Issue	Solution
TimerTask: appeared cancelled or already scheduled	Prior to instantiation a detector was added to determine whether it already existed.
Null pointer: indicates that the system will crash when there is pointer uncertainly	When a pointer's initialization value is null, developer should pay special attention to check whether the value of pointer will be cleared when it return to main activity.
Fragment: the ViewPager initially worked but the application subsequently crashed.	This issue only appear when the database is emptied during testing. In other words, as long as there is no empty database in normal using, it will not be a problem.

Table 3. Debugging actions

The application was installed and uninstalled repeatedly and these actions were unproblematic. Similarly, no problems were found with the interface; the menu options, buttons, bookmarks, history, settings, and navigation flow function as intended. Project team members find the application easy to use. With Android 4.0 and above, the application is compatible with a range of mobile devices, browsers, screen sizes and versions of the operating systems

The Tablet configuration has been secured by username and password. The default one is "ISSEwatus". We recognised that the encryption of URLs or "deep links" might be too complicate as it requires the password for every access which could potentially prevent the householder from using the system. For the sake of both simplicity and security we deliberately leave the main security protection to the web server and encode the web URLs along with password control. We believe it could be sufficiently secure and acceptable to the householders as well.

The source code of the DSS is available from the project server http://212.106.179.154/DSSabout

A field trial of the DSS application will form both the final stage of verification process and the pilot stage of the validation process.

Chapter 4 DSS functions

Instruction manuals and videos are available for everyday users of the DSS as well as for installers.

4.1 Daily usage

The first DSS screen displays a menu of operational tabs overlaying the 'Daily Usage' page. The graph in the daily usage screen displays the last 23 hours' consumption in litres per minute for each monitored appliance. The dials below show the most recent water usage for each appliance.

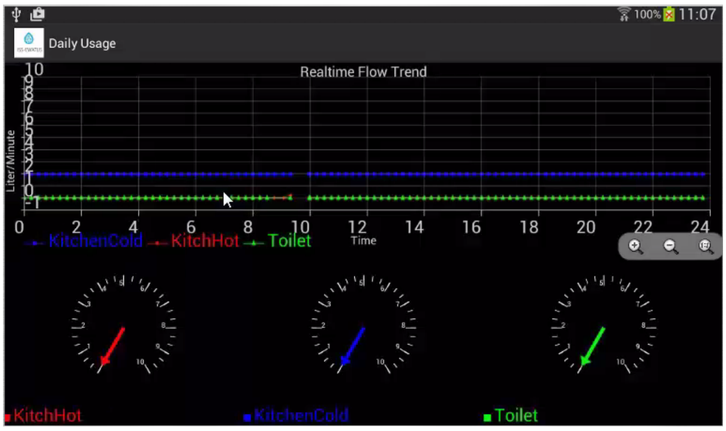


Figure 17 Daily usage

4.1 Rate Diagram

The rate diagram page provides a water consumption benchmark which allows the user to compare their household's recent daily monitored water consumption against their historical average. The benchmark represents the household's average sensor-monitored consumption prior to the implementation of the ICT intervention. The seven 'current trend' boxes display daily water consumption in litres across the previous week (with -7 referring to seven days previously and -1 referring to the previous day). These boxes are colour coded and aligned with the rating schema on the left. The darkest green indicates very low household consumption (Band A: at least 30% below the household's historical average). Yellow (Band D) indicates the historical average. Red (Band G) indicates very high water consumption (at least 30% higher than the household's historical average).

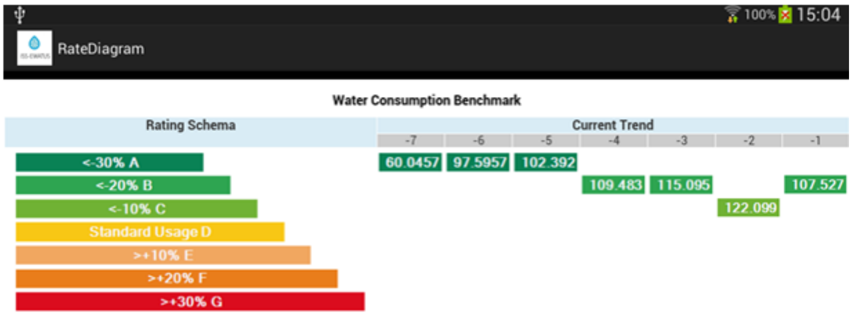


Figure 18 Rate diagram

4.3 Summary diagram

The summary diagram page provides information on the household's water consumption in litres for different appliances. From left to right, the symbols indicate: kitchen taps; dishwasher; bathroom taps; washing machine; toilet; and shower. The user can scroll between time frame displays: last seven days (daily); last four weeks (weekly) and last three months (monthly).

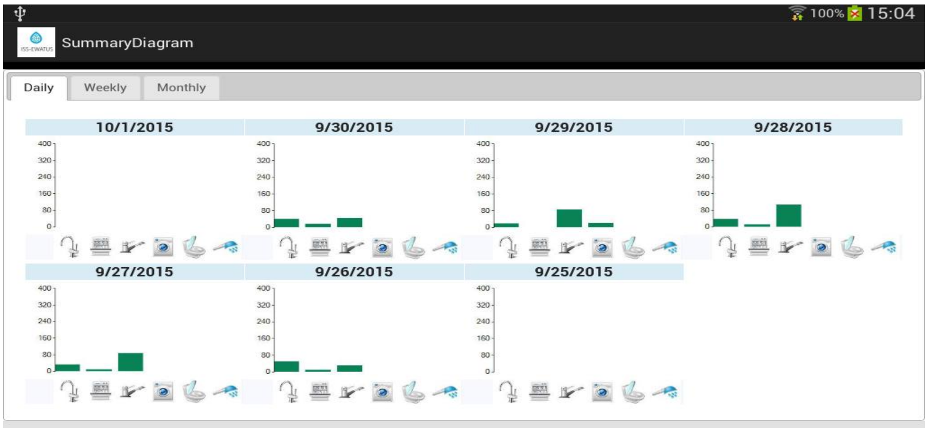
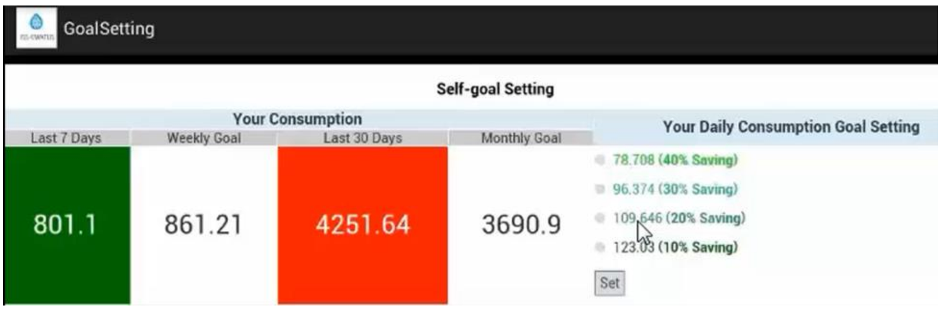


Figure 19 Summary diagram

4.4 Goal setting

The Goal Setting page gives a summary of household consumption across the previous seven and 30 days. It allows the user to set a target for reducing the household's water consumption and monitor daily progress towards this goal. Target consumption can be 10%, 20%, 30% or 40% below the benchmark (historical consumption). Feedback on recent consumption (i.e. seven or 30 days) is colour coded; green indicates that the goal has been reached and red indicates it has not. In the example presented in below the user has specified the goal of achieving a 10 per cent reduction in consumption compared with the household's historical average. A 10% saving is calculated as consumption at 123.03 litres per day (861.21 litres across seven days; 3690.0 litres across 30 days). In the example given here, consumption across the previous seven days (801.1 litres) is below the weekly goal and so is displayed in green while consumption across the previous 30 days (4251.64) is above the monthly goal and so is displayed in red. This would be consistent with a household that had only recently adopted water saving behaviours.



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [619228]

Figure 20 Goal setting

4.5 News

The News tab provides water saving tips and information organized into three categories: Water Saving, Environment Impact and General Knowledge. The user clicks on a tab or swipes the screen to switch between categories. Clicking on a tips title displays the tip.

Figure 21 News

End-users are presented only with tips which are relevant to their situation. Some of the tips can be considered as 'educational tips' described in 'expertise' and 'reduction' strategies and are associated with references or links to outside sources. The computed tips include:

1. *Fixing the leaky taps,* whenever the service finds the enormous water usage which happened in a short period of time. This script is computed every 10 minutes.
2. *You are above average,* shows when the water usage from the previous day exceeds the average for the whole neighbourhood.
3. *You are below average,* the opposite of the above tip.
4. *Increased water usage,* shown when there is an more than 15% increase of water usage day-to-day
5. *Decreased water usage,* the opposite of the above tip.
6. *Heavy user,* when user is one of the 10 users who use the most water in their neighbourhood.
7. *Be proud! T*he opposite of above situation, when the user is among 10 users with minimal water usage.
8. *Are you in a hurry?* Shown when the user is among the 10% of users who use water most often. Here, we also ask the user to look for the faulty taps and leaks.
9. *Disciplined,* the opposite of the above tip.
10. *Increasing trend,* computed using the Linear Regression model, shown when the monthly trend for the user predicts elevated water usage.
11. *Decreasing trend,* the opposite of the above tip.
12. *Expected water usage* is a fully personalised tip which uses the ARIMA model in order to predict the expected water usage for the following day.
13. *Water in kitchen,* shown as a warning to those users, who have the biggest water usage in the kitchen. This tip also suggests installing special equipment in the kitchen to save more water (e.g. aerators).
14. *Water in bathroom,* the same as before, but for the appliances in the bathroom. The user is presented with the web link where he or she can check whether their laundry machine or other equipment is water-saving.

15. *Shower water,* shown when the shower usage for the user is particularly high.
16. *Toilet flush,* shown when the toilet usage is abnormally high. The user is then presented with the tip involving the installation of dual-flush toilet.

4.6 WaterDiary

The WaterDiary requires household members to identify their personal water usage in a fixed range of time (e.g. daily or weekly). The necessity of identifying of the usage records is signaled by an alarm. It would also be possible to invoke competition between program members by rewarding them for fulfilling their obligations.

In the first WaterDiary screen the user provides data about each water usage. In the column "Behaviour" the user specifies the purpose that the water was used for (behaviours are placed in a dropdown list) and in column "Family member" (family members are placed in dropdown list) who used the water. The user is also able to select a period of time (dates below "From" and "To") to retrieve readings only from the specified range of time.

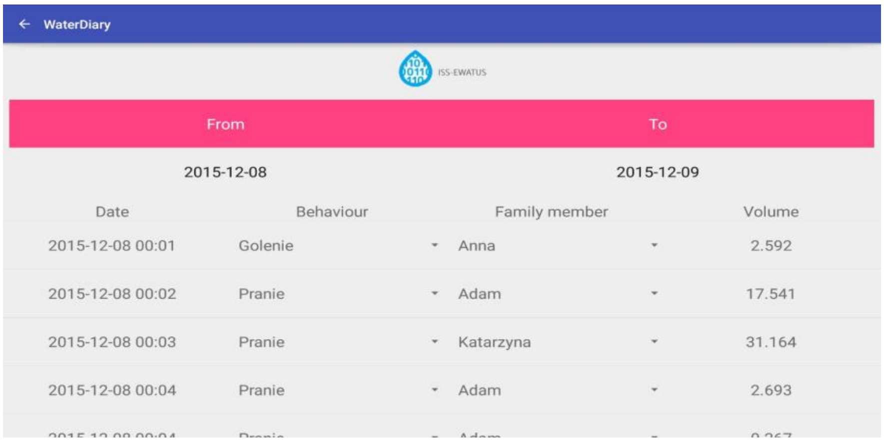


Figure 22 All readings in the chosen period

Figure 23 Unidentified readings

The 'Unidentified screen' is similar to the first one but it presents only these readings which have not yet been described (by choosing "Behaviour" and "Family member)" by the user.

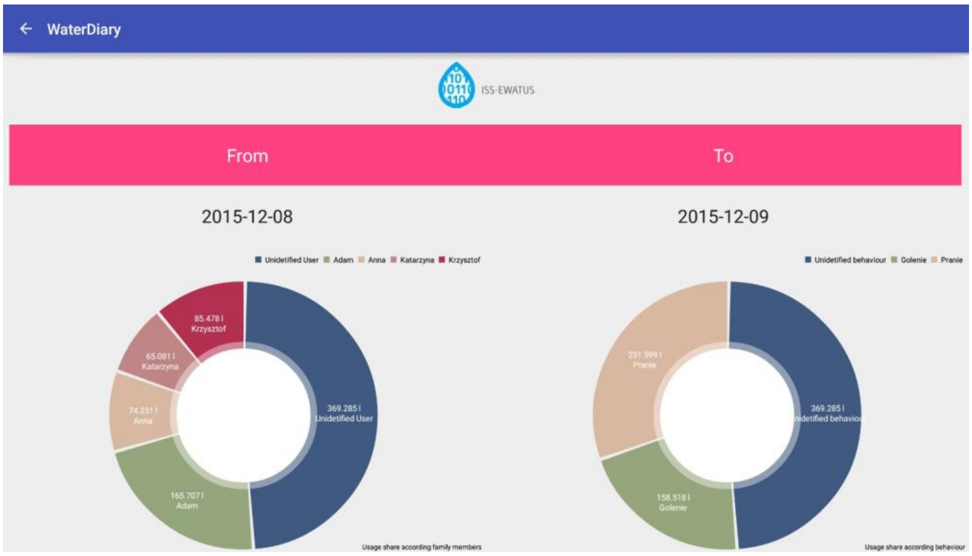


Figure 24 Water usage charts

On the water usage screen, the user see diagrams that present water usage in behaviour and family member contexts. The user is also able to select the period that should be presented.

The end-user has the ability to submit these data after each and every water use from their home (in another words, the application works in near-real time). If the user forgets to do so, once per day a notification is shown asking her or him to fill-in the necessary data.

4.7 Water User Classification Survey

Within Work Package 3, an external application has been developed which augments, and thereby strengthens, the core DSS; this is the water user classification survey.

Interventions which aim to reduce domestic water consumption differentiate between technological solutions and those associated with curtailment (i.e. engaging in water conserving behaviour). Efficiency measures may entail a significant one-off expense (e.g. the replacement of an old, inefficient appliance) or short-term effort (e.g. sourcing, buying and fitting tap aerators). By contrast, behavioural curtailment may entail ongoing inconvenience and resolve, for example, routinely taking a very brief shower. People who are motivated to conserve water by environmental or economic concerns may feel that they achieve their goal by engaging in one or other of these strategies. The water user classification function (WUC) juxtaposes an individual's position on technological (efficiency); usage (curtailment) and environmental (value) dimensions. Feedback is generated which incorporates the three dimensions and highlights where there is a value action gap (i.e. where technology and/or user behaviour are at odds with the consumer's values). Recognition of the value action gap should invoke uncomfortable cognitive dissonance and motivate users to modify their behaviour or appliances. The value action gap is a key feature of the intervention model.

The WUC is accessed through the same tab as the social media site developed by Work Package 5. The rationale behind the WUC is that consumers who are concerned about the environment and have invested in efficient technologies may experience cognitive dissonance if they receive the following feedback:

> "You are a **high tech/high use** consumer. High tech households like yours save water and energy by adopting efficient technology ☺. However, although you are very concerned about the environment, your everyday routines use a lot of water and energy ☹."

Similarly, users who are use water wisely because they are concerned about the environment, but have inefficient appliances, may be discomforted by the feedback:

> "You are a **careful but low tech environmentalist**. Your frugal everyday routines help you to save water and energy ☺. However, although you are very concerned about the environment, your home lacks the efficient technology that would help you save water and energy ☹."

By contrast, consumers who 'practice what they preach' would get the following reinforcement:

> "You are a **Green environmentalist**. Households like yours save water and energy by adopting efficient technology ☺. You are very concerned about the environment and your frugal everyday routines help to conserve water and energy ☺."

4.7.1 Survey

As with the intervention model, the development of the WUCS represents collaboration between team members with social science and computer science expertise. Respondents are presented with 20 questions. They are first asked their age and gender; in the interests of not overburdening them, these are the only socio-demographic characteristics collected. Six questions relate to household technology and nine to the respondent's water use practices. The final three items address their environmental attitudes.

Seven of the 20 questions are not used to generate feedback or route questions. This reflects the fact that the survey has an additional function of providing data for secondary analysis. This will offer insight into the circumstances, behaviour and attitudes of intervention participants and will contribute to the validation phase. Most of these subsidiary questions relate to water use practices in summer. These indicators are not included in the derivation of the feedback due to the extreme differences in summer temperatures between the intervention areas (in Poland and Greece).

4.7.2 Classifying water users

The technology dimension collects information about the efficiency of the household's toilet(s) and showerhead(s) and whether the property is fitted with solar panels. A related question asks how much consideration the household would give to buying a water- and energy efficient appliance. While solar panels do not directly impact upon water consumption, it is proposed that their presence indicates a propensity to adopt resource-efficient technologies around the home.

A count is undertaken with each of the following characteristics scoring one point (maximum 4): one or more toilet is dual flush; one or more showerhead is water efficient; solar panels are installed; and the household would give *a lot* of consideration to buying a water- and energy efficient appliance. "Don't know" responses are viewed as an indication of low awareness of water-related issues and are treated as a "no" answer. For feedback generation, users with a score of 2 or more are designated 'high tech' (HT) while zero is 'low tech' (LT); a score of 1 is 'intermediate' (IT).

Respondents are asked about the frequency of showers and baths and the duration of a typical shower. These questions are asked for winter and summer. For feedback generation, mean daily minutes spent in the shower is calculated, for winter only. Where respondents only take baths and not showers, a bath is equal to a ten minute shower. This reflects the calculation that a bath has a capacity of 80 litres compared with an eight litres a minute flow rate for a typical (non-power) shower (Unilever 2011). Less than seven minutes per day was selected as an indicator of low shower usage rather than the five minutes proposed in the literature. This choice is based on qualitative interviews that were carried out to inform the construction of the practice model (as reported in D3.1 'Data and practice models of water consumption at household level'). While it was common for Polish interviewees to report taking daily showers of between five and ten minutes, longer showers were the norm in Greece. As discussed in the context of the practice and intervention models (Chapter 2), interventions that set a standard that is perceived to be unattainable may undermine participant motivation.

Respondents are also asked how long they would wear a pair of jeans or casual trousers (or skirt, if female) before putting the item in the laundry. Again, this question is asked for winter and summer. Wearing jeans for five or more days is classified as low laundry usage; 3 and 4 days is intermediate; one or two days is high usage. The usage dimension is a composite indicator of winter shower use and winter laundry generation. A low user (LU classification) is both a low shower user and a low laundry user. A high user (HU classification) is either a high shower user or a high laundry user. All others are intermediate (IU).

The final, environmental, dimension is based on responses to three statements:

- "The so-called environmental crisis facing humankind has been greatly exaggerated"
- "Water pollution is a real problem for our rivers, lakes and coastal waters" and
- "Over-extraction of water is damaging our groundwater, rivers and lakes".

Response categories are: strongly disagree; somewhat disagree; somewhat agree; strongly agree; and don't know. For the first statement, 'strongly disagree' is treated as a pro-environmental response while for the remaining two it is 'strongly agree'. The number of pro-environmental responses is calculated for each respondent (maximum 3). A score of three identifies the respondent as an environmentalist (a) while a score of one or two identifies the respondent as environmentally aware (b). A score of zero is neither (c).

The columns in Table 4 identify the three classes of technology: High tech (HT); Intermediate tech (IT); and Low tech (LT). The rows denote the three classes of usage: High usage (HU); Intermediate usage (IU); and Low usage (LU). The nine cells thus derived each have three sub-classifications. Suffix 'a' denotes 'environmentalist'; 'b' denotes 'environmentally aware' and 'c' denotes neither of these. The environmental dimension has a lesser status to the technological and usage dimensions. Ultimately, users get positive feedback if they live in a high tech home or are frugal in their water use practices; they do not get validation for simply having pro-environmental attitudes. The environmental dimension is merely used as leverage where it is at odds with technology or usage.

		Technology		
		High tech	Intermediate	Low tech
Usage	High usage	**HTHU** **a b c**	**ITHU** **a b c**	**LTHU** **a b c**
	Intermediate	**HTIU** **a b c**	**IT/IU** **a b c**	**LTIU** **a b c**
	Low usage	**HTLU** **a b c**	**ITLU** **a b c**	**LTLU** **a b c**

Table 4. Dimensions of User Classification

4.7.3 *Feedback*

Table 5 outlines feedback components associated with the different elements of Table 4. The feedback that a respondent receives is a composite of the components associated with their position on the three dimensions. For technology, the intermediate feedback is a moderated version of the negative feedback associated with low technology. For usage, the intermediate feedback is a moderated version of the negative feedback associated with high usage. For the primary dimensions of technology and usage, emojis clarify whether the feedback should be interpreted as positive (☺) negative (☹) or neutral (😐).

	Feedback component
High tech (HT)	High tech households like yours save water and energy by adopting efficient technology. ☺
Int. Tech (IT)	Your home lacks some simple technologies that could help you save water and energy. 😐
Low tech (LT)	Your home lacks the efficient technology that would help you save water and energy. ☹
Environmentalist (a)	You are very concerned about the environment.
Environmentally aware (b)	You are aware of environmental issues relating to water consumption.
Environmentally unaware (c)	Compared with most people in Poland/Greece you have a low level of awareness of environmental issues.
High usage (HU)	Your everyday routines use a lot of water and energy. ☹
Int. usage (IU)	Your everyday routines use too much water and energy to make you a green consumer. 😐
Low usage (LU)	Your frugal everyday routines help you to save water and energy. ☺

Table 5. Feedback components

Feedback on technology precedes feedback on usage apart from cases where usage warrants positive feedback (i.e. is low) but technology does not (i.e. is intermediate or low). In this case, usage is placed first to offer maximum potential for highlighting inconsistency between initial validation and subsequent lack of validation. If the respondent is an environmentalist or is environmentally aware, this feedback component is linked to the first negative element from the technology or usage dimensions. Where both are positive, the environmental reference is attached to the second (usage) feedback. For an environmentally unaware classification, the reference is placed at last. Feedback components are concatenated using syntactically appropriate conjunctions. Respondent feedback begins with a label that locates them on the technology and usage dimensions. Some labels differentiate further on the basis of the environmental dimension. Labels are shown in Table 6.

		Technology		
		HT	**IT**	**LT**
	HU	High tech/high use consumer	High use consumer	High use/low tech consumer
Usage	**IU**	Technology focussed consumer	Inactive environmentalist (a) Environmentally aware but inactive consumer (b) Unconcerned consumer (c)	Low tech consumer
	LU	Green environmentalist (a)	Careful environmentalist (a)	Careful but low tech environmentalist
		Green consumer (b and c)	Careful consumer (b and c)	Careful but low tech consumer (b and c)

Table 6. User labels

The results screen (Figure 25) gives textual feedback and also graphically depicts the respondent's position on the three dimensions. The 'traffic light' colour scheme builds upon the 'ambient display' behaviour change strategy described in the Section 2.3. Subliminally, red has negative connotations (low technology and high usage) while green is positive (high technology and low usage).

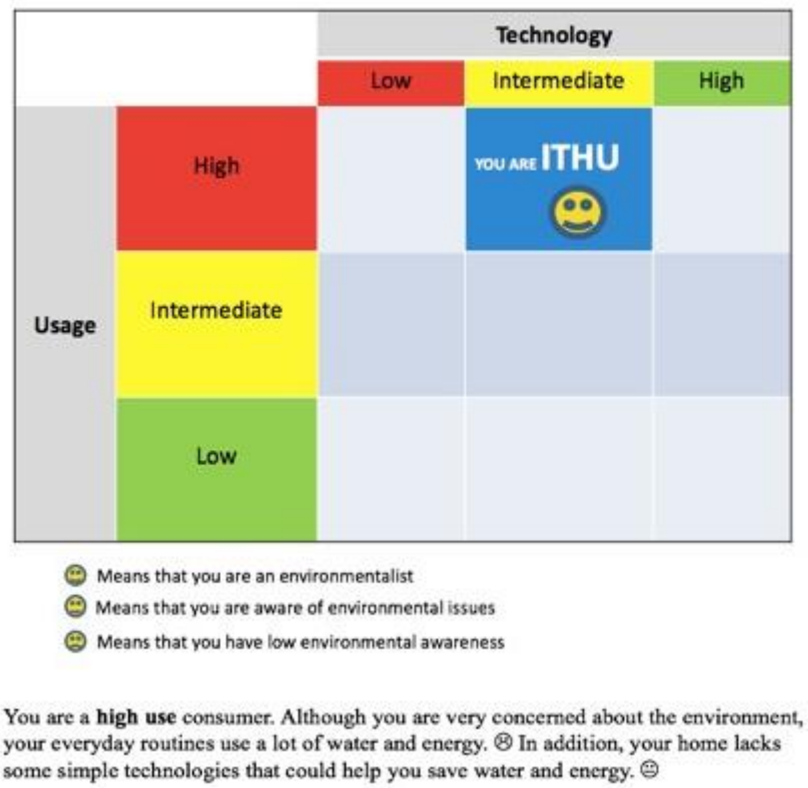


Figure 25 Results screen

As indicated previously, a number of questions were included in the survey purely to facilitate secondary data analysis. These include indicators of water usage practices in summer. Seasonal variations in water consumption address the 'context' component of the practice model and may offer valuable insight into factors that affect water demand. One question taps into user perceptions of nondiscretionary consumption. This asks, "If you were in a hurry, how quickly could you take a shower and still be adequately clean and presentable? How many minutes would you spend under the water?" Nondiscretionary consumption is the amount required to function, and is therefore (in the mind of the user) non-negotiable. The discretionary component denotes the amount that could be conserved by behaviour change. An intervention could seek to persuade users to reduce consumption so that it is in line with their self-assessed discretionary level. However, it could additionally seek to moderate the user's perception of what is nondiscretionary, thereby increasing the amount that could be saved. This may be achieved by increasing the user's knowledge or by harnessing social norms.

Chapter 5 Summary

Work Package 3 (WP3) of the ISS-EWATUS project is tasked with developing and testing the effectiveness a Decision Support System (DSS) application (app) for the efficient use of water at household level. This publication reports on the fulfilment of the second of three WP3 objectives, namely, the production of an app-based water demand reduction intervention.

Chapter 2 outlines the design of the behaviour intervention model while Chapter 3 describes the architecture of the DSS. The design of, and the rationale for, the tips service is described in Section 3.2. The DSS was extensively tested in laboratory conditions and found to be robust (Section 3.4).

Chapter 4 describes the screens and functions presented to the user. These provide feedback on water consumption associated with individual appliance. Users can set goals for reducing water consumption and monitor their progress (Section 4.4). A tips service provides bespoke water-related tips via the News screen (Section 4.5). A WaterDiary function seeks to encourage household members to monitor their own consumption (Section 4.6).

A Water User Classification Survey offers users the opportunity report their household appliances, personal water use practices and environmental beliefs (Section 4.7). On the basis of their answers, they can receive feedback on the type of water consumer that they are. This is designed to promote cognitive dissonance where behaviour is inconsistent with beliefs; the discomfort invoked by this dissonance may then encourage users to adopt curtailment and efficiency measures.

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Annex Water User Classification Survey

1 How old are you? _____

2 Are you
- Female
- Male

3 How many toilets do you have in your home?
- 1
- 2
- 3 or more

4a [If just one toilet] Is the toilet dual flush (can you choose to use a half flush?)
- No
- Yes
- Don't know

4b [If two or more toilets] Are any of the toilets dual flush (can you choose to use a half flush?)
- No
- Yes, some of them
- Yes, all of them
- Don't know

5 How many showers do you have in your home?
- 0
- 1
- 2
- 3 or more

6a [If just one shower] Is the shower fitted with a water efficient shower head?
- No
- Yes
- Don't know

6b [If two or more showers] Are any of the fitted with a water efficient shower head?
- No
- Yes, some of them

- Yes, all of them
- Don't know

7 Highly efficient appliances can be more expensive than basic models. If your household had to buy a new washing machine or dishwasher, how much consideration would you give to buying an energy and water efficient model?

- Very little or none
- Some
- A lot
- This is not our responsibility
- We could not afford to replace an appliance

8 Does your home have solar panels?

- No
- Yes

9 Thinking about your habits in the **winter** months: In winter, how many showers or baths do you personally take in a typical week? ________

10 For a typical shower, how many minutes do you spend under the water?

_____ • I only ever take baths

11 [skip if only ever takes baths] If you were in a hurry, how quickly could you take a shower and still be adequately clean and presentable? How many minutes would you spend under the water? _____

12a [If male] In winter, on how many days would you wear a pair of jeans (or casual trousers) before you put the item in the laundry? ________

12b [If female] In winter, on how many days would you wear a pair of jeans (or casual trousers or skirt) before you put the item in the laundry? ________

13 [All] And in winter, how long would you wear a t shirt (or causal top) before you put it in the laundry?

- Less than a day
- A day
- Two days
- Three or more days

14 Thinking about your habits in the **summer** months: In summer, how many showers or baths do you personally take in a typical week? ________

15 And for a typical shower in summer, how many minutes do you spend under the water?

_____ • I never take showers, only baths

16a [If male] And in summer, on how many days would you wear a pair of jeans (or casual trousers) before you put the item in the laundry? ________

16b [If female] And in summer, on how many days would you wear a pair of jeans (or casual trousers or skirt) before you put the item in the laundry? ________

17 [All] And in summer, how long would you wear a t shirt (or causal top) before you put it in the laundry?

- Less than a day
- A day
- Two days
- Three or more days

How do feel about the following statements?

18 The so-called environmental crisis facing humankind has been greatly exaggerated

Strongly disagree	somewhat disagree	somewhat agree	strongly agree	Don't know
•	•	•	•	•

19 Water pollution is a real problem for our groundwater, rivers, lakes and coastal waters

Strongly disagree	somewhat disagree	somewhat agree	strongly agree	Don't know
•	•	•	•	•

20 Over-extraction of water is damaging our groundwater, rivers and lakes

Strongly disagree	somewhat disagree	somewhat agree	strongly agree	Don't know
•	•	•	•	•