FROM SMART METERS TO SMART DECISIONS: WEB-BASED SUPPORT FOR THE WATER EFFICIENT HOUSEHOLD

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Smart water metering technologies for residential buildings offer, in principle, great opportunities for sustainable urban water management. However, much of this potential is as yet unrealized. Despite several ICT solutions having already been deployed aiming at optimum operations on the water utilities side (e.g. real time control for water networks, dynamic pump scheduling etc.), little work has been done to date on the consumer side. This paper presents two closely related web platforms targeting primarily the household end user. The first one, termed the household analytics platform, enables consumers to monitor and control, on a real-time basis, the water demand of their household providing feedback not only on the total water consumption and relevant costs but also on the efficiency (or otherwise) of specific indoor and outdoor uses. At the same time, the second platform, the eLearning platform aims to support and motivate users to understand and change their water consumption through a simple and gradually engaging educational process. This paper discusses the rationale, structure and technologies upon which these platforms have been based and presents an early prototype of the various tools, applications and facilities. It is suggested that the combined strength of such developments is in closing the gap between technology availability and usefulness to end users and could help both the uptake of smart metering and awareness raising, leading, potentially, to significant reductions of urban water consumption.

INTRODUCTION

The advent of new technologies on smart metering along with innovative technologies on data management, storage and communication, offers even greater opportunities for sustainable urban water management [1]. However, despite several ICT services already deployed on the utilities side aiming at improving the management and planning of water infrastructures (including for example, real time control of water networks, dynamic pump scheduling etc.), little work has been done to date targeting the consumer side. In principle however, it is now possible to provide detailed, accurate and real-time measurement of water consumption at the household level, through for instance Advanced Metering Infrastructures (AMI) enabling the
integrated monitoring and management of both the supply and demand sides of the potable water equation [2]. Utilities can process this new high-resolution data from smart meters to develop insights on user attitudes and consumption behaviors, especially in combination with feedback from socio-demographic surveys ([3], [4]). The household on the other hand, can better understand its consumption, identify wasteful (and potentially costly) behaviors and make informed water saving choices.

This paper brings the consumer at the center of this discussion presenting prototypes of web-based applications and services that exploit high-resolution water consumption data from smart meters at the household level in order to deliver valuable information to the end user, with the ultimate goal of improving domestic water and energy efficiency.

TWO WEB PLATFORMS FOR THE WATER EFFICIENT HOUSEHOLD

Use Cases

The design of the web-based platforms and system architecture was implemented following a systematic process based on the concept of use cases. Use cases enable the efficient derivation of functional and non-functional system requirements by considering the possible interactions between the user and the system [5]. This process also facilitates the determination of technological solutions, tools and methodologies to be implemented during system development.

A list of the system use cases was compiled, with special focus on improving water and energy efficiency using consumption data from smart meters. The main processes and functionalities of the iWIDGET system are briefly outlined described in the following six high-level use cases [6]:

- **Obtain feedback on water demand** - This system functionality is devoted to real-time monitoring of consumption at the household level, using data from smart water meters. The platform displays detailed information on the progress of total domestic water demand and how the latter is allocated into various uses and appliances.

- **Obtain feedback on energy consumption related to water demand** – This high-level use case comprises the processes for the real-time monitoring of energy consumption associated with water demand. Using high-resolution energy data from smart meters along with the corresponding from water meters, the platform provides information on domestic water-energy nexus. The feedback concerns not only the total energy consumption and the corresponding cost, but also the breakdown into appliances that consume water and energy simultaneously, adding up to the carbon footprint of the household.

- **Understand water consumption** - This high-level use case comprises all functionalities, which support householders to better understand the water consumption profile of their household. Aiming to motivate users to alter potentially wasteful attitude towards water, the system enables users to compare their current consumption with: (i) other neighbouring consumers; (ii) consumers of similar characteristics; (iii) other efficient households; (iv) past consumptions of the same household. Through these comparisons, possible wasteful behaviours and inefficient uses are identified and presented in the form of notifications and messages. In the same framework, the system detects various faults, such as bursts and leakages. Furthermore, the analysis of long-term water consumption trends enables the detection of abnormal situations, which could be linked to other factors, such as health.

- **Understand energy associated with water consumption** – Similarly to the previous use case, the platform enables householders to monitor and understand better their energy
consumption profiles, associated with water demand. The system provides comparative statistics about past energy consumption and the breakdown of total energy consumption into various uses.

- **Get assistance to increase water use efficiency** - The function of this high-level use case aims at supporting householders to improve the water efficiency of their household. The system provides customised and alternative suggestions that include practices, tips and interventions. The system, based on the specific needs and characteristics of the household, is also able to compose and perform different hypothetical but realistic scenarios, using combinations of innovative technologies, such as water-efficient appliances, rainwater harvesting systems, greywater treatment systems, advanced gardening systems etc. These scenarios enable users to see what types of savings they would get if they installed advanced water demand management measures in their houses.

- **Control water use** - This use case comprises more advanced (and potentially less realistic in the short run) functions that support users to optimize their water/energy bills by optimally scheduling water and energy related activities according to, for example, tariff structures, weather conditions and other specific needs of the household.

  Each of them was further broken down into a set of more detailed, lower level use cases that provide additional information on specific system functionalities.

**Methodology and tools**

The development of system architecture and platform analytic components was based on a series of state-of-the-art, flexible and advanced programming tools and technologies.

The core of the web platform is a system able on the one hand to acquire and handle raw data from household smart meters, and on the other hand to process and visualize those data in the form of meaningful information via analytics. For that purpose the “Enhydris” database system for storage and management of hydrological and meteorological data was extended in order to support the specific needs of the web-based platform [7]. Enhydris is an open source system developed in the National Technical University of Athens and is written in Python/Django with some parts implemented in C. The system uses PostgreSQL RDMS as its database engine while its extensible RESTful API can be used for communication with external machines and databases, allowing the direct incorporation and integration of the platform with other systems, such as remote Utility databases etc.

The eLearning platform on the other hand was mostly developed using the Moodle online platform which enables the development of a virtual learning environment for community-based educational processes [8]. Moodle stands for Modular Object-Oriented Dynamic Learning Environment and is an open source web application designed for producing Internet-based educational courses and training programs. It contains essential tools like discussion forums, quizzes, wikis, dictionaries and file sharing, but its modular nature enables also extensions by creating plugins for specific new functionalities, such as those developed in our work, which are presented in the next sections.

**An early prototype of the web-platforms**

The system is able to acquire and store not only raw and processed high-resolution water and energy data from smart meters but also several important additional information including, inter alia, instrument characteristics, geospatial data, household characteristics as well as information essential for the operation of analytic components. Some information is static, i.e. geospatial data, while other information changes dynamically. Household characteristics fall into this latter
category. The platform enables end-users to set up and/or modify their personal profile providing the system with specific information on family, property and water appliances characteristics.

The system is accessible via a web portal using secure password and username credentials. The water consumption data are presented in the form of dynamic time series charts as well as overview tables that summarize and outlines the water consumption profile of the household. Charts are refreshed automatically on a regular basis to enhance the “real time” impression. The level of presented information is determined via options that control the time-resolution of time series graphs, i.e. 15-minutes, hourly, daily, weekly, monthly and annually, as well as the units, i.e. litres, cost, per capita litres etc., enabling a more detailed or a more coarser aggregation of water consumption – as the user desires – in real time. At the most detailed level of information, the system gives access to full time series, downloadable for further external processing by the user. Along with time series charts, some pie charts are also displayed, presenting nightly/daily water consumption breakdown for hourly data and summer/winter breakdown for monthly data. Pie charts are also dynamic and give the opportunity to the household to monitor the water consumption trend within a day or a year. Figure 1 presents the time series charts at different time scales as they are displayed via the web-platform.

![Figure 1: Presentation of real-time water consumption data through the web-based platform](image)

Further to data acquisition and visualization, the web-based platform comprises smart applications that aim to support users to improve their domestic water and energy efficiency. In this framework, the web system is integrated and closely associated the second web facility, the eLearning platform, which is developed using the Moodle environment. The eLearning platform comprises several facilities and applications that support end-users to both understand their water consumption profile and its components, as well as to identify alternative and affordable interventions (either technical or behavioural) which could contribute to the improvement of domestic water efficiency. The platform is built around an interactive, multi-stage educational process which begins with a preparatory (“Exposing”) stage in which the users receive useful information and feedback about their “water identity”, continues through a self-assessment (“Understanding”) stage and finally provides (customized) smart and cost-
effective tips and suggestions (“Acting” stage). The learning process consists of various components, such as educational questions and answers, quizzes, tips, dictionary etc. In the following paragraphs we focus on the two most advanced web applications related to the understanding and alteration of the domestic water demand profile.

(1) The Water Calculator - Water Sense application is a fully customised tool that enables the exploration of the consumption profile of the household, i.e. the average daily water consumption as well as their breakdown into different uses and activities as a percentage of the total amount. As input parameters, the application receives specific information about property characteristics and daily habits (Figure 2b). The daily water consumption of the different water appliances, in liters per day, is estimated as follows, where italics are the user-defined parameters:

1. Bath = 80 L/use × Weekly_baths_in_residence_per_person/7 × occupancy
2. Shower = 6 L/min × Average_shower_time × Weekly_showers_per_person/7 × occupancy
3. Toilet = Average_number_of_daily_flushes_per_person × Flush_volume/7 × occupancy
4. Faucet = 4 L/min × Average_daily_use_per_person × Average_use_duration/7 × occupancy
5. Dishwasher = 30 L/use × Times_washed_by_hand_weekly/7 + Dishwasher_loads_per_week/7 × Water_usage_per_load
6. Laundry = Loads_of_laundry_per_week/7 × Water_usage_per_load(L)
7. Lawn = 5 L/min × Lawn_watering_per_week/7 × Watering_duration(min)
8. Outdoor = 3 L/min × Outdoor_uses_duration(min/week)/7

The results of these calculations are displayed along with average household values corresponding to typical use of water [9], via a spider graph as presented in Figure 2b.

Values greater to 1 correspond to consumption greater than the average whereas values smaller than 1 correspond to consumption lower than the average. Additionally, the breakdown of total daily consumption to various water uses is displayed in the form of a pie chart.

![Figure 2: a) Household water details required by Water Calculator; b) Results of Water Calculator](image-url)
(2) The Water Planner is a what-if online modelling tool that can simulate the use of low-consumption appliances and advanced demand management infrastructures. The tool, which is also resides within the eLearning platform, relies on the UWOT model ([10], [11], [12]) for the simulation of the household water network and operates under three different household setups: (a) a baseline without any water recycling schemes, (b) a configuration with only rainwater harvesting system and (c) a configuration with both rainwater harvesting and greywater recycling. Unlike the available conventional online calculators, Water Planner takes into account the climatic conditions of the area (the user can select between Oceanic, Mediterranean, or Desert climatic conditions). Climatic conditions, strongly influence the evapotranspiration and potential garden irrigation needs, as well as, importantly change the estimation of the contribution of the rainwater harvesting system to the households overall water demand reduction. Occupancy, roof area, garden area if available and pervious areas are defined by the user, while in the case of rainwater harvesting and greywater recycling the capacity of the local tank and the treatment unit are also user-defined parameters. The user can also choose between conventional water appliances and Best Available Technologies Not Entailing Excessive Costs (BATNEEC) that can operate in all three settings, hence creating 6 possible household infrastructure scenarios per climatic zone.

For each configuration, suitably customized by user input as discussed, the Water Planner presents the simulation results in the form of time series charts that display the daily energy consumption in household water appliances, the runoff volume, the water infiltrating in pervious areas and garden as well as the potable water demand for one year period. In the case of the rainwater and greywater systems, the system also calculates and displays two nomograms of the dependence of potable demand on the local tank capacity and on the percentage of green roof to total roof area. Figure 3, presents indicative results of simulation with conventional appliances and Oceanic climatic conditions, without water demand management technologies. The consumed energy in the water appliances is constant, the runoff volume and the water infiltration follow the rainfall pattern whereas potable water demand increases during summer because of garden watering.

Figure 3: Results of simulation without water recycling schemes as they derived from Water Planner
Figure 4 below, presents results of a simulation for a hypothetical household that includes a rainwater harvesting system. Results illustrate significant reductions in potable water demand that can be, for example, achieved, using a typical 1000 L tank. At the same time, the total runoff volume from the roof, garden and pervious areas of the household (excluding garden) also decreases, while a small energy increase can be observed due to the operation of the rainwater harvesting system.

CONCLUSIONS AND FURTHER STEPS
This paper presented two web-based platforms that aim to support consumers to monitor, control and hopefully improve the water consumption profile of their households exploiting the significant opportunities that smart metering technologies have to offer. For each platform the alternative uses and facilities were identified while early prototypes of the developed tools and initial results of their application were presented.

The household analytics platform enables end-users to monitor their water consumption, in real-time, using a variety of data visualization methods (e.g. dynamic charts, reports, overview tables etc.) and at the same time, receive warnings when leakages or other abnormal patterns are observed. This understanding of consumption is further supported by an eLearning platform that helps the users to improve their domestic water consumption following a multistage educational process, supported by advanced water calculators that allow planning of water saving interventions.

The paper sets the groundwork for the further design and development of applications that exploit emerging opportunities for the water sector from the deployment of smart metering and ICT technologies. It is expected that through such initiatives a promising future unfolds for the use of “smart” technologies supporting more water-aware households, able to understand, assess and modify their water consumption, leading hopefully, in the near future to water “wiser” cities.
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REFERENCES


