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Citation style: Yang Lili, Yang Shuanghua, Magiera Ewa, Froelich Wojciech, Jach Tomasz, Laspidou Chrysi S. (2017). Domestic water consumption monitoring and behaviour intervention by employing the internet of things technologies. "Procedia Computer Science" (Vol. 111 (2017), s. 367-375), doi 10.1016/j.procs.2017.06.036

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 111 (2017) 367–375

Procedia Computer Science

www.elsevier.com/locate/procedia

8th International Conference on Advances in Information Technology, IAIT2016, 19-22 December 2016, Macau, China

Domestic water consumption monitoring and behaviour intervention by employing the internet of things technologies

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Abstract

As the water resource is becoming scarce, conservation of water has a high priority around the globe, study on water management and conservation becomes an important research problem. People are increasingly becoming more individual households, which tend to be less efficient, requiring more resources per capita than larger households. In order to address these challenges, this paper presents the achievements of monitoring domestic water consumption at the appliance level and intervening people's water usage behavior which have been made in ISS-EWATUS (www.issewatus.eu), an European Commission funded FP7 project. The water amount consumed by every household appliance is wirelessly recorded with the exact consumption time and stored in a central database. People's water consumption behavior is likely affected by the real-time water consumption awareness, instant practical advices regarding water-saving activities and classification of water consumption behavior for individuals, all of which are provided by a decision support system deployed as a mobile application in a tablet or any other mobile devices. Only the enhanced water consumption awareness is presented in this paper due to the space limitation. The integrated monitoring and decision support system has been deployed and in use in Sosnowiec in Poland and Skiathos in Greece since March 2015. The domestic water consumption monitoring system at appliance level and the local DSS for affecting people's water consumption behavior are innovative and have little seen before according to the knowledge of the authors.

Peer-review under responsibility of the organizing committee of the 8th International Conference on Advances in Information Technology

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Peer-review under responsibility of the organizing committee of the 8th International Conference on Advances in Information Technology
10.1016/j.procs.2017.06.036

Keywords: Water consumption; behaviour intervention; Intenet of Things; decision support system;

1. Introduction

In the history of humanity, water plays a key role in sustaining life and building of social structures. With the climate change and population growth, it has posed potential threats towards water resources sustainability. The right access to a sufficient amount of safe drinking water for personal and domestic uses has been recognised as a fundamental human right by the United Nations in September 2010. Conservation of water has a high priority around the globe. Study on water management and conservation becomes an important research problem. To meet the growing demand of water resources, novel and interdisciplinary solutions have to be in place.

There are two main categories of water saving measures to reduce water use: technical measures include network improvement, repair leaks, developing water-efficient appliances; non-technical measures cover information, education, awareness that may change consumptive habits. This paper focuses on the non-technical measure and presents the ways of intervening people's water consumption behaviour by using the Internet of Things (IoT) technologies. The work was conducted as part of an on-going European Commission funded research collaborative project ISS-EWATUS (Integrated Support System for Efficient Water Usage and resources management). The project detail can be found from the project website www.issewatus.eu.

The rest of the paper is organised as follows. Section 2 briefly reviews the latest development in the IoT technologies and water consumption behaviour research. Section 3 introduces an IoT system for households developed in the ISS-EWATUS, giving consumer precise information on their water consumption on a single water-using appliance scale; the structure of the global IoT system and its features. Section 4 describes a practice model, an intervention model, and a data model which will be used in deriving the decision support system tailored for improving people's water consumption behaviour. Decision support system for households is presented in Section 5. The functions include providing water consumption awareness, generating practical advices regarding water-saving activities and classifying water consumption behaviour for individuals, where advices and behaviour classification were automatically generated through the analysis on the actual water consumption data. Section 6 concludes the paper.

2. Literature review

2.1. Internet of Things

The concept of the Internet of Things (IoT) is to make every single 'network enabled' object in the world network connected[1], and represents a vision in which the Internet extends into the real world embracing everyday objects and people together with software. Santucci et al pointed out "the Internet of Things is an emerging network superstructure that connects physical resources and people together with software"[2]. The term "Internet of Things" was popularized by the work of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), which in 1999 started to design and propagate a cross-company RFID infrastructure. IoT is also normally described as a self-configured dynamic global network infrastructure with standards and interoperable communication protocols where physical "things" are seamlessly integrated into the information infrastructure. The purpose of the IoT is to create an environment in which the basic information from any one of the networked objects can be efficiently shared with others in real-time. With more powerful and efficient data collection and sharing ability, such envision is promising and capable of supporting sophisticated decision support systems by providing services in a more accurate, detailed and intelligent manner [3].

In our previous work[3] the fundamental characteristics of what the IoT technology does were summarized as

(i) The IoT is a global and real-time solution; The IoT technology is Internet-based or other wide-area network-based, the scope of the IoT has no any physical boundary. Any object linked with the network can be incorporated into the IoT. Furthermore, the data communication over the IoT has time constraints and could be treated as real-time or near real-time.

(ii) It is mainly wireless oriented and able to provide comprehensive data about their surroundings in both indoor and outdoor environments. Wireless sensor networks (WSN) or RFID are employed for interfacing with physical world and data gathering is often implemented in a wireless manner. This feature significantly increases the richness of information.

(iii) It has the ability of remotely monitoring the environments and tracing or tracking objects. By combining the use of RFID sensor networks with other technologies such as global positioning system (GPS), or infrared sensor detection, RFID sensor networks provide the ability of wireless, real-time monitoring and tracking of any tagged objects in an indoor or outdoor environment to provide complete visibility of the resources.

2.2. Water consumption end use behaviors

'End use' refers to sites where water is used in the home, such as toilets, showers and washing machines. Water end use behaviors describe the water consumption activities that happen in people's daily lives. This information could help identify appropriate targets for behavior change interventions relating to daily use of water.

There are several water consumption behavior studies over the last few decades. Using the kitchen as an example, the dishwashing habits in four European countries has been analysed to gather common habits in the water end-use of households[4]. Empirical data was based on water consumption measurements in 81 households together with the simultaneous webcam observation of the kitchen sink; it was possible to assign the metered consumption data to a specific water use, such as cleaning drinking or cooking. This way it was possible to estimate to what extent particular kitchen tasks are influential for water consumption in the kitchen. Further research led to find out an optimal way to clean the dishes by hand[5]. A mathematical model of water consumption was presented in[6], the results of the same study (558 households included) showed a greater consumption of water for males while the single-female households are these that use the lowest quantities of water. It has been also shown that the complexity of water use/waste whilst doing the dishes is partly derived from the cultural, behavioral and geographical circumstances[7]. A behaviorally based modelling of Domestic Water Use was proposed in[8]. A review of existing studies on sustainable handling of resources at household is presented in[5].

3. IoT technology based domestic water consumption monitoring

The information generated by smart-meters can be used to display instantaneous consumption to the occupants. While this is undoubtedly a step in the right direction, the actual water demand reductions provided by the current generation of water smart-meters may be as little as 1%[9] and interim results from the current large-scale UK trials of smart-meters have not yet shown any statistically significant reductions[10]. The poor impact can be explained because smart-meters will only address certain aspects of water use in the home. Existing sociology and anthropology studies[11] show very well that people do not think in terms of water use, but think in terms of specific practices and the values they associate with them. In this section an IoT technology based domestic water consumption monitoring system is established which can monitor the water consumption at the individual appliance level. Therefore people's water consumption behavior might be influenced by providing their water use at such a detail level.

3.1. System architecture

The domestic water consumption monitoring system is a typical IoT system which was designed for collecting detailed information on the amount of water used in every appliance at a household. The system, as shown in Fig. 1, consists of a remote central server and as many unified wireless water sensing systems as required deployed in each household without any geographical constraints. The local wireless monitoring unit includes a few wireless data collectors, a WiFi router and a WiFi gateway. The remote central server is responsible for receiving data from multiple household wireless sensing systems. The wireless sensing system collects water consumption data in every appliance in each household.

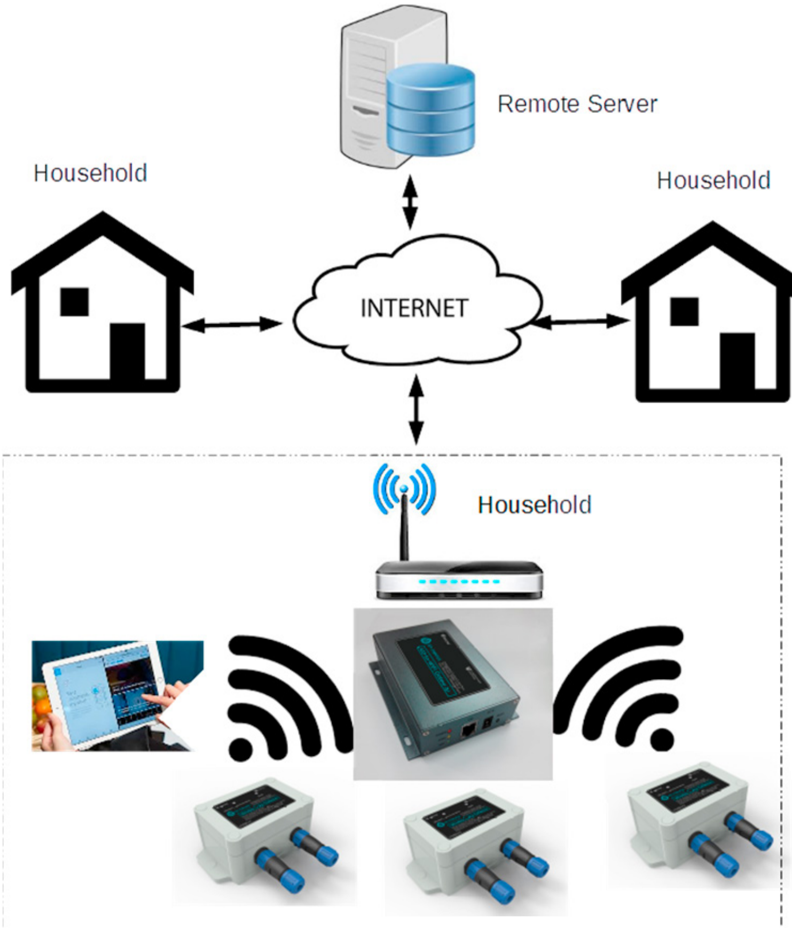

Fig. 1. System Architecture[12]

3.2. Wireless hardware design

The categories of the tailored hardware of the unified wireless water sensing system are a wireless data collector and a WiFi gateway. The tailed wireless data collector was designed as shown in Fig. 2 to collect water flow rate and water temperature and then send to the WiFi gateway wirelessly. No configuration is required as the data collector can automatically connect with the nearest WiFi gateway. The flow rate/temperature sensor used together with the wireless data collector is a commercial available product which can be replaced by other types of the sensors, not necessary for water flow and water temperature if the application domain is changed. Sensors are installed on water supply pipes for all the appliances at different spots in a household, such as kitchen tap, dishwasher, washing machine, shower, toilet and etc., to detect flow rate/temperature for different uses.

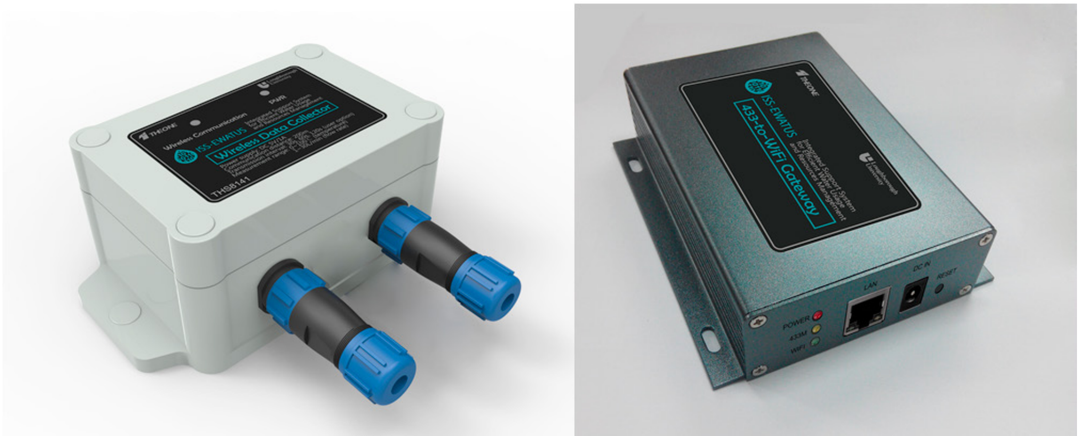

Fig.2. Wireless sensing device and wireless gateway. Left side is the data collector, right side is the gateway

A tailored wireless gateway was designed as shown in Fig. 2. The WiFi gateway has two functions: (a) wirelessly receiving data from one or more wireless data collectors; (b) converting the signal into a WiFi signal and passing it to the WiFi router. It works regularly in a predefined interval although data received from wireless data collectors may arrive at the gateway at any moment. There is no synchronization mechanism between the wireless data collectors and the gateway. The WiFi gateway can be configured wirelessly through smart phone, tablet, PC and other mobile devices at the household where the wireless sensing system is located.

3.3. Remote server software design

Server software was also developed as a part of the system to receive the sensed data from households in different locations. The server software is developed based on Visual Studio 2012 and Microsoft SQL server 2014. The server requires .NET framework 4.5 or above. The central server can be located in any geographical location if there is the Internet connection there.

3.4. System testing and implementation

The system was first tested for six months in the laboratory at Loughborough University before massively implementing in Sosnowiec in Poland and Skiathos in Greece in March 2015. In total, 10 households in Sosnowiec and 20 in Skiathos have been equipped with the wireless water sensing systems. Fig. 3 illustrates the implementation of the systems at sink, shower and toilet in the pilot households.

Fig. 3. Massive implementation in pilot households

4. Water consumption behavior intervention

Intervention strategies for this work must address two essential characteristics; the intervention must promote pro-environmental behaviour and its implementation must be ICT based. The field of 'Persuasive Technology' explores the interactive use of computers and computing technologies for persuading users to change, shape or reinforce their attitude and/or behaviour[13]. If a pro-environmental behaviour change intervention is to have a meaningful impact, its outcome should be sustainable over the long term and the design must be simple, and does not overwhelm the consumer with too much information ('low effort') but does require consumer participation. The "persuasive technology" approach builds on the assumption that human behaviour and attitudes may be influenced by technology and focuses on computer-human persuasion.

Factors identified by the literature review and the understanding of real-time data collected from the domestic water consumption monitoring system described in the previous section informed the selection of intervention strategies which formed a coherent intervention[14,15]. The retained intervention strategies were structured in a way in which technical descriptions of correspondent functionality in the DSS were specified so that the development process could seamlessly transition from intervention designers to software engineers.

5. Decision support system for households

There is a lack of decision support system (DSS) stimulating changes of people behaviour towards the efficient water usage based directly on the data gathered from their households. In this section a DSS is presented to implement the functions derived from the intervention model described in the previous section. These functions are classified into four groups: enhanced water consumption awareness, water saving advices (tips), water diary to distinguish the behavior among the family members, and water user classification. Each household is awarded a tablet installed with the DSS software which is in use since April 2016. We only discuss the DSS architecture and the enhanced awareness of water consumption in this paper. Detail of water saving advices, water diary and water user classification can be found from our previous publications[16,17].

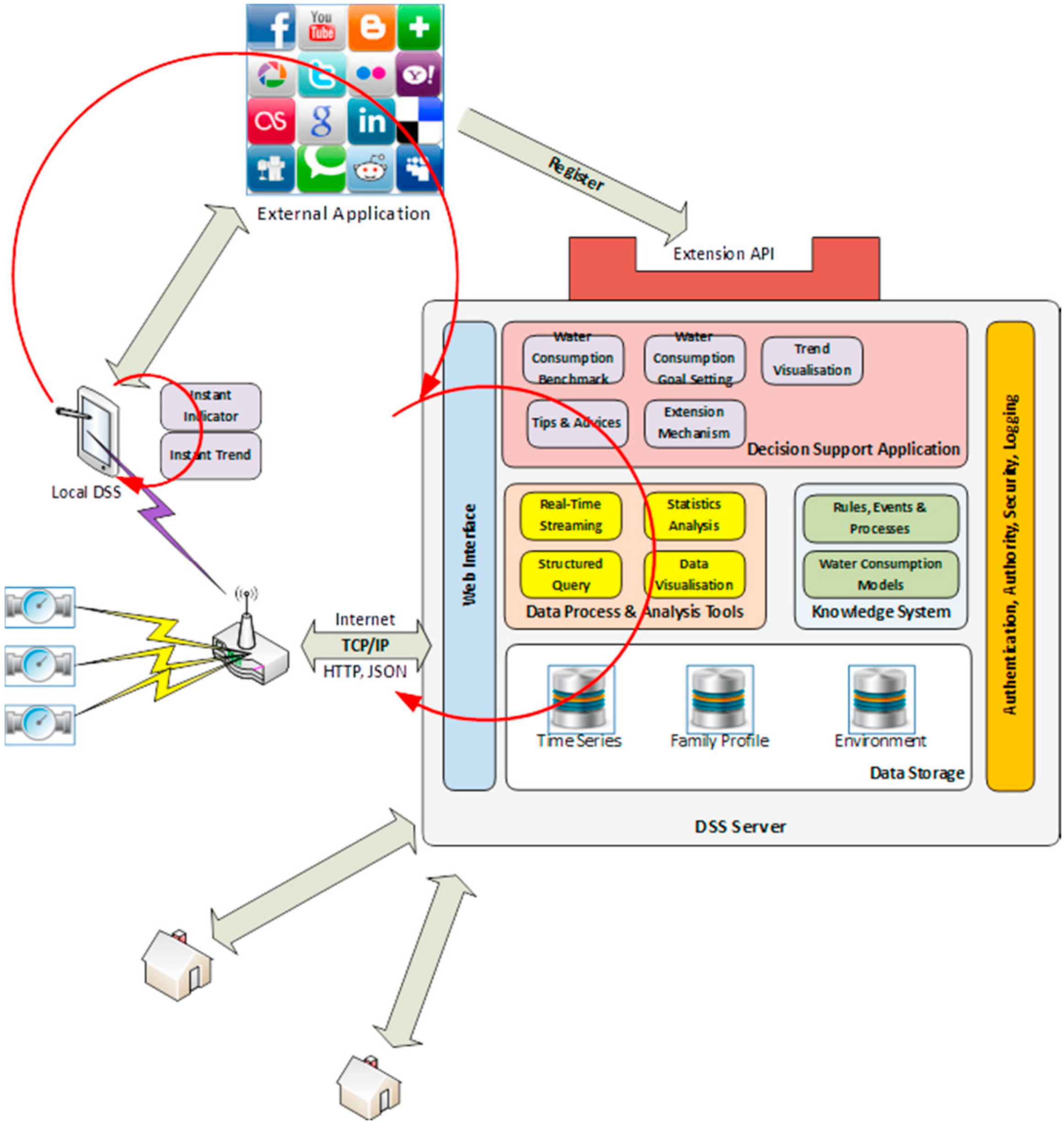

Fig. 4. DSS overall architecture

5.1. DSS components

A developed local DSS app for water consumption reduction was based on mobile devices, such as smart phones or other tablets, and connected with both a remote central database and a local domestic water consumption monitoring system in the household.

The overall DSS system components are illustrated in Fig. 4. 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.

5.2. Enhanced awareness of water consumption

The local DSS aims to provide the householder a good awareness of water consumption in a meaningful and effective presentation. The awareness was presented in various DSS functions such as daily usage, summary diagram, rate diagram, and goal setting et al. To illustrate the functions a summary diagram is shown in Fig. 5. The daily or weekly or monthly water consumption for all the appliances equipped in a specific household is presented in a bar chart.

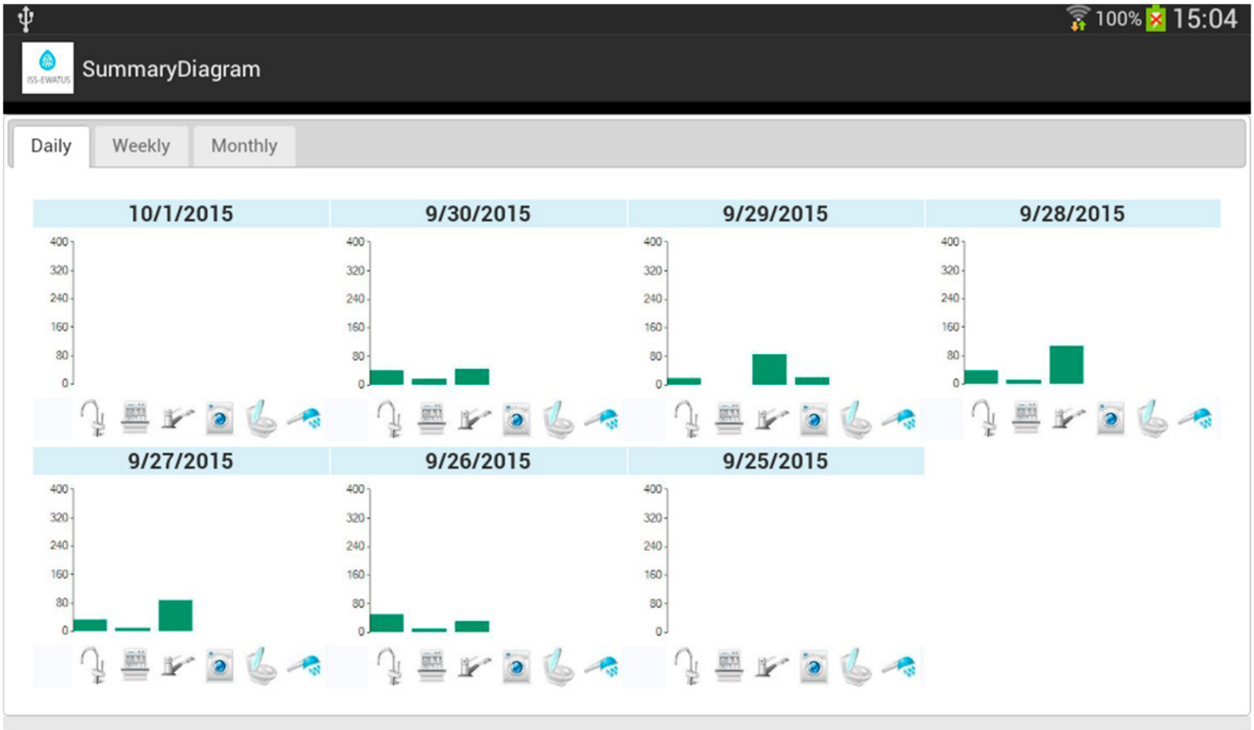

Fig. 5. Summary diagram of water consumption at each appliance

6. Conclusion

The purpose of this work conducted in the ISS-EWATUS project was to develop and test the effectiveness of a Decision Support System (DSS) for the efficient use of water at household level. This article reports the experience of fulfilling the project purpose by demonstrating the design, development, and implementation of the DSS. The functions of the DSS were derived from the behavior intervention model. The intervention was developed by an interdisciplinary team which drew upon expertise in the fields of intervention design, software engineering and social psychology. The domestic water consumption monitoring system at appliance level and the local DSS for affecting people's water consumption behavior are innovative and have not been reported before according to the knowledge of the authors.

Acknowledgements

This work is part of the ISS-EWATUS project (www.issewatus.eu) and has been funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no (619228). Appreciation also goes to our former research associates Dr Xi Chen, Dr Xiaomin Chen, Dr Kim Perren, and Dr Yixing Shan who have worked in Loughborough University on the project at various stages.

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