Global Water Crisis: Concept of a New Interactive Shower Panel Based on IoT and Cloud Computing for Rational Water Consumption

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Abstract: The present paper describes the problem and effects of water scarcity and the possibility of rational use of this resource in the idea of a Circular Economy (CE) and sustainable development. Rational water management requires innovation, due to the growing demand for this raw material. It seems that water is widely available, e.g., in Poland, there is no problem with drought. Unfortunately, Polish water resources are shrinking and modern solutions, as well as the construction of new and modernisation of old infrastructure, are some of the few solutions that can protect against a shortage of potable water. Water is also an essential resource for economic development. It is used in every sector of the economy. Limited water resources lead to an inevitable energy transformation because, in its present state, the Polish energy industry consumes huge amounts of water. Due to the above statements, the authors propose a solution in the form of an interactive shower panel that contributes to more rational water management (e.g., in households or hotels) based on the latest technological achievements. This device enables the creation of water consumption statistics based on accurate liquid flow measurements and the transfer of data to the user’s mobile device. This innovation aims to make the user aware of the amount of water used, which in turn can contribute to lower water consumption.

Keywords: water consumption; IoT; cloud computing; smart home; interactive shower panel; Industry 4.0

1. Introduction

It is well known that many countries around the world have critical access to drinking water. Fresh water accounts for only 3% of the world’s water resources, 70% of which are glaciers, which means that the water available for consumption is around 1%. Today, over a billion people do not have access to potable water. By 2050, at least one in four people are likely to live in a country suffering from chronic or recurring drinking water shortages.
There are 2.3 billion people currently living without basic sanitation. Currently, 90% of all natural disasters are related to water and the demand for fresh water is constantly increasing. This is due to the growing population (it is currently 7 billion, and, by 2050, it is estimated to be 9 billion), the improvement of the standard of living in more developed countries, and consumerism. An example may be the food production market, where around 15,000 L of water are used to produce 1 kg of beef [1].

Water scarcity also affects the economy, especially in Poland, where electricity production is mainly based on conventional power plants, which use hard coal and lignite as fuel. These facilities must be cooled with water, and low levels cause downtime, which affects the energy-intensive industry and, in the long term, affects other sectors of the economy. This aspect ultimately affects consumers, who have to bear the higher cost of living [2].

One of the sustainable development goals is to ensure universal access to clean water and sanitation by 2030.

In the context of the water crisis, the authors—guided by the idea that resources can be saved through awareness-raising and adequate education—proposed their own concept, which may contribute to a partial solution to the discussed problem. As part of this concept, an interactive shower panel has been designed to create highly accurate water consumption statistics. In traditional (commercially available) shower systems (shower panels and simple solutions based on one outlet), the user does not know how much water has been used. The authors suggest a solution whereby the user is informed about water consumption on a liquid crystal display in real time. In addition, the created water consumption statistics are sent to the user’s mobile device. This concept can be used in households as well as hotels and gyms. The device discussed in this article will notify the administrator of a public building of any failure involving an uncontrolled outflow of water, enabling a quick reaction, such as shutting off the main water supply. According to the authors, this seemingly small contribution to solving a massive problem may be significant because it can increase awareness in a wider group of people and contribute to more rational water management.

The article presents the problem of water scarcity in the world and the possibility of the rational use of this resource within the framework of a Circular Economy (CE) and sustainable development [3,4].

2. The Effect of Greenhouse Gas Emissions on Drought

Poland is one of the largest CO$_2$ emitters in Europe because energy is obtained from coal combustion (74% of the energy generated in Poland comes from coal) and due to the production of cement (Poland is the 3rd largest producer of cement in Europe; 1 Mg of produced cement is almost 1 Mg of CO$_2$ emissions and over 1 Mg of consumed raw materials). It is known that the emission of greenhouse gases causes an increase in the world temperature, and in Poland the average temperature has increased by 1.7 °C in the last 70 years [5,6].

In 1992, the UN Framework Convention on Climate Change was adopted, which aims to “stabilize the concentration of greenhouse gases in the atmosphere at a level that will prevent dangerous anthropogenic impacts on the climate system”. In 2009, in Copenhagen, the parties to the Convention determined that increasing the global average temperature by 2 °C would have a dangerous impact on the climate system. Maintaining such a temperature increase (preferably 1.5 °C) is based on natural variability over the last million years and raising the temperature above pre-industrial levels. A temperature increase of more than 2 °C may exceed the Earth’s climate system [5].

Rising temperature and climate changes in 2018 and 2019 caused a long-lasting agricultural drought in Poland. Despite heavy rainfall in May 2020, Poland is still struggling with the problem of drought. This is due not only to global warming but also to the lack of adequate water retention infrastructure. Sudden rainfall causes flooding of farmland and destruction of crops, and standing water and decomposing organic substances emit CO$_2$ into the atmosphere [7,8]. Due to the lack of, for example, an adequate number of retention
reservoirs, the water runs off, the soaked soil evaporates, and a quick return to soil drought occurs. In terms of water availability, Poland is similar to Zimbabwe [9]. Figure 1 presents the annual availability of fresh water for Europe (average for 1990–2010) [9].

The average rainfall in Poland is nearly 600 mm per year. Due to the clash of continental and oceanic influences, precipitation is highly unpredictable. Poland’s problem is snowless winters, which do not supply surface and underground watercourses [9].

The annual availability of fresh water varies greatly across Europe. The most critical situation is in Spain and Poland. The greatest amount of renewed water is recorded in Ireland, Great Britain, and Scandinavian countries.

3. Water Consumption

Despite the shrinking water resources, they are consumed in an upward trend. World population growth, industrialisation, and consumerism contribute to the excessive use of water resources. Figure 2 illustrates the world’s water consumption by specific sectors. The chart shows the real need for water use by agriculture after subtracting the water used for food discarded by consumers [10,11].
According to the Food and Agriculture Organization of the United Nations (FAO), one third of the food produced is wasted annually, which is around 1.3 billion Mg of food and 1000 km$^3$ of water used for its production [9,11].

3.1. Water Consumption in the Power Industry

The production of electricity and heat involves the consumption of gigantic amounts of fresh water. Water for the commercial power industry is a necessary raw material. Poland’s water resources for entities from the energy sector are critical because the Polish energy mix is based mainly on coal. Coal energy consumes around 70% of the water used in Poland and around 7% of the water used for industrial purposes. Water in this sector is needed at several stages, starting with coal mining [12]. For this purpose, groundwater is pumped out, and the suspension formed during coal washing often enters water reservoirs, causing their contamination. However, the largest amounts of water are used for the production of electricity in power plants based on the steam cycle, where water is necessary to replenish losses in boiler feed and heating installations, as well as for slag and dust removal processes, and above all for cooling energy devices, hence the frequent location of conventional power plants with large water reservoirs. Water is also used in the extraction of raw materials such as crude oil and natural gas. Water is forced under pressure into gas or oil deposits to “squeeze” them to the surface. The most water-consuming process is extraction from unconventional deposits—the so-called shale—where the amount of one-time injected water is from 10,000 to 14,000 m$^3$ [13]. Countries such as the United States, experiencing the “shale revolution”, experience the impoverishment of water resources.

Figure 3 shows water consumption with different energy production methods (water consumption in cubic meters per megawatt-hour of energy produced in different technologies) [12].
The amount of water used differs depending on the energy carrier and the type of cooling used, so it is important to choose technologies that minimise water consumption, primarily using the most water-consuming fuels for energy production. Renewable sources for energy production use the smallest amounts of water. Most of this raw material is used to generate energy from coal and nuclear power plants (Figure 3) [12,14].

3.2. Water Consumption in Agriculture and Food Production

The agricultural industry is the most water-consuming economic sector in the world. Agriculture also wastes the most water due to unused and discarded food. Practices aimed at reducing water consumption are, limiting meat consumption (for example, for 1 kg of beef meat, you need 14,500 L of water; 1 kg of pork requires 5990 L of water; 1 kg of poultry requires 4330 L of water) and the rational economy of produced and purchased food (the average Polish citizen throws away 235 kg of food). According to Eurostat research, those most responsible for wasting food are consumers (53%), followed by processors (19%), gastronomy (12%), producers (11%), and shops (5%) [1,15].

4. Solutions for Minimising Water Consumption and Intake

The low availability of fresh water is a global problem, but solutions to this problem should be sought locally. In 10 years, the world population will be around 8.5 billion people. If 5% of them use the household water recycle system, water abstraction will not increase. Any other solution introduced will contribute to the reduction of water consumption despite population growth [14].

4.1. Water in the Atmosphere

One cubic meter of air at a temperature of 25 °C can contain up to 23 g of water (maximum moisture content). Air cooling reduces the amount of water in the air, but this is not always proportional to the temperature rise. In desert areas, air humidity can fluctuate between around 8% during the day and 40% at night. Despite such extremely low air humidity, the use of air conditioning can significantly increase the amount of water used.
humidity, a device can obtain 200–250 mL of drinking water within 24 h. Such solutions are particularly suitable for wet areas with low access to drinking water or the development of uninhabited or dry places. Obtaining water from the atmosphere can be an element of the development of new cities and human habitats, where modern solutions will be used, such as a substitute for soil from waste or the use of Renewable Energy Sources (RES). It is estimated that there is six times more water in the atmosphere than in all the rivers on Earth [16].

4.2. Water in the Idea of Cleaner Production

Cleaner Production (CP) is primarily about designing, managing, and controlling production to minimise pollution formation. Cleaner Production aims to reduce the generation of used water, energy, or waste and recycle the used raw material on site after cleaning and treatment. The idea behind CP is to oppose the linear economy and support waste-free production. Implementation of CP is a stage of preparation for the certification of the environmental management system according to the EN-ISO 14 001:1996 standard [17]. An example of CP is product or process eco-innovation. Closed circuits in industrial installations are associated with natural resources and financial savings [18].

4.3. Dual Installation

The dual installation is a simple solution that uses additional elements in the sanitary installation in the household. The dual installation allows the consumer to collect water, e.g., from bathing or washing hands, and re-use it, e.g., for rinsing waste. The basic solution serves the purpose of water storage. However, it is possible to extend such an installation with additional elements such as filters. A dual system has many advantages. Among other things, it affects the reduction of bills and the consumption of natural resources. It also reduces the pollution of waterways. The cost of a dual plant and its maintenance are still high, which is one of the main disadvantages of this solution [19].

4.4. Retention Infrastructure

Retention reservoirs are used to retain and store water during rainfall. They significantly reduce the risk of drought and flooding [20]. For example, in Poland, there are not enough retention reservoirs and other infrastructure to accumulate water, e.g., ponds. Therefore, despite heavy rainfall, Poland is struggling with drought and flooding. Flood banks are a solution for small and medium-sized floods and provide the possibility of extending the evacuation time in extensive floods. They also cause the water in the riverbed to rise and run off faster. The construction of storage reservoirs will reduce the damage or destruction of buildings, roads, bridges, crops, communication problems, and other material, measurable, and immeasurable losses [19]. The construction of retention reservoirs also protects against the contamination of available clean water. Water accumulated during floods occurring mainly in inhabited or industrialised areas washes away pollutants, entering the environment in an uncontrolled way, causing them to be transported with the watercourse [19,20].

4.5. Measurement of Water Consumption as an Essential Element of Rational Resource Management

Correct measurement of water consumption indirectly influences the rational use of this resource. Due to the correct water measurement, it is possible to quickly diagnose a possible fault in the water supply network [21]. The current technology and its projected development may allow for the acquisition of real-time measurement data. This would allow for responsible water resource management and make it possible to control pump performance regularly. These measures would also contribute to reducing the failure rate of devices and faster leak detection. Unfortunately, Polish water resources are improperly and inaccurately metered, and the water supply network is insufficiently monitored. The water supply systems in Poland are outdated and do not prevent over-consumption. There is a need to create financial incentives to save water. A similar issue seems to be solving
problems at the level of the water supply network, where it is often not economically viable to remove leaks. It is well known that even a small leak over a long time causes significant water loss, but the process is rarely viable and it is often hard to locate the leak. Adequate water balance in the network is the basis for modern water systems, but it requires reliable information about all the processes. Cyclic measurements without the need for human intervention, i.e., in a fully automated, remote manner, would eliminate water supply network problems, such as leak detection. Accurate metering of water consumption would allow the end customer to become an active participant in the water market by introducing variable tariffs. One solution is the Advanced Metering Infrastructure (AMI) intelligent measurement system supported by the European Parliament. It allows remote two-way communication with the data collection system on the use of given media, e.g., water [22]. Accurate measurements also allow for the determination of water consumption profiles, which are characterised by annual, seasonal, monthly, weekly, daily, hourly, and secondly variability over time. These profiles, through the coefficient of irregularity, allow for the more efficient design of sanitary installations [23].

4.6. Clean Water Supply Networks

In order to maintain good water quality, it is essential to clean the aquifers. This also prevents the destruction of network elements, the replacement of which is associated with water losses, an increase in the amount of waste, and a shortening of the Life Cycle Assessment (LCA) of changed elements [24]. There are different methods for cleaning pipes, from metal sponges or other modern cleaning devices to technologies such as ice pigging. Ice pigging consists of cleaning pipes with crushed ice; the advantage is low invasiveness (less possibility of pipe damage and no possibility of blocking the device), while the disadvantage is the amount of waste generated, equal to the volume of the pipelines being cleaned. In this case, it is important to develop other methods of cleaning the resulting fluid and rational management of pollutants [21,25].

4.7. Household Treatments

The easiest to implement, but the most difficult to promote, is to instil and develop society’s habits [26]. A dripping tap can waste 5000 L of water per year, while flushing the toilet requires 6–15 L of water, depending on the flush model. Creating and publicising pro-ecological behaviour and solutions can contribute to thousands of litres of water being saved. Solutions exist to support water management at the household level [27]. One of them is Hydraloop (water recycling system), a device that purifies used water and allows for the recycling of up to 85% in the household. It uses sedimentation, flotation, dissolved air flotation, and biological treatment to purify water. Hydraloop saves an average of 30,000 L of water per year in a household. Purified water is suitable for cleaning the house, flushing the toilet, or watering the garden [28,29]. Another noteworthy solution is the classification of faucets. It allows consumers to consciously choose solutions with higher water and energy efficiency [30].

5. Concept of a New Interactive Shower Panel for Rational Water Consumption

As a result of the authors’ research and analysis, which was aimed at the sustainable use of resources in the shower panel (such as water and hygiene fluids), Figure 4 shows a developed innovative interactive shower panel prototype. This device integrates the latest technologies related to water flow control, temperature measurement, fluid dosing systems, recording parameters in computing clouds, the Internet of Things, and the specially developed software. It is also an example of a solution that fits in with the assumptions of Industry 4.0 [31,32] and Internet of Things solutions. In addition, this device has the function of collecting data about used resources to analyse all statistics in a dedicated cloud computing system. The full concept of the created device is presented in Figure 5. From the available works in which attempts were made to create this type of device, such as the Autonomous Smart Shower [33], it can be concluded that the audio systems were ignored.
entirely or were of poor quality. Therefore, in this work, a high-quality audio system using signal processors was also developed.

**Figure 4.** A prototype of the developed interactive shower panel.

**Figure 5.** A concept of the main controller unit of the interactive shower panel.

The main control unit is also responsible for controlling the available multimedia system. This solution is based on the Android operating system [34] and uses a Wi-Fi connection.
Due to the device’s direct connection to the Internet, the Trusted Platform Module [35] is used to ensure a secure connection to the Internet. It secures access to the most popular data clouds, such as Azure or AWS. In the presented solution, the data sent to the cloud or received from the cloud are secure.

It ensures the security of:

- remote reprogramming;
- sending information about the state of media, hygiene fluids, device operating parameters;
- transferring information about water consumption and liquid hygiene products to the Cloud Computing system;
- transferring information about potential failures and errors in the shower panel.

Access to such information by a Cloud System Administrator is crucial in saving resources because it allows a reaction. This enables the analysis of water consumption in real time and allows the user to be informed when the predetermined average consumption values are exceeded. In the approach proposed by the authors, the shower panel will contribute to reducing water consumption by educating the user and making the user aware of the need to protect resources and the environment.

A concept of the water controller unit is presented in Figure 6. The water controller unit’s main functionalities are valve control and the test mode activation for device configuration. It is connected with the solenoid main valve and allows the shower panel to shut off the water supply completely, especially when electricity is off. It also controls the water flow counter and temperature sensors responsible for monitoring water consumption and regulating water temperature according to the user’s expectation.

Figure 6. A concept of the water controller unit of the interactive shower panel.

Figure 7 shows the second module concept, responsible for controlling the dosing of hygiene fluids connected to the main controller unit. The soap controller unit, along with dedicated software, allows the choosing of one of four dispensers displaying their fill level. After selecting the dispenser (hygiene fluid), fluid dispensing is activated when the hand is close to the sensor. The specially developed software allows the consumer to set the correct dose of dispensed liquid and prevents the liquid from dripping. The soap controller unit module also integrates the proximity sensor and enables the configuration of the hand’s distance from the sensor in order to start dispensing. The software, together
with the designed communication, uses the I2C bus. It has also been adapted to all the needs and functionalities required for the designed interactive shower panel’s failure-free operation. Moreover, the presented device also has the function of fighting Legionella bacteria through the programmed functionality of automatic (or remotely controlled) short-term water outflow from the upper rain shower, the temperature of which is set above 60 °C (this procedure is performed when the user is outside the shower cabin).

Figure 6. A concept of the water controller unit of the interactive shower panel.

Figure 7. A concept of the soap controller unit of the interactive shower panel.

6. Conclusions

The constant need for both development and a higher standard of living, and growing consumerism, are among the many reasons for the reduction of natural resources, including water. Unfortunately, its quantity is not unlimited, so there is a need for its rational management. This requires modern, innovative solutions based on the Circular Economy, where water should be re-used many times. An important issue is the awareness of the amount of water needed and consumed and the detection of possible failures and undesirable losses. Measurements of used water are not only aimed at determining economic aspects but are also necessary for the proper operation of machines and devices and the proper course of many processes. Incorrect estimation of the amount of water used leads to its excessive use, often unnecessarily. The water market requires extraordinary solutions and new technologies to obtain water from sources such as humid air or seas and to assess it in a safe and economically viable manner. An important issue is the modernisation and expansion of the infrastructure used for water treatment and transport, so that it is clean and does not adversely affect human health, and its losses are reduced to practically zero. When considering water resources, attention should be paid to the economy and its key sectors, such as energy and agriculture. They consume huge amounts of water, and the simplest solution seems to be to reduce food waste. The energy transformation in Poland is needed not only because of water resources but also climate change; the impact of coal-based energy on the impoverishment of water resources is significant. Unfortunately, without education and raising public awareness, measures to save water resources will be useless. This can be helped by the real-time reading of water consumption at the level of final elements of sanitary installations, which will allow users to participate in the water market—for example, by using tariffs.

As a result of the problem defined above, this work presents an invention aimed at the sustainable use of resources (such as water or liquid hygiene products) in a shower panel. This device integrates many modern technologies and implements a designed cloud environment. As a result, it also meets the assumptions following the idea of Industry 4.0. It is possible to monitor resource consumption in real time to react and inform the user, if
significantly exceeding the limits. It also becomes possible to automatically detect potential failures and immediately react to them, e.g., by cutting off the water until the arrival of the repair service.

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