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Analysing the financial efficiency of use of water and energy saving systems in single-family homes

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ABSTRACT

Increasing demand for water and energy sources, accompanied by continued increases in the prices of these sources, has been observed worldwide. This has resulted in the need to seek alternative sources. In response to this statement, a cost-effective analysis has been carried out to enable the use of selected systems to reduce demands for potable water and natural gas used for heating in single-family homes. The study includes the Drain Water Heat Recovery System, Gray Water Harvesting System and Rainwater Harvesting System. The Life Cycle Cost methodology has been applied as a tool for the analysis. Depending on the number of users and rate of piped water consumption the determined Life Cycle Cost indicator ranged from €11519 to €19678. The study has shown that the highest life cycle cost are characteristic of the graywater recycling variant. In circumstances where water consumption in homes for purposes of showering and toilet flushing exceeded 300 L per day, the most cost-effective is the option that combines all systems analyzed. The most preferred, in the other cases was the use of Rainwater Harvesting System. The sensitivity analysis carried out has also shown that costs changes associated with building water supply and sewerage facilities has had the greatest impact on life cycle costs of each solution. The analysis have shown that the systems under consideration could serve as alternatives for traditional installations. Their use has resulted in reductions in the consumption of fossil fuels and natural water resources, thus contributing to environmental improvements.

1. Introduction

Meeting human health and hygiene needs would not be possible without sustainable access to water and energy sources for heating purposes, amongst others. World economic growth is accompanied by continuous increases in demand for these valuable resources, although this is not concurrent with their increased use, thus resulting in increased interests in the use of unconventional saving methods (Duić et al., 2015). This process has become even more complicated as a result of increased energy costs and fees being paid for the supply of water and sewerage to buildings (Kępa et al., 2013). Methods aimed at reducing energy consumption can be considered from varied aspects, which include, amongst others, the use of energy efficient appliances as well as suggest behaviours aimed at energy saving (Mardookhy et al., 2014). Significant reduction in demands for fossil energy fuels is also attainable through the exploitation of alternative energy sources, which include renewable energy sources such as solar energy (Rodat et al., 2016), wind power (Wang and Teah, 2017), geothermal energy (Bravi and Basosi, 2014), and energy from wastes, including warm wastes (Moralez-Ruiz et al., 2016). Demand for portable water supplies to individual consumers could be drastically reduced by exploiting technologies that rely on alternative sources of water, which include first of all graywater (Hyde, 2013) and rainwater (Ghimire et al., 2012).

The problem of over-exploitation of natural resources applies also to Poland. For instance, the nation's water resources, which in dry years amount to 1100 m^3/person/year (Walczykiewicz, 2014), are rated as one of the lowest in Europe. Although water scarcity has not yet been experienced, the predicted climate change (Pavlik et al., 2014) may contribute to diminishing levels of water availability in coming years, which could eventually lead to a deterioration of the quality of life for future generations. Fossil energy resources are not also limitless (Speirs et al., 2015). Over the decades, they have been significantly reduced, and their availability is decreasing with each successive year (Cao and Pawłowski, 2013). Hence, there is a need for the introduction of technologies whose aim is to reduce the amount of water and energy consumption in all

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sectors of the economy, including the housing sector, which is one of the largest consumers of those goods.

One of the way that can influence the declining water resources is the economic use of rainwater. Rainwater Harvesting Systems (RWHS) are used in many countries in the world and they are seen as one of the ways to adapt the water sector to the changing climate (Mwenge Kahinda et al., 2010; Salas et al., 2009) and also as a response to the growing demand for water, as an outcome of increasing world population (UN-Water, 2011).

Rainwater is most commonly used for flushing toilets (Matos et al., 2013; Słyś and Stec, 2014; Domènech and Saurí, 2011), washing (Imteaz et al., 2012; Morales-Pinzón et al., 2014), car washing, irrigation of farmlands and irrigation of green areas (Zhao et al., 2009). Depending on the location and type of building, climatic conditions, size of the drained area and the demand for water, savings in municipal water supplies may reach different levels (Imteaz et al., 2013, 2014). The choice of an optimal solution of the rainwater harvesting system should take into account investments incurred in the construction of the system and operating costs resulting from its exploitation in their lifetime (Roebuck et al., 2011; Ghimire et al., 2012). The financial viability of the solution depends mainly on the tank's volume, the roof's surface and the water demand of the building (Bocanegra-Martínez et al., 2014; Imteaz et al., 2011).

The increasing world population is being accompanied by a growing range of urban areas, which in turn increases the roofing surface area as well as the amount of rainwater being discharged into sewer system. Therefore, RWHSs can not only serve as an alternative source of water in these areas, but must also contribute significantly to reducing storm water runoffs from the roof drainage systems, thus relieving sewerage and storm water overflows, as well as limiting the occurrence of urban floods (Basinger et al., 2010; Mahmoud et al., 2014).

Another way to reduce the consumption of water intended for human consumption, and consequently the fees paid for its delivery and water treatment, is the use of graywater (Hyde, 2013). Graywater as defined in the European standard (EN 12056-1, 2000), as opposed to black water, is free from faeces and urine. It is discharged each day from sanitary facilities, such as showers, sinks or washing machines, and its composition is fundamentally different from the composition of the waste water from the flushing toilet bowls (Marleni et al., 2015). The concentration of nutrients in graywater is definitely lower than in the black water (Thibodeau et al., 2014). However, it is characterized by a significant content of organic compounds (Antonopoulou et al., 2013; Santasmasas et al., 2013), which forces the potential users to install additional devices dedicated to graywater pretreatment (Grčić et al., 2015).

The concentration of various pollutants of graywater is mainly dependent on the source of their formation (Vakil et al., 2014). They can indeed vary within a wide range (Donner et al., 2010), but the most contaminated fluid is that from the kitchen (Table 1). It often contains oils and other adverse substances whose presence in the wastewater disqualifies its use for flushing toilet bowls and watering of gardens, meaning it is not put to normal use (Oron et al., 2014). However, some authors (Li et al., 2009) suggest that water discharged from the sink and dishwasher should be mixed with other types of graywater and then subjected to a process of biological treatment.

Wastewater generated during washing clothes contains significant amounts of detergents and bleach, and although researches on its use are on-going (Misra and Sivongxay, 2009; Misra et al., 2010), it can still raise a lot of controversy, especially that the wastewater discharged from laundries, may still contain enteric pathogens (O'Toole et al., 2012).

For this reason, the internal use of Graywater Harvesting Systems (GWSH) are usually designed for the flow resulting from the volume of wastewater discharged from showers, bathtubs and washbasin. Examples of such systems are described, among other things, in works by Eriksson et al. (2009). Bathroom graywater may include soap, shampoo, detergents or hair (NSW Government, 2008), and if there are children or elderly people in the household, one can also trace some amounts of fecal matter (Ottoson and Stenström, 2003). The total concentration of impurities in them is relatively small compared with the wastewater discharges from other sanitary facilities, and that is why they can be re-used after the primary pretreatment process.

Graywater pretreatment systems, which are based on physicochemical processes, are mostly based on the filtration and disinfection. Sometimes some systems for biological treatment of wastewater, discharged from the individual sanitation, are also used. In the latter case, primarily systems with the water treatment facilities in membrane processes are applicable (Allen et al., 2010).

Pretreated graywater from households is mainly used for flushing the toilet bowls and watering the garden (Penn et al., 2013), sometimes in conjunction with rainwater (Agudelo-Vera et al., 2013; Morales-Pinzón et al., 2015). In both situations, the operators of such systems may come with a number of disadvantages (Domènech and Saurí, 2010), however, if properly designed and used, the risk can be reduced to the minimum. A proof of this propriety of this thesis is the experience gained from the operation of pilot systems of graywater recycling functioning in different places around the world, examples of which have been described in the works of Friedler and Gilboa, 2010; Gual et al., 2008.

Another way to manage graywater is the recovery of the heat carried by this sewage. For larger objects heat pumps (Hepbasli et al., 2014), or Drain Water Heat Recovery (DWHR) units (Wong et al., 2010) are most often applied. These can be also successfully applied in single-family houses (Kordana et al., 2014). Both of these devices can also be used simultaneously. The efficiency of such solutions has been studied by Wallin and Claesson (2014a; 2014b).

Depending on the design, DWHR units can be mounted either in the drain of graywater to the sewage system or directly on to the sanitary system, which is usually the shower. The choice of a particular solution for the heat exchanger and the method of wiring for the plumbing system is very important from the point of view of the users of this system. It has an influence on the efficiency of heat recovery from graywater in the subsequent years of managing the system, and also on the profitability of the project (Słyś and Kordana, 2014).

The application of the described technology can contribute

Table 1
Characteristics of graywater depending on its source (based on: Crook, 2009; WHO, 2006).

Graywater source	Graywater quality
Bathtub, shower, washbasin	Suspended solids, oil and grease, organic matter, hair, soaps and detergents, hair dyes, skin particles, turbidity, bacteria
Automatic clothes washer	Suspended solids, detergents, oil and grease, organic matter, nitrates and phosphates, foam, sodium, high pH and salinity, turbidity, bacteria and viruses
Kitchen sink, dishwasher	Food particles, oil and grease, organic matter, soaps and detergents, suspended solids, odor, bacteria