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Water and energy saving in urban water systems: the ALADIN project

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Abstract

The ALADIN project was aimed at contributing to environmental and energy sustainability of the urban water system by means of a decision support tool able to allow an evaluation of the energy impact related to each different macro-sectors of urban water cycle highlighting the main energy flows and to assess the system energy balance and identify the possible energy-efficient solutions. Moreover the tool suggests the most efficient actions in reducing water losses. In the present paper the main features of the developed tool are presented.

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Keywords: energy saving; urban water systems; water saving; performance indicators; monitoring; decision support system

1. Introduction

Energy cost represents about the 35% of the operating costs for water utilities and this share is expected to increase due to population growth and tightening drinking water regulations. Energy is needed in every phase of water use, from extraction through conveyance, treatment, use, and disposal (Fig. 1) [1]. The amount of energy consumed is

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strictly related to water system location, resources availability and quality, area topography, supply network topology, and water and wastewater treatments. If freshwater resource is not available and desalination is considered as alternative [2, 3], the energy intensity, expressed as energy per cubic meter of water, can run up to 15 kWh/m^3, as reported in Nogueira Vilanova and Perrella Balestieri [4].

It is widely known that the presence of water losses affects the amount of energy required to supply water. Namely, the water volumes supplied to the network are greater respect to the actual users demand due to leakages, consequently pumps are oversized and a proportional energy waste occurs [5, 6]. Since the pumping cost is considered one of the major operational cost and even a small overall increase in pumping efficiency may result in significant cost savings [7-9], water losses reduction allows to achieve two goals: the water and energy saving.

The EU [10] as well as academia and water industries have shown interest in investigating water-energy interaction [11] as well as greenhouse gas (GHG) emissions [12-15] in the urban water system. Understanding such relationship is an important issue to reach a sustainable and cost effective water management. Several studies have been already carried out in Australia [16, 17] and United States [18-20], but still an integrated approach is needed to improve the energy management in such complex systems [1, 2].

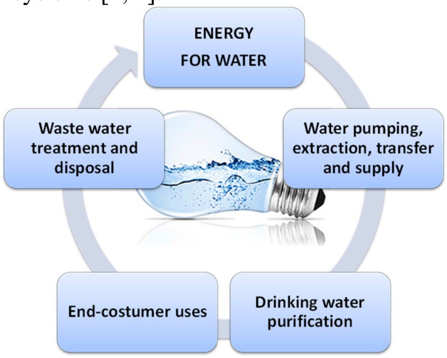

Fig. 1 Energy consumptions in integrated water systems

It is well-known that the urban water system management presents several problems due to the extension of the water supply networks, the difficulty in monitoring every point of the system, as well as the multiplicity and variety of water and wastewater treatment plants. Moreover, only overall energy consumption is usually available and its allocation to the system sections is hardly to accomplish. As consequence, the water service management focused on water and energy saving, is difficult to achieve. To overcome such difficulties, identifying the energy impacts associated to each macro-area of urban water system and analysing the potential interactions between them are essential requirements. Afterwards several water and energy saving strategies, in terms of system design, operation and maintenance, should be evaluated according to the existing interactions between water losses, energy consumptions and GHG emissions. Namely, the active control of water losses can lower the energy consumption [6], the use of renewable energy sources can cut the GHG emission amount [21-23] and the adoption of a suitable energy tariff can further reduce the energy cost [21].

In order to face with the water and energy saving issues in the urban water systems, the ALADIN project aimed to develop a decision support tool able to identify each contribution to the water and energy balance relating to the whole system and to suggest strategies finalized to the energy and water losses management improvement. The energy allocation contributes to find the most energy-intensive areas of the system for which several actions are proposed. Due to the existing interactions between water losses, energy and GHG emissions, the identification of reliable strategies requires a multi-criteria analysis able to outline the possible actions and energy conservation measures without negatively affecting the system hydraulic performance or water quality.

In the present paper the basic features of the abovementioned tool are provided in section 2 where the ALADIN prototype is described. Following the hydraulic modelling and monitoring data management into the prototype in section 3, and the decision support tool based on multi-criteria procedure in section 4 and finally conclusions are presented.

2. Basic Features

The ALADIN system structure has three information sources outer layers (OPERATOR, KNOWLEDGE BASE and MONITORING) which provide inputs to the system core constituted by three main modules (OPERATIONAL ACTIONS, INTEGRATED MODEL and DSS) whose functions are interrelated and interdependent by exchanging input and output data (Fig. 2).

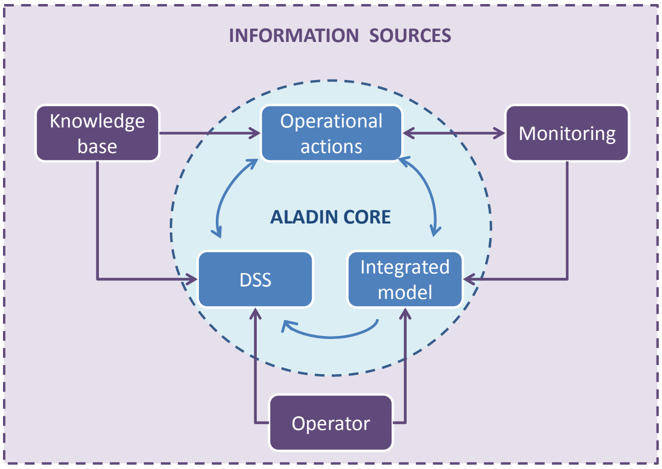

Fig. 2 ALADIN system structure

Namely, firstly the ALADIN system receives input data from different information sources. These data are used to evaluate the water and energy balance of the analysed water system or sub-system. Secondly, the water losses and energy impact related to each sub-systems are highlighted.

2.1. The integrated water system model

In the ALADIN project the whole urban water system is modelled as set of entities. Each entity is described by several variables depending on the selected class e.g. well, spring, water treatment plant, main water supply, distribution network, sewer, wastewater treatment plant. Moreover, further classes were arranged in order to take into account energy consuming devices as well as RES (renewable energy systems) e.g. pump, motor, wind and solar power plants. Therefore, two different entities can be distinguished: water and energy entities. The former are grouped in five sub-systems: water resources, water supply and distribution network, water treatment, urban drainage and wastewater treatment. The latter can belong to a water entity or simply considered as supplementary (auxiliary) services.

Variables can be edited by operators or evaluated by parsing the output of hydraulic modelling software (e.g. EPANET) or remote monitoring systems.

2.2. Analysis tool

Once the system data definition is accomplished, the analysis tool provides the water and energy balance as well as the system performance by means of individual and composite indicators [24].

The water balance is defined according to the Italian law DM 99/97 [25] whose rates are easily overlapped to the well-known IWA water balance [26]. The energy balance takes into account both energy consuming and producing devices, thermal energy is also considered. To each class or sub-system an energy rate is accomplished both in terms of electrical energy consumption and production.

Performance indicators (PIs) specifically refer to water leakages reduction, energy consumption, environmental impact, quality of service and financial cost aspects. The PIs set was defined according to [27] and slightly modified for the ALADIN purpose. Moreover, new indicators are included to analyse other aspects such as system *exergy* [28, 29]. The full-list of indicators with their definition is not reported here due to maximum pages limit but it is available by consulting the project final reports. For each PI value a performance score is obtained by means of a penalty curve which was suitably defined by taking into account the judgment of experts and data collected by statistics conducted by government or research agencies at national and international level (Fig. 3). Specifically, the performance is adapted to the level of service, ranging from a "no service" and an "optimum service" condition, and the curve is devised to penalize the behavior far from "optimum service" conditions. The performance score varies between 0 and 5, and an action threshold is defined for each PI in order to point out critical issues for the selected system. According to performance scores, operator goals and technical feasibility, ALADIN guides the operator in the selection of operational actions.

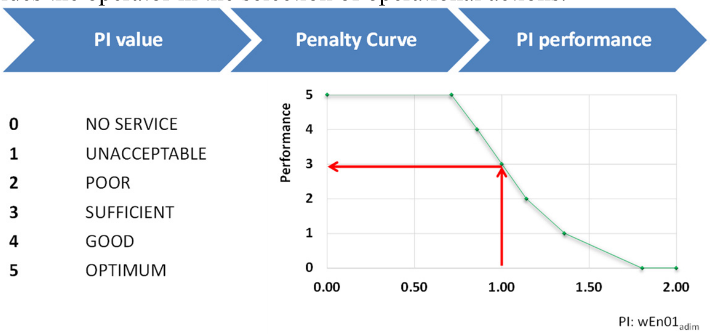

Fig. 3 Performance assigned to each PI value by means of specific penalty curve

2.3. Operational actions and scenarios

The ALADIN embedded operational actions are mainly focused to some aspects of urban water system management such as water losses, energy consumption and GHG emission reduction. Nevertheless, the financial as well as operational aspects linked to the quality of service (e.g. minimum pressure level for water distribution network, effluent concentrations for wastewater treatment plant) are taken into account. The actions can be distinguished as follows:

- water losses reduction
- energy saving and recovery in/at:
  - pressurized pipes
  - drainage system
  - water and wastewater treatment plant
  - customers level
- energy production from RES

For each action the technical features and the possible influences on the system efficiency are reported.

In order to verify the effect of the selected actions on the system performance, the operator can define several scenarios. In particular, a user interface allows to implement the actions in the system by providing spreadsheets accurately developed by experts and enabling editing of the correlated variables. As mentioned above, the variables can be manually edited by operator or evaluated by means of hydraulic modeling software.

3. Monitoring and hydraulic modelling

The complexity of the urban water system leads to the application of monitoring systems and hydraulic models in order to understand the system response respect to a combination of events or actions. The pressure management for leakages reduction as well as the installation of turbines for energy production require preliminary data and subsequent simulations for assessing their technical feasibility. In the following, some key features about monitoring and hydraulic modelling integrated into ALADIN are presented.

3.1. The system monitoring: SESAMO

In ALADIN the information system called SESAMO is integrated. It is an operating system which is coupled with ICT (*Information and Communication Technology*) architecture based on the ECSS (*European Cooperation for Space Standardization*) protocol. In particular SESAMO is able to transfer and store georeferenced data coming from sensors or non-homogeneous dataset, to elaborate them for further applications and to manage several user profiles for data sharing [30]. The SESAMO monitoring system was tested in several domains (e.g. early warning system for landslides, precision farming), but only the water distribution network application was considered for the ALADIN purpose [31-33]. The selected sensors were basically associated to pressure, flow rate and water volume measurements.

3.2. The hydraulic modelling software

Many software are available for hydraulic simulations but no one is able to model the whole urban water system. Water supply networks, sewers and treatment plants are often modelled into specific software environment depending on the water utilities or designer preferences. Moreover, some simulations are often time consuming. In order to overcome such issues, ALADIN envisages to run offline simulations with any software and subsequently upload the output files. Each file is parsed in order to extract information which are properly handled for ALADIN purpose. At the time of writing, four different file parsing have been already implemented, according to the output of the well-known software: EPANET, SWMM, STOAT and WEST but other can be added in the future. Specifically, the file parsing works as a plugin of the main system, then introducing a new software means simply developing a new plugin. The abovementioned software were selected according to their availability, peculiarities and possible interaction with other software tools (e.g. GIS – Geographical Information System; SCADA - Supervisory Control And Data Acquisition) and also input and output procedures.

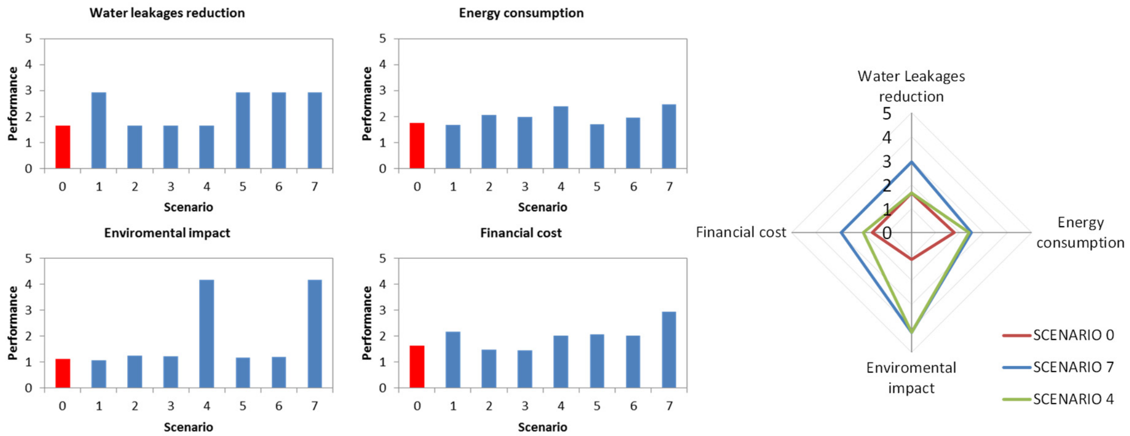

Fig. 4 Scenarios comparison in terms of global performance

4. The decision support tool

The Decision Support Tool provides a ranking of the operator-based scenarios. Moreover, it allows the comparison between them with regard to each investigated performance aspects (e.g. water leakages reduction, energy consumption, environmental impact, quality of service and financial cost) (Fig. 4). For each of these aspects, the tool evaluates the global system performance score by combining the PIs into a composite indicator [24, 34, 35]. Therefore, a pairwise comparison is carried out between scenarios: the global performance of each scenario is pair to pair compared with the others and a score equal to 2 is assigned to the specific scenario when the performance is higher, while 0 when is equal or lower. The global score of each scenario results from the sum of all pairwise comparisons scores. Greater is the scenario score, better is its overall performance.

5. Conclusions

In this paper the key features of the prototype developed during the ALADIN project were presented. The project aimed to develop a tool for water utilities but also professionals and public administrations in order to improve knowledge about the urban water system or part of it and verify some operational actions before doing investments.

The urban water system is modelled as set of water entities in which several energy devices can be considered. The integration of hydraulic modelling software output as well as remote system monitoring was accomplished.

The water and energy balances together with the PIs evaluation provide information about system efficiency in terms of water leakages reduction, energy consumption, environmental impact, quality of service and financial cost. The global system performances show the level of service for specific aspects respect to which the decision support tool gives a ranking among the implemented scenarios. The pairwise comparison reveals to be a suitable methodology for the scope of the project.

Great efforts have been made to develop a user interface, but some issues have to be fixed in order to realize a commercially competitive product. On the other hand, ALADIN provides only the basis of a more complex tool. Therefore, further development will include the enhancement of the user interface and the integration of a spatial data representation like GIS.

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