Research article

A tool for calculating energy audits in water pressurized networks

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Abstract: This paper presents a matlab-based educational software (UAenergy) developed to compute the energy audit of a water pressurized network. This analysis allows accounting for all the energy involved in the water distribution stage in the urban water cycle, showing that the energy balance is maintained —the energy input to the pressurized network is equal to the energy output plus the energy dissipated through friction. This energy audit requires a previous water balance and the hydraulic model of the network, both of which are necessary to know the energy flows through the system's boundaries. Obtained results show the energetic effect of every element (pipelines, pumps, valves, etc.) in the water distribution and also the influence of water losses in a leaky network. This software can be used for students and practitioners in the water sector, and it is possible to identify the improvement actions that will make the system more efficient.

Keywords: energy audit; water pressurized networks; matlab; leakage

Notation: A_i: Section of compensation tank i ; $\Delta H_i(t)$: Pressure variation through the leak at node i; $E_f(t)$: Friction energy for the simulation period; $E_{input}(t)$:Input energy for the simulation period; $E_L(t)$: Energy through leaks for the simulation period; $E_N(t)$: Energy supplied by the reservoirs for the simulation period; $E_P(t)$: Energy supplied by pumping stations for the simulation period; $E_U(t)$:Energy supplied to users for the simulation period; $h_{ni}(t_k)$: piezometric head (m.w.c.) supplied from each of the water tanks at time t_k ; $h_i(t_k)$: piezometric head (m.w.c.) at node i and time t_k ; n: Number of demand nodes of the network; n_p : Number of pumps; n_n : number of reservoirs; m: Number of pipes of the network; P_{i-ser} : minimum service pressure required for supplied demand; $q_j(t_k)$: Flow rate at line j at time interval t_k ; $q_{ni}(t_k)$: flow rate (m^3 s^{-1}) injected by the reservoir into the system; $q_{li}(t_k)$: Leakage flow rate at node i at time interval t_k ; $q_{lj}(t_k)$: Leakage flow rate at line j at time interval t_k ; $q_{ui}(t_k)$: flow rate delivered to users (m^3 s^{-1}); t_k : Time interval; $V_L(t)$: Total leakage volume for

the simulation period; $V_{inj}(t)$: Total volume injected for the simulation period; V_R (t): Total volume consumed by users for the simulation period; $z_i(t_p)$: the levels of the free surface of water of tank i at the initial times; $z_i(t_1)$: the levels of the free surface of water of tank i at the final times; α: Emitter exponent; γ: Specific weight of water; $\Delta H_i(t)$: Pressure variation through the leak; $\Delta E_C(t)$: Total variation of the energy compensation of the tanks; Δt_k: is the time interval (s).

1.   Introduction

Water and energy nexus in water pressurized networks (WPN) is probably one of the most relevant challenges that utility managers have to deal with around the world as managing water has been proved to be one of the biggest consumptive uses of energy and since only the adequate energy diagnosis entails the good efficient and energy sustainable management, a question also proposed in buildings [1,2] or museums [11]. In 2016, the International Energy Agency [19] stated that energy used in the water sector in 2014 is equivalent to 4% of global electricity consumption plus 50 million tons of oil equivalent of 2040.
The situation is similar in Europe, where the water sector is a major consumer of energy [20] and the energy consumption is equivalent to 3% of global electricity consumption [4–6]. In Spain, water sector consumed 5.8 % in 2008 [17], but these figures is explained as primary energy consumed in Spanish households are not included in this study.

In the water distribution step in the urban water cycle, energy use is within the ranges 0.1-0.6 kWh/m^3 as stated by some approaches [8,9], and water losses flowing through breaks in pipelines are estimated as 12% in the United States, 24% in Europe [19], 30% in Spain and 8% in Alicante city [7]. Water losses represent one of the most difficult problems utility managers should address as an appropriate quality of service must be maintained (water should be delivered meeting pressure and quality requirements) while reducing water and energy consumption. Leakage produced in pipelines is calculated with regard to material, length and inlet pressure [15] and the water and energy relationship is also considered in WPN [12–14]. In order to reduce energy consumption in the distribution stage of the urban water cycle, some approaches have been proposed for the definition of performance indicators to assess practitioners and decision-makers [15,16], for pipeline rehabilitation [17,18], for the quantification of potential energy recovery [19,20] and the allocation of micro turbines[3].

In this context, the energy audit (with results in kWh) in WPNs [6] identifies the energy entering the system and also their end uses. This analysis shows that the energy balance is maintained —in other words, energy supplied by reservoir and pumps are equal to the sum of the energy consumed in taps and through leaks, energy dissipated in pipes and in valves and the energy stored or supplied by tanks—. With these calculations, the energy lost through leakage is quantified, and such energy loss results not only from the energy leaving the system through leaks (high figures depending on the energy footprint of water, e.g., desalinated water) but also the energy needed to overcome additional friction losses created by higher circulating flow rates through pipelines. Moreover, a performance assessment system that characterizes the network has been defined [5] to obtain valuable results to make right decisions in operation and management of water utilities. The use of models for the hydraulic simulation of WPN allowed practitioners to calculate flowrates and head losses in pipelines, demands and heads in nodes for the energy audit calculation. As WPN and District Metering Areas (DMA's) analysed can entail thousands of Km and consumption nodes, these formulas should not be manually but automatically computed (for high values of the calculation time).

The objective of this work is to propose a matlab-based educational software which allows practitioners to calculate the energy audits. This software is aimed for educational and professional purposes, as a tool useful to understand and calculate the energy audit losses in WPNs. The reader is encouraged to download the software package and source codes available at https://bit.ly/2FbNqdr. To ease the use, a graphical user interface (GUI) manages all the process guiding the users during the process and a video describing how to run the software has been released in youtube (in English and also in Spanish) (https://youtu.be/H59DgJKIbBQ). Some case studies in some municipalities [18,26] and in irrigation networks [25,26] have been performed with this software. This software is the first open-source software performing these calculations. Case A has been solved by civil engineers in University of Alicante and they tested this software after developing their own hand calculations. This experience has shown that UAEnergy allow students to move forward the learning process.

The work is organized as follows. Section 2 describes how to calculate the amount of energy used in WPN. UAEnergy software is described in section 3. Software requirements, input data required to run the model and the results are also commented herein. The cases studies analysed here are presented and discussed in section 4.

2. Materials and methods

A calibrated hydraulic simulation model is required to solve the hydraulic problem. In order to perform the analysis in an extended period (t_p, which can take values such as 1 year, 1 month, 1 day, etc.), it is necessary to divide duration time into n_i intervals of time (Δt_k; 5, 10, 15, 60 minutes, etc.). Thus, the total energy consumed in the extended period ($t_p = n_i \cdot \Delta t_k$) is obtained from the sum of the energies consumed in each time interval of the steady state simulation.

2.1. Energy supplied by the reservoir

The external energy supplied by reservoirs is:

$$E_n(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{i=1}^{n_n} q_{ni}(t_k) \cdot h_{ni}(t_k) \right) \cdot \Delta t_k \tag{1}$$

here γ is the specific weight of water, n_n is the number of reservoirs, $q_{ni}(t_k)$ and $h_{ni}(t_k)$ are, respectively, the flow rate (m³ s⁻¹) and piezometric head (m.w.c.) supplied from each of the water tanks at time t_k, where Δt_k is the time interval (s). This term represents the natural incoming energy into the system (in other words, the amount of energy which is available to supply water to the WPN).

2.2. Energy supplied by pumping stations

The shaft work supplied by the pumps is:

$$E_p(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{i=1}^{n_p} q_{pi}(t_k) \cdot h_{pi}(t_k) \right) \cdot \Delta t_k \tag{2}$$

here $q_{pi}(t_k)$ and $h_{pi}(t_k)$ are respectively the flow rate pumped by the station (m³ s⁻¹) and the pump head (m.w.c.) at time t_k. This calculation needs to be done for the n_p pumping stations that

supply shaft work to the system at each discrete time t_k. This energy is water energy and by considering the performance of each pumping unit (an essential parameter for energy optimisation) the electrical equivalent can be calculated. In this paper, and since the focus is on shaft work supplied by pumps and not energy consumed from electricity grids, these energy losses (pump efficiency and asynchronous motor efficiency) have not been included in the analysis. This term represents the incoming energy into the system required to satisfy water demand in consumption nodes. The water utility has to pay for this consumption of grid electicity (in other words, the energy operation costs in the WPN). The greater shaft work values, the more useful (and important) the energy audit will be (for the direct cost involved).

2.3. Energy delivered to users at consumption nodes

The energy delivered to users is:

$$E_u(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{i=1}^{n} q_{ui}(t_k) \cdot h_i(t_k) \right) \cdot \Delta t_k \tag{3}$$

Where n is the number of demand nodes of the network, $q_{ui}(t_k)$ and $h_i(t_k)$ are respectively the flow rate delivered to users (m³ s⁻¹) and the piezometric head (m.w.c.) at node i and time t_k. The energy delivered to users shows the efficiency of the use of the energy injected to the system (in an ideal WPN every energy input should convert into energy delivered to users).

2.4. Energy through leaks

Water losses are classified as background and bursts outflows (Lambert, 1994) and bursts are generally the natural evolution of background leakages generating changes of WPN hydraulic functioning, detectable as anomalies in monitored flow/pressure data. Since the location of background leakages is not known, it can be assumed that leakage is uniformly distributed along every pipeline of the water distribution system. Based on common modeling assumptions, water leakage at nodes is equal to the water losses produced in the half of all pipes connected to it and fully described in many approaches [27,28].

Leaks represent energy leaving the system, formally analogous to the energy delivered to users although from the point of view of the audit it is lost energy. This term is:

$$E_l(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{i=1}^{n} q_{li}(t_k) \cdot h_i(t_k) \right) \cdot \Delta t_k \tag{4}$$

With n being the number of nodes in the network, $q_{li}(t_k)$ the leaked flow rate (m³ s⁻¹) in the pipes adjacent to node i (and therefore associated with this node) at time t_k, and $h_i(t_k)$ is the piezometric head (m.w.c.) at time t_k in the node where the leak $q_{li}(t_k)$ has been concentrated. The energy lost through leaks are energy losses which have arisen in WPN because of the number of breaks along pipelines, being equal to zero in an ideal leak-free WPN.

2.5. Energy dissipation in pipes

The energy dissipated by friction is divided into energy dissipated in pipes and in control valves [25] to take into account the singularities of the headlosses originated by friction in pipes and also the influence of regulating valves (their influence is much lower in urban water networks than in irrigation networks).

The energy dissipated due to friction in pipes is:

$$E_f(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{j=1}^{n_l} q_j(t_k) \cdot \Delta h_j(t_k) \right) \cdot \Delta t_k \tag{5}$$

where n_l is the number of lines of the network, $\Delta h_j(t_k)$ are friction losses (m.w.c.) in line j at time t_k (this term is the difference in piezometric heads between the initial and final nodes), $q_{uj}(t_k)$ and $q_{lj}(t_k)$ are, in line j, the flow rate necessary to satisfy the users demand and the flow rate that finally is lost through leaks, respectively. Therefore, the total flow rate in line j, $q_j(t_k)$, is the sum of the two previous values. This term shows the hydraulic capacity of the network. A higher value indicates lower efficiency. Although this can be brought to values very close to zero, eliminating friction losses implies a very costly design. Target values depend on a balance between investment and running costs.

2.6. Energy dissipation in hydraulic valves

The energy dissipated in hydraulic valves is:

$$E_v(t_p) = \gamma \cdot \sum_{t_k=0}^{t_k=t_p} \left(\sum_{j=1}^{n_v} q_{vj}(t_k) \cdot \Delta h_{vj}(t_k) \right) \cdot \Delta t_k \tag{6}$$

Where $q_v(t_k)$ is the flow rate ($m^3\ s^{-1}$) flowing through the hydraulic valve j at time t_k, n_v is the number of valves and $\Delta h_{vj}(t_k)$ is the piezometric head (m.w.c.) lost in the hydraulic valve j (calculated as the difference between the upstream and downstream nodes of the valve). This term is also energy dissipated in WPN (this as a matter of pressure-flows regulation). Higher values may show potential energy savings using turbines (or pumps as turbines; PATs) for energy recovery.

2.7. Energy compensation of the downstream tank

Many WPN accumulate water during nights (low consumption) in a tank which release this amount of water during the day (peak consumption). If the simulation period is short (one or two days according to experience), the tanks can be considered mass and energy sources but if the simulation period is large, the contribution of this tank to the long-term analysis is zero.

The variation of potential energy stored in tanks is:

$$\Delta E_C(t_p) = \sum_{i=1}^{i=n_C} \left(E_{C_i}(t_p) - E_{C_i}(t_1) \right) = \gamma \cdot \sum_{i=1}^{i=n_C} \left(A_i \cdot \left(z_i{}^2(t_p) - z_i{}^2(t_1) \right)/2 \right) \tag{7}$$

With A_i being the section of compensation tank i and $z_i(t_p)$, $z_i(t_1)$ the levels of the free surface of water of tank i at the initial and final times. The maximum variation of this energy, ΔE_{Cmax}, obviously corresponds to total oscillation between empty and full tanks of the whole system.

2.8. Final balance

From the preceding terms, where t_p is the period of calculation of the expressions (commonly one day or one year), the following final balance results:

$$E_{input}(t_p) = E_n(t_p) + E_p(t_p) = E_u(t_p) + E_l(t_p) + E_f(t_p) + E_v(t_p) + \Delta E_C(t_p) =$$

$$= E_{output}(t_p) + E_{dissipated}(t_p) + \Delta E_C(t_p) \qquad (8)$$

Equation (8) states that the energy supplied by reservoirs and pumps to the water coming into the network is equal to the energy delivered to the users (throughout the water supplied) plus the losses (leakage and friction). From this balance, energy losses can be evaluated and efficient actions aimed to improve system's efficiency can be planned.

3. Software description

UAEnergy software is described in this section. Input data required to run the model—the software used here for solving the hydraulic problem in the WPN is Epanet [31] —, the internal process and the results are also commented herein

3.1. Software requirements

UAEnergy have three key requirements:

- A programming software like Matlab® running in the PC (its performance is similar on Windows®, Mac OS® X, and Linux®).
- Matlab® requires the user to choose a supported compiler installing a new compiler or selecting one of the multiple compilers installed in the personal computer.
- To have installed the Epanet programmer's toolkit, which is a dynamic link library (DLL) of functions that allows developers to customize Epanet computational engine for their own specific needs. The functions can be incorporated into 32-bit (and also into 64-bits) Windows applications written in C/C++, Delphi Pascal, Visual Basic, or any other language that can call functions within a windows DLL.

Some additional information for installing this has been released in the following link: https://personal.ua.es/en/mpardo/downloads/uaenergy/uaenergy.html. (In English and also in Spanish).

The key limitations of UAEnergy are that it requires to have the WPN modelled in Epanet (which may be a problem in some municipalities) and the user must know how to run Matlab® in his personal computer.

3.2. Input data

The input form data creates a GUI (Graphical User Interface) for the user to enter the model of the water pressurized network to send to the simulation program (Figure 1). The user can create the input file in two ways, by exporting the network through the application (Epanet) graphic interface or by writing directly in a notepad file (inserting the data in a specific order and separated by tabs). Once the input file (.inp extension) is created, no errors should appear when running this hydraulic simulation as any error in Epanet returns an error in UAEnergy. The most common errors in Epanet are missing data (in pipes, junctions, etc.), disconnected junctions/tanks/reservoirs, and negative pressures. The user has to check that when running the .inp model return successful hydraulic calculations.

3.3. Graphical User Interface (GUI)

The software consists of a variety of functions that apply the presented methodology. As it requires the application of a specific workflow, a GUI is programmed to guide the user through all the

process (Figure 1). The button of the GUI is automatically activated after each step. Initially, the load button is active. The user can only press this button, which opens a menu to load the input file. Once the water network model is successfully loaded, 'Run' button is activated. There are not any additional input parameters that control the process.
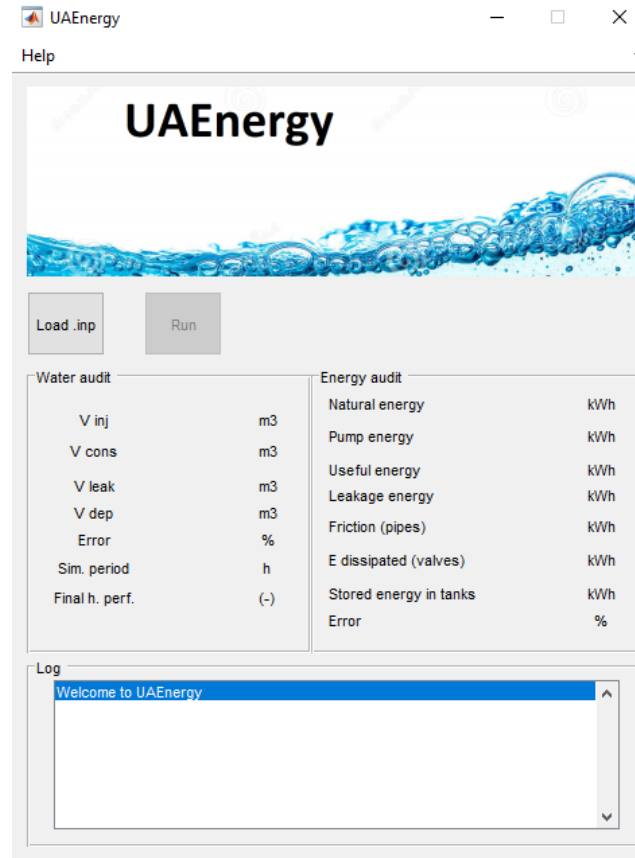

Figure 1. Screen-shot of UAEnergy.

The model loaded into UAEnergy has to consider the physical features of the WPN, which means data in nodes (base demands, elevation and hourly demand patterns), pipes (length, diameter, roughness, etc.), reservoirs (head), tanks (initial, minimum and maximum level of water, diameters, etc…), pumps (H-Q curves) and valves (type, settings, etc..) should be considered in the model. Moreover, the model has to be calibrated to represent real operation appropriately (which involves using observed flows/pressures in pipes/junctions). Without any doubt, the better the model represents real operation functioning, the more accurate the energy audit will be.

Leakage should be considered as pressure-dependent of node demands in the WPN model with the idea of adding an emitter—a device that models the flow through a nozzle— at each node of the network [18,28].

If the user wants to consider leakage in their WPN models, these emitters can be calibrated using an open source software called "UAleaks" which has also been developed and is available for downloading at: (http://bit.ly/2BmQjVP). A video describing the operation of this other software can be found at (http://bit.ly/2SvwF3O; [24]).

3.4. Output data

The outputs of the graphical user interface UAEnergy (Figure 2) are the water and energy audits shown in the graphical user interface in numbers, in graphs (Figure 2)
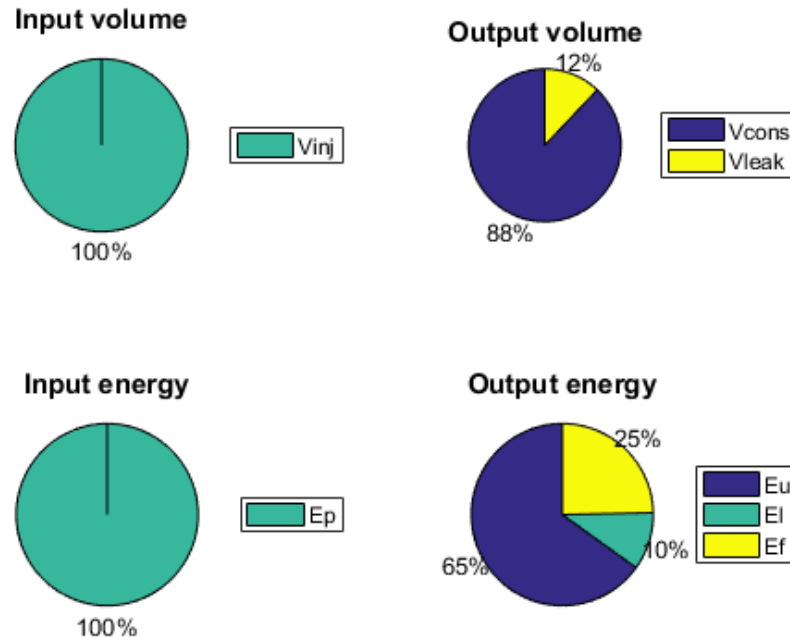
Figure 2. Results: pie charts of input and output volume and energy.

Moreover, a report file called "Name.inp – report.txt" and stored in the network path (this information is shown in the log menu shown Figure 1). This report file contains date of the simulation, the website where to download the software, the path where to find the model (whose energy audit has been calculated) and figures obtained for the water and energy audit. The user may import these figures in a spreadsheet for future analysis and also the graphs may be stored as an image in every format required (jpeg, tiff, pdf, etc…).

With the values of the water audit (which is calculated by UAEnergy as a consequence of the input hydraulic model considered), the student is allowed to check that the new model is taking into account the leakage flowrates, and the energy audit is shown to make the users understand that the outcoming water through leakage has a huge effect on energy losses.

4.   Numerical example

The objective of the following case studies is to demonstrate the effectiveness of the proposed software in some water pressurized networks. Case A, B and C are synthetic networks to help students/users understand these concepts while case D, and E are real cases in urban areas (D is a district metering area in a Mediterranean city) and in irrigation networks (E represents the irrigation network in the University of Alicante).

4.1. Network analyzed by MSc students

This software has been used by every student of the course "Maintenance and operation of water

distribution networks" and by some other MSc or Ph.D. students (in some other countries) who have known the existence of this software after some mailings and other advertises made by the software developers'. Although the key objective of this software it has been for students, some practitioners have shown their use in professional projects when managing WDNs. The explanation of these techniques involved two sessions (4 hours) to allow students to calculate the energy audit. The students informed about the good and quick results obtained in comparison with their hand calculation made and also commented that undertaking the audits in a real WDN would take a huge amount of time for a network such as a case A. In short, the students knew how to perform the calculation (and the high effort) manually.

Table 1. Line and node data Network A.

Line	Initial Node	Final Node	Length (km)	Diameter (mm)	Node	Base demand (l/s)	Elevation (m)	Emitter Coeff.	Pattern
10	9	21	2	300	11	5.8	5	0.006569	1
11	11	12	2	250	12	4	5	0.007507	1
12	12	13	2	250	13	2	3	0.006569	1
21	21	22	2	100	21	3	4	0.014076	1
22	22	23	2	100	22	2	8.5	0.013137	1
31	31	32	2	100	23	0	4	0.010322	1
111	11	21	4	150	31	1	2	0.005630	1
112	12	22	4	150	32	0	5	0.009853	1
113	13	23	4	150	33	0	2	0.006099	1
121	21	31	4	150	Res	-	1		2
122	22	32	4	150					
123	23	33	4	150					
32	33	32	2.5	100					
1	22	11	1	100					
2	21	32	1	150					
3	23	32	1	100					
4	22	13	1	100					

Figure 3 shows the network layout and Table 1 shows the node and line data (number of nodes, n=9; number of lines, m=17). The values of the hourly coefficients, which consider water consumption at different hours of the day, are depicted in Table 2. Pipe roughness is 0.1 mm and the emitter exponent is $\alpha=1,2$ (corresponding to a mixed pipe-network [32,33].

```
                              A.inp - report
UAEnergy. Pardo, Miguel Angel and Riquelme, Adrian
Report. 06-Feb-2019.
http://rua.ua.es/dspace/handle/10045/76947
File: C:\MATLAB\RUNENERGY\A.inp

Water audit:
Injected volume:3783.5167  m3
Consumed volume: 3326.3997  m3
Leakage volume: 457.1169  m3
Stored / Injected volume by the tanks: 0  m3
Volumetric error: 5.7596e-07  Simulation period: 24  h
Final hydraulic performance: 0.87918
Energy audit:
Natural energy:549.2389  kWh
Pump energy: 0  kWh
Useful energy: 549.2389  kWh
Leakage energy: 56.1916  kWh
Friction (pipes): 135.546  kWh
Dissipated energy (valves): 0 kWh
Stored energy in tanks: 0 kWh
Error: -5.5107e-07
```

Figure 3. Text file exported when running UAEnergy for Case A.

Table 2. Hourly coefficients of water demand modulation (pattern 1) and for simulating water pressure in the reservoir (pattern 2), Network A.

Pattern1	Time	1	2	3	4	5	6	7	8	9	10	11	12
	Coeff.	0.6	0.5	0.45	0.45	0.5	0.6	0.7	1.1	1.3	1.2	1.1	1
	Time	13	14	15	16	17	18	19	20	21	22	23	24
	Coeff.	1.1	1.45	1.5	1.3	1.2	1.1	1.1	1.25	1.3	1.4	1	0.8
Pattern 2	Time	1	2	3	4	5	6	7	8	9	10	11	12
	Coeff.	56.49	57.03	57.29	57.29	57.03	56.49	55.9	53.19	51.62	52.42	53.19	53.19
	Time	13	14	15	16	17	18	19	20	21	22	23	24
	Coeff.	50.36	49.92	51.62	52.42	53.19	53.19	52.03	51.62	50.79	53.92	55.28	56.49

4.2. Other cases analyzed

In order to show this methodology can be used in some other networks, four additional cases are presented. Figure 4 shows the layout of networks B, C, D and E.

Case B (Figure 4) shows the network layout proposed for performing the very first energy audit calculations [6] while Case C is the anytown network (a very well-known hydraulic model used in many scientific works [34,35].
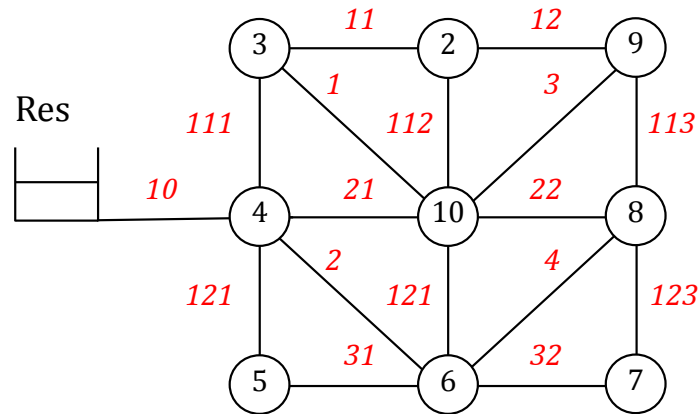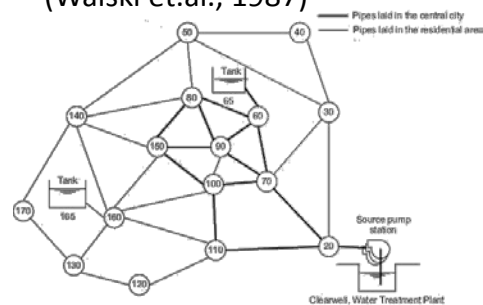
Figure 4. The layout of Network A.

Case D shows a district metering area (DMA) in a western Mediterranean city of Spain [26] and it supplies water to 10000 inhabitants and consists of 561 nodes and 617 pipes, its total length is 10,61 km. Finally, case E is the University of Alicante irrigation network [14]. The irrigation area of this garden has grown through time and new species have been added to the grass meadow (*Festuca arundinacea, Pennisetum clandestinum* and *Poa annua*), spread over an area of about 67 Ha. The network consists of 861 nodes, 891 pipes, a water well and four impeller pumps running in parallel and 160 electro valves upstream of the water discharge outlets, which are the hydrants. The total length of the network is 23 km.
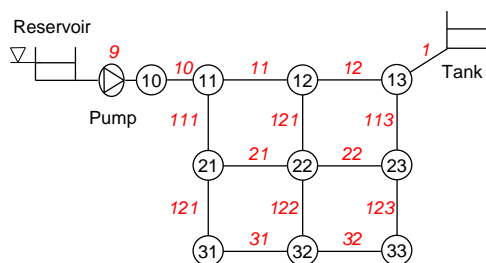
Figure 5. The layout of cases B, C, D and E.

4.3. Results and discussion

As Case A is a synthetic WPN, each student had different level of leakage to calculate the energy audit. Table 3 shows the outputs obtained when the level of leakage is equal to 0.85 (it means that 15 % of the injected water into the WPN left the network through bursts). The computational time obtained was below 5 seconds. On the other hand, students have reached the same result but they informed that the calculation process was very time consuming (2 or 3 hours) and it made impossible to perform in usual District Metering Areas or WPNs (in which 1000 nodes and pipes are usual values) as this calculation time increases exponentially with regard to the number of nodes and lines.

These results show the energy lost in water leaving the system through leakage and the comparison with some other models considering different levels of leakage show that the increase of water losses involves the increase of energy losses. If the network efficiency is 90 or 85%, the input energy is 536.29 kWh/day, which 352.10 kWh/day (61.94%) are delivered to final users, 71.42 kWh/day (12.57%) are lost through leakage and 144.95 kWh/day (25.49%) are dissipated in friction (Table 3).

Table 3. Students and UAEnergy results in Case A.

	UAEnergy	Student
Injected water (m^3)	3913.45	3913.45
Delivered water (m^3)	3326.40	3326.40
Real losses (m^3)	587.05	564.91
Volumetric error (%)	0.000000	0.5657
Hydraulic Performance (%)	84.9991	85.5649
En (kWh)	568.47	568.48
Eu (kWh)	352.10	352.10
El (kWh)	71.42	71.41
Ef (kWh)	144.95	144.94
Energetic error (%)	-0.0000	4.3361 10^-4

Case B correspond to daily simulations for a synthetic leaky network. The hydraulic time step used to calculate the simulations is 1 minute for the simulation (Table 4). These values are exactly the same showed in [6] as the model corresponds to the daily simulation described there. This numbers can be obtained manually and they are showed here for the reader to be able to validate results.

Anytown (case C) includes two compensation tanks and three pumps working in parallel. The results showed that most of the energy input into the system (94.44%) is energy consumed by pumps while only 306.44 kWh/day is energy supplied by the reservoir. As this anytown network is not considering leakage and as it is also oversized, energy dissipated in pipes only represents 19.13% of the total amount of energy input into the WPN.

Case D intend to check the power of UAEnergy in real WPN supplying water to consumers. The UAEnergy user should identify these this WPN is oversized (Table 4; very low energy dissipated due to friction in pipes), a usual situation when operating WDN in urban areas. Results are obtained and the computational time is less than a minute when running the software and it seems to be impossible (or at least very time-consuming) to perform these hydraulic simulations in networks with so many pipes and nodes.

Case E represents the University of Alicante irrigation network where the energy is supplied by

the reservoir (80.43%) and pumps (19.57%). These figures (Table 4) show that 4.38% of the input energy is dissipated by friction and the 95.62% left is delivered to crops.

Table 4. Energy audit results with the UAEnergy software.

	B	C	D	E
En (kWh)	386.65	306.44	282.94	590.48
Ep (kWh)	977.75	8917.53	0	143.66
Eu (kWh)	453.2	7068.18	253.90	701.94
El (kWh)	232.67	0	28.11	0
Ef (kWh)	549.8	1758.63	0.94	31.88
ΔE_C (kWh)	128.51	367.98	0	0
Simulation period (h)	24	24.	48	72

5. Conclusion

This manuscript presents an open source engineering tool called UAEnergy. This software has been programmed with a general public license and an open source distribution to promote the download, use and share of the code and is available in a public repository. Practitioners are encouraged to undertake these calculations manually and to use UAenergy as a tool to validate results. Moreover, professional civil and hydraulic engineers also run this software with positive feedbacks, which means, in short, that they reached similar results with lower computational time.

Energy audits are calculated as the key result of this software. As the energy audit requires to have solved the hydraulic problem first, the water audit is also computed (not being the key result of this software) as water demands and leakages rates are required for the energy calculations. Five cases (two of them are real cases) have been performed and results highlight energy losses result not only from the energy leaving the system through leaks (which can be quite significant, e.g., desalinated water) but also the energy needed to overcome additional friction losses created by higher circulating flow rates through the pipes. Moreover, it also shows that these two real networks are oversized because of low values of energy dissipated through friction. It has also been pinpointed that this studies are relevant in WPN whose energy is consumed from electricity grids (Cases B, C and E).

Conflict of interest

All authors declare no conflicts of interest in this paper.

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