WATenERgy CYCLE
Urban water full cycle: from its source to its end-users and back to the environment

WP4 Common methodology & tools
Joint Del. 4.3 Energy efficiency & recovery

PP4 - University of Thessaly-Special Account Funds for Research-Department of Civil Engineering

Project co-funded by the European Union and National Funds of the participating countries

WP4: Common methodology & tools

- Responsible partner: PP4 - University of Thessaly-Special Account Funds for Research-Department of Civil Engineering

- Partners involved: ALL

- Budget: 115,507.68 €

Project co-funded by the European Union and National Funds of the participating countries

WP4.3: Energy Efficiency & Recovery

- The operation of Water Distribution Systems (WDSs) generally require high amounts of energy, which vary in relation to the characteristics of the served area, but also from design and management choices (Bolognesi et al, 2014).

- The assessment of energy efficiency in water distribution systems is strongly influenced by the nature of the **water-energy nexus** in pressurized networks (Gay et al., 2010; Lenzi et al., 2013).

- A systematic energy analysis is required to evaluate separately the influence of pumping stations, network and water loss and can allow to highlight problems in the design and management that are reflected the water-network nexus.

- Energy Audit will allow understand, a) **how much energy is lost**, and most important, **where is lost.** Well addressed **local actions** can optimize the energy consumption of WDSs.

WP4.3: Energy Efficiency & Recovery (Road Map Description)

- Initial requirements assessment: Assessment of water consumption. Exploring potential demand reduction in sustainable and optimal levels.
- Diagnosis of the system: System's losses (pumps, leaks, friction etc), network topography and system layout.
- Analysis of the required and topographic energy: Water and Energy audits are required
- Proposed Actions: These actions can be operational (do not require investments) or structural involving investments in the system (pumping station refurbishments and pipe replacements). Also recovering topographic energy is possible with PATs.
- Cost benefit analysis of the proposed actions.
- Certification and validation of the systems efficiency. (Cabrera et al, 2017)

Project co-funded by the European Union and National Funds of the participating countries

Energy characterization of a water system (Cabrera et al., 2014)

1st stage
- ***Basic diagnostic***
- *from basic data (energy and water injected into the system, water demands, pressure required and physical and topographical characteristics of the system), to do a diagnosis of the system*

2nd stage
- ***Water audit***
- *If the diagnostic say that the PWS is efficient, it is not necessary to go further. But not, it is urgent to know why and where energy is lost and how to reverse the situation. To do this, a water audit of the system, is required. Water is the energy carrier. From this point of view leaks are both water and energy losses.*

3rd stage
- ***Energy audit.***
- *The destination of the energy entering into the control volume that bounds the system must be identified. It is equal to the sum of the energy supplied to users and the energy losses (pump and motor drive inefficiencies, pipe's friction, valve's dissipation and, in some urban water networks, the energy lost in domestic tanks where water is depressurized).*

4th stage
- ***Analysis of operational actions.***
- *energy consumption can be reduced by improving the system's operation. In the urban case adjusting the pressure to requirements can be used. Either with variable speed pumps or with pressure reducing valves, that does not reduce energy costs but, as it reduce leaks, results in a final saving. Last pumps must work at their highest performance or when energy cost are lower.*

5th stage
- ***Analysis of structural actions.***

6th stage
- ***Label the energy efficiency of PWS***

Basic energy indicators (1/3)

- *The first "context indicator" C1 shows which portion of the energy delivered to the system is natural and ranges from 0 to 1, with the maximum being reached when all the injected energy is gravitational, being provided by a high water source.*
- *The second context information c2, considers how demanding from an energy point of view the network is. As the ratio between the minimum useful energy defined in each node from the minimum required head and a theoretical minimum required energy (for a flat, leak free and frictionless network). Since this ideal network corresponds to a flat layout with all nodes located at the same maximum height z_{max}, the best possible value of c2 is one.*

(Cabrera et al, 2010)

C_1 Energy nature	C_2 Network energy requirement
$C_1 = \frac{E_N(t_p)}{E_{Input}(t_p)}$	$C_2 = \frac{E_{min,useful}}{E_{min,flat}} = \frac{\gamma \cdot \sum_{k=t_1}^{k=t_p} \sum_{i=1}^{n} q_{ui}(t_k) \cdot (h_{Min})_i \cdot \Delta t}{\gamma \cdot \frac{P_{min}}{\gamma} \cdot \forall_U(t_p)} = \frac{\sum_{i=1}^{n} \forall_{u,i}(t_p) \cdot h_{min,i}}{\frac{P_{min}}{\gamma} \cdot \forall_U(t_p)}$

Basic energy indicators (2/3)

- *The first indicator, I_1, is the ratio between the real energy entering the system and the minimum useful energy.*
- *I_2, is a measure of the efficiency of the use of the energy injected to the system (which fraction of the total energy input is useful).*
- *I_3 represents 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.*

(Cabrera et al, 2010)

I_1 Excess of supplied energy	I_2 Network energy efficiency	I_3 Energy dissipated through friction
$I_1 = \frac{E_{input}(t_p)}{\sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}$	$I_2 = \frac{E_U(t_p)}{E_{Input}(t_p)}$	$I_3 = \frac{E_F(t_p)}{E_{Input}(t_p)}$
I_4 Leakage Energy	I_5 Standards compliance	
$I_4 = \frac{E_L(t_p) + E_F(t_p) - E_F^{'}(t_p)}{E_{Input}(t_p)}$	$I_5 = \frac{E_U(t_p)}{\gamma \cdot \sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}$	

Interreg Balkan-Mediterranean WATenERgy CYCLE

Project co-funded by the European Union and National Funds of the participating countries

Basic energy indicators (3/3)

- *The fourth indicator, I_4, measures the energy loss due to leakage, which results from the sum of energy loss through leaked water and the additional energy required to overcome friction with the increased flow rate needed to overcome leakage (difference between the actual energy dissipated in friction losses and the value of friction losses in a leak-free network,).*
- *I_5, is the direct ratio between the energy delivered to users and the minimum required useful energy. It is a network-level indicator that averages the overall condition of the system but may leave sector performance unnoticed (the average condition may be good while some sectors are performing poorly).*

(Cabrera et al, 2010)

I_1 Excess of supplied energy	I_2 Network energy efficiency	I_3 Energy dissipated through friction
$I_1 = \frac{E_{input}(t_p)}{\sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}$	$I_2 = \frac{E_U(t_p)}{E_{Input}(t_p)}$	$I_3 = \frac{E_F(t_p)}{E_{Input}(t_p)}$

I_4 Leakage Energy	I_5 Standards compliance
$I_4 = \frac{E_L(t_p) + E_F(t_p) - E_F^{'}(t_p)}{E_{Input}(t_p)}$	$I_5 = \frac{E_U(t_p)}{\gamma \cdot \sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}$

Interreg Balkan-Mediterranean WATenERgy CYCLE

EUROPEAN UNION

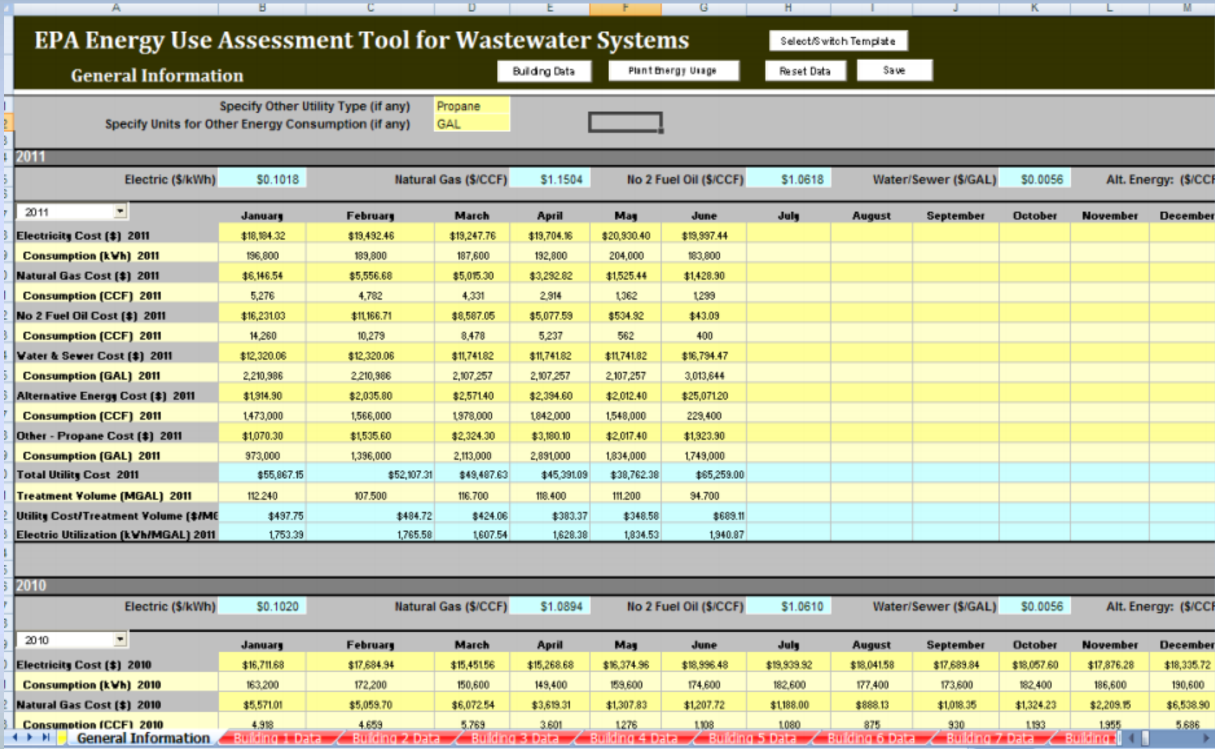
Project co-funded by the European Union and National Funds of the participating countries

Performance Indicators (energy efficiency)

A/A	GROUP	PERFORMANCE INDICATORS	MEANING	FORMULA	MEASURED IN
Ph4	Pumping	Pumping utilisation	[Sum, for all installed pumps, of the number of operation hours of the maximum energy consumption day during the assessment period multiplied by the nominal power of the pump / (maximum nominal power that can be used simultaneously in the system x 24)] x 100	Ph4=[D2/(C7*24)]*100	%
Ph5		Standardised energy consumption	Energy consumption for pumping during the assessment period / Sum of the volume elevated during the assessment period multiplied by the pump head / 100	Ph5=D1/D3	kWh/m3/100m
Ph6	Treatment	Reactive energy consumption	Reactive energy consumption for pumping during the assessment period / total energy consumption for the pumping during the assessment period multiplied by the pump head x 100	Ph6=(D4/D1)*100	%
Ph7		Energy recovery	(Energy recovered by the use of turbines of reverse pumps during the assessment period / total energy consumption for pumping during the assessment period) x 100	Ph7=(D5/D1)*100	%
Op12	Electrical & signal transmission equipment inspection	Emergency power system inspection	[(Sum of the nominal power of the emergency power systems inspected during the assessment period x 365) / assessment period)] / total nominal power of the emergency power systems	Op12=[(D16*365)/H1]/C18	/ year
Op13		Signal transmission equipment inspection	[(Number of the signal transmission units inspected during the assessment period x 365) / assessment period)] / total number of signal transmission units	Op13=[(D17*365)/H1]/C19	/ year
Op14		Electrical switchgear equipment inspection	[(Number of electrical switchgear units inspected during the assessment period x 365) / assessment period)] / total number of electrical switchgear units	Op14=[(D18*365)/H1]/C20	/ year
Op21	Pumps rehabilitation	Pump refurbishment	[(Total nominal power of pumps subject to overhaul during the assessment period x 365) / assessment period)] / total nominal power of pumps] x 100	Op21=[(D25*365)/H1/C6]*100	% / year
Op22		Pump replacement	[(Total nominal power of pumps replaced during the assessment period x 365) / assessment period)] / total nominal power of pumps] x 100	Op22=[(D26*365)/H1/C6]*100	% / year
Op30	Failure	Pump failures	[(Sum, for all pumps, of the number of days during the assessment period when the pump is out of order x 365) / assessment period] / total number of pumps	Op30=[(D27*365)/H1]/C4	days / pump / year
Op34		Power failures	[(Sum, for all pumps, of the number of hours each pumping station is out of service due to power supply interruption during the assessment period x 365) / assessment period] / total number of pumping stations	Op34=[(D31*365)/H1]/C5	hours / pumping station / year
Fi10		Electrical energy costs	(Electrical energy costs / running costs) x 100, during the assessment period	Fi10=(G11/G5)*100	%

Energy Audit Tools

EPA's Energy Use Assessment Tool is free of charge, downloadable tool based in Excel that can be used by small and medium water and wastewater systems. It allows a utility to conduct a utility bill analysis to assess baseline energy use and costs, drills down to equipment level, it has a printable summary report. It also depicts the presentation of energy consumption & costs (broad to detail), Graphs energy use over time and highlights areas of energy efficiency.


EPA Energy Use Assessment Tool for Wastewater Systems

General Information

Select/Switch Template | Building Data | Plant Energy Usage | Reset Data | Save

Specify Other Utility Type (if any): Propane

Specify Units for Other Energy Consumption (if any): GAL

2011

Electric ($/kWh) $0.1018 | Natural Gas ($/CCF) $1.1504 | No 2 Fuel Oil ($/CCF) $1.0618 | Water/Sewer ($/GAL) $0.0056 | Alt. Energy: ($/CCF

2011	January	February	March	April	May	June	July	August	September	October	November	December
Electricity Cost ($) 2011	$18,184.32	$19,492.46	$19,247.76	$19,704.16	$20,930.40	$19,997.44						
Consumption (kWh) 2011	196,800	189,800	187,600	192,800	204,000	183,800						
Natural Gas Cost ($) 2011	$6,146.54	$5,556.68	$5,015.30	$3,292.82	$1,525.44	$1,428.90						
Consumption (CCF) 2011	5,276	4,782	4,331	2,914	1,362	1,299						
No 2 Fuel Oil Cost ($) 2011	$16,231.03	$11,166.71	$8,587.05	$5,077.59	$534.92	$43.09						
Consumption (CCF) 2011	14,260	10,279	8,478	5,237	562	400						
Water & Sewer Cost ($) 2011	$12,320.06	$12,320.06	$11,741.82	$11,741.82	$11,741.82	$16,794.47						
Consumption (GAL) 2011	2,210,986	2,210,986	2,107,257	2,107,257	2,107,257	3,013,644						
Alternative Energy Cost ($) 2011	$1,914.90	$2,035.80	$2,571.40	$2,394.60	$2,012.40	$25,071.20						
Consumption (CCF) 2011	1,473,000	1,566,000	1,978,000	1,842,000	1,548,000	229,400						
Other - Propane Cost ($) 2011	$1,070.30	$1,535.60	$2,324.30	$3,180.10	$2,017.40	$1,923.90						
Consumption (GAL) 2011	973,000	1,396,000	2,113,000	2,891,000	1,834,000	1,749,000						
Total Utility Cost 2011	$55,867.15	$52,107.31	$49,487.63	$45,391.09	$38,762.38	$65,259.00						
Treatment Volume (MGAL) 2011	112.240	107.500	116.700	118.400	111.200	94.700						
Utility Cost/Treatment Volume ($/MG	$497.75	$484.72	$424.06	$383.37	$348.58	$689.11						
Electric Utilization (kWh/MGAL) 2011	1,753.39	1,765.58	1,607.54	1,628.38	1,834.53	1,940.87						

2010

Electric ($/kWh) $0.1020 | Natural Gas ($/CCF) $1.0894 | No 2 Fuel Oil ($/CCF) $1.0610 | Water/Sewer ($/GAL) $0.0056 | Alt. Energy: ($/CCF

2010	January	February	March	April	May	June	July	August	September	October	November	December
Electricity Cost ($) 2010	$16,711.68	$17,684.94	$15,451.56	$15,268.68	$16,374.96	$18,996.48	$19,939.92	$18,041.58	$17,689.84	$18,057.60	$17,876.28	$18,335.72
Consumption (kWh) 2010	163,200	172,200	150,600	149,400	159,600	174,600	182,600	177,400	173,600	182,400	186,600	190,600
Natural Gas Cost ($) 2010	$5,571.01	$5,059.70	$6,072.54	$3,619.31	$1,307.83	$1,207.72	$1,188.00	$888.13	$1,018.35	$1,324.23	$2,209.15	$6,538.90
Consumption (CCF) 2010	4,918	4,659	5,769	3,601	1,276	1,108	1,080	875	930	1,193	1,955	5,686

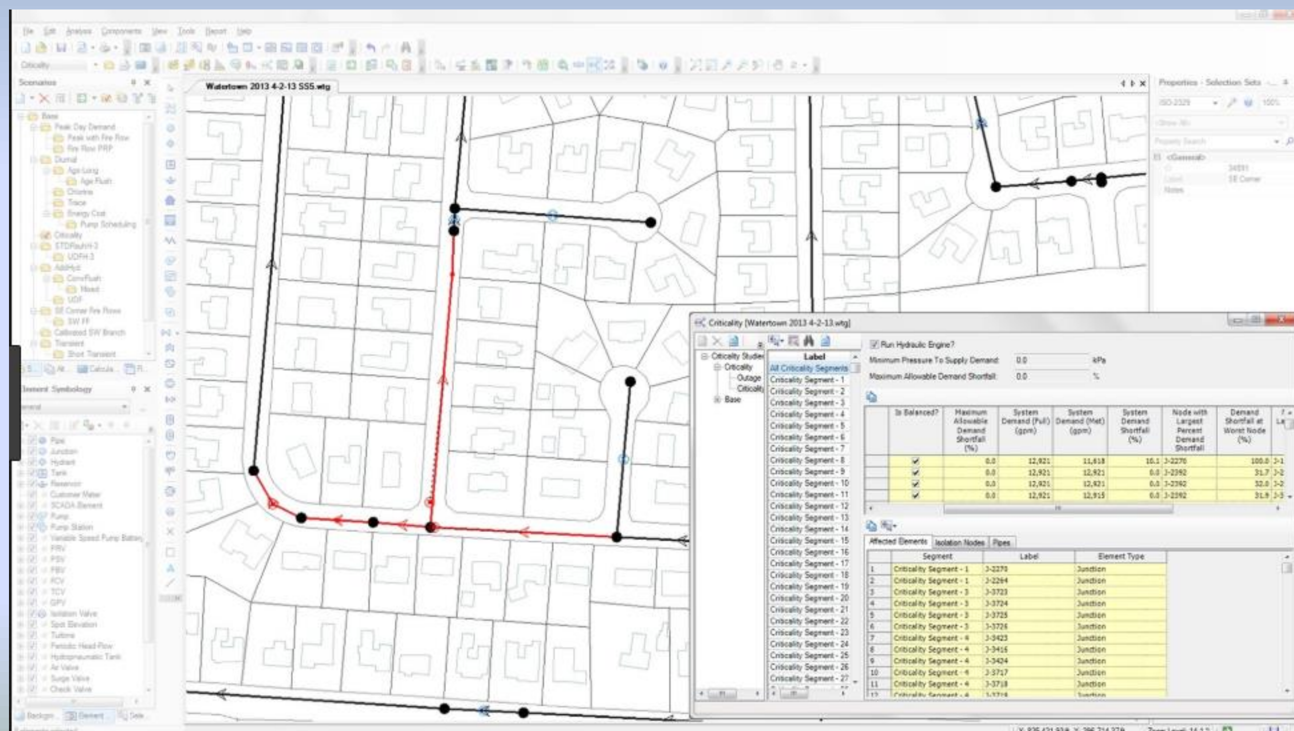
General Information | Building 1 Data | Building 2 Data | Building 3 Data | Building 4 Data | Building 5 Data | Building 6 Data | Building 7 Data | Building

Interreg Balkan-Mediterranean WATenERgy CYCLE

Project co-funded by the European Union and National Funds of the participating countries

Energy Audit Tools

WaterGEMS is a hydraulic simulation software that provides a comprehensive yet easy-to-use decision-support tool for water distribution networks. Regarding water distribution system modelling, model pumps accurately using hydraulic modeling, including complex pump combinations and variable speed pumps, to understand the impact that different pump operational strategies have on energy usage. The software can minimize energy related to pumping costs while maximizing system performance.



Operational Strategies to improve energy efficiency

(Cabrera et al, 2017)

- Operate the pumping system at its BEP (Best Efficient Point): Flow must always be as close as possible to the pump’s BEP.
- Avoid surplus energy by improving regulation of the system. This action can be structural if major investments are required for this purpose.
- Minimize leaks: This is an operational action when water losses are minimized through active leakage control or, alternatively, with pressure control. It should be structural if pipes are renewed.
- Minimize friction losses: This is an operational strategy if reduction is achieved through operational actions (e.g. forcing a more uniform flow distribution).

Project co-funded by the European Union and National Funds of the participating countries

Structural Strategies to improve energy efficiency

(Cabrera et al, 2017)

- Use more efficient pumps (old pumps can be refurbished or replaced by new, more efficient ones)
- Recover or reduce the topographic energy installing Pumps as Turbines, -to recover energy- or dividing the system in separate sectors with different geometric levels (energy platforms).
- Improve old designs and layouts: Networks have been traditionally designed on the back of energy efficiency criteria,
- Avoid losses not included in previous sections: (e.g. break pressure recovery).

Project co-funded by the European Union and National Funds of the participating countries

WATenERgy CYCLE
Urban water full cycle: from its source to its end-users and back to the environment

WP4 Common methodology & tools
Joint Del. 4.3 Energy efficiency & recovery

PP4 - University of Thessaly-Special Account Funds for Research-Department of Civil Engineering

Project co-funded by the European Union and National Funds of the participating countries