सत्यमेव जयते

Ministry of Housing and Urban Affairs
Government of India

Energy Efficient Water Supply System

TRAINING MANUAL

NIUA | C3
Climate Centre for Cities

ClimateSmart Cities Assessment Framework

Water Management

सत्यमेव जयते
Ministry of Housing and Urban Affairs
Government of India

Energy Efficient Water Supply System

TRAINING MANUAL

ClimateSmart Cities Assessment Framework

Water Management

NIUA | C3
Climate Centre for Cities

Energy Efficient Water Supply System
Training manual

Developed by:
Climate Centre for Cities, NIUA

Author
Kanagaraj Ganesan, Rajkumar Balasubramaniyan and Ankit Anand

Editors
Umamaheshwaran Rajasekar and Vaishnavi T. G Shankar

December, 2021

Contact information
Climate Centre for Cities
National Institute of Urban Affairs

1st Floor, Core 4B, India Habitat Centre,
Lodhi Road, New Delhi -110003, India
Telephone: (91-11) 24617517, 24617543, 24617595
Website: www.niua.org, www.niua.org/c-cube


Photo Credits: Michal Matlon on Unsplash

Executive Summary

On one hand, cities are a significant contributor of carbon emissions aggravating climate change and on the other, cities are considerably impacted by climate disasters. The recently released Global Climate Risk Index 2021 ranks India as the 7th most affected country from climate related extreme weather events (storms, floods, heatwaves etc.). Further, studies indicate that poor planning and urban management are expected to cost Indian cities somewhere between $2.6 and $13 billion annually.[1] Cities are increasingly at the forefront of addressing both urbanization and climate change and to strengthen climate-sensitive urban development, a holistic understanding of the urban development from a climate lens is crucial. The ClimateSmart Cities Assessment Framework (CSCAF) launched in 2019 by the Ministry of Housing and Urban Affairs (MoHUA), Government of India aimed to address this gap. This first-of-its-kind assessment with 28 progressive indicators across 5 thematic areas helps cities to benchmark their development, understand the gaps and further prioritize climate relevant development.

With a focus on building local capacities to develop and adopt climate measures, the Climate Centre for Cities (C-Cube) at the National Institute of Urban Affairs (NIUA) initiated a series of training aligned to the thematic areas of CSCAF - Energy and Green Buildings, Urban Planning, Green Cover & Biodiversity, Mobility and Air Quality, Water Management, Waste Management. The focus of the training is to provide a step-by-step approach of conducting studies, assessments and stakeholder consultations, establishing committees, developing action plans and implementing relevant measures that not only makes the cities climate resilient but also helps them progress across the assessment of CSCAF. This training focuses on the ‘energy efficient water management’ under the thematic areas of water management in the CSCAF.

Water and wastewater treatment plants are the most energy-intensive facilities operated by local governments, accounting for anywhere from 30–60% of a municipality’s total

[1] *Mani, M. et al., 2018. South Asia’s Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards, WashingtonD.C.: World Bank Group.*

energy bill.[2] Next to operator salaries, electricity is the second highest operating cost wherein electricity used for pumping is the highest. As energy prices rise, cities are confronted with the need to balance operations in response to higher costs. The key to addressing rising costs is an informed decision-making by understanding the gaps in to enhance energy efficiency of the water supply system.

In order to address this gap, an indicator on 'Energy Efficient Water Supply' has been included in the CSCAF 2.0. The intent of this indicator is to help the cities understand the principles of energy efficiency in urban water supply and compare the performance between them so as to implement projects to reduce the energy consumption and the associated GHG emissions.

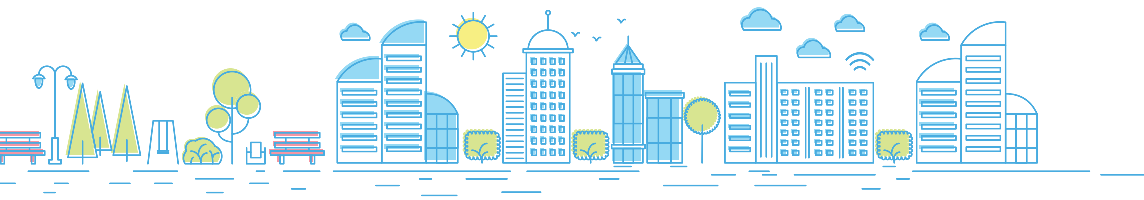
The training on this indicator includes methods for embedding energy savings and ways for enhancing environmental quality. This training manual is aimed to act as a guidebook for the cities to understand the steps required to perform the scoping and implementation of energy efficiency measures in the water supply system.

The objective of the module is to develop the elements of a leadership-training program on energy efficiency for financial decision makers, supervisory personnel, and plant operators working in the fields of water supply systems.

The key concepts under this training module include the need for energy efficiency in the urban water supply system, potential of energy efficiency measures in reducing GHG emissions and operational costs, conducting energy assessment for the urban water supply system, identification of technological solutions available for enhancing energy efficiency, techno-commercial analysis required for decision making and the financing options available for the implementation of measures.

---

[2] *Kumar, P., 2013. Energy and Water Efficiency in Municipal Water Supply System. Guwahati: CSE India. http://cdn.cseindia.org/userfiles/ pradeep_kumar_director.pdf*



Who is the training manual designed for?

What is the focus of the training manual?

How to make use of this manual?

What are the Learning outcomes of the training?

Scope and limitations of the training

The manual is designed keeping in mind the elements of a leadership-training program on energy efficiency for engineers and technicians in the urban water supply department. The financial decision makers, supervisory personnel, and plant operators working in the water supply department may also benefit from this training.

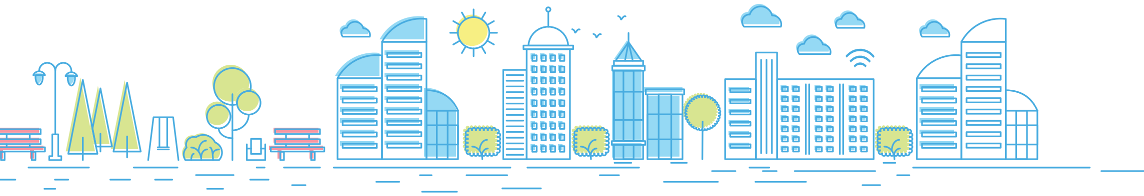
The focus of the training is to provide an understanding of the water and energy flows in the urban water supply system. Further, insights on organizing the energy audit and measures to enhance energy efficiency are also elaborated in detail.

The manual can be used as a guide for technical assessment of energy use in the water supply system.

The learning outcomes of the training includes identifying potential areas for reducing energy consumption, identifying the steps for conducting an energy audit for the water supply system, and understanding the rules, regulation and standard guidelines.

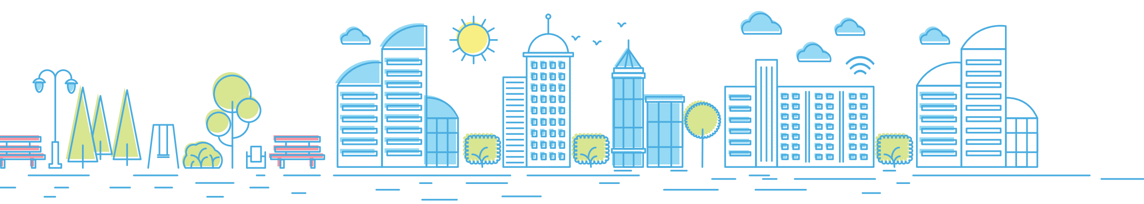
The manual does not explain the engineering calculations for designing a water supply or treatment system. The scope of the manual will be limited to the assessment of water supply systems and identifying and implementation of energy conservation measures.

Contents



List of Figures

List of Tables

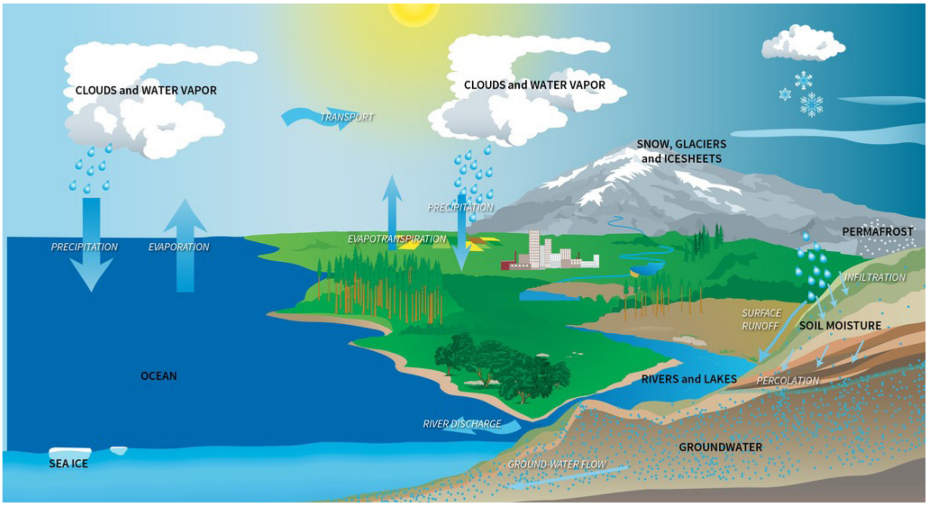


1

Introduction

Water is key for life on earth which is continuously circulating through one of earth's most powerful systems: the water cycle. Water flows endlessly between the ocean, atmosphere, and land. The water cycle describes how water evaporates from the earth's surface, rises into the atmosphere, cools, condenses to form clouds, and falls again to the surface as precipitation.

Figure 1: Water Cycle



Of all the water that exists on our planet, roughly 97% is saltwater and less than 3% is freshwater. Most of earth's freshwater is frozen in glaciers, ice caps, or is deep underground in aquifers. Less than 1% of Earth's water is freshwater that is easily accessible to us to meet our needs (Bank. W, 2021)

1.1. Municipal Water Supply and Treatment System

India, being the second most populated country, has only 4% of this total freshwater resources (WWF India, 2020) . With the country's economy growing at a higher rate over the past few decades, the standard of living of the population, particularly in the cities, has improved significantly. However, this growth has also resulted in the higher resource consumption, mainly energy and water.

The focus on water treatment in the context of energy arises for three reasons. First, water is an essential basic service that is required for healthy human existence. Water supply and wastewater treatment are major components of the country's water budget. Second, the sources of potable water are limited and the quality of water is of concern as well. Thus, for most cities, the acquisition of water requires transportation, which consumes energy. Water is heavy, weighing 1000 kilograms per cubic meter. For every cubic meter of water that needs to be transported, energy must be expended. Third, the energy intensity of water and wastewater treatment depends on factors that vary across locations. Energy intensity is affected by: quality of source water; pumping requirements to deliver water to end users; removing waste from pre-processed water; and the efficiency of the water system.

Due to the high energy demand from the urban water management practices and the disconnect between the water and energy sectors, the potential for both energy and water resource conservation has not been realized. Addressing this problem immediately can reduce the energy consumption in the water supply system and thereby mitigating carbon emissions. Implementation of energy efficiency measures can bring combined benefits in terms of water resource conservation and its associated energy and carbon footprint.

Water and wastewater treatment plants are the most energy-intensive facilities operated by local governments, accounting for anywhere from 30–60% of a municipality's total energy bill (Kumar, P. 2013). Next to operator salaries, electricity is the second highest operating cost, with most of this used in the electricity costs for pumping. As energy prices rise, cities are confronted with the need to balance operations in response to higher costs. The key to addressing rising costs is an informed decision-making by understanding the gaps in to enhance energy efficiency of the water supply system.

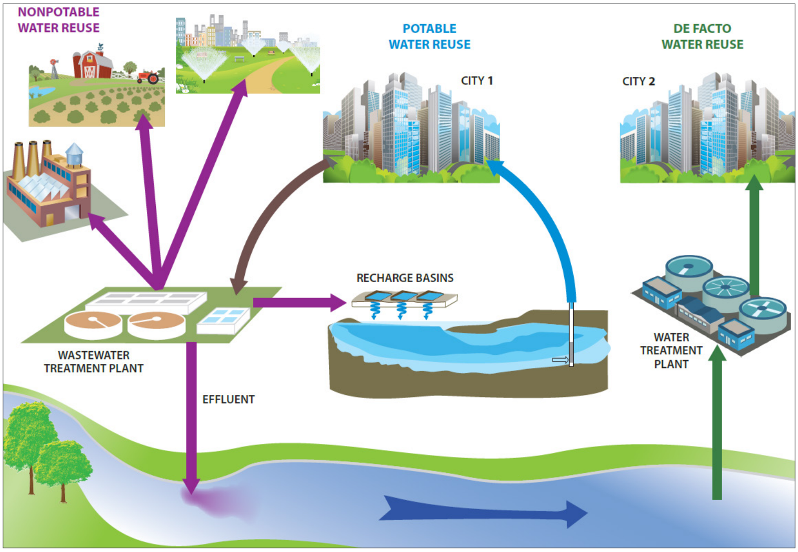
Figure 2: Snapshot of Indian Urban water Supply System (Kumar, P. 2013)

Snapshot of Indian Urban Water Supply System

- Second Largest Municipal System in the World*.
- Consumes 4% of total electricity consumed in the country*
- 60% of urban population receives pipeline Water Supply*
- Projected Energy Consumption by Public Water Works - 36,861 MUs (2021-22)*
- Costs 40-60% of operating expenditure of water supply system*

The content of the manual includes steps to identify the issues in the water supply and treatment system, measures to achieve higher energy savings, maintenance or enhancement of water delivery quality as related to energy usage, codes and standards in practice, methods to avail funding from government initiatives, and professional development of plant staff.

Figure 3: Layout of water supply system in cities



Source: National Academies Press – Understanding Water Reuse

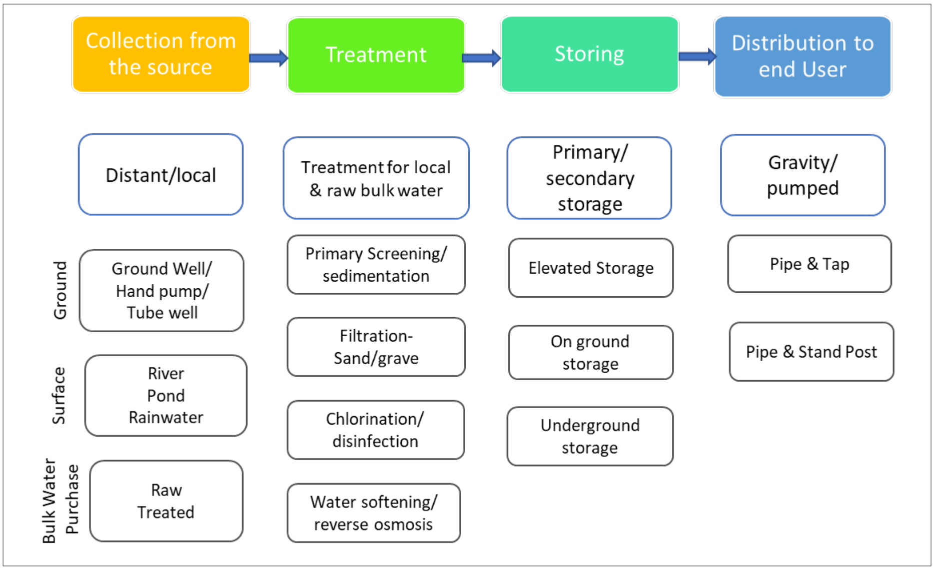
Photo Credits: Thisisengineering Raeng on Unsplash

2

Identification of Issues in the Urban Water Supply System

The urban water supply consists of the components as shown in the figure.3. The sources or methods used in water supply differs across the country mainly due to the geography and the water availability. Urban water supply infrastructures include sources of water like rivers, reservoirs, seawater, ground water sources (well, tube wells etc.). It also includes transmission pipes and canals, treatment and storage facilities, and distribution network elements.

Figure 4 Components of Urban Water Supply System



2.1. Challenges in the urban water supply systems

The energy intensity in the water supply system depends the water treatment required and the location of the source from which water needs to be pumped or conveyed. In general, most urban water supply originates either as surface or ground water. The challenges experienced by cities include:

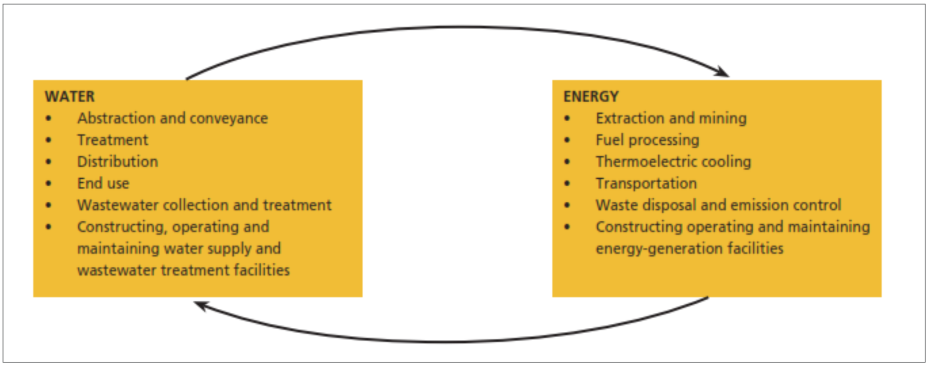
- Design of water supply systems to cater to the changing demography
- Leakage and losses in transmission, storage, and distribution
- Lack of efficient maintenance and management
- Aging infrastructure
- Absence of 24/7 monitoring to identify inefficiency in the system

Potable water is a basic need. While the focus in on providing access to water, implementation of energy efficiency strategies has been largely voluntary. Further, water utilities have few incentives to adopt energy efficiency strategies. However, in the pursuit of cost savings, more attention is needed on energy efficiency. Increased efficiency in water supply can not only decrease municipal energy bills but also reduce air pollution and carbon emissions.

2.2. Water-Energy Nexus

Energy plays a crucial role in the supply, treatment, and utilization of water. Energy is an integral part of potable water life cycle (extraction, production, conversion, distribution, use and disposal). This interdependence between water and energy is called the water–energy nexus or watergy. Figure 4 shows the schematic illustration of the water–energy nexus. Every litre of water that passes through a supply system incurs a significant energy cost. The Watergy approach with a technical and managerial framework helps cities realize significant savings in energy consumption, water losses, and energy bills.

Figure 5 :Schematic illustration of the water–energy nexus



Efficiency in the water supply system includes the supply of water and its end use. The most promising areas for intervention within water supply systems are:

- Improving the pumping system,
- Leakage reduction,
- Automating system operations, and
- Regular monitoring (preferably with metering of end use).

Pumping of water consumes a significant amount of energy share in the water supply system. This results in a significant share of the energy cost. Any water losses in the system also impacts the energy consumed. Hence, enhancing pumping system can greatly help in bringing in energy efficiency besides reducing energy bills. A range of measures from low cost measures like soft starters for motors, trimming impellers (when pumps are over-sized) and re-winding motors, to higher cost measures like replacing inefficient pumps with efficient ones and installing variable speed drives can be considered.

System automation saves water, energy and operation costs, improves service, and lengthens equipment life. Automation handles operational functions in real time in response to changing situations. For instance, optimizing pressure in the network, triggering alarms in case of emergency, and turning off pumps.

Regular monitoring of the system components, operations, and performance is essential in order to track performance and evaluate it against a set of benchmarks and targets.

Effective management of leaks can save enormous quantities of water and energy. Leakage rates can be lowered dramatically with automated controls that reduce pressure in the network, especially at night. Water access can be expanded much more quickly and inexpensively through efficiency than new infrastructure, deferring the need for additional infrastructure investment.

Table 1 Water and Wastewater Utility Systems that Use Energy

Stage	Operation	Energy-Using Systems
Extraction	Deep well extraction	Submersible or shaft turbine deep well pumping systems
	Extraction from a surface source	Horizontal or vertical centrifugal pumping systems
Treatment	Chemical (disinfection and clarification	Piston-type dosing pumps
	Physical (e.g., filtration and sedimentation)	Pumping systems, fans, agitators, centrifugal blowers
Piping Between Source and Distribution Network	Sending the drinking water to the distribution grid	Submersible or shaft turbine deep well pumping systems; horizontal or vertical centrifugal pumping systems
	Booster pumping	Horizontal or vertical centrifugal pumping systems used to increase pressure of water going into the distribution system or to pump water to a higher elevation
Distribution	Distribution to end users	Horizontal or vertical centrifugal pumping systems
Storm and Sanitary Sewer Systems	Piping of sewage and/or rainwater	Horizontal or vertical centrifugal pumping systems
	Wastewater treatment and disposal	Pumping systems, fans, agitators, centrifugal blowers
Support Systems	Support functions associated with the utility building(s)	Lighting systems, HVAC (Heating, Ventilation and Air Conditioning), etc

2.3. Barriers to Energy and Water Efficiency

The barriers can be grouped into five main categories.

- **Lack of Awareness:** Some people are not aware towards efficiency and its cost-benefits arguments for doing so.
- **Aversion to Risk:** Deviating from the usual routine is associated with risk, real or perceived, such as added burden on staff or financial risk.
- **Change May Imply a Problem with the Status Quo:** It is not uncommon for staff to be resistant to new ideas and procedures due to a feeling that suggestions for change imply criticism of their performance and ability.
- **Subsidies:** Although subsidies have a role in providing essential services to the poor, when they are poorly planned or imple mented, they often greatly reduce the cost incentives inherent in efficiency.
- **Financing Efficiency:** Quite a few Watergy measures are low cost. For those that do require capital outlays, performance contracting approaches pay for project costs from the cost savings on water and energy.

The first step in improving energy efficiency in the urban water supply is to conduct an energy and water audit of the city. The following chapter explains the steps in conducting water and energy audits in the urban water supply system.

3

ClimateSmart Cities Assessment Framework

The indicator **Energy-efficient water supply system in the city** focuses on enhancing energy efficiency of the water supply to support in the reduction of carbon emissions. Here, Water Supply System is defined as the water collected from the source, treated, stored and supplied to the end user i.e., entire chain from source to the user. There are number of equipment that use energy in a water supply system. This indicator aims to quantify the use and reduction of energy (per MLD of water supplied to the city) by using different options and solution used/ implemented by the city. This is calculated based on the below formula

$$\text{Trend of reduction in energy consumption per MLD} = \frac{\text{(Energy Consumption of previous year – Energy Consumption of Current Year)}}{\text{Water Supplied in Million Litres per Day}}$$

Table 2 Performance evaluation

	1	2	3	4	5
Progression Levels	City has not conducted the Energy Audit including for pumping stations and treatment plants.	City has conducted the Energy Audit and the most recent energy reduction reported per MLD by the city during 2016-20 is <10% of baseline data.	Most recent energy reduction reported per MLD by the city during 2016-20 is >10% to 15% of baseline data	Most recent energy reduction reported per MLD by the city during 2016-20 is >15% to 20% of baseline data	≥Most recent energy reduction reported per MLD by the city during 2016-20 is >20% of baseline data
Evidence/ Data sources	Energy Audit Report (2016-20)				
Responsible Department/ Agency	ULB/ Water Utility/ Water Boards/ Flood and Irrigation Department/ Any SPV and or any other relevant implementation agency				
Reference Documents	Manual for the Development of Municipal Energy Efficiency Projects. BEE (2008) https://tinyurl.com/w6omgtt A Primer on Energy Efficiency for Urban water and Wastewater Utilities (ESMAP; 2012) https://tinyurl.com/sw6qja5				
Score	0	25	50	75	100

Figure 6 ClimateSmart Cities Assessment Framework

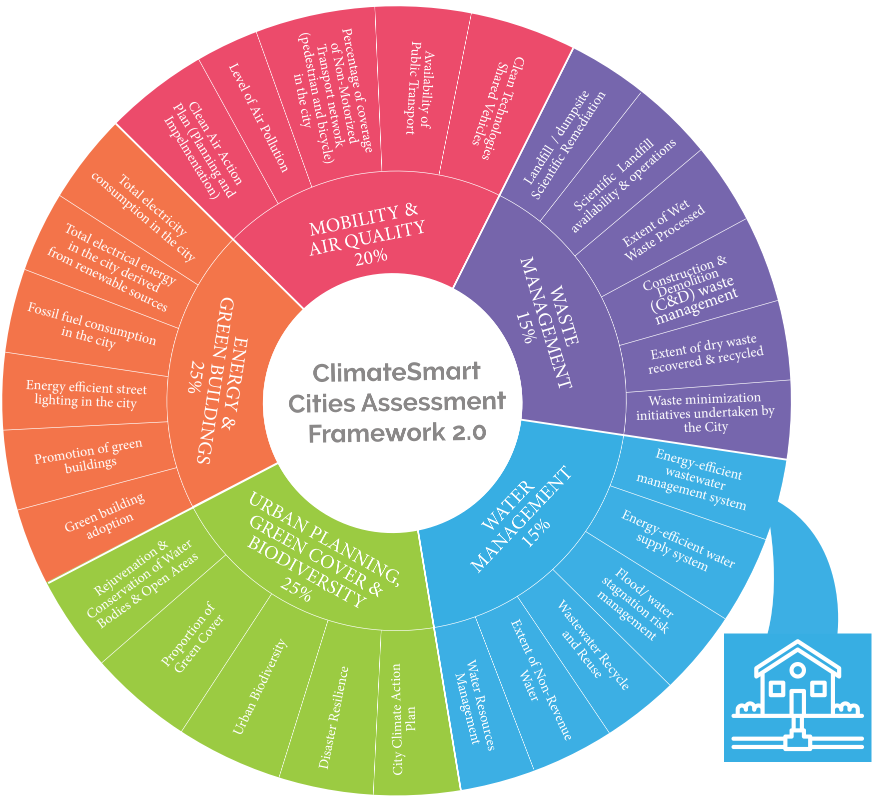



Photo Credits: Ivan Bandura on Unsplash

4

Water and Energy Audit

4.1. Water Audit

A water audit is a study of quantifying all the flows of water in a system to understand its usage, reduce losses and improve water conservation. The audit traces water flow from its source to the end user. The systematic process of the audit includes measuring flow of water from the site of water withdrawal or treatment, through the distribution system, and into areas where it is used and finally discharged. Conducting a water audit involves calculating water balance, water use and identifying ways for saving water.

Figure 7 International Water Association (IWA) standard water balance chart

<table>
<tr><td rowspan="9">System Input Volume (A)</td><td rowspan="4">Authorised consumption (B1)</td><td rowspan="2">Billed authorised consumption (C1)</td><td>Billed meter consumption (D1)</td><td rowspan="2">Revenue water (E1)</td></tr>
<tr><td>Billed un metered consumption (D2)</td></tr>
<tr><td rowspan="2">Unbilled authorised consumption (C2)</td><td>Unbilled metered consumption (D3)</td><td rowspan="7">Non-Revenue Water (NRW) (E2)</td></tr>
<tr><td>Unbilled unmetered consumption (D4)</td></tr>
<tr><td rowspan="5">Water losses (B2)</td><td rowspan="2">Apparent losses (C3)</td><td>Unauthorised consumption (D5)</td></tr>
<tr><td>Metering inaccuracy (D6)</td></tr>
<tr><td rowspan="3">Real losses (C4)</td><td>Leakages on transmission and/ or distribution mains (D7)</td></tr>
<tr><td>Leakages and overflows at Utility's storage tanks (D8)</td></tr>
<tr><td>Leakage on services connections up to point of customer metering (D9)</td></tr>
</table>

4.1.1. Steps for water audit

1. **System Input Volume (A):** Volume of water in the transmission system and/or purchased water from concerned agency.
   - ✓ Identify various sources of water production
     - Surface water: Intake of dam, river, lake, or reservoir
     - Groundwater: Tube/bore wells
     - Bulk raw and/or treated purchase
   - ✓ Measure the quantity from each source
     - Quantity of water at various points need to be measured by flow meters.
     - Quantity of bulk purchase water is generally available from water bill received by ULB
   - ✓ Installation of portable flow meter

2. **Billed Authorized Consumption (C1 = D1+D2)**
   Volume of metered and non-metered water taken by billed consumers. Zone/ward-wise billed metered water connections to be obtained from ULB's billing system and volume of metered water to be extracted from ULB records
   - ✓ Billed metered consumption (D1)
     - Identify metered connections
     - Measure quantum of metered use
       - Billed unmetered consumption (D2)
       - Identify unmetered connections

- Estimate quantum of unmetered water use. For this, the following can be considered:
- Billed unmetered consumption can be calculated by test zone flow measurement [like District Metered Area (DMA)] or representative sample survey method
- Measurement can be done by installing water meter during measurement period
- Billed quantity is measured in various test zones and subsequently, extrapolated at city level.
- Selection of test zone should be based on the following criteria:
  - ~ It should cover all the housing category like HIG, MIG, LIG and Slums
  - ~ Availability of detailed distribution maps
  - ~ Availability of consumer data like number of consumers, size of connections, existing water meter details etc.
  - ~ Preferably, smaller zones with about 50 to 60 house service connections
- If meters are already installed, then check its accuracy and replaced inaccurate meters. Installation of meters if meters are not installed.
- Reading should be taken every day and calculations of losses.
- Exercise should be carried out for at least one week.

3. Calculate the volume of Non-Revenue Water (NRW)(E2)

NRW is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of Unbilled Authorised Consumption and Water Losses.

Non-Revenue Water = System Input Volume – Revenue Water

4. Calculate the Unbilled Authorised Consumption (C2 = D3 + D4)

Unbilled authorised consumption covers metered and unmetered free supply.

- ✓ Unbilled metered consumption (D3) (Zone/ward wise metered unbilled water connections and consumption details can be obtained from ULB)
  - Identify unbilled metered authorised connection
  - Measure quantum of meter use
- ✓ Unbilled unmetered consumption (D4)
  - Identify the unmetered authorised connections (This component typically includes items such as public stand post, tanker supply, government offices, schools, hospitals, gardens, public toilets etc)
  - Measure quantum of unmetered authorised use. This includes:
    - Water consumption in municipal property (municipal schools, offices, gardens etc.)
    - Estimation of water supply from public stand post: volumetric f low measurement can be deployed for sample stand post

- Water supply through tankers to unserved areas is calculated by estimating trips, capacity of tankers and estimating increase in tanker supply in summer seasons.

5. **Calculate Authorised consumption (B1)**
   Authorised consumption includes billed and unbilled consumption

   Authorised consumption =

   Billed authorised consumption (C1) + Unbilled authorised consumption (C2)

6. **Calculate water losses (B2)**

Water losses includes apparent losses and real losses

Water losses = System input volume – Authorised consumption

7. **Calculate the apparent losses (C3 = D5 + D6)**
   Apparent losses also known as commercial losses which includes unauthorised consumption and all types of meter inaccuracy and data handling error.
   - ✓ Unauthorised consumption (D5)
     - Identify unauthorised connection and then estimate quantum of unauthorised use
   - ✓ Metering inaccuracy (D6)
     - Estim ate the inaccuracy of meters (D6)

8. **Calculate real losses (C4)**
   Real losses also known as physical losses. Volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering

   Real losses = Water losses (B2) – Apparent losses(C3)

9. **Assessment of Real Losses**
   - ✓ Identify potential water losses like
     - Leaks at raw water transmission lines
     - Evaporation losses
     - Water treatment losses
     - Leaks/seepage of reservoirs
     - Overflows of reservoirs
     - Leaks at distribution mains
     - Leakages from valves and air valves
     - Leakages from services connections up to meter

10. **Measure or estimate quantum of losses by type (D7, D8, D9)**

Exercise 1

Estimation of Water Demand[1]

Estimate the total daily demand of water required (in cubic metres per day) in the city if the water requirement per person per day is 135 Litres/Day. Person and the total population is 50,000 and average seasonal usage impact is 95%.

Exercise 2:

Estimate the water losses at different stages of the urban water supply system and the total losses across the system, based on the inputs from the table below. Also calculate the energy costs expended (Electricity price: INR 10 per kWh) due to the losses in the water.[2]

Stage	Quantity of water (m^3/day)
Water collected at source	6,412
Water leaving treatment unit	6,220
Water stored at the local distribution tanks	5,847
Water pumped to the end users	5,379
Water billed to the users	5,217

Stage	Quantity of water lost (m^3/day)	% of losses
Source to treatment unit	A	A1
Treatment unit to local distribution tanks	B	B1
Local distribution tanks to end user supply	C	C1
End user supply and billing	D	D1
Total	E	E1

[1] *Answer: 6,412.5 m3/day*

[2] *Answer: A=192, B=373, C=468, D=162, E=1,195, A1=2.8%, B1=6%, C1=8%, D1=2.2%, E1=19%*

Methods for real losses assessment

The following methods has been used for measuring and estimating losses from identified leaks.

1. Portable Ultrasonic Flow Meter
   - ✓ Ultrasonic Flow Meter helps estimate the flow of water inside the water pipeline using ultrasonic sound waves, without having to puncture the pipe surface. For measurement principles, visit the link *https://www.youtube.com/watch?v=vopAJLuHwJY*

2. Volumetric measurement
   - ✓ Volumetric measurements using containers of known volume with time measurements using stopwatch can be helpful to understand the flow difference between source and the delivery points across the water pumping or distribution system.

3. Measurements by partially filled pipe, V-Notch etc.
   - ✓ Measurement principles and calculations can be understood from the link - https://www.brighthubengineering.com/hydraulics-civil-engineering/65701-open-channel-flow-measurement-4-the-v-notch-weir/

- Leaks at raw/treated water transmission lines: Measure inlet and outlet of pipelines, using any one of the methods mentioned above.
- Evaporation losses: Evaporation rate should be measured using Meyer's formula, as explained in this video (*https://www.youtube.com/watch?v=N55zxDwhNcI*) and with the help of capacity curve, losses should be calculated.
- Water treatment losses: Inlet and outlet of treatment plant should be measured
- Overflows of reservoirs: Calculated based on frequency and flow rates using V-notch method mentioned above
- Leaks of distribution mains: Measure inlet and outlet flow rates in the pipelines
- Leakages from valves and air valves: Can be calculated using volumetric methods or simply using bucket and stopwatch method
- Leakages from services connections up to meter: By deducting the mains leakage and storage tank leakage from the total volume of physical losses.

Table 3 Water Audit template

S. No	Item	Water Volume		
		Subtotal (MLD)	Total Consumption (MLD)	Percentage of Total Supply
1	At head works			
2	At storage reservoir			
3	At consumer end			
4	Total			
4a	Domestic			
4b	Non-domestic			
5	Corrections - Low flow rates not measured in the meter			
A	Total corrected water flow rate			
6	Free water use			
B	Total authorized water use			
7	Unauthorized consumption from illegal connections			
C	Total apparent loss			
8	Loss of water from source to GSR			
9	Loss of water at storage tanks			
10	Loss of water in distribution system			
D	Total real loss (8+9+10)			

4.2. Energy Audit of Water supply

An energy audit is an assessment and analysis of energy flows in a process or system, aimed at reducing the amount of energy input into the system without negatively affecting the output(s). The main objective of an energy audit is to inspect the existing infrastructure and operational practices in the urban water supply system and explore various possibilities for energy conservation. An energy audit requires a thorough and detailed study of every aspect of the system, through the performance of various tests and measurements. Energy auditing of the municipal water supply system is essential for identification of energy conservation measures and to eradicate the water losses in the system. The major steps and the levels of assessment for energy audit process is derived from the handbook by EMC Kerala - Manual for Energy Auditing.

Steps in an Energy Audit

- Collect and analyze historical energy usage.
- Study pumping systems and their operational characteristics.
- Identify potential modifications that will reduce the energy usage and/or cost.
- Perform an engineering and economic analysis of potential modifications.
- Prepare a rank-ordered list of appropriate modifications.
- Prepare a report to document the analysis process and results

Levels of Assessment

- **Level I Assessment-** Preliminary Energy Use Analysis & Walk-Through Analysis is a simple assessment based on available documents and information, physical inspection, and staff interviews to create a baseline and identify obvious energy efficiency measures which are easy to implement.
- **Level II Assessment –** Energy Survey and Analysis includes review of data, existing and newly gathered, to identify all energy saving measures and identify high potential measures for further investigation.
- **Level III Assessment –** Detailed Analysis of Capital-Intensive Measures also known as Investment Grade Audit used to give a detailed assessment of costs and benefits derived from capital intensive energy conservation measures.

Water Systems

The audit involves carrying out various measurements and analysis of the following three systems to assess losses and the potential for energy efficiency improvements.

- Pumps & Pumping Systems
- Electrical Systems
- Electric Drives

Measurement

- Data collection
  - ✓ Specifications of pumps and motors
  - ✓ Diagram of water distribution air network
  - ✓ Water pressure required for the system
  - ✓ Number of pumps in operation
  - ✓ Design/specified water temperature required

- Water flow rate of pumps at various operating conditions. Refer to the video for ultrasonic flow meter based measurement- *https://www.youtube.com/watch?v=vopAJLuHwJY*
  - ✓ Individual pipelines (In the main line) or
  - ✓ Parallel lines branching from the main discharge line of the pump
- Water flow velocity in pipelines (Calculation from the flow rate measured in the step above and dividing it by total cross sectional area of the discharge pipeline)
- Suction & discharge pressure of pump, measured using pressure gauges
- Power consumption and motor electrical parameters: - The electrical parameters like Current, Voltage, Power Factor and Power (Active, Reactive and Apparent Power) in the motor needs to be monitored under the following conditions:
  - ✓ During operation of individual motors
  - ✓ During parallel operation of motors in the water distribution network
  - ✓ At various valve openings
- Flow control methods
- Main water collection and distribution pipelines – ON/OFF Status monitoring
- Operating hours and pump schedule
- Variations in flow requirement
- User area operating schedule
- Measurement of water flows to the users
- Segregation of users based on operating hours
- Any modifications carried out in the pumps such as replacement of impeller, trimming of impeller, others
- Operation and maintenance practices

Data Analysis and Energy Conservation Measures (ECMs)

- Written description of each ECM to include:
  - ✓ Existing conditions and data collection approach (snapshot, short-term, or long-term measurement of data)
  - ✓ Recommendations include discussion of facility operations and maintenance procedures that will be affected by ECM installation and implementation.
- Baseline energy use:
  - ✓ Summary of all utility bills
  - ✓ Base year consumption and description of how the base year was established.
- Savings Calculations:
  - ✓ Base year energy use and cost
  - ✓ Post-retrofit energy use and cost
  - ✓ Savings estimates including analysis methodology, supporting calculations, and assumptions used
  - ✓ Operations and maintenance savings
  - ✓ If manual calculations are employed, formulas, assumptions, and key data shall be stated.

- Cost Estimate:
  - ✓ Engineering/design costs
  - ✓ Contractor/vendor estimates for labour, materials,
  - ✓ Construction management fees
  - ✓ Commissioning costs
  - ✓ Other costs/fees
- Auditors should consider the following while analysing potential energy and water saving measures:
  - ✓ Maintenance problems
  - ✓ Operating energy use of the water supply system, connected electrical loads in the system, verification of the sizing of equipment like pumps, pipelines, valves and control equipment, pump and total system mechanical and electrical efficiencies, and hours of operation
  - ✓ Current operating condition
  - ✓ Remaining useful life of the pumps and electrical equipment connected with the water supply system in order to define the preventive maintenance mechanisms to avoid lower performance or shutdown of the equipment
  - ✓ Feasibility of system replacement
  - ✓ Future plans for equipment replacement or pumping station renovations
  - ✓ System operation and maintenance procedures that could be affected
  - ✓ Hazardous materials and other environmental concerns

Energy Audit Report Format

The table of contents for the report shall be as per the headings listed below:

- Executive Summary
- Background
- Energy Scenario
- Inventories
- Baseline Parameters & Adjustments
- System Mapping Details
- List of Potential Energy Saving Projects
- Detailed Financial Analysis (including Payback, Net Present Value, Internal Rate of Return)
- Details of Approved Projects
- Measurement and Verification Plan
- Risk Assessments & Mitigation Plan
- Annexure

Report format attached in the link -
https://drive.google.com/drive/folders/1Uc7xCMl1EhytYbUZaqFaUYVrXluwzEU

5

Institutional framework

5.1. Government stakeholders and their functions

Ministry of Jal Shakti:

The main institution responsible for water resources management is the Ministry of Jal Shakti, established by merging the Ministry of Water Resources and the Ministry of Drinking Water and Sanitation. The Ministry's objective is to conserve water and ensure equal distribution across the country and within the states through water resource management.

National Bureau of Water Use Efficiency:

This institution is expected to be established as provided under the 2019 National Water Framework, Ministry of Jal Shakti.

Bureau of Indian Standards (BIS)

BIS is working on the development of STAR rating criteria for water fittings in India. The proposed rating system covers water closets, urinals, faucets, and overhead showers which are categorized into three rating levels based on flow rates.

Bureau of Energy Efficiency (BEE)

The main objective of the agency is to provide policy recommendations for energy efficiency and establish strategies to monitor and verify energy performance. BEE has designed various programs for energy efficiency including the initiation of the standards and labelling (S&L) scheme for appliances and equipment in 2006. This includes S&L for storage water heaters (also known as geysers; mandatory labelling) and solar water heaters (voluntary labelling), both of which will be addressed in the policy section below.

5.2. Industry Associations

Indian Plumbing Association (IPA):
IPA is the principal organization of plumbing professionals in the country. It was formed in 1993 to redefine plumbing standards and promote advancements of the plumbing industry in India.

Plumbing Codes and Standards India Private Limited (IAPMO):
Founded in 2007 to assist local plumbing professionals, IAPMO India creates awareness about the issues and prospects concerning the industry. It collaborated with IPA to establish extensive plumbing codes and education programs and is a member of the World Plumbing Council.

5.3. Programs and policies

National Water Policy (NWP):
The primary goal of this policy was setting up a standardized national database of hydrological information and setting priorities for water allocation for domestic consumption, followed by irrigation, hydro-electric power, navigation and industrial use. It sets the overarching water framework to advance water efficiency in relation to irrigation and water supply management. However, no programs or measures were developed to improve water efficiency for domestic products.

Jal Jeevan Mission

The mission is a long-term vision plan by the Ministry of Jal Shakti under the Department of Drinking Water and Sanitation initiated in 2019. It aims to ensure drinking water supply to every rural household in India i.e., Functional Household Tap Connection (FHTC) by 2024. Out of 189 million rural households in India. 46 million households (24%) have been provided with tap connections as of July 2020.

The National Water Framework Bill of 2016

The Bill aims to conserve, manage, regulate and protect the use of water while providing a framework which ensures executive action on water at all levels of governance. It emphasizes access to water as a right of every individual, the protection of ecosystems depending on water, the treatment and use of wastewater, people-centered water management and water security planning.

Photo Credits: Jani Brumat on Unsplash

6

Achieving Energy Efficiency in Urban Water Supply System

Energy efficiency measures in the urban water supply and wastewater treatment can be implemented in the existing water networks across the city with up to 35% savings in energy costs and in the new networks with more than 50% savings than the conventional networks.

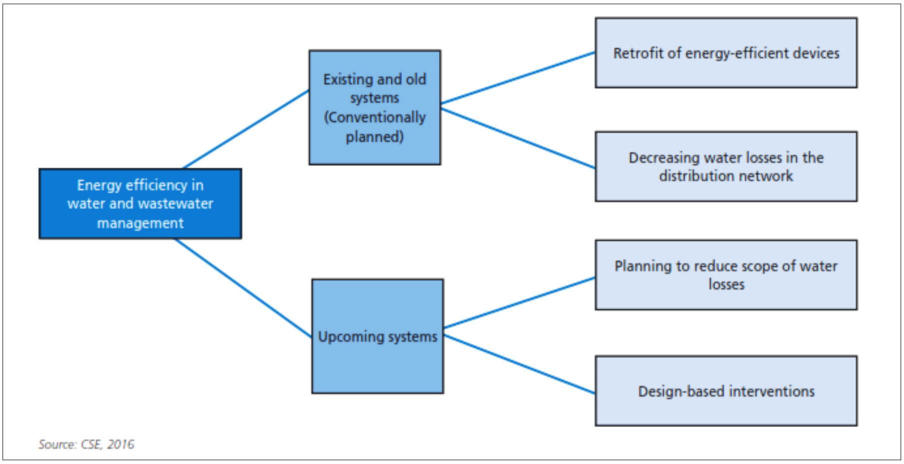
6.1. Retrofitting of Existing Water Networks

Existing systems can be retrofitted to make them energy-efficient based on comprehensive assessment studies and recommendations. Municipal engineers or consultants can perform energy audits or install monitoring devices that feed into their Supervisory Control and Data Acquisition (SCADA) system to learn where energy is being used in their facility and identify opportunities for EE improvements.

Technology options for more EE in the transmission of water (from the source to the point of treatment) include:

- Improving the efficiency of the pumping system (pump, motor, and valves) within the pumping stations boundary.
- Replacement of inefficient (and often over-sized) pumps and motors with efficient and properly sized ones.
- Application of Variable Frequency or Speed Drives (VFD/VSD).
- Regular preventive inspection and maintenance, including cleaning or replacing impellers and checking the lubrication of bearings.
- Rewinding motors, when there is insufficient fund to replace them.
- Trimming impellers, where pumps are too large for the application but are otherwise suitable for the job.
- Transmission pipeline renovation and leakage reduction.
- Installation of capacitors to improve the power factor.

Figure 8: Approaches for energy efficiency in water and wastewater management



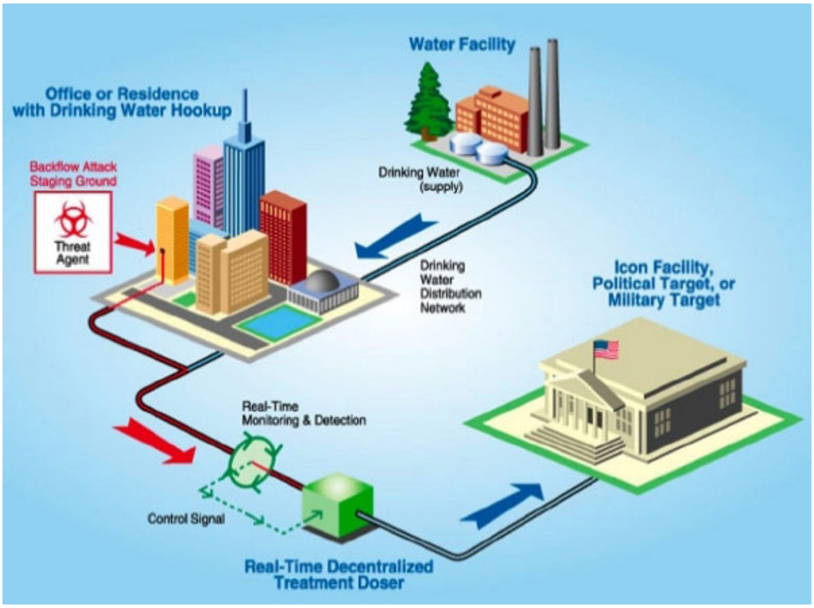
Technology options for more EE in the of distribution of water include:

- Improving the efficiency of transmission and distribution pipelines, metering, and pumping and tampering storage equipment.
- Pipeline renovation and optimization (to reduce losses due to friction).
- Leakage detection and repair.
- Improving efficiency of aeration equipment and anaerobic digestion.
- Pressure management within the network.
- Measuring and managing minimum flow.
- Installation and maintenance of water meters.

Technology options for EE in the overall system include:

- Automating data and information, remote controlling, regular monitoring, and proper reporting systems. The system shall consist of:
  - ✓ Measurement of energy and water supply system performance parameters
  - ✓ Automatic shutoff or adjustment controls installed at several points of the water network and pumping stations
  - ✓ Integrated visual interface to understand real-time operation of the system

Figure 9: Scada Systems



- System performance tracking, benchmarking, and targeting.
  - ✓ Comparison of the energy performance of the water supply with other cities (For example, using Climate Smart Cities Assessment Framework (CSCAF))
  - ✓ Setting of targets for reduction in energy consumption and water loss mitigation (for example, becoming net zero by 2030).

6.2. Energy Efficiency Solutions for New Water Networks

The selection of technologies plays an important role from the point of view of energy consumption over the lifetime of the system.

Areas of intervention for EE in upcoming water and wastewater management projects and new water networks

- Hydraulic modelling of the new water network or the project
- Implementation of design efficiency measures
- Selection of appropriate technology
- Pumping systems (pump, motor, valves, and piping)
- Leak reduction management
- System piping (distribution network)
- Local recycle and reuse of treated wastewater (avoid long distance pumping requirements)
- System automation, metering, and monitoring

Energy-efficient design considerations

The parameters that a municipal engineer or consultant should consider during the selection or design of a pumping system include:

- Minimizing over-sized pumps [1]
- Selection of the right types of efficient pumps and motors
- Installation of Variable Frequency or Speed Drives (VFD/VSD).
- Segregation of high-head and low-head pumps
- Utilization of gravity flow
- Utilization of pumps
- Parallel operation of pumps[2]
- Piping design

System Flexibility

During the design stage, municipal engineers, officials, or consultants involved should suggest a modular approach to allow flexibility in addressing future water supply needs. Although the flexibility of pumping systems does not have an immediate direct bearing on EE, a flexible system can increase long-term efficiency by enabling appropriate changes to be made to the running capacity of the pumping stations throughout the facility's lifetime.

---

[1] *Pumps designed for head and/or flowrate more than 15% of the requirements on-site. Refer to Energy and Water Efficiency in Municipal Water Supply System by CSE India*

[2] *Reducing single large pump capacities for larger water distribution area into smaller sized pumps, operated parallelly so as to provide resilient and energy efficient water flow during the time of failure of one or more pump(s).*

6.3. Selection of energy-efficient technology

Use of efficient technology is vital for achieving significant increases in Energy efficiency. Energy-efficient technologies can be adopted most easily at the design stage, when the additional costs involved are only marginal, in comparison to the benefits of long-term energy efficient operations. The integration of energy efficiency solutions can be adopted as follows:

Treated source: Use efficient pumping systems (pumps, motors, and variable frequency drives) and store water to avoid pumping at times of peak energy cost.

Water treatment: Install SCADA, use efficient pumping systems (pumps, motors, and variable frequency drives) and install efficient disinfection equipment

Water end uses: Use efficient pumping systems (pumps, motors, and variable frequency drives), reduce distribution leaks and implement automatic meter reading

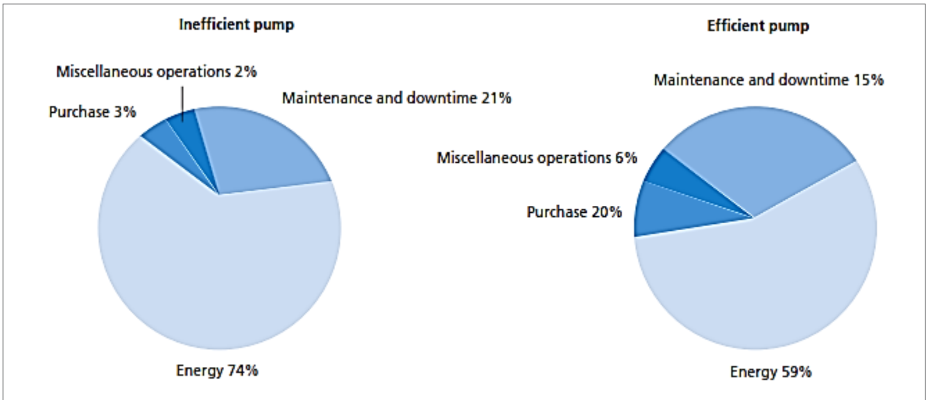
Photo Credits: Patrick Federi on Unsplash

7

Lifecycle cost analysis

Another key component to an overall cost–benefit analysis is understanding life-cycle costs. This is especially critical in the case of pumps, since pumping systems account for most of the energy usage in water supply and wastewater treatment systems. The selected pump needs to be analyzed for not only their immediate benefits, but also with the impact of life-cycle costs like discounting, increase in energy price, maintenance costs, and replacement costs if the lifetime of the product is lesser than defined life cycle of the project. All the strategies need to be checked for cost vs their impact on energy savings and also the time duration for implementation.

Figure 10 Lifecycle costs of an inefficient vs efficient pump



Source: Watergy: Energy efficiency in municipal water supply and wastewater treatment, 2007


Photo Credits: Tejj on Unsplash

8

Benefits of Energy Efficiency Measures

Implementation of energy efficiency measures in the urban water supply system not only brings energy savings but also several qualitative benefits to the municipal administration, as listed below:

- 20% to 50% saving potential.
- Payback period of 2 to 3 years
- Reduced energy and water demand and supply gap at the national/state level
- Improving EE reduces the pressure of adding new power generation capacity
- Reduced energy intensity will help climate change mitigation efforts.
- Reduced costs for facility management.
- Support in catering to the growing population.
- Help to ensure the long-term fiscal stability of this basic service

The table below explains the cost and benefits in implementing different energy efficiency measures.

Table 4 Energy conservation strategies and benefits

Strategies	% Savings Potential	Cost
Planning of storage and distribution points to avoid overloading (Reduced Head & Flow)	Up to 25%	Lowest
Hydraulic Modelling and preventive maintenance	Up to 30%	Low
Storage of water to avoid pumping during peak energy cost hours	Up to 15%	Low
Installation of capacitors to improve the power factor	Up to 10%	Medium
Use of Renewable Energy like Micro-Hydro and Solar Pumping	Net Zero Potential	Highest
Energy Capture at water source (Water moving downhill or in a slope)	Up to 10%	Low
Efficient Pumping (Pumps and Motors)	Up to 45%	High
Use of Variable Frequency Drives	Up to 15%	Medium
Use of monitoring systems like SCADA	Up to 20%	High
System performance tracking, benchmarking and targeting	Continuous improvement till Net Zero	Lowest

9

Financing of Energy Efficiency project

For the municipalities to access funding or technical resources for conducting energy audits or implementing energy conservation measures in the water supply system, a concept note needs to be developed mentioning the scope of work to be completed and the resources required to complete the project. The following are the methods to avail finance for the energy efficiency projects for urban water supply:

1. Funds from State and Central Government Schemes for cities
   - ✓ Smart Cities Mission
   - ✓ AMRUT Mission

Drinking Water Security Mission under Jal Shakti Abhiyan

2. Inclusion of the project into the city budget
3. Approaching Bureau of Energy Efficiency &/ or EESL for use of existing or new programmes to execute the project
   - ✓ The municipalities can engage with Bureau of Energy Efficiency for advisory related to energy auditing and financial mechanisms through ESCO projects. Previous and current programmes of BEE with SIDBI for availing Partial Risk Sharing Guarantee Fund (PRSGF) scheme can reduce the risks of capital costs by the municipal corporation by engaging an ESCO company who will avail credit guarantees from SIDBI for implementing the project.

4. Approaching international development banks for funding the project
   - ✓ The cities can reach out to the international cooperation, development and philanthropical organizations working in the fields of energy efficiency and sustainable development for accessing resources (Technical and Financial) to implement the activities for improving energy efficiency of the water supply system. The scope can be applied to both conducting energy audits or executing energy conservation measures after the audit.

The table below explains the prerequisite documents and the agencies for reaching out to avail funding and technical resources.

Table 5 Financing prerequisites and agencies

Category	Prerequisite documents	Financing requirements	Agency/ Mission to connect with
Municipalities which have not conducted energy audits	Concept note with project brief and resources required	Energy Audits	BEE, AMRUT Mission, Jal Shakti Abhiyan, International Development agencies
Municipalities which have conducted energy audits	Project DPR	Project Implementation	SIDBI, EESL, BEE, Jal Shakti Abhiyan, International Development agencies
Municipalities which have conducted energy audits and have an ESCO company in place to implement the project	Project DPR and Energy Performance Contract between municipality and ESCO	Bank Guarantee for project implementation	SIDBI, EESL

10

Exercise

10.1. Exercise 1: Calculation of Specific Energy Consumption of Water Supply

What is the Specific Energy Consumption of Water Supply if 23,08,320 cubic metres of water is supplied by using 3,50,00,000 kWh of electricity?

Option A: 25 kWh/m3
Option B: 10 kWh/m3
Option C: 15 kWh/m3
Option D: 30 kWh/m3

10.2. Exercise 2: Total Energy Losses due to Water Losses

What is the total energy loss due to water losses if 1,195 m3/day of water is lost per day? Consider the Specific energy consumption from the previous problem (15 kWh/m3).

Option A: 17,925 kWh
Option B: 35,500 kWh
Option C: 10,000 kWh
Option D: 30,000 kWh


Photo Credits: Markus Spiske on Unsplash

11

Case Studies

11.1. Project On Energy and Water Efficiency in Water Distribution, Fortaleza, Brazil[1]

Background

During the energy crisis and drought of 2000 and 2001, all consumers were required to reduce energy consumption by 20 percent as 70 percent of the energy generated in Brazil comes from hydropower.

The Alliance to Save Energy worked alongside Companhia de Água e Esgoto do Ceara (CAGECE) in the Northeast of Brazil in 2001 to develop and implement measures for more efficient use of water and energy. This partnership aimed to improve the distribution of water and the access to sanitation services, while reducing operational costs and environmental impacts

Interventions implemented

The following energy efficiency intervention measures were implemented in the project:

- Establishing baseline of energy consumed and water distributed.
- Implementing efficiency measures that led to a reduction in operational energy consumption.
- Development of EE projects, cost–benefit analysis, and specifications of equipment that could be financed.

[1] *Alliance to Save Energy (2005)*

- Automation of operations, rewinding and replacement of motors, maximizing existing pump systems efficiency, and increasing storage capacity to allow the shutdown of pumps during peak hours.

The objectives of the automation of the water supply system of Fortaleza were to:

- Optimize operations to reduce energy costs.
- Improve system management by centralizing control.
- Speed up recognition of and response times to maintenance needs using sensors and by acting through controlling devices.
- Generate system diagnostics using historical records of operational data.

Key Results

Total energy savings of around 88 GWh over four years was achieved after the implementation of the project. Further benefits included:

- 88,000 new households were connected to the water supply system while water consumption remained constant, achieved due leakage and mechanical loss reduction.
- $2.5 million saved per year with an initial investment of $1.1 million

11.2. Water Supply Energy Efficiency Project, Pune, India

Background

Pune is a city in Maharashtra which relies on freshwater resources. The city has a storage capacity of approximately 30 per cent of its total daily requirement and a distribution network of about 2,500 km. The topography of the city is undulating, and the distribution network is old and unplanned, which adds to the challenges faced by the city in reducing the energy cost and efficiency.

PMC collaborated with the urban development department (UDD) of government of Maharashtra in January 2005 and took an initiative in consultation with Alliance to Save Energy for this project.

Intervention

- An energy audit was conducted on PMC's bulk water supply systems by Alliance.
- To build technical and managerial capacity at the PMC, a hands-on training for 45 PMC engineers was conducted.
- PMC contributed a total of Rs 85 lakh to implement a series of capital-intensive efficiency measures.
- PMC municipal engineers implemented additional low- and no-cost EE measures at the pumping stations, including distribution pumping stations, because of their improved knowledge from the trainings.

Key Results

- Energy savings: 3.8 million kWh/ year.
- CO_2 emissions avoided: 38,000 tonnes/year
- Cost savings: Rs 146 lakh/ year
- Water pumped:10 per cent more water delivered to the community with no addition to capacity.
- The efficient operation of the largest pumping station, Parvati Water Works, reduced the energy intensity of water supply by 6 per cent, from 375 to 352 kWh/million litre.

Photo Credits: Faucet on Pxhere

12

List of additional materials

List of Readings for each Chapter including and not limited to

1. Technical documents

- ✓ Mainstreaming Energy Efficiency in Urban Water And Wastewater Management in the wake of Climate Change, by Centre for Science & Environment, Ministry of Urban Development. (Link: *https://cdn.cseindia.org/attachments/0.73120800_1505297784_Policy-Paper-Mainstreaming-Energy-Efficiency-in-Urban-Water.pdf*)
- ✓ Operations and Maintenance of Water Supply system and Basics of Water Supply System- Training Module for Local Water and Sanitation Management, Maharashtra Jeevan Pradhikaran (MJP), CEPT University, 2012 (Link: *https://www.pas.org.in/Portal/document/ResourcesFiles/pdfs/Module_2%20Operation_maintenance%20of%20water%20supply%20system.pdf*)
- ✓ Developing the Capacity of ESCWA Member Countries to Address the Water and Energy Nexus for Achieving Sustainable Development Goals, UN ESCWA (Link: *https://archive.unescwa.org/publications/water-energy-nexus-renewable-energy-module*)
- ✓ Basic energy training & energy management planning program development for water & wastewater treatment plants – A case study in Pennsylvania, by Apalachian Regional Commission (Link: *https://dusp.mit.edu/hced/project/basic-energy-training-energy-management-planning-program-development-water-wastewater*)
- ✓ Environmental Protection Agency (EPA) of USA – Resource material packages for energy assessment in water utilities (Link: *https://www.epa.gov/sustainable-water-infrastructure/energy-efficiency-water-utilities*)]
- ✓ All other technical documents can be availed in this Google Drive Link - *https://drive.google.com/drive/folders/10nR1pPkzJBDsm1GEwFeomDIyptCaEIPz?usp=sharing*

2. Toolkits

✓ Water-Energy Nexus Operational Toolkit, UN ESCWA

- This module was prepared as part of the United Nations Development Account project on developing the capacity of ESCWA Member Countries to address the water and energy nexus for achieving Sustainable Development Goals.
- It highlights the utilization of renewable energy (RE) to strengthen the water and energy nexus by providing the power needed by water-related activities such as water distribution and wastewater treatment.
- RE technologies can also strengthen energy security and diversify national energy mix by providing alternative sources that are less water intensive, availing modern energy services and reducing the dependence on fossil fuel, which contributes to the mitigation of greenhouse gases emissions.
- Link:*https://archive.unescwa.org/publications/water-energy-nexus-renewable-energy-module*
- Energy assessment Excel sheets and user guide can be found in this link *https://drive.google.com/drive/folders/1bndqnruOOT_tHa2hYqjzgQsxLAAalZy?usp=sharing*

3. Relevant videos

✓ Designing Smart Urban Water Systems: Marcus Quigley at TEDxBeaconStreet

- This video details about the strategies to manage the water supply in the cities using modern technologies and management practices.
- Link: (*https://www.youtube.com/watch?v=3-1qxKcOSeg*)

✓ Smart Water Management (Seosan City Project)

- This video details about the case study of Season City whereseveral energy efficiency and IOT based smart automation concepts are used for sustainable management of the urban water supply system.
- Link: https:*//www.youtube.com/watch?v=tuN0Cs2XiEc*

References

- AECOM Design Build Civil, M. E. (2001). The Mathematics of Pumping Water.
- Alliance to Save Energy (2005). Watergy case study, Fortaleza, Brazil. [Online] Avaialble at: https://www.ase.org/sites/ase.org/files/fortaleza_brazil.pdf (accessed 7th December 2021)
- Bank, W. (2021). Earth's Water. [Online] Available at: https://olc.worldbank.org/sites/default/files/sco/E7B1C4DE-C187-5EDB-3EF2-897802DEA3BF/Nasa/chapter1.html. (Accessed 7th December 2021)
- CPHEEO. (2012). Manual on Water Supply & Treatment.
- Kumar, P., 2013. Energy and Water Efficiency in Municipal Water Supply System. Guwahati: CSE India. http://cdn.cseindia.org/userfiles/ pradeep_kumar_director.pdf
- University, C. (n.d.). Module 1 BASICS OF WATER SUPPLY SYSTEM - Training Module for Local Water and Sanitation Management, Maharashtra Jeevan Pradhikaran (MJP).
- Weebly. (n.d.). Design water supply system. Retrieved from http://designwss.weebly.com/: http://designwss.weebly.com/
- WWF India, 2020. [Online] Available at: https://www.wwfindia.org/news_facts/pres/?19602/Cities-across-the-globe-face-an-alarming-rise-in-water-risks#:~:text=About%2030%20Indian%20cities%20including,Dr. [Accessed March 2021].

Notes:

Notes:

सत्यमेव जयते

Ministry of Housing and Urban Affairs
Government of India