

Cooling Towers -Energy Auditing Guidelines

1. Introduction

Cooling is essential in industrial processes, room air conditioning, power generation and electrical systems. During cooling processes, the working fluid extracts heat from the system of interest and dumps it into a heat sink. A cooling tower is one of the mechanisms used for dumping the heat. There are two types of cooling tower configurations: air- and water-cooling towers. They can further be categorised into natural draft and mechanical draft cooling towers. Mechanical draft towers use fans to force to create draft and move air through circulated water. On the other hand, natural-draft cooling towers work on the buoyancy principle of the exhaust air rising in a tall chimney to provide the draft. They are generally larger compared to mechanical draft; designed for water flow rates above 45,000 m³/h and mainly used for large coal and nuclear power plants.

The water cooling tower configuration is commonly used in large systems because water has a higher specific heat capacity, and is easier to handle compared to air. In this guidebook we shall focus on mechanical draft water cooling towers since they are ones widely used in all industrials set ups.

It is important for an energy auditor to understand the configuration and working principle of a cooling tower. The auditor should therefore familiarise themselves with the basic interactions between the cooling towers and the processes being audited. Table 1 presents some of the processes where a cooling tower is applied.

Table 1 Processes where a cooling tower is applied

Process	Description
Gas compression cycle of a HVAC system	It is used for extraction of heat from the refrigerant of the gas compression cycle in the condenser
Extraction of edible oil from seeds	In the process of extraction of edible oil, hot solvents like hexane are used to dissolve the oil from the seeds. After dissolving the oil, there is need to separate the oil and solvent. This can be achieved through cooling since they have different boiling points.
Oil refineries	It is used for cooling oil products for storage

Alcohol distilleries	During fractional distillation, different alcohol products are separated based on their boiling points, in vapour form. They require cooling to condense back into liquid, and to be packaged. The cooling tower is used as a heat sink in this process.
Extrusion of plastic pipes	In extrusion of plastic pipes, metallic dies are used to give the pipes the shape and form. Since these pipes are hot, the dies are heated in the process. This makes them susceptible to thermal expansion, which can alter the size and shape of the pipes. Thus, there is need to cool them to maintain their shape and size.
Lubricating oils for moving machine parts	The moving parts of a machine need to be lubricated to reduce friction. They should also be cooled to extract heat generated during the unavoidable friction between the parts. Oil is used as both a lubricant and cooling agent. To achieve the results, the viscosity and temperature of the oil must be maintained using a cooling tower. Examples include bearings of thermal and steam turbines, and rolling mills.

The heat transfer process, to the atmosphere, can either be through conduction, convention or evaporative cooling, mainly referred to as cooling through mass transfer. To facilitate the heat transfer to the atmosphere cooling towers are mainly employed in most industrial and electrical generating plants.

For the cooling tower to achieve the desired working conditions in the aforementioned processes, it must be configured as demonstrated in *figure 1*:

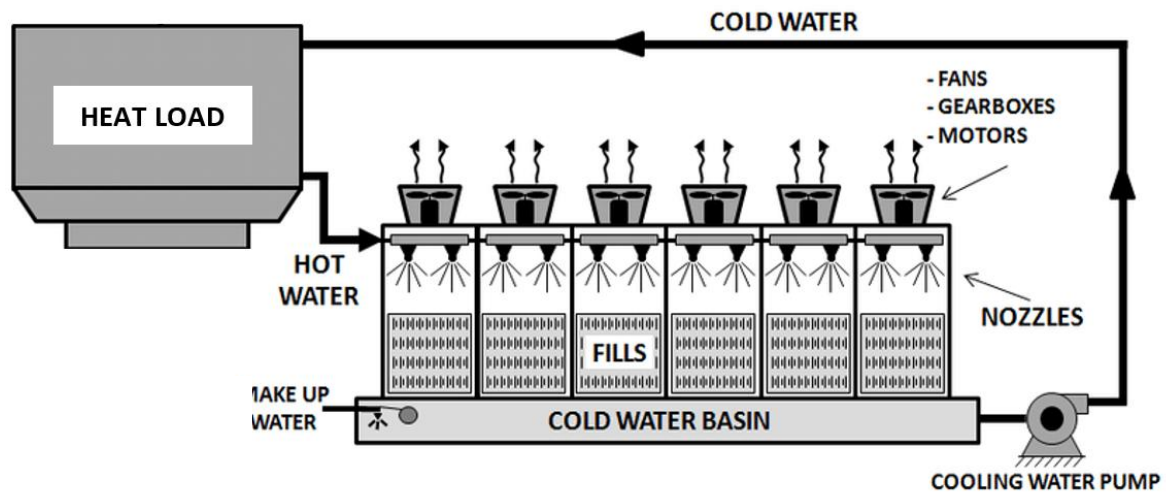


Figure 1 Configuration of a cooling tower

The heat load could be hot oil, used for lubricating moving machine parts, hot refrigerant in the condenser of a compression gas cycle, or cooling fluid from pipe extrusion dies. The water in the cooling tower is used as a heat transfer fluid from the heat load to the ambient. The water in the cooling tower loses the heat to the air through sensible and latent cooling. This process is mediated by several components.

2. Components of a water cooling tower

Figure 2 illustrates the components of a water-cooling tower

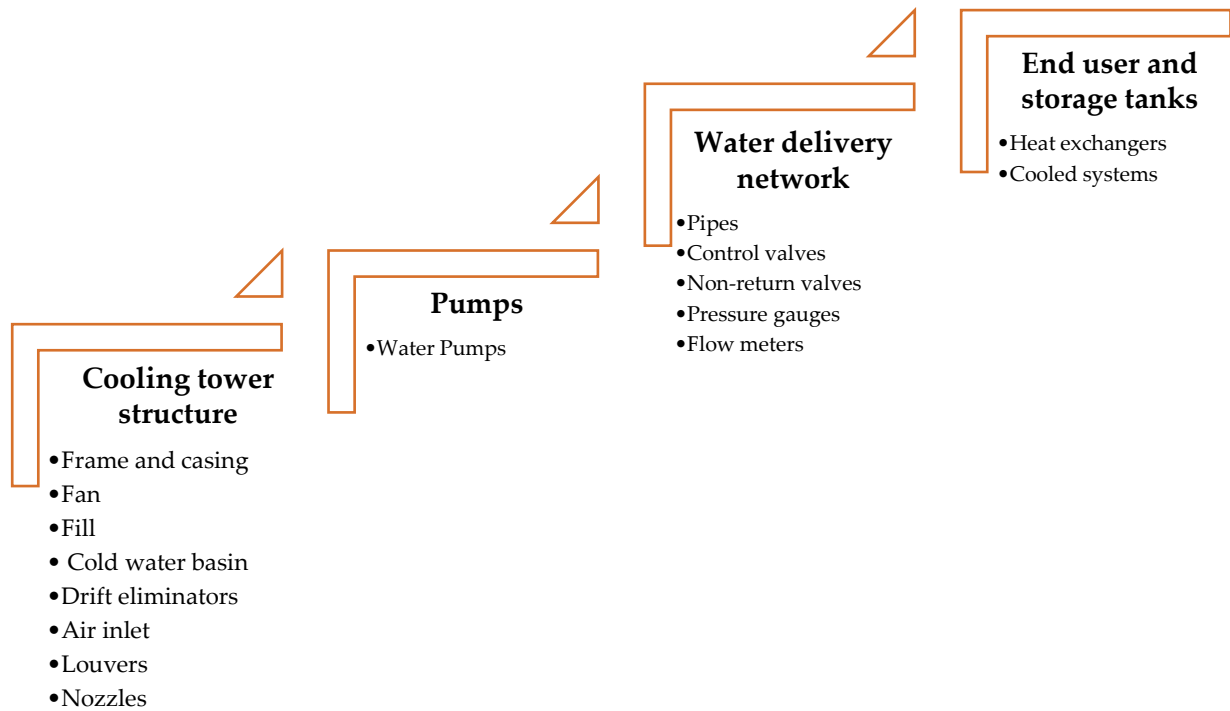


Figure 2 Components of a water-cooling tower

The working principle of a water cooling tower depends on a combination of different components. Energy auditors should therefore consider the whole system during the energy audit. The auditing process will depend on the cooling application. To understand the detailed working principle of the cooling tower configuration presented in *figure 1*, we break this down into specific components as illustrated in *figure 3*.

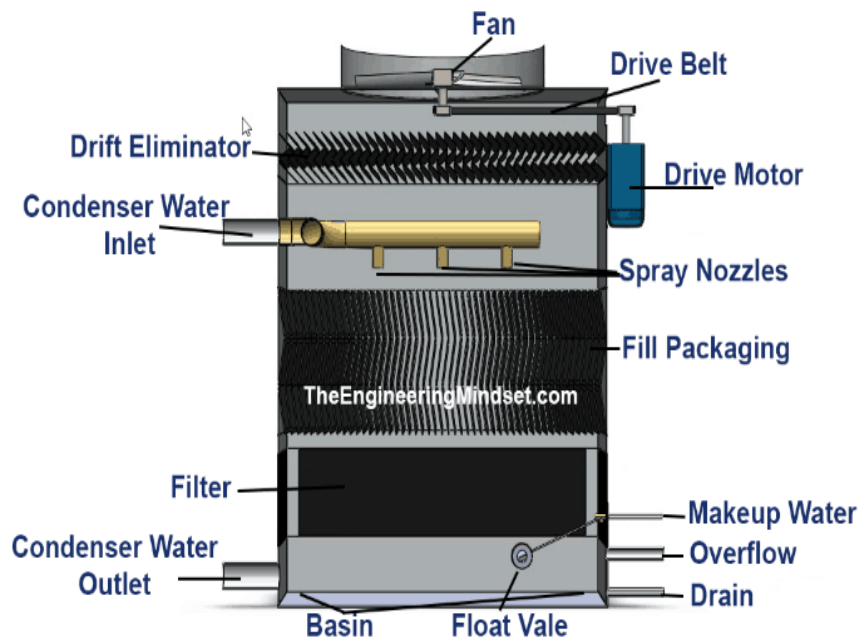


Figure 3 Parts of a cooling tower structure

The casing of a cooling tower provides space within which air and water exchange heat. The base of the casing, known as the basin, holds water, which is pumped and circulated between the cooled space (heat load) and the cooling tower. For effective heat transfer, water returning to the cooling tower should be atomized. This atomization is achieved using the spray nozzles. This process results in a drop in the pressure, leading to evaporative cooling. Additionally, atomization increases the contact surface area of the water. Recall, heat transfer is directly proportional to the surface area.

The cooling air is drawn into the cooling tower by use of a fan. The fan moves cooler ambient air through the filters, fill packaging and drift eliminator, taking away heat from the water. The filters are used to reduce the amount of particulate matter in air entering the cooling tower. The fill packaging is used to increase the contact time between the air and water droplets, as well as increasing heat transfer surface area. The drift eliminator minimizes water droplets escaping from the cooling tower. There is a tendency of the fan to suck water droplets which can escape into the atmosphere. The drift eliminator traps the water, minimizing the amount of makeup water required. In addition, the drift eliminator deflects the motion of air towards the periphery of the cooling tower. This deflection is important, without which the air would be directed to the fan, leaving some nozzles unattended.

The cold-water basin, located at or near the bottom of the tower, is a reservoir for cooled water. It has a water outlet through which cooled water exits from the cooling tower to the system being cooled. Additionally, it has a point for makeup water and overflow. Makeup water is the additional water used to replace water lost during evaporative cooling, while overflow is the point at which excess water flows out of the basin into the drain. The drain is the section through which water is drained out of the basin for maintenance purposes, and solid impurities are released during operation. Circulation of water in the system is done by the pump and the associated delivery network. Details of the pumping systems are discussed in a separate **chapter/volume** of this guidebook.

Categories of Mechanical Draft Cooling Towers.

There are three major categories of mechanical draft water cooling towers:

- i. Counter flow induced draft
- ii. Counter flow forced draft
- iii. Cross flow induced draft

In a counter flow induced draft cooling tower, the fans are located at the top of the tower; while in a counter flow forced draft cooling tower, the fans are located at the bottom of the tower. In the counter flow cooling towers, return water from the cooled system enters at the top and moves in the opposite direction of air as shown in *figure 4*.

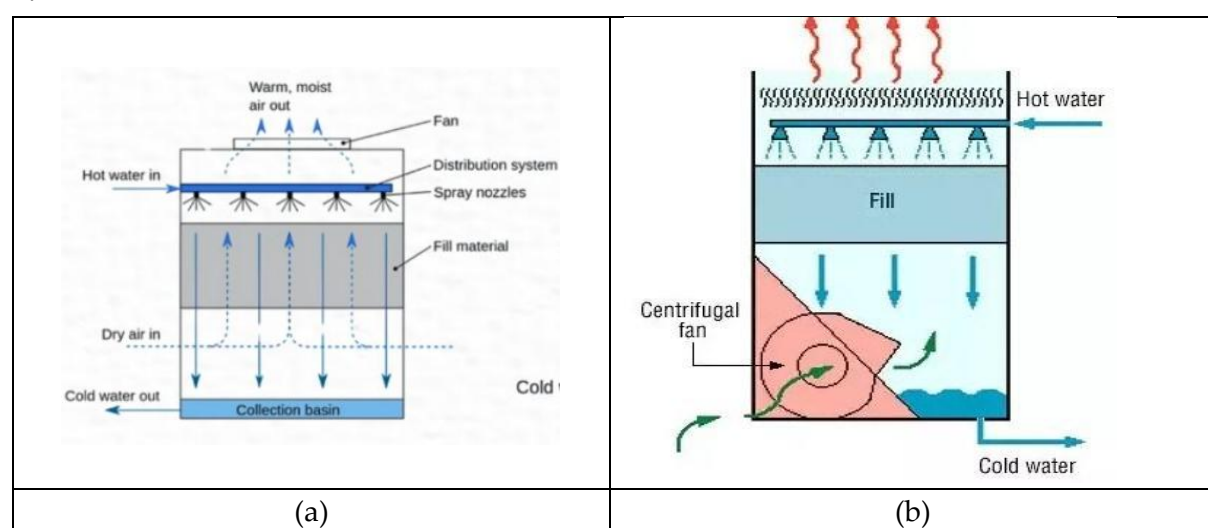


Figure 4 (a) Induced draft counter flow cooling tower (b) Forced draft counter flow cooling tower.

The choice of configurations (a) and (b) mostly depends on space availability.

In a cross flow induced draft cooling tower, return water flows vertically through the fill, while air flows horizontally across the flow of the falling water as shown in *figure 5*.

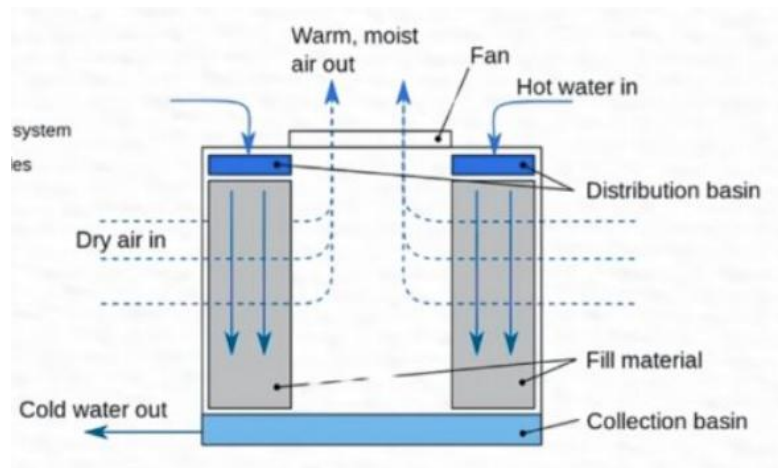


Figure 5 Cross flow induced draft cooling tower

Air can either be introduced on both sides, (double-flow tower) or on a single side (single-flow tower). Compared to the counter flow configuration, the cross-flow configuration minimizes the reduction of temperature gradient due to lower head requirements.

3. Cooling Tower Performance

To analyse the performance of a cooling tower, there are system variables that an auditor needs to understand and analyse. The system variables are:

Cooling tower effectiveness (CTE)	Evaporation loss (EvL)	Range
Cycles of concentration (CoC)	Cooling capacity (CC)	Approach
Liquid-Gas (L/G) ratio	Blow down losses	

Figure 6 illustrates approach and range as used in cooling tower performance analysis.

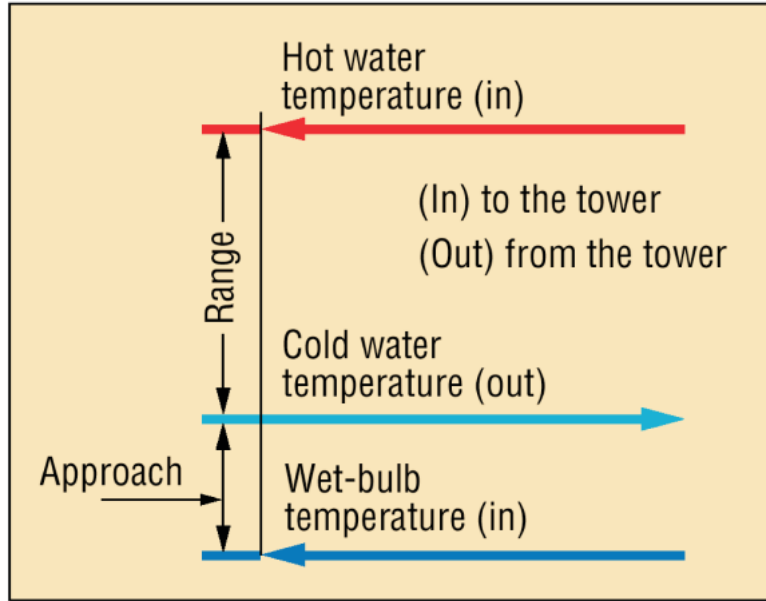


Figure 6 Approach and range as used in cooling tower performance

i. Range:

Range is the difference in temperature of the water at the inlet and outlet of the cooling tower. Equation 1 is used to calculate the range of a cooling tower.

$$\Delta\theta (^{\circ}\text{C}) = \theta_{\text{outlet}} - \theta_{\text{inlet}} \quad (1)$$

It is determined by the heat load being cooled by the tower, and the rate of water circulation through the whole system. Equation 1 is used to calculate the range of a cooling tower.

$$\text{Range } (^{\circ}\text{C}) = \frac{\text{Heat Load } (\frac{\text{kJ}}{\text{h}})}{\text{Water Circulation Rate } (\frac{\text{l}}{\text{h}})} \quad (1)$$

ii. Approach:

Approach is the difference between the cooling tower outlet temperature and ambient wet bulb temperature. Approach is a better indicator of the cooling tower performance

compared to the range because it measures evaporative cooling. The smaller the approach the better the cooling tower performance.

iii. Cooling Tower Effectiveness (CTE)

Cooling tower effectiveness (expressed as a percentage) is the ratio of measured range to the ideal range. The ideal range is the difference between inlet water temperature and the wet bulb temperature. During an energy audit, the auditor should take measurements of the range and the approach. The CTE is then determined using *equation 2*.

$$CTE = \frac{\text{Measured Range}}{\text{Ideal Range}} \times 100 \quad (2)$$

Where:

The ideal range is determined by the summation of measured range and measured approach. *Equation 2* therefore becomes:

$$CTE = \frac{\text{Measured Range}}{\text{Measured Range} + \text{Approach}} \times 100 \quad (3)$$

NOTE: From *equation 3*, as the approach tends to zero, the CTE tends to 100%.

Cooling towers are normally specified to cool at a certain flow rate from one temperature to another temperature at a given wet bulb temperature. For example, the cooling tower can be specified to cool 5000 m³ /h from 50.0°C to 32.0°C at 25.0°C wet bulb temperature.

During an energy audit always take note of the wet bulb temperature or relative humidity because it is a key parameter in the performance of a cooling tower.

iv. Cooling Capacity

Cooling capacity is the heat rejected by the cooling tower, presented in kJ/h. The rejected heat is also referred to as heat load. It is the product of mass flow rate of water, specific heat capacity of water and temperature difference as shown in *equation 4*.

$$Q_{cc} = \dot{m}_w \times C_{pw} \times \Delta\theta \quad (4)$$

Where:

$\dot{m}_w$	Mass flow rate of water
C_{pw}	Specific heat capacity of water
$\Delta\theta$	Range

v. Evaporation loss

Evaporation loss is the maximum quantity of water required to evaporate to remove the heat (known as the cooling load, or cooling duty) from the cooling tower. Theoretically, it is given by the cooling load divided by the latent heat of vaporisation of water at a given inlet temperature. This is given by *equation 5*.

$$L_{ev} = \frac{Q_c}{H_{vap}} \quad (5)$$

Where:

L_{ev}	Evaporation loss in kg/h
Q_c	Cooling Load in kJ/h
H_{vap}	Latent heat of vaporisation in kJ/kg

For example, a cooling load of 1,000,000 kJ/h at an inlet water temperature of 50°C will cause an evaporation loss of about 0.420 m³/h of water.

In a practical situation, the evaporation loss calculated using the cooling load is less than the actual amount of water evaporated. The actual amount of water evaporated is given by *equation 6*.

$$L_{ev,real} = (W_{out} - W_{in}) \times \dot{m}_a \quad (6)$$

Where,

$L_{ev,real}$	Real evaporation loss in kg/h
W_{out}	Humidity ratio of air at cooling tower air outlet
W_{in}	Humidity ratio of air at cooling tower air inlet
$\dot{m}_a$	Air flowrate through the cooling tower kg/h

vi. Liquid-Gas (L/G) ratio

Liquid-Gas ratio in cooling towers is the ratio of the mass flow rate of water to the mass flow rate of air. The Laws of Thermodynamics dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air.

Therefore, the liquid-gas (L/G) ratio is calculated using *equation 7*.

$$L/G = \frac{h_{a2} - h_{a1}}{\theta_{w1} - \theta_{w2}} \quad (7)$$

Where:

θ_{w1}	Temperature of water at inlet
θ_{w2}	Temperature of water at outlet
h_{a1}	Enthalpy of air-water vapour mixture at inlet
h_{a2}	Enthalpy of air-water vapour mixture at outlet

Seasonal variations during operations require adjustment of water and air flow rates to get the best possible cooling tower effectiveness (CTE). This can be done by adjusting the blade angles of the fans, or use of VFDs on fans and pumps.

NOTE: The optimal L/G ratio is not a fixed number. It is a dynamic value that should be optimized for the specific tower and operating environment, to balance energy consumption and water usage for optimal cooling performance.

vii. Cycles of concentration (CoC)

Cycles of concentration is the ratio of total dissolved solids (TDS) in circulating water, to the total dissolved solids in makeup water. It assists in determining the rate of blowdown.

$$CoC = \frac{TDS_{circulating}}{TDS_{makeup}} \quad (8)$$

viii. Blow down losses

Blowdown losses are losses associated with concentration of dissolved solids in water. They depend on cycles of concentration. The blowdown losses are calculated using *equation 9*.

$$L_{blowdown} = \frac{L_{ev}}{CoC - 1} \quad (9)$$

Where:

L_{ev}	Evaporation loss in kg/h
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Blowdown losses can be reduced by using makeup water with less total dissolved solids.

Cooling towers are designed to cool at a certain flow rate from one temperature to another temperature at a given wet bulb temperature. Once a cooling tower is designed, it is tested under specific conditions which are flow rate, water inlet temperature, water outlet temperature and wet bulb temperature. For example, a cooling tower may be tested at a flow rate of 5000 m³ /hr, from 50.0°C to 32.0°C, at 25.0°C wet bulb temperature.

During an energy audit always take note of the wet bulb temperature or relative humidity because it is a key parameter in the performance of a cooling tower.

4. Energy auditing of a water-cooling tower system

Auditing the energy use of a water-cooling tower entails three fundamental steps, as illustrated in *Figure 7*:

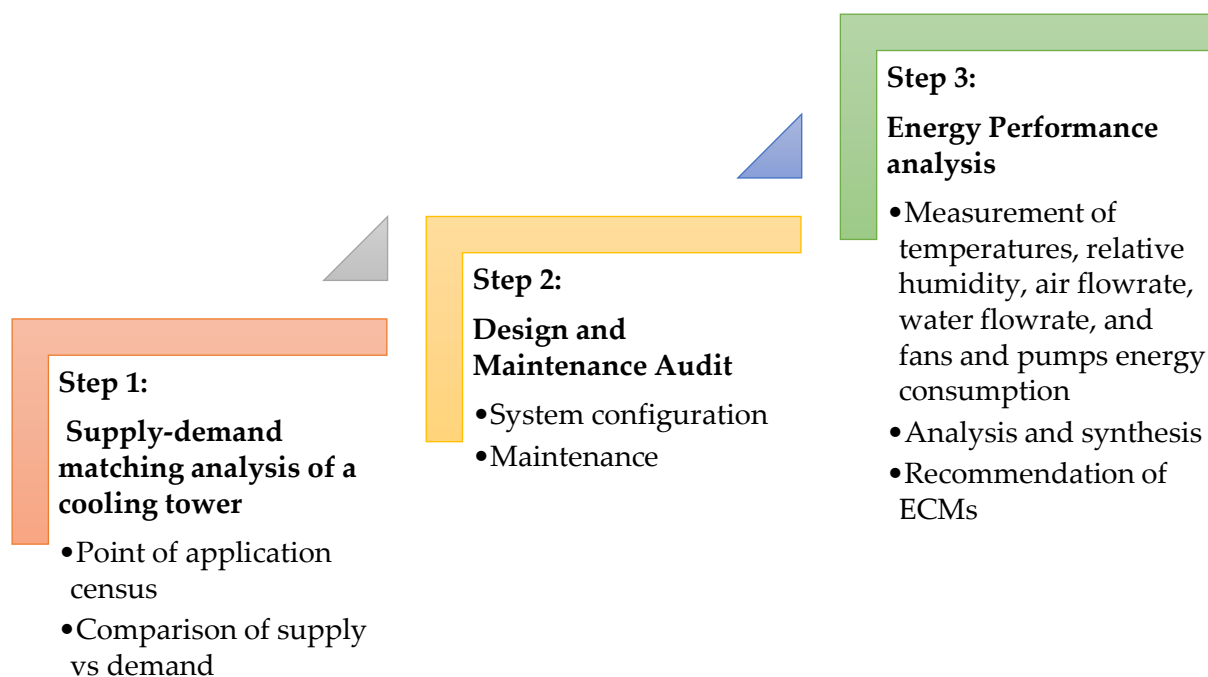


Figure 7 Steps in auditing cooling tower systems

The processes illustrated in Figure 7 are sequential. The results from one step inform the analysis of the subsequent step.

Step 1: Supply- Demand Matching Analysis

For efficient operation of a cooling tower system, its design capacity should match the cooling load requirements. Supply-demand matching can be determined by comparing the size of the cooling fan with the heat load. The amount of air induced by the fan should produce a cooling effect equal to the heat load. A cooling tower with a design capacity higher than the cooling load is an indication of inefficient operations. As a rule of thumb, the cooling load should be at least 75% of the design capacity. In cooling towers, overcooling can lead to wastage of water.

Efficient operation can be achieved by adjusting the air flow (and thus the L/G ratio) using variable speed fans to match the heat load and prevailing ambient conditions. This adjustment requires monitoring of the air wet bulb temperatures, relative humidity and heat loads. In a stable operation, the heat load should be constant, with less than 2% variance. This means that only ambient air properties should be

monitored. The thermo-fluid conditions of the cooling water can only be changed if the cooling load requirements vary

The heat extracted by air through evaporative cooling, which should be equal to the heat load, is calculated using equation 9.

$$Q_a = \dot{m}_a \times (h_{out} - h_{in}) \quad (9)$$

Where:

Q_a	Heat extracted by the cooling tower
$\dot{m}_a$	Average Air mass flowrate
h_{out}	Enthalpy of air exiting the cooling tower
h_{in}	Enthalpy of air entering the cooling tower (ambient air near the cooling tower)

The results from this calculation should be compared to the cooling capacity (CC) of the tower calculated using *equation 4*. Ideally, the two values should be equal. However, a variance of 2% is acceptable.

If the extracted heat is higher than the cooling capacity:

- i. The fan is drawing more air than required
- ii. The heat load is lower than the design capacity

On the other hand, if the extracted heat is lower than the cooling capacity:

- i. The ambient temperature may be relatively low such that most of the heat is lost through sensible cooling
- ii. The fan is drawing less air than required

NOTE: During an energy audit, water and air flow rate are measured in litres per second (LPS) or cubic metres per second (m³/s). Conversion to mass flow rate is done using equations 10 and 11.

$$\dot{m}_w = \dot{V}_w \times \rho_w \quad (10)$$

$$\dot{m}_a = \dot{V}_a \times \rho_a \quad (11)$$

$\dot{m}_w$	Mass flowrate of water
$\dot{m}_a$	Mass flowrate of air
V_w	Volumetric flowrate of cooling water
V_a	Volumetric flowrate air cooling water
ρ_w	Density of water
ρ_a	Density of air

Demand-supply matching can be demonstrated using *Example 1*.

Example 1

During an energy audit of a food processing facility, the following information on cooling tower system was collected and presented in table 1. Heat load was calculated using equation 3. Dry bulb temperature and relative humidity were measured using a psychrometer. The other parameters were obtained using a psychrometric chart.

Table 2 Measurements and calculation obtained from an energy audit of a water tower cooling system

Time	Power Demand (kW)	Pressure (bars)	Flow (cc/s)	Hydraulic %Eff	Water Temp to CT	Water Temp from CT	dT	Inlet air Dry Bulb Temp (degree C)	Wet Bulb temp	Water density (kg/ccm)	Mass flow rate(kg/s)	Specific heat capacity of water (kJ/kgC)	Heat Load (kJ/s- kW)LxOxQ
0	18.27	3.99	0.0325	0.709	24.5	18.5	6	18	16.7	1000	32.48	4.1870	815.88
1	19.58	4.86	0.0298	0.739	24.3	20.3	4	18	16.7	1000	29.77	4.1870	498.57
2	17.31	3.36	0.0382	0.740	23.8	18.8	5	17	16.4	1000	38.15	4.1870	798.68
3	17.20	3.28	0.0381	0.727	24.2	20.2	4	17	15.9	1000	38.12	4.1870	638.46
4	19.46	4.78	0.0297	0.731	24.2	19.2	5	17	15.7	1000	29.75	4.1870	622.75
5	19.81	5.02	0.0298	0.755	23	18	5	15	14.4	1000	29.81	4.1870	624.14
6	17.20	3.28	0.0381	0.727	23.1	20.1	3	15	14.4	1000	38.12	4.1870	478.85
7	19.69	4.94	0.0298	0.747	23.1	20.1	3	15	14.4	1000	29.79	4.1870	374.21
8	17.43	3.44	0.0382	0.753	23.8	19.8	4	18	16.5	1000	38.18	4.1870	639.43
9	18.03	3.83	0.0354	0.752	24.2	20.2	4	21	15.4	1000	35.38	4.1870	592.48
10	18.74	4.31	0.0326	0.748	23.9	19.9	4	21	16.0	1000	32.57	4.1870	545.56
11	18.39	4.07	0.0325	0.719	24.1	18.1	6	22	15.8	1000	32.50	4.1870	816.50
12	17.91	3.75	0.0324	0.679	24.1	18.1	6	23.5	16.7	1000	32.40	4.1870	814.04
13	20.17	5.25	0.0299	0.778	24.7	19.7	5	24	16.0	1000	29.88	4.1870	625.54
14	19.58	4.86	0.0298	0.739	24.8	19.8	5	25	16.3	1000	29.77	4.1870	623.21
15	19.81	5.02	0.0298	0.755	25.1	20.1	5	25.5	16.9	1000	29.81	4.1870	624.14
16	17.20	3.28	0.0381	0.727	26	21	5	25	17.3	1000	38.12	4.1870	798.08

17	19.46	4.78	0.0297	0.731	25.9	20.9	5	25	18.0	1000	29.75	4.1870	622.75
18	19.81	5.02	0.0298	0.755	25.6	19.6	6	23.5	16.3	1000	29.81	4.1870	748.97
19	17.20	3.28	0.0381	0.727	26.1	19.1	7	22	15.8	1000	38.12	4.1870	1,117.31
20	19.69	4.94	0.0298	0.747	25.8	19.8	6	21	16.0	1000	29.79	4.1870	748.41
21	17.43	3.44	0.0352	0.695	24.3	21.3	3	20	15.6	1000	35.24	4.1870	442.68
22	18.03	3.83	0.0324	0.689	23.6	20.6	3	19	15.9	1000	32.43	4.1870	407.33
23	18.74	4.31	0.0311	0.714	22.8	19.8	3	19	15.9	1000	31.09	4.1870	390.57
0	18.39	4.07	0.0325	0.719	22.6	19.6	3	18	15.4	1000	32.50	4.1870	408.25
1	17.91	3.75	0.0324	0.679	22.7	20.7	2	18	15.5	1000	32.40	4.1870	271.35
2	20.17	5.25	0.0299	0.778	23.2	21.2	2	17	15.2	1000	29.88	4.1870	250.22
3	19.58	4.86	0.0298	0.739	23.1	21.1	2	17	15.1	1000	29.77	4.1870	249.28
4	17.91	3.75	0.0324	0.679	23.3	19.3	4	17	15.2	1000	32.40	4.1870	542.69
5	20.17	5.25	0.0299	0.778	22.2	18.2	4	16	14.8	1000	29.88	4.1870	500.43
6	19.58	4.86	0.0298	0.739	22.4	18.4	4	16	15.4	1000	29.77	4.1870	498.57
7	19.81	5.02	0.0298	0.755	22.6	20.6	2	16	15.4	1000	29.81	4.1870	249.66
8	17.20	3.28	0.0381	0.727	23.1	19.1	4	17	15.7	1000	38.12	4.1870	638.46
9	19.46	4.78	0.0297	0.731	22.8	18.8	4	18.1	16.3	1000	29.75	4.1870	498.20
10	19.81	5.02	0.0298	0.755	22.5	18.5	4	21	17.2	1000	29.81	4.1870	499.31
11	17.20	3.28	0.0381	0.727	22.4	18.4	4	21	17.2	1000	38.12	4.1870	638.46
12	18.27	3.99	0.0325	0.709	24.8	20.8	4	23	17.4	1000	32.48	4.1870	543.92
13	19.58	4.86	0.0298	0.739	25.3	20.3	5	24	17.6	1000	29.77	4.1870	623.21
14	17.31	3.36	0.0382	0.740	26.9	21.9	5	25	18.0	1000	38.15	4.1870	798.68
15	17.20	3.28	0.0381	0.727	27.7	22.7	5	24.7	17.6	1000	38.12	4.1870	798.08
16	19.46	4.78	0.0297	0.731	27.1	20.1	7	25	17.3	1000	29.75	4.1870	871.85
17	19.81	5.02	0.0298	0.755	27.3	21.3	6	24	16.5	1000	29.81	4.1870	748.97
18	17.20	3.28	0.0381	0.727	27.1	21.1	6	23.2	14.9	1000	38.12	4.1870	957.70
19	19.69	4.94	0.0298	0.747	26	19	7	22	15.4	1000	29.79	4.1870	873.15
20	20.17	5.25	0.0299	0.778	25.7	18.7	7	20	15.6	1000	29.88	4.1870	875.75
21	19.58	4.86	0.0298	0.739	24.1	19.1	5	20	16.1	1000	29.77	4.1870	623.21
23	19.81	5.02	0.0298	0.755	23.3	19.3	4	19	16.5	1000	29.81	4.1870	499.31
0	17.20	3.28	0.0381	0.727	23.1	19.1	4	19	17.2	1000	38.12	4.1870	638.46
Av	18.72	4.29	0.03	0.73	24.30	19.80	4.50	20.16	16.1	1000	32.64	4.19	614.70

Table 2 shows properties of air entering and leaving the cooling tower. Heat extracted by air through evaporative cooling from the cooling-tower is calculated using equation 6, 9, 10 and 11.

Table 2: Measurements of air properties entering and leaving the cooling tower

Time	Fan power Demand (kW)	Fan 1 Air Flow (cc/m)	Fan2 Air Flow (cc/m)	Fan3 Air Flow (cc/m)	Total Air Flow (ccm/m)	Inlet air Dry Bulb Temp (degree C)	Inlet Relative Humidity (%)	Outlet Dry Bulb Air Temp Deg Cel	Outlet Air Relative Humidity (%)	Humidity Ratio (kgw/kg a)1	Humidity Ratio (kgw/kg a)2	dW	Specific Volume	Min=60sec	Mass Flow rate(kg/s)	Enthalpy h2	Enthalpy h1	dh	Heat extracted from cooling tower flow kJ/s
0	2.22	639.3	640.86	703.252	1983.43	18	88	21.5	97.3	0.011712345	0.016206391	0.004494046	0.87	60.00	38.157	62.809	47.793	15.017	572.98
1	2.13	522.8	524.7	470.529	1518.07	18	88	21.2	98.5	0.011712345	0.01610473	0.004392386	0.87	60.00	29.204	62.240	47.793	14.447	421.93
2	2.15	694.3	696.9	833.184	2224.40	17	94	20.7	99.2	0.011745816	0.015718575	0.003972759	0.86	60.00	42.938	60.742	46.850	13.892	596.48
3	2.09	580.1	582.2	580.1	1742.39	17	90	21	98.1	0.011236964	0.015836854	0.00459989	0.86	60.00	33.660	61.353	45.561	15.792	531.55
4	2.23	579.3	581.5	579.3	1740.13	17	88	20.7	98.3	0.010982845	0.015572397	0.004589552	0.86	60.00	33.630	60.370	44.917	15.453	519.69
5	2.22	638.2	640.7	702.042	1980.92	15	94	18.3	99.1	0.010313273	0.013478155	0.003164882	0.86	60.00	38.590	52.577	41.171	11.406	440.17
6	2.23	521.5	523.5	469.314	1514.24	15	94	18.8	100	0.010313273	0.014045832	0.003732559	0.86	60.00	29.499	54.533	41.171	13.361	394.15
7	2.21	394.1	395.6	268.007	1057.77	15	94	19	100	0.010313273	0.014226471	0.003913199	0.86	60.00	20.606	55.197	41.171	14.026	289.02
8	2.20	580.0	582.2	580	1742.20	18	86	21.6	100	0.011441258	0.016773253	0.005331995	0.87	60.00	33.530	64.353	47.106	17.248	578.32
9	2.18	243.8	244.7	102.3826	590.83	21	56	24.7	99.6	0.008942688	0.020260234	0.011317546	0.87	60.00	11.300	76.450	43.841	32.609	368.47
10	2.22	278.0	279.1	133.4477	690.55	21	60	24.4	89.1	0.009591302	0.017731931	0.00814063	0.87	60.00	13.193	69.699	45.488	24.210	319.41
11	2.13	463.8	465.5	371.072	1300.46	22	53	25.2	88.6	0.00899886	0.018517784	0.009518924	0.87	60.00	24.785	72.532	45.006	27.526	682.22
12	2.15	451.3	453.0	352.0202	1256.31	23.5	51	26.9	88.3	0.009491377	0.020469217	0.01097784	0.88	60.00	23.804	79.279	47.794	31.485	749.47
13	2.09	272.8	273.8	128.2325	674.88	24	44	28.1	87.9	0.008424546	0.021907128	0.013482583	0.88	60.00	12.787	84.203	45.590	38.613	493.77
14	2.23	185.4	186.1	59.32032	430.79	25	41	28.9	88.6	0.0083333045	0.023176966	0.014843922	0.88	60.00	8.136	88.285	46.378	41.906	340.96
15	2.22	208.9	209.7	75.19392	493.74	25.5	42	28.9	87.7	0.008800588	0.022932854	0.014132266	0.88	60.00	9.303	87.661	48.081	39.581	368.20
16	2.23	295.5	296.6	150.7019	742.83	25	47	29.1	88.7	0.00957128	0.023484267	0.013912987	0.88	60.00	14.002	89.280	49.533	39.747	556.54
17	2.21	249.3	250.2	107.1865	606.68	25	51	29	89.1	0.010399477	0.023453042	0.013053565	0.89	60.00	11.421	89.095	51.643	37.452	427.73
18	2.20	255.0	256.0	112.2106	623.23	23.5	48	27.1	90.6	0.00892505	0.021277209	0.012352159	0.88	60.00	11.819	81.549	46.353	35.197	416.00

19	2.18	493.0	494.9	419.05	1406.90	22	53	25.4	90.5	0.00899886	0.01916044 8	0.01016158 8	0.87	60.00	26.814	74.378	45.006	29.37 2	787.56
20	2.09	429.5	431.0	317.827	1178.37	21	60	24.4	90.7	0.00959130 2	0.01805959 5	0.00846829 4	0.87	60.00	22.513	70.533	45.488	25.04 5	563.83
21	2.23	261.2	262.2	117.809 9	641.25	20	64	23.6	92.5	0.00961893	0.01753956 3	0.00792063 3	0.87	60.00	12.293	68.378	44.535	23.84 3	293.10
22	2.22	307.3	308.5	162.893 9	778.76	19	73	22.9	92.1	0.01032158 1	0.01671907 8	0.00639749 7	0.87	60.00	14.963	65.564	45.293	20.27 1	303.32
23	2.23	231.5	232.4	92.608	556.54	19	73	22.8	91.8	0.01032158 1	0.01655980 4	0.00623822 3	0.87	60.00	10.693	65.055	45.293	19.76 2	211.32
0	2.21	261.7	262.7	117.753 8	642.10	18	77	22.3	92.6	0.01022423 5	0.01619518 1	0.00597094 5	0.86	60.00	12.382	63.610	44.021	19.58 9	242.54
1	2.20	188.3	189.0	61.1885 6	438.45	18	78	22.1	98.1	0.01035922 9	0.01696995 6	0.00661072 7	0.86	60.00	8.453	65.372	44.363	21.00 9	177.58
2	2.18	197.3	198.0	67.0711 2	462.35	17	83	20.6	98.3	0.01034843 7	0.01547433 2	0.00512589 5	0.86	60.00	8.944	60.018	43.311	16.70 7	149.44
3	2.21	197.0	197.7	66.9786 4	461.72	17	82	20.5	99.1	0.01022170 8	0.01550508 7	0.00528337 9	0.86	60.00	8.934	59.992	42.990	17.00 3	151.90
4	2.20	342.4	343.7	202.037 2	888.21	17	83	21.1	100	0.01034843 7	0.01625369 7	0.00590526	0.86	60.00	17.183	62.515	43.311	19.20 4	329.99
5	2.18	451.8	453.5	352.385 3	1257.64	16	88	19.3	100	0.01029434 6	0.01450135 7	0.00420701 1	0.86	60.00	24.416	56.204	42.149	14.05 6	343.19
6	2.22	475.4	477.3	389.857 5	1342.55	16	94	19.7	100	0.01100865 6	0.01487531 7	0.00386666 1	0.86	60.00	26.035	57.566	43.956	13.61 0	354.34
7	2.13	225.7	226.5	88.0050 6	540.14	16	94	20.4	99.6	0.01100865 6	0.01548697 8	0.00447832 1	0.86	60.00	10.475	59.843	43.956	15.88 7	166.41
8	2.09	580.5	582.6	580.5	1743.59	17	88	20.2	89.1	0.01098284 5	0.01364457 7	0.00266173 2	0.86	60.00	33.697	54.959	44.917	10.04 2	338.37
9	2.23	580.9	583.1	580.9	1744.93	18.1	84	21.3	88.6	0.01124214 7	0.01453947 4	0.00329732 7	0.87	60.00	33.582	58.367	46.704	11.66 3	391.68
10	2.22	335.6	336.9	194.641	867.10	21	69	24.6	88.3	0.01105557	0.0177858	0.00673023 1	0.87	60.00	16.528	70.044	49.208	20.83 6	344.38
11	2.23	516.5	518.5	459.655 6	1494.57	21	69	24.8	87.9	0.01105557	0.01792189 1	0.00686632 2	0.87	60.00	28.488	70.598	49.208	21.39 0	609.38
12	2.21	237.8	238.7	97.4811 9	573.91	23	58	26.6	88.6	0.01048947 7	0.02017007	0.00968059 3	0.88	60.00	10.875	78.203	49.821	28.38 2	308.66
13	2.20	191.5	192.2	63.1837 8	446.84	24	54	28.1	98.5	0.01037114 1	0.02465365 8	0.01428251 7	0.88	60.00	8.440	91.216	50.545	40.67 1	343.28
14	2.18	272.3	273.3	127.989 5	673.65	25	51	28.8	99.2	0.01039947 7	0.02590927 4	0.01550979 7	0.89	60.00	12.681	95.160	51.643	43.51 7	551.86
15	2.09	272.5	273.4	128.055 7	673.96	24.7	50	28	98.1	0.01000844 9	0.02440140 3	0.01439295 5	0.88	60.00	12.708	90.467	50.339	40.12 8	509.94
16	2.23	272.4	273.5	128.033 6	673.91	25	47	28.2	98.3	0.00957128	0.02475095 6	0.01517967 6	0.88	60.00	12.703	91.570	49.533	42.03 7	533.99
17	2.23	272.6	273.6	128.122	674.37	24	47	27.5	99.1	0.00900726 5	0.02392323 7	0.01491597 2	0.88	60.00	12.766	88.721	47.073	41.64 7	531.67
18	2.21	272.8	273.8	128.210 4	674.83	23.2	41	26.5	100	0.00746938 1	0.02272150 5	0.01525212 4	0.88	60.00	12.840	84.605	42.342	42.26 3	542.67
19	2.20	272.2	273.3	127.945 3	673.43	22	50	26.5	100	0.00848254 4	0.02272150 5	0.01423896 2	0.87	60.00	12.845	84.605	43.694	40.91 1	525.51
20	2.18	330.5	331.8	188.409 5	850.74	20	64	23.3	100	0.00961893	0.01865407 9	0.00903514 8	0.87	60.00	16.308	70.902	44.535	26.36 7	430.01
21	2.09	296.0	297.0	150.936	743.91	20	68	23.2	99.6	0.01023000 2	0.01846201 5	0.00823201 3	0.87	60.00	14.247	70.309	46.086	24.22 4	345.11

23	2.23	545.1	547.2	512.399 6	1604.71	19	78	22.1	89.1	0.01104108 8	0.01537459 5	0.00433350 7	0.87	60.00	30.798	61.316	47.118	14.19 8	437.28
0	2.22	562.8	564.9	545.910 2	1673.65	19	84	22.6	97.3	0.01190666 1	0.01736204 4	0.00545538 3	0.87	60.00	32.077	66.888	49.313	17.57 5	563.74
AVE	2.19	373.5	374.88	278.653	1027.02	20.1562 5	69.020833	23.8020 8	94.91042	0.01014265 4	0.018489	0.0083463	0.87	60.00	19.709	71.024	46.021	25.00 4	426.02

Table 3 shows comparison of heat load and heat extracted by air from cooling tower through evaporative cooling.

Table 3: Comparison heat load and heat extracted by air from cooling tower through evaporative cooling.

Hour	Heat Load (kJ/s-kW)	Heat Extracted through evaporative cooling	% of heat extracted through Evaporative cooling to Heat Load
0	815.88	572.98	70.2%
1	498.57	421.93	84.6%
2	798.68	596.48	74.7%
3	638.46	531.55	83.3%
4	622.75	519.69	83.5%
5	624.14	440.17	70.5%
6	478.85	394.15	82.3%
7	374.21	289.02	77.2%
8	639.43	578.32	90.4%
9	592.48	368.47	62.2%
10	545.56	319.41	58.5%
11	816.5	682.22	83.6%
12	814.04	749.47	92.1%
13	625.54	493.77	78.9%
14	623.21	340.96	54.7%
15	624.14	368.2	59.0%
16	798.08	556.54	69.7%
17	622.75	427.73	68.7%
18	748.97	416	55.5%
19	1,117.31	787.56	70.5%
20	748.41	563.83	75.3%
21	442.68	293.1	66.2%
22	407.33	303.32	74.5%
23	390.57	211.32	54.1%
0	408.25	242.54	59.4%
1	271.35	177.58	65.4%
2	250.22	149.44	59.7%
3	249.28	151.9	60.9%
4	542.69	329.99	60.8%
5	500.43	343.19	68.6%
6	498.57	354.34	71.1%
7	249.66	166.41	66.7%
8	638.46	338.37	53.0%
9	498.2	391.68	78.6%
10	499.31	344.38	69.0%
11	638.46	609.38	95.4%

12	543.92	308.66	56.7%
13	623.21	343.28	55.1%
14	798.68	551.86	69.1%
15	798.08	509.94	63.9%
16	871.85	533.99	61.2%
17	748.97	531.67	71.0%
18	957.7	542.67	56.7%
19	873.15	525.51	60.2%
20	875.75	430.01	49.1%
21	623.21	345.11	55.4%
22	499.31	437.28	87.6%
23	638.46	563.74	88.3%
Average	614.7	426.02	69.3%

Table 3 shows that 69% of cooling takes place through evaporative cooling while the other 31% of cooling is through sensible cooling.

The 31% from sensible cooling can be attributed to a good temperature gradient between that of cooling water and ambient air, that is, $24.30 - 20.12 = 4.18^{\circ}\text{C}$.

Additionally, the length of water pipes, configuration and size of cooling water basin can contribute the same.

Example 2

During an energy audit of an edible oil extraction plant, the following information on the cooling water system was collected and presented in table 4. Heat load was calculated using equation 3. Dry bulb temperature and relative humidity were measured using a psychrometer. The other parameters were obtained using a psychrometric chart.

Table 4: Measurements and calculation results of an energy audit in a water-cooling tower system, cooling water system.

Time	Power Demand (kW)	Pressure(bars)	Flow (cc/s)	Hydraulic %Eff	Water Temp to CT	Water Temp from CT	dT	Inlet air Dry Bulb Temp (degree C)	Wet Bulb temp	Water density (kg/ccm)	Mass flow rate(HxO)	Specific heat capacity of water (kJ/kgC)	Heat Load (kJ/s- kW)LxOxQ
0.0	17.74	4.03	0.0208	47.34	25.00	18.00	7.00	18.00	16.69	1,000.00	20.84	4.19	610.70
1.0	19.01	4.91	0.0191	49.31	24.80	19.80	5.00	18.00	16.69	1,000.00	19.10	4.19	399.84
2.0	16.81	3.39	0.0245	49.37	24.30	18.30	6.00	17.00	16.37	1,000.00	24.48	4.19	614.90
3.0	16.70	3.31	0.0245	48.50	24.70	19.70	5.00	17.00	15.94	1,000.00	24.46	4.19	512.03
4.0	18.89	4.83	0.0191	48.76	24.70	18.70	6.00	17.00	15.72	1,000.00	19.08	4.19	479.45
5.0	19.24	5.07	0.0191	50.37	23.50	17.50	6.00	15.00	14.40	1,000.00	19.13	4.19	480.52
6.0	16.70	3.31	0.0245	48.50	23.60	19.60	4.00	15.00	14.40	1,000.00	24.46	4.19	409.63
7.0	19.12	4.99	0.0191	49.84	23.60	19.60	4.00	15.00	14.40	1,000.00	19.11	4.19	320.11
8.0	16.93	3.47	0.0245	50.22	24.30	19.30	5.00	18.00	16.46	1,000.00	24.50	4.19	512.81
9.0	17.51	3.87	0.0227	50.17	24.70	19.70	5.00	21.00	15.39	1,000.00	22.70	4.19	475.15
10.0	18.20	4.35	0.0209	49.94	24.40	19.40	5.00	21.00	15.95	1,000.00	20.90	4.19	437.53
11.0	17.85	4.11	0.0209	48.00	24.60	17.60	7.00	22.00	15.80	1,000.00	20.85	4.19	611.16

12.0	17.39	3.79	0.0208	45.31	24.60	17.60	7.00	23.50	16.74	1,000.00	20.79	4.19	609.32
13.0	19.59	5.31	0.0192	51.93	25.20	19.20	6.00	24.00	16.01	1,000.00	19.17	4.19	481.60
14.0	19.01	4.91	0.0191	49.31	25.30	19.30	6.00	25.00	16.29	1,000.00	19.10	4.19	479.81
15.0	19.24	5.07	0.0191	50.37	25.60	19.60	6.00	25.50	16.85	1,000.00	19.13	4.19	480.52
16.0	16.70	3.31	0.0245	48.50	26.50	20.50	6.00	25.00	17.32	1,000.00	24.46	4.19	614.44
17.0	18.89	4.83	0.0191	48.76	26.40	20.40	6.00	25.00	17.98	1,000.00	19.08	4.19	479.45
18.0	19.24	5.07	0.0191	50.37	26.10	19.10	7.00	23.50	16.27	1,000.00	19.13	4.19	560.61
19.0	16.70	3.31	0.0245	48.50	26.60	18.60	8.00	22.00	15.80	1,000.00	24.46	4.19	819.25
20.0	19.12	4.99	0.0191	49.84	26.30	19.30	7.00	21.00	15.95	1,000.00	19.11	4.19	560.19
21.0	16.93	3.47	0.0226	46.36	24.80	20.80	4.00	20.00	15.62	1,000.00	22.61	4.19	378.69
22.0	17.51	3.87	0.0208	45.99	24.10	20.10	4.00	19.00	15.87	1,000.00	20.81	4.19	348.44
23.0	18.20	4.35	0.0199	47.67	23.30	19.30	4.00	19.00	15.87	1,000.00	19.95	4.19	334.11
0.0	17.85	4.11	0.0209	48.00	23.10	19.10	4.00	18.00	15.43	1,000.00	20.85	4.19	349.23
1.0	17.39	3.79	0.0208	45.31	23.20	20.20	3.00	18.00	15.54	1,000.00	20.79	4.19	261.14
2.0	19.59	5.31	0.0192	51.93	23.70	20.70	3.00	17.00	15.17	1,000.00	19.17	4.19	240.80
3.0	19.01	4.91	0.0191	49.31	23.60	20.60	3.00	17.00	15.06	1,000.00	19.10	4.19	239.90
4.0	17.39	3.79	0.0208	45.31	23.80	18.80	5.00	17.00	15.17	1,000.00	20.79	4.19	435.23
5.0	19.59	5.31	0.0192	51.93	22.70	17.70	5.00	16.00	14.76	1,000.00	19.17	4.19	401.33
6.0	19.01	4.91	0.0191	49.31	22.90	17.90	5.00	16.00	15.39	1,000.00	19.10	4.19	399.84
7.0	19.24	5.07	0.0191	50.37	23.10	20.10	3.00	16.00	15.39	1,000.00	19.13	4.19	240.26
8.0	16.70	3.31	0.0245	48.50	23.60	18.60	5.00	17.00	15.72	1,000.00	24.46	4.19	512.03
9.0	18.89	4.83	0.0191	48.76	23.30	18.30	5.00	18.10	16.33	1,000.00	19.08	4.19	399.54
10.0	19.24	5.07	0.0191	50.37	23.00	18.00	5.00	21.00	17.17	1,000.00	19.13	4.19	400.44
11.0	16.70	3.31	0.0245	48.50	22.90	17.90	5.00	21.00	17.17	1,000.00	24.46	4.19	512.03
12.0	17.74	4.03	0.0208	47.34	25.30	20.30	5.00	23.00	17.39	1,000.00	20.84	4.19	436.21
13.0	19.01	4.91	0.0191	49.31	25.80	19.80	6.00	24.00	17.63	1,000.00	19.10	4.19	479.81
14.0	16.81	3.39	0.0245	49.37	27.40	21.40	6.00	25.00	17.98	1,000.00	24.48	4.19	614.90
15.0	16.70	3.31	0.0245	48.50	28.20	22.20	6.00	24.70	17.57	1,000.00	24.46	4.19	614.44
16.0	18.89	4.83	0.0191	48.76	27.60	19.60	8.00	25.00	17.32	1,000.00	19.08	4.19	639.27
17.0	19.24	5.07	0.0191	50.37	27.80	20.80	7.00	24.00	16.51	1,000.00	19.13	4.19	560.61
18.0	16.70	3.31	0.0245	48.50	27.60	20.60	7.00	23.20	14.89	1,000.00	24.46	4.19	716.84
19.0	19.12	4.99	0.0191	49.84	26.50	18.50	8.00	22.00	15.35	1,000.00	19.11	4.19	640.22
20.0	19.59	5.31	0.0192	51.93	26.20	18.20	8.00	20.00	15.62	1,000.00	19.17	4.19	642.13
21.0	19.01	4.91	0.0191	49.31	24.60	18.60	6.00	20.00	16.14	1,000.00	19.10	4.19	479.81
23.0	19.24	5.07	0.0191	50.37	23.80	18.80	5.00	19.00	16.48	1,000.00	19.13	4.19	400.44
0.0	16.70	3.31	0.0245	48.50	23.60	18.60	5.00	19.00	17.19	1,000.00	24.46	4.19	512.03

Table 5 shows properties of air entering and leaving the cooling tower. Water evaporated during cooling from the cooling-tower is calculated using equation 5 and 6.

Table 5: Properties of air entering and leaving the cooling tower

Time	Fan power Demand(kW)	Air Flow (ccc/m)	Air Flow (ccc/m)	Air Flow (ccc/m)	Total Air Flow (ccm/m)	Inlet air Dry Bulb Temp (degree C)	Inlet Relative Humidity (%)	Outlet Dry Bulb Air Temp Deg Cel	Outlet Air Relative Humidity (%)	Humidity Ratio (kgw/kg a)1	Humidity Ratio (kgw/kg a)2	dW	Specific Volume	Mass Flow rate	Enthalpy h2	Enthalpy h1	dh	Heat flow kJ/s	Water evaporated during Cooling kg/s
0	30.15	1,218.94	1,221.88	1,340.84	3,781.66	18	88	21.5	97.3	0.011712345	0.016206391	0.00449405	0.87	72.750	62.809	47.793	15.017	1,092.46	0.3269
1	14.76	996.80	1,000.46	897.12	2,894.38	18	88	21.2	98.5	0.011712345	0.01610473	0.00439239	0.87	55.681	62.240	47.793	14.447	804.45	0.2446
2	14.90	1,323.81	1,328.73	1,588.57	4,241.10	17	94	20.7	99.2	0.011745816	0.015718575	0.00397276	0.86	81.866	60.742	46.850	13.892	1,137.27	0.3252
3	14.49	1,106.03	1,110.02	1,106.03	3,322.08	17	90	21	98.1	0.011236964	0.015836854	0.00459989	0.86	64.178	61.353	45.561	15.792	1,013.47	0.2952
4	15.46	1,104.51	1,108.76	1,104.51	3,317.77	17	88	20.7	98.3	0.010982845	0.015572397	0.00458955	0.86	64.120	60.370	44.917	15.453	990.85	0.2943
5	15.39	1,216.85	1,221.50	1,338.53	3,776.88	15	94	18.3	99.1	0.010313273	0.013478155	0.00316488	0.86	73.577	52.577	41.171	11.406	839.24	0.2329
6	15.46	994.23	998.05	894.81	2,887.09	15	94	18.8	100	0.010313273	0.014045832	0.00373256	0.86	56.243	54.533	41.171	13.361	751.49	0.2099
7	15.32	751.45	754.32	510.99	2,016.76	15	94	19	100	0.010313273	0.014226471	0.0039132	0.86	39.289	55.197	41.171	14.026	551.06	0.1537
8	15.25	1,105.84	1,110.04	1,105.84	3,321.72	18	86	21.6	100	0.011441258	0.016773253	0.00533199	0.87	63.930	64.353	47.106	17.248	1,102.64	0.3409
9	15.11	464.77	466.52	195.21	1,126.50	21	56	24.7	99.6	0.008942688	0.020260234	0.01131755	0.87	21.544	76.450	43.841	32.609	702.54	0.2438
10	15.39	530.07	532.10	254.43	1,316.61	21	60	24.4	89.1	0.009591302	0.017731931	0.00814063	0.87	25.154	69.699	45.488	24.210	608.99	0.2048
11	14.76	884.37	887.62	707.49	2,479.48	22	53	25.2	88.6	0.00899886	0.018517784	0.00951892	0.87	47.255	72.532	45.006	27.526	1,300.74	0.4498
12	14.90	860.47	863.67	671.17	2,395.32	23.5	51	26.9	88.3	0.009491377	0.020469217	0.01097784	0.88	45.385	79.279	47.794	31.485	1,428.96	0.4982
13	14.49	520.19	522.07	244.49	1,286.75	24	44	28.1	87.9	0.008424546	0.021907128	0.01348258	0.88	24.381	84.203	45.590	38.613	941.43	0.3287
14	15.46	353.44	354.80	113.10	821.35	25	41	28.9	88.6	0.008333045	0.023176966	0.01484392	0.88	15.513	88.285	46.378	41.906	650.08	0.2303
15	15.39	398.24	399.76	143.37	941.37	25.5	42	28.9	87.7	0.008800588	0.022932854	0.01413227	0.88	17.737	87.661	48.081	39.581	702.02	0.2507
16	15.46	563.40	565.56	287.33	1,416.29	25	47	29.1	88.7	0.00957128	0.023484267	0.01391299	0.88	26.697	89.280	49.533	39.747	1,061.11	0.3714
17	15.32	475.27	477.08	204.36	1,156.71	25	51	29	89.1	0.010399477	0.023453042	0.01305356	0.89	21.775	89.095	51.643	37.452	815.53	0.2842
18	15.25	486.23	488.08	213.94	1,188.26	23.5	48	27.1	90.6	0.00892505	0.021277209	0.01235216	0.88	22.535	81.549	46.353	35.197	793.15	0.2784
19	15.11	939.97	943.50	798.97	2,682.44	22	53	25.4	90.5	0.00899886	0.019160448	0.01016159	0.87	51.123	74.378	45.006	29.372	1,501.57	0.5195
20	14.49	818.89	821.84	605.98	2,246.70	21	60	24.4	90.7	0.009591302	0.018059595	0.00846829	0.87	42.924	70.533	45.488	25.045	1,075.02	0.3635
21	15.46	498.05	499.96	224.62	1,222.63	20	64	23.6	92.5	0.00961893	0.017539563	0.00792063	0.87	23.438	68.378	44.535	23.843	558.83	0.1856

22	15.39	586.00	588.24	310.58	1,484.81	19	73	22.9	92.1	0.010321581	0.016719078	0.0063975	0.87	28.529	65.564	45.293	20.271	578.31	0.1825
23	15.46	441.42	443.12	176.57	1,061.11	19	73	22.8	91.8	0.010321581	0.016559804	0.00623822	0.87	20.388	65.055	45.293	19.762	402.91	0.1272
0	15.32	498.92	500.81	224.51	1,224.24	18	77	22.3	92.6	0.010224235	0.016195181	0.00597095	0.86	23.607	63.610	44.021	19.589	462.43	0.1410
1	15.25	358.96	360.33	116.66	835.96	18	78	22.1	98.1	0.010359229	0.016969956	0.00661073	0.86	16.116	65.372	44.363	21.009	338.58	0.1065
2	15.11	376.12	377.53	127.88	881.52	17	83	20.6	98.3	0.010348437	0.015474332	0.0051259	0.86	17.054	60.018	43.311	16.707	284.92	0.0874
3	15.32	375.60	377.03	127.70	880.33	17	82	20.5	99.1	0.010221708	0.015505087	0.00528338	0.86	17.034	59.992	42.990	17.003	289.62	0.0900
4	15.25	652.90	655.37	385.21	1,693.48	17	83	21.1	100	0.010348437	0.016253697	0.00590526	0.86	32.761	62.515	43.311	19.204	629.16	0.1935
5	15.11	861.37	864.61	671.87	2,397.84	16	88	19.3	100	0.010294346	0.014501357	0.00420701	0.86	46.552	56.204	42.149	14.056	654.33	0.1958
6	15.39	906.48	909.95	743.31	2,559.74	16	94	19.7	100	0.011008656	0.014875317	0.00386666	0.86	49.639	57.566	43.956	13.610	675.60	0.1919
7	14.76	430.24	431.82	167.79	1,029.85	16	94	20.4	99.6	0.011008656	0.015486978	0.00447832	0.86	19.971	59.843	43.956	15.887	317.28	0.0894
8	14.49	1,106.80	1,110.78	1,106.80	3,324.37	17	88	20.2	89.1	0.010982845	0.013644577	0.00266173	0.86	64.248	54.959	44.917	10.042	645.15	0.1710
9	15.46	1,107.56	1,111.81	1,107.56	3,326.93	18.1	84	21.3	88.6	0.011242147	0.014539474	0.00329733	0.87	64.028	58.367	46.704	11.663	746.78	0.2111
10	15.39	639.84	642.30	371.11	1,653.24	21	69	24.6	88.3	0.01105557	0.0177858	0.00673023	0.87	31.513	70.044	49.208	20.836	656.60	0.2121
11	15.46	984.71	988.49	876.39	2,849.59	21	69	24.8	87.9	0.01105557	0.017921891	0.00686632	0.87	54.317	70.598	49.208	21.390	1,161.85	0.3730
12	15.32	453.32	455.04	185.86	1,094.22	23	58	26.6	88.6	0.010489477	0.02017007	0.00968059	0.88	20.735	78.203	49.821	28.382	588.50	0.2007
13	15.25	365.05	366.44	120.47	851.96	24	54	28.1	98.5	0.010371141	0.024653658	0.01428252	0.88	16.093	91.216	50.545	40.671	654.51	0.2298
14	15.11	519.21	521.16	244.03	1,284.40	25	51	28.8	99.2	0.010399477	0.025909274	0.0155098	0.89	24.179	95.160	51.643	43.517	1,052.19	0.3750
15	14.49	519.48	521.35	244.15	1,284.98	24.7	50	28	98.1	0.010008449	0.024401403	0.01439295	0.88	24.229	90.467	50.339	40.128	972.26	0.3487
16	15.46	519.39	521.39	244.11	1,284.88	25	47	28.2	98.3	0.00957128	0.024750956	0.01517968	0.88	24.220	91.570	49.533	42.037	1,018.12	0.3676
17	15.46	519.75	521.74	244.28	1,285.77	24	47	27.5	99.1	0.009007265	0.023923237	0.01491597	0.88	24.340	88.721	47.073	41.647	1,013.69	0.3631
18	15.32	520.10	522.08	244.45	1,286.64	23.2	41	26.5	100	0.007469381	0.022721505	0.01525212	0.88	24.482	84.605	42.342	42.263	1,034.66	0.3734
19	15.25	519.03	521.00	243.94	1,283.97	22	50	26.5	100	0.008482544	0.022721505	0.01423896	0.87	24.491	84.605	43.694	40.911	1,001.95	0.3487
20	15.11	630.22	632.59	359.23	1,622.04	20	64	23.3	100	0.00961893	0.018654079	0.00903515	0.87	31.094	70.902	44.535	26.367	819.87	0.2809
21	14.49	564.27	566.30	287.78	1,418.35	20	68	23.2	99.6	0.010230002	0.018462015	0.00823201	0.87	27.163	70.309	46.086	24.224	657.99	0.2236
23	15.46	1,039.31	1,043.31	976.95	3,059.57	19	78	22.1	89.1	0.011041088	0.015374595	0.00433351	0.87	58.720	61.316	47.118	14.198	833.73	0.2545
0	15.39	1,073.04	1,077.14	1,040.85	3,191.02	19	84	22.6	97.3	0.011906661	0.017362044	0.00545538	0.87	61.159	66.888	49.313	17.575	1,074.84	0.3336

Using equations 4 and 5, the expected and real water evaporated during at the cooling tower are calculated and represented in table 6.

Table 6: Expected and real water evaporated during at the cooling tower

Time	Expected Water Required for cooling (kg/s)	Real Water for cooling Used(kg/s)	Water wasted (kg/s)	Water wasted (kg/h)
0	0.2702	0.3269	0.0567	204.20
1	0.1769	0.2446	0.0677	243.55
2	0.2721	0.3252	0.0532	191.35
3	0.2266	0.2952	0.0686	247.13
4	0.2121	0.2943	0.0821	295.69
5	0.2126	0.2329	0.0202	72.87
6	0.1813	0.2099	0.0287	103.25
7	0.1416	0.1537	0.0121	43.57
8	0.2269	0.3409	0.1140	410.28
9	0.2102	0.2438	0.0336	120.91
10	0.1936	0.2048	0.0112	40.24
11	0.2704	0.4498	0.1794	645.83
12	0.2696	0.4982	0.2286	823.03
13	0.2131	0.3287	0.1156	416.23
14	0.2123	0.2303	0.0180	64.67
15	0.2126	0.2507	0.0380	136.93
16	0.2719	0.3714	0.0996	358.40
17	0.2121	0.2842	0.0721	259.55
18	0.2481	0.2784	0.0303	109.06
19	0.3625	0.5195	0.1570	565.18
20	0.2479	0.3635	0.1156	416.24
21	0.1676	0.1856	0.0181	65.08
22	0.1542	0.1825	0.0283	102.01
23	0.1478	0.1272	-0.0207	-74.34
0	0.1545	0.1410	-0.0136	-48.86
1	0.1155	0.1065	-0.0090	-32.42
2	0.1065	0.0874	-0.0191	-68.88
3	0.1062	0.0900	-0.0162	-58.16
4	0.1926	0.1935	0.0009	3.19
5	0.1776	0.1958	0.0183	65.75
6	0.1769	0.1919	0.0150	54.06
7	0.1063	0.0894	-0.0169	-60.74
8	0.2266	0.1710	-0.0556	-199.99
9	0.1768	0.2111	0.0343	123.60
10	0.1772	0.2121	0.0349	125.66
11	0.2266	0.3730	0.1464	527.02
12	0.1930	0.2007	0.0077	27.76
13	0.2123	0.2298	0.0175	63.15
14	0.2721	0.3750	0.1029	370.54
15	0.2719	0.3487	0.0769	276.67
16	0.2829	0.3676	0.0848	305.23
17	0.2481	0.3631	0.1150	413.97
18	0.3172	0.3734	0.0562	202.35
19	0.2833	0.3487	0.0654	235.58
20	0.2841	0.2809	-0.0032	-11.48

21	0.2123	0.2236	0.0113	40.69
23	0.1772	0.2545	0.0773	278.20
0	0.2266	0.3336	0.1071	385.50
Average	0.2133	0.2647	0.0514	184.9854

From table 6, the expected water required for cooling is 0.2133kg/s which translates to 767.8875kg/h. However, it is observed that the actual water consumed by the cooling tower was on average 0.2647kg/s which is 952.92kg/h. This indicates that 184.99 kg of water is wasted per hour, 24% more than the water required for cooling. This is an indication of both water and energy losses. This loss can be attributed to excess air passing through the cooling tower. Water wastage can be reduced by reducing speed of the fans. At the same time, the design of the cooling tower can be changed to allow for fountain cooling towers which do not require fans.