

EUROVENT REC 9/13 – 2019

EVAPORATIVE COOLING EQUIPMENT: HOW TO EVALUATE AND MINIMISE THE WATER CONSUMPTION

Published on 15 October 2019 by
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DOCUMENT HISTORY

This Eurovent Industry Recommendation / Code of Good Practice supersedes all of its previous editions, which automatically become obsolete with the publication of this document.

MODIFICATIONS

This Eurovent publication was modified as against previous editions in the following manner:

Modifications as against	Key changes
1 st edition	Present document (Evaporative cooling equipment: How to calculate water consumption and how to minimise it)

PREFACE

IN A NUTSHELL

This Recommendation aims to clarify the fundamentals of the water consumption of open and closed-circuit wet cooling towers.

It addresses:

- **Water consumption due to evaporation**
- **Water consumption due to blow down**
- **Water consumption due to drift loss**
- **How to minimise the water consumption**

A comparison between the results of a well-known water consumption calculation formula and of a proper simulation is also provided.

AUTHORS

This document was published by the Eurovent Association and was prepared in a joint effort by participants of the Product Group 'Evaporative Cooling Equipment' (PG-CT), which represents a vast majority of all manufacturers of these products active on the EMEA market.

ADOPTION

It has been approved and adopted through a formal voting procedure by Europe's national member associations from 20+ European countries, which ensures a wide-ranging representativeness based on democratic decision-making procedures. More information on these members can be found at **www.eurovent.eu**.

IMPORTANT REMARKS

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1. INTRODUCTION

Waste heat from industrial, refrigeration or air conditioning applications is commonly rejected to the atmosphere. When air is used as coolant (for example, air blown by a fan across the radiator of a car) one speaks of cooling using sensible heat transfer. If water is used to enhance the heat transfer (for example, by the wetting of a surface) one speaks of evaporative heat transfer. A good example of this is the human body, which is cooled by the evaporation of sweat during hot days. The evaporative cooling principle is used in wet cooling towers, where water is distributed over a heat exchange surface. Simultaneously, air is blown over that surface, causing a small portion of water to evaporate. The evaporation heat is withdrawn from the remaining water or the heat exchange surface depending on the design principle of the wet cooling tower. Before heat can be withdrawn by evaporation, however, the air led over the heat exchanger needs to be saturated. Depending on the condition of the ambient air (dry or wet) more or less water is needed for that purpose.

A large variety of evaporative cooling equipment exists, with different design principles, sizes and construction materials. Here, only the water consumption of open and closed-circuit wet cooling towers is described.

For the heat rejection equipment using evaporative cooling only partially, such as wet/dry or hybrid cooling towers, the principles of water consumption calculation also apply for the latent heat transfer portion, but for the annual operation period also the amount of sensible heat rejection must be considered. Wet/dry and hybrid cooling towers are not within the scope of this document.



2. WATER CONSUMPTION

The water consumption of open and closed-circuit cooling towers is due to the water evaporation as well as the water blow down.



Fig. 1: Fundamentals of water consumption

2.1 WATER CONSUMPTION DUE TO EVAPORATION

The heat transfer capability of evaporative cooling equipment by design is based on the latent heat transfer. Due to the intense and turbulent contact between water and air, a small portion of water evaporates, to:

- Humidify the air until saturation (wet bulb temperature) is reached
- Transfer heat to the air by the evaporation of water (latent heat transfer)

It is not necessarily so that the air discharged from the wet cooling towers is fully saturated.

For closed circuit wet cooling towers in particular, there is a small amount of sensible heat transfer, which results in slightly undersaturated discharge air. For open wet cooling towers, the discharge air is usually close to full saturation.

However, for the purpose of water consumption evaluations it is acceptable to assume fully saturated discharge air for both open and closed-circuit wet cooling towers.

As it can be seen later in this document, a number of factors influencing water consumption can only be estimated. Compared to the uncertainty introduced by these estimations, the potential error introduced by the assumption of full saturation is negligible.

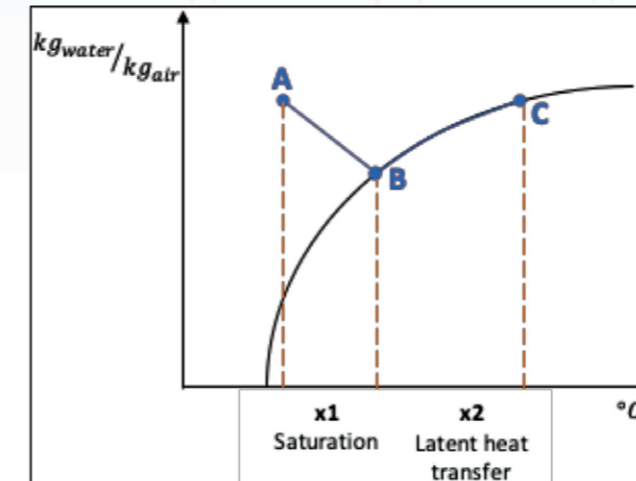


Fig. 2: Evaporation loss

2.1.1 HUMIDIFICATION

As explained above, the intense contact between water and air causes the full saturation of the air moved through the cooling tower.

Which are the parameters that influence the water consumption caused by humidification?

First, there is the amount of air that needs to be saturated (e.g. the air flow of the cooling tower). The design air flow for a particular cooling tower is provided by the manufacturer and is hence always available/can hence always be known. It should however be mentioned that air flow measurements are generally not very precise and hence the data provided by manufacturers might have a considerable level of uncertainty.

This is not the only issue to be considered. In many cases, operators chose to apply some form of capacity control, which is usually done by adjusting the air flow to the actual operating conditions. The knowledge of the design air flow is therefore not sufficient; it will also be necessary to understand the type of capacity control (for example: fan cycling/ modulating) and how this actually affects the air flow during the operating period.

Lastly, there are the climatic conditions. The relative humidity of the ambient air depends on the climate for the cooling towers site and the time of year (winter/ summer). In practice, this means that for a particular cooling tower site, one must have available year-round climate data, giving dry bulb and relative humidity data and the frequency of their occurrence throughout the operating year.

These data can be obtained from meteorological institutes for a large number of locations throughout the world. It needs to be realised however that these are statistical data and actual weather conditions for a particular year may be different. This leads to the conclusion that the results of a water consumption calculation by humidification are only estimations. It also leads to the conclusion that climate data for the exact location may not be needed for the water consumption estimation. Instead, 'typical' climate conditions for the location may suffice.

2.1.2 LATENT HEAT TRANSFER

There are also a number of parameters that influence the water consumption caused by heat transfer.

First of all, there is the amount of heat to be rejected; the more heat to be rejected, the larger the amount of water to be evaporated. In many applications, the heat load varies throughout the operation period (seasonal load profile). For water consumption calculations, the operator must provide an annual load profile. It is quite obvious that a seasonal load profile cannot always be exactly predicted, let alone the climatic conditions.

If, for every wet bulb temperature occurring during the operating period, the specific evaporation heat/ kWh is known, then the cooling tower air flow is not needed for the calculation.

If, however, one needs to find the temperature of the (saturated) discharge air and from the psychometric chart find the absolute water content/kg air for the entering wet bulb and the leaving air temperatures and from the difference calculate the amount of water, which is picked up by the air, then also the air flow of the cooling tower must be known as input. Here the same considerations as listed above (under the section on humidification) apply.

2.1.3 CONCLUSIONS

From the above, it can be concluded that the calculation of water consumption for wet cooling towers is everything but simple. A lot of data must be available, many of which are estimated (load profile) or based on statistics (climate data).

The result of such calculations is therefore approximate and can never be the subject of a performance guarantee. Nevertheless, and despite the inherent uncertainty of water consumption calculations, they are not worthless. If a good simulation and calculation programme with sufficient meteorological data is available, then calculation results can come close to reality – good enough for the determination of economic or ecological feasibility.

2.2 WATER CONSUMPTION DUE TO BLOW DOWN

Due to the fact that only pure water evaporates, the impurities dissolved in the cooling water will concentrate. This concentration may reach an unacceptable level, unless it is controlled. Such control is achieved by the blow down of a certain amount of circulating water with higher concentration of impurities and replace it by the same amount of fresh water with lower concentration of impurities.

The acceptable concentration of impurities (E) is a function of the quality of the fresh supply water and the choice of construction materials of the cooling system. The application of water treatment (for example softening) can also significantly influence the acceptable concentration of the circulating cooling water. Once the acceptable concentration is known, the amount of blow down can be calculated with the formula below:

$$A = \frac{\text{Evaporation loss}}{(C-1)} \quad [1]$$

Where:

C = f (Water quality/Material selection)

C = Concentration factor

A = Desalination

2.2.1 CONSTANT BLOW DOWN

It was common practice in the past to install a simple blow down valve in the cooling water piping and adjust it for a calculated amount of blow down water. This calculation was usually based on the maximum amount of evaporation. As we have seen though, evaporation is a function of heat load and climate, and therefore many operating conditions may occur, where the actual evaporation is much less than the calculated maximum.

In such a case, the concentration of impurities in the circulating water is also much lower than the acceptable maximum. This may still be an acceptable solution for constant load profiles. However, in most European regions the cost of water and its scarceness prohibits the use of constant blow down devices.

2.2.2 LOAD DEPENDENT BLOW DOWN

If the blow down is done in a way that it is proportional to the evaporation loss, two things can be achieved:

- Concentration of impurities is kept at the acceptable level (and not above)
- Amount of blow down water is not more than necessary to keep the concentration at the desired level

It is clear that such a blow down solution is much preferred over a simple constant blow down device, especially since load dependent blow down devices are not very costly. There are several technical approaches to load dependent blow down: the technology most commonly used is blow down based on conductivity control.

2.2.3 CONCLUSIONS

For constant blow down, the amount of water wasted is purely a function of the operating time; hence this figure is quite accurate. For load dependent blow down calculations, the evaporation loss must be calculated first, and all the uncertainties associated with this calculation logically also become part of the blow down calculation.

2.3 WATER CONSUMPTION DUE TO DRIFT LOSS

The principle of evaporative heat transfer is based on effective mixing of water and air. Whilst mixing water and air effectively is desired inside the cooling tower, it is not desirable to discharge this mixture into the atmosphere (drift loss). To prevent the loss of a large water quantity due to excessive drift, drift eliminators are installed in all cooling towers. Despite their designation as 'eliminators', drift eliminators do not eliminate all the water in the discharge air stream. Depending on their design and efficiency they will separate most of the droplets from the airstream. Drift losses are extremely small and hence do not contribute much to the total water consumption of the cooling tower. In fact, for the calculation of annual usage, drift losses can be neglected.

It is important to note that drift eliminators are an integral part of the cooling tower design. If, for example, the velocity of the discharge air exceeds the breakthrough velocity of the eliminator, this will cause a major occurrence of drift.

2.4 WATER CONSUMPTION CONSIDERATIONS

As it has been explained above, there is no way to exactly calculate the water consumption of a cooling tower so that the outcome of the calculation matches the actual water usage on site. What can be done, is to simulate the operational behaviour of a cooling tower with assumed climate and load conditions and, based on that, make an estimation of water usage throughout the operation period. Such programs have been developed by a number of cooling tower manufacturers and should be used for water consumption estimations rather than simple formulas, such as the below equations:

$$V = 0,4 \times Q \quad [2]$$

Where:

V = Evaporation loss [l/s]

Q = Heat rejection capacity [MW]

$$B = \frac{V}{(C-1)} \quad [3]$$

Where:

B = Blow down loss [l/s]

C = concentration factor

The error occurring when using the above formula can be significant.

3. OTHER WATER USAGE ASSOCIATED WITH EVAPORATIVE COOLING

In order to control the risk for Legionnaire's Disease, it is necessary to take measures for proper hygiene in the evaporative cooling system. Some of these measures require draining and replenishment of the cooling water system. This may for example be necessary after a prolonged shut down during which the system had been drained. Also draining and replenishment of the system is needed after every cleaning/disinfection cycle.

The frequency of such actions is determined by the hygienic condition of the cooling system and its operation mode. The quantity of water needed for this depends on the system volume and is hence site related. It is therefore not possible to predict such water usages without knowledge of the actual conditions on site. In comparison to the operational water consumption, the water usages caused by hygiene measures are small.

4. FINAL CONSIDERATIONS

To minimise water consumption, the construction materials of the cooling system should have a good level of corrosion resistance, so that the high concentration level of dissolved impurities can be accepted. Furthermore, load dependent blow down systems, preferably with conductivity control, should be used.

For larger cooling systems with open cooling towers, it can be recommended to separate the cooling tower circuit with a heat exchanger close coupled to the cooling tower from the rest of the cooling water piping. This way the water volume, which occasionally must be drained and replenished, is small. Alternatively, to the installation of a separating heat exchanger, closed circuit cooling towers can be used, which inherently have a limited water volume. Water consumption represents a considerable portion of the operational resource requirements of an evaporative cooling system. Water consumption calculations are based on statistical (climate) and estimated (load profile) data and therefore are only approximate. Nevertheless, it should be avoided to use simplified formulas for such calculations. **Instead, simulation programs, where available, should be used.**

ANNEX A

A.1 WATER CONSUMPTION OF AN OPEN CIRCUIT COOLING TOWER: COMPARISON BETWEEN THE RESULTS OF THE SO-CALLED 'RULE OF THUMB' AND OF A PROPER SIMULATION CONSIDERING LOAD PROFILE AND CLIMATE CONDITIONS

As it has been already explained, there is no way to exactly calculate the water consumption of a cooling tower by just making use of the calculation formulas [2 - 3] (known also as 'Rule of thumb').

It is to be noted that the Rule of thumb does not take into account any specific load profile and climate conditions.

A more accurate water consumption estimation can only be done by simulating the operational behaviour of a cooling tower working in well-defined climate and load conditions.

A.1.1 LOAD PROFILE

It has been considered a typical yearly HVAC load profile:

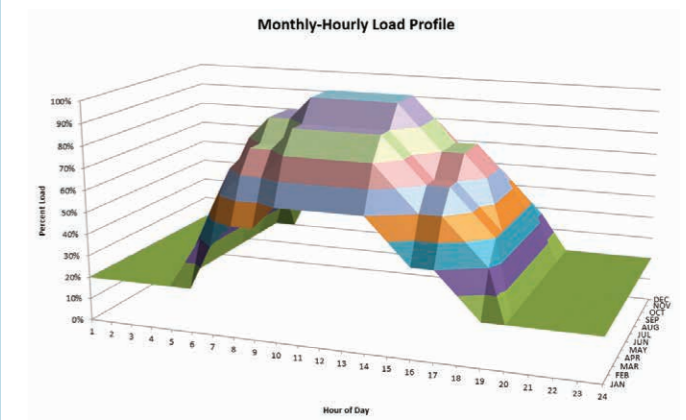


Fig. 3: Yearly HVAC load profile



A.1.2 CLIMATE CONDITIONS

Two different climate conditions have been considered: Brussels and Athens.

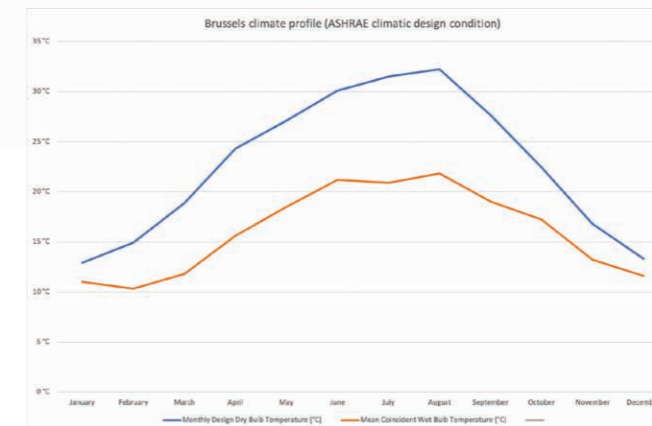


Fig. 4: Brussels climate profile (source: ASHRAE climate design conditions 2017)

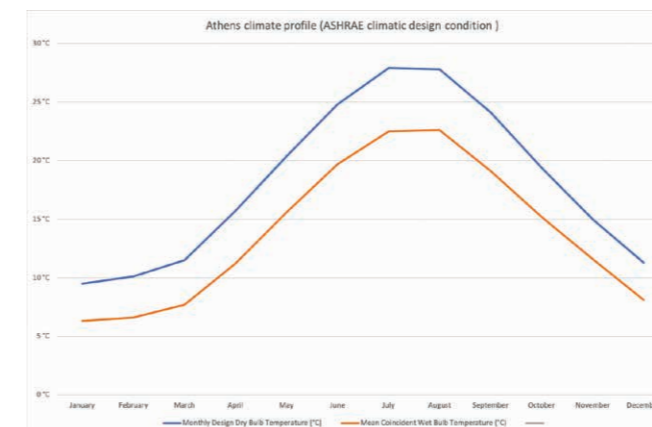


Fig. 5: Athens climate profile (source: ASHRAE climate design conditions 2017)

A.1.3 WATER CONSUMPTION ESTIMATION

Brussels

Q = 1,7 MW

Rule of thumb: 35.700 m³/year (it does not take into account the load profile and the climate conditions).

Simulation taking into account the load profile and the climate conditions: 7.600 m³/year

Athens

Q = 1,8 MW

Rule of thumb: 37.800 m³/year (it does not take into account the load profile and the climate conditions).

Simulation taking into account the load profile and the climate conditions: 11.700 m³/year

A.1.4 CONCLUSIONS

The error occurring when using the 'Rule of thumb' approach is extremely significant and leads to misleading indication. This has contributed in generating all the false myths on the water consumption of wet cooling towers.

ABOUT EUROVENT

Eurovent is Europe's Industry Association for Indoor Climate (HVAC), Process Cooling, and Food Cold Chain Technologies. Its members from throughout Europe, the Middle East and Africa represent more than 1.000 organisations, the majority small and medium-sized manufacturers. Based on objective and verifiable data, these account for a combined annual turnover of more than 30bn Euros, employing around 150.000 people within the association's geographic area. This makes Eurovent one of the largest cross-regional industry committees of its kind. The organisation's activities are based on highly valued democratic decision-making principles, ensuring a level-playing field for the entire industry independent from organisation sizes or membership fees.

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Our 'Members' are national associations from Europe, the Middle East and Africa that are representing manufacturers in the area of Indoor Climate (HVAC), Process Cooling, Food Cold Chain, and Industrial Ventilation technologies.

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