# Noise control of large wet cooling towers

Miklós Márkus
FONOR Ltd., Budapest, Hungary
András Muntag
EnviroPlus Ltd., Budapest, Hungary

**Summary**
One of the most widespread industrial cooling technologies is the evaporative wet cooling tower. In our case, the subject of our survey is the cooling towers of Hungary's largest chemical factory. To assess the noise-generating mechanism and the noise emission parameters of the cooling towers, we have carried out several analyses between 2013 and 2017. We have investigated the cooling towers of the same design and technology, and we have also purposefully operated the noise sources that determine the noise emission. Based on calculations done with IMMI software noise model, the dominance order of the noise sources is the following: air inlets, fans, water circulating pumps and fan motors. There are many primary and secondary solutions to reduce the noise emission of the sources, however their applications can have technological and cost constraints. In our case, the management of the plant refused all technical interventions that could change the operation of the cooling tower, because the facility has already operated above the nominal cooling capacity. In the case of a noise source of this size, only the possibilities of intervention by propagation remain. Nevertheless, since the cooling tower originally had no waterfall noise reduction installed, it was crucial to reduce the collision noise of the water.

**PACS no. 43.28.Hr, 43.50.Gf, 43.50.Rq**

## 1. Introduction

The efficiency of several chemical processes depends on temperature, pressure and the efficiency of heat removal. In the present case the cooling technology is an open evaporative wet cooling system; therefore, the cooling agent is in contact with the environment. In the cooling tower, the airflow, which is required for heat transfer, is generated by fans. The cooling agent contacts the air in a droplet form. Part of the water evaporates during the heat transfer, and another part of it is cooled by the heat transfer. [1]

To avoid the recirculation of the discharged air which is saturated with vapour, the fans are placed as high as possible. On induced draft towers the fans located in the exiting air stream. The distance between the discharge and intake locations of the air should be as large as possible (at least as large as the height of the entry surface). Moreover, fan stacks optimally form the flow of the air in order to achieve optimum airflow parameters. [2]

## 2. Noise sources

### 2.1. The typical noise sources

The typical noise sources of the cooling technology discussed are the following:

- the fans and the airflow (mechanical and aerodynamic noise),
- the fan motors (mechanical noise)
- the hermetically sealed water circulating pumps (mechanical noise),
- the droplets falling into the water basin (the impact noise of the water mass).

The way of noise emission depends to a large extent on the structure of the tower, since in the case of coating materials with smaller specific mass (e.g. FRP), the sound energy flowing through the coating will also be more significant. In the case of reinforced concrete constructions, the sound insulation of the coating is so great that the sound energy passing through the concrete structure is practically negligible.

---

### 2.2. The fans

The components of the noise generated by the fans are fall into the mechanical and aerodynamic categories. In the case of a properly constructed and operated fan, the mechanical noise components are negligible compared to the aerodynamic noise components. Apart from the rotational noise that generates pure sound and the rotor-casing interaction, the components of aerodynamic noise can also include the vortex noise and the turbulence-induced noise generating broadband noise emission. [3] [11]

### 2.3. The cooling agent

Of course, the cooling agent stored in the basin of the cooling tower is not a noise source on its own. The noise itself is generated by the water droplets falling on the water surface of the basin. During the impact, the motion energy is transformed in a very short time, and a significant part of that energy will be lost in the form of sound energy, heat energy and the energy of the permanent transformation. The reason for this is that water is basically not compressible, so the collision will resemble the physical parameters of an ideally inflexible collision. The noise emission is affected by the size and the mass of the water droplets, their falling height and their falling speed. Based on the known correlation of the motion energy, the effect of speed that affects the motion energy is more significant; therefore, a decrease in noise emission is expected to be achieved by decreasing the speed.

## 3. Case study

### 3.1. BorsodChem

BorsodChem is currently one of the leading chemical raw material manufacturing company of Central Europe. Its premise in Kazincbarcika is Hungary's largest chemical factory, where the focus of production is isocyanates and PVC. The entire industrial area is nearly 4 km$^2$, wedged in between the towns of Kazincbarcika and Berente.

In the industrial area there are more than 20 stand-alone facilities (PVC, MDI, TDI, VCM, Chlorine, Nitric Acid, Ammonium, etc.), which operates continuously day and night with thousands of individual noise sources. These facilities are in a close technological relation with each other, so practically the whole industrial area operates as one factory.

### 3.2. The cooling tower of the Nitric Acid Plant

The cooling tower is located in the north-western part of BorsodChem’s densely built-up production and development area surrounded by the residential area of Kazincbarcika. The houses that are the closest to the industrial area are approximately 400 m away from the cooling tower.

The cooling tower has reinforced concrete structure, two separated cells with common water basin. The tower is 12 m high. The air inlets are on both sides, and the total area is about 150 m$^2$ on one side. The cooling fans are 8-blade fans with a diameter of 30 feet. The rotating parts are in the roof level of the tower. The fan stacks are 2 m high light-frame flared diffusers (with no significant sound dampening).

Between the fan stacks there are 2 fan motors with variable-frequency drive. During the warm season, the fans operate at nominal speed. During the cold season, the rotational speed of the fans may be reduced, but they can never stop working, because the loss of water will increase and the fan blades could be frozen.

The amount of the cooling agent is constant in winter and summer as well. The water circulating pumps are located directly next to the cooling tower in a semi-open shaft below ground level.

## 4. Analyses

### 4.1. Methods of the analyses

To assess the noise-generating mechanism and the noise emission parameters of the open wet cooling towers, we have carried out instrumental analyses in the vicinity of the cooling towers which are of the same design and the same technology. Since the production area of BorsodChem is full of plants and noise sources with considerable noise emission, the analyses were carried out close to the noise sources so that the measured values will not be affected by the noise emitted by the surrounding noise sources.

In order to achieve the objectives set, a complex noise analysing instrument system had to be implemented, the units of which support the objective opinion by supporting each other:

Subjective analysis based on hearing:

- identifying typical noise sources and sound radiation directions,
- determining the tone and time function in the vicinity of the noise sources,
- exploring noise sources with critical radiation directions.

Frequency analysis:

- recording and analysing frequency spectrum in the vicinity of the noise sources,
- comparing frequency spectrums generating at the evaluation points,
- identifying noise sources with typical noise emission (e.g. narrowband nature).

Noise measurement:

- surveying environmental noise pollution at the evaluation points,
- surveying impacts affecting sound propagation at reference measuring points,
- measuring sound pressure levels emitted by noise sources in the vicinity of sources,
- surveying geometric parameters and radiation characteristics,
- determining sound power level by measurement and calculation.

Software noise model (IMMI):

- building a detailed model based on close-proximity measurements and source data,
- calibrating noise model with the measurement results recorded at the reference points,
- modelling sound propagation in horizontal and vertical raster,
- determining the dominance of noise sources at the evaluation point,
- modelling and analysing the impact of noise reduction solutions.

The cooling towers, in a significant part of the year, operate according to the technological requirements, in a strictly set technological system, basically in accordance with the cooling needs. Consequently, the purposeful operation of the mechanical units is only possible in the cold season (when the demand for cooling decreases) and during the annual shut down of the factory. To achieve our goals, the noise sources of the cooling tower had to be surveyed independently of each other, because the radiated sound energy will be combined during the joint operation of the dominant sources.

## 4.2. Measurement results of the fans

While measuring the noise emission of the fans, our aim was to determine how the sound power would change in different rotational speeds. A set of surveys was carried out at different cooling towers during which the fully turned off fans were rotated at maximum speed gradually (with variable-frequency drives).

During the measurements, we carried out a logging with a sampling time of 100 ms simultaneously at multiple measuring points (above the fan, in front of the air inlet and at the reference points farther away from the cooling tower). The results of the measurements, carried out at different cooling towers at different distances (but at the same operating conditions), characterize the same sound power level. The total sound power level of the tested fan (at nominal speed) is:

$$L_{AWmax} = 102 \pm 1\ dB\,/\,64\ m^2.$$

The sound power level of the fan engines is:

$$L_{AW} = 91 \pm 1\ dB.$$

The fans of the surveyed cooling towers operate with variable-frequency drives, so the sound pressure level changes of different rotational speeds were measurable for both cooling tower. According to the measurements, the degree of noise attenuation with 10 % rotational speed reduction is $\Delta L = 3\ dB$, while the degree of noise attenuation with approx. 50 % rotational speed reduction is $\Delta L = 6\ dB$.

It can also be stated that the difference in the sound pressure level between the discharge and intake sides (at maximum rotational speed) is 13 dB. Of course, part of the difference is due to the fact that on the inlet side the propagation is obstructed by the technological units under the fan (e.g. drift eliminators, water distribution system, exchange surface, etc.); moreover, the noise source is located farther away on that side from the measuring point.

## 4.3. Measurement results of the air inlets

Based on the measurement results of the air inlets, it can be stated that the total sound power level of the entire surface of the air inlet, irrespectively of the cooling tower, is:

$$L_{AW} = 97 \pm 1\ dB\,/\,137\ m^2.$$

### 4.4. Measurement results of the pumps

The results of the measurements carried out at the different water circulating pumps (at the same operating conditions) do not correlate as much as the above-described results, so the uncertainty of the calculated sound power levels is significantly higher here:

$$L_{AW} = 92 \pm 3\ dB / 27\ m^2.$$

### 4.5. Frequency analysis

Based on the analysis of the frequency spectrums, it can be stated that the characteristic tonal frequency of the noise emitted by the fans results from the rotational speed and the number of blades. At *50 Hz* drive frequency, the rotational speed of the rotating part is *120 RPM*, which means 2 full turns per second. Therefore – since the rotor is equipped with 8 blades – we have to calculate on a total of 16 blades passing per second, namely *16 Hz* basic frequency, and the harmonic *32 Hz* frequency also appears in the spectrum. The significant sound energy between *80-200 Hz* is generated by the aerodynamic noise.

Based on the noise measurements carried out at the air inlets, it can be stated that noise generated by the impact of water droplets is broadband; most of the sound energy appears in the range of high tones *(3.15-16 kHz).* Nevertheless, some low-frequency 1/3 octave frequency bands are emerging from the spectrum, because the internal space of the cooling tower could probably be induced by these frequencies.

### 4.6. Dominant noise sources

By using the measurement results, the standard calculation methods and the IMMI software propagation model, it is possible to determine the dominance order and noise attenuation need of the noise sources. The results of the sound propagation calculations done with the model are compared to the sound pressure levels recorded at the measuring points.

During the iteration procedure we gradually calibrate and refine the noise model step by step. After the calibration of the measurement results recorded near the noise sources, the sound pressure levels at the evaluation points can be calculated.

The propagation of sounds between the noise sources and the perception points is greatly affected by the meteorological factors. The influence of meteorological factors on the propagation of sound always makes the results of such surveys uncertain.

During the dominance analyses, the effect of meteorological conditions on sound propagation can be eliminate by using the software propagation model, because the noise mapping software always calculates with the best sound propagation parameters, modelling an extreme, but realistic weather situation in all directions. Consequently, the software calculation method eliminates possibilities of errors to a certain extent in the measurement methods, errors resulting from non-reproducible operating conditions and measurement conditions.

Based on calculations done with the software model, the dominance order of the noise sources at the critical evaluation point (in terms of noise pollution) is the following:

1st Air inlets: $L_{Aeqi} \approx 45\ dB$ at the evaluation point
2nd Fans: $L_{Aeqi} \approx 40\ dB$ at the e.p.
3rd Pumps: $L_{Aeqi} \approx 25\ dB$ at the e.p.
4th Fan motors: $L_{Aeqi} \approx 10\ dB$ at the e.p.

Assuming that environmental conditions are favourable to the propagation of sound, the noise pollution caused by the surveyed cooling tower at the evaluation point is so much that if it would operate alone in the plant (i.e., all other noise sources of BorsodChem would be shut down), it would still cause a noise pollution that exceeds the limit.

## 5. Noise reduction

### 5.1. Principles of noise reduction

The methodological principle of noise control and the priority order for noise reduction solutions (with examples) are the following:

- Primary: reduction of noise at source (emission)
- Secondary: attenuation of sound during propagation (transmission)
- Tertiary: protection of protected areas (immission)

Of course, the most effective way to reduce the noise emitted by the cooling towers is the preliminary acoustic design and dimensioning, because the maximum noise reduction can be achieved by selecting the proper distance and direction of the noise source. Subsequent noise reduction is practically an unfavourable solution, because it is not only more costly than choosing the more silent technology during investing, but it could also increase the operating and maintenance costs. [3]

It seems obvious, but in this line of thought it should be emphasized that regular scheduled maintenance is also one of the most effective ways of noise reduction. The proper operation and maintenance of the equipment keeps the emission of noises within well-regulated boundaries.

The fundamental issues to be addressed in relation to noise reduction solutions are well known: the total acquisition cost, the degree of noise reduction (under certain conditions), the maintenance requirement and cost (over a minimum of 10-year perspective), how does it affect the operation of the cooling tower (e.g. pressure drop) and is it achievable without significant transformations.

### 5.2. Primary noise reduction measures

Primary noise reduction measures reduce the sound energy (sound power level) emitted by the sound source, directly intervening during the noise-generating mechanism (emission). Such a solution may be:

- the aerodynamic sophistication or replacement of fans,
- the regulation of the rotational speed with a variable-frequency drive,
- the reduction of the impact noise of water droplets.

Of course, we have to exclude the technological change of the existing cooling system, because the realisation of a more efficient cooling technology would be too expensive (and the facility surveyed in this presentation is not considered obsolete at all). If the change of the cooling technology is not possible, transforming the existing technology can reduce environmental impacts.

At the same time, reducing environmental impacts may be accompanied by a reduction in cooling performance, which may require higher power fans and therefore greater energy consumption. Therefore, besides the noise reduction considerations – taking into account the BAT guidelines – the expected environmental impact of each intervention should always be surveyed in a complex way. The simplified analysis of the primary solutions is the following:

Advantages:

- the cooling performance changes only slightly or does not decrease at all,
- in many cases, energy efficiency can be improved,
- cost savings can be achieved over a longer period of time,
- the geometry and the environment of the cooling tower do not change.

Disadvantages:

- the invention options are limited,
- usually the achievable noise reduction is less than it could be with post solutions,
- in the case of a complex solution, intervention will be needed at several points with significant costs,
- in the case of a more complicated solution, the chance of breakdown will be much higher,
- the number of maintenance tasks and their costs will increase.

### 5.3. Replacement of fans

A typical component of the noise emission of fans is the vortex noise and the turbulence-induced noise, which can be reduced with aerodynamically optimised blade profiles and aerodynamic inserts. [4]

The proper aerodynamic design – or subsequent optimisation – directly intervenes where the noise is generated without reducing the efficiency of the fan. The direct benefit of interventions within the fan housing is that, since there is less noise inside the fan housing, less noise is radiated through the casing. In principle, we could set an aim to increase the efficiency of the cooling tower in parallel with reducing its noise, reduce vapour formation and ultimately save money by increasing energy efficiency and reducing maintenance costs.

One of the most commonly used primary noise reduction solution is the SX series fan manufactured by Howden (in this case, the 30-foot 6-blade version can be used). Due to the unique design of the blades, according to the manufacturer's catalogue, the blade's noise is less than *8 dB(A)*. At the same time, according to the manufacturer, if this is combined with a smaller fan speed, the SX range reduces noise by up to *20 dB(A)* compared with standard cooling fans. Comparing the data of the current Cofimco 9144-8-36N/G2.0T fan and the recommended Howden 30-SX 6-blade fan, the noise reduction expected after the fan replacement is:

$$\Delta L \approx 9\ dB.$$

Nevertheless, in the case of a fan replacement, such Howden SX fans typically require higher fan housing than normal type fans, i.e. the housing needs to be rebuilt and elevated (but it is not certain that the existing fan housing is structurally adequate to withstand an additional element). Moreover, if the fan housing is equipped with a diffuser, it is also necessary to examine whether it is possible to insert another housing part under the diffuser.

Apart from the fan, it is likely that the motor and the drive shaft have to be replaced as well, because they would rotate the new fan slower than the current one, but the power on the shaft would be higher. Moreover, it is also necessary to examine whether the variable-frequency drive or the electrical switchgear corresponds to the higher power requirements. Alternatively, it may be possible to rotate the engine more slowly with the variable-frequency drive, but in this case the engine should be examined to see whether it can withstand higher power at a lower rotational speed.

As you can see, the replacement of the fan blades is not a simple technical intervention. It is expected that a lot of related equipment will need to be replaced and modified, which means that the cost of a new fan can be quite expensive.

## 5.4. Variable-frequency drive

The Variable-Frequency Drive (VFD) controls the speed of the fan motor and the rotational speed of the fan wheel (and the amount of air delivered). In a noise protection aspect, the control of the speed is particularly effective, because the sound power of the flow-based noise component is proportional to the power of the typical speed.

So, when the rotational speed is halved, the expected noise reduction is not *3 dB* but *6 dB*! At this time, the amount of air delivered is about 60 % of the total capacity. [2]

During July and August the fans of the cooling tower constantly operate at maximum speed (in Hungary), so the operating condition that generates the highest environmental noise emission is practically achieved. At the same time, the ambient temperature can be sufficiently reduced at night, so it may be sufficient to operate the fans of the cooling towers at a lower rotational speed. As the ambient noise pollution limits at night are stricter with *10 dB*, the limit value will be significantly exceeded even at night.

According to our analyses, the frequency of the drives (from the nominal *50 Hz*) was reduced to no more than *43 Hz* in the summer during night time, and with that the maximum noise reduction possible would only be:

$$\Delta L \approx 2\ dB.$$

Therefore, a significant noise reduction can only be achieved, if the temperature drops below 20 °C during the night time. The use of the VFD can have its own risks, so its use for noise protection is essentially determined by whether the desired result can be achieved from an environmental point of view.

## 5.5. Waterfall noise reduction

A major component of the noise emission is the impact noise caused by the water droplets when they fall into the basin. This noise is essentially depends on the mass of the water drops and their impact speed.

It goes without saying that by changing the size of the water droplets, the mass of the falling droplets will also be reduced, and this way the emitted sound energy will be less as well. At the same time, reducing the size of water drops can also reduce the amount of water flowing through per unit time, and this way reduce the cooling capacity of the cooling tower as well. Therefore, in order to achieve efficient heat transfer, the maximum amount of cooling agent should be contacted with the cooling air along the air inlet with the given cross section. Namely, reducing the size of water droplets in this respect is not appropriate.

The noise generated by the impact of water droplets is essentially due to the fact that the collision is inflexible, as the colliding bodies cannot be compressed. If the collision becomes elastic (i.e., at least one of the impacting bodies goes through an elastic deformation), a significant part of the movement energy will not turn into sound energy.

By using the retrofitting waterfall noise reduction mats, the falling water droplets collide with a flexible surface instead of the surface of the cooling agent, so the collision becomes elastic, and the emitted sound energy will decrease depending on the thickness (in some cases the number of layers) of the mats.

The degree of noise reduction achieved with the mats depends on the present droplet noise and essentially depends on the drop height of the droplets and the number of layers of the applied mat. According to the manufacturer's data, the expected noise suppression rate is [5] [6] [7]:

$$\Delta L \approx 4\text{-}9\ dB.$$

Basically it is essential that the waterfall noise reduction mat must float on the surface of the water, because the required noise reduction can only be achieved, if the falling droplets do not directly contact the surface of the water, except through the material. This can be accomplished in such a way that the material is initially floating on the surface of the cooling agent, or a support structure has to be installed above the basin, which structure could hold the noise reduction mat.

## 5.6. Secondary noise reduction measures

In cases where it's not possible to modify or replace the noise sources or reduce the sound power by transforming the existing technology, an effective method of reducing environmental noise is to prevent the propagation of sound. Such a solution may be:

- using absorbing silencers,
- creating acoustic louver panels,
- building sound barrier walls.

When using secondary noise reduction solutions, it is generally assumed that subsequent technical interference with propagation results in a pressure drop, which can reduce the cooling capacity and energy efficiency of the cooling tower. Therefore, these solutions can be used with great certainty only when the tower is sufficiently oversized to compensate for the pressure drop generated by the subsequent noise reduction solution. The simplified analysis of the secondary solutions is the following:

Advantages

- it does not interfere directly with the cooling tower technology,
- it can be implemented step by step,
- there are more solution options,
- sometimes the available noise reduction is greater than in the case of the (subsequent) primary intervention.

Disadvantages

- its cost exponentially increases depending on the noise reduction requirement,
- it generally results in a pressure drop,
- the cooling capacity and energy efficiency of the cooling tower can be reduced,
- access to mechanical units may be more difficult,
- maintenance tasks and costs will increase,
- the geometry and the environment of the cooling tower will change.

## 5.7. Absorbing silencers

Absorbing silencers are effective in a wide range of frequencies. The sound absorption at low frequency is limited by the finite thickness of the built-in sound absorbing material, while at high frequency it is limited by the decrease of the bending ability of the sound waves. The degree of acoustic absorption of absorbing silencers is determined by the size of the free cross-section between the louvers and the length of the absorbing inserts. The smaller the gap between the louvers, the greater the noise reduction that we can achieve. The operational principle of the louvered silencer is that the sound energy is absorbed in the louvers that are in the path of the flowing agent, so we usually have to assume that this solution results in a pressure drop. [3]

## 5.8. Louvered air inlets

When designing air inlets and outlets, it is essential that the cooling agent does not leave the internal space of the tower, and the sunlight must not reach the surface of the basin and must not heat the cooling agent (this way the algae formation will be reduced).

For this purpose, it would be advisable to use vertical drift eliminators which affect the flow speed to some extent, and which are individually dimensioned for forced or induced draft cooling towers. The water separation efficiency of the drift eliminators and the pressure drop are approximately proportional; therefore, the inadequately selected drift eliminator can cause a significant pressure drop, thus reducing the cooling performance, the efficiency and the lifetime of the fan.

### 5.9. Sound barrier walls

In our case, to ensure maximum cooling performance, it is crucial to use a solution, which can provide maximum noise reduction with the lowest pressure drop. Therefore, in the present study, the possibility of an intervention by propagation is limited to sound shielding, which, when properly designed, achieves the reduction of the noise emitted by the fans and the air inlets.

The effectiveness of the barrier is dependent on the mass and height of the barrier, and its distance from the noise source and the receiver. To be effective a barrier must block the line of sight between the highest point of a noise source and a barrier must be long and continuous to prevent sounds from passing around the ends. Nevertheless, the flow principle associated with the placement of the barrier wall is that in the case of cooling towers which have air inlets on both sides, the distance between the barrier and the tower must be larger than the height of the air inlet (in case of a cooling tower which only has air inlet on one side, the distance doubles).

The structure of the wall should be chosen so that the sound reduction of the wall structure must be much larger than the expected reduction, because the dimensioning is essentially meant for diffraction and not transmission. The sound absorption and sound insulation requirements for the wall block or wall structure that is used are the following:

- sound absorption at the sound source side is at least: $\alpha \geq 0.8$
- the degree of airborne-sound reduction is at least $R_W \geq 25\ dB$

The design of the sound barrier wall is basically depends on the area to be protected from noise and on the location of the points of evaluation.

Sound energy emitted by fans can also be reduced with a sound barrier wall. It would be possible to construct a sound barrier wall on the edge of the cooling tower (which is statically the strongest), but – taking into account the sound power of the fans, the size and location of the noise sources – the required wall height would be so great (at least 7 m), which is not recommended on the edge of the tower, because of the wind pressure. Accordingly, the proposed solution is to construct fan stacks suitable height instead of the existing diffusers, or to construct, directly around the existing diffuser, circular (or polygonal) barrier with sound absorbing design on the inner surface, with the required additional support structure.

## References

[1] B. Crewe, B. Gaudio: Silence Is Golden. Acustica 4 (1964) 154-168.

[2] Tibor Várszegi: The Basics of Cooling Technology, Presentation No. 2. - Evaporators, Condensers and Supplementary Components of Compressor Refrigerators (Hungarian), Szent István University, Gödöllő, Hungary, 2014.

[3] Georges Hoeterickx (Evapco Europe): Good cooling tower practises, 3rd International District Cooling Conference (Strategic Session #4), Dubai, 2008.

[4] Dr. Endre Domokos, Dr. Béla Horváth, Attila Kováts, Gábor Koscsó: Environmental Engineering Knowledge Repository, Noise and Vibration Protection (volume 13), 2nd revised edition (Hungarian), Pannon University - Institute of Environmental Engineering, Veszprém, Hungary, 2011.

[5] Industrial Noise and Vibration Centre (INVC): How to attenuate fan noise – without silencers or reduced fan efficiency, Industrial Noise and Vibration Centre (INVC), Slough – Berks, United Kingdom, 2013.

[6] Environmental Protection Department: Good Practices on Ventilation System Noise Control, Government of Hong Kong Special Administrative Region, Hong Kong, 2006.

[7] EUROFILL: WATER NET 100, EUROFILL Energy & Water srl, Biassono, Italy, 2016.

[8] Bonar bv: Enka-Silence® Product Information, Bonar bv, Arnhem, Netherlands, 2014.

[9] John C. Hensley: Cooling Tower Fundamentals, SPX Cooling Technologies, Inc., Overland Park, Kansas, USA, 2009.

[10] Howden Group Limited: Cooling Fan technology - http://www.howden.com, Howden Group Limited, Netherlands, 2015.

[11] Peter Van Hoof: Plume abatement for cooling towers, Baltimore Aircoil International NV, Baltimore, Maryland, USA, 2008.

[12] Jack E. Made, Donald W. Kurtz: NASA Technical Report 32-7462 A Review of Aerodynamic Noise From Propellers, Rofors, and Liff Fans, Jet Propulsion Laboratory, California Institute Of Technology, Pasadena, California, USA, 1970.