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Research paper

Acoustic performance of cooling towers on neighbor residential building and noise reduction methods

H. S. Seddeq [2] *, A. M. Abdel-Aziz [1], Mahfouz. El-Sayed Shalaby [1], A. Y. Elmasry [2]

[1] *Faculty of Eng. Al- Azhar University, Egypt*
[2] *Housing & Building Research Center, Egypt*
**Corresponding author E-mail: hudaseddeq@gmail.com*

Abstract

The purpose of this research is to present an assessment of the noise impact of cooling equipment and determine if the noise levels comply with the permissible limits or not. Also, it presents two calculation methods to predict the acoustic performance of the cooling towers on a neighbor residential building. Comparison of the actual measurements vs. the predicted levels was carried out to select the appropriate calculation method to perform analysis for different noise reduction techniques and determines the best way to achieve the acceptable noise criteria. The results showed that the most effective methods for noise control are obtained by using variable frequency control for the cooling tower fans and lined plenum champers together or individual.

Keywords: *Cooling Towers; Outdoor Noise Propagation; Noise Criteria; Noise Reduction; Barrier; Variable Frequency Control*.

1. Introduction

The development of society has led to more sound sources giving higher noise levels. Noise is one of the most widely and most frequently experienced problems of the industrial sources environment. It affects man physically, psychologically and socially. Noise can damage hearing, interfere with communication, be annoying, cause tiredness and reduce efficiency [1].

Equipment of building services producing high noise levels can cause problems that cannot be easily resolved after installation. Their solutions, if be possible can be very expensive. Therefore, it is desirable to have design tools available to predict emitted sound levels in the design stage to define the best way for impact noise assessment and mitigation. [2], [3].

The sound pressure produced by a sound source outdoors at a location in the vicinity depends on the properties of the sound source, the geometry of the sound field, ground effects, and on meteorological conditions [3]. Acoustic prediction models are very important to use in the design stage to save time, effort and cost. A wide range of prediction methods are available for the evaluation of attenuation of sound during propagation outdoors. They range from uncomplicated models for spreading loss to sophisticated models for atmospheric absorption, propagation over ground through turbulence and over barriers [4].

To decide what approach is most appropriate to select the best method for predicting outdoor sound propagation from industrial sources application, the current literatures on outdoor noise propagation have to be reviewed. Researchers have developed many methods to help in estimation of current noise levels and to evaluate potential noise mitigation solutions. There are several engineering methods for modeling outdoor noise propagation, including the international standard ISO 9613-2 [5], the Nordic standard Nord 2000 [6], and the European Union standard CNOSSOS-EU [7]. Engineering methods are standardized geometrical approaches; they are given the focus here because of their importance for modeling outdoor noise propagation and because they can make some additional simplifying assumptions. The international standard ISO 9613-2 method efficiently approximate outdoor sound levels from industrial sources. [8].

2. Material and methodology

The work activity firstly was made to measure the sound pressure levels and evaluate the noise emitted from the cooling equipment on a neighbor building. Secondly build calculation models to noise analysis and select the best method for cooling equipment noise reduction. The calculation models were constructed according to ISO 9613-2 and manufacturer equipment instruction for sound. The results of each calculation were compared to the results obtained from measurements to select the closet model.

Cooling units were installed behind a mall building in El Obour Street in – New Cairo (El Qahira El Gedida) – Egypt. These cooling units are opposite to residential building compound. There are 3 water cooling towers that installed on steel structures. Two double cell units of cooling towers are usually used for operation and the third double cell unit is for reciprocal operation. The type of cooling towers is Double Cell Unit with standard fan type [9]. Specifications data of the installed cooling towers and Sound power for all fan units is given below.

Model information	Specification
Product line	New series 3000
Model	S3E-1222-060
Number of units	2
Fan type	Standard fan
Total standard Fan power	22.38 BKW/ unit
Flow rate	181.02 I/S
Inlet water temperature	35°C
Outlet water temperature	29 °C
Operating weight	10.8 kg
Dimensions (L×W×H)	3.60 ×6.57 ×3.31m

Sound power level (dBA)	Octave band frequency (Hz)							
	63	125	250	500	1k	2k	4k	8k
Fan1	106	105	105	99	94	88	84	80
Fan2	103	102	102	98	94	88	83	78
Fan3	100	99	100	95	90	84	79	76
Fan4	98	94	91	85	80	76	72	65

ISO 9613-2 Calculation Method

The constructed acoustic calculation model for prediction outdoor sound pressure levels is based on ISO 9613-2. The model is calculating the attenuation of sound which emitted from an assembly of multisource industrial sources. Specific terms are provided in algorithm for the following effect:

- Geometrical divergence,
- Ground effect
- Reflection from surfaces
- Screening by obstacles

Considering the source is directional, the radiation of sound may be generally modeled by the following expression:

$$L_p = L_{wt} + D - \sum A_i \quad dB \tag{1}$$

Where

L_{wt}: octave band sound power level of all noise sources

D: Directivity Index = (10 log Q) in dB that defines the reflective surfaces around the sources of noise and, Q accounts for the reflective planes that bound the source of noise. These planes act as reflectors focusing the sound or bounding the sound to a certain area. Directivity factors for various radiation patterns have the following values [10].

Directivity factor Q	Radiation patterns
1	Free space and no reflecting surfaces
2	single reflective flat surface (ground)
4	two large flat reflective surfaces
8	three large reflective surfaces

ΣAi is the term used to account for all the elements that can affect the sound level (atmospheric loss, barriers, ground effects, etc...). [5].

A: the total excess attenuation in dB [5], [11].

is given in Eq. 2 as:

$$\mathrm{A} = \mathrm{A_{abs}} + \mathrm{A_{div}} + \mathrm{A_{gr}} + \mathrm{A_{misc}} + \mathrm{A_{bar}} \tag{2}$$

Where,

A_{abs}: Attenuation due to air absorption

A_{div} : Attenuation due to geometrical divergence

$$= [20\ \log(\mathrm{d})] - 11\ \mathrm{dB} \tag{3}$$

A_{gr}: Attenuation due to ground absorption

A_{misc}: Attenuation due to surrounding housing

$A_{bar:}$ Attenuation due to barrier

d: is the distance from source to receiver, in m

Consideration and assumption

- Attenuation due to ground absorption was calculated for flat horizontal ground source region A_S and receiving region A_r . The middle region =0 because distance between the source and receiver is less than the required distance given in Table 3- ISO 9613-2. The ground effect was calculated according to Eq. 4 and considering the ground factor, G = 0.

$$A_{gr} = A_S + A_r \tag{4}$$

- Attenuation due to air absorption neglected for distance less than 100 m [11].
- Attenuation due to neighboring housing calculated as Eq. 5:

$$A_{housing} = A_{housing1} + A_{housing2} \quad (5)$$
$$A_{housing1} = 0.1 * B * Sb \quad (6)$$

$$A_{housing2} = -10\log[1-(\rho/100)] \text{ dB} \quad (7)$$

Where,
Sb is the length of sound path through the housing area.
B is the area density ratio of buildings (total plan area/total ground area),
ρ is the percentage of the length of the facades ≤ 90 %.
Calculation Method According to Manufacturer Instruction
The sound pressure levels calculated according to BAC mathematical process for sound are depend on sound power emitted by the source and environmental sound effects as the following [12].

- Distance effect
- Effects of reflecting walls
- Background effect
- Screening by barrier
- Mechanical noise reduction method

The outdoor sound pressure level is obtained by Eq. 10:

$$L_{out} = L_W - C - K - BG - BA - AMC \text{ dB} \quad (10)$$

Where
L_{out} : Outdoor octave band sound pressure level
C: Appropriate correction for distance attenuation
K: Adjustment value due to the of effect of the reflecting surface
BA: Attenuation due to barrier wall
BG: Outdoor background sound correction factor
AMC: Attenuation due to mechanical noise control method
The sound pressure level inside neighbor building is obtained by Eq. 11 [12].

$$L_{in} = L_{out} - R \text{ dB} \quad (11)$$

Where
L_{in} : Indoor octave band sound pressure level
R: Approximate sound reduction of exterior wall of neighbor building
The sound level meter type 2270, frequency analysis software BZ-7223 (B&K) and 1/2 inch microphone type 4189 (B&K) were used for noise levels measurements emitted from installed cooling towers. The sound level meter was calibrated before the measurement by using an acoustic calibrator type 4231.
The sound pressure levels are measured at 2 m from façade apartment No. 323 (P2) in the third floor of the opposite building to the cooling tower. The lowest sound pressure level values were at (P3) inside the apartment No. 323 in the third floor of the opposite building, when the window were closed because of the sound attenuation of the façade. The measurements at 2 m from façade of apartment No. 023 (P1) at the ground floor is close to the measurements at point (P2). The measured values were compared to the permissible noise limits appointed for Egypt. Where the maximum permitted A- weighted sound pressure level in the front of a building façade is 55 dBA for a residential area at daytime from 00:7 am to 00:10 pm, whereas the permitted value is 50 dBA at nighttime from 00:10 pm to 00:7 am. The maximum permissible noise level inside the living room is 40 dBA [13].

3. Results and tables

Fig. 1 gives the results of the measured values in the front of façade and inside the apartment. The measured sound pressure levels in dBA at position 1, 2, 3 are 69, 68, 49 respectively as given in table 1. It can be noticed that the measured outdoor and indoor noise levels are greater than permissible limits. The results of measurements confirm the need for noise reduction methods.

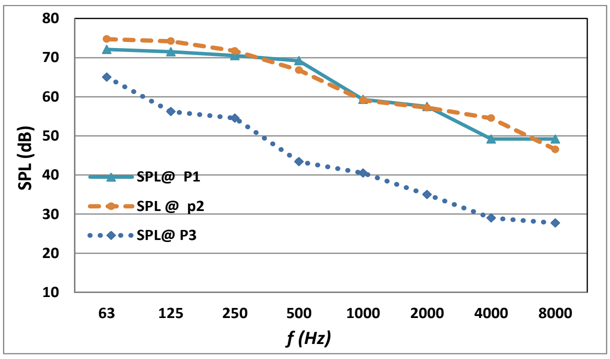

Fig. 1: Results of Measured Octave Band Sound Pressure Levels at Positions 1, 2, 3.

The sound pressure levels were calculated by different methods in locations (P1) and (P2). All calculated results compared to the measured values are at the same locations. ISO 1913-C is legend for ISO 1913-2 calculation method and IF-C legend for calculation method according to the manufacturer instruction. Fig. 2 shows that the calculated values based on ISO 1913-C is closer to the measured values at low frequencies; less than 500 Hz. The calculated values according to IF-C are closer to the measured values at higher frequencies greater than 500 Hz. This may be because of attenuation effect at high frequencies caused by the different objects existing in site, such as scrub, fences, grass, etc…, that were not considered in the calculation method ISO 1913-C. Also position (P1) is near the ground level that may affect by the ground attenuation at high frequencies. Fig. 3 shows the calculated values at location (P2) according to the two methods is closer to the measurements because of the increase of distance from the ground. The calculated sound pressure levels using manufacturer instruction method are closer to the measurement values than the results using ISO 1913-2. This may be because factory perform designing, testing, measuring and analyzing to get the best calculation method for their products. Generally this figure shows that the estimated sound pressure levels in dB using manufacturer method (IF-C) are more close to the measurement value compared to the calculation method ISO 1913-C. Also table 1 summarized the predicted and measured sound pressure levels in dBA at positions 1, 2, 3. These values are greater than the permissible noise limits. Noise reduction analysis is needed to select the best method for noise control. The calculation model according to manufacturer method was selected to perform the noise reduction analysis, because it is closer to the measured values than the calculation results using ISO 1913-C.

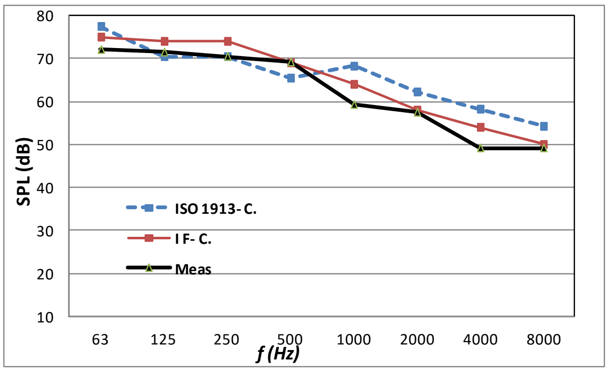

Fig. 2: Comparison between Measured and Calculated Octave Sound Levels at Position 1.

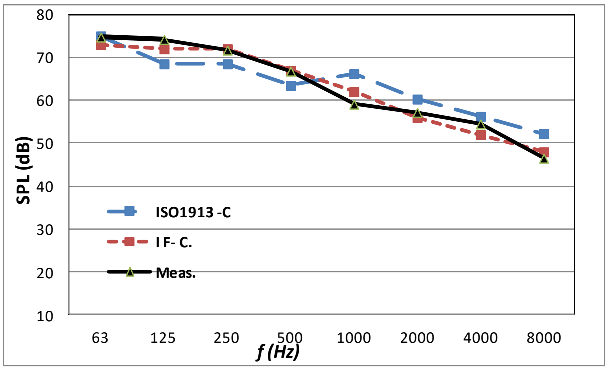

Fig. 3: Comparisons Between the Measured and Calculated Sound Pressure Levels at Position 2.

Table 1: Evaluation Calculated and Measured Sound Pressure Levels in Dba

Location	SPL in dBA ISO 1913-2	IF-C	Measured values
P1	71	70	69
P2	69	69	68
P3	-	48	49

Predictions of Indoor Sound Levels and Evaluation

The indoor sound pressure levels were calculated at location (P3) by calculation model IF-C that is based on Eq. 10.

The façade of neighbor building is hollow concrete block of 150 kg/m^2 with single glass window 1.5 m^2. Table 6 gives the sound attenuation of the façade with glazed windows [12]

Fig. 4 shows the calculated values at position (P3) inside the apartment no. 323 in the third floor. The results are close to the measured values except the sound pressure level at 63 Hz. This because the sound reduction of the façade at octave band 63 Hz may be actually greater than the values given in the manufacturer instruction.

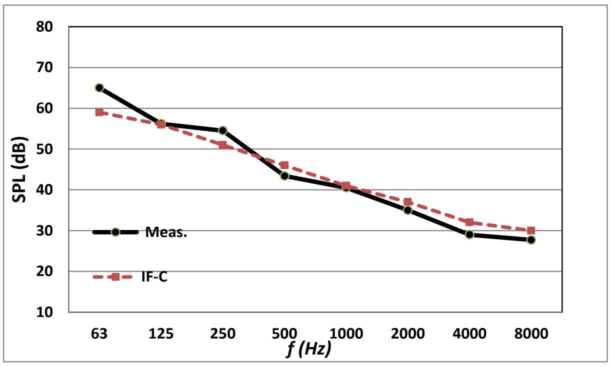

Fig. 4: Comparison Between the Measured and Predicted Sound Pressure Level Values at Location 3.

Analysis of Noise Reduction Methods

The most effective way to reduce the noise emitted by the cooling towers is to consider the suitable preliminary acoustic design and to make the proper dimensioning. Subsequent noise reduction is practically an unfavorable solution, because it is not only more cost than choosing the more silent technology during investing, but it could also increase the operating and maintenance costs. [14]. Reduction of sound pressure levels is required to achieve the permissible limits. The mechanical noise reduction method for can be [12, 14]:

1) Controlling the fans
2) Intake and discharge sound attenuation
3) Installing a low sound fan
4) Whisper Quiet Fan (very low sound fan)
5) Constructing barrier walls

Centrifugal fans have inherent low sound characteristics. The ability of centrifugal fan units to overcome higher static pressures allows for the units to be ducted. The overall sound pressure levels of centrifugal fan cooling towers can be about 5 to 7 dB lower than those of axial fan of cooling towers for the same cooling capacity [12].

Operating the equipment at various speeds by utilizing Variable Frequency control, VFC is efficient method for decreasing the motor speed, and therefore the fan rpm, that can decrease sound levels significantly. This is a normal nighttime situation. VFC can provide about 60% of full-load capacity on a unit and can give approximately the following octave band dB noise reductions. VFC octave band dB noise reductions can be as the following [12]:

Freq.	63	125	250	500	1000	2000	4000	8000
Noise reduction (dB)	4	6	8	10	8	8	6	4

The discharge attenuator is a lined plenum chamber, LPC. Adding sound attenuation dampens the sound propagating from the unit. Lined plenum chambers, to be effective, (1) must be fairly large, (2) should contain a thick absorbent lining, and (3) should be arranged such that the sound path through the plenum includes does not allow line-of sight. Depending on the degree to which the plenum chamber conforms to these three requirements, its sound reduction may range in the order of 5 to 10 dB for low frequency noise up to 10 to 20 dB for high frequency noise [12].

Another option for reducing the sound that the equipment produces is to select a low sound fan, LSF. The Low Sound Fan option reduces sound levels up to 9 dB [12]. For the most extreme sound limitations, Whisper Quiet Fan, QF can reduce sound 10-20 dB.

A solid wall barrier, B of height that must “cover” by line-of-sight the entire sound source as observed from the neighbor’s position. For our case the height of the barrier is 6 m to cover the view the sound sources installed at a distance 3m from the sources.

Reduction of noise due to different methods was estimated according to the IF-C calculation method. Fig. 6 shows the sound pressure levels with different noise reduction methods compared to the sound pressure levels without any method of noise control. Fig. 6-A shows the attenuation of each noise reduction method individual. The applying noise reduction methods are given in Table 2. The greatest attenuation can be achieved when applying whisper quiet fan that is adequate to achieve the noise criteria for daytime and nighttime. Low sound fan and lined plenum champers achieved individually good sound attenuation that is adequate to achieve the noise criteria for daytime. The attenuation of centrifugal fan units or variable frequency control or barrier is not adequate for achieving noise criteria at daytime and nighttime as given in Table 2. Fig. 6-B shows the attenuation for applying two noise reduction methods together. It can be noticed that applying variable frequency control & lined plenum champers or lined plenum champers & barrier or low sound fan & barrier achieved excellent attenuation for daytime and nighttime as given in Table 2. Applying variable frequency control & wall barrier have adequate attenuation for daytime but they have insufficient attenuation for nighttime. The most effective methods for noise control are the use of variable frequency control and lined plenum champers together or individual because they have assembly sufficient attenuation to achieve the noise criteria at daytime and nighttime but the lined plenum champers have sufficient attenuation to achieve the noise criteria at daytime. Besides reduction the noise the variable frequency control allows to save the energy.

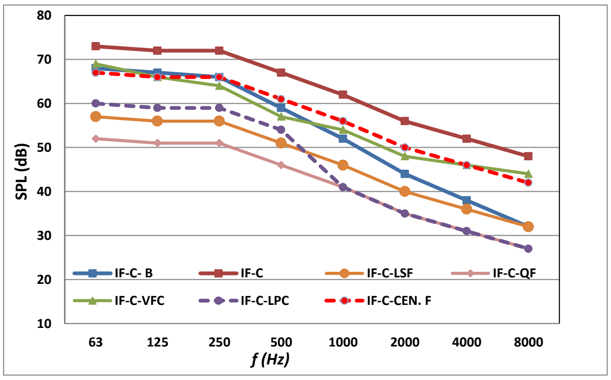

Fig. 6: A) Calculated Outdoor Sound Pressure Levels with Different Noise Reduction Methods.

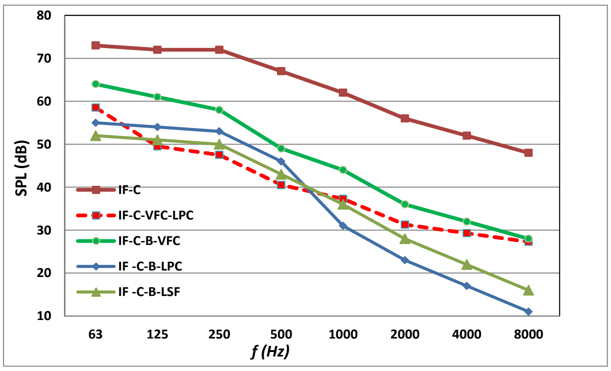

Fig. 6: B) Calculated Outdoor Sound Pressure Levels with Different Assembly Noise Reduction Methods.

Table 2: Summarized Sound Pressure Level in Dba with Different Noise Reduction Methods

Symbol	Calculating sound pressure levels in dBA		Noise limits in dBA	
	Control method	IF -C	Daytime	Nighttime
_	Without any control	68.6	55	50
CEN. F	Centrifugal Fan Units	62.6		
VFC	Variable Frequency Control	60.3		
LPC	Lined plenum champers	54.2		
LSF	Low sound fan	52.6		
QF	Quit Fan	47.6		
B	Barrier	60		
VFC & LPC	Variable Frequency Drive & Lined plenum champers	45.7		
VFD & B	Variable Frequency Drive & Barrier	52.7		
LPC & B	Lined plenum champers & Barrier	47.3		
LSF & B	Low sound fan with Barrier	44.9		

4. Conclusion

The activity in this paper is divided in two parts, the first was to assess the impact noise of particular installation cooling equipment and determine, if these levels complied with the permissible limits or not. The second part was to predict the acoustic performance of the cooling towers on the neighbor residential building by two different methods and select the best to perform analysis for noise reduction techniques. The calculations of outdoor sound levels emitted from the cooling tower equipment are based on the models specified in ISO 9613 -2 and the acoustic calculation methods specified in manufacturer instructions. The achieved model is constructed to calculate the attenuation of noise emitted from cooling towers units. The effect of geometrical divergence, ground effect, reflection from surfaces and screening by obstacles are considered for the models specified in ISO 9613 -2.

The sound pressure levels calculated according to manufacturer method depend on sound power emitted by the source and environmental sound effects of distance effect, effects of reflecting walls, background effect, screening by barrier. Comparison of the field measured values vs. the predicted levels was carried out for evaluation. The results showed that the acoustic calculations based on the methods of manufacturer instruction are close to the measured value than those based model of ISO 9613 -2. So the method of manufacturer instruction was used for analysis the noise reduction methods and determine the best way to achieve the acceptable noise levels. The octave band sound pressure levels were predicted outside and inside the opposite residential building with applying different noise reduction methods. These methods were the speed control of the fans, sound attenuation on intake and discharge, installing a low sound fan, constructing barrier walls located between the equipment and neighbor, whisper quiet fan (very low sound fan). The obtained results showed that the most effective methods for noise control are variable frequency control and lined plenum champers together or individual, because they have assembly sufficient attenuation to achieve the noise criteria at nighttime but the lined plenum champers have sufficient attenuation to achieve the noise criteria at daytime. Besides noise reduction, the variable frequency control grantees the energy saving.

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