Noise reduction strategies for Heating, Ventilation and Air-Conditioning Systems (HVAC)

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Abstract:
After the great technological development and its entry as a basic component in contemporary buildings, the importance of the architect's knowledge of various sciences outside his/her specialization, the necessity of this is stemming from the fact that these modern components are greatly affecting the comfort of the user of architectural spaces.
Among these modern elements, air conditioning in buildings, such elements have become necessary and indispensable to provide comfort to building users, and on the other hand, these devices cause loud noises during their operation, which causes noise that harms users and affects their hearing comfort.
This research discusses the issue from all its aspects and presents types of these devices and their mechanisms of action and how to provide barriers that prevent the transmission of noise inside buildings so that user of architectural spaces enjoys thermal and audio comfort at the same time.

Keywords:
Heating, Ventilation and Air Conditioning Systems HVAC, Noise control, Indoor & outdoor noise.

Research purpose:
Heating, Ventilation and Air Conditioning Systems (HVAC) produce serious environmental noise pollution outdoor and indoor. Outdoor noise is generated by exhaust fans, cooling towers and condensing units etc. it must be considered regarding its impact on neighbors and occupancy in the building itself. Indoor Noise is generated by fans, ducts, dumpers and diffusers etc. it must also be considered due to its impact on the indoor environment of the spaces. So, acoustic analysis and noise control for HVAC must be established early in the design in order to achieve acceptable sound pressure level.

Research aims:
The research aims to introduce the air-conditioning system in buildings and elements that cause noise pollution in them, and then aims to introduce the various sound insulation strategies and means in order to determine the best strategies in resisting the noise resulting from the air-conditioning system in buildings.

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Research problem:

Air conditioning devices in buildings have become necessary and indispensable to provide thermal comfort to building users, and on the other hand, these devices cause loud noises during their operation, which causes noise that harms users and harms their hearing comfort.

Research methodology:

The research follows the inductive approach in monitoring the most important types of equipment used in the refrigeration and air conditioning system, then an analytical approach to the outputs of these devices and how to control them by means and different insulation strategies.

1. Fundamentals of the noise:

Noise is any unwanted sounds, level of annoyance depends not only on the quality of the sound, but also on our attitude towards it, as any perceived sound that is objectionable to a human being. Noise is broadband sound, without distinguishable frequency characteristics, such as the sound of waterfalls. This definition is appropriate when one sound is used to mask another, as when controlled sound level radiated into a room from a well-designed air-conditioning system is used to mask or hide low level intrusive sounds from adjacent spaces to increase privacy. This sound is called noise, but not in the context of unwanted sound; rather, it is a broadband, bland sound that is frequently unobtrusive. In examining building acoustics, it is mainly concerned with sound vibrations through the air, whereas in the subject of noise control we are equally concerned with vibrations transmitted through solid materials such as pipe work, concrete plinths and building structures. (Thompson 2017)

2. Sound Power vs. Sound Pressure:

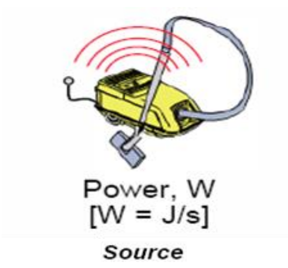
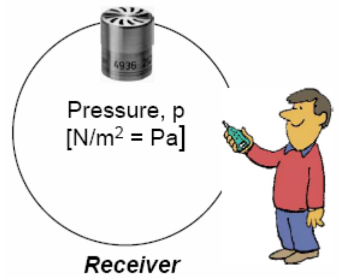
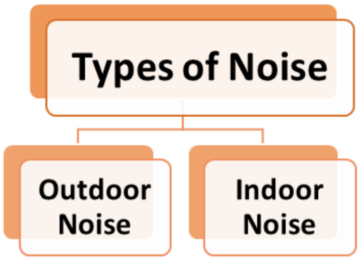
Sound Power level (L w).	**Sound Pressure level (L p).**
is dependent on the surroundings, which causes it to be a difficult means for measuring the sound level of equipment.	is the sound energy released by a sound source, it cannot be “heard”, but it can be used to be estimated if the space conditions are known.
	
▪ Calculated at the source point. ▪ Independent of the surroundings. ▪ It is a noise rating of the equipment.	▪ Measured at the receiver point. ▪ Dependent of the surroundings. ▪ It is an evaluation of annoyance of noise sources.

Table 1: Sound Power vs. Sound Pressure (Vorländer 1995)

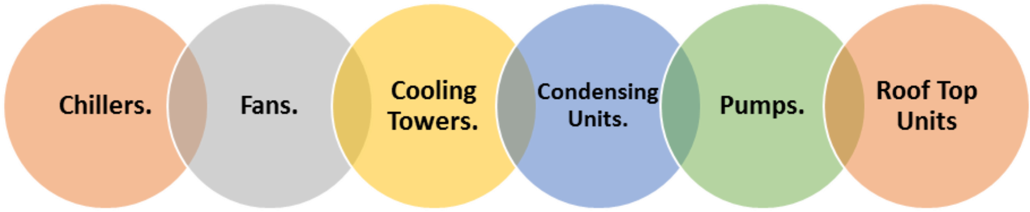
3. Types of Noise:

There are many types of noise, but in HVAC acoustical analysis we will focus on two types of noise:



- **Outdoor Noise**

Outdoor noise is the noise produced from the equipment located outdoor of the HVAC equipment. The outdoor HVAC equipment are:



Pic1: Types of outdoor noise sources

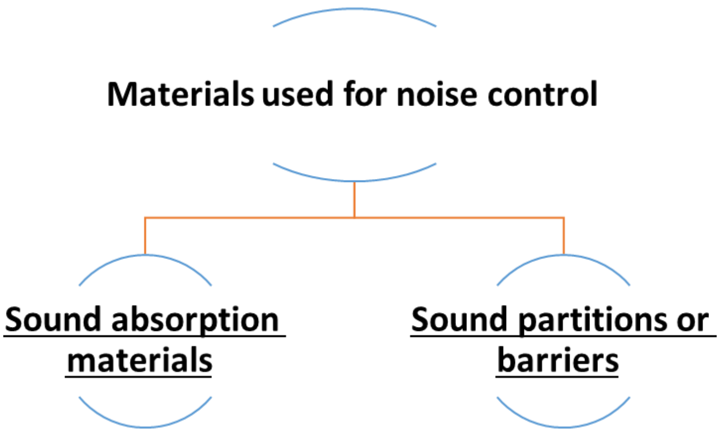
- **Indoor Noise**

Indoor noise is the noise produced from the indoor HVAC equipment's. This equipments are located inside buildings. The indoor HVAC equipment's are: (Sikora 2021)

Pic2: Types of indoor noise sources

4. Basic classes of insulation materials:

Two classes of materials are often used for engineering noise control:



Pic3 Materials used for noise control, done by the researcher.

- **Sound absorption materials:**

They are the materials that absorb sound; reduce reflections from surfaces and decrease reverberation within spaces. Sound absorbing materials are usually fibrous, lightweight and porous.

- **Sound partitions or barriers:**

They reduce sound transmission between adjacent spaces. These materials are usually non-porous and a good reflector of sound. A sound barrier material is a poor absorber of sound and an absorbent material is a poor barrier, the most common types of absorbing materials are rock wool, fiberglass, cloth, polyurethane and cellulose fibers. All these materials are different in a sense that these do not absorb sound of all frequencies equally well. Sound absorption is influenced by factors such as material density thickness and, in case of fibrous insulation products, fiber size and diameter, generally fine small diameter fibers will give superior absorption than coarser fiber blends. (Domínguez-Muñoz, F., Anderson, B., Cejudo-López, J. M., & Carrillo-Andrés, A. 2010)

5. Sound Absorbion Coefficient (SAC)

The sound absorption coefficient indicates how much of the sound is absorbed by the material over a range of frequencies.

- **Mean Absorption Coefficient**

The mean absorption coefficient for the room can be expressed as: am = A/S

Where: • am = mean absorption coefficient

• A = the absorption of the room (m^2 sabin)

• S = total surface in the room (m^2)

A room acoustic characteristic can be calculated with the formulas above, or estimated for typical rooms. The table below gives mean sound absorption coefficient values and reverberation time for some typical rooms:

Typical room	Room Characteristics	Reverberation Time	Mean Sound Absorption Coefficient
Radio and TV studio	Very Soft	0.40	0.2 < Ta < 0.25
Restaurant, Theater and Lecture Hall	Soft	0.25	0.4 < Ta < 0.5
Office, Library, Flat	Normal	0.15	0.9 < Ta < 1.1
Hospital, Church	Hard	0.10	1.8 < Ta < 2.2
Large church, Factory	Very Hard	0.05	2.5 < Ta < 4.5

Table 2: A room acoustic characteristics (Vorländer 1995)

The mean sound absorption coefficient should be calculated when more accurate values are needed.

- **Noise Reduction Coefficient (NRC)**

In sound absorption applications the term NRC is often used as a performance indicator of how absorptive a measure is. The higher the NRC, the greater will be the sound absorption at those frequencies. (Nor, M. J. M., Jamaludin, N., & Tamiri, F. M. 2004)

6. Partitions, barriers & enclosures:

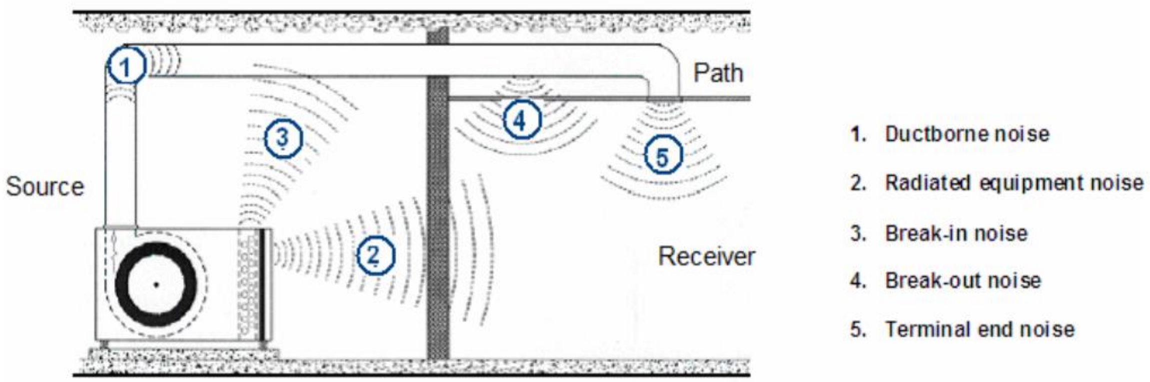
Partitions, barriers and enclosures are the products used for restricting the passage of an airborne acoustic disturbance from one side to the other. These are nonporous and dense materials often having the structural properties. Typical barrier materials are steel, lead, plywood, gypsum wallboard, glass, brick, concrete, concrete bloc etc. The quantity used to rate a sound attenuating material is transmission loss in d B. The sound transmission loss for different materials is given in the table below: (Bhatia 2014)

Material	Thickness (mm)	Surface Density (kg/m3)	Sound Transmission Loss (dB)		
			125 Hz	500 Hz	2000 Hz
Plaster Brick Wall	125	240	36	40	54
Compressed Strawboard	56	25	22	27	35
Acoustic panel (Sandwiched type steel sheet with fiber glass)	50	27	19	31	44
Chipboard	19	11	17	25	26
Plaster board	9	7	15	24	32
Plywood	6	3.5	9	16	27

Table 2: The sound transmission loss for different materials (Bhatia 2014)

- **Noise Points in HVAC Systems:**

Sound and vibration are created by a source, they are transmitted along one or more paths and reach a receiver. It is important to know which of these paths is most likely to cause acoustical problems so that it can be dealt with in the design phase of the project. The design of ducted HVAC systems must address five distinct but related issues. (Magrans 1993)



Pic4: typical mechanical system noise component
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- **Noise reduction strategies in HVAC systems:**

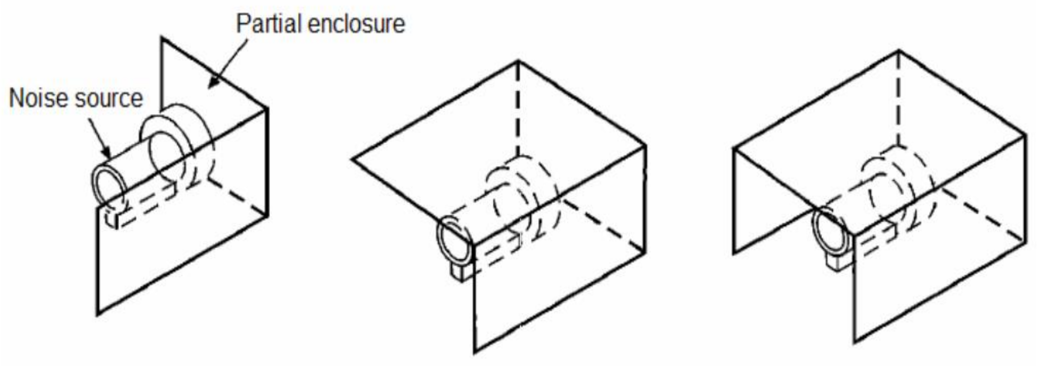
In HVAC systems, the source of noise is a combination of different processes, such as mechanical noise from fan(s), pump(s), compressor(s), motor(s), control dampers, VAV boxes and air outlets such as diffusers, grilles, dampers and registers. The HVAC noise that ultimately reach indoor space is made up of: (Magrans 1993)

Low-frequency fan noise	Mid-frequency airflow or turbulence-generated noise	High-frequency damper and diffuser noises
• Centrifugal fans generate highest noise in the low frequency range in or below the octave centered at 250-Hz.	• Terminal units, variableair-volume (VAV) boxes produce their highest noise levels in the mid frequency range in the octaves centered at 250, 500 and 1000 Hz bands.	• Diffusers, and grilles, however, typically generate the highest noise levels in the octaves centered at 1000 Hz, or above.

Table 3: Noise reduction strategies in HVAC systems (Bennet 1998)

- **Reducing noise transmission from outdoor machines:**

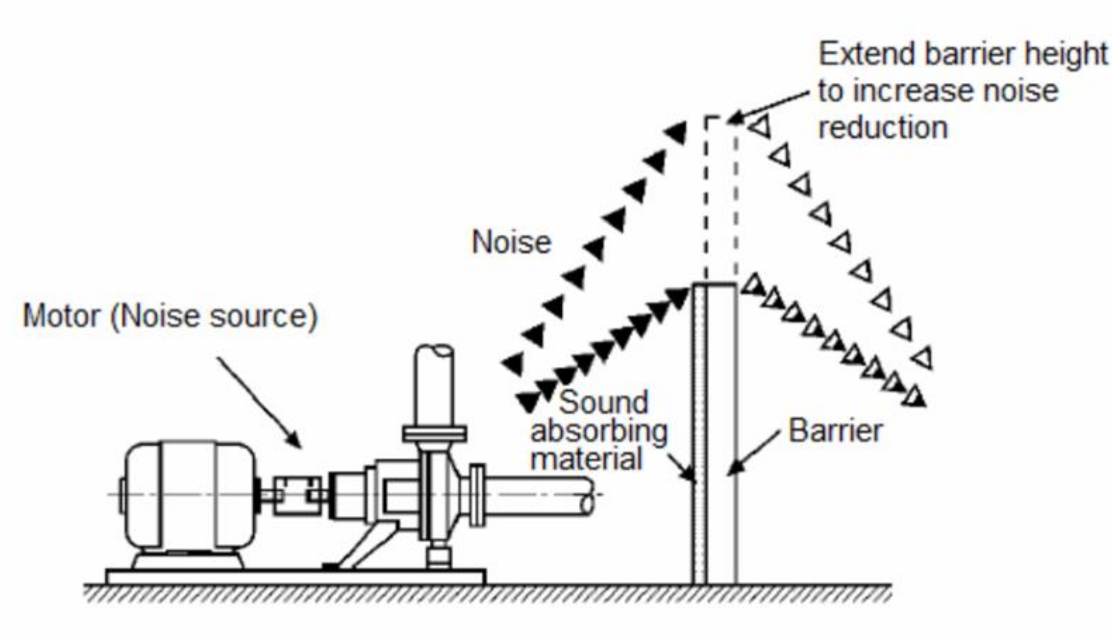
Sound enclosures, barriers and partitions reduce sound transmission between adjacent spaces. Complete Enclosures when a noise reduction of 20dB (A) or more is required, it is generally necessary to use a complete enclosure especially if the noise problem is a result of air-borne noise transmission. The enclosure should be internally lined with 2-inch-thick sound absorbing material (e.g. fiber glass). Ventilation of enclosures should not be overlooked as most equipment, such as motors, air cooled condensers or cooling towers require an adequate air supply either to prevent overheating or to enable them to function efficiently. Partial Enclosures are structures erected around a source of noise, but not fully enclosing the source and leaving space for natural ventilation, which will be effective only when there is no line of sight between the noise source and the receiver. The use of partial enclosures has advantages over complete enclosures in terms of cost, accessibility, and ventilation, but design and construction should be done carefully. Ideally, a reduction of up to 20dB (A) can be achieved. (Cowan 2014)



Pic5: partial enclosure (Cowan 2014)

7. Barriers:

To be effective, an acoustic barrier needs to be placed as close as possible either to the noise source or the receiving position. There should be no gap or joint in the barrier through which noise will leak. The surface density of the barrier must be at least 10kg/m^2. Ideally, the length of the barrier should be at least 5 times its height. Line of sight between the source and the receiver must be cut off completely. A reduction of noise level of between 5dB (A) to 10dB (A) can generally be resulted. Noise reduction will be greater if the barrier is lined with sound absorbing material at the surface of the barrier facing the noise source or is extended as high as possible above the line of sight. (D Duhamel & V. W Sparrow 2015)



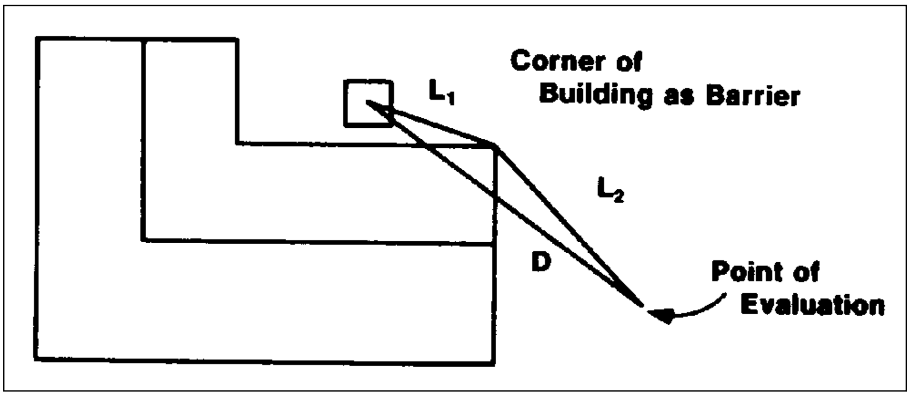
Pic6: Barriers (D Duhamel & V. W Sparrow 2015)

- **Types of Barriers:**

There are four types of barriers in order to attenuate noise emitted from HVAC: infinite barrier, finite barrier, edge of a building and a screen. Infinite barrier and the edge of the building have almost the same algorithm. Therefore, finite barrier and the screen have almost the same algorithm (Picture 7.8.9). Infinite barrier is the best because it is surrounding the equipment on all four sides or often three sides. (Kurze 1974)

Pic7: Infinite Barrier (Kurze 1974)

Pic 8: Finite Barrier (Kurze 1974)



Pic9: Edge of a Building (Kurze 1974)

- **Barrier Design Considerations:**

Barrier Height:

$$Optimum = H_{bar} = 4 * h_{los}$$

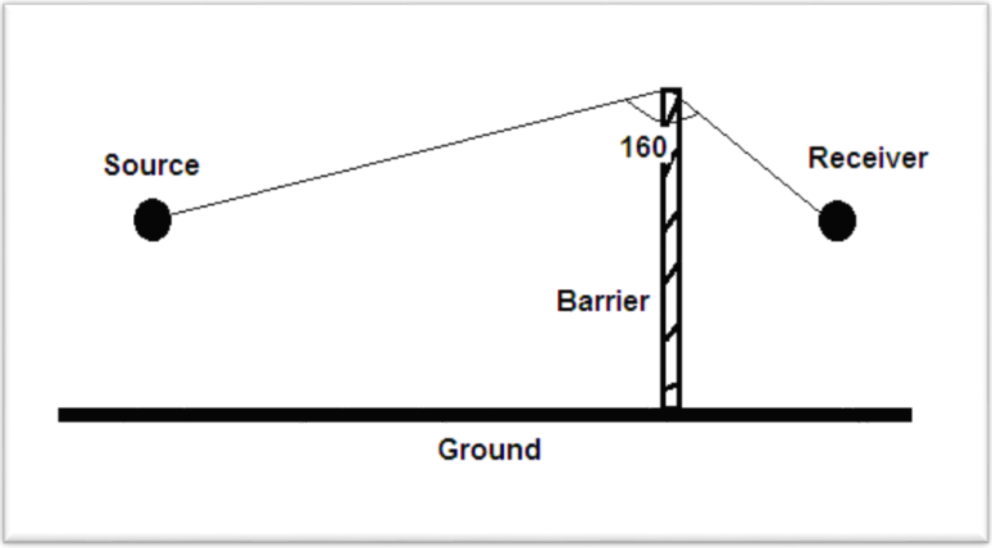
Barrier Width:

The best sound barriers surround the equipment on all four sides, but when the barrier is opened:

$$Optimum = W_{bar} = 6 * H_{bar}$$

Barrier Location:

Very close to the receiver or the source. (160 degree at least). Barrier Absorption Material and its side: At source side. (Q Li, D Duhamel, Y Luo, H Yin 2020)



Pic10 Barrier Location (Q Li, D Duhamel, Y Luo, H Yin 2020)

8. Strategies for Outdoor and Indoor HVAC Noise Control:

A-Strategies for Outdoor HVAC Noise Control by	**B- Strategies for Outdoor HVAC Noise Control by**
• Acoustic design of barrier. • Acoustic enclosures.	• By Acoustic design of lining ducts. • By Acoustic design of silencer. • By Reduction of fan speed.
	

Table4: Strategies for Outdoor and Indoor HVAC Noise Control (by the researcher)

In addition to that:

- Establishment of HVAC system according to Refrigerating and Air-Conditioning Egyptian Code **[5, 6].** (HBRC 2011) (HBRC, Study Of Noise Emitted From HVAC Systems And Noise Control Techniques: Report 1 2010)
- The total sound pressure level at outdoor or indoor must be according to the standards Tables (5,6).

Space	RC (N)	NC
Private residences, apartments, condominiums	25-35	25-35
Hotels / Motels		
Individual rooms or suits	25-35	25-35
Meeting/banquet rooms	25-35	25-35
Halls, corridors, lobbies	35-45	35-45
Services, support areas	35-45	35-45
Office Buildings		
Executive and private offices	25-35	25-35
Conference rooms	25-35	25-35
Teleconference rooms	25 max	25 max
Open plan offices	30-40	30-40
Circulation and public lobbies	40-45	40-45
Hospitals and Clinics		
Private rooms	25-35	25-35
Wards	30-40	30-40
Operating room	25-35	25-35
Corridors	30-40	30-40

Public areas	30-40	30-40
Performing Arts		
Drama theaters	25 max	25 max
Concert and recital halls	A	A
Music teaching studios	25 max	25 max
Music practice rooms	25 max	25 max
Laboratories		
Testing/Research, minimal speech communication	45-55	45-55
Research, extensive phone use, speech communication	40-50	40-50
Group teaching	35-45	35-45
Mosques, Churches, Synagogues	25-35	25-35
With critical music program	A	A
Schools		
Classrooms up to 750 ft^2	40 max	40 max
Classrooms over 750 ft^2	35 max	35 max
Lecture rooms for less than 50	35 max	35 max
Libraries	30-40	30-40
Courtrooms		
Unamplified speech	25-35	25-35
Amplified speech	30-40	30-40
Indoor Stadium and Gymnasiums		
School and college gymnasiums and natatoriums	40-50	40-50
Large seating capacity spaces	45-55	45-55

Table (5): Design Guidelines for Sound in the Indoor (HBRC, Study Of Noise Emitted From HVAC Systems And Noise Control Techniques: Report 1 2010)

TYPE OF AREA	Permissible Limit for Noise Intensity Decibel (A)					
	Day		Evening		Night	
	From	To	From	To	From	To
Commercial, administrative and downtown areas	55	65	50	60	45	55
Residential areas in which can be found some workshops or commercial establishments or which are located on a main road	50	60	45	55	40	50
Residential areas in the city	45	55	40	50	35	45
Residential suburbs with low traffic	40	50	35	45	30	40
Residential rural areas, hospitals and gardens	35	45	30	40	25	35
Industrial areas (heavy industries)	60	70	55	65	50	60

Table (6): Design Guidelines for Sound in the Outdoor (HBRC, Study Of Noise Emitted From HVAC Systems And Noise Control Techniques: Report 1 2010)

Day from 7 a.m. to 6 p. m &Evening from 6 p.m. to 10 p. m. & Night from 10 p.m. to 7 a.m.

In HVAC system design, controlling three types of sound propagation are important:

1. Air-borne noise is transmitted through both interior partitions and the exterior facade. Sources include mechanical rooms (interior), rooftop equipment, and fans exhaustion to the exterior via louvers or stacks. Mechanical equipment noise can also come from neighboring buildings. Control of air-borne mechanical noise can be achieved using appropriate partition construction and detailing, building facade design, site planning, silencers, acoustic louvers, barriers, and selection of quieter equipment.
2. Duct-borne noise travels efficiently through ventilation ducts to any space that is serviced by the system. Duct-borne noise is best reduced at the source by selecting quieter fans or by adding silencers. Duct layouts should incorporate space for silencers. Duct layouts should enhance privacy and sound isolation.
3. Structure-borne noise is caused by vibration from mechanical equipment entering the structure where it can propagate efficiently and be re-radiated as air-borne noise. Structure borne noise is best controlled at the source using rubber or spring isolators and inertia bases. (Y Wen, J Leng, X Shen, G Han, L Sun & F Yu. 2020)

9. Conclusion and Recommendations:

- HVAC system is designed to provide its serving occupants the maximum comfort standards.
- The sound power generation of given HVAC equipment performing a specific task is best obtained from the fan manufacture's test data.
- Manufacture's test data should be obtained from AMCA, ANSI or ASHRAE.
- General factors should be considered when selecting HVAC equipment and when designing air distribution systems to minimize the noise.
- The barrier must be done and used according to standard tables published in scientific references or has been measured at the laboratories.
- Complete building air-conditioning system acoustical analysis, vibration isolation for equipments especially roof-mounted or upper floors, and effect of equipment at a room to the outer surroundings.
- The total sound pressure level at outdoor or indoor must be according to the standards and design guidelines.
- Apply Strategies assisting design professionals in predicting the acoustical performance of air-conditioning system during pre-design stage.

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