Progress in Energy and Environment

Journal homepage: http://www.akademiabaru.com/progee.html
ISSN: 2600-7762

Technologies for Indoor Noise Attenuation: A Short Review

Open Access

Wen Jun Chin [1,*], Kai Sheng See[1], Yu Han Ng[1], Jie Ling Gan[1], Sing Yee Lim[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, UCSI University, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 15 May 2019
Received in revised form 15 June 2019
Accepted 28 June 2019
Available online 9 July 2019

Keywords:
Noise pollution, Indoor noise, Noise attenuation technologies

ABSTRACT

In this era of globalisation and modernisation, the proliferation of machineries and alarming city noises have created detrimental effect to the health of the human. The issue has received the attention from world and therefore noise reduction has been a critical problem that cannot be side-lined. For an ergonomic indoor workplace especially in the manufacturing plants, noise pollution shall be controlled and mitigated. Various noise control techniques have been proposed up-to-date, and the objective of current paper is to provide a short yet comprehensive review on the available noise attenuation strategies nowadays.

1. Introduction

Noise can be defined as “unwanted sound” which is harmful for human health. Noise can be classified into indoor noise and outdoor noise. For indoor noise, it can be divided into two types of sound, which are airborne and structure-borne sound respectively. Airborne sound is a type of sound that travels directly through air. When airborne sound hits a wall, the vibration will be induced within the wall before being transmitted to another room. Besides than transmitting through building structure, airborne sound can leak easily through holes or slits such as windows and doors. Meanwhile, structure-borne sound can be defined as the noise that directly causes vibrations to the building structures such as a wall. The sources of structure-borne sound can be any vibrating machines such as washing machine, turbine, jet engine and compressor. Structure-borne sound is generated by the sound wave, which is created by vibration from both sides of the wall.

Noise can cause serious impacts to human. For example, they can cause health problems like heart diseases, decrement in efficiency, hypertension, lack of concentration, sleep disturbance, and the most common one especially for industrial workers – hearing impairment [1]. There are around 120 to 250 million people worldwide estimated to have certain level of hearing loss. Thus, hearing loss became a serious problem, or notable the 15th major health problem in worldwide health problem ranking [2]. Sleep disturbances will be incurred if human are exposed to the noise of 70 dBA of night-time indoor noise level, while hearing impairment might happen when humans are exposed to noise level of 75dBA

[*]*E-mail address: winson.chin96@gmail.com*

for over 24 hours [3,4]. Moreover, the work of Kim et al. [5] showed that workers will have better performance in a surrounding with noise level of 75-86 dB.

Since noise can cause indispensable impact to humans, noise control technologies or techniques should be applied to reduce the adverse effects. Usually, noise control strategies can be separated into three categories: noise control at the noise source, control in the transmission path and control at the receiver. Noise control at source can reduce the noise product directly from the source. Some examples of noise control at source are reduction of speed and pressure, reduction of friction or reduction of vibration. Noise control in the transmission path refers to the control of the propagation of noise from source to the receiver, in which a portion of unwanted sound along the noise's transmission path can be absorbed to reduce the noise level. Technologies that are applied to administer noise control at the receiver is usually the last resort in almost any scenario of noise control, due to the low efficiency of this method and various limitations that an individual will be put under when using any hearing protections.

2. Noise Control Strategies from Source

Controlling noise at the source is regarded to be the most fundamental and economical approach to relieve the noise pollution problem [6]. Often, the noise generated was due to mechanical vibration, unbalanced rotation of mechanical components, collision and friction between metal parts and irregular flow of fluid [7]. With the aim of reducing noise generated by such reasons, the following approach can be taken to reduce the resulting noise at the source itself.

2.1 *Impact Minimisation*

Many appliances come with parts that hit against another part, resulting in sounds from the impacts. Impact noise can be produced from simple actions such as closing the cabinet to machines and forging a metal part. The noise can be minimised by reducing the mass and size of the object and its height of fall or distance from the surface. Shock absorbing material can be placed in between as well. Besides, minimising the impact force and extending the time of impact are effective ways too [8]. The noise level caused by two metallic surfaces is high and therefore, one should avoid such situation to prevent resonance by replacing one of the surface into an object made from non-metal [2,3].

2.2 *Speed and Pressure Reduction*

Fast rotating and moving components in all the electrical appliances and machineries can cause unwanted sound. Even though it is unavoidable in some circumstances, the speed and pressure can still be reduced to the lowest possible level while meeting the required needs of the user. Equal, centrifugal or squirrel-cage type of fans are said to be producing lower level of sound compared to vane, axial or propeller type. In an air ventilation system, when the speed of airflow is halved, the resulting sound pressure level can be reduced by 10-20 dB [8]. Lowering the speed, pressure and fluid flow rate in different machineries is able to lower down the turbulence and noise radiation.

2.3 *Friction Minimisation*

Friction can be induced by different factors such as misalignment of parts, rough contacting surfaces and so on, which lead to the generation of noise. Noise propagated from electrical appliances or machineries that are old and worn is often caused by the loosen parts within the machine are needed to undergo maintenance once in a while to re-adjust their positions or replace with new parts. Lubricants need to be applied unto the moving parts such as doors, windows and any other openings to reduce the friction between the surfaces [7]. Next, to smoothen the contacting surface, tools such as sandpaper and grinder can be used for polishing and removal of the unwanted pieces from the surface [8].

2.4 *Radiation Area Minimisation*

Sound can be transferred through three different mediums, which are solid, liquid and gas. The arrangement of the particles in solid is the closest compared to others. As sound is generated through the vibration of particles, the transmission of sound is the fastest in solid. Hence, by reducing the size of the parts which are vibrating and unnecessary, or create some openings and holes at the part's surface, the resulting noise level can be effectively reduced [8]. At the meantime, one should also be careful not to sacrifice too much of the material strength and cause the component to fail during operation.

3. Control in Transmission Path

Noise control at transmission path is the control of the propagation of noise from the source to the receiver. In most industries, it is often difficult to achieve fundamental design changes to equipment to reduce their noise. Thus, effective additional noise control technology during the transmission of sound must be implemented.

3.1 *Acoustic Barriers*

Acoustic barriers are a form of partial enclosure between noise sources and receivers, for reducing the effect of one-directional sound field transmitted to the receiver. In some cases, acoustic barriers are treated with sound absorbing materials to attenuate reverberant sound field levels. Sonic crystals (SCs) could also be used as acoustic barriers made of cylinders using recycled materials using the principle that SCs are structures made of sound scatterers periodically arranged in a lattice that forbid sound propagation for some frequency bands [9]. The barriers consist of only three rows of perforated metal shells filled with rubber crumb porous absorptive media. It was found that it could be used as building blocks whose physical parameters can be optimized in order to design efficient barriers adapted to different noisy environments.

In addition, sonic crystals acoustic screens (SCACs) made up of rigid cylinders as scatterers introduce versatile overlapping model of barriers as shown in Fig. 1. It was found that SCACs are acoustically competitive compared to classical acoustic barriers. Its increased tunability also allowed noise control of wide range of sound frequency [10].

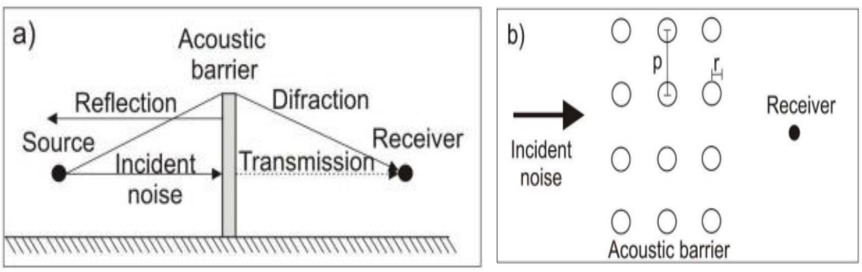

Fig. 1. (a) Acoustic performance of acoustic barrier (b) Array of SCs [10]

3.2 *Sound Absorbing Materials*

Sound absorption is the absorption of sound by converting sound acoustic energy into thermal energy. It happens when sound waves encounter an obstacle which is made of sound absorbing materials which are dissipative structure in nature. Sound acoustic energy is then transformed into thermal energy due to viscous flow losses by wave propagation in the material and internal frictional losses caused by motion of the material's fibres [11].

In the upsurge in research on the use of recyclable and biodegradable materials in manufactured products especially for automotive industry, three types of needle punched nonwovens in the ratio of 50:50 were tested for sound absorption by ASTM E 1050. It was found that bamboo/polypropylene nonwoven had the highest absorption coefficient in all frequency levels due to its compact structure, higher tensile strength, higher stiffness, lower elongation, lower thermal conductivity, lower air permeability, and higher absorption coefficient [12].

On the other hand, irregular-shaped cavity backed micro-perforated panel absorber (CBMPPA) may achieve better absorption performance at the troughs in the absorption curve compared to conventional micro-perforated panel (MPP) absorber with constant air gap as shown in Fig. 2. It was achieved by varying the cavity depth in the conventional MPP absorbers to allow more effective vibroacoustic coupling between the MPP and the cavity, providing the flexibility for tuning the effective absorption range of the absorber. Due to its irregular shape, it also exhibits obvious local characteristics [13].

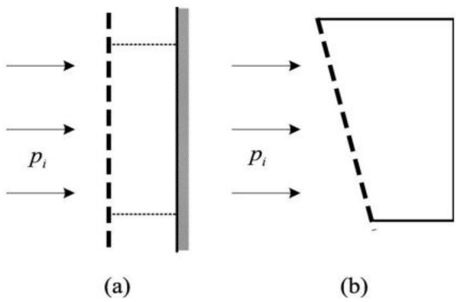

Fig. 2. (a) Conventional MPP absorbers (b) Irregular-shaped (trapezoidal) CBMPPA [13]

3.3 *Active Noise Control*

Active control of noise is the reduction of existing noise by introducing one or more additional secondary sound sources. One of the frequently used mechanisms is the sound field cancellation, whereby the secondary sound is anti-phase to the original sound to give cancellation effect. When the secondary sound propagates from its source point, “local zones of quiet” or “local cancellation” on a small particular area or zone is created. An error or residual sensor is placed close to the secondary source to feed information about attenuation results for feedback control. Sometimes, a reference sensor will also be employed to detect noise upstream near the primary source for feedforward control [14]. The mechanism is shown in Fig. 3.

Another mechanism of active noise control is the suppression of sound generation, whereby the secondary sound changes the primary sound’s radiation impedance so that it radiates less. In this case, the secondary sources are large enough to suppress the sound power radiated by the primary source by making its radiation impedance reactive with only a negligible real part. Generally, the secondary sources are close to the primary sources so that its radiation impedance will be affected significantly. Both the primary and secondary sources must also have similar sizes and similar volume velocity outputs in order to achieve effective suppression of sound [11].

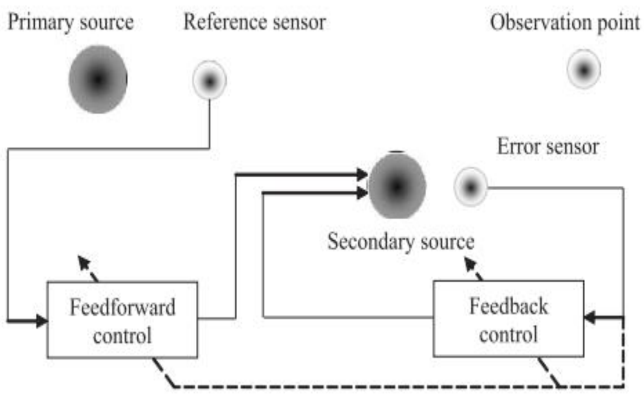

Fig. 3. Active Noise Control strategies [14]

3.4 *Mufflers*

Mufflers are devices that allow fluids to pass but restricting the free passage of sound simultaneously. They are commonly used for controlling noise levels from sources such as internal combustion engine exhausts, high pressure gas or steam vents, compressors and fans. The combination of muffler and ANC was found to provide greater noise reduction, more transmission loss and insertion loss than the effect of ANC or muffler only. Furthermore, the hybrid system had the advantages over a traditional muffler when the muffler is not designed for the frequency of the noise. Additionally, it was found that when ANC system was set in front of a muffler. It was less effective than the system of the opposite setup sequence [15].

3.5 *By Natural Means*

In urban areas, one of the noise sources is due to transportation. Road traffic noise can be reduced by planting row of trees behind noise walls to improve the noise wall efficiency under downwind conditions at short distance behind the wall. Additionally, numerical analysis found that tree belts as narrow as 15 m could provide relevant noise reduction with the condition that specific design rules are followed. For houses and courtyards, green roofs are particularly helpful to achieve noise reduction when compared to traditional rigid roofs [16,17].

4. Control from Receiver Side

One of the method of noise reduction is attenuation at the receiver side. Where the receiver is usually referred as the human ear.

4.1 *Ear Shields*

Ear shields refer to devices or apparatus used to cover the ear or obstruct the ear passage where sound propagate through to achieve reduction of noise reaching the eardrum and then interpreted by the auditory system [18]. They are usually categorised into the external and internal shields. The selection between this two will then depend on the type of work conducted, the period of exposure and the condition of the receiver. The two different type can also be used together most of the time. For example, the KUDUwave audiometer used for clinical hearing test uses both external and internal shields to ensure that patients with their hearing being tested do not hear anything from the surroundings but only sounds from the inside of the ear shield [19]. The KUDUwave audiometer consists of dual circumaural ear cups and insert earphones attached to the inside of the ear cups as shown in Fig. 4.

Fig. 4. A KUDUwave audiometer [19]

4.1.1 External Shields

Refers to devices that cover and form a barrier around the entire circumscription of the ear. The usage of this type of attenuation is recommended for high level of noise in terms of decibel because they have better noise insulation compared to the internal shields and also for work that do not require much attention. The also work better at high frequency noise. The examples of external ear shields are earmuffs, headphone and helmets [20].

External noise reduction equipment such as earmuffs are important for the mental and physical health of individuals exposed under high noise level or sensitive individuals [21]. According to a research by Duran et al. [22] that studied the effects of noise reduction by using earmuffs on physiological responses and behaviours of low birth weight preterm infants, it was noticed that preterm infants who wore earmuffs while sleeping were in the quiet sleep state for a longer period of time. It was important to protect the preterm infants from surroundings noises such as infants' cries, phones ringing and also alarms sounds as a low noise level in the neonatal intensive care unit (NICU) or incubator rooms is important for the sleeping quality of the infants. Sleep is important for healthy neurodevelopment of the infants and they might be under risks of negative effects on blood pressure, oxygen saturation, breathing and heart rates if they are exposed to unwanted noise. Besides, from the results of the experiment, it was concluded that preterm infants who had earmuffs on were observed to be in the quiet sleep state of Anderson Behavioural State Scoring System (ABSS) more often (87.5% of the test subjects) compared to the ones without earmuffs on (29.4% of the test subjects) [22]. Fig. 5 shows a preterm infant, which was one of the test subjects of the research wearing earmuffs while sleeping.

Fig. 5. A preterm infant wearing earmuffs [22]

4.1.2 Internal Shields

Internal shields usually refers to devices or objects that are inserted into the auditory canal to obstruct the passage where sound travels through and reach the auditory system. This type of ear shields is usually lighter in weight, more durable, cheaper, much simpler in structure and application and can be used in environments with high temperatures. The examples of internal ear shields are: earplugs, stoppers or tampons, materials are usually cotton, rubber or [20]. Fig. 6 shows a pair of foam ear plugs attached to chords used for easy removal and to prevent loss of the earplugs.

Fig. 6. Foam ear plugs [20]

Other more advanced shields are sound restoration protectors, communication protectors, flat response protectors and active noise cancellation (ANC) protectors. An ANC protector applies the nature of superposition to cancel out unwanted noise [23]. As sound waves are basically acoustic pressure with alternating rarefaction and compression, a specially-designed speaker mounted in the ANC protector will emit sound waves of the same amplitude but with different phase or “antiphase” to the detected sound wave input. Destructive interference of waves effectively dampens out each other hence noise reduction is achieved [24]. Fig. 7 shows how an ANC protector emits sound waves that cancel out the noise source’s sound waves.

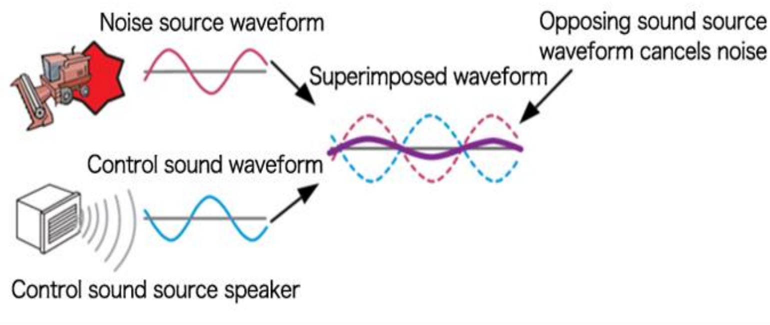

Fig. 7. Working principle of an active noise cancellation protector [23]

4.2 *Sound Reducing Enclosure*

Ear shields can only reduce noise levels to a certain degree and can sometimes be insufficient for excessive or long exposure of high noise level. This is because noise can be transmitted as vibration through the bones in our heads into the auditory system even when the auditory canal is covered or blocked with ear shields [18]. For situations as such, sound reducing enclosures can be used [25]. A sound reducing enclosure are usually formed by solid barriers connecting side to side to form a “container” that surrounds either a noise source or noise-receiving individuals to reduce the amount of noise entering the receiving individuals' ears. In this case, the latter will be discussed. Most of the enclosures are made up of sides with firm outer layers and sound-absorbing materials on the inner side. The outer layer provides rigidity or acts as support and also reflects noise back to its source's direction. The sound-absorbing material on the inner side damps the sound waves and their structure. As illustrated in Fig. 8, a noise source – a pump is enclosed in a small-sized acoustic enclosure that has sides consist of a rigid outer layer of MDF board and a sound-absorbing inner layer of SA25ff/B/6 foam.

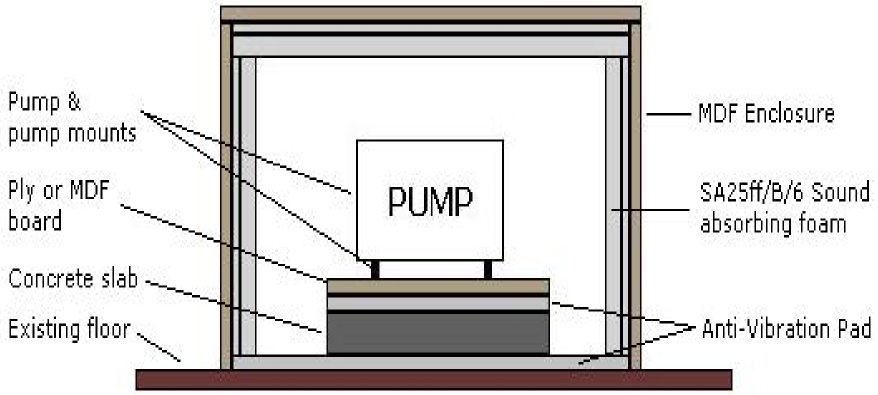

Fig. 8. An acoustic enclosure for a pump [25]

Various forms of sound reducing enclosures exist for different usages and they are: acoustic enclosures, industrial enclosures, NEMA and IP enclosures, modular enclosures, rack enclosures and PC enclosures. For noise reduction at receiver side, acoustic enclosures will be selected as they are larger in size compared to the others and are designed for human enclosure [26].

Besides that, enclosures can be divided into sealed enclosures and partial enclosures. Sealed enclosures refer to those that have no openings or gaps on them and are sealed completely from the outside environment while partial enclosures have gaps or openings that might be either accidental or intentional. Intentional openings can be used for air circulation and machineries basic functioning requirements [27]. Most of the time the frames of the enclosures are made of wood, glass, loaded vinyl, stucco, metal or concrete. While the sound absorbing layers will be made of perforated vinyl, perforated foil or perforated metal. These enclosures remove the ability of sounds from penetrating into the inside of them.

Effective acoustic attenuation is dependent on applying acoustic mass law or application of layers of absorptive materials, and this will result in heavy enclosures. The other method was using thick material to increase the attenuation efficiency but this method is also unsatisfactory because in order for this to be efficient, the thickness has to be in similar magnitude with the acoustic wavelength and it is not easy to achieve most of the time and is impractical [28]. However, the performance or degree of attenuation of an acoustic enclosure can be improved by adding different resonant structures. These structures are usually in the form of honeycomb panels. Resonant cells with smaller scale than the targeted structural wavelengths are used to form metamaterials with stop band characteristic. Then, stop band characteristic can be created in any system that local resonant behaviour occurs in [29]. Stop bands are actually zones that free wave propagations are absent or they are frequencies bands between specified limits in a system that do not allow signal to pass through, in this case, the signal will be sound waves [28]. Fig. 9 shows examples of resonant structure panels with a honeycomb or hexagonal core panel on the left and a rectangular core panel on the right.

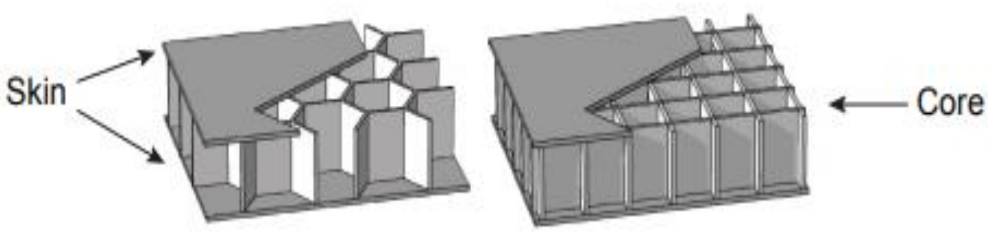

Fig. 9. Different form of resonant structure panels [9]

According to a study by Claeys, C. et al. [28,29], it can be concluded that enclosures with resonant structure panels applied outperform normal enclosures without resonant panels in terms of degree of acoustic attenuation. Fig. 10 shows a graph that compares the measured insertion loss for an enclosure with metamaterial resonant structure panel applied and a regular enclosure without resonant panels and it is observed that between the range of 700 Hz to 1000 Hz, the enclosure with metamaterial resonant structure panels applied performs better.

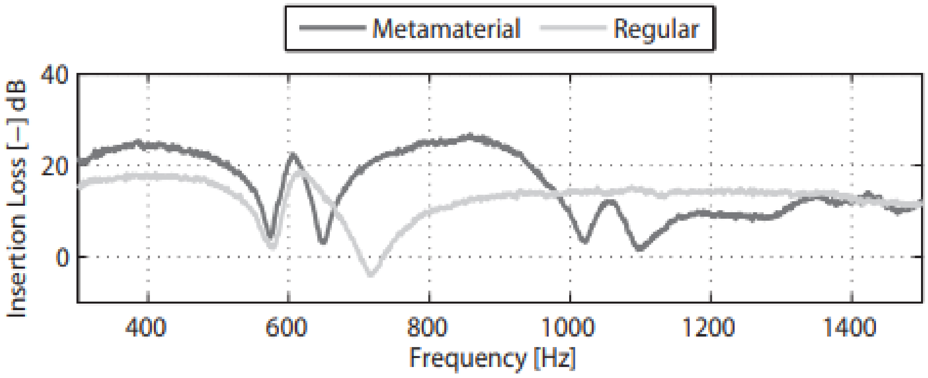

Fig. 10. Comparison between the measured insertion loss for enclosure with metamaterial resonant structure panels applied and a regular enclosure [29]

References

[1] W. Passchier-Vermeer, W. Passchier, Noise Exposure and Public Health. Environmental Health Perspectives, 108, p.123, 2000.

[2] D. Nelson, R. Nelson, M. Concha-Barrientos, M. Fingerhut, The global burden of occupational noise-induced hearing loss, American Journal of Industrial Medicine 48(6) (2005) pp.446-458.

[3] S. Stansfeld, M. Matheson, Noise pollution: non-auditory effects on health. British Medical Bulletin 68(1) (2003) 243-257.

[4] S. Stansfeld, C. Clark, Mental Health Effects of Noise. Reference Module in Earth Systems and Environmental Sciences, 2019.

[5] S. Kim, K. Park, K. Kim, The study on affecting subject accomplishment by noise. Journal of the Ergonomics Society of Korea 29(1) (2010) 121-128.

[6] S.I. Gvozdkova, L.E. Shvartsburg, Analysis of Sources and Methods for Reducing Noise by Minimizing Vibrations of Engineering Technological Processes, Procedia Engineering, 206 (2017) 958–964.

[7] C.H. Hansen, B.I.F Goelzer, G.A. Sehrndt, Engineering Noise Control, Occupational Exposure to Noise: Evaluation, Prevention and Control 10 (1996) 245-296.

[8] I.V. Muralikrishna, V. Manickam, Chapter Fifteen - Noise Pollution and Its Control, Environmental Management (2017) 399-429.

[9] J. Sánchez-Dehesa, V.M. Garcia-Chocano, D. Torrent, F. Cervera, S. Cabrera, F. Simon, Noise control by sonic crystal barriers made of recycled materials, The Journal of the Acoustical Society of America 129(3) (2011) 1173-

1183.
[10] S. Castiñeira-Ibañez, C. Rubio, J.V. Sánchez-Pérez, Environmental noise control during its transmission phase to protect buildings - Design model for acoustic barriers based on arrays of isolated scatterers, Building and Environment 93 (2015) 179-185.
[11] C.H. Hansen, B.I.F. Goelzer, G.A. Sehrndt, G. A., Engineering noise control, occupational exposure to noise: Evaluation, prevention and control, 10 (1996) 245-296.
[12] G. Thilagavathi, E. Pradeep, T. Kannaian, L. Sasikala, Development of natural fiber nonwovens for application as car interiors for noise control, Journal of Industrial Textiles 39(3) (2010) 267–278.
[13] C. Wang, L. Cheng, J. Pan, G. Yu, Sound absorption of a micro-perforated panel backed by an irregular-shaped cavity, The Journal of the Acoustical Society of America 127(1) (2010) 238–246.
[14] M. Pawelczyk, Active noise control - A review of control-related problems, Archives of Acoustics 33(4) (2008) 509-520.
[15] S.R. Chen, G.P.J. Too, Simulations and experiments for hybrid noise control systems, Applied Acoustics 70(2) (2009) 247-255.
[16] T. Van Renterghem, J. Forss´en, K. Attenborough, P. Jean, J. Defrance, M. Hornikx, J. Kang, Using natural means to reduce surface transport noise during propagation outdoors, Applied Acoustics 92 (2015) 86-101.
[17] T. Van Renterghem, M. Hornikx, J. Forssén, The potential of building envelope greening to achieve quietness, Building and Environment 61 (2013) 34-44.
[18] S. Stenfelt, Linköping University Post Print A coustic and physiologic aspects of bone conduction hearing, Univ. Print. 71 (2011) 10–21.
[19] F. Maclennan-Smith, D.W. Swanepoel, J.W. Hall, Validity of diagnostic pure-tone audiometry without a sound-treated environment in older adults, Int. J. Audiol. 52 (2013) 66–73. doi:10.3109/14992027.2012.736692.
[20] T. Claudia, N. Valentin, L. Gabriel, Actual stage of industrial noise reduction, 17 (2011) 89–95.
[21] M. Basner, W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, S. Stansfeld, Auditory and non-auditory effects of noise on health, Lancet. 383 (2014) 1325–1332. doi:10.1016/S0140-6736(13)61613-X.
[22] R. Duran, N.A. Çiftdemir, Ü.V. Özbek, U. Berberoĝlu, F. Durankuş, N. Süt, B. Acunaş, The effects of noise reduction by earmuffs on the physiologic and behavioral responses in very low birth weight preterm infants, Int. J. Pediatr. Otorhinolaryngol. 76 (2012) 1490–1493. doi:10.1016/j.ijporl.2012.07.001.
[23] B. Rudzyn, M. Fisher, Performance of personal active noise reduction devices, Appl. Acoust. 73 (2012) 1159–1167. doi:10.1016/j.apacoust.2012.05.013.
[24] Y. Kajikawa, W.S. Gan, S.M. Kuo, Recent advances on active noise control: Open issues and innovative applications, J. Institutional Econ. 1 (2012). doi:10.1017/ATSIP.2012.4.
[25] D.H. Bies, C.H. Hansen, R.H. Campbell, Engineering Noise Control, J. Acoust. Soc. Am. 100 (2005) 1279–1279. doi:10.1121/1.416038.
[26] R.O. Kuku, N.A. Raji, T. Bello, Development and performance evaluation of sound proof enclosure for portable generators, Res. J. Appl. Sci. Eng. Technol. 4 (2012) 2600–2603.
[27] L. Zhou, A.E. Carter, D.W. Herrin, J. Shi, D.C. Copley, Airborne path attenuation of partial enclosures: Simulation and sensitivity study, Appl. Acoust. 72 (2011) 380–386. doi:10.1016/j.apacoust.2010.12.012.
[28] C.C. Claeys, K. Vergote, P. Sas, W. Desmet, On the potential of tuned resonators to obtain low-frequency vibrational stop bands in periodic panels, J. Sound Vib. 332 (2013) 1418–1436. doi:10.1016/j.jsv.2012.09.047.
[29] C.C. Claeys, B. Pluymers, P. Sas, W. Desmet, Design of a resonant metamaterial based acoustic enclosure, Proc. 26th Int. Conf. Noise Vib. Eng. (ISMA 2014). (2014) 3351–3358.