DESIGN AND DEVELOPMENT OF NOISE SUPPRESSION SYSTEM FOR DOMESTIC GENERATORS

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Abstract

Increase in demand for standby power sources and disruption in power supply has increased the use of generators manifold for domestic and industrial consumers leading to objections on their use concerning noise pollution. The work presented here aims to focus on how generator set noise is propagated, controlled and reduced to a limit as defined by domestic laws. The presented work is in fact a feasibility of a simple and effective design of an acoustic enclosure for portable generators aims at reducing the radiated noise. This effort is a multi-disciplinary work that comprises acoustics, heat transfer and material science. Heat generation and requirement of cooling air leads to a heat transfer model with internal forced convection. The design is a balance of noise control and thermal management. Noise generating areas have been identified and conventional passive noise control techniques have been used to control and reduce the noise. Acoustic barriers and insulation are used to control the noise propagation at its transmission path. In the conclusion comparison and results of noise are plotted using sound measuring techniques and devices as well as the thermal profiles of cylinder head are compared with and without canopy.

Keywords: Sound Mapping, Acoustic enclosure, Heat transfer, Noise Suppression

Introduction

Growing gap between power production and consumption around the globe has compelled the consumers to look for standby energy sources. Among available options, generators are considered to be cost effective, user friendly and reliable power generation source[1,2]. However systems in use at the domestic, commercial and industrial level are polluting the environment due to high noise levels [3,4,5]. The noise laws and regulations of different countries do not allow the use of generators in their domestic and commercial areas, hence forcing consumers to adopt less efficient and costly backup power sources [6]. Typical noise levels of different sources and their surrounding environment is depicted in Figure 5. Intensity of sound is measured in decibel (dB). Typical generator set noise lies between 80-105 dB at 21 ft which falls in very loud to uncomfortably loud category with respect to sensitivity of human ears and hence, making electrical generators a source of noise pollution to environment**.** Laws and regulations typically, in United States for example, allow noise in domestic residential areas up to a maximum of 67 dB while for industrial areas the allowable limit is up to 72 dB. Much of the earlier research for generator noise control is focused on the selection of materials that can be used for design of an isolated enclosure to suppress the noise [7-11]. Although effective noise supression methods for large scale generators is quite common, however, the same are not availbe for the medium to small scale generators, mainly due to cost considerations. The basic aim of this research work is to design and develop a suitable solution for the noise suppression and thermal management of small sized generator sets for domestic use for a tyical family size of 5 to 10 people. For this study, therefore, a generator set of 4.5 kVA is selected whose sound levels are measured with a suitably accurate dB meter. For effective noise control different methods have been proposed for reduction of noise produced by machinery and other equipment[12-14]. This paper presents a study on selection of appropirate noise suppressent materials suitable for the generator canopy as well as effective heat transfer methodology to ensure stable generator operations. Extensive measurements of noise levels as well as generator cylinder head temperatures, before and after the installation of designed canopy around the generator, has been carried out to show the effectiveness of the proposed design for reduction in noise pollution.

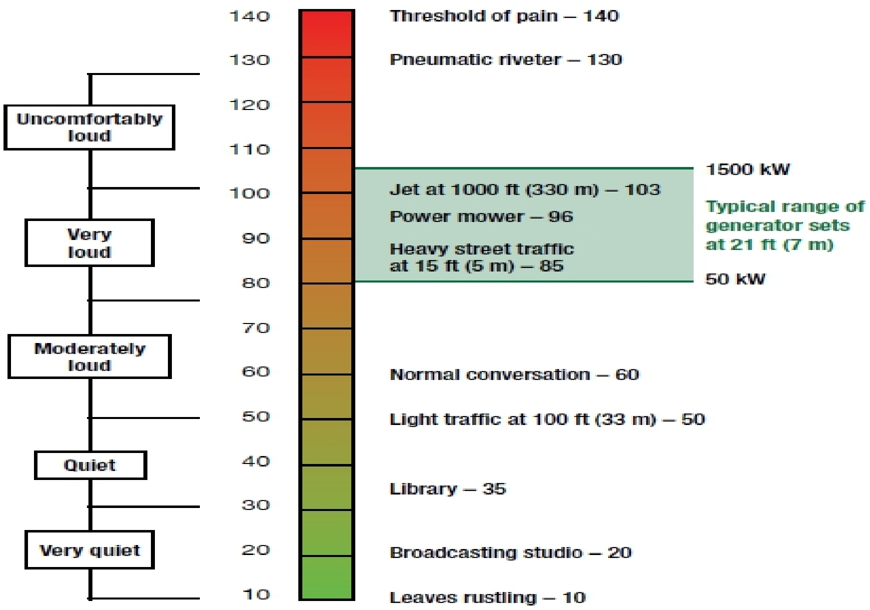

Figure 5.Various sources of sound with their typical noise levels, measured in (dB) [6].

Sound/Noise Mapping

In this study, for the consistency in noise measurement technique, a methodology has been defined so that straight forward comparison can be made for the noise levels of the generator in both outdoor and indoor environments. For this purpose, a simple experiment is performed for which a test space of 50 ft x 50 ft in open air is selected. Sound source i.e. the generator is placed in the center of test space and the sound levels are then measured using dB meter, in a 8 x 8 space matrix format. The numerically measured noise values in (dB) and their corresponding 2D plot is shown in Figure 6 as a spectrogram of noise produced by the generator.

		SOUND LEVEL (dB)							
WIDTH (ft)	50.000	78.2	77.9	80.6	81.2	82.2	81.9	81.6	80.9
	42.857	78.7	80.1	81.4	82.3	84.1	84.9	83.9	81.7
	35.714	79.1	81.8	83.3	85.6	86.3	87.2	84.3	82.2
	28.571	79.5	82.8	85.6	87.9	88.9	87.9	85.8	82.7
	21.428	79.2	83.1	86.1	91.5	90.4	86.5	86.2	83.7
	14.285	78.7	82.4	84.9	89.2	86.6	84	84.7	84.6
	7.143	78.4	81.7	82.8	87.6	84.8	83.7	83.2	83
	0.000	78.1	79.8	80.6	82	81.2	82.9	81.7	82.5
		0	7.1428	14.285	21.428	28.571	35.714	42.857	50
		LENGTH (ft)							

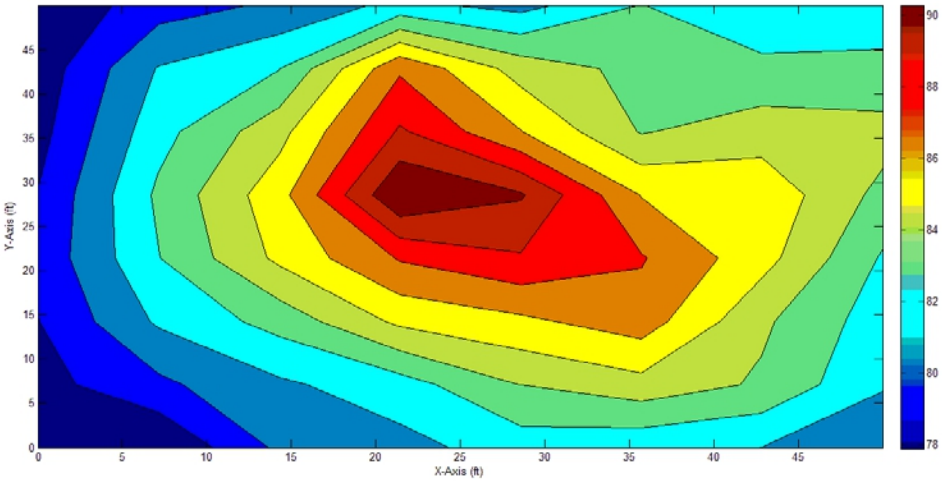

Figure 6. A typical 8x8 space matrix for noise measurements along with Spectrogram, for generator without enclosure in open environment

Material Selection and Noise Control

Noise control is always been a key environmental concern in all industrial and domestic areas. Noise produced from machinery and other equipment can be controlled by using either active or passive methods, depending upon cost of the solution. The Contour plot of noise levels produced by the generator, as shown in figure 2, indicates that noise from the generator is almost symmetric in all dimensions, with small variations due to the non symetric shape of the generator. Therefore, for the purpose of finding cost effective solution for the domestic users, it is imperative to have noise control done at its source and along its transmission path. Thus, in this study passive noise control techniques have been explored. For this reason, the generator is proposed to be enclosed in a suitable enclosure made of suitable noise suppression materials. This shall significantly reduce the noise on one hand and on the other hand, the heat accumulated inside the enclosure may raise the temperature of the generator beyond its safe operating limits. Thus the challenge in this design is to find a balance between reduced noise leveles as well as sufficient heat transfer from the enclosure for the domestic generator to noiselessly operate for a long duration.

In general, noise control at its transmission path design is accomplished through installation of acoustic barriers and use of insulation material. In proposed scheme an enclosure to place the generator set for reduction in noise emission to environment has been perceived. At first different rigid materials are considered for the canopy design to achieve the desired results. Factors considered for selection of material for canopy fabrication include transmission loss, thickness, weight, cost, material properties and ease of fabrication. As scope of the work is focused to noise suppression, so transmission loss and thickness parameters are preferred. Values for thickness and transmission loss parameters of different materials considered are tabulated in Table 1. Steel is selected from considered materials for its minimum thickness and maximum transmission loss. Further survey revealed that different standard working gauges of steel are readily available in market. As there are fabrication issues with the Standard Working Gauge (SWG) 14 which is listed high during parameter comparison therefore, SWG 16 gauge steel with thickness of 1.63 mm and transmission loss of 27 dB is selected for fabrication of canopy. It is a known fact that most materials absorb sound. There is a wide variety of insulation materials available in the market, with an equally wide variance in form, performance, sustainability and cost-effectiveness. The absorption coefficient is a common parameter used for measuring the sound absorption of a material, defined as ratio of energy absorbed by a material to the energy incident upon its surface. Rockwool is selected with a maximum sound absorption coefficient of 0.65.

Table 1. Materials Thickness and Sound Transmission

Material	Thickness (mm)	Surface Density (kg/m^2)	Transmission Loss (dB)
Dense Concrete	100	244	40
Light Concrete	100	161	36
Brick	150	288	40
Steel	**0.64 – 1.97**	**4.9 – 15.20**	**18 – 30**
Aluminium	1.59 – 6.35	4.4 – 17.1	23 – 27
Wood	25	18	21
Ply Wood	25	16.1	23

Heat Transfer Model

Understanding and computations of heat transfer are important in this work as it will affect the generator operation when isolated inside an acoustic enclosure. Initial heat transfer design considerations are done with the operating temperatures of engine, exhaust and surrounding environment. A resistance thermocouple is used to measure the generator cylinder head temperature. From figure 3, it is seen that maximum generator cylinder head temperature of 200 ^oC is reached after a 20 minutes of operation and then does not rise even after complete operation time of 30 minutes. Since the maximum allowable temperature defined by OEM i.e., 270^{o}C for the selected generator, therefore it is important that adequate heat transfer measures must be taken to ensure that even in the enclosed canopy, the generator cylinder heat temperature do not rise closer to this limit. Ambient temperature at the time of the test is measured as 30 ^{o}C.

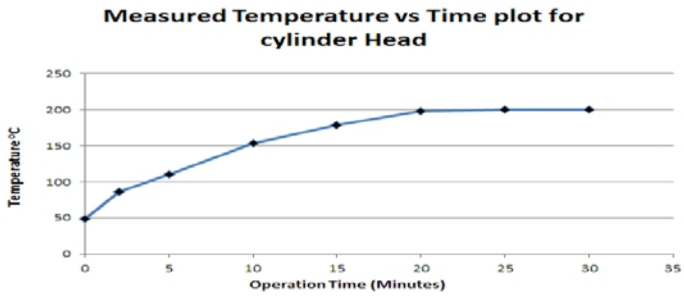

Figure 7. Cylinder head temperature history when generator is in open location without canopy

A model for heat transfer calculations is shown in figure 4. The generator and its canopy is modelled as a six sided rectangular box, as shown in the figure 4, across which the heat is transfered out to its surroundings from 5 of its sides (the lower side of the box touching the ground is assumed to be insulated).

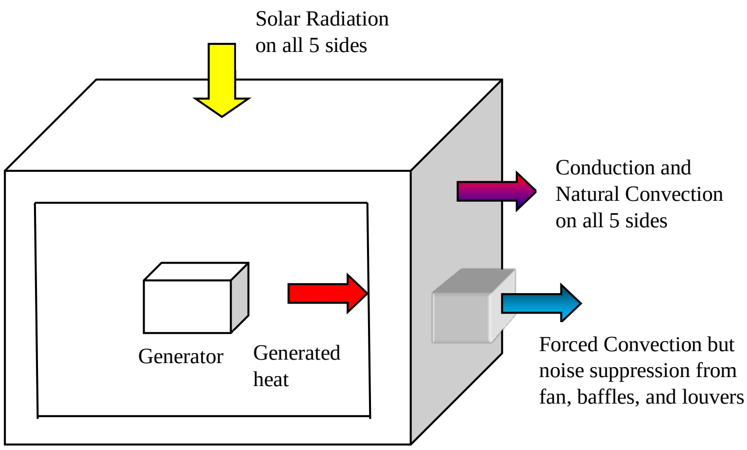

Figure 4. Heat Transfer model of generator inside the canopy

Applying energy balance, it is realized that for a steady generator operation, all the heat energy given away by the generator during its operation plus the solar radiation coming into the canopy must be conducted out of the canopy and through natural convection from all 5 sides to the surroundings and through forced convection from the cooling fan. Mathematically,

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{Q}_{gen} = \frac{\partial Q}{\partial t} \quad (1)$$

In this equation 1, the right hand side is essentially zero for steady state operation. For the solar radiation coming into the canopy,

$$\dot{Q}_{in} = \epsilon\sigma A(T_s^4 - T_\infty^4) \quad (2)$$

where, T_s is the surface temperature of the canopy, T_∞ is the ambient temperature, A is the 5 face areas of the canopy, ϵ is the emissivity of the surface, and σ is the stephen Boltzman constant. $\dot{Q}_{gen}$ in equation 1 is estimated from the known surface temperature profile of the cylinder head. $\dot{Q}_{out}$ in equation 1 comprises of heat conducted out through the walls of the canopy and naturally convected to the surroundings. This is estimated from the equation 3 :

$$\dot{Q}_{natconv} = \frac{(T_{Cyl} - T_\infty)}{R_{Total}} \quad (3)$$

where, T_{cyl} is the generator cylinder head temperature in its steady operation and R_{Total} is the thermal resistance in the path of the heat energy from the generator to the outside environment and is given by equation 4 below:

$$\mathbf{R_{Total} = R_{conv,\,1} + R_{wall,\,1} + R_{wall,\,2} + R_{conv,\,2}} \quad (4)$$

where, $R_{conv,1}$ is the convection resistance from the generator body to the inside wall of the canopy. $R_{wall,1}$ is the thermal resistance of the noise suppressent material, $R_{wall,2}$ is the thermal resistance of the body of the canopy, $R_{conv,2}$ is the natural convection resistance to the atmosphere. From the material properties and geometrical shapes, all these resistances can be well estimated. However, the contribution of this mode of heat transfer is much lower and is not sufficient of keep the generator cylinder head temperature within safe and stable operation. To improve heat transfer, the help of forced convection through a suitable sized fan is felt necessary. Therefore the other component of $\dot{Q}_{out}$ is the forced convection through the duct with fan which can be estimated by solving equation 1 and using equations 2, 3, and 4. Thus, the fan must be of suitable size as not to open up the channel for noise to go out but of sufficient size to convect the accumulated heat out as Q_{out} in equation 1. This design objective can be achieved by carefully installing louvers and silencing baffels in the convection path of the fan which supresses the noise but allows effective cooling. The total heat load that the fan must transfer out through forced convection, Q_{fan}, is calculated to be 1135 W for the 4.5 KVA generator used in this study. Now to transfer this energy either a powerful fan with small opening can be employed but which may generate its own noise and also may not be available commercially. Thus, using market survey for the available fans with least noise and fulfilling the thermal energy transfer requirements of 1135 W, the fan with radius 0.0635 m is selected and from its given rpm, the velocity of the fan is calculated to be 3.91 m/s. To verify the suitability of fan for ΔT of 35 ^oC above ambient, the heat convected out by the fan is about 1152 W which is just sufficient for our design requirements. The margin of about 17 W in excess of required heat transfer is justified, especially because the thermal design for this study is highly linearized for the estimates of fan heat load calculations. However, the practical test on generator cylinder head temperature, as given in figure 7, verified the estimated heat transfer calculations.

Results and discussion

After installation of generator inside the canopy, sound mapping is again done at the same space as per defined methodology in the earlier part of paper. The sound mapping results, as shown in figure 5, reveals a significant sound reduction after installation of the generator inside the designed canopy.

		SOUND LEVEL (dB)							
WIDTH (ft)	50	61.3	63.8	64.3	63.8	63.4	63.1	63.2	62.2
	42.857	63.9	64.8	67.1	69.1	66.2	65.8	65.5	62.7
	35.714	64.9	65.9	67.6	72.7	69.7	68.1	67.5	63.3
	28.428	64.7	66.8	71.1	72.6	76.2	71.7	69.6	66.5
	21.428	64.6	67.6	76.3	68.4	74.3	72.7	69.2	66.8
	14.285	63.4	66.2	67.1	65.7	68.3	69.2	67.6	65.9
	7.1428	62.1	64.6	65.4	64.7	64.3	65.4	64.7	64.5
	0	60.4	62.1	63.2	62.8	62.5	62.4	62.4	62.1
		0	7.142	14.285	21.428	28.571	35.714	42.857	50
		LENGTH (ft)							

Figure 5. Sound level measurements of Generator inside the designed canopy in open environment.

A qualitative comparsion of sound levels of the Generator with and without canopy can be visually appreciated by plotting their sound maps together, as shown in figure 6. The significant reduction in the noise levels, before (upper plot) and after the canopy (lower plot), in figure 6, are clearly visible.

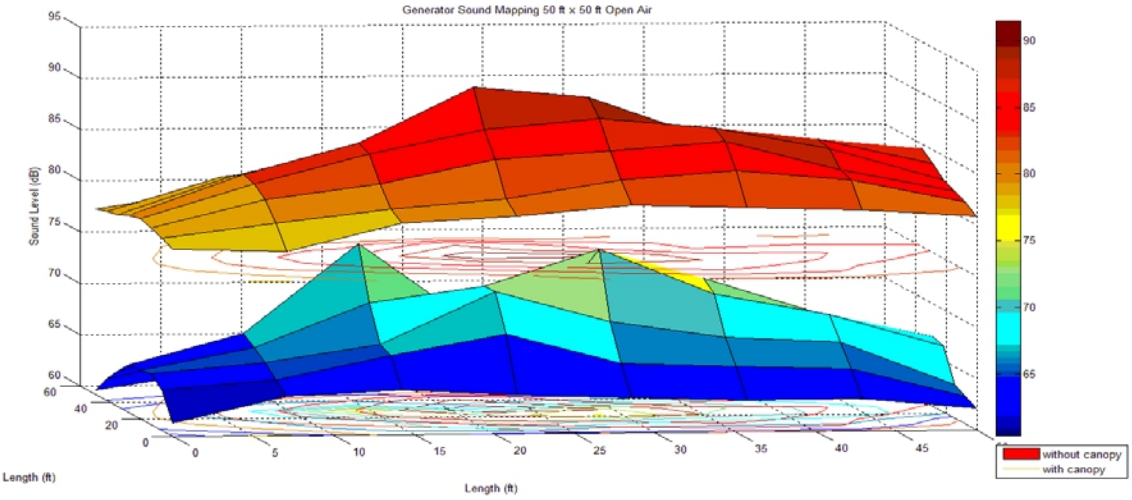

Figure 6. Noise distribution plots for the Generator with canopy (lower) and without canopy (upper)

A quantitative comparsion of the sound mapping results can be done in various ways, however, suffice is to show that the maximum and minimum noise levels are both significantly reduced after the installation of Generator inside the canopy. Table 2 shows that about 15 dB reduction in the maximum noise level and more than 17 dB reduction in the minimum noise level has been achieved with the use of designed canopy for the operation of the domestic generator.

Table 2. Comparison of Sound Level for Open Environment (dB)

Sound Level	Without Canopy (dB)	With Canopy (dB)	Reduction (dB)
Maximum	91.5	76.3	15.2
Minimum	77.9	60.4	17.5

The reduction in noise (of about 15 dB) acheived in this project is very significant if the absolute values of noise are compared with the acceptable noise levels dipicted in figure 1. It is realized that the domestic generator noise category has been reduced due to the designed canopy from 'Very Loud' to 'Moderately Loud'. This reduction in noise category thus gains importance in localities where legal noise limits may not allow operation of domestic generators with 'Very Loud' categories and only allow for lower noise category generators.

To ensure that the temperature of the Generator inside the canopy does not go beyond safe limits, figure 7 shows that the steady state cylinder head temperature which is achieved at maximum temperature of 220 ^{o}C. Expectedly, this temperature is little more than the generator head temperature without the canopy. Thus, the comparison of the two temperature histories of cylinder head indicates the suitability of heat transfer model for fan selection and effective heat transfer.

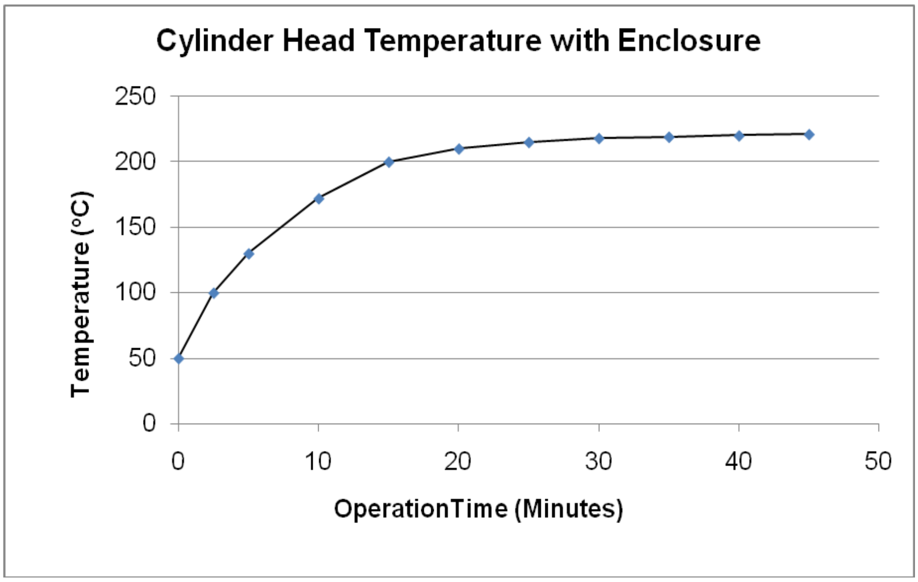

Figure 7. Cylinder Head Temperature history when generator is inside the Canopy

Conclusion

In this study, an effective noise control methodology has been applied in the design of sound proof canopy for the use of domestic Generators. Heat transfer calculations play equally important role in this design where enhanced cooling requirement in the enclosed spaces for the generator is inversely proportional to the noise control methodologies. Therefore, an appropriate balance between the two opposing requirements is an essential step in such designs. The successful implementation of the design in this study has demonstrated the effectiveness of sound proof canopy for the domestic Generator by lowering its noise category from 'Very Loud' to 'Moderately Loud'.

References:

Reed, R., *Electric generator unit*, 1939, Google Patents.

Tanaka, Y., et al., *Portable engine-operated electric generator*, 1989, Google Patents.

Ikeda, S. and D. Von Winterfeldt, *Standards against noise pollution: the case of Shinkansen trains in Japan.* J. Environ. Manage.;(United States), 1982. **14**(1).

Nijland, H. and G. Van Wee, *Traffic noise in Europe: a comparison of calculation methods, noise indices and noise standards for road and railroad traffic in Europe.* Transport reviews, 2005. **25**(5): p. 591-612.

Sagar, T.V. and G.N. Rao, *Noise pollution levels in Visakhapatnam city (India).* Journal of Environmental Science and Engineering, 2006. **48**(2): p. 139.
McNamara, D.E. and R.P. Buland, *Ambient noise levels in the continental United States.* Bulletin of the Seismological Society of America, 2004. **94**(4): p. 1517-1527.
Hansen, C.H. and D.A. Bies, *Engineering Noise Control*, 1995, Spon.
Tandon, N., et al., *Noise control of engine driven portable generator set.* Applied Acoustics, 1998. **55**(4): p. 307-328.
Tandon, N. and B. Nakra, *Noise control of portable generator set.* Noise & Vibration Worldwide, 1999. **30**(11): p. 15-24.
Siong, O.G.Y., *Reduction of noise transmission in The Adephi, Singapore*, 2004, University of Southern Queensland.
Ji, H., et al., *An improved system of active noise isolation using a self-sensing actuator and neural network.* Journal of Vibration and Control, 2009. **15**(12): p. 1853-1873.
Ellison, A. and C. Moore. *Acoustic noise and vibration of rotating electric machines*. in *Proceedings of the Institution of Electrical Engineers*. 1968. IET.
Vary, P., *Noise suppression by spectral magnitude estimation—mechanism and theoretical limits—.* Signal Processing, 1985. **8**(4): p. 387-400.
Zweighaft, J., M.H. Moyer, and C. Koerner, *Digital acoustic noise reduction in electric motors driven by switching power amplifiers*, 1998, Google Patents.
Incropera, F.P. and D.P. Dewitt, *Fundamentals of Heat and Mass Transfer*.