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Experimental Investigation of the Passive Way Performance on Portable Home Generator Noise

Dalal Kareem Attwan*, Abbas J. Jubear, Hussain R. Al-Bugharbee

Mechanical Engineering Department, College of Engineering, Wasit University, Wasit, Iraq

*Email: dalakareem301@uowasit.edu.iq

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Abstract

The study aims to assess how a locally constructed enclosure affects a portable generator's noise generation and heat buildup, to address the risks posed by generator noise. This study compares working conditions with respect to sound level and engine temperature across three enclosure models and non-closure cases. The first model uses an air cavity between the plywood panels; the second model uses reeds as the insertion material; and the third model uses shredded plastics as the insertion material. The sound intensity (dB) at 3 and 5 m is obtained. In addition, the generator engine temperatures are also recorded. These recordings were obtained for generator loads of 0%, 25%, 50%, 75%, and 100%, both during the day and at night. The results show that the third model (i.e., the shredded-plastics model) achieves the most significant noise reduction. In contrast, the first model (i.e., the best in thermal performance) achieves the best thermal performance.

Keywords: Generator Canopy, Generator Noise, Noise Suppression Enclosure, Portable Generator, Sound Suppression, Soundproof Enclosure.

1. Introduction

Local and international populations are exposed to noise pollution daily, particularly in summer, due to the widespread use of portable generators. Undoubtedly, this affects the people near these generators and causes many injuries, for instance, stress, nuisance, lack of sleep, and hearing problems. Many researchers have long sought to address this problem using various methods [1]. Askhedkar et al. [2] studied the enclosure as a rectangular structure made of mild steel, with an absorbing material layer applied inside. Then, using MATLAB, a Field Data Multivariate (FDBM) regression model and an Artificial Neural Network (ANN model were used to estimate noise levels outside the acoustic enclosure. This model forecasts the noise of a canopy-equipped diesel generator set as a function of several independent characteristics, including enclosure thickness, engine load, and system foam thickness density. Yadav et al. [3] investigated a rectangular sheet metal enclosure with a volume of 18.7 m^3 consisting of two doors, one of which is made from glass, and the inner walls are lined with rock wool. A vibroacoustic study of an enclosure for a larger diesel generator set is conducted using a statistical energy analysis (SEA) approach, supplemented by experimental data. They found that the amount of noise reduction was 3 dB. Mushiri et al. [4] constructed a box from plywood, polyurethane foam, ground glass, and composite sawdust, with dimensions of 735×495×605 mm. A heat exchanger was used to manage heat within the canopy. This heat exchanger was considered a challenging and costly component in the study. Their experimental work mentioned that AutoCAD and SolidWorks are among the software used. The enclosure's design also removes the accumulated heat via a heat exchanger and a fan. In the study of Arslan et al. [5], the dimensions of the enclosure were (4.5×1.75×2) m, and the materials were arranged as steel plates, steel stiffeners, Rockwool supported with steel sheets, glass windows, and the computer-aided Design (CAD) view of the enclosure structure. The reduction was 7 dB. Only non-resonant sound radiation from the walls is considered. At the same time, enclosure details are simplified, and the thickness of the wall panels is adjusted to improve the FE model. ANSYS analyzed this method. whereas Amos et al. [6] made the enclosure from mild steel sheets, mineral wool, and padded with plywood with dimensions (900×780×720) mm. The study investigated the noise attenuation of a 2.5 KVA generator at different distances ranging from 0.6 to 4.2 meters. The comparison showed that a reduction of 9.5 dB can be achieved at a distance of 0.6 m and 15.5 dB at a distance of 4.2m. In this study, the maximum number of fans was two, one for drawing cool air and another for exhausting hot air. These fans were silent centrifugal fans, whose flow rate depended on the generator power, and the palaces were used to mount the fans on the sides, upper side, and lower side of the enclosure. To dissipate exhaust gas into the atmosphere, a flexible pipe connects the generator exhaust pipe, thereby reducing or eliminating exhaust heat. In the early stages of optimization, Premaratne et al. [7] employed a constrained genetic algorithm. This algorithm modifies a population of individual solutions regularly. Unlike genetic algorithms, particle swarm optimization (PSO) converges to the global optimum. As a result, PSO was used for additional analysis. The sound-absorbing capacity of an enclosure made of galvanized sheet, polyurethane foam, plywood, and particle board was studied by Okoli et al. [8]. The noise source was 2 kW, 220 V portable generator. The results showed that the emitted generator noise decreased from 86.23 dB to 69.34 dB under no-load conditions, while the loading level decreased to 23.2 dB. The study conducted by Adeboye et al. [9] reports the design of soundproof enclosures for portable generators used in many homes in developing economies such as Nigeria. The design employed passive absorption. The enclosure was made from plywood, acoustic foam, and rubber dampers, and the interior of the shell was padded with acoustic foam. The case was made of 15mm-thick plywood, with dimensions of 535 × 520 × 520 mm. An air-gap layer approximately 150 mm thick has been introduced between the casing walls and the generator. The results of the evaluation of the acoustic envelope performance showed that the sound pressure level decreased from 65.2 to 58.6 (6.6 dB), from 63.1 to 56.1 (7 dB), from 59.7 to 53.7 (6 dB), from 58.2 to 53.3 (4.9 dB), and from 58.1 to 52.9 (5.2 dB), respectively, at 0.5 m, 1, 0m, 2.0m, 3.0 m, and 4.0m from the generator. Al-Bogharbee et al. [10] used an enclosure with dimensions of 100×83×62 cm, manufactured from plywood, foam, sponge, and galvanized iron sheet. This enclosure achieved a 50% reduction in noise. In this study, thermal performance was evaluated with and without the enclosure. However, over time, the temperature difference between the two generator conditions approaches 99%. The methodology is analysed using MATLAB with the Fast Fourier Transform (FFT). Although all previous researchers have focused on the rectangular and box-shaped enclosures, Agbo [11] examined the vertical duct at different heights, starting with 400mm, 800mm, 1200mm, 1600mm, 2000mm, and 2400mm. The bottom box was lined with polyurethane and covered with rubber, and the outer surface was made of composite laminate. The height was 400 mm, and the other dimensions were 600×600 mm. These characteristics of the box were applied to other boxes assembled to achieve different heights. This study addressed heat transfer without employing heat models or equations, and the heat within the enclosure was treated experimentally in various ways.

A 2 KW generator is used in the experiment of Kareem et al. [1], and the sound intensity for the two cases—one with an enclosure and one without—is compared. Plywood, galvanized sheet, glass wool, cork, and compressed sponge make up the chamber. The sound intensity was measured at two different distances, at zero to full load, throughout the day. The results demonstrated reductions of 10.3 dB at night and 9.6 dB during the day. Furthermore, when the enclosure is used, the engine temperature remains within the permissible 300 °C range for air-cooled generators. As a result, the enclosure's maximum temperature at 100% load was recorded as 91.75 °C during the day and 77.86 °C at night.

In the present study, an experimental investigation of the acoustic and thermal performance, in terms of the reduction of generator noise transmission and the accumulation of generator heat, was conducted, and the results are presented. The parameters considered in the current study are the distance between the microphones and the reg, variable applied loads (0%, 25%, 50%, 75%, 100%) used, the type of the enclosure's materials also changed, and two different periods (time of operating, i.e., morning and night) were investigated.

2. Experimental Test Reg

The experimental test reg (the enclosure) was constructed from various materials with varying dimensions, all chosen to be low-cost, readily available, and recyclable. The materials were selected based on their noise reduction coefficient (NRC), which quantifies the amount of sound reduction. A soundproof product can absorb, on average, as represented in "Table 1". The canopy's materials were arranged from inside to outside as two sides with dimensions (100×94) cm and the other two sides with dimensions (100×84) cm and thicknesses as follows (galvanized iron 2mm, glass wool 10mm, cork 25mm, an air gap 30mm, compressed sponge 30mm, and MDF 16mm) for the first model as illustrated in "Fig. 1". In the second model, the air gap was filled with reeds, as shown in "Fig. 2"; in the third model, the air gap was filled with shredded plastic, as shown in "Fig. 3".

The ups and downs sides are made of three layers (MDF 16 mm, cork 25 mm, and MDF 16 mm), as shown in "Fig. 4". Then, two fans were placed on each side (C and D). The discharge value of 110 m^3/h was determined using the relationships presented in [11]. Fig. 5 shows the final shape of the enclosure with the front view of the layers of the first model.

3. Methodology

In the experimental tests, the following methodology was followed:

- Non-enclosure case

  In this state, the generator was without enclosure, and the measurements of heat and sound were taken as follows:

- The heat measurements: Eight thermocouples of type (K) and a data acquisition (DAQ) device. Four thermocouples were placed 5cm from the generator on the four sides (A, B, C, and D). There are two thermocouples for the cylinder head and combustion chamber, and one thermocouple fixed at the end of the exhaust tube. The last environmental condition was set at 50 cm from the generator, in the direction of side A. The thermocouples were wired to the data logger, which sent a signal to the computer via the USB wire, and the computer read the temperature for each thermocouple using software (PICO log).

Table 1. NRC of the chosen materials.

Materials	Noise reduction coefficient
Galvanized iron	1
Mineral wool	0.78
cork	0.7
Compressed sponge	0.47
Medium-density fiber	0.7

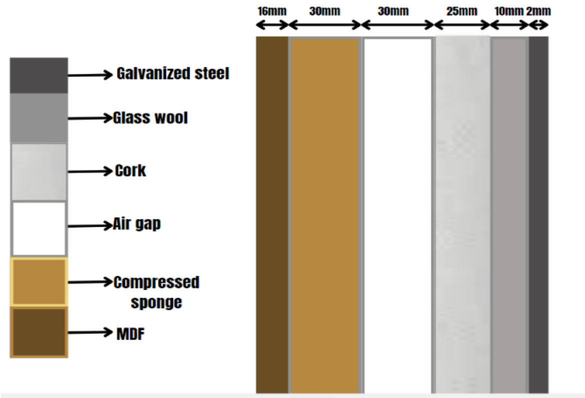


Figure 1. The first model of the enclosure.

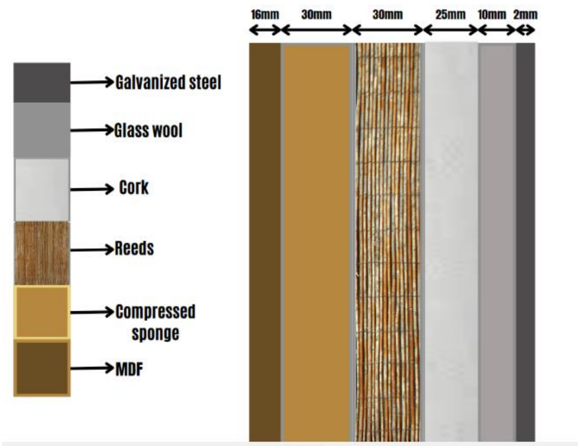


Figure 2. The second model of the enclosure.

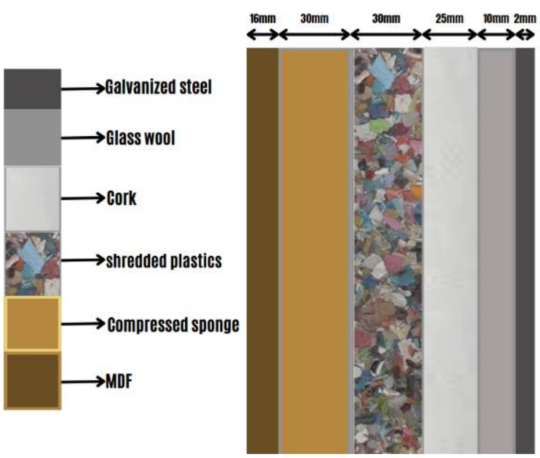


Figure 3. The third model of the enclosure.

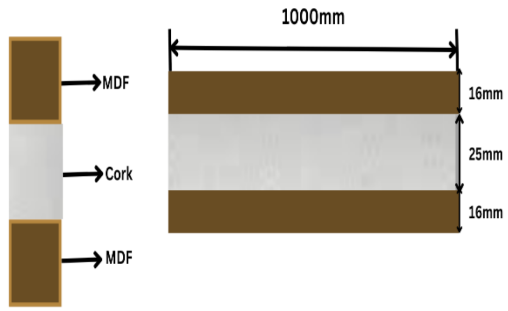
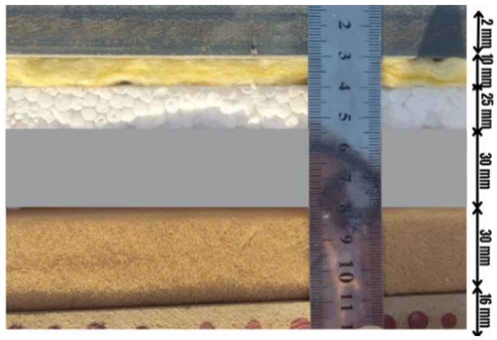
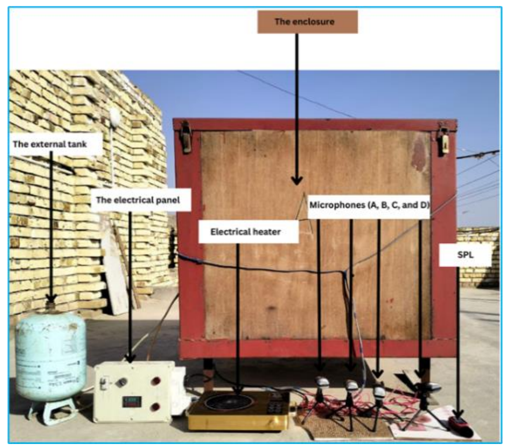


Figure 4. The advantages and disadvantages of the enclosure.



(A)



(B)

Figure 5. (A) The real layer's view of the first model (B). The final shape of the enclosure.

- The sound level and intensity: To measure the sound level, a sound level meter (UT 353) was used. This device was placed at distances of 3m and 5m on the four sides, and measurements were taken 20 minutes after generator start-up. Each measure requires 10 minutes per load. The generator's sound signals were recorded using four SF 920 rounded condensation microphones (A, B, C, and D) located at distances of 3 m and 5m. Each measure required 10 minutes per load.
- The electrical load: The load was controlled by an electrical load panel and heater, as shown in "Fig. 6". The load applied on the generator in the form (0%, 25%, 50%, 75%, 100%). The rated load of the generator used was 2 kW.

(A)

(B)

Figure 6. (A) The electrical panel (B) and the heater.

- ➢ The first model

  In this model, the air gap was empty, and all the following steps were done to take the measurements:

- The heat measurements: There were eight thermocouples of type K and a data acquisition (DAQ) device, as mentioned before.
- The sound level and intensity: To measure the sound level of the generator when it was put inside the enclosure, a sound level meter (UT 353) was used.

- ➢ The second model

  The air gap in this model was filled with reeds, and its measurements are similar to those of the first model.

- ➢ The third model

  In this model, the air gap was filled with shredded plastic. The measurements for the first and second models.

"Fig. 7" presents the schematic diagram of the test reg. It depicts the configuration of the devices used to measure sound and heat.

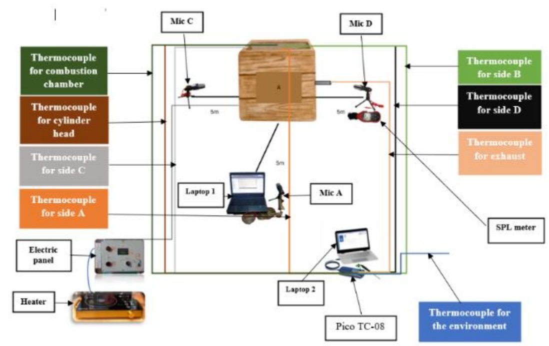


Figure 7. Schematic diagram of the experimental work tests.

4. Results and Discussion

The results are divided into two categories: sound and thermal performance.

4.1 The Sound Results.

In this study, to compare the performance of the non-enclosure and the first model, the sound signal intensity is taken at the following specifications:

- Load 0%
- 5m distance
- Daytime

The X-axis represents the number of data points, and the Y-axis represents the microphone output (amplitude). In this work, the sampling rate was 4.8 MHz. The blue plot shows the sound signal for the non-enclosure case, whereas the red plot shows the sound signal for the first model. From "Fig. 8," the sound intensity of the non-enclosure case is greater than the empty gap model because the enclosure walls isolate the sound and fragment the sound wave [1], [9]. The principle behind how acoustical enclosures work is that sound energy is trapped by large impermeable layers that catch noise from the source of the sound and release it via the sound-absorbing lining. The experimental results showed that the sound intensity in the third model was lower than in the first, second, and non-enclosure cases. An obstruction in the audio signal path from the generator to the recording pickup (the enclosure) causes the amplitude to drop.

To shed more light on how employing the enclosure can lessen noise from the generator. The sound levels were recorded and contrasted for all models. For both the generator operating in an open environment (no enclosure) and the soundproof device in the three models, the sound pressure level decreases with increasing distance from the generator. When the generator runs in an open environment, the sound level pressure of the generator ranges between (81.45 and 74.8) dB at night and (77.85 and 73.6) dB during the day, while the measured distances range between (5m and 3m).

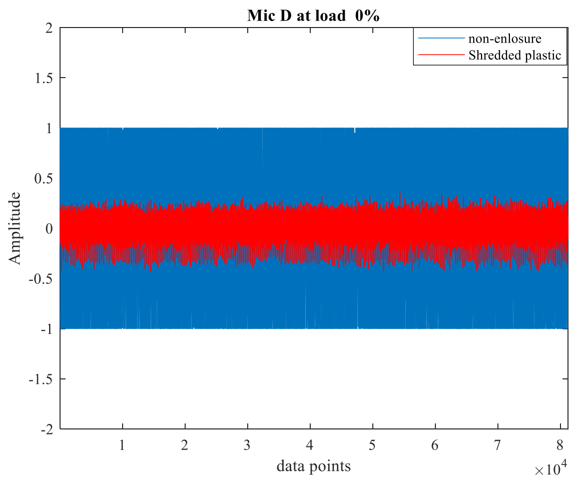


Figure 8. The sound intensity comparisons for the non-enclosure case and the first model at 5 m.

Continuous exposure to this type of noise at this sound pressure level, without a corresponding period of recovery, will almost certainly result in one of the noise's health effects. This level of noise is regulated under Iraqi Law No. 41 on noise control [12].

“Fig. 9” and “Fig. 10” compare the reduction percentages of the three models at night and day at a distance of 3 m. Y-axes represent the noise reduction percentage (%), while X-axes represent the generator load (%). The third model is better than the other models. This is because the plastic substance has sound-absorbing qualities that lessen sound waves' ability to travel through it. When there is an air gap within an enclosure, sound waves can travel through it, reducing the enclosure's ability to block sound or prevent sound leakage. Shredded plastic fills the space between, absorbing or dampening sound waves to effectively reduce sound transmission and enhance the enclosure's overall acoustic performance. The behavior suggests that increasing the panel mass could improve soundproofing efficiency. However, multilayer panels can be used with a combination of materials to enhance soundproofing by increasing wall mass [13][14], as can be seen in “Fig. 11” and “Fig. 12” [9].

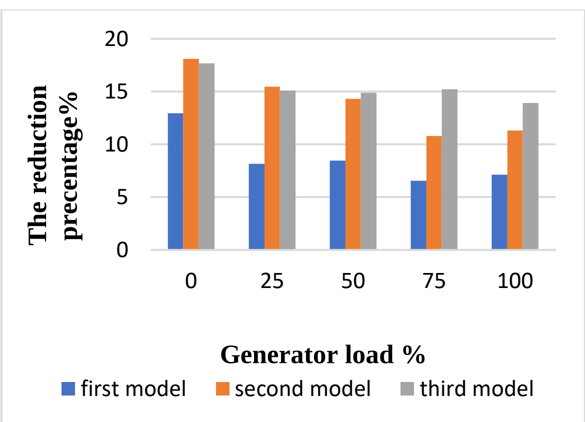


Figure 9. Comparison between the reduction percentage of the three models at nighttime and 3m distance.

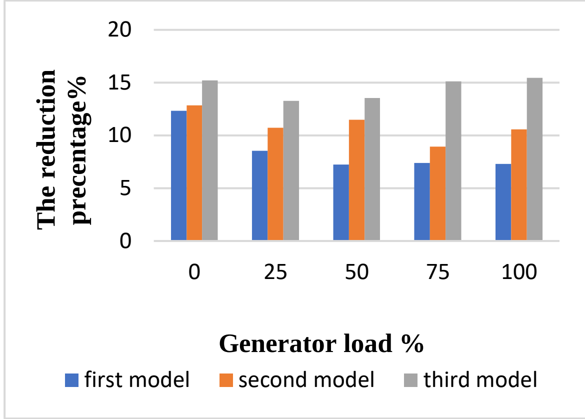


Figure 10. Comparison between the reduction percentage of the three models at daytime and 3m distance.

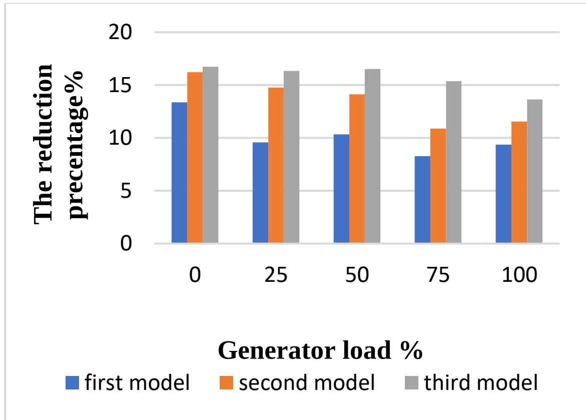


Figure 11. Comparison between the reduction percentage of the three models at nighttime and 5m distance.

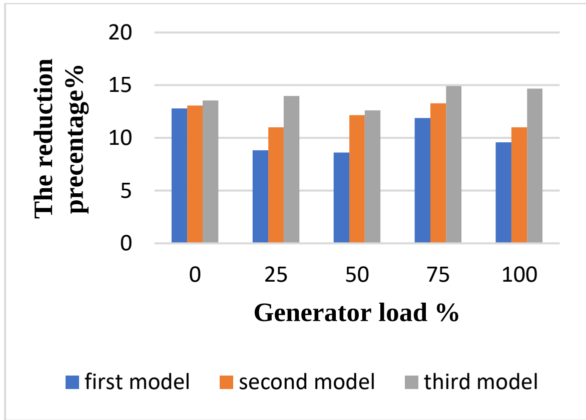


Figure 12. Comparison between the reduction percentage of the three models at daytime and 5m distance.

4.2 Thermal Performance

Cylinder head temperature was the primary consideration when the enclosure was constructed and attached to the generator to prevent failure of generator components. “Fig. 13” depicts the thermal performance of the generator with and without enclosure during the daytime. The X-axis represented the time in minutes, and the cylinder head temperature was represented by the Y-axis (Th). “Fig. 13” shows that the temperature of the cylinder head in the first model is greater than the temperature of the cylinder head in the non-enclosure case. The generator was installed in the enclosure, thereby increasing the combustion temperature. In the first model, the heat-transfer level between the rounded air and the cylinder head is lower because the heat-transfer area is smaller than in the non-enclosure case [4]. In each case, the temperature didn't exceed the allowable cylinder head temperature of an air-cooled engine (300˚C) [15]. The steady-state cylinder head temperature of the first model was 114 °C after 40 minutes of generator startup.

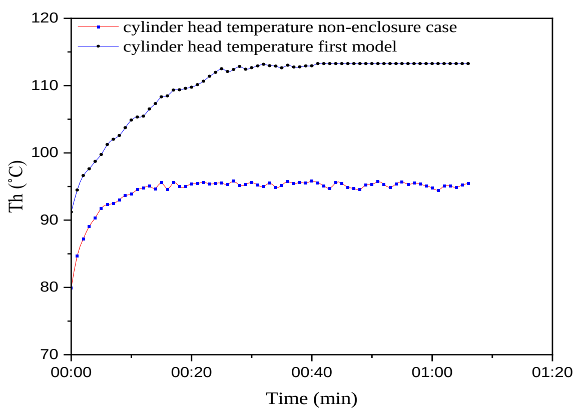


Figure 13. The thermal performance comparison between the non-enclosure case and the first model in daytime for zero load.

To compare the three models with the non-enclosure case, "Fig. 14" represents the cylinder head temperature at daytime. The X-axis shows the generator applied load (%), whereas the Y-axis shows the cylinder head temperature (°C). The results indicate that the cylinder head temperature of the third model is higher than that of the other three cases. Because the heat transfer process in this case is more pronounced, the results for Th and Ts are higher. In addition, the accumulation of heat inside the enclosure increased during the work process at each load and exhibited the same behavior at nighttime, as shown in "Fig. 15". According to cylinder head temperature measurements, the daylight cylinder head temperature is always higher than the nighttime temperature. This finding suggests a relationship between time of day and cylinder head temperature, which is expected given that daytime air temperature is higher than nighttime air temperature, daytime cooling is lower, and applied loads increase with load. Several criteria, including ambient temperature, heat dissipation, engine operation, and other external factors, will determine the specific factors influencing the temperature change between day and night. Air movement is restricted when a generator is placed in an enclosure that confines the surrounding air, thereby limiting natural convection and impeding heat transfer.

The geometry and characteristics of the enclosure control depend on how the Nusselt number is impacted. The Nusselt number, which reflects convective heat transfer between a solid surface and a fluid, is influenced by factors such as flow characteristics, surface roughness, and enclosure design [16][17]. The Nusselt number behavior of each model is shown in "Fig. 16" for daytime and "Fig. 17" for nighttime. The values of Nusselt were found by using the following relationships:

$$Nu = \frac{hl}{K} \tag{1}$$

$$h = \frac{q}{A\Delta T} \tag{2}$$

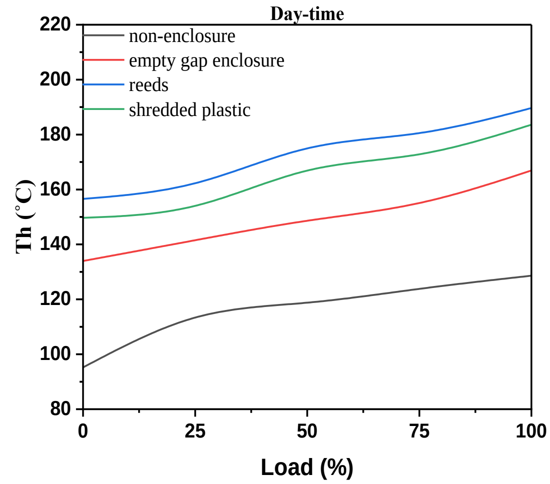


Figure 14. Cylinder head temperature for the four models during the day.

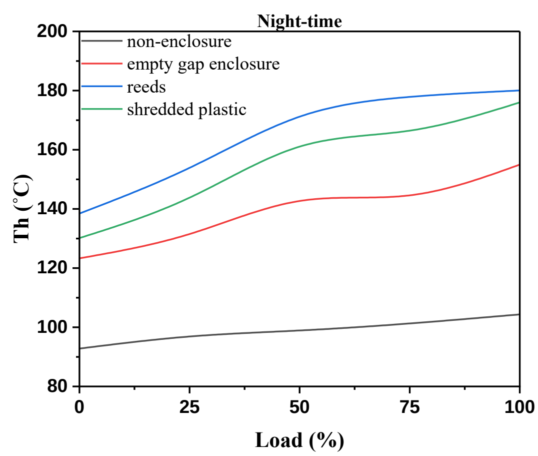


Figure 15. Cylinder head temperatures for the four models at night.

Where $\frac{q}{A}$=1022.12$\frac{W}{m^2}$This value for the chosen generator was calculated.

$$\Delta T = T_h - T_s \tag{3}$$

Where, T_h is the cylinder head temperature, and T_s is the surrounding temperature around the generator inside the enclosure.

From "Fig. 16" and "Fig. 17," it is apparent that as the load increases during the day and at night, the Nusselt number typically decreases, along with the heat-transfer coefficient. The Nusselt number decreases as the load increases and the temperature difference between the heat source and the surrounding medium increases. The temperature difference, which increases with load, directly affects the Nusselt number. This phenomenon is frequently observed in heat-transfer research [18]. The highest Nusselt number of all cases recorded when the generator was outside of its container with value 311.298 at load 0%, while at the same load for the other cases recorded (205.33, 219.22, and 309.39) for (the gap filled with reeds, the gap filled with shredded plastic, and empty gap enclosure) respectively at daytime, and the same for nighttime 302.21 for the case without enclosure, and other cases (260.04, 199.09, and 231.7. There are a few circumstances that, in contrast to other cases, lead to larger Nusselt numbers when a generator is positioned outside an enclosure at night, for instance, greater exposure across a larger surface area: When the generator is outside the enclosure, it is usually exposed to outside air from all sides [19][20].

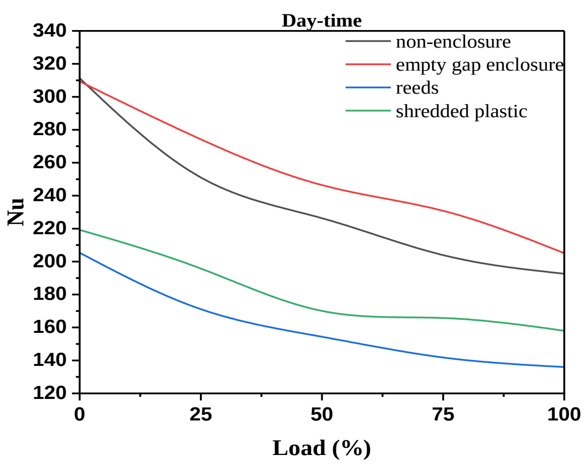


Figure 16. Nusselt number comparison of the four models during the day.

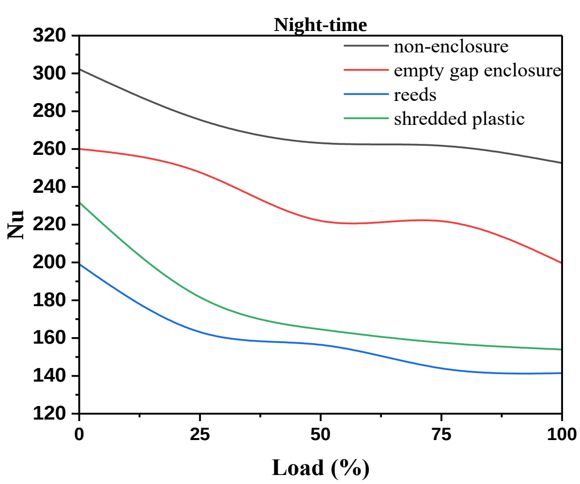


Figure 17. Nusselt number comparison of the four models at nighttime.

Natural convection:

By positioning the generator outside the cage, heat can be transported by natural convection, in which air moves due to density differences and carries the heat.

Reduction in boundary layer thickness:

The proximity of the generating surface to any neighboring surfaces, such as enclosure walls, is reduced when the generator is located outside the enclosure.

4. Conclusions

An effective noise-control methodology was employed to design a soundproof canopy for portable generators in this study. Heat transfer calculations are also necessary in this design because the generator's enhanced cooling requirements in enclosed spaces are inversely proportional to noise-control methodologies. The allowable cylinder head temperature is 300˚C. When the generator inside the canopy had not exceeded that degree or approached it. The third model recorded the maximum cylinder head temperature of (183.61) ˚C during the day and (176) ˚C during the night. As a result, striking an appropriate balance between the two opposing requirements is a critical step in such designs. The successful implementation of the design in this study demonstrated the effectiveness of a soundproof canopy for the portable generator, reducing its noise level from 90 dB to the allowable limit under Iraqi law (41 of 2015). The enclosure filled with shredded plastic at 5 m met the permissible limit under Iraqi Law, with a daytime limit of 58.9 dB at 75% load. It approached the allowable limit overnight under a 50% load, reaching 56.1 dB.

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Abbreviations

h	The convective heat transfer coefficient (W/(m^2
K	Thermal conductivity of the luid $(W/_{mK})$
l	The characteristic length of (0.44 m)
Nu	Nusselt number
q/A	The amount of heat transfer ($W/_{m^2}$)
Δ..T	The temperature difference (˚C)
Th	The temperature of the cylinder head. (˚C)
Ts	The surrounding temperature (inside the enclosure)

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Dalal Kareem Attwan performed the computations and investigations, discussed the results, and contributed to the final manuscript.

Abbas J. Jubear and Hussain R. Al-Bugharbee proposed the research problem, verified the analytical methods, and supervised the findings of this work.

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