Simple Noise Control Solutions for Building Systems - Three Case Studies

Ramani Ramakrishnan
Aiolos Engineering Corporation
51 Constellation Court, Suite 200, Toronto, Ontario, M9W 1K4, Canada

ABSTRACT

Conventional methods of controlling noise generated by building HVAC (Heating, Ventilation and Air-Conditioning) systems depend on using silencers, lagging, barriers and or room treatments. Cost benefits of these approaches as well as physical feasibility of applying these methods, for retrofit situations in particular, prohibit any meaningful applications. Three severe noise situations demanded serious rethinking of applying conventional methods and demanded innovative approaches. The investigation of the noise concerns as well as the methods applied to attenuate and/or eliminate the noise problems are presented in this paper.

SOMMAIRE

Les méthodes conventionnelles de contrôle du bruit généré par les systèmes HVAC (chauffage, ventilation et climatisation) dépendent de l'utilisation de silencieux, de revêtements, de barrières et/ou du traitement de l'habitacle. Les avantages financiers de ces approches, ainsi que la faisabilité pratique de ces méthodes dans des situations de modification en particulier, ne permet pas au recours à des modifications signica-tives. Trois situations sévères de bruit ont exigés une révision sérieuse de l'application coventionnelle de ces méthodes et ont requis des approches innovatrices. La recherche des sources de bruit ainsi que les mé-thodes appliquées pour atténuer et/ou éliminer les problèmes de bruit sont discutés dans cet article.

1. Introduction

Two processes are usually applied to control noise propagation from building systems used for commercial applications such as office towers and strip plaza developments. The first process involves evaluating the noise levels of the building systems and designing control methods at the planning stages of the development. This is usually instituted to satisfy municipal by-law requirements and sometimes if the owner decides to build a quality development. The above process is the preferred method for it provides a wider latitude for noise control engineers and acoustic consultants in designing an acceptable noise environment within a preset budget. Simple solutions normally found in elementary acoustic textbooks [1,2] and seminar literature and trade journals [3, 4] can then be easily instituted in the design. These solutions could be silencers, acoustic barriers, enclosures and duct lagging materials.

The second process comes into effect as a result of complaints from neighbours and/or tenants. The owner of the building complex is forced to retain a noise control engineer to design suitable remedial measures. In such retrofit conditions, simple solutions are usually impractical due to lack of space and/or cost. The noise control engineer is then forced to think of innovative methods to provide satisfactory solutions. Fundamental principles and practices of noise control play a major role in the design process [5].

Three such instances were investigated. In cach of these cases the noise problems were severe and the complaints were also serious. They merited serious attention by a noise control engineer. The investigation of these three cases involved basic measurement techniques to isolate the severity of the problem. Simplistic solutions were found to be not feasible and some of the principles highlighted by Ingemansson [5] were successfully applied. Three configurations of fans were used in these cases: propeller type fans for a set of nine roof-top air-cooled condensers; centrifugal fan of a small compartment unit that served part of the floor of a high rise office complex and three axial fans that supplied an area of a high rise office complex. The results of these three case studies are presented in this paper.

2. Rooftop Air Cooled Condenser

2.1 Background

Air-cooled condensers are slowly becoming an alternate sys-

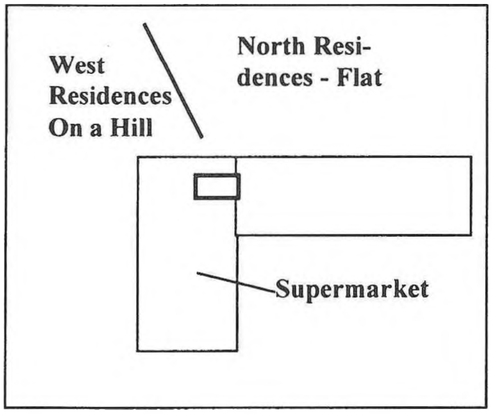

Figure 1. Details of the Strip Plaza and the Residential Developments.

tem for the rejection of hot air into the environment. In particular, they are replacing the onerous requirement for a cooling tower for applications such as grocery store or supermarket of a strip plaza complex that serves local residential subdivisions. In many instances, the downside of a bank of condensers with propeller type fans is the serious noise impact, as these units are usually placed at the edge of the roof of these super markets. The residential units are usually located adjacent to the strip plaza complex without any intervening buffer zones and the noise complaints from new subdivision developments, once the residents start occupying the houses, are one of the major consulting projects handled by the majority of noise control engineers. The severity of these noise concerns is highlighted by the following investigation.

The supermarket under study is part of a typical 'L' shaped strip plaza. The strip plaza is located in a valley and residential subdivisions are located along the west, north and east of the strip plaza. The north side development was under construction during the current investigation. The north side development is at the same elevation as the strip plaza and hence the development has minor shielding from roof top equipment. On the contrary, the west and northwest developments are elevated compared to the strip plaza. There is a direct line-of-sight from the back deck of the nearest houses and the roof top equipment of the supermarket. The layout plan of the strip plaza and the residential developments are shown in Figure 1. The bold box shown in Figure 1 represents the bank of air-cooled condensers. These condensers are screened by a 1.5 m high thin sheet metal barrier.

2.2 Noise Impact Report

A noise impact report was prepared for the north side developments as part of the Ontario planning process. One of the requirements was to establish the noise levels that could impact the proposed development and design control measures if required. The report measured the noise levels from the bank of nine (9) air-cooled condenser fans and predicted the noise levels at the second story bedroom windows of the development. The prediction methods used adjustments for distance, and shielding by the roof screen. The predicted noise levels were only 3 dB more than the noise limit of 45 dBA. Hence the report concluded that a minor modification to the screen would attenuate the noise levels and that the impact from the strip plaza would be within the guideline limits of the Provincial Ministry of the Environment. However, the report did not measure the spectrum of the noise. Hence, some of the adjustment factors as well as the effectiveness of the control measure recommendation were not accurate. The north side developments were approved on this basis and were under construction.

2.3 Current Investigation

After a few months of operation of the strip plaza, while the north side developments were under construction, the west side residences lodged severe complaints against the supermarket. The supermarket retained us to investigate the complaints, review the above noise impact report and comment on the feasibility of the control measures recommended by the noise impact report.

The noise levels from different roof top equipment were measured using a 2-channel real time analyzer fitted with a Type-1 microphone. The levels were measured near the unit, at the back deck of the nearest resident, and at the north-western edge of the roof of the supermarket.

The measurement results are shown in Figures 2, 3 and 4. The results are shown in terms of 1/3 octave band spectrum from 25 Hz to 10000 Hz. The over-all levels in dBA and dB are also shown in the figure. It must be pointed that there is a direct line of sight to the supermarket's roof from the back deck. One actually looked down on the equipment from the bedroom of these houses. The noise levels at the resident's back deck are shown in Figure 2. In contrast to the levels reported in the noise impact report, the overall level was 52 dBA with a strong tone in the 160 Hz band. If one added a tonal penalty of 5 dB as per the provincial guidelines, the amount of noise reduction required would be 12 dB and not 3 dB as suggested by the impact report.

The noise report (Section 2.2) recommended the following measures for noise control: a) to treat the screen with acoustic lining; b) increase the height of the screen slightly and/or c) treat the condensers with acoustic absorption material. It is immediately obvious that none of the above treatments would provide the required amount of noise reduction and it is even doubtful if they would provide any reduction at all.

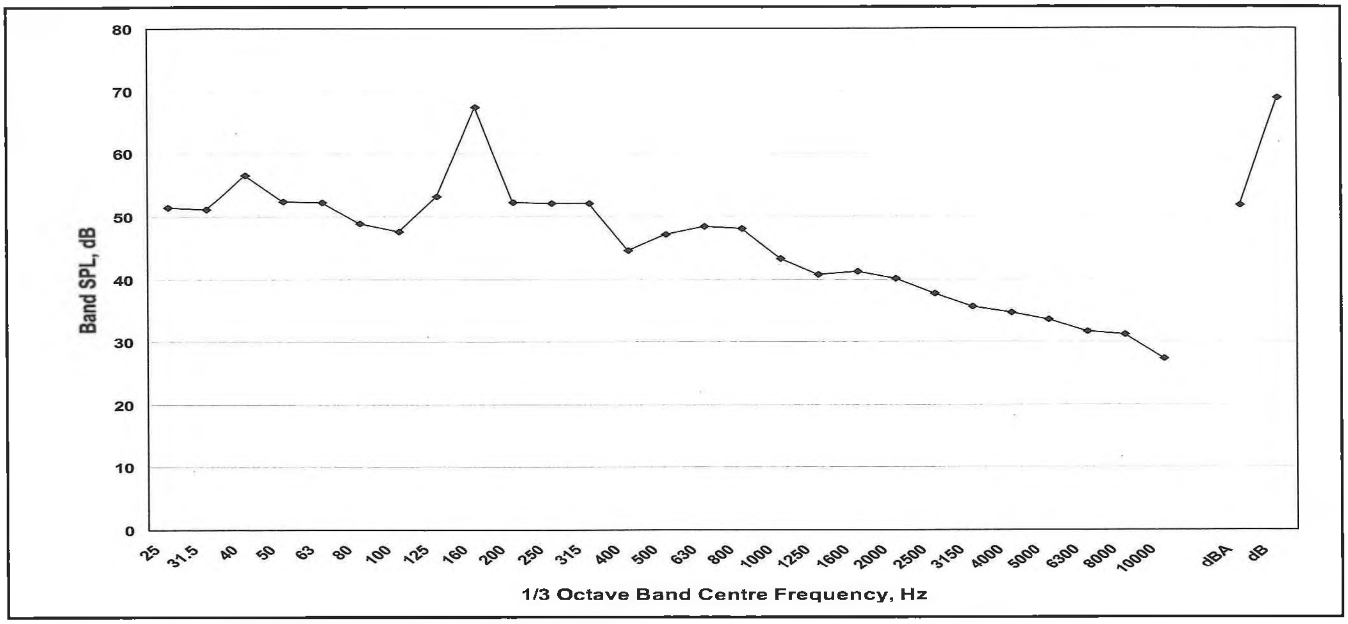

Figure 2. Noise Levels at the Backdeck of the Nearest Receptor.

Three possible conventional treatments could have been considered to attenuate the noise levels at 160 Hz and are discussed below.

Passive exhaust silencers could be installed on each of the nine fans with the insertion loss requirement of 12 dB at 160 Hz. The concept is feasible, but impractical. The length of such a silencer would be in excess of 10 feet and the building roof load may not be adequate to support the weight of the nine silencers. In addition, the warranty on the condenser would be voided if such a silencer were to be installed. Hence such a solution is not possible.

One could build a complete enclosure around the nine bank condenser units with requirement amount of opening for airflow. However, an enclosure is impractical for the same reasons outlined above.

An acoustic barrier with an insertion loss of at least 12 dB at 160 Hz could be built on two sides of the condenser unit. The barrier would be placed at a distance of about 5 feet from the units. The height and weight of the barrier would be prohibitively large since the wavelength at 160 Hz is 2.14 m. Further the height to break the line of sight between the fan and the bedroom windows of the west side residences may be in excess of 10 m.

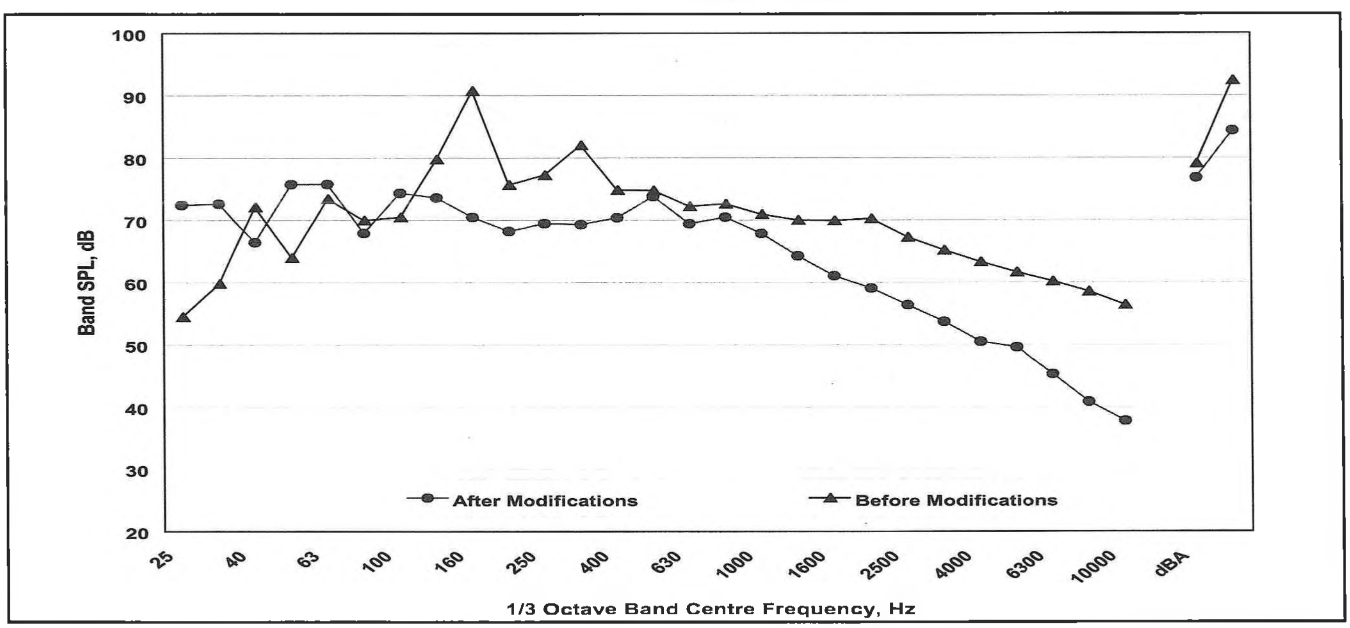

Figure 3. Noise Levels near the Air-cooled Condenser Units.

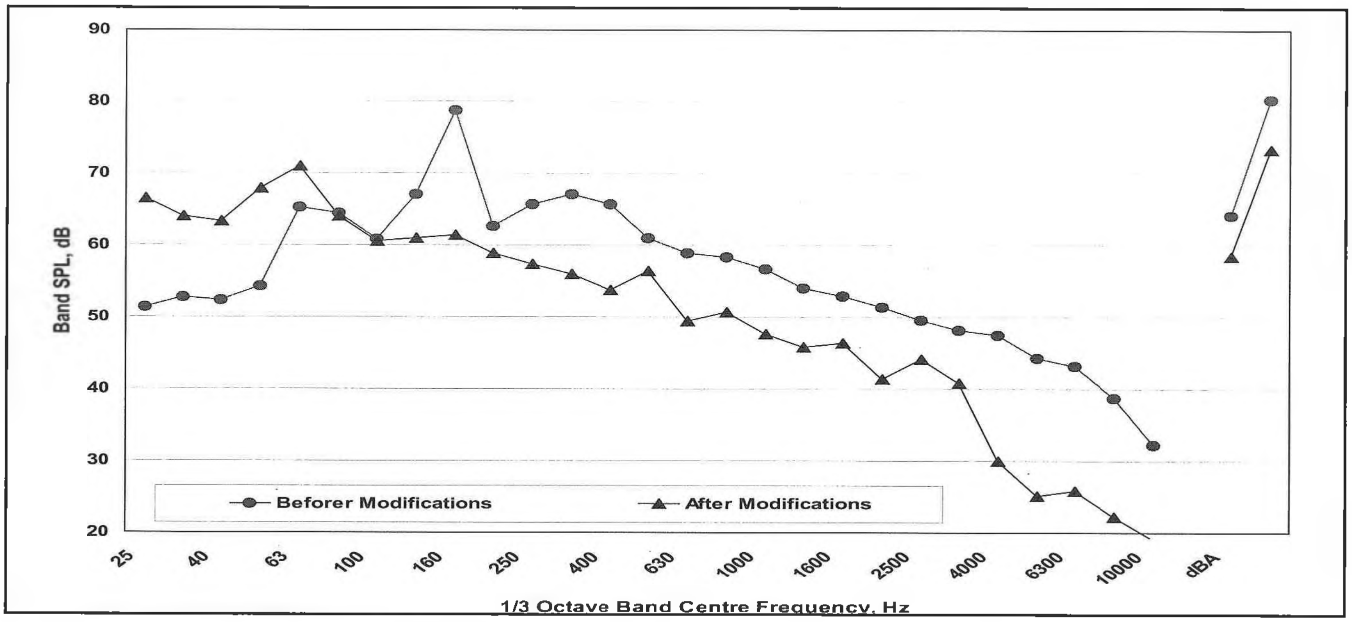

Figure 4. Noise Levels at the Northwest Edge of the Supermarket Roof.

It is seen that conventional treatments are not practical for the above application. However a closer reading of the results show that the noise level at 160 Hz near the condenser units (Figure 3) is in excess of 90 dB. This suggested that perhaps the units are not operating at the design point of these fans and a maintenance check may have to be performed first before attempting to design an attractive solution. Such a practice is unusual in typical noise control applications. However, the current noise conditions precluded an immediate application of conventional control methods. The air-cooled condenser manufacturer was contacted and was requested to balance the units. It was found on inspection that the units indeed were not operating properly. The 4-blade fans were adjusted as follows. The blade pitch was changed from 22° to 29° and the rotational speed was reduced from 1140 RPM to 840 RPM. The noise levels on the roof were remeasured after the modifications and the new noise levels were also shown in Figures 3 and 4. The improvements were dramatic. The noise level at 160 Hz reduced by 20 dB and the 160 Hz tone completely disappeared. The cost of the above fix was a maintenance visit by the manufacturer. The west side residents stopped their complaints and actually complimented the supermarket for responding to their concerns in a timely fashion.

3. Compartment Units

3.1 Background

Compartment units of air-conditioning and heating systems have become popular during the last decade for high rise office complexes. Instead of requiring large mechanical rooms and large duct passages, the compartment units are very compact and are also attractive for being amenable for easy zoning. The only downside of compartment units is the proximity of these units to occupied spaces and the resulting noise levels may be objectionable.

One such installation is a seven (7) story office complex, with two units serving each floor, where noise became a serious concern. The details of the compartment unit (plan and section of a unit) with centrifugal fan are shown in Figure 5. The compartment unit shown is a typical layout used by most of the manufacturers. A prototype of the above unit was tested in a mock-up of an office layout for compliance for noise emission. The mock-up test results showed that the design for a 10000 cfm unit would satisfy the office levels of NC-40 or less. The units when installed on site in the office complex produced severe noise levels. The investigation of the noise complaints and the resolution of the

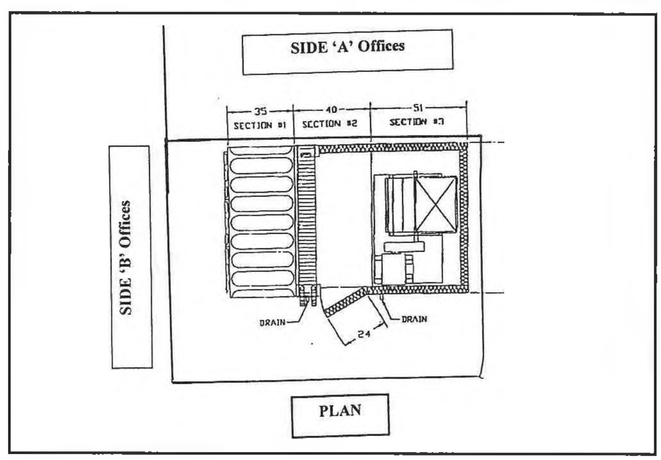

Figure 5a. Layout Plan of the Compartment Unit and Adjacent Offices.

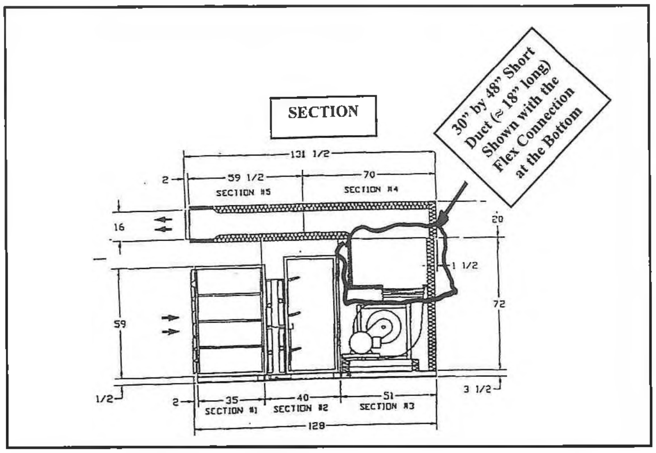

Figure 5b. Section through the Compartment Unit.

noise issue are presented in this section.

The seven story office complex had two 10000 cfm units serving two parts of each floor. The units were contained in a small mechanical room with offices on two sides (Sides A and B) and a simple double layer drywall construction for the walls. The walls extended to the underside of floor beams as the ceiling plenum is used for return air. The unit had its discharge along Side B into the adjacent offices. The high noise levels, even though seemed to be acute in one floor, were present in every floor. Further, the noise levels were severe only on Side A, adjacent to the wall that is along the long side enclosure panel of the compartment unit. The noise levels on the Side B, below the discharge duct of the unit, were well below the NC-40 values. The results of these measurements are shown in Figures 6 thorough 9. The noise levels measured inside the compartment unit for two speeds (80% and 100% of speeds) are shown in Figure 6. The rated speed of the fan is 1800 RPM. The noise levels on the Side B office, below the discharge duct, are shown in Figure 7. The noise levels at two locations on Side A, approximately 10 feet (middle) and 15 feet (aisle) from the wall separating the mechanical room, are shown in Figures 8 and 9. The two locations represent a strong standing wave pattern. A strong tone at the full rated speed in the 63 Hz band is evident from the measurements. The levels in the 63 Hz band are presented in Table 1 below.

Table 1. Noise Level in the 63 Hz Band. (Fan Speed 1800 RPM)

Location	Noise Level, dB
Inside Unit	101
Side B	59
Side A, Middle	87
Side A, Aisle	74

Even though only clerical offices are located adjacent to the compartment unit, the noise levels exceeds the NC-40 by more than 15 dB. A strong standing wave pattern is evident, not only in the general office space but also in the private offices located on Side A. The noise levels at the blade passage frequency around 250 Hz band and its harmonics are also evident in the spectrum shown in Figure 6.

The building management office conducted its own investigation and found similar noise levels. Further, they found the noise levels were reduced, if the short duct that is downstream of the fan was dampened. The main transmission path was found to be the casing of the unit, the drywall sep-

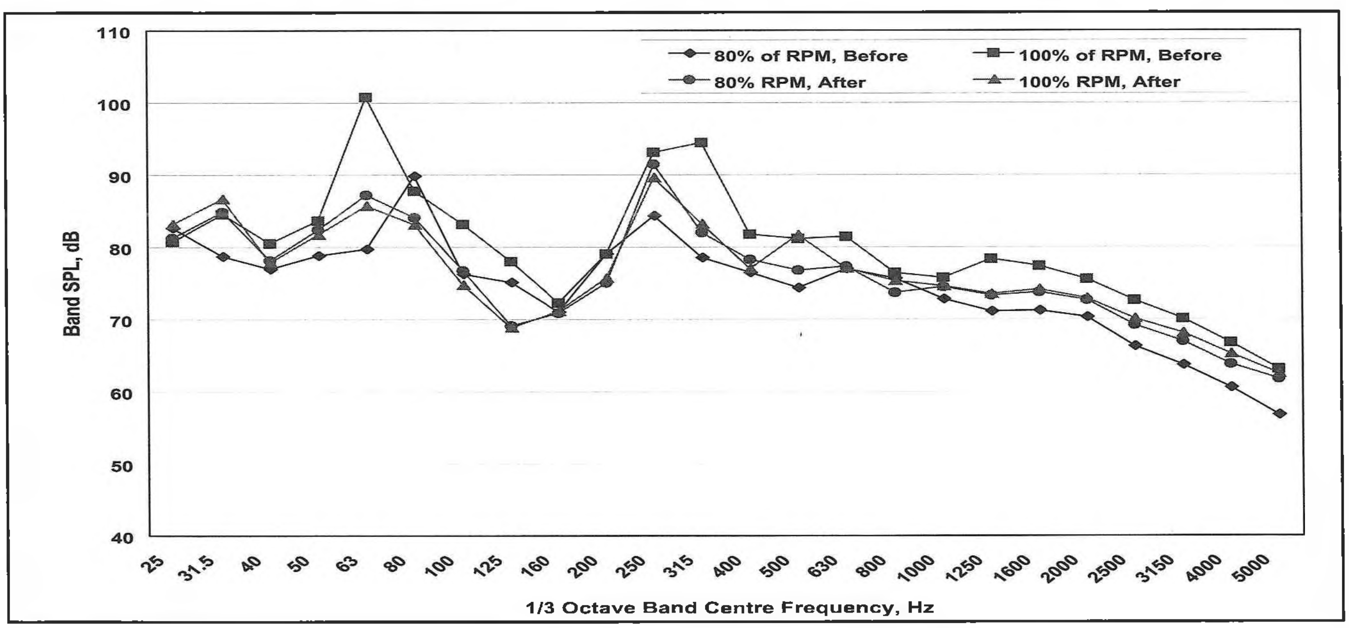

Figure 6. Noise Levels inside the Compartment Unit.

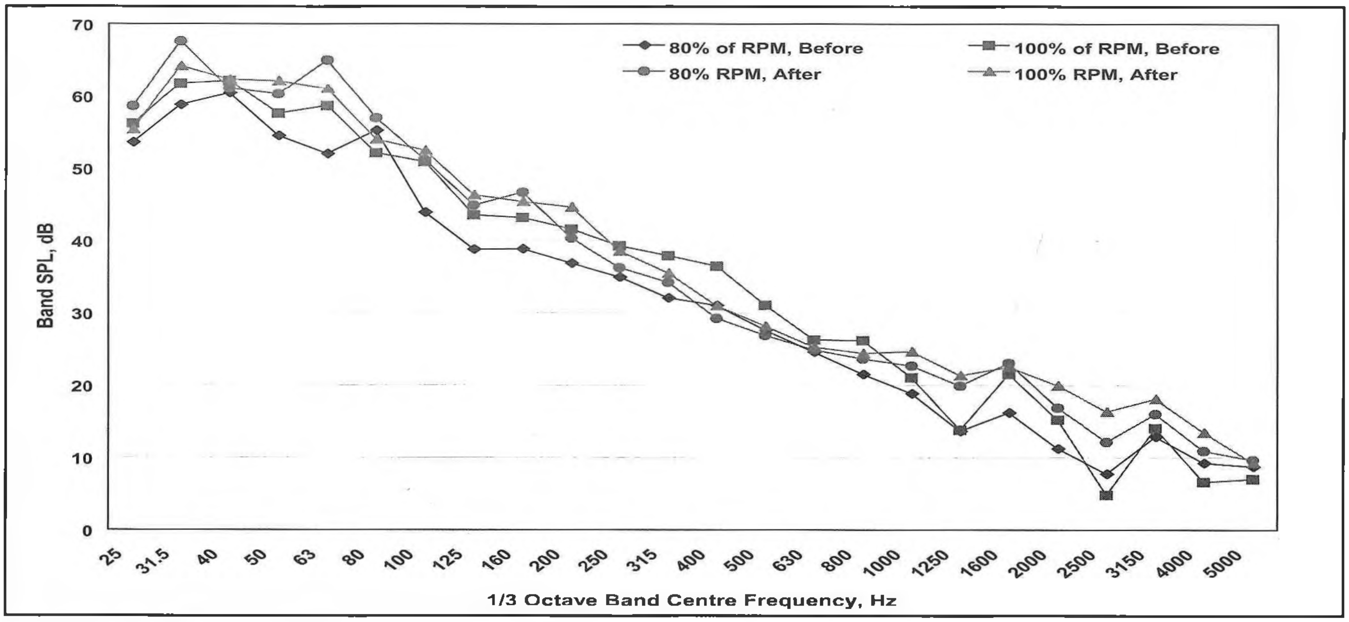

Figure 7. Noise Levels in East Side Offices.

aration between the mechanical room and the offices. Some of the recommended solutions were the conventional solution of increasing the mass and damping of the casing, increasing the mass of the drywall by adding another layer so as to remove the resonance of the wall. Even a quarter wave resonator inside the compartment was considered to absorb the strong 63 Hz tone at the source.

Our noise measurements confirmed most of the findings of the earlier investigations. Our findings showed the existence of the strong standing wave pattern in all the floors. Many of the suggested conventional recommendations were not practical and their performance was also not certain. Our next stage included a detailed vibration measurement programme in and around the compartment unit. Before we started the next stage, the collected data was analysed. The review of the drawings showed that the 30" by 48" short duct (approxi-mately 18" long and highlighted in Figure 5) was supposed to have been connected to the fan discharge through a flexible connection. But visual inspection showed that the flexible connection was at the discharge end of this plain duct. This explained the reason for the strong vibration of this short duct. Earlier measurements indicated that the noise levels seemed to reduce if this duct was dampened. It was hypothesized that the short duct was set into resonance and re-radiated high levels of noise. The casing of the unit

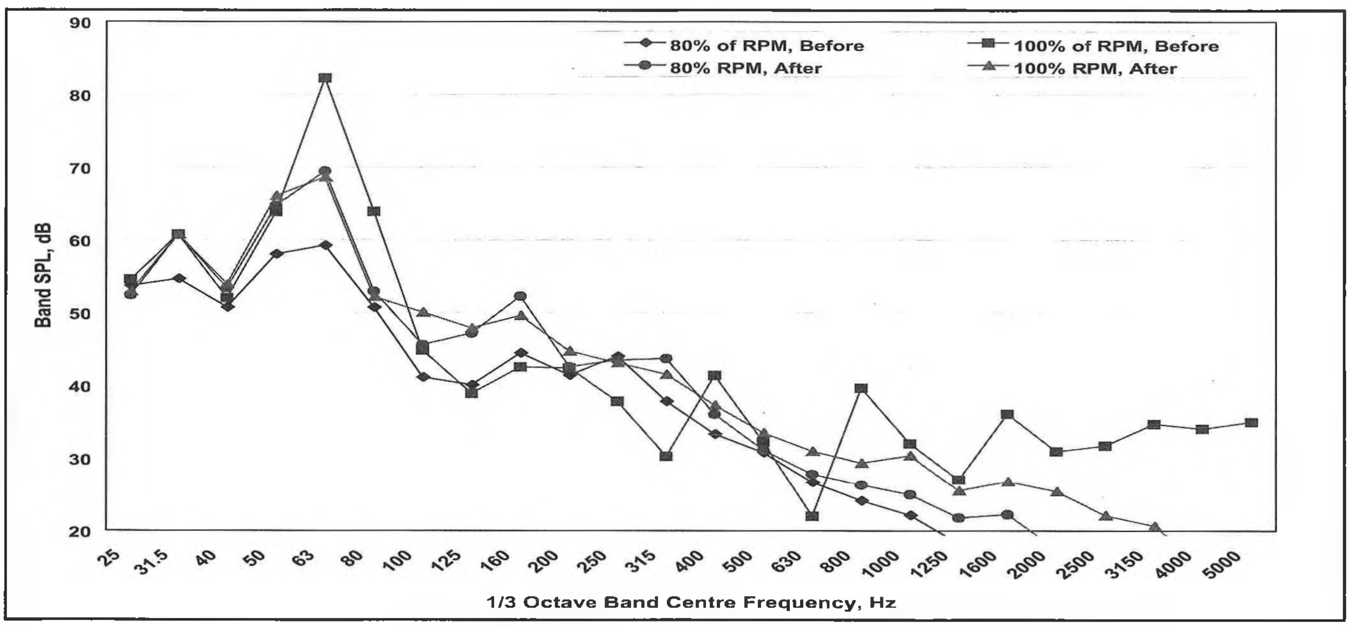

Figure 8. Noise Levels in North Side Offices, Middle.

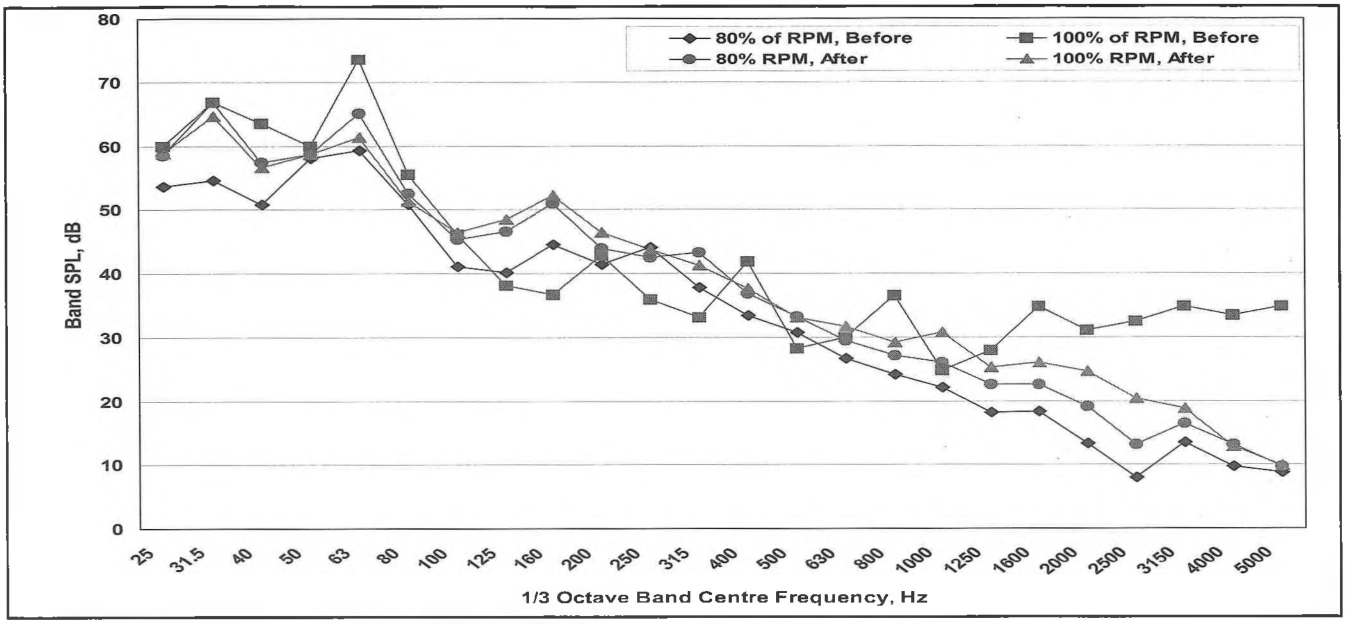

Figure 9. Noise Levels in North Side Offices, Aisle.

and the drywall partition of the mechanical room provided only about 15 dB of noise reduction at 63 Hz due to coupling effects and hence the office room levels were in the 80 dB range. This was further complicated due to the strong standing wave pattern at 63 Hz, resulting in amplified noise levels within the office space. Whereas, along the inlet and discharge side, higher noise reduction was possible due to uncoupled transmission through the casing and the mechanical room wall. The lining and the flexible connection attenuated the discharge duct noise levels adequately so that the Side B office noise levels were below the NC-40 limits. We concluded therefore that the noise source was confined to within the compartment unit. Our first recommendation, the only recommendation as it turned out to be, was to interchange the short duct and the flexible connection. This was undertaken before our Stage 2 measurement programme and it involved the mere unscrewing and screwing of approximately 12 to 16 screws per unit. The noise levels in the most severe floor were remeasured.

The measurements, conducted after the modifications, were influenced by higher ambient levels such as computer fans, and shredding machine fans. Even then, the results were dramatic. The strong tone within the compartment unit at 63 Hz reduced by 15 dB and similar reduction was seen in the general office areas. The levels were below the NC-40 val-

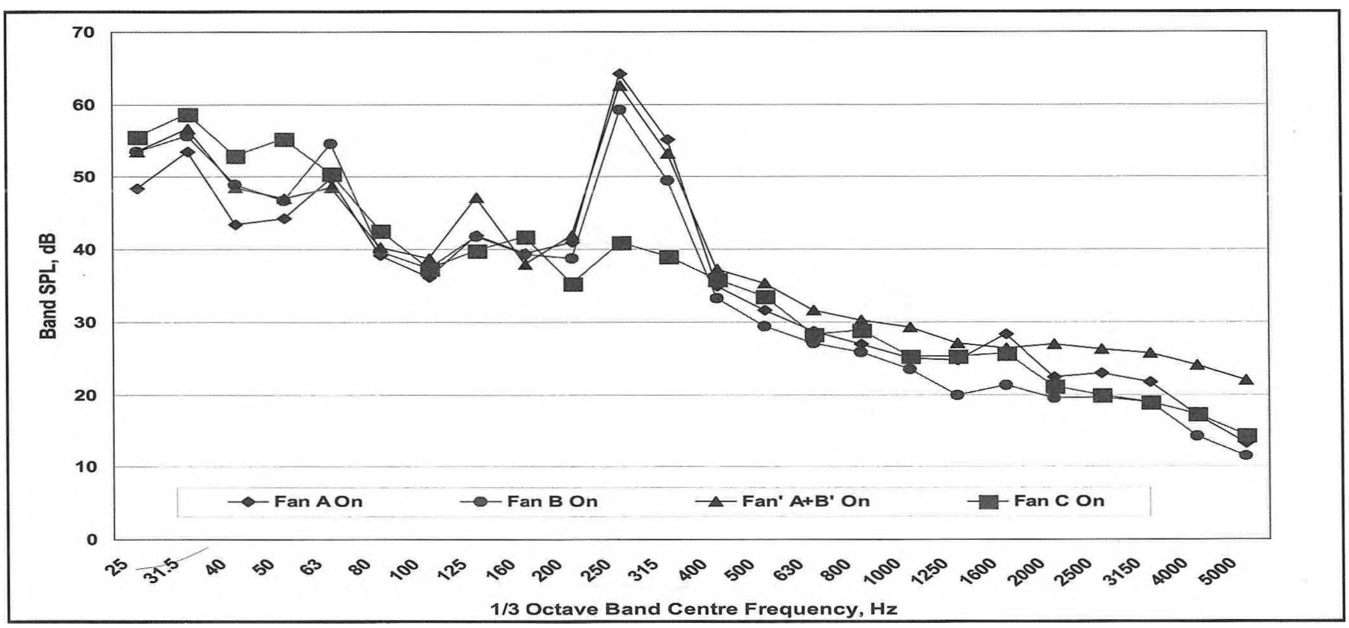

Figure 10. Noise Levels in the Open Area.

ues and the noise complaints were satisfactorily resolved.

4. Axial Supply Fans

4.1 Background

The final case study involves the severe noise generated by a set of three axial fans that were supplying conditioned air to the southwest corner of a seven story Head Quarters building of a public service organization. The three axial fans were located in a large double high (approximately 35 feet) mechanical room. The drawings showed that the fans were in a large inlet plenum and were isolated by spring isolators from the plenum. The large plenum was not connected to the ceiling slab (At least the drawings showed no connection). A small department with three private offices and a reception area was located above the mechanical room. Two of the fans (Fans A and B) were on one side of an expansion joint in the ceiling slab. Fan C was located on the other side of the expansion joint. Two of the fans would be operating at any time. It is seldom that one of the fans would be operating in isolation. All the three fans may operate together under severe load conditions (mid-winter or mid-summer).

The three fans are the axial type (4 blades, 3600 rpm) and severe complaints were received from the department staff. The levels were audible everywhere inside the three private offices. However, the levels were the maximum at two locations - inside one private office and just outside that office.

The measured noise levels in the open area, just outside the private office, are shown in Figure 10. The results show a strong tone at the blade passing frequency in the 250 Hz band. Fan 'C' does not seem to have any effect. Fan 'A' is seen to be the worst culprit. The determination of the trans-mis-sion path and possible control measures follow traditional consultant's short project methods and are described below. Vibration measurements were not conducted since no strong vibration signatures were observed. The main observations of the noise measurements were:

The noise levels were mainly from the operation of Fans A and B;

Strong standing wave pattern was noted in the general office area;

The three fans were isolated by spring hangars from the plenum structure;

No visible connection of the plenum to the ceiling slab;

The noise levels in the 250 Hz band were of the same magnitude from each of the three fans - (i.e.) each fan produced between 90 and 92 dB in the 250 Hz band inside the plenum;

The discharge duct from each of the fan joined the main supply duct with radiused turning vanes and had sharp turns depending on its location. Fan 'C' had the longest length and its connection was smoother than the other two. Fan 'A' had the sharp edge and the shortest length to the main supply duct - schematic details of the layout are shown in Figure 11.

The main conclusions (how wrong we were!) drawn from these observations were:

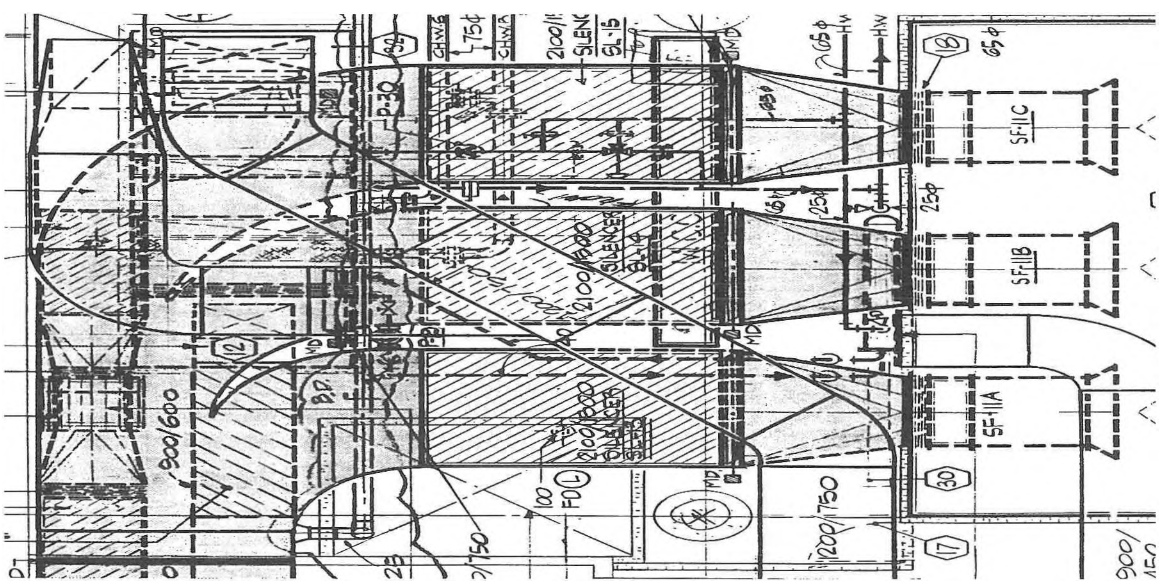

Figure 11. Details of the three Fans inside the Plenum and the sharp Discharges.

The generated noise was transmitted into the office areas through the supply duct;

The length of the discharge duct and the sharp corner for Fan 'A' created a separated flow and generated strong tones at the blade passage frequency;

The effect was slightly smaller for Fan 'B' when compared to Fan 'A';

At least 10 dB of noise reduction must be provided by any control measure.

The observations and the conclusions (wrong ones) made us decide on the following course of remedial action. The space available to install a conventional passive silencer was very limited. In addition, the system could not handle any extra pressure drop by the silencer. So it was felt that active noise control with a preset system from one of the main suppliers would be an ideal solution. Further, the system could be installed with minimal pressure drop and at the entry point of the branch supply duct to the office area. The client was very interested in the system and the cost was also within the budget allocated.

A site visit was arranged with the active noise control system unit's manufacturer. During the site visit, a lightly loaded metal cabinet was in the private office (which was not there during the earlier site visit) and was visibly vibrating a lot. The active noise control designer requested that we isolate the cause of the vibration before designing an active system.

One had to go back to the drawing board again and conduct a series of vibration measurements. [A lesson for all noise control engineers - Never trust the drawings completely and visually double check everything]. The vibration levels were measured on the floor over the carpet (this floor was above the plenum of the three fans in the mechanical room) through a lead plate. The measured levels on the floor near the door of the private office were:

Table 2. Vibration Level at the Blade Passing Frequency of 269 Hz.

Condition	Vibration Level, dB re. 10 m/sec^2
Fan A	-25
Fan B	-41
Fan C	-84

The above measurements completely invalidated the earlier conclusions and remedial actions. A local installer climbed on the plenum structure and found eight (8) rods connecting the plenum structure to the floor slab above. The rods were approximately 24" long. The reasons for the earlier noise emissions became obvious immediately. The revised conclusions were:

The rods above Fan 'C' were across the expansion joint and hence had no major influence on the office area under study;

The main rods, structurally, transmitted the vibrations from Fan 'A' and to a lesser degree from Fan 'B' and the vibrations levels were re-radiated as noise by the drywall construction.

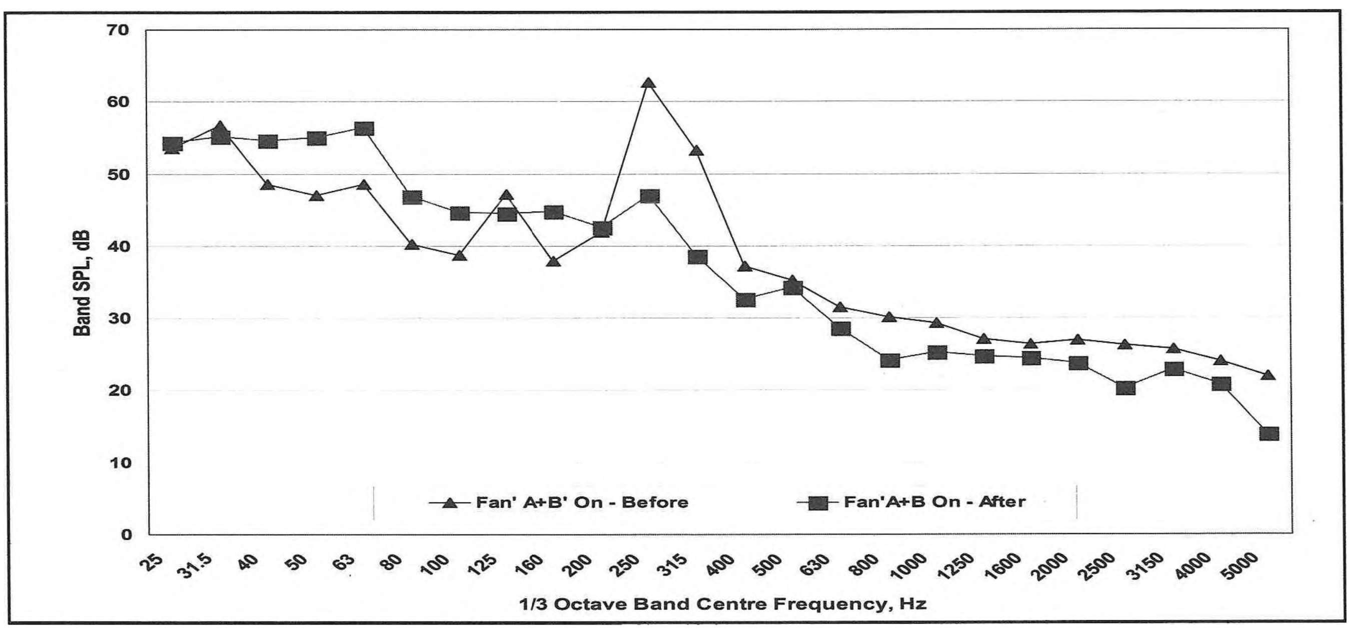

Figure 12. Noise Levels in the Open Area.

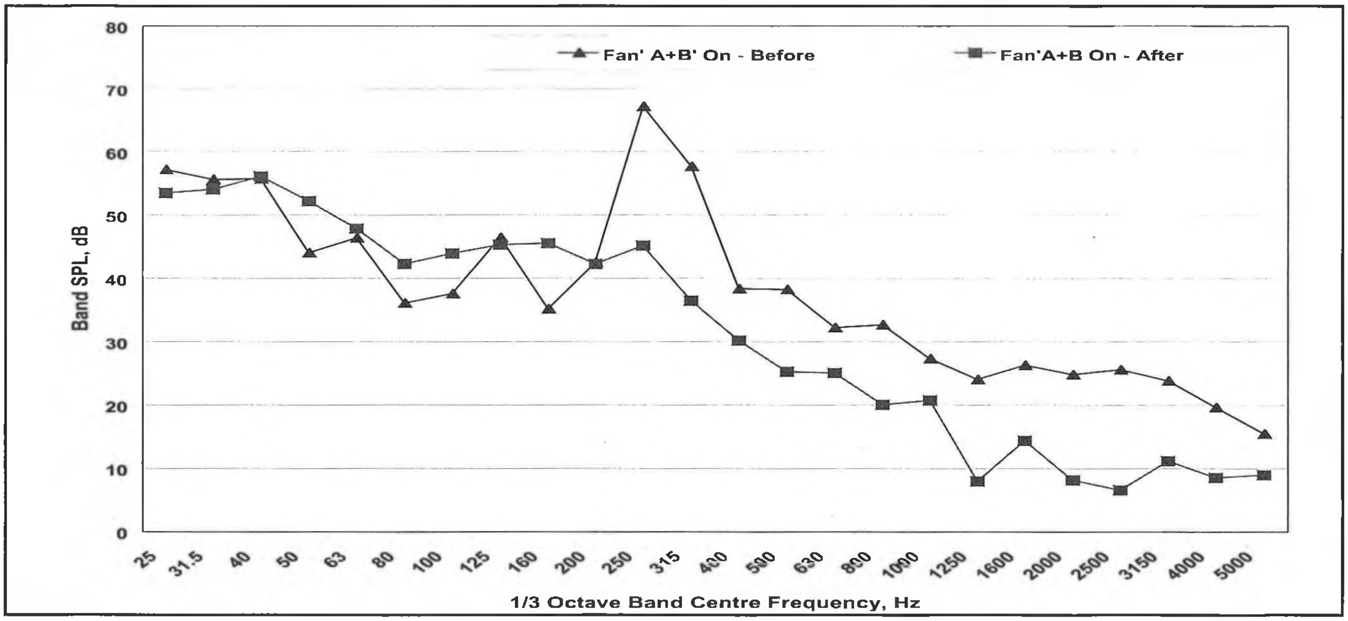

Figure 13. Noise Levels in the Private Office.

The remedial actions became clear from the measurements and vibration isolation was recommended. The isolation hangars within the plenum (4 per fan) were all replaced to provide a minimum of 1" deflection. The ceiling rods were replaced with isolation hangars with a minimum of 1" isolation. More than 1" deflection was not possible due to space limitation and installation difficulties.

The vibration and noise levels were measured again after the installation of the vibration isolators. The vibration results are presented in Table 3 below.

Table 3. Vibration Level at the Blade Passing Frequency of 269 Hz.

Condition	Vibration Level, dB re. 10 m/sec^2
Fan A	-57
Fan B	-70
Fan A + B	-50

The vibration levels reduced by 25 dB or more, which was a substantial reduction. The noise levels in the two office areas are shown in Figures 12 and 13. The noise levels are attenuated by more than 20 dB. However, the blade passage frequency is still audible, albeit slightly over the ambient, in the occupied spaces. The above investigation shows that the conventional method of passive silencing would not have been fruitful.

5. Conclusions

Three case studies of severe noise concerns of fans were investigated. In all the three cases, any attempt to install conventional treatments would have been a wasted effort. Proper analysis, with in depth visual observation, was necessitated and slightly unusual methods were instituted, successfully in the end, to ameliorate the noise concerns.

6. Acknowledgements

The above investigations and noise control consulting were undertaken while the author was a senior consultant at Vibron Limited in Mississauga, Ontario. The case studies are published with permission from Vibron Limited and we acknowledge their cooperation during the preparation of this paper.

7. References

1. J. D. Irwin and E. R. Graf, "Industrial Noise and Vibration Control" Prentice-Hall, New Jersey, 1979.

2. D. D. Reynolds, "Engineering Principles of Acoustics, Noise and Vibration Control" Allyn and Bacon Inc., Toronto 1981.

3. P. Jensen, C. R. Jokel and L. N. Miller, "In-dustrial Noise Control Manual" National In-stitute for Occupational Safety and Health, U. S. Department of Health, Cincinnati, Ohio, 1978.

4. Laymon L. Miller, "Noise Control for Build-ings and Manufacturing Plants" Bolt Beranek and Newman Inc., Cambridge, MASS, 1981.

5. Stig Ingemansson, "Noise Control - Principles and Practice" Noise/News International. From June 1994 issue.