National Research Council Canada | Conseil national de recherches Canada

Institute for Research in Construction | Institut de recherche en construction

CLIENT REPORT

for

CMHC National Office
Policy, Research and Programs Sector
Sector Administration Unit
682 Montreal Road
Ottawa, Ontario K1A 0P7

Acoustical Testing of Residential Exhaust Fans
Revised Report

Author J.D. Quirt

Approved A.C.C. Warnock
Quality Assurance

Approved J.D. Quirt
Head, Acoustics Section

Report No. CR-5899.1, Revised
Report Date: 18 February 1991
Contract No. CR-5899
Reference: Application for test dated 24 March 1989
Section: Acoustics

30 Pages
Copy No. 6 of 6 Copies

INTRODUCTION

A CSA standard has been developed for laboratory testing of residential ventilation fans to provide air-handling and sound emission ratings. A study is underway to evaluate these laboratory test methods, and to assess the relationship between the laboratory ratings and actual field performance. The study was commissioned by a consortium of interested parties, including the Research Division of Canada Mortgage and Housing Corporation (the direct client for the work reported here).

The first phase of that study is laboratory testing of 11 ventilation units to rate both airflow and sound power emission according to the current draft of CSA C260. The second phase will be field testing of these same units after installation in residences.

This report describes the acoustics part of the first phase of that study. These tests were structured to verify that the method is practicable and to evaluate factors likely to affect reproducibility of the test method.

The main body of the report presents an overview of the work performed, and a general discussion of the significant issues. This presentation is divided into five parts:

1. Measurement procedures and installation details;
2. Overview of sound power measurement results;
3. Dependence of emitted sound power on installation and operational details;
4. Precision of the test method;
5. Conclusions.

The summary is followed by appendices to tabulate data or present topics of secondary interest. These include:

Appendix A: sound power data for each ventilation unit tested;

Appendix B: collected comments of the test operators on difficulties encountered and questionable features of the draft standard;

Appendix C: Ratings of sound emission in Sones.

1. MEASUREMENT PROCEDURES AND INSTALLATION DETAILS

CSA Standard C260 requires that sound power measurements be made in accordance with ANSI S1.31-1980, with several additional requirements, including both device installation requirements (based on those of the existing industry standard prepared by the Home Ventilation Institute) and acoustical requirements (extracted from ANSI S1.32-1980 and British Standards Institution standard BS848: Part 2:1985). The tests reported here conformed to all mandatory requirements of CSA C260 and exceeded some; specific extensions and limitations are identified below.

1.1 Laboratory Size and Characteristics

CSA C260 requires use of a reverberation chamber whose volume is greater than 200 m^3; the IRC chamber is 255 m^3. The standard does not require use of a rotating vane in the reverberation room. The vane in the IRC laboratory was not operated during these tests; the results should therefore be indicative of the performance for a barely conforming reverberation chamber.

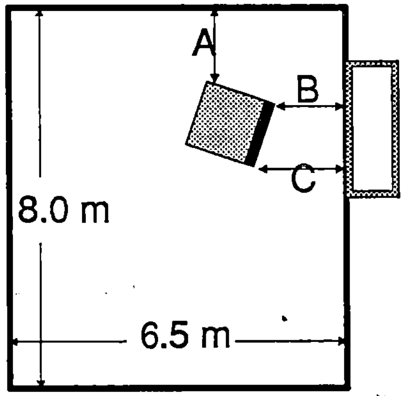
1.2 Microphone Positions

The standard requires measurements at a minimum of three positions in the reverberation room (and recommends the use of more) to obtain a reliable estimate of the sound power, and at least a minimal estimate of variation of sound pressure level in the chamber. If the standard deviation of these samples exceeds specified limits, additional microphone or source positions are required. Normal practice at IRC is to measure at nine microphone positions distributed around the room; this practice was followed in these measurements, as an essential part of assessing probable uncertainty of the test procedure. Analysis of precision in part 4 below includes an assessment of how precision would be affected by using fewer microphone positions.

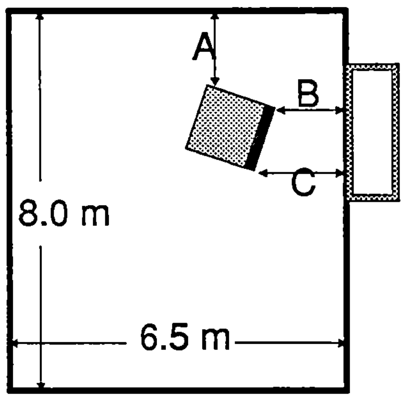
1.3 Source Positions

The standard permits the use of only one source position, but recommends the use of additional positions, especially if tonal signals are observed. Normal practice at IRC is to measure sound power (at nine microphone positions) for each of several source positions; the mean of these results is taken as the sound power. To evaluate the effect of using only one source position, each of the exhaust fans was tested with the stand at three positions, and the results for individual stand positions were retained to permit analysis of the effect of using multiple positions. Stand positions used are shown in Figure 1.

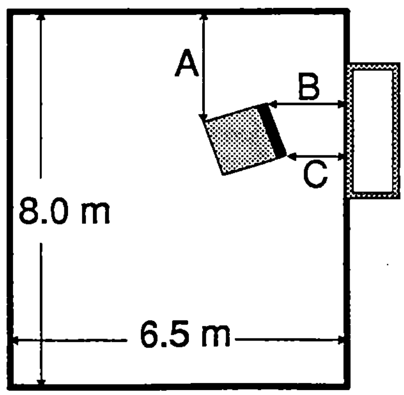
Figure 1: Locations for the test stand in the reverberation chamber. All locations conformed to the requirements that the stand be at least 1 m from chamber walls and angled at least 10 degrees from parallel to the adjacent wall.



A = 1.55
B = 1.96
C = 2.20



A = 1.78
B = 1.91
C = 2.13



A = 1.70
B = 2.08
C = 1.96

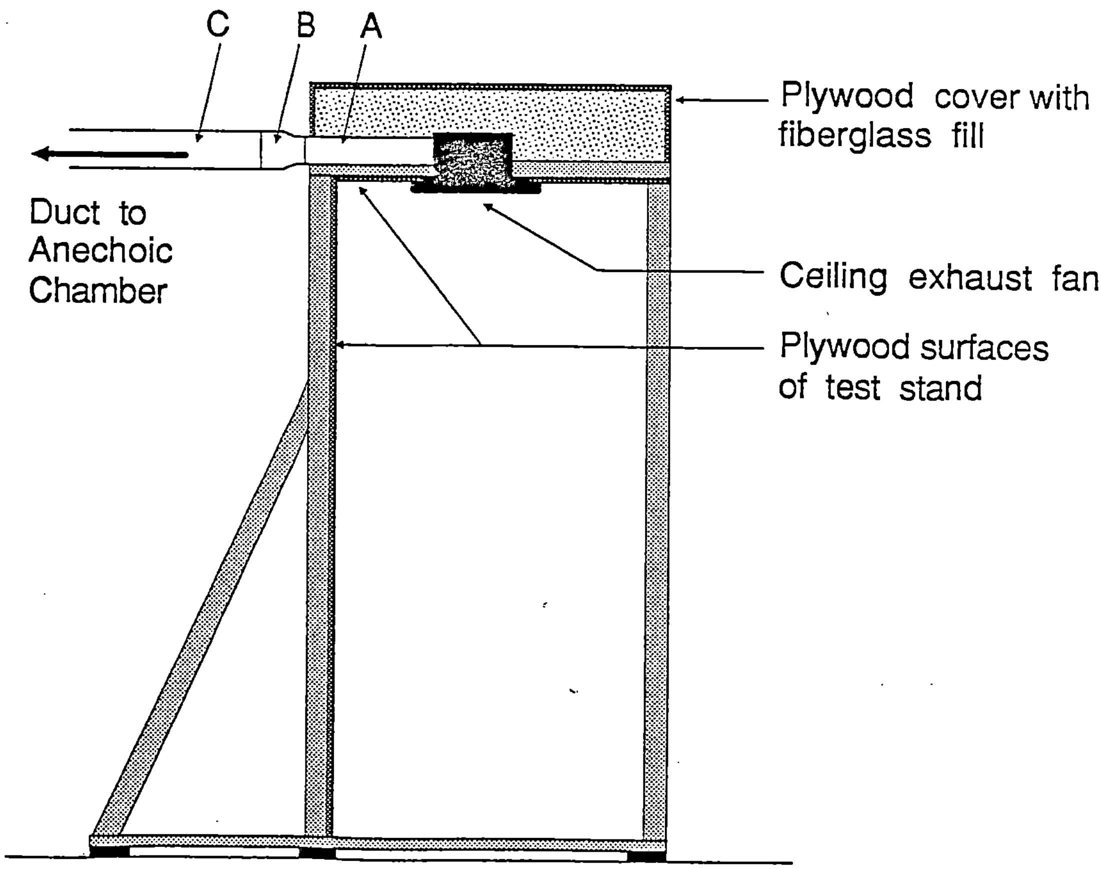
1.4 Adjacent "Anechoic" Space

The CSA C260 standard requires the use of an adjacent space to which ducts normally going outdoors may be connected. This space is required to be "a substantially sound absorptive environment so that reflected and reverberant sound from this space does not significantly affect" measurements in the reverberation room. An opening from this space provides the return air path to the reverberation room. The chamber constructed for these tests had a simple absorptive lining of the walls (equivalent of 50 mm thick fiberglass). Acoustic intensity measurements showed negligible sound power flow to the reverberation room via this opening, indicating this simple chamber was adequate.

1.5 Test Stand and Ducts for Ceiling Exhaust Fans

The test stand was made from wood studs and plywood, and conformed to the design specified in CSA C260. The fan was mounted on the upper plywood surface, as shown in the drawing in Figure 2. A plywood cover was installed on the top of the stand; removing this cover increased the overall measured sound power by about 2 decibels.

Figure 2: Installation of ceiling exhaust fan on the test stand. Duct element A was a 50 mm diameter duct matching the discharge opening of the fan. Element B was a transition to 150 mm diameter, and C is the main duct (2 m long and 150 mm in diameter, with adjustable elbows at both ends).

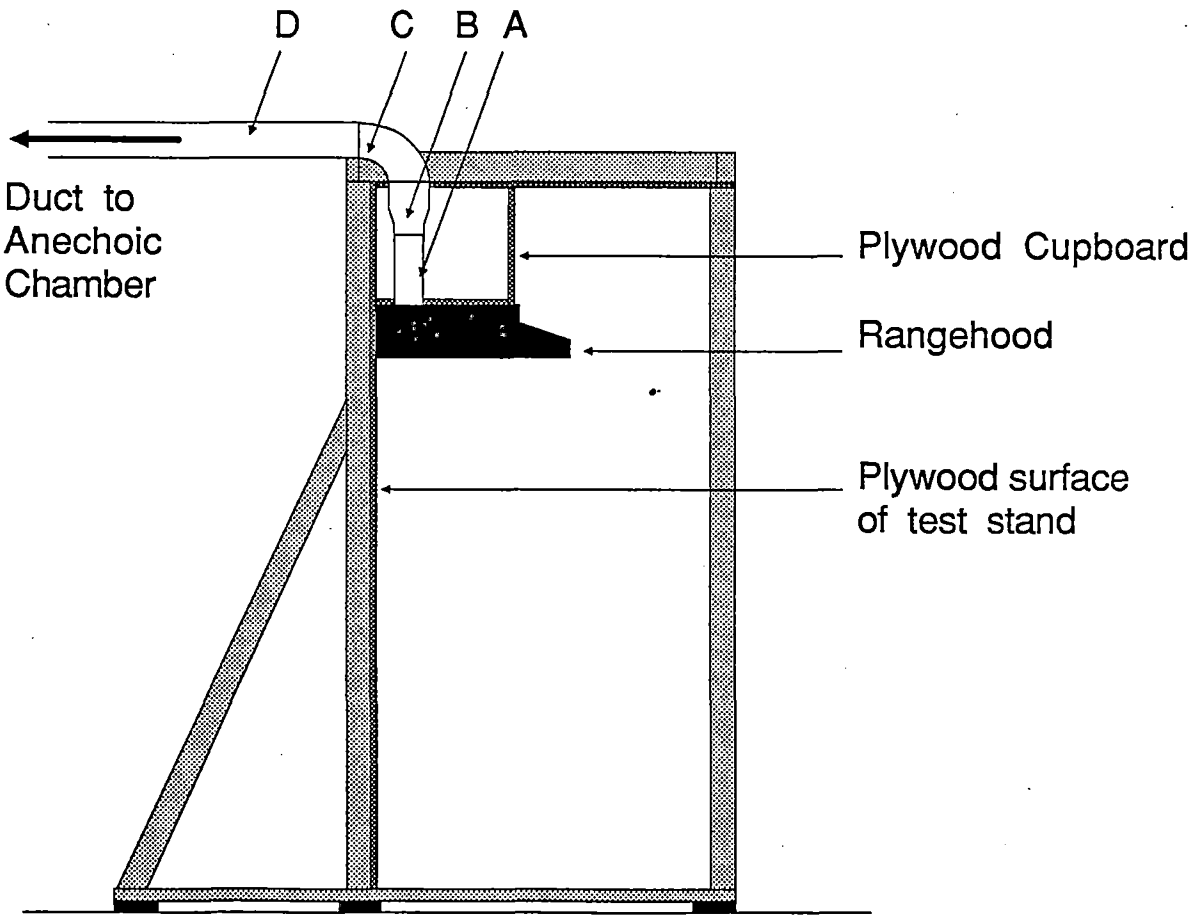


The standard requires that ducts be provided between equipment mounted on the test stand and the adjacent "anechoic" space, to handle airflow that would be ducted to or from outdoors in normal installation. A conventional round galvanized steel duct lined with 5 kg/m² damping material was used. Adjustable elbows where the duct joined the test stand and where it entered the "anechoic" space permitted relocation of the stand with minimal bends in the duct. Acoustic intensity testing indicated negligible sound power was emitted from the surface of this duct.

1.6 Test Stand and Duct for Range Hood

The test stand was made from wood studs and plywood, and conformed to the design specified in CSA C260. The fan was mounted under the plywood cupboard, as shown in the drawing in Figure 3. This cupboard was 900 mm wide, 450 mm high, and 300 mm deep (as required by the standard).

Figure 3: Installation of the range hood exhaust fan on the test stand. Duct element A was a 75 by 250 mm rectangular duct matching the discharge opening of the fan. Element B was a transition to 150 mm diameter, and C is an elbow of that diameter. D is the main duct (2 m long and 150 mm in diameter, with adjustable elbows at both ends).

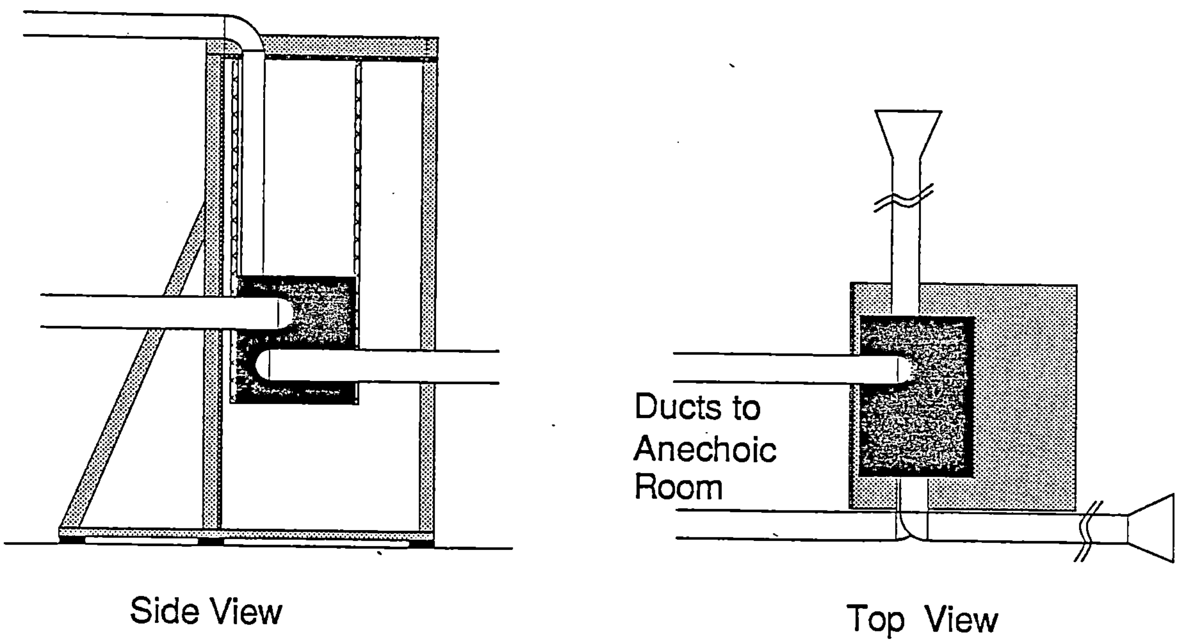


The ducts were connected to the 75 by a 250 mm rectangular outlet on the top of the unit, for conformity with the case tested for airflow measurements. However, the ducting arrangement used here (which conforms to the C260 requirements for the sound test) is very different from that for the airflow testing. This issue is examined in more detail in the discussion below of factors affecting the results.

1.7 Test Stand and Duct for Heat Recovery Ventilator

The test stand was made from wood studs and plywood, and conformed to the design specified in CSA C260. The fan was suspended from the stand using screw-in metal eyes and rope, as shown in the drawing in Figure 4. (No mounting hardware or installation instructions were supplied with the unit.) The top of the unit was 1.2 m from the top surface of the stand.

Figure 4: Installation of heat recovery ventilator on the test stand.



Because of the complex duct connections, only one stand position was used. The ducts from the unit to the anechoic space (labelled as "fresh air from outside" and "exhaust air to outside") were 150 mm diameter conventional round galvanized steel duct, lined with 5 kg/m^2 self-adhesive damping material. The two ducts normally connected to indoors extended 1.8 m into the reverberation chamber; these were the same as the other ducts, with omission of the damping material. The unit was tested both with plain ends on the ducts opening into the reverberation chamber, and with flared ends as required by CSA C260.

Electrical connections were made directly to the fan motor, and the damper was fixed in the open or closed position to test sound emission in the "circulation" and "exchange" modes separately.

2. OVERVIEW OF SOUND POWER MEASUREMENT RESULTS

This section of the report provides a basic overview of the test results for the three types of ventilation units. More detailed analyses of dependence on fan operating conditions and other factors affecting the reproducibility of the tests are given in following sections.

All units were previously labelled by Ortech when performing the airflow testing, and fan identifications here are consistent with those labels. Each fan was operated at a rotation speed within 1% of that identified as the rating point for the airflow test, as required by CSA C260 clause 5.3.1.

2.1 Ceiling Exhaust Fans

Five ceiling exhaust fans (Nutone Model QT80-CA) were tested. For the ceiling exhaust fans, a 150 mm diameter duct from the test stand to the discharge space was needed to achieve the required fan speeds with 120 volt power (matching the voltage used for the airflow test, as required in C260 clause 5.3.2). The exact speed was regulated by partially blocking the return air passage from the discharge space to the reverberation chamber.

The data in Figure 5 show very strong similarity among the fans tested. Rating fan models would be meaningful if other products showed comparable consistency. Data for specific fans are tabulated below. The mean sound power emission is 57.1 dBA, with a standard deviation of 0.6 decibels. Even in direct side-by-side listening comparison, most human subjects would be unable to consistently identify which of these fans was louder or quieter.

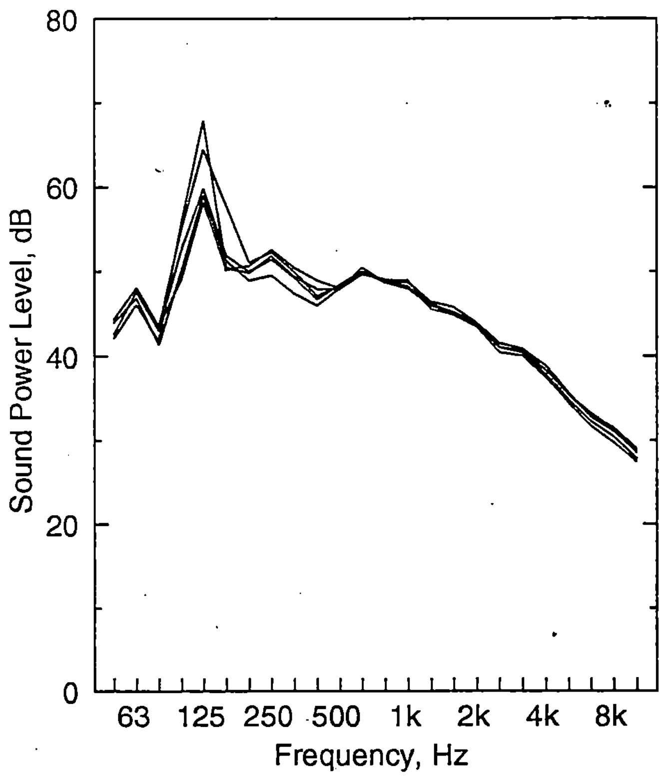


Figure 5: Mean sound power results for the five ceiling exhaust fans tested. Each curve is the mean obtained for nine microphone positions with each of three stand positions (27 measurements).

Unit	Fan Speed (rpm)	Sound Rating (dBA)
Ceiling fan #1	1360	56.7
Ceiling fan #2	1370	57.6
Ceiling fan #3	1390	56.6
Ceiling fan #4	1340	57.9
Ceiling fan #5	1300	56.9

Figure 6 presents both the measured one-third-octave data and the corresponding A-weighted values. A-weighting lowers the values at high- and low-frequency extremes in a standardized approximation of the reduced sensitivity of human hearing at these frequencies. Thus, the A-weighted curve provides a better indication of the relative contribution of each frequency band to perceived loudness.

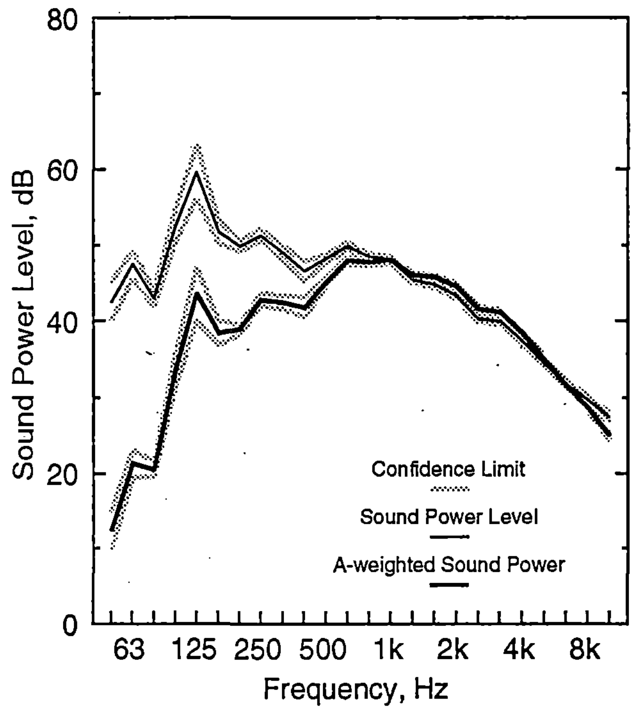


Figure 6: Results for one specific ceiling exhaust fan, to illustrate the value of presenting A-weighted sound power results.

A strong peak in measured sound power is evident around 125 Hz in Figure 6. This peak is due to a pure tone, presumably coming from the fan motor; this causes a significant increase in the standard deviation of results around 125 Hz, discussed in the section on precision below. This peak actually contributes less to the A-weighted sound level than is contributed by the mid-frequency bands around 1 kHz. Low-frequency tones that apparently dominate the un-weighted sound power data (and that may force additional microphone and stand positions according to CSA C260 clause 5.4.4) may have little effect on the overall dBA rating, and using the A-weighted curve makes this immediately obvious.

2.2 Range Hood Exhaust Fans

Five range hood exhaust fans (Broan Model 790031) were tested. For the range hood exhaust fans, even removing the duct from the test stand to the discharge space did not achieve the required fan speeds. With a 150 mm diameter duct, the speed did come within 4% of the rated speed. The final increment of fan speed adjustment was achieved by adjusting the speed control on the front of the unit. The effect of controlling the fan speed by the applied voltage rather than static pressure is examined further later in the report.

Clause 5.3.3 of CSA C260 requires that sound emission from units with variable speed controls be checked at a range of speeds. This was done for each range hood; all exhibited their maximum sound emission with the control set to the highest speed. The sound power with the fan speed equal to that for the airflow rating was therefore used for the detailed sound power measurements.

The data in Figure 7 show very strong similarities among the range hoods tested. Data for specific units are tabulated below. The mean sound power emission is 66.7 dBA, with a standard deviation of 0.6 decibels. This inter-fan variation is comparable to that observed for the ceiling exhaust fans.

The sound emitted by the range hood fans did not exhibit a significant low-frequency tone like that from the ceiling exhaust fans. There was evidence of weak tones at 125 and 250 Hz, but these had little effect on the overall sound power or measurement uncertainty.

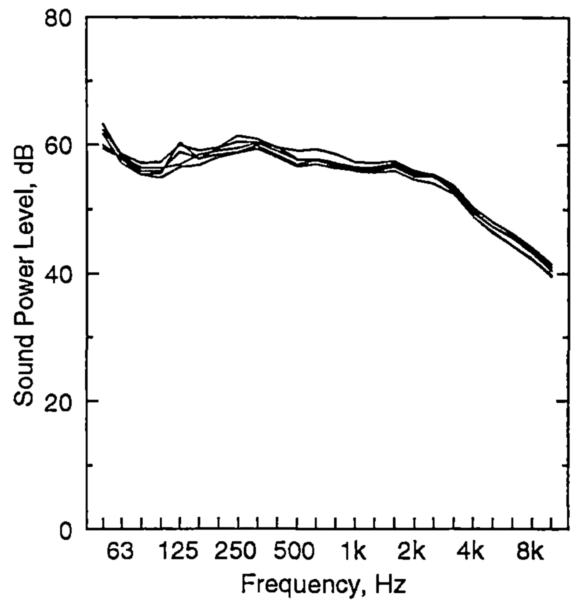


Figure 7: Mean sound power results for the five range hood exhaust fans tested. Each curve is the mean obtained for nine microphone positions with each of three stand positions (27 measurements).

Unit	Fan Speed (rpm)	Sound Rating (dBA)
Range hood fan #1	2637	66.9
Range hood fan #2	2490	66.2
Range hood fan #3	2490	66.0
Range hood fan #4	2655	67.6
Range hood fan #5	2564	66.8

2.3 Heat Recovery Ventilator

One heat recovery ventilator (Venmar Model HRV-3055) was tested. Voltage was applied directly to the fan motor, and was adjusted to provide a fan speed of 1590 rpm, the speed at the rated static pressure in the airflow testing. The unit was tested with both "indoor" ducts simultaneously radiating sound power. Emission from the ends of these two ducts was clearly the dominant source of sound power.

The unit had two operating modes, identified by the manufacturer as "air exchange" and "circulation". It was tested in both operating modes. The results are shown in Figure 8. Sound power emission was very similar for the two modes.

3. EFFECT OF OPERATIONAL AND INSTALLATION DETAILS

3.1 Effect of HRV Duct Bell-mouth

For units with inlet or outlet ducts radiating sound power into the reverberation room, CSA C260 requires the use of an air stabilizer at the open end of the duct "to prevent eddies and edge effect". Clause 5.2.3 of the standard specifies a transition to open end dimensions twice the duct diameter.

The effect of these duct terminations was examined by testing the sound power emission from the HRV both with plain duct ends and with the required termination. The results are given in Figure 9. Adding the termination increases the emitted sound power in the mid-frequencies, giving an increase in the overall A-weighted sound power of approximately 1 decibel.

The termination functions like the horns on public address loudspeaker systems, increasing radiation efficiency for sound whose wavelength is comparable to the cross-section of the termination. Because typical duct terminations have a qualitatively comparable expansion, retaining the requirement is reasonable. It is, however, ironic that this requirement was included at the suggestion of a manufacturer.

3.2 Fan Speed Variation

The standard requires that sound emission testing be done with the fan operating within 1% of the fan speed (and nominally at the same static pressure) as that for the airflow testing. Because of the very different ducting required for the sound test, achieving this proved difficult. In addition, fan speed was not totally stable for all the fans and required several minutes of stabilization in some cases;

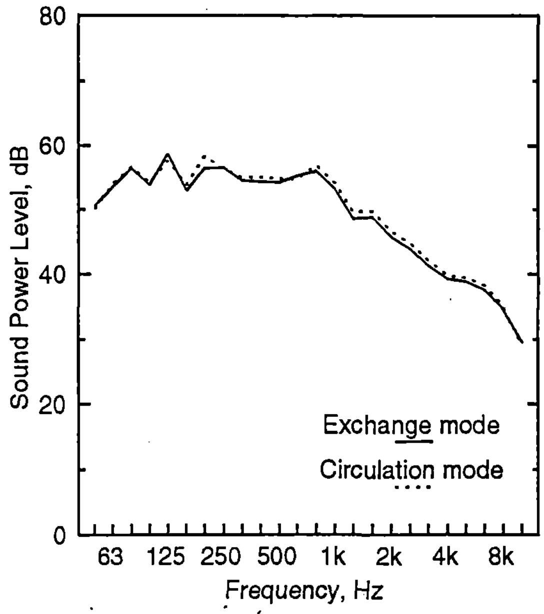


Figure 8: Sound power emission from the heat recovery ventilator in "air exchange" and "circulation" modes. Overall sound power ratings were 62.3 dBA and 61.7 dBA, respectively.

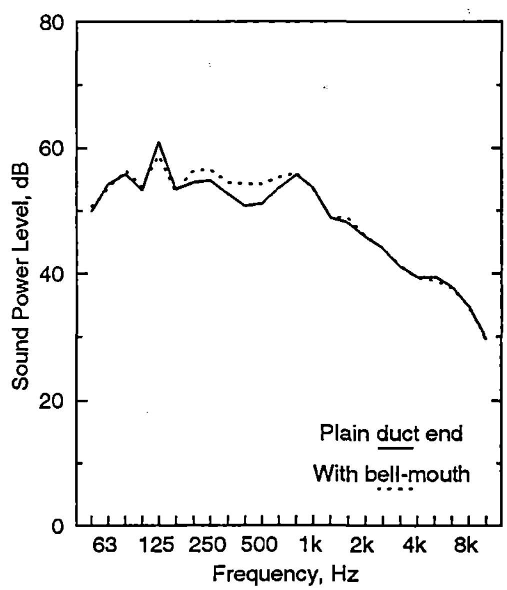


Figure 9: Effect of duct termination on sound power emission from a heat recovery ventilator. Data are for the HRV in "exchange" mode; a nearly identical effect was observed in the other mode. The overall sound power is 50.6 dBA with the termination, and 49.8 dBA without the termination.

thus, setting the speed within the required 1% tolerance involved repeated adjustment and checking.

Given the difficulty of ensuring the desired fan speed and static pressure, the variation of emitted sound power was studied as a function of span speed, to determine the potential effect on reproducibility.

Fan speed was changed by varying the applied voltage and the restriction of airflow. The procedure used was to begin with the fan at the rating speed, and then to raise fan speed by restricting the airflow return to the reverberation room. Leaving the airflow return at the most restricted (i.e., the highest static pressure), the fan speed was then reduced by reducing the applied voltage. The results are shown in Figures 10 and 11.

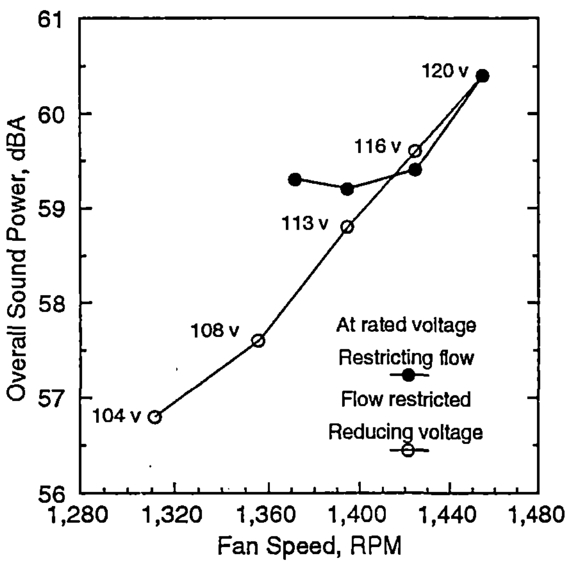


Figure 10: Effect of fan speed on sound power emitted by a bathroom exhaust fan. A Variac was used to reduce the voltage from 120 volts (open circles).

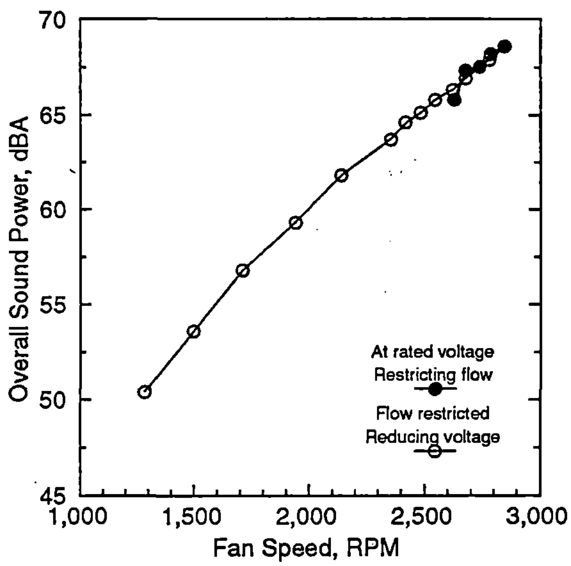


Figure 11: Effect of fan speed on sound power emitted by a range hood. The control on the front of the unit was used to reduce the voltage at the fan.

In both cases, there is a repeatable variation in the overall sound power as a function of fan speed. However, the emitted sound power is dependent not just on fan speed but also on the voltage and static pressure to achieve that speed. This is most obvious in the case of the ceiling exhaust fan, where the spectrum shape (and especially the low-frequency tone) appeared to depend on flow restriction. However, even the largest deviations observed between results at a given fan speed were only about 1 dBA - a change comparable to the overall measurement uncertainty.

3.3 Effect of Fan Mounting Details

It is expected that details of fan mounting could affect the sound power emission, especially if vibration transmission to the test stand (and resulting sound radiation from the stand) is significant.

The ceiling exhaust fans had non-resilient mountings which allowed considerable variation in the fan location within the outer housing. To examine the possible effect of these variations, fan #1 was tested when mounted at four different positions within the housing. Extreme positions were deliberately chosen; actual variation in subsequent installations should be significantly smaller. The results are shown in Figure 12.

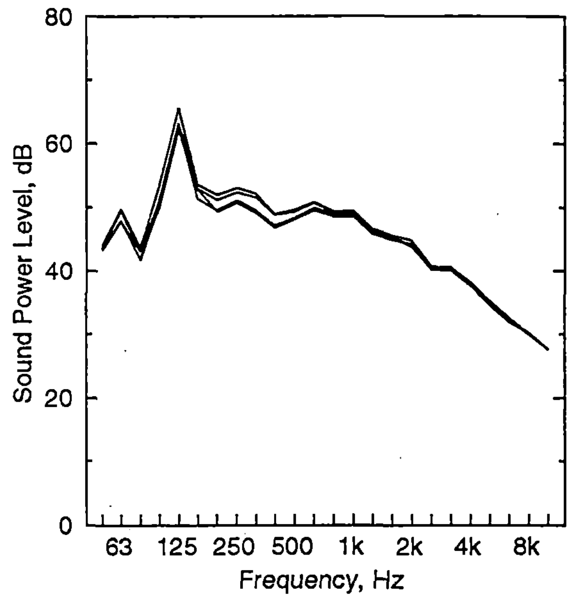


Figure 12: Sound power from ceiling exhaust fan #1, mounted at four different positions within its outer housing.

Moving the fan within the housing did produce variations in the emitted sound power, especially in the 125 Hz band. The total range in the overall A-weighted sound power was 1.3 dBA. These variations were marginally larger than the repeatability of measurement, but were smaller than the overall measurement uncertainty including effects such as the variation with test stand position discussed below.

3.4 Effect of Source Position

In principle, one would expect that moving the sound source to different positions in the reverberation room would cause variations in measured sound power equivalent to the inter-microphone differences observed for a given source position. Thus, averaging over approximately equal number of source positions and microphone positions should give optimal measurement precision.

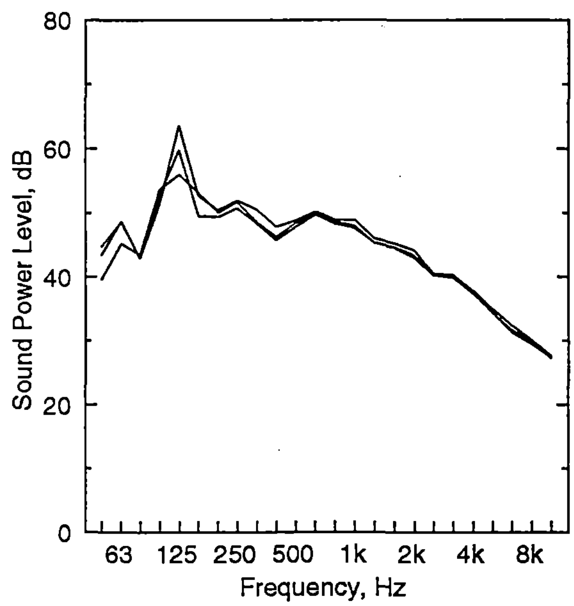


Figure 13: Sound power for ceiling exhaust fan #1 at three different stand positions.

In practice, moving the test stand is far more difficult than switching microphone positions, and CSA C260 therefore permits measurement with only one stand position, although using more is recommended. Figure 13 shows the measured sound power for one fan with the stand at three positions.

Some fans showed larger effects than that illustrated in Figure 13, and others showed less. In general, the effect was largest around 125 Hz, and the variation was smaller for the range hoods (which had no pronounced low-frequency peak). Dependence on the source position is significant, but the strongest effect is at frequencies below 500 Hz. Because the sound from residential ventilation fans is apparently dominated by higher frequencies, the impact on precision of the overall rating is not huge.

Because each fan was remounted at each stand position, the variation in Figure 13 includes the effect of remounting the fan, minor differences in voltage or static pressure, etc. Although this effect is believed to be primarily dependence on source position, it is really more legitimately uncertainty associated with all effects other than inter-microphone differences.

4. PRECISION OF THE TEST METHOD

For each of the five ceiling exhaust fans and each of the five range hoods, the sound power was measured at nine microphone positions for each of three stand positions. This provided enough data for a preliminary estimate of probable measurement uncertainty. However, the results should not be treated as the equivalent of a proper inter-laboratory round robin determination of reproducibility of the test method.

Data analysis was structured to minimize dependence of the estimates of precision on the performance of the individual fans. Results for the range hood and the ceiling fans were analyzed separately, because the different pure tone contributions affected the results. The inter-microphone standard deviation for each type of fan was calculated by averaging the 15 results (five fans, three positions). The source-position standard deviation for each type of fan was calculated by averaging the 15 differences (five fans, three positions) between results at each position and the mean result for that fan.

Obviously, these provide rather crude estimates of the population standard deviation, but they are the best available with the limited data. The source position statistics (based on only three stand positions) are most suspect.

The calculated standard deviation of the sample for inter-microphone differences with one source position (s_{mic}) and for source position differences of 9-microphone averages (s_{source}) are given in the Table on the following page.

If these values are treated as estimates of the standard deviation for the population, the confidence limits for the mean of a set of measurements at n microphone positions for each of k source positions can be estimated.

The confidence interval is given by:

Frequency (Hz)	Ceiling exhaust fans		Range hoods	
	s_{mic}	s_{source}	s_{mic}	s_{source}
50	5.0	1.5	4.6	1.2
63	3.0	1.2	4.6	0.7
80	1.9	0.7	1.7	0.8
100	3.5	1.4	1.1	0.5
125	5.0	2.6	2.5	1.1
160	2.2	1.1	1.2	0.3
200	1.3	0.5	0.9	0.5
250	0.8	0.7	0.8	1.1
315	0.8	0.7	0.6	0.4
400	0.6	1.1	0.5	0.3
500	0.4	0.4	0.6	0.6
630	0.4	0.4	0.4	0.2
800	0.5	0.3	0.5	0.3
1000	0.3	0.4	0.4	0.3
1250	0.3	0.3	0.3	0.3
1600	0.3	0.3	0.2	0.3
2000	0.4	0.3	0.3	0.3
2500	0.4	0.4	0.3	0.3
3150	0.4	0.3	0.4	0.4
4000	0.3	0.3	0.4	0.5
5000	0.4	0.3	0.5	0.5
6300	0.6	0.4	0.6	0.4
8000	0.7	0.3	0.7	0.3
10000	0.7	0.4	0.9	0.3

The factor t depends on the confidence required and the number of samples used to determine the mean value. For 95% confidence (results fall within the specified range 19 times out of 20) in a two-sided interval (this much above or below the mean), the factor t approaches 2 if the number of samples is large.

5. CONCLUSIONS

The results of this study suggest the basic test method is practical, and will provide adequate precision for meaningful labelling of products.

However, there are several aspects of the CSA C260 standard which should be reviewed:

1. **Fan operating conditions**: The standard should reduce the difference between the philosophy of the airflow test (which rates fans in ideal configurations where the static pressure may be significantly lower than that in practical installations) and that in the sound testing (which attempts to mimic practical conditions). One option is to do airflow testing including a "typical" duct system between the fan and the airflow apparatus. Another is to specifically recommend inclusion of a fan in the sound testing system to adjust the static pressure experienced by the unit under test, by controlling the relative static pressure of the "anechoic" space. Given the observed dependence of sound power on fan speed, the tolerances of 1% for voltage and fan speed are appropriate.

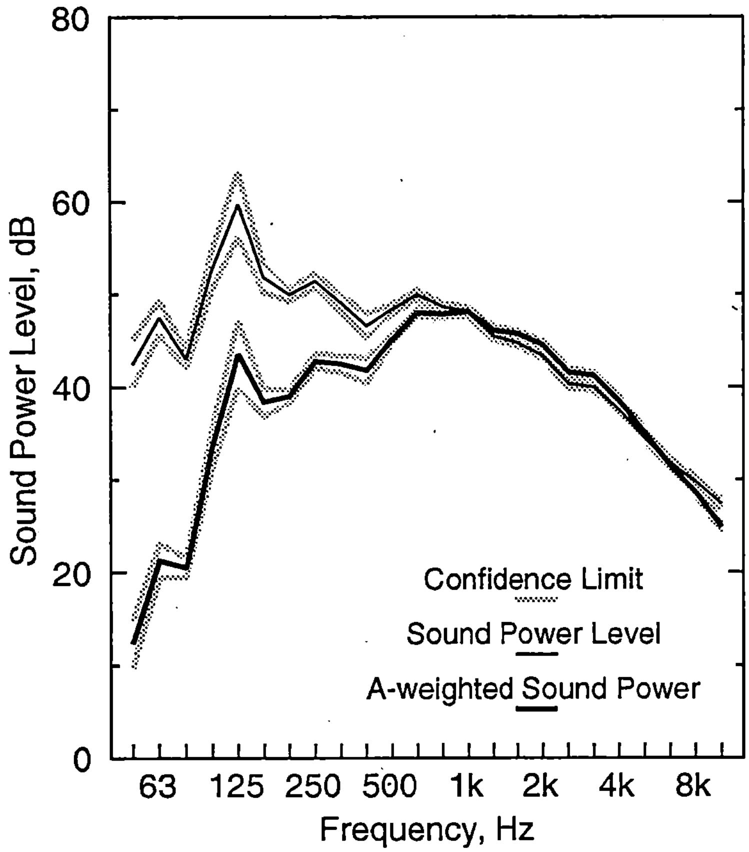
2. **Acceptable precision**: Existing standards such as ANSI S1.31 and S1.32 discuss precision only in terms of results for individual one-third-octave bands. CSA C260 simply copies these. For this application, the really significant issue is the uncertainty in the A-weighted sound power level. It is the estimated precision in the dBA value that should be stated with the rating and used to determine whether additional microphone or source positions are needed.

3. **Graphical presentation of results**: The standard does not identify whether graphical presentation of results should use A-weighted or un-weighted values for the one-third-octave sound power. To emphasize the relative importance of frequency bands to the overall rating (the A-weighted sound power), presenting A-weighted levels in the graph is strongly recommended.

APPENDIX A: SOUND POWER DATA FOR UNITS TESTED

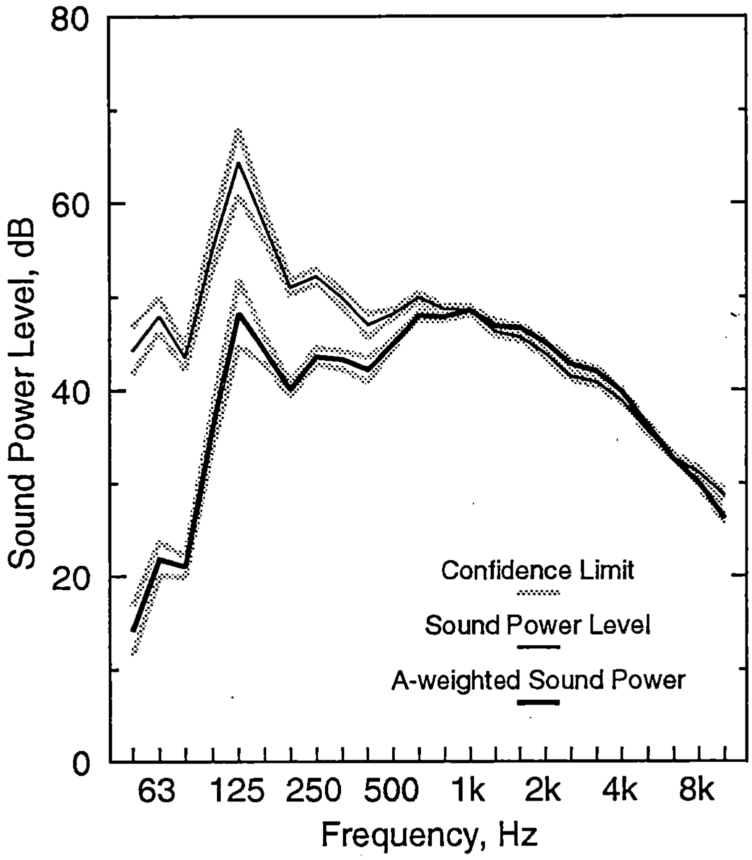
Data for specific fans tested are presented on the following pages.

Figure A1: Sound power and A-weighted sound power for ceiling exhaust fan #1. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 56.7 dBA.



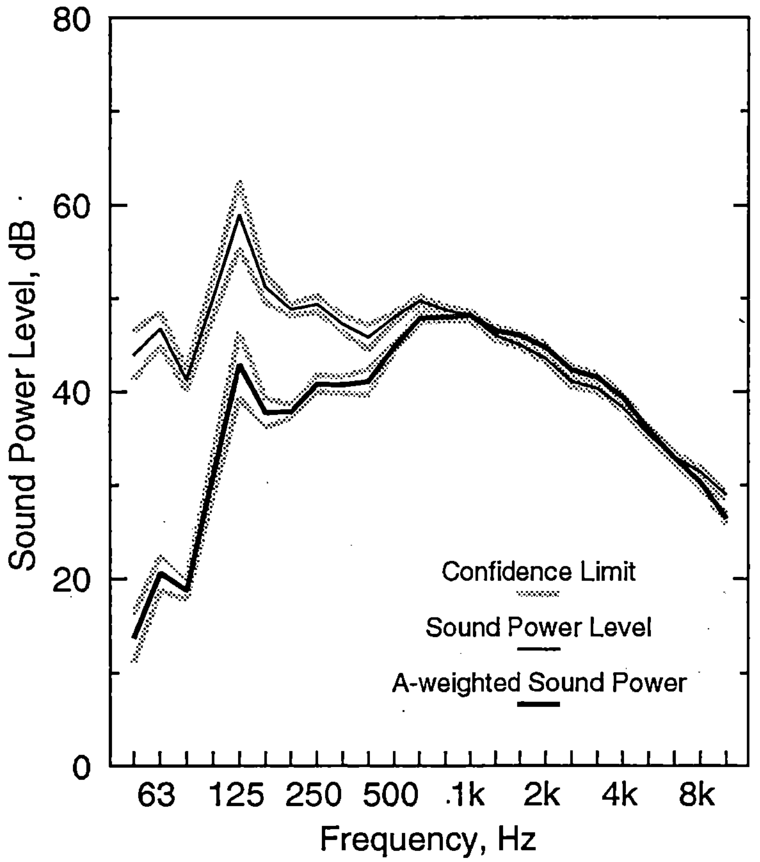
Frequency Band, (Hz)	Sound Power, (dB)
50	42.5
63	47.5
80	43.0
100	52.5
125	59.7
160	51.8
200	49.9
250	51.4
315	49.1
400	46.6
500	48.3
630	49.9
800	48.6
1000	48.1
1250	45.5
1600	44.8
2000	43.4
2500	40.3
3150	40.0
4000	37.5
5000	34.4
6300	31.7
8000	29.7
10000	27.4
Overall (dBA)	56.7

Figure A2: Sound power and A-weighted sound power for ceiling exhaust fan #2. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 57.6 dBA.



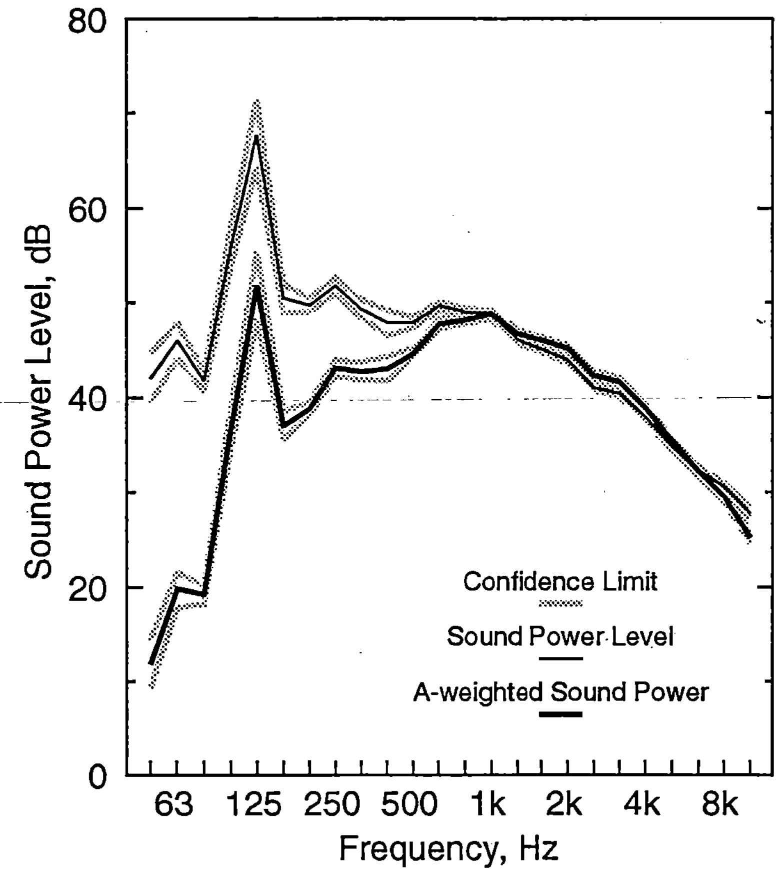
Frequency Band (Hz)	Sound Power (dB)
50	44.3
63	48.0
80	43.5
100	55.0
125	64.4
160	57.7
200	51.0
250	52.2
315	49.9
400	47.0
500	48.2
630	49.9
800	48.7
1000	48.6
1250	46.3
1600	45.7
2000	43.9
2500	41.4
3150	40.8
4000	38.8
5000	35.6
6300	32.7
8000	31.1
10000	28.7
Overall (dBA)	57.6

Figure A3: Sound power and A-weighted sound power for ceiling exhaust fan #3. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 56.6 dBA.



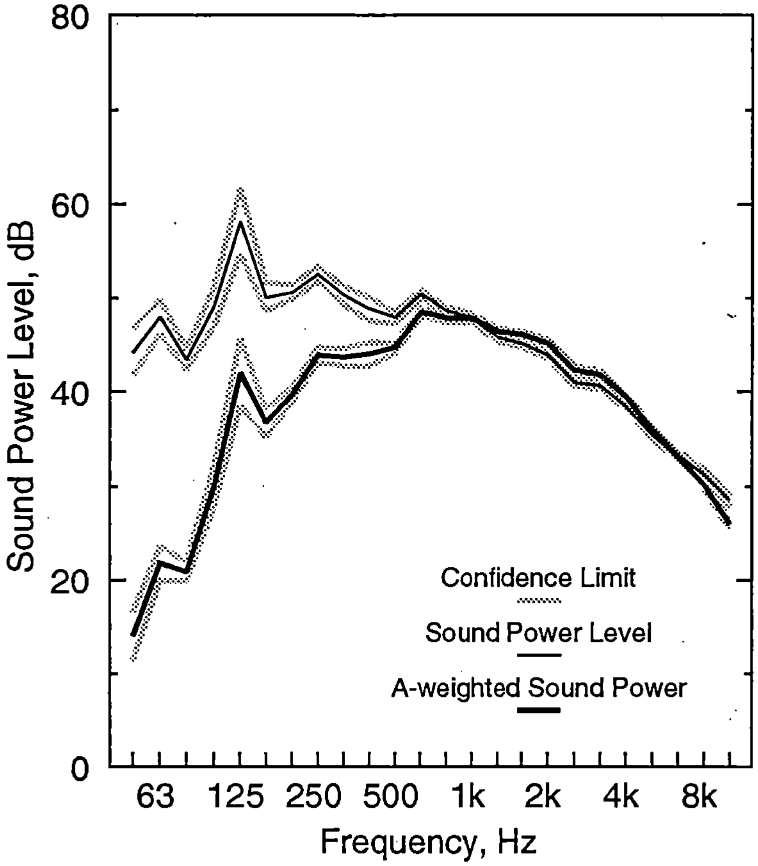
Frequency Band, (Hz)	Sound Power, (dB)
50	43.9
63	46.8
80	41.3
100	50.0
125	59.0
160	51.2
200	48.8
250	49.4
315	47.3
400	45.8
500	47.9
630	49.7
800	48.7
1000	48.1
1250	45.9
1600	45.0
2000	43.5
2500	41.0
3150	40.3
4000	38.3
5000	35.4
6300	33.0
8000	31.4
10000	28.9
Overall (dBA)	56.6

Figure A4: Sound power and A-weighted sound power for ceiling exhaust fan #4. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 57.9 dBA.



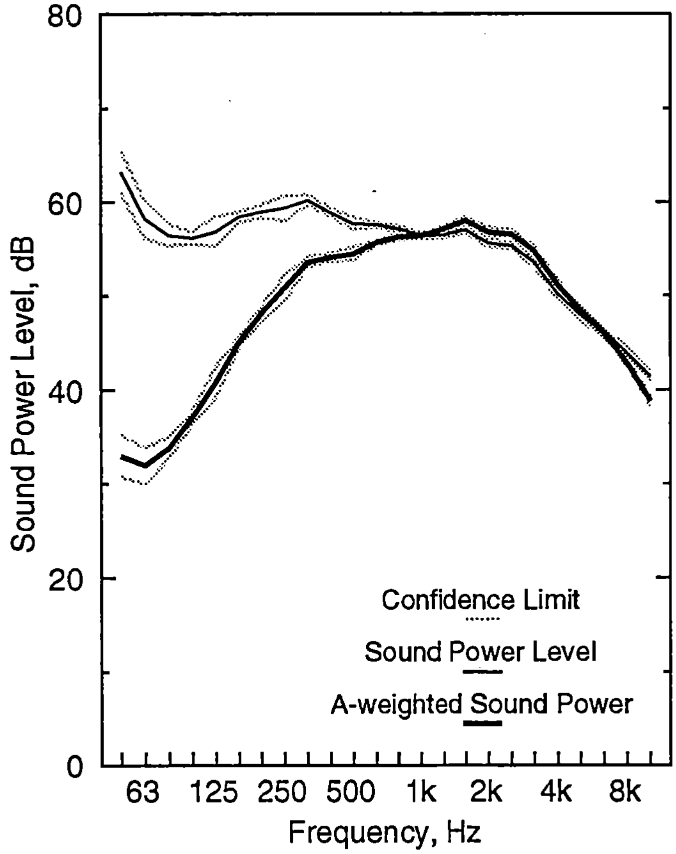
Frequency Band, (Hz)	Sound Power, (dB)
50	42.0
63	46.0
80	41.7
100	55.7
125	67.8
160	50.4
200	49.7
250	51.7
315	49.3
400	47.8
500	47.8
630	49.6
800	48.9
1000	48.8
1250	46.1
1600	45.0
2000	43.9
2500	41.0
3150	40.4
4000	37.8
5000	34.8
6300	32.2
8000	30.5
10000	27.7
Overall (dBA)	57.9

Figure A5: Sound power and A-weighted sound power for ceiling exhaust fan #5. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 56.9 dBA.



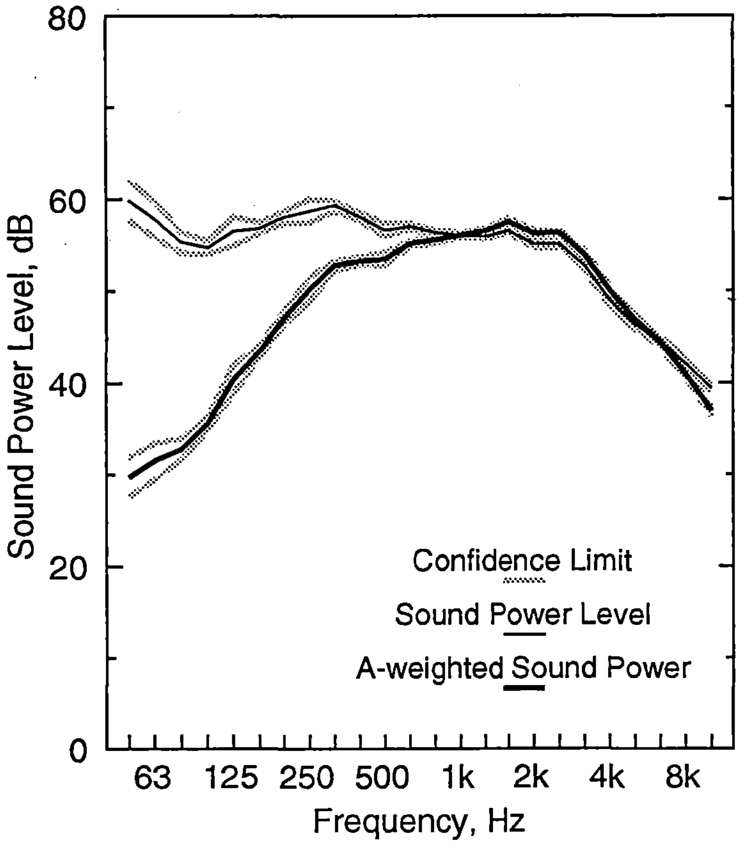
Frequency Band, (Hz)	Sound Power, (dB)
50	44.2
63	48.0
80	43.4
100	49.0
125	58.1
160	50.1
200	50.6
250	52.5
315	50.3
400	48.8
500	47.9
630	50.4
800	48.6
1000	47.8
1250	45.8
1600	45.1
2000	43.9
2500	41.0
3150	40.6
4000	38.4
5000	35.4
6300	33.2
8000	31.3
10000	28.5
Overall (dBA)	56.9

Figure A6: Sound power and A-weighted sound power for range hood exhaust fan #1. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 66.9 dBA.



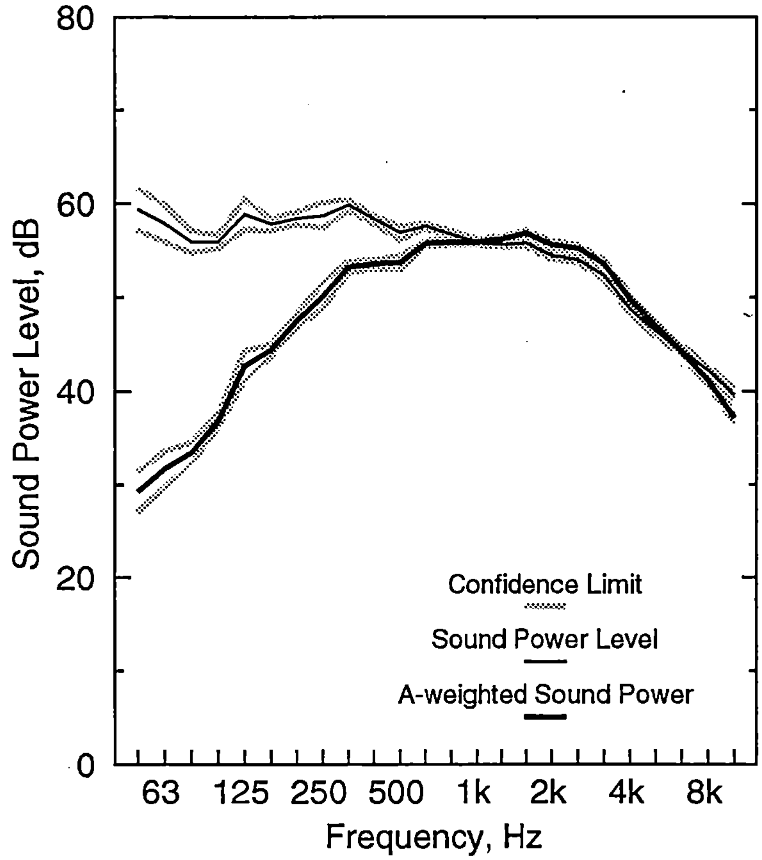
Frequency Band, (Hz)	Sound Power, (dB)
50	63.2
63	58.2
80	56.4
100	56.2
125	56.9
160	58.4
200	59.0
250	59.4
315	60.2
400	58.9
500	57.7
630	57.6
800	57.1
1000	56.4
1250	56.5
1600	57.0
2000	55.6
2500	55.3
3150	53.6
4000	50.1
5000	47.9
6300	46.1
8000	43.9
10000	41.3
Overall (dBA)	66.9

Figure A7: Sound power and A-weighted sound power for range hood exhaust fan #2. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 66.2 dBA.



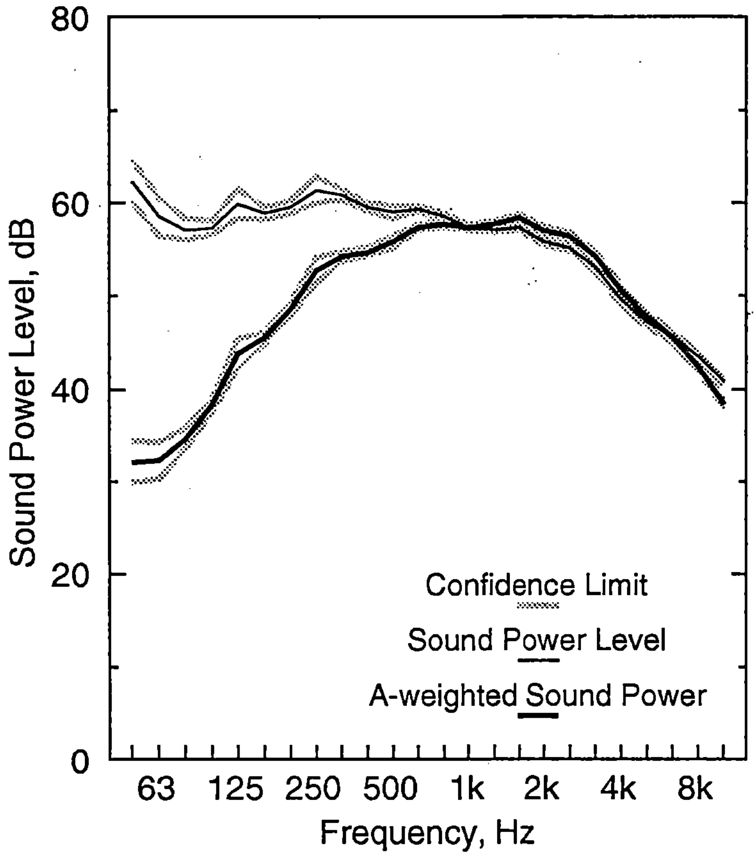
Frequency Band, (Hz)	Sound Power, (dB)
50	59.9
63	57.8
80	55.3
100	54.7
125	56.5
160	56.8
200	58.0
250	58.7
315	59.3
400	58.0
500	56.6
630	57.0
800	56.3
1000	56.0
1250	55.9
1600	56.5
2000	55.0
2500	55.0
3150	52.6
4000	48.8
5000	46.3
6300	44.3
8000	42.0
10000	39.4
Overall (dBA)	66.2

Figure A8: Sound power and A-weighted sound power for range hood exhaust fan #3. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 66.0 dBA.



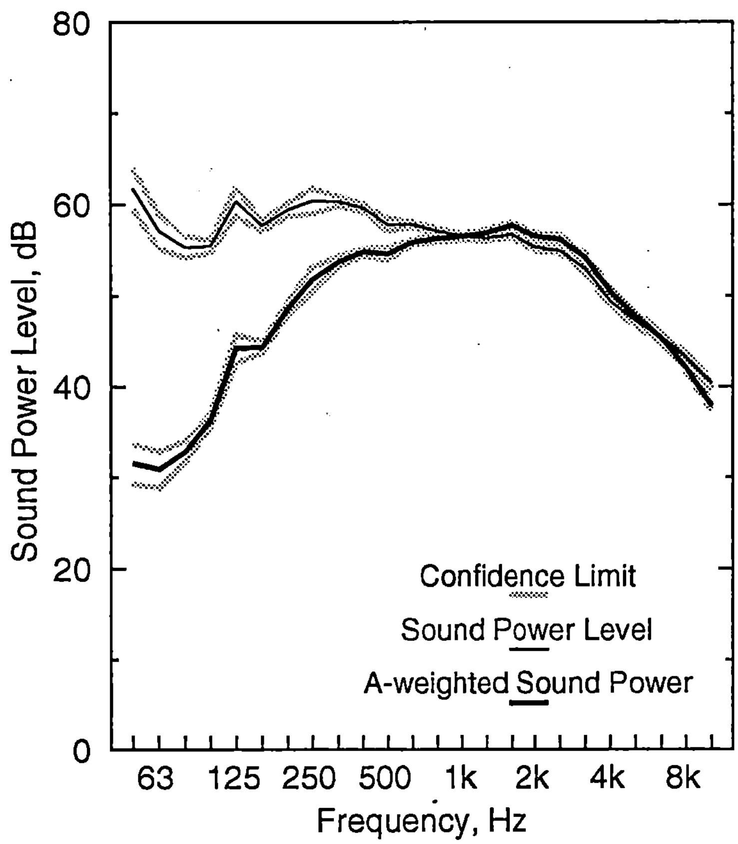
Frequency Band, (Hz)	Sound Power, (dB)
50	59.4
63	57.9
80	55.9
100	55.9
125	58.8
160	57.8
200	58.4
250	58.7
315	59.8
400	58.3
500	56.9
630	57.6
800	56.7
1000	55.9
1250	55.6
1600	55.8
2000	54.4
2500	53.9
3150	52.3
4000	48.7
5000	46.4
6300	44.3
8000	42.2
10000	39.6
Overall (dBA)	66.0

Figure A9: Sound power and A-weighted sound power for range hood exhaust fan #4. Table beside graph is measured (not A-weighted) sound power. Gray lines show 95% confidence limits. Results are mean for three stand positions. Overall rating is 67.6 dBA.



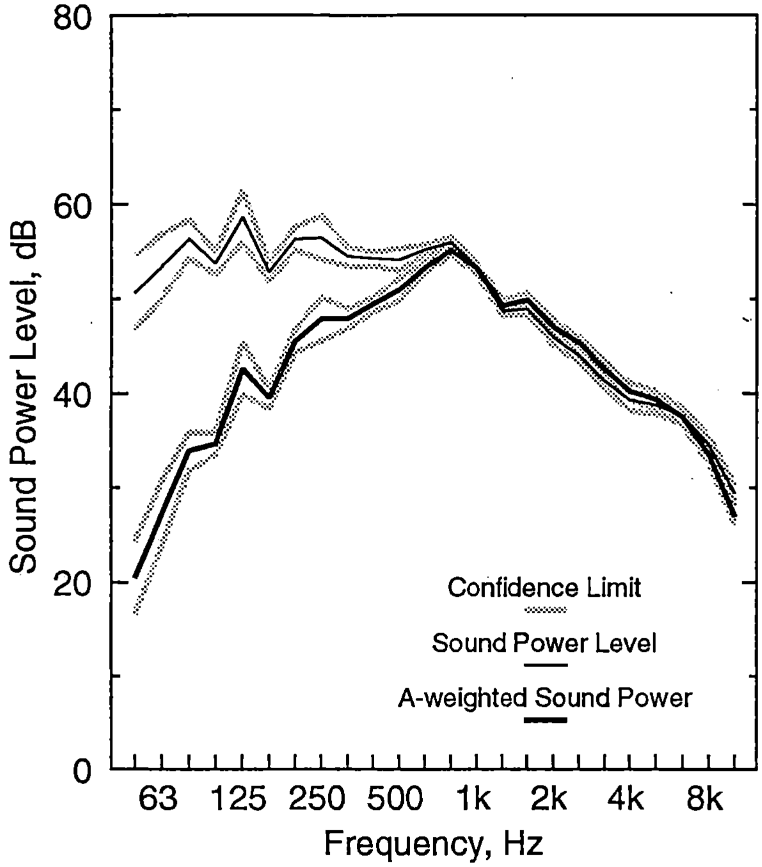
Frequency Band, (Hz)	Sound Power, (dB)
50	62.3
63	58.5
80	57.1
100	57.3
125	59.9
160	58.9
200	59.5
250	61.3
315	60.8
400	59.5
500	59.0
630	59.3
800	58.5
1000	57.3
1250	57.1
1600	57.4
2000	55.8
2500	55.1
3150	53.1
4000	49.6
5000	47.2
6300	45.6
8000	43.5
10000	40.8
Overall (dBA)	67.6

Figure A10: Sound power and A-weighted sound power for range hood exhaust fan #5. Results are mean for three stand positions. Gray lines show 95% confidence limits. Table beside graph is measured (not A-weighted) sound power. Overall rating is 66.8 dBA.



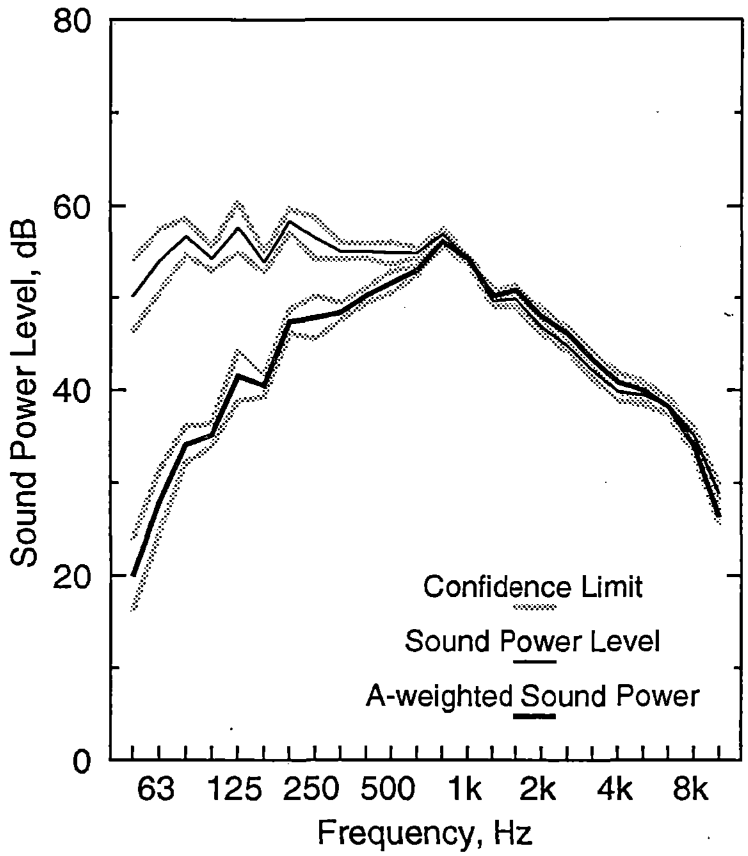
Frequency Band, (Hz)	Sound Power, (dB)
50	61.7
63	57.1
80	55.3
100	55.4
125	60.3
160	57.7
200	59.4
250	60.4
315	60.3
400	59.6
500	57.8
630	57.8
800	57.1
1000	56.5
1250	56.3
1600	56.7
2000	55.3
2500	54.9
3150	53.0
4000	49.3
5000	47.2
6300	45.4
8000	43.1
10000	40.3
Overall (dBA)	66.8

Figure A11: Sound power and A-weighted sound power for heat recovery ventilator. Results are for operation in exchange mode, with a bell mouth on both "indoor" ducts. Table beside graph is measured (not A-weighted) sound power. Overall rating is 61.7 dBA.



Frequency Band, (Hz)	Sound Power, (dB)
50	50.6
63	53.5
80	56.4
100	53.8
125	58.7
160	52.9
200	56.4
250	56.5
315	54.5
400	54.3
500	54.2
630	55.3
800	56.0
1000	53.3
1250	48.7
1600	48.9
2000	45.9
2500	44.0
3150	41.3
4000	39.2
5000	38.8
6300	37.6
8000	34.6
10000	29.4
Overall (dBA)	61.7

Figure A12: Sound power and A-weighted sound power for heat recovery ventilator. Results are for operation in circulation mode, with a bell mouth on both "indoor" ducts. Table beside graph is measured (not A-weighted) sound power. Overall rating is 62.3 dBA.



Frequency Band, (Hz)	Sound Power, (dB)
50	50.1
63	54.0
80	56.6
100	54.2
125	57.6
160	53.8
200	58.3
250	56.4
315	55.0
400	55.0
500	54.8
630	54.8
800	56.9
1000	54.2
1250	49.6
1600	49.8
2000	46.8
2500	44.8
3150	42.1
4000	39.8
5000	39.4
6300	38.2
8000	35.0
10000	28.8
Overall (dBA)	62.3

APPENDIX B: COMMENTS BY TEST OPERATORS

The work on this project was divided into three parts: testing of the ten exhaust fans, subsequent evaluation of dependence on fan speed and other factors, and testing of the heat recovery ventilator. These tasks were handled by different operators. What is presented here is a collection of their notes, roughly organized by topic.

Because the actual measurement of sound power is computer-controlled and proceeded uneventfully, the comments relate to setup problems and non-standard checks. Fan noise was well above background noise level.

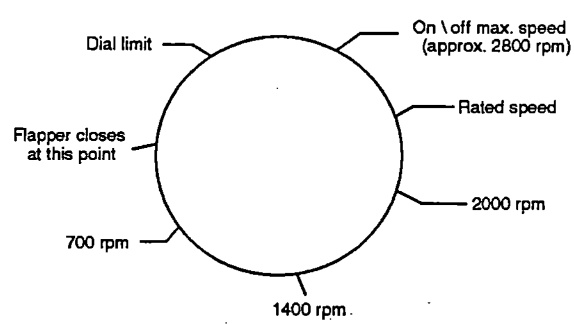
1. Measurements to check sound radiation from the stand were very difficult. Acoustic intensity scan over ducts and over back surface of the stand showed that intensity from these surfaces was at least 20 dBA below that 0.5 m from fan. This shows negligible radiation from surface of ducts.

2. Acoustic intensity scan over the opening from the adjacent anechoic chamber showed net (small) sound energy flow out of the reverberation chamber through the opening.

3. With HRV, the sound pressure level (dBA) near duct openings into reverberation chamber was more than 10 dBA above the level near the unit. Similar loudness was noted at the two duct ends. It would be easier to install the HRV in the anechoic space, and just extend the duct(s) into the reverberation room.

4. Monitoring fan speed with a stroboscope was difficult to do to the required 1% precision; it seemed the stroboscopes were not stable. Subsequent monitoring using a light beam shining through the blades to the detector was harder to set up, but permitted continuous monitoring that showed that the fan speeds were not stable. Drift in speed of ceiling exhaust fans was over 1% in the first 10 minutes of operation, but then settled.

5. The quick check method (Clauses 5.4.5 and 5.3.3) requires measurements with the fan speed control at positions spaced evenly around the dial, but the sound from range hoods dropped to a negligible level in a small part of the control range. A diagram of speed versus position is shown at right; sound power can be determined using Figure 11.



APPENDIX C

The main sound rating used in CSA standard C260 is the A-weighted sound power (expressed in decibels) calculated from the measured one-third-octave band sound power levels. However, the North American fan industry has used the Home Ventilating Institute procedure for many years, and that produces a rating in sones from the measured sound power levels.

To permit comparison with manufacturers' sound ratings for the fans tested, the Sone ratings were calculated from the measured sound power levels. The comparison is complicated by the problem of selecting the "appropriate" example of fan performance, and by incomplete specification of the procedure in CSA C260 (an oversight by the author) as discussed below:

- For purposes of this report, the mean sound power for each group of fans was used for the Sone calculation. The HVI document does not identify the sampling procedure used; if the procedure permits the use of the lowest level obtained in repeated testing, then the manufacturers' ratings might be significantly lower than the results here. Systematic discrepancies might also occur for fans with strong pure tones (such as the bathroom exhaust fans) because the HVI measurement procedure, which uses only one source position and one microphone position, could significantly reduce apparent tone strength.

- Clause 5.5.3 of CSA draft standard C260 states that a sone rating, if desired, may be calculated by subtracting 14.65 decibels from measured one-third-octave band sound power levels, and then determining loudness in sones following ANSI Standard S3.4-1980. Unfortunately, ANSI S3.4 permits calculations with either octave band or one-third-octave band levels, and these may give slightly different results. The HVI procedure matches the ANSI S3.4 calculation for octave bands.

Fan Type	dBA	Sones (octave)	Sones (1/3-octave)	Sones (HVI)
Bathroom exhaust	57.1	3.0	2.7	1.5
Rangehood	66.7	6.0	6.0	5.5
HRV	62.0	4.2	4.1	

Results of the sone calculations are presented in the table above; published HVI ratings are in the final column. Discrepancies between the present results and the HVI ratings could have several causes. Measurement uncertainty and variation among tested fans could account for part of the discrepancy. Differences in operating conditions might be significant - the HVI rating of 1.5 sones for the bathroom exhaust fan is at 8 cfm flow, and the rating of 5.5 sones for the rangehood is with vertical discharge at 200 cfm. Differences in the "appropriate result" selection process may also account for some of the difference.