A SENSITIVITY ANALYSIS OF FACTORS THAT EFFECT SOUND TESTING IN A SEMI-REVERBERANT SOUND CHAMBER

A Thesis

by

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ABSTRACT

The need to understand and control factors influencing sound testing of range hood and bathroom ventilation fans in a semi-reverberant sound chamber is of great importance to both certification bodies, such as the Home Ventilation Institute, and private designers of household demand-controlled ventilation fans. The use of sones as a unit for fan noise is superior to decibels as it captures the human perceived sound loudness. The maintenance and improvement of procedures requires consideration of many possible sound testing influences, such as weather influences on the Resonant Sound Source (RSS) used during testing, the impact of the RSS on final sone values, and various sources of variability as evaluated by a gauge repeatability and reproducibility study.

Data taken for the investigation of possible correlations between measured RSS with weather spanned a period of four quarters starting in the fourth quarter of 2017 and was made up of ten randomly selected sound tests per quarter performed at RELLIS Energy Efficiency Laboratory (REEL).

Also considered in this study was the effect the RSS has on final sone values. This was quantified by the ratio of the room characteristic ratio to fan sound power levels. This study identified key conditions that cause the RSS to contribute maximally to sones. The role of the critical frequency band for a given sound test was examined by correlating the room characteristic ratio with the frequency of the critical band over a sample of 40 tests per RSS type, showing a -52% correlation coefficient relation.

The gauge repeatability and reproducibility analysis showed the total gauge repeatability and reproducibility (GR&R) of the entire sound measurement system as a percent of the total

standard deviation was found to be 5.57%, which is less than the commonly accepted value of 10% for most measurement systems. This GR&R value was used for comparison to recent variation due to requalification efforts involving changing microphone type (free field vs. diffuse), showing that the variance of requalification for new microphone types is less than the normal expected variance of the measurement system due factors such as changing operators, mounting and dismounting, etc.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

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NOMENCLATURE

a	Alpha; one minus the confidence level (nondimensional)
AD	Air Density (lbm/ft^3)
ANOVA	Analysis of Variance Method
ASHRAE	American Society of Heating, Refrigerating & Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
CFM	Cubic Feet per minute
F Statistic	Ratio of the Mean Squares of Interaction and Repeatability
HVAC	Heating Ventilation & Air Conditioning
HVI	Home Ventilation Institute
L_{pf}	Fan Sound Pressure Level (dB)
L_{pr}	RSS Sound Pressure Level (dB)
L_{wf}	Fan Sound Power Level (dB)
LCL	Lower Critical Level
MSA	Measurement System Analysis
N	Total degrees of freedom
P Statistic	Significance; Right tailed probability distribution (nondimensional)
R&R	Repeatability and Reproducibility
RCR	Room Characteristic Ratio (nondimensional)
REEL	RELLIS Energy Efficiency Laboratory
RH	Air Relative Humidity (%)
RPM	Revolutions per minute

RSS	Resonant Sound Source
S	Final Sound Value (sone)
s_{max}	Critical sone value (sone)
SSA	Sum of Squares for the Appraiser ($sone^2$)
SSAB	Sum of Squares for the interaction between Appraiser and Parts ($sone^2$)
SSB	Sum of Squares for the Parts ($sone^2$)
SSE	Sum of Squares for Repeatability ($sone^2$)
T	Time (s)
TSS	Total Sum of Squares
UCL	Upper Critical Level

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1. INTRODUCTION

The analysis of factors affecting the HVI standard loudness in the unit sone is important for the engineering and design for certification and verification testing of demand-controlled ventilation fans [1]. Due to these applications, further experimental data analysis has become necessary to understand the parameters at work during a sound test, especially for any possible impact on final sone test results. The sone unit is important for applications of fan technology where human comfort level is a design concern as sones were developed using human testing of perceived sound loudness. Although the theory of sones is well understood, examination of historic data needs to be done to continually optimize procedures and to insure control of variables during testing.

As a result, such metrics as historical ambient conditions, repeatability, and reproducibility must be used to quantify efficacy of the sound chamber and the sensitivity of sones. The aim of this research is to use historical Resonant Sound Source data and weather data to identify any possible trends in conjunction with gauge repeatability and reproducibility (GR&R) in order to determine the sensitivity of a semi-reverberant sound room.

1.1 Objectives

The objective of this study is to determine the sensitivity of a sound chamber with respect to ambient conditions, variations in the resonant sound source (RSS), and variations in gage R&R. The RSS studies will be used to determine if or when the RSS impacts sone values and the extent of these impacts. The GR&R studies will provide an overall system variation that will then be used for comparison purposes to any variation caused from the RSS or other equipment changes or sound room requalification efforts.

1.2 Scope

The scope of this study will focus on the following:

- An analysis of historic influences on RSS over a year long period to determine the possible influences of weather on the RSS used during sound testing. The weather variables considered include temperature, air density, and relative humidity.
- RSS influences on sones and critical bands will be analyzed using parameters such as RCR/L to evaluate correlation statistics for any extant trends.
- A repeatability and reproducibility study will then be used to quantify system variation and to ensure all influences on sone values are in control and to ensure that the measurement system is functioning efficiently and effectively with respect to several sources of variation (operator, mounting changes, etc.)

1.3 Literature Review

The ground work studies for the current HVI sound loudness rating procedure are those conducted by Stevens in the early 1960s [2]. Stevens proposed and developed the sone unit to scale well with human perception, as opposed to dB which are more mechanical in perspective. To implement the psychological aspect of sound perception Stevens devised equal loudness curves to be applied as a weighting to fan sound power levels before the final sone value is calculated [3].

The standard that defines the requirements for sound performance and calibration for resonant sound sources used for HVI testing is ISO 6926 [4]. This standard and its supporting research seeks to provide parameters for RSS sound output steadiness, spectral characteristics, and directivity. In addition, level calibration data and uncertainty requirements for RSS sound power levels under A weighting and reference meteorological conditions are also relevant topics these standards address.

The standard that the Home Ventilation Institute references for uncertainty in measurement is ISO 98-1 which is supported by many studies on measurement science [5]. Recent papers discuss the ANOVA method's origination in inferential statistics used to evaluate and compare the variability of data. Case studies are often used in this literature as examples of determining if a measurement system is stable and in statistical control across many contributing factors of variability [6].

2. BACKGROUND

2.1 REEL Sound Facility

The semi-reverberant sound chamber at RELLIS Energy Efficiency Laboratory (REEL) is the subject for this study. The RELLIS Laboratory contains several testing facilities and among these are the semi-reverberant sound chamber. Here, sound testing is performed in a diffuse field on bath and range hoods for verification and certification purposes. The sound tests performed at this facility rely on another facility at REEL, the air flow testing station. Air flow tests for CFM and Power are performed on the fan units to be sound tested. These air flow tests are then used to ensure that sound tests are carried out at the required static pressure recorded during air flow testing. This allows for sound tests to be commonly rated at 0.1 and 0.25 static pressure, with sones typically increasing with increases in static pressure. A schematic detailing the major components of the sound chamber can be found in Figure 1.

The main components of the sound chamber are the anechoic muffler where the fan unit is mounted, the baffles used for hard surface reverberation, the Resonant Sound Source, and an array of six microphones used for sound power level averaging within the diffuse field reverberation radius of the fan. Air enters the chamber through the external boost blower and exits through the anechoic chamber.

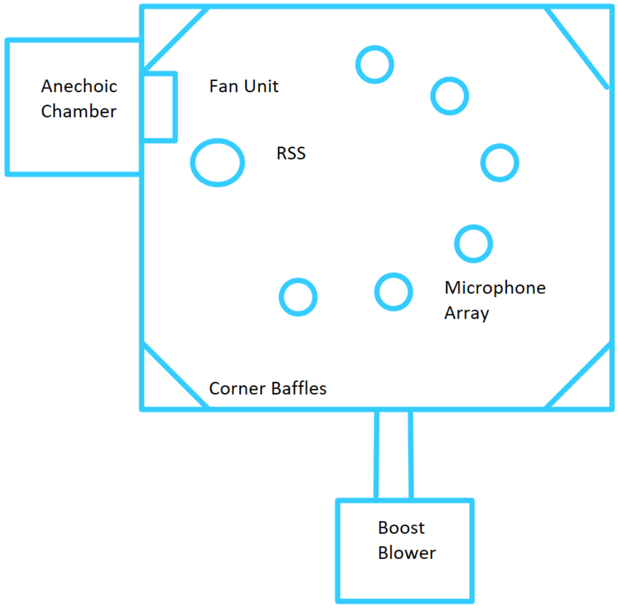

Figure 1: Semi-reverberant sound chamber diagram.

The RSS is used to create an upper limit for sound loudness and allows for the characterization of individual sound test facilities by way calculating the Room Characteristic Ratio (RCR). Background measurements taken during testing are used as a sound loudness floor and are subtracted from other measurements to remove ambient noise from sound measurements.

2.2 Data Measurements and Processing

The HVI 915 Loudness Testing Standard outlines the process for calculating sones. A sound test is made up of several measurements that are recorded and then processed by calculator procedures produced by the Home Ventilation Institute (HVI). During a sound test, four spectral parameters are measured; Fan + Background, Background, RSS + Background, and a second background to check for steadiness. The first background is subtracted from the Fan + Bkg and RSS + Bkg respectively. The room characteristic ratio is then calculated by subtracting the measured RSS from calibrated RSS data, this difference is a ratio due to the logarithmic nature of decibels [7].

After that, the fan sound power level, L_{wf}, is computed by simply adding together the Fan and the characteristic ratio. This value, once converted to sound pressure by subtracting a constant 14.65 dB across all bands, is the final step before HVI look up tables are used to find the equal loudness in sones. The sound power therefore represents the term where both the RSS and the Fan are combined into a single value.

$$\boldsymbol{L_{wf} = L_{pf} + RCR} \qquad \text{Eq. (1)}$$

The definition of the room characteristic ratio is then used to show the three components that make up Fan sound power, namely, the sound pressure levels of the fan, RSS, and RSS calibration data. Clearly, the smaller the difference between the measured RSS and its calibration data, the smaller the impact of RCR on sones will be. By extension, small RCR values translate into a small overall impact that any RSS has on final sone values.

$$\boldsymbol{L_{wf} = L_{pf} + L_{wr} - L_{pr}} \qquad \text{Eq. (2)}$$

The final sone value is then calculated using look up tables for decibels to find the equal loudness in sones. These look up tables are based on equal loudness curves plotted from human testing studies to determine the perceived loudness across a spectrum of frequencies. An important aspect of the final sone value is the sone level of the critical band, s_{max}. This frequency band alone makes up 85% of the final sone value.

$$\boldsymbol{S = 0.85 s_{max} + 0.15(s_1 + s_2 + \cdots + s_{23} + s_{24})} \qquad \text{Eq. (3)}$$

Typical critical bands are usually chosen based on the blade pass frequency of the particular fan being tested. Blade pass frequency is found by dividing the product of RPM and the number of fan blades by sixty and is typically observed in the middle of the audible frequency range (500 – 5,000 Hz).

3. METHODOLOGY

Three main analysis were performed in this study; a historic examination of RSS data in conjunction with seasonal weather data, a statistical study on spectral RSS data and its effect on sones, and a gauge repeatability and reproducibility study for measurement system evaluation. In determining the sensitivity of the sound measurement system to variables such as weather, RSS, and different sound technicians, etc., it is necessary to quantify the systems variability in terms of gauge repeatability and reproducibility (GR&R). An R&R study has a twofold application. First, it gives the expected variation of the measurement system under normal testing conditions. Also, it allows for comparison to other sources of variability outside of the scope of R&R. Such sources of variation often arise when major equipment changes are made to the sound room such as microphones or RSS type, resulting in the need for a third party requalification.

3.1 Historic Influences on RSS

A study has been performed on RSS data gathered from REEL sound testing to determine the effect, if any, ambient conditions have on the RSS. Two resonant sound sources (denoted B&K of Bruel and Kjaer Sound and Vibration and ILG of ILG Electric Ventilation Co.) were analyzed and compared over a common period starting from December of 2017 to July of 2018. From the four quarters represented in this sample the critical band data of ten random tests per quarter were selected for each RSS. Further test specific data were also compiled such as CFM, static pressure, RPM, and sones. The weather parameters studied are listed below.

Ambient Weather Variables

- Temperature
- Relative Humidity
- Air Density

Each weather variable were correlated with the RSS data for tests done on a given day to show possible trends over time. These variables were selected as they were thought to have the most impact on RSS performance and also based on the humid southwest region REEL is located within. Hot summers are common and seasonal trends are easily identifiable in the weather data. Counter trends with temperature should be identifiable in air density correlations since temperature and air density are inversely proportional.

3.2 RSS Influences on Sones

Different sound rooms set up to the same standards can give different choices for critical bands when the same unit is tested in both rooms. Since the choice of the critical band plays such a large role in the calculation of the final sone value (85%) a study was performed to determine how large of a contribution the Room Characteristic Ratio (RCR) has on sones. RCR/L would be the contribution of the RSS to the final sone value. RSS/RCR represents how much the measured RSS contributes to the characteristic ratio and since the RCR is meant to be fairly constant this ratio allows different critical bands across different tests may be compared. These ratios were studied for the time period to determine the RSS's impact on sones.

The sound power represents the term where both the RSS and the Fan are combined into a single value. Then RCR/L would be the contribution of the RSS to the final sone value. Since the choice of the critical band plays such a large role in the calculation of the final sone value (85%) a study was performed to determine how large of a contribution the RCR has on sones.

3.3 Quantifying Expected System Variation with R&R

Measurement System Analysis (MSA) is carried out with the goal of qualifying measurement uncertainty. This consists of accuracy, bias, and precision (including repeatability and reproducibility). Ensuring the consistency and stability of these quantities over time is the purpose of MSA. Repeatability is the variability in the sound testing procedure caused by the devices taking the measurement. Reproducibility is the variability in the sound testing procedure caused by elapsed time between gauges and changing operators of the devices taking the measurement.

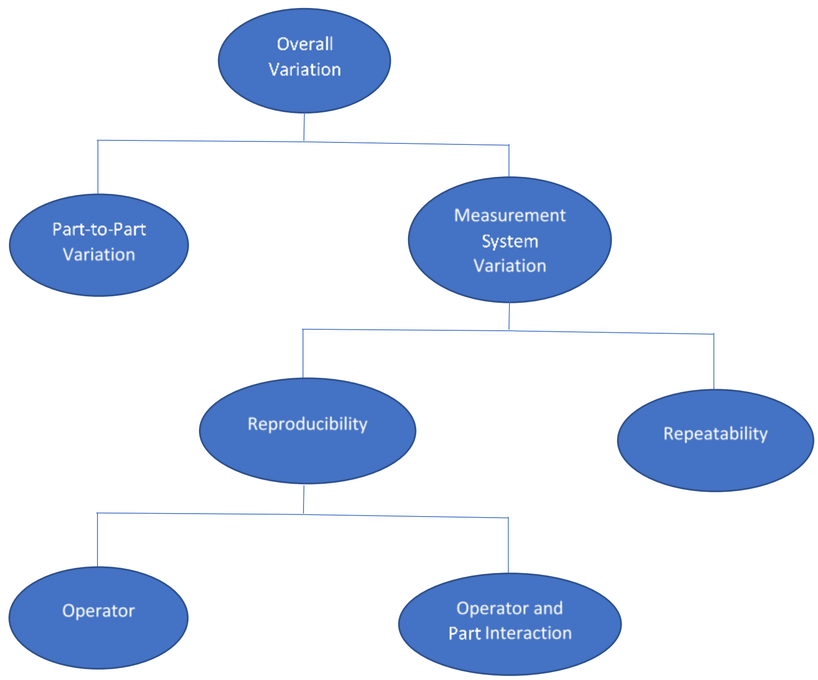

Figure 2: The structure of a repeatability and reproducibility study.

A gauge R&R study was done to determine whether the measurement system variability due to operator and equipment is small when compared to the variation of actual values the system is capable of measuring. Gauge R&R can be facilitated by the Analysis of Variance method (ANOVA). Using multiple populations of data, ANOVA calculations estimate the differences between the sample means of the different populations and therefore allows analysis of respective variances. The ANOVA method is currently considered the most accurate method to determine gauge R&R.

ANOVA divides the data into distinct groups so that sum of squares calculations may be performed for each group. The ANOVA design used is a two-way, fixed effects model with replications used to perform R&R. Replications refers to the test setup being nested, meaning it is possible to test the same unit multiple times. The typical ANOVA table layout is presented below, showing the setup of a R&R study consisting of some number of appraisers, a, making measurements on some number parts, b, each with a given number of trials, n. The total number of measurements, N, is used to find the total number of degrees of freedom and Y_i represents the sample mean for the i^{th} group.

Table 1: The structure of a typical ANOVA table.

Source of Variability	Degrees of Freedom	Sum of Square	Mean Square	F Test
Appraiser	$a-1$	SSA	$MSA=\frac{SSA}{a-1}$	$F=\frac{MSA}{MSE}$
Parts	$b-1$	SSB	$MSB=\frac{SSB}{b-1}$	$F=\frac{MSB}{MSE}$
Interaction (Appraiser, Parts)	$(a-1)(b-1)$	$SSAB$	$MSAB=\frac{SSAB}{(a-1)(b-1)}$	$F=\frac{MSAB}{MSE}$
Gage Error	$ab(n-1)$	SSE	$MSE=\frac{SSE}{(ab)(n-1)}$	
Total	$N-1$	TSS	-	

The sum of squares equations are given below which utilize four different means; the grand mean and the means for measurements with the same part, the same operator, and the same part and operator (repeatability).The Sum of Squares (SS) for the appraiser is calculated by summing each part for individual trials for each appraiser, then subtracting the grand mean squared divided by the total degrees of freedom.

$$\boldsymbol{SSA = \sum_{i=1}^{a} \frac{(Y_{i..})^2}{bn} - \frac{Y_{..}^2}{N}} \quad \text{Eq. (4)}$$

The SS for the parts is found by summing over each trial across all appraisers and then subtracting the grand mean.

$$\boldsymbol{SSB = \sum_{j=1}^{b} \frac{(Y_{.j.})^2}{an} - \frac{Y_{..}^2}{N}} \quad \text{Eq. (5)}$$

The Sum of Squares for Appraiser and Part interaction (SSAB) is calculated summing over individual parts for individual appraisers. This squared sum less the grand mean and SSA and SSB gives the SSAB.

$$\boldsymbol{SSAB = \sum_{i=1}^{a}\sum_{j=1}^{b}\frac{(Y_{i..})^2}{n} - \frac{Y_{..}^2}{N} - SSA - SSB} \quad \text{Eq. (6)}$$

The Total sum of Squares (TSS) is found by simply squaring all measurements, then summing all of these values, and finally subtracting the grand mean.

$$\boldsymbol{TSS = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} Y_{ijk}^2 - \frac{Y_{..}^2}{N}} \quad \text{Eq. (7)}$$

The sum of squares for repeatability when appraiser part interaction is significant is found by the following equation. A similar equation is used for SS of repeatability whenever interaction is insignificant, the modification being that the SSAB term does not appear.

$$\boldsymbol{SSE = TSS - SSA - SSB - SSAB} \quad \text{Eq. (8)}$$

The ‘F test’ in ANOVA determines whether the averages in each group population are equal and can be thought of between group variability over within the variability with the group. This means that for populations where the between group variability is large or where the mean square of interaction is large relative to the mean square of repeatability, the F statistic will be large.

$$\boldsymbol{F = \frac{MS_{Part*Op}}{MS_{Rep}}} \quad \text{Eq. (9)}$$

The column denoted ‘P-statistic’ is the right tailed F probability distribution for two data sets, also known as level of marginal significance, and it gives the degree of diversity for two data sets. Alpha is one minus the confidence level which are 95%, making typical alphas to test the interaction p values 0.05.

These values are used to determine whether interaction is significant, or when alpha is greater than the p-value. When interaction is significant, it is incorporated into calculations of repeatability and reproducibility variance. An interaction is said to occur when the differences between operators varied from one part to another. The expression used for standard deviation is shown below, where standard deviation is the square root of variance.

$$\boldsymbol{\sigma_{repeat}} = \sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n-1} \qquad \text{Eq. (10)}$$

4. RESULTS OF RSS ANALYSIS

4.1 Overview of RSS Analysis

The results of the RSS take two main forms; identifying if any seasonal weather trends are evident in the measured RSS data and determining the impact that the RSS has on final sone values. For the first study the RSS sum and average are used and for the second study the RCR/L ratio is used to quantify RSS impact on sones.

4.2 Weather Influences on RSS

4.2.1 Average RSS Data

A statistical analysis of the historical data for the RSS sum and average for both RSS's across four quarters starting in the fourth quarter of 2017 and ending in the third quarter of 2018 is shown in Tables 2 and 3. In general, the B&K outputs higher decibels than the ILG, however the two RSS show great similarity over the various statistics. For both the ILG and B&K RSS the second quarter has the highest average RSS value. Also, the average sum for each RSS over the year long period varies little.

Table 2: RSS data analysis for both ILG and B&K over Q4 of 2017 and Q1 of 2018.

	Q4 2017				Q1 2018			
	ILG		B&K		ILG		B&K	
	RSS Sum	***RSS Avg***	***RSS Sum***	***RSS Avg***	***RSS Sum***	***RSS Avg***	***RSS Sum***	***RSS Avg***
Average	1,671.49	69.69	1,791.94	74.14	1,680.84	70.03	1,789.21	74.51
Standard Deviation	38.74	1.74	7.00	1.77	236.82	9.87	4.69	0.13
Correlation with Temperature	-0.09	-0.10	0.72	0.61	-0.11	-0.11	0.64	0.85
Correlation with Relative Humidity	-0.03	-0.05	0.91	0.35	-0.20	-0.20	0.17	0.68
Max	1,780.27	74.59	1,801.91	75.08	1,799.50	74.98	1,799.66	74.67
Min	1,651.90	68.83	1.780.63	69.17	1,167.7	48.65	1,781.37	74.22

Table 3: RSS data analysis for both ILG and B&K over Q2 and Q3 of 2018.

	Q2 2018				Q3 2018			
	ILG		B&K		ILG		B&K	
	RSS Sum	***RSS Avg***	***RSS Sum***	***RSS Avg***	***RSS Sum***	***RSS Avg***	***RSS Sum***	***RSS Avg***
Average	1,676.96	69.87	1,797.22	74.98	1,662.89	69.29	1,783.59	74.32
Standard Deviation	44.60	1.86	4.15	0.32	43.76	1.82	1.76	0.08
Correlation with Temperature	-0.14	-0.14	-0.18	-0.30	-0.60	-0.60	-0.82	-0.84
Correlation with Relative Humidity	0.37	0.37	0.21	0.14	0.24	0.24	-0.45	-0.49
Max	1,802.64	75.11	1,803.83	75.77	1,786.96	74.46	1,785.50	74.40
Min	1,649.02	68.71	1,792.87	74.70	1,641.59	68.40	1,780.83	74.20

Key RSS parameters where also examined for dependence on seasonal weather trends. The data shown in Table 4 shows these parameters each correlated with temperature, relative humidity, and air density. The strongest correlations occur between air density and both the measured air RSS and RSS/RCR. However, both correlations are around 0.50 indicating no strong correlation.

The weakest correlations occur for the critical band (the frequency band for which fan sound power levels are greatest) and the RCR, and since RCR is an indicator of the RSS's effect on sones, this means weather does not have a large impact on final sone values.

4.2.2 Spectral RSS Data

The RSS data was also analyzed by breaking each test down into its spectral components. To have a qualitative view of the spectral RSS data, three dimensional plots were generated of sound power level versus frequency versus temperature for each RSS. These visualizations in Figures 3 and 4 further demonstrate the weak negative correlation between temperature and seasonal measured RSS data.

Table 4: Weather influences on two different RSS (ILG and B&K).

Parameter	Correlated To	ILG	B&K
	Correlation Statistics		
RCR/L	*Temperature*	0.20	0.31
	Relative Humidity	0.26	0.17
	Air Density	-0.16	-0.36
RSS/RCR	*Temperature*	-0.29	-0.46
	Relative Humidity	-0.33	-0.37
	Air Density	0.25	0.50
RSS	*Temperature*	-0.24	-0.43
	Relative Humidity	-0.27	-0.31
	Air Density	0.17	0.47
RCR	*Temperature*	0.26	0.37
	Relative Humidity	0.32	0.23
	Air Density	-0.21	-0.38
Critical Band	*Temperature*	-0.01	-0.22
	Relative Humidity	0.04	-0.22
	Air Density	0.00	0.24

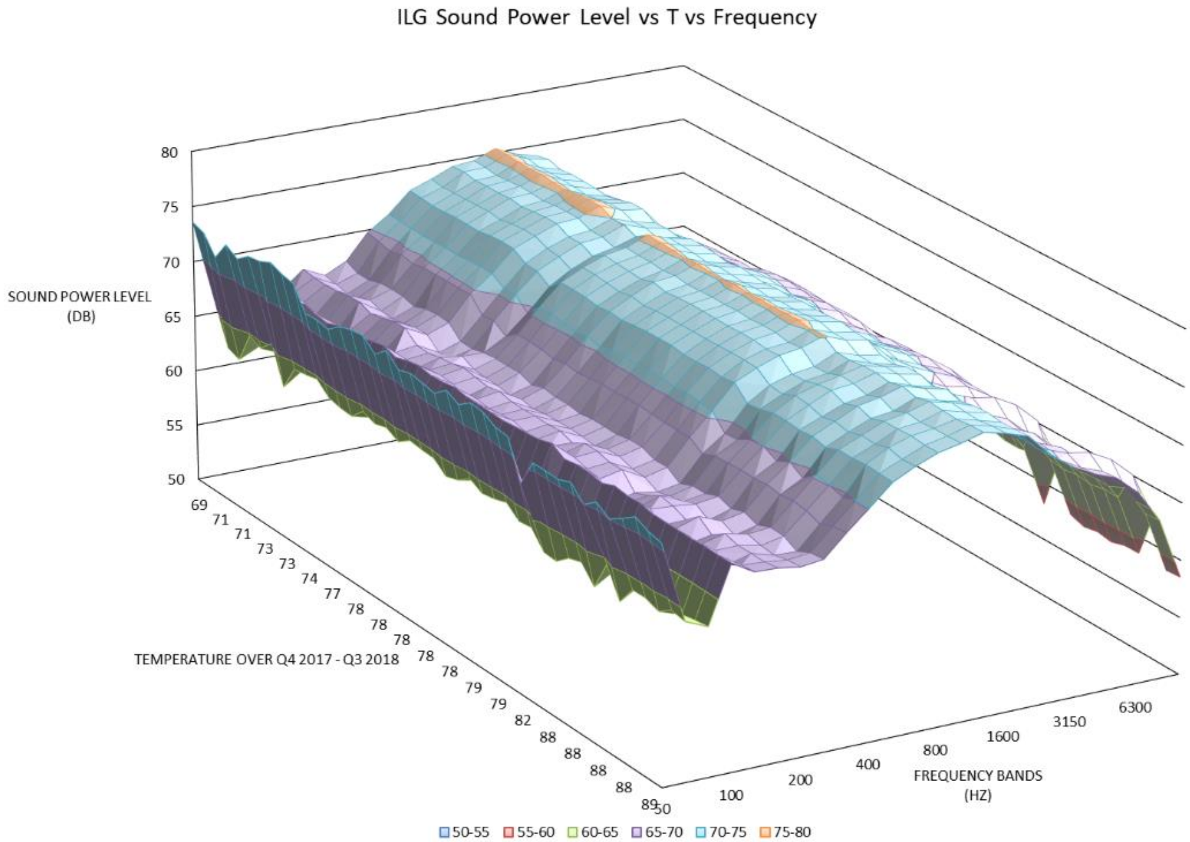

Figure 3: Three-dimensional plot of sound power level, temperature, and frequency for the ILG RSS.

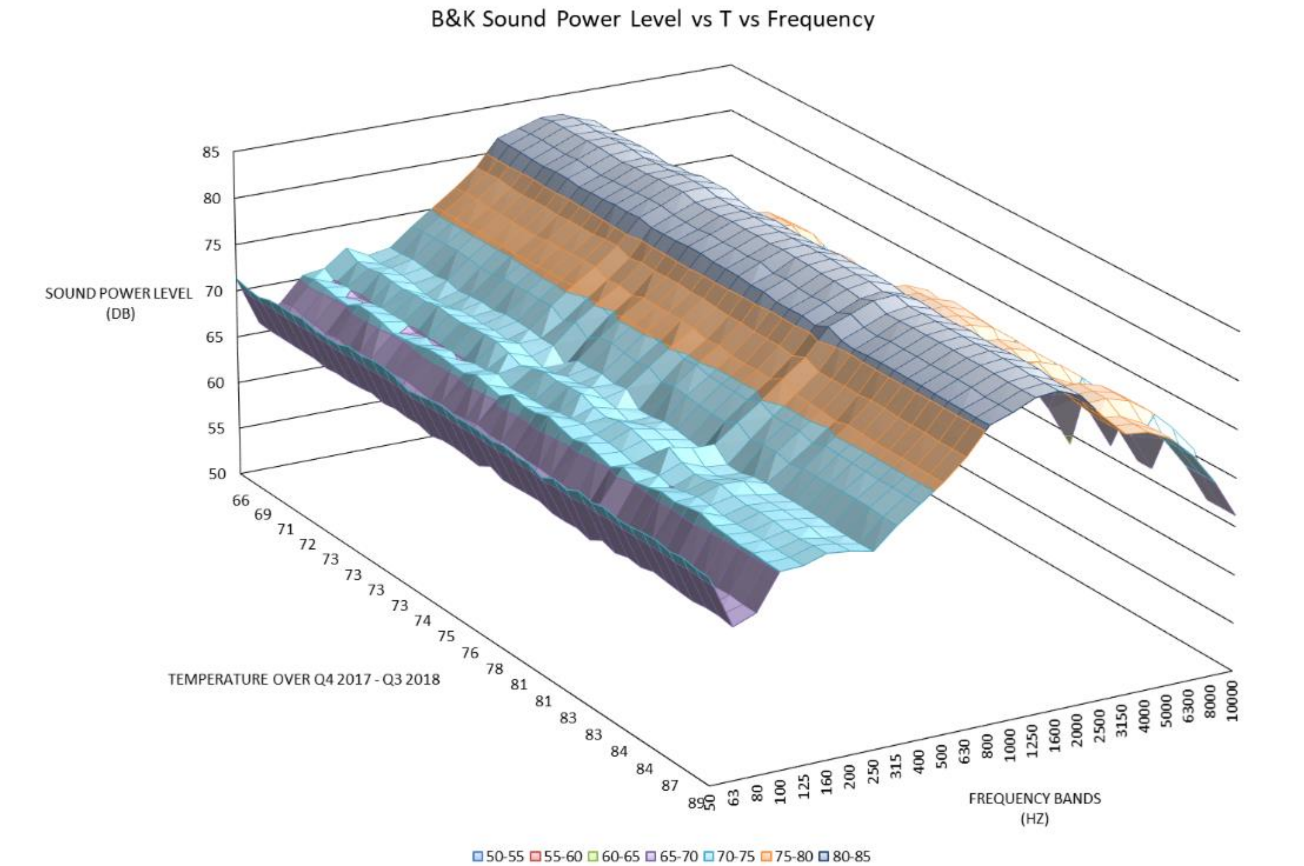

Figure 4: Three-dimensional plot of sound power level, temperature, and frequency for the B&K RSS.

4.3 RSS Influence on Sone Values

4.3.1 RCR Impact on Sones

The room characteristic ratio is generated from spectral differences in the RSS calibration data and the measured RSS sound power levels. This difference, particularly for the critical band represents, the RSS's contribution to the final sone result. Tests that have a high RCR/L ratio will have a particularly large contribution to final sone values. This RCR/L parameter may then be used to characterize tests as having an overly high contribution of the RSS to the final sone value. Figures 5 and 6 show charts of this parameter set above the corresponding weather data for each test.

For the ILG the highest percentage occurs at the extreme bands, particularly the lower bands. These bands include the range of 200 to 400 Hz. Extreme bands on the high end of the spectrum include the range 1250 to 2000 Hz. The B&K RSS shows a similar trend of higher percentages at extreme bands, however the critical bands chosen with the highest RCR/L percentage occur at the highest extreme bands. These graphs both show that there is no strong correlation between weather and impact on sones for any bands.

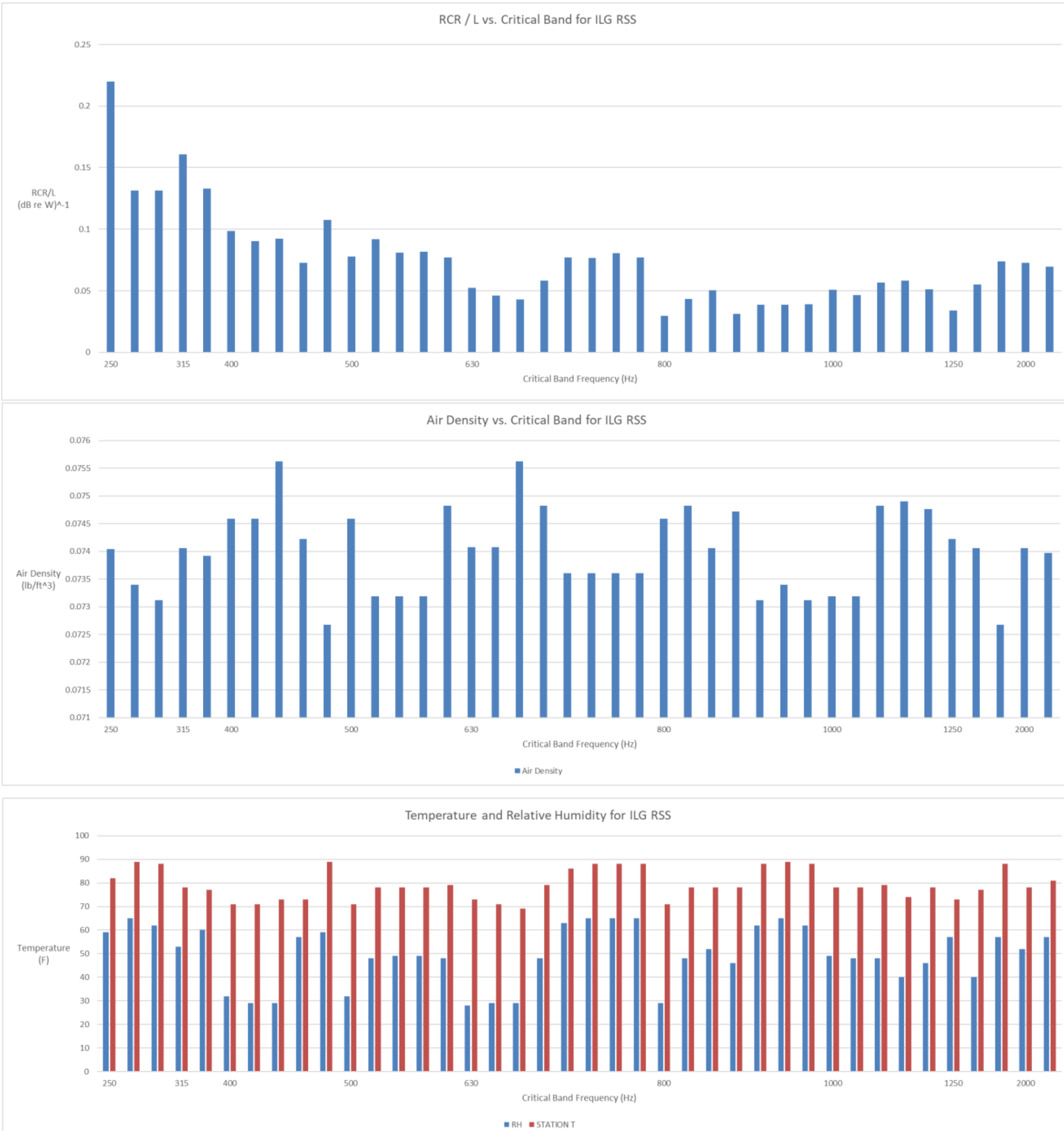

Figure 5: RCR/L charts above weather data for corresponding test days for the ILG RSS.

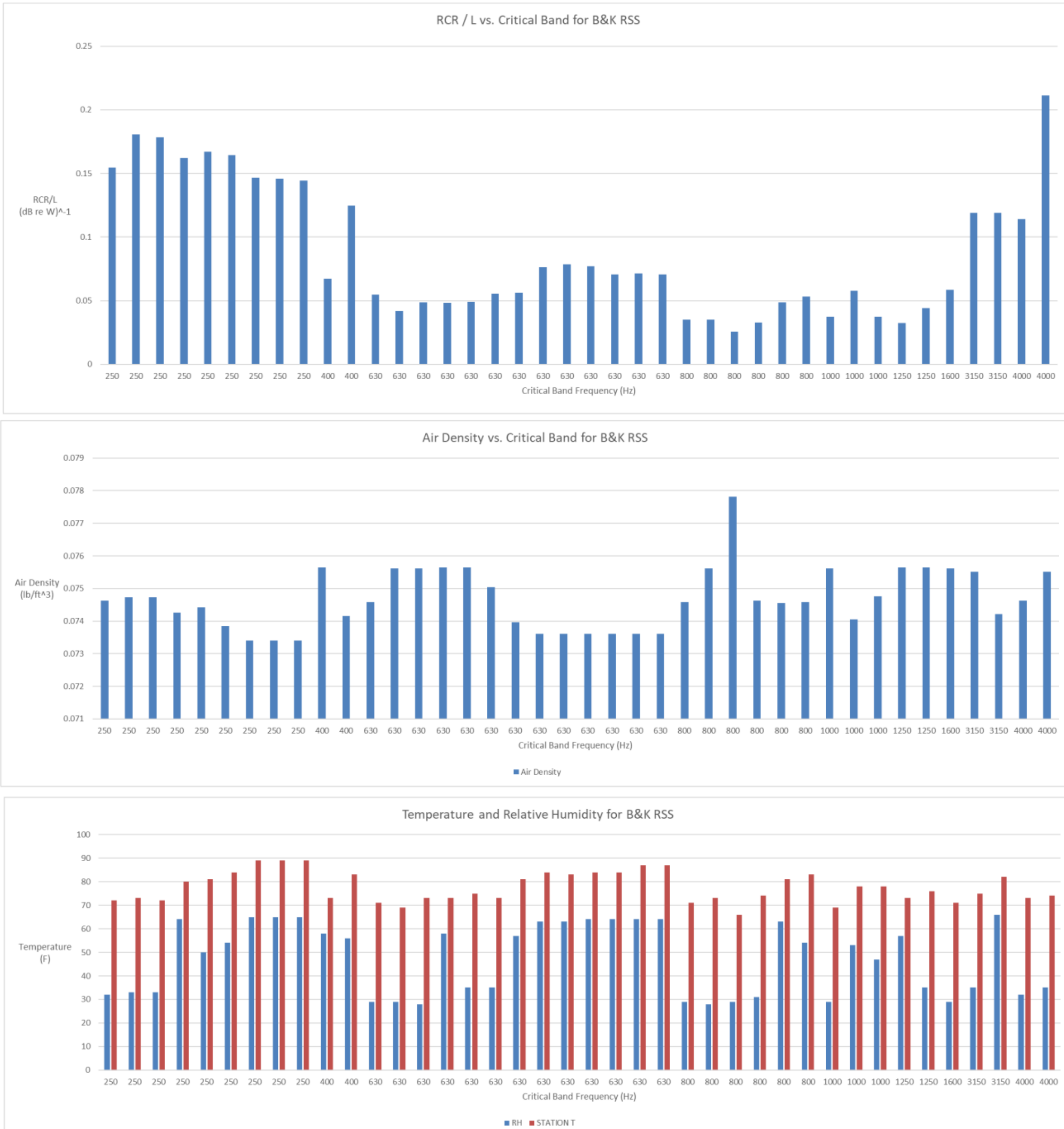

Figure 6: RCR/L charts above weather data for corresponding test days for the B&K RSS.

This occurrence of extreme bands being chosen as critical bands was further investigated by plotting RSS/RCR and RCR/L for each test in the sample. The interpretation of these graphs would be that tests that have low RSS/RCR would be those that have specifically low measured

RSS and dividing by the RCR allows for better comparison of tests. Tests that have high RCR/L would be those that have uniquely high contribution of the RSS as previously discussed. Looking for the smallest RSS/RCR and the largest RCR/L allows for the identification of a key area on Figures 7 and 8 of the bottom right hand corner. These scatter plots show the majority of tests falling in the mid to upper left-hand corner, with the bottom right-hand corner containing a few rare cases where the measured RSS is low, creating a large RCR, and at the same time this large RCR is a significant portion of the fan sound power level.

Typical Critical band frequencies for tests that have RCR/L values above 10% are 250 – 400 Hz or 3150 -4000Hz. While these band ranges are on the edges of the audible range, the current HVI testing procedure fully allows for this occurrence. The typical critical band is that which is generated by the unique blade pass frequency of the fan being tested.

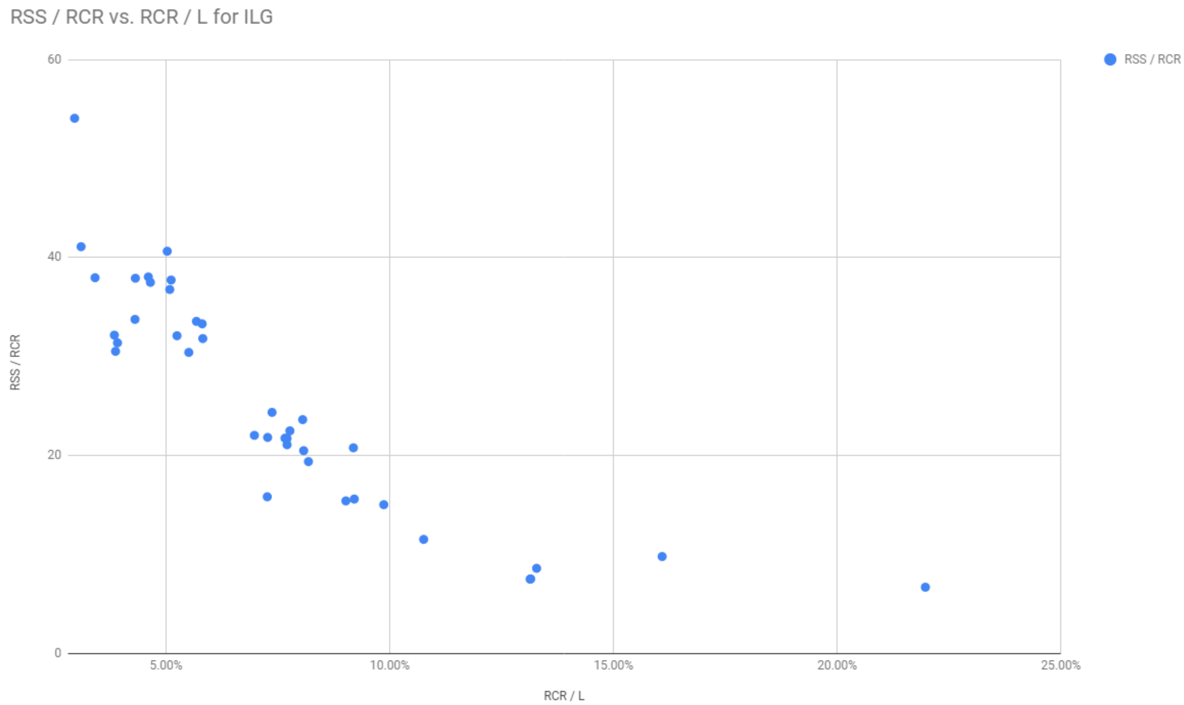

Figure 7: RSS/RCR vs. RCR/L for tests across four quarters for the ILG RSS.

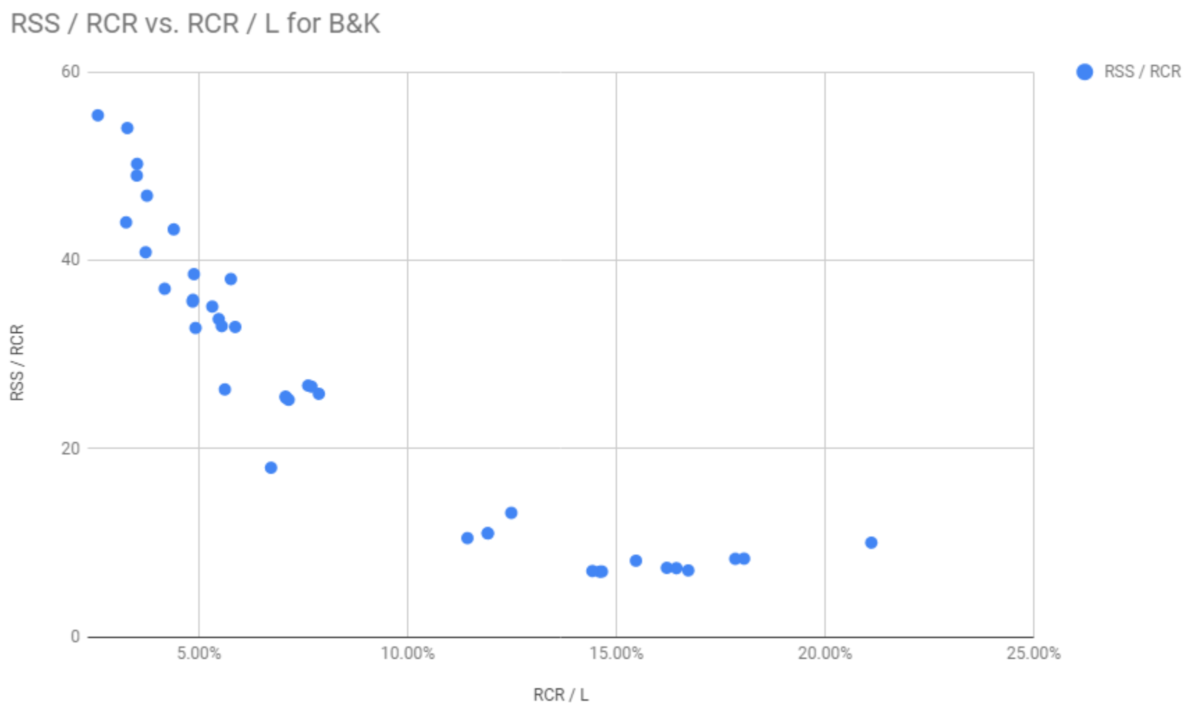

Figure 8: RCR/L charts above weather data for corresponding test days for the B&K RSS.

In Table 5, the 52% negative correlation of critical band with RCR for the ILG reiterates that most of the high RCR/L tests occur at low frequency critical bands. Since, for the B&K RSS, such high RCR/L values also occur at high frequencies this correlation is much weaker. Over all tests analyzed, these weak correlations and the even weaker correlations for RSS and RCR show that the choice of critical band is not routinely influenced by any particular RSS or measured RSS decibel values in general.

Table 5: Critical band correlation statistics for both RSS.

		Correlation Statistics	
Parameter	**Correlated To**	**ILG**	**B&K**
Critical Band	RSS	0.67	0.26
	RCR	-0.52	0.04
	FAN	-0.09	-0.03

4.3.2 RSS Similarity

Previous studies show that the ILG or B&K RSS can rarely affect the choice of critical band's within the acceptable audible range. These topics raise questions of RSS similarity in terms of the magnitude of RCR and the frequency with which each RSS generates large values of RCR for the critical band. Figures 9 and 10 show typical measured RSS data and RSS calibration data plotted together for each RSS. As previously mentioned, the largest gaps between these two lines are mostly found at the extreme bands, creating large RCR values.

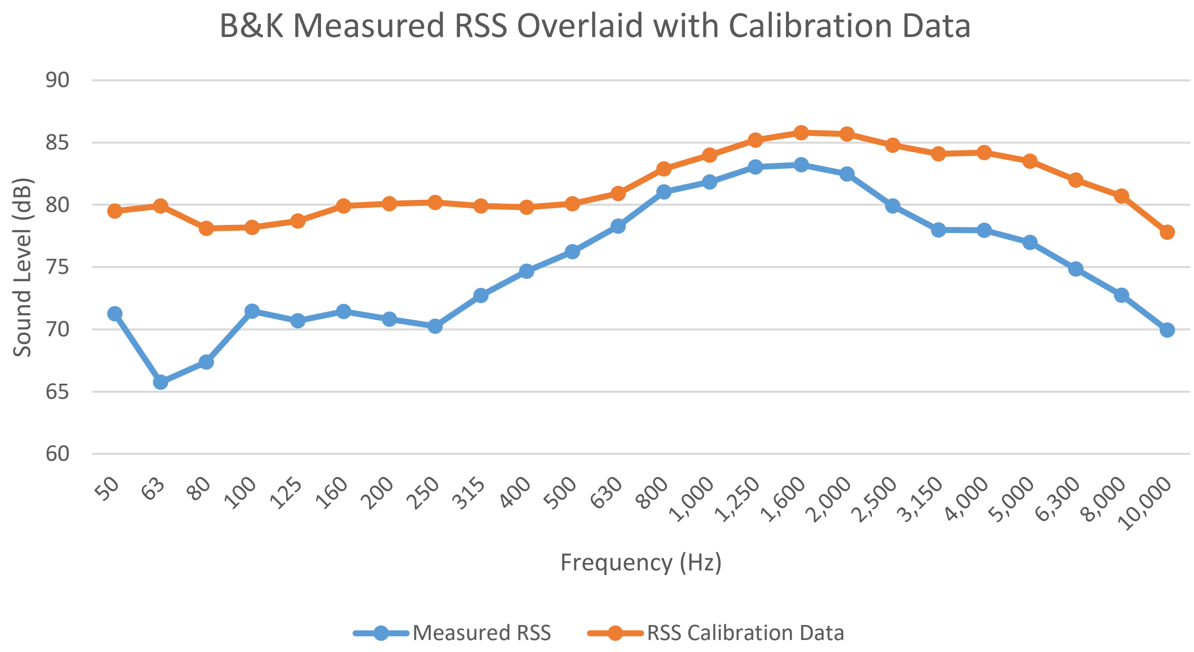

Figure 9: Typical measured RSS data plotted with calibration for the B&K RSS.

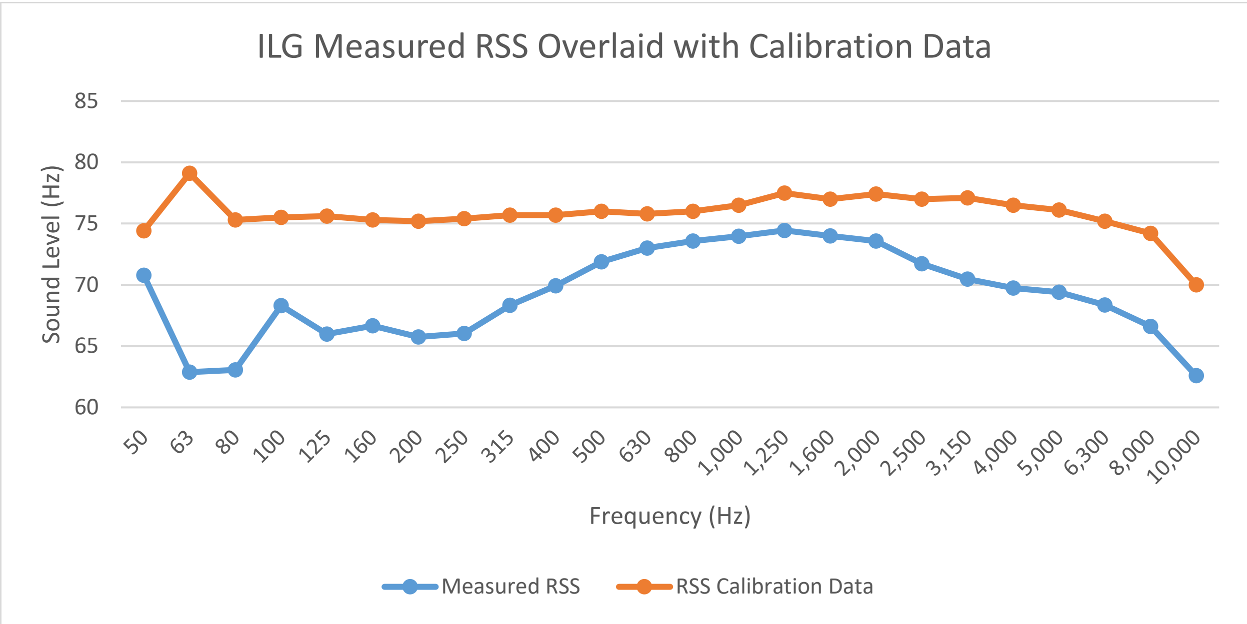

Figure 10: Typical measured RSS data plotted with calibration for the ILG RSS.

RSS similarity was further investigated in terms of RCR in Figure 11. To compare the RCR for both RSS types the RCR data was averaged over each quarter and the standard deviations from each sample were used as error bars. Similarity all within one standard deviation can be seen for each quarter except for the second.

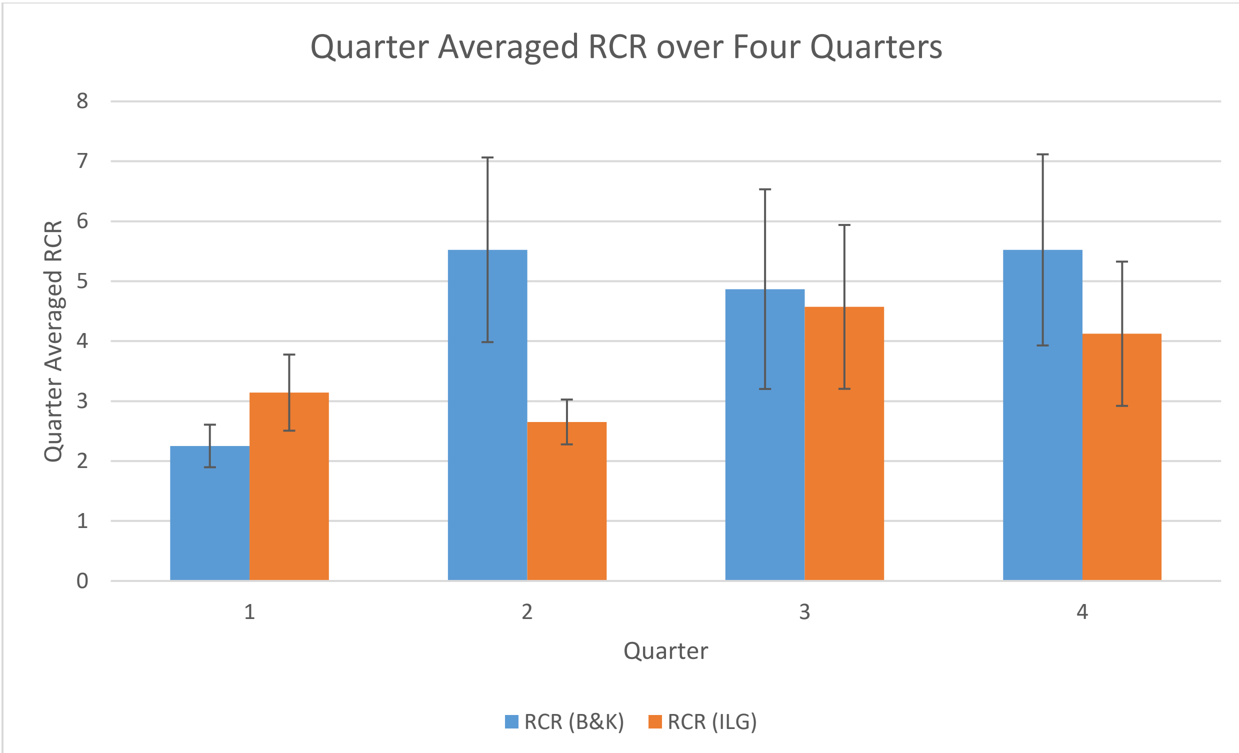

Figure 11: Average Room Characteristic Ratio for both RSS.

5. RESULTS OF R&R ANALYSIS

5.1 Overview of R&R Analysis

The first steps taken in this study involve examining the data for broad trends such as higher variation observed when wait time is used between testing trials. This data is used to calculate a percent difference between testing trials involving immediate repeat testing and trials involving repeat testing with a day of wait time between each test. Then, ANOVA is used to calculate the GR&R of the current test set up as well as break down of the expected variances due to repeatability and reproducibility. These results are then used to compare variation due to sound chamber requalification with expected measurement system variation (GR&R).

5.2 Experimental Data

The results of five different fans each with twelve trials done using the B&K RSS are presented in Tables 6 and 7 and Figure 12. Half of the trails were conducted with no wait time between measurements and the other half were carried out with a day of wait time between each measurement. The mean, or arithmetic average, shows the sone values measured. The standard deviation, mostly trending higher for higher sone fans, provides a measure of dispersion for each unit. The coefficient of variation is a relative standard deviation and numerically is the standard deviation divided by the average. As expected, ranges (high minus low value) for the sone values in the data set below mostly trend larger as sone level increases.

Table 6: Statistics done on three trials for each fan performed with no wait time in between.

Immediate Trials

Test Unit	Average	Std Dev	Min	Max	Coefficient of Variation	Range
<0.3 Sone Bath Fan	0.277	0.005	0.273	0.283	1.91%	0.01
~1 Sone Bath Fan	0.824	0.005	0.819	0.829	0.60%	0.01
2.3 Sone Bath Fan	2.556	0.015	2.543	2.573	0.60%	0.03
6 Sones Range Hood	6.889	0.082	6.8	6.962	1.19%	0.162
11.5 Sone Range Hood	12.495	0.036	12.46	12.53	0.29%	0.07

Table 7: Statistics done on six trials for each fan with one day of wait time in between.

Daily Trials

Test Unit	Average	Std Dev	Min	Max	Coefficient of Variation	Range
<0.3 Sone Bath Fan	0.287	0.018	0.273	0.317	6.28%	0.044
1 Sone Bath Fan	0.908	0.068	0.819	1.011	7.55%	0.192
2.3 Sone Bath Fan	2.653	0.126	2.461	2.789	4.75%	0.328
6 Sone Range Hood	6.787	0.138	6.56	6.975	2.04%	0.415
12 Sone Range Hood	12.531	0.346	11.87	12.81	2.76%	0.937

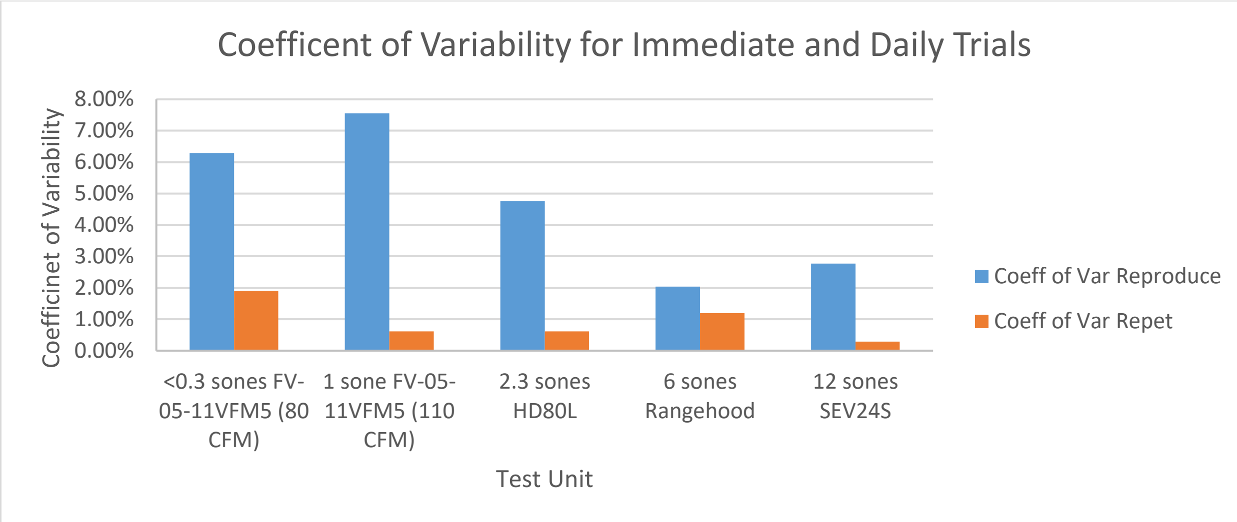

Figure 12: The added variability that arises due to mounting and dismounting (daily trials).

Also of interest is the difference in coefficient of variation between tests ran with one day of wait time in between trails and those with no wait time. These results can be seen in Table 8 below which illustrates the added variability from mounting and dismounting of the fan test unit between trials resulting in an increased coefficient of variation. The average across all fans for this statistic was 3.76%. An outlier exists for the six sone rangehood which may be explained by a particularly sonically stable fan.

Table 8: Showing the variational difference between tests ran with no wait time and those with one day of wait time between replications.

Test Unit	Difference in Coefficient of Variation Between Daily and Immediate Trials
<0.3 Sone Bath Fan	4.37%
1 Sone Bath Fan	6.94%
2.3 Sone Bath Fan	4.15%
6 Sone Range Hood	0.85%
12 Sone Range Hood	2.48%

5.2.1 Current Test Set Up Repeatability and Reproducibility

To analyze the current sound testing system configuration, the R&R set up consisted of 3 appraisers (fan technicians), 2 trials, with 5 parts (fan units) each measured in a random order. All other test parameters were controlled for including the Resonant Sound Source (RSS) used during testing. The RSS used for this study is the Bruel and Kjaer (B&K) RSS and the data collected for the study is shown in Table 9. The parts of the study are chosen for the gauge that represents the range of variation in sones that testers will encounter (<3 to ~12 sones).

Table 9: Data collected by three different appraisers, twice each, for five parts.

Appraiser	Trial	Part Number				
		1	2	3	4	5
Appraiser 1:	1	0.283	0.828	2.551	6.870	12.460
	2	0.273	0.821	2.543	6.860	12.530
Appraiser 2:	1	0.297	1.010	2.789	6.800	12.775
	2	0.317	0.909	2.713	6.728	12.805
Appraiser 3:	1	0.273	0.819	2.664	6.975	11.600
	2	0.293	0.906	2.543	6.940	11.868

An ANOVA table was generated to calculate the total gauge R&R as well as the individual variance contributions of appraisers and parts. Table 6 shows the break down the sum of square results, an intermediate step in the R&R calculation. It can be seen clearly using the F statistic in Table 10 that the between group variability is relatively large for groups of parts. For the group of appraisers, the F test shows that this variability is much lower. Here, interaction is significant due to the part – appraiser p-value being less than an .05 alpha corresponding to a 95% confidence level.

Table 10: ANOVA table results showing interaction is significant.

Source of Variability	Count	Degree of Freedom	Sum of Squares	Mean Squares	w/ Interaction	
					F	*P-Value*
Appraiser:	3	2	0.26	0.13	0.990	0.413
Part:	5	4	607.74	151.93	1175.652	0.000
Appraiser x Part (Interaction):		8	1.03	0.13	31.435	0.000
Repeatability w/ AP Interaction:	2	15	0.06	0.00		
Repeatability w/o AP Interaction:	2	23	1.10	0.05		
Total: (TSS)		29	609.09	21.00		

The appraiser – part interaction term states whether each individual appraiser's measurement of the same part over several trials varies enough to be considered a source of system variability. This determination is made by a p test using the F statistic, a statistical significance method common to ANOVA. The variance due to reproducibility sums the variance due to appraiser and variance due to appraiser-part interaction whenever interaction is significant, and the part-appraiser interaction enters into repeatability variance as a term during the sum of squares calculations.

It can be seen in Table 11 below that repeatability is less than reproducibility. The repeatability, or the variation from measuring one part several times, accounts for 1.27% of the total standard deviation or dispersion of the study, and this indicated that the instruments and measurement system used are working satisfactorily. This statistic also verifies the system as having a low within part variation.

Reproducibility, or the variation caused by different appraisers, is a sum of the variability of the appraisers (2.21%) and the appraiser-part interaction (4.96%). It is noteworthy that the part-appraiser interaction contribution to the total standard deviation is higher that of the appraiser. This is explained by a higher variation within each appraiser than across different appraisers. Ideally both variations should be minimized but this shows that changing appraisers does not add more variability than that which is expected from a single appraiser. The total Gauge R&R as a percent of the total standard deviation is 5.57%, which is less than the commonly accepted value of 10% for most measurement systems [8].

Table 11: Repeatability and reproducibility results.

Source of Variability	Variance	% of Total Variance	Standard Deviation	% of Total Std Dev.
Total Gage R&R:	0.079	0.31%	0.281	5.57%
Repeatability:	0.004	0.02%	0.064	1.27%
Reproducibility:	0.075	0.29%	0.274	5.43%
Appraiser:	0.012	0.05%	0.111	2.21%
Appraiser x Part:	0.063	0.25%	0.250	4.96%
Part-to-Part:	25.322	99.44%	5.032	99.72%
Total Variation:	25.463	100.00%	5.046	100.00%

This study can be broken down into two categories: fans whose sone value is greater or less than 3 sones. This corresponds to two constituent studies:

- Less than 3 sone fans: three appraisers, 2 trials, 3 parts.
- Greater than 3 sone fans: three appraisers, 2 trials, 2 parts.

Results for these R&R studies are presented in Tables 12 and 13. Part-appraiser interaction was found to not be significant for the study of below three sone fans, while interaction was significant for fans above three sones, meaning that the reproducibility will be relatively larger for the above sone fans. This has implications for increasing the total gauge R&R for the above 3 sone fans.

For the fans below three sones, the amount of variation due to R&R as a percentage of the total standard deviation was 6.75%, while for the greater than three sone fans this value was 12.89%.

This large value can be explained by a large reproducibility generated by the large range of sone values the higher sone fans. This takes the form of a large interaction term which dominates as the variance of individual appraiser groups is high at higher sones.

Table 12: Results for R&R study involving fans with sone values less than three.

Source of Variability	Variance	% of Total Variance	Standard Deviation	% of Total Std Dev.
Total Gage R&R:	0.007	0.46%	0.082	0.067
Repeatability:	0.002	0.15%	0.047	0.038
Reproducibility:	0.005	0.31%	0.068	0.056
Appraiser:	0.004	0.25%	0.061	0.050
Appraiser x Part:	0.001	0.06%	0.031	0.025
Part-to-Part:	1.486	99.48%	1.219	0.997
Total Variation:	1.493	100.00%	1.222	1.000

Table 13: Results for R&R study involving fans with sone values greater than three.

Source of Variability	Variance	% of Total Variance	Standard Deviation	% of Total Std Dev.
Total Gage R&R:	0.257	1.66%	0.507	12.89%
Repeatability:	0.007	0.05%	0.084	2.13%
Reproducibility:	0.250	1.62%	0.500	12.71%
Appraiser:	0.049	0.32%	0.222	5.66%
Appraiser x Part:	0.200	1.30%	0.448	11.39%
Part-to-Part:	15.000	97.04%	3.873	98.51%
Total Variation:	15.458	100.00%	3.932	100.00%

The agreement of all three operators can be seen in Figure 13, a histogram of operator's measured sones vs part. The two trials are averaged for each operator over the whole range of sones to demonstrate the range the measurement system can measure accurately. The precision of the measurement system can be further characterized visually using charts such as the average (X bar) and range charts.

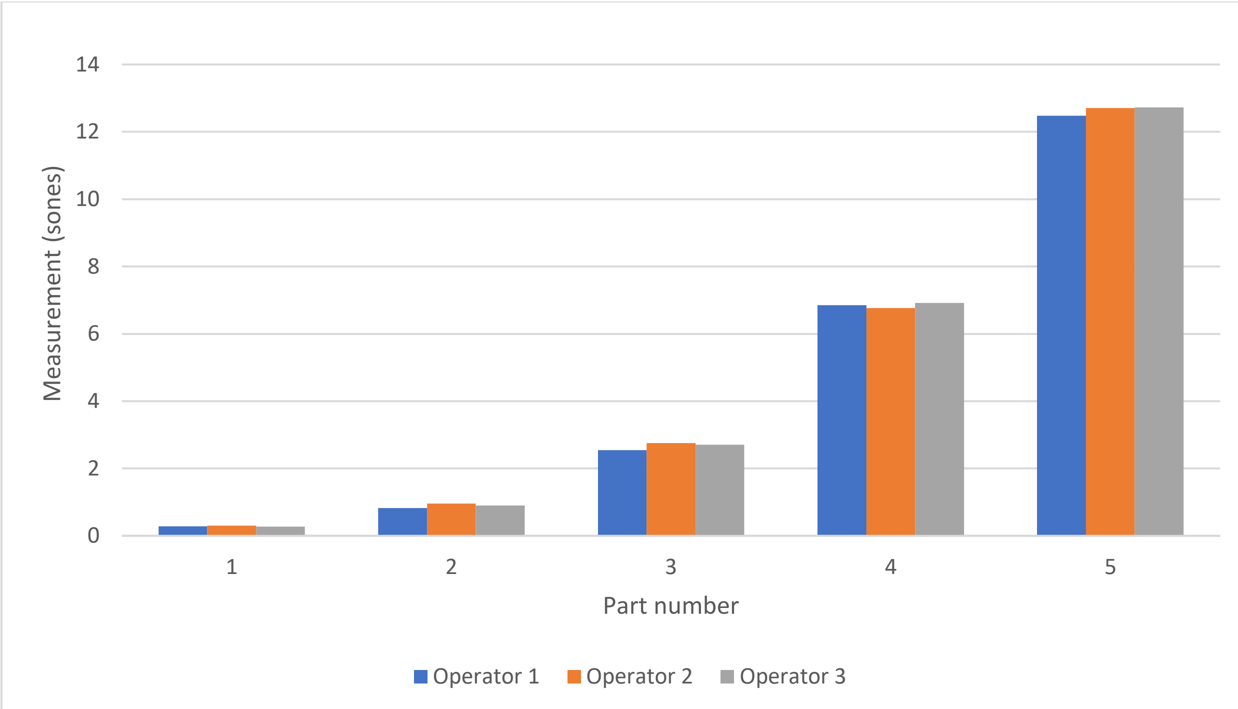

Figure 13: Overlaid plots of all operators for all parts.

Figure 14 shows what is known as an average chart and it provides a visual representation for the efficacy of the measurement system [9]. The averages across trial for all appraisers are plotted together and the grand average and control limits (upper control limit and lower control limit) are determined using the average range. The area between the control limits is known as the measurement sensitivity, or the noise. Since the group of parts represents the process variation, at least half or more points should fall outside the control limits which tells the analyst that the measurement system has adequate resolution to detect part-to-part variation as well as no strong operator-to-operator differences. Qualifying both of these points helps to validate an R&R study's results.

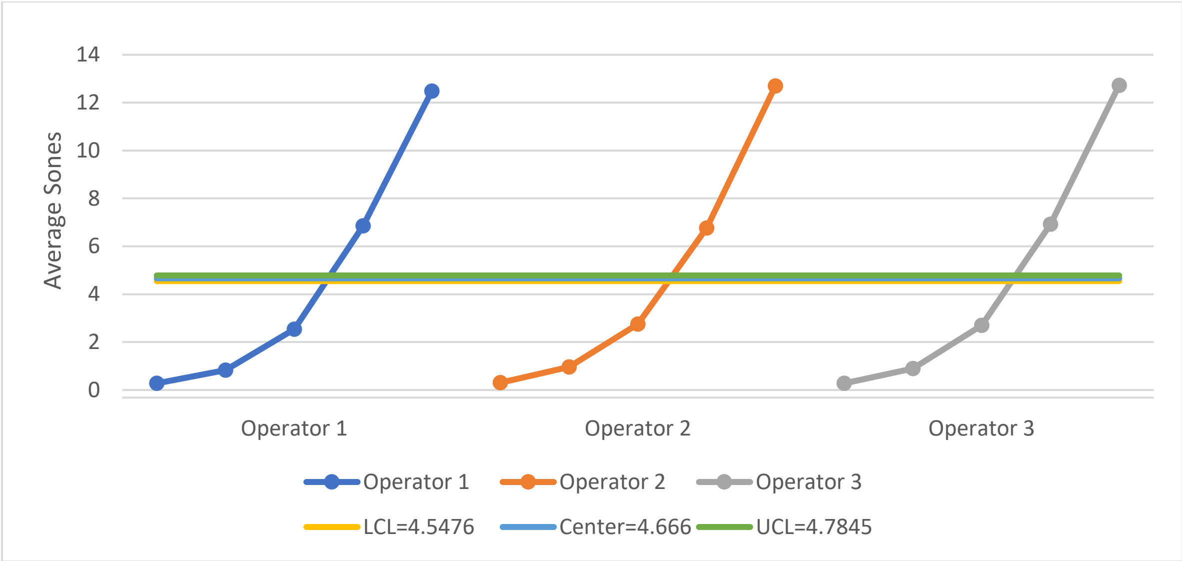

Figure 14: Average Chart showing part to part resolution for the measurement system.

Figure 15 shows an unstacked range chart used to determine whether a process is in control with the center line representing the average range. The Upper Control Limit (UPC) is calculated as the sum of the average range and constants based on the size of the study's part groups. If all plotted ranges are in control, then all appraisers are doing the same job, however this chart does not display patterns concerning appraisers or parts as the ranges are not ordered [10]. This chart shows statistical control with respect to repeatability since all points are in control, as well as the consistency of the measurement system with respect to measurements between appraisers for each part. It is also evidenced by this chart that no outlier ranges exist for any part, or no points lie outside of the upper and lower control limits.

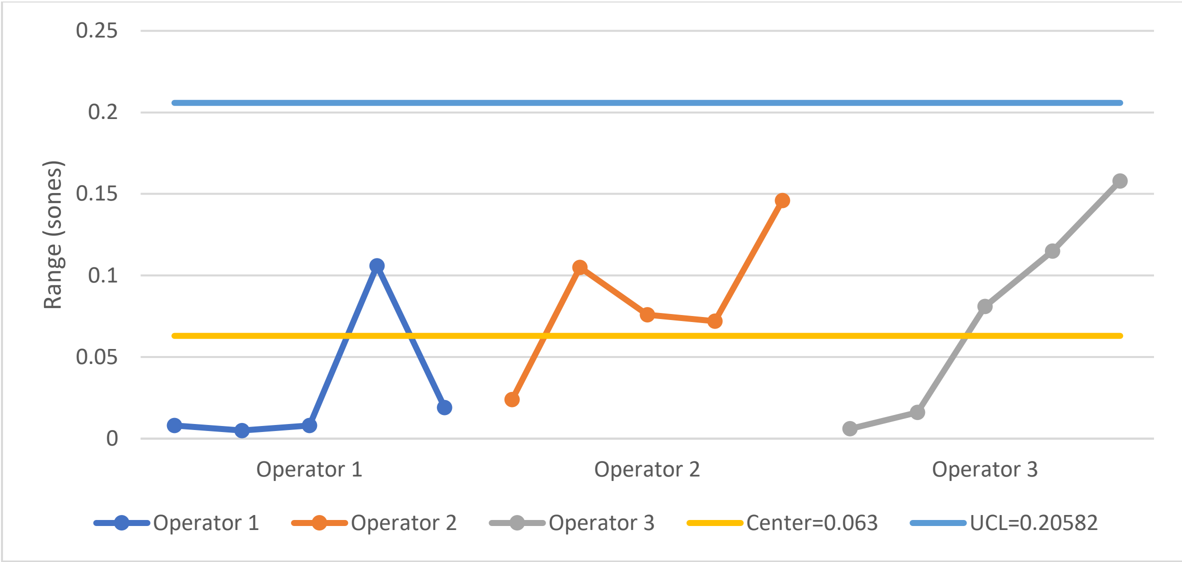

Figure 15: Range chart showing that all parts are under control.

5.2.2 Requalification Effects

After major changes to a sound test facility's equipment are made a requalification must be conducted by a well-established third party. To ensure that final sone values aren't changed more than the expected total variation of the measurement system, a requalification study was performed on test data taken before and after the requalification performed in April 2018. This test data is shown in Tables 14 and 15 below. The mixed mic category pertains to test data that was done with the 4190 mics before April and the 4240 mics after April.

Table 14: Historical Requalification data where the mic used remains constant across the study (4190 mics).

	RSS	Test Unit	Before Requalification	After Requalification	% Difference
4190 Mics	*ILG*	2.3 Sone Bath Fan	2.451	2.539	3.59%
	B&K	6 Sone Range Hood	8.134	8.179	0.55%
	ILG	11.5 Sone Range Hood	11.608	11.96	3.03%

Table 15: Historical requalification data where the mics vary from before April to after April (4190 to 4240).

	RSS	Test Unit	Before Requalification	After Requalification	% Difference
Mixed Mics	*ILG*	2.3 Sone Bath Fan	2.451	2.561	4.48%
	B&K	6 Sone Range Hood	8.134	8.283	1.83%
	ILG	11.5 Sone Range Hood	11.608	12.37	6.56%

The total expected variation of the measurement system was evaluated using gage Repeatability and reproducibility. The different R&R studies used in this study include the following data setups (all data found in Appendix A):

- ILG RSS and 4190 mics (2 appraisers, 1 trial, 5 parts)
- ILG RSS and mixed 4190 and 4240 mics (3 appraisers, 2 trials, 5 parts)
- B&K RSS and 4190 mics (2 appraisers, 2 trials, 5 parts)
- B&K RSS and mixed 4190 and 4240 mics (3 appraisers, 4 trials, 5 parts)

All data for these setups can be found in Appendix A. In Table 16 these R&R results were compared to the variances calculated across the requalification. Comparing the average variance of requalification with the R&R variance shows that for all test set ups the variance of requalification is less than the normal expected variance of the measurement system as described by the R&R variance. Further, comparing the average percent difference across the requalification with the total gage R&R also shows that the requalification percent difference fits below the expected total repeatability and reproducibility of the whole measurement system.

Table 16: Requalification and R&R comparison results.

	Mics	Avg Variance of Requalification	R&R Variance	Avg % Difference of Requalification	% Total Gage R&R
ILG	*4190*	0.032912	0.064537	3.31%	3.66%
	Mixed	0.148186	0.302733	5.53%	11.21%
B&K	*4190*	0.001012	0.00577	0.55%	1.55%
	Mixed	0.061952	0.135797	1.83%	3.61%

6. FUTURE WORK

Continuing work needs be done to both isolate certain ranges of sone values for R&R improvement and set goals to lower the total gage R&R of the measurement system. As has been demonstrated on a small scale with the current testing set up study, sone ranges may be isolated and analyzed separately to identify where variability is arising. Floor and ceiling targets could be set as tolerances above and below expected sone values. It is predicted somewhat shown by this study that as sone level increases, so does the observable variability of sone measurements.

A reasonable estimate of the highest sone value measured by the system is 12 -13 sones. Thus a study could involve separating the range of sones that the system encounters 0 -13 out into categories such as 0 – 2, 2 -4, 4-6, etc. These ranges are expected to be roughly linear with measurement variance. Once such a plot was generated, goals on lowering the slope of such a line would correspond to decreasing the total gage R&R of the measurement system across all sone levels. Such a method could be used to evaluate system proficiency.

Further sensitivity parameters such as microphone placement need to be studied to increase knowledge on what effects sound testing. Other factors considered during room requalification such as the effect the angle of the sound room baffles have on sone results would also be of interest.

7. CONCLUSIONS

The sound test facility at the RELLIS Energy Efficiency Laboratory is used to perform tests on residential bath and range hood fans for certification and verification. In support of this effort, it becomes necessary to quantify the expected system variation and the variation of possible influences on the final reported sone values. Data taken for the investigation of possible correlations between measured RSS with weather spanned a period of four quarters starting in the fourth quarter of 2017 and was made up of ten randomly selected sound tests per quarter performed at RELLIS Energy Efficiency Laboratory (REEL). This analysis showed no strong seasonal trend exists for key RSS parameters, such as the measured RSS sound power level and the room characteristic ratio, as typical correlation values were around 30%. The RSS type that showed the strongest correlation with RSS data was the B&K which showed a -43% correlation with temperature, a -31% correlation with relative humidity, and a 0.47% correlation with air density.

Also considered in this study was the effect the RSS has on final sone values. This was quantified by the ratio of the room characteristic ratio to fan sound power levels. The extreme bands were found to cause the most RSS influence on sone values when these bands were chosen as the critical band. This study identified key conditions that cause the RSS to contribute maximally to sones. The role of the critical frequency band for a given sound test was examined by correlating the room characteristic ratio with the frequency of the critical band over a sample of 40 tests per RSS type, showing a -52% correlation coefficient relation. Since the choice of critical band and RCR for a given test are loosely anti-correlated this suggests that the highest RCR occurs at the lowest frequency bands which is further demonstrated by experimental data.

The gauge repeatability and reproducibility analysis showed the total gauge repeatability and reproducibility (GR&R) of the entire sound measurement system as a percent of the total standard deviation to be 5.57%, which is less than the commonly accepted value of 10% for most measurement systems. This GR&R value was used for comparison to recent variation due to requalification efforts involving changing microphone type (free field vs. diffuse), showing that the variance of requalification for new microphone types is less than the normal expected variance of the measurement system due factors such as changing operators, mounting and dismounting, etc. The measurement system was found to be in control for all of these normally encountered sources of variation, meaning the final GR&R value signifies the REEL sound chamber to be a quality measurement system capable of precisely measuring sone values across the desired range (0 -12 sones). Comparing the average percent difference across the requalification (1.83%) with the total gauge R&R illustrates that the requalification percent difference is within the 5.57% expected total repeatability and reproducibility of the whole measurement system. Finally, the repeatability and reproducibility study found that for requalification after changing mics, comparing the average variance of requalification (0.148) with the R&R variance (0.303) shows that for these test setups the variance of requalification is less than the normal expected variance of the measurement system.

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APPENDIX A: REPEATABILITY AND REPRODUCIBILITY DATA

ILG:

Model	Mic Type	
	4190	4942
<0.3 sones Bath Fan	0.277	0.269
	0.273	0.276
	0.276	0.268
~1 sone Bath Fan	0.864	0.847
	0.869	0.849
	0.852	0.85
2.3 Bath Fan	2.604	2.561
	2.56	2.546
	2.574	2.571
5.3 Range Hood	5.329	5.315
	5.334	5.326
	5.339	5.359
6 sone Rangehood	6.636	6.757
	6.636	6.82
	6.662	6.808
8 sones Range Hood	8.204	7.807
	8.214	8.279
	8.259	8.307
10 sones Range Hood	9.636	9.566
	9.596	9.399
	9.611	9.405
11.5 sone Range Hood	11.96	12.37
	12.1	12.38
	12.14	12.45

B&K:

Model	Mic Type	
	4190	**4942**
<0.3 sones Bath Fan	0.288	0.283
	0.281	0.275
	0.268	0.273
~1 sone Bath Fan	0.828	0.829
	0.821	0.824
	0.821	0.819
2.3 Bath Fan	2.575	2.551
	2.569	2.543
	2.586	2.573
5.3 Range Hood	5.349	5.322
	5.333	5.382
	5.401	5.419
6 sone Rangehood	6.872	6.810
	6.942	6.906
	6.996	6.962
8 sones Range Hood	8.179	8.329
	8.184	8.283
	8.216	8.357
10 sones Range Hood	9.691	9.451
	9.764	9.568
	9.644	9.566
11.5 sone Range Hood	11.96	12.46
	12.02	12.49
	12.06	12.53

Daily Trials B&K RSS

Model	4942 Mics
<0.3 sone Bath Fan	0.293
	0.317
	0.275
	0.281
	0.273
	0.297
1 sone Bath Fan	1.011
	0.906
	0.893
	0.909
	0.819
	0.987
2.3 sone Bath Fan	2.789
	2.713
	2.745
	2.664
	2.543
	2.461
6 sones Rangehood	6.8
	6.728
	6.975
	6.86
	6.8
	6.56
12 sones Range Hood	12.775
	12.629
	11.805
	12.647
	12.464
	11.868
	11.868

APPENDIX B: RSS AND WEATHER DATA

ILG	Q4 2017 1	2	3	4	5
Contract	17-PROFA2_check1_ILG	18-963A2	17-ES921BC_4_	17-ES921BD2	17-ES921BD2
Model	FV-05VK1	7107-05	Qindao: SES80	VFB25ADH	VFB25ADH
Company	REEL	Homewerks	HVI	HVI	HVI
Date	2017-12-13	2017-12-13	2017-12-14	2017-12-14	2017-12-14
CFM	52.2	113.3	84.2	99.6	74.6
SP	0.25	0.1	0.1	0.1	0.25
RPM	892	830	810	940	1142
RSS SUM	1652.48	1651.9	1655.2	1657.71	1657.27
RSS AVG	68.85	68.83	68.97	69.07	69.05
CHAMBER T	-	-	-	-	-
RH	28	29	29	32	32
STATION T	73	71	71	71	71
SONES	0.85	0.83	1.63	0.55	1.06
TYPE	Bath fan	Bath fan	Bath fan	Bath fan	Bath fan

ILG	6	7	8	9	10
Contract	17-V936BE	17-V936BH	18-974B	17-V936BF	17-V936BG
Model	Hunter 81021	FRAK 130	BPT14-70CL-2	Broan 678	Broan 670
Company	HVI	HVI	Zhongshan Aochuange	HVI	HVI
Date	2017-12-14	2017-12-15	2017-12-15	2017-12-18	2017-12-18
CFM	52.4	110.5	86.9	63.3	49
SP	0.1	0.1	0.1	0.1	0.1
RPM	1455	1303	1070	2883	1798
RSS SUM	1780.27	1659.75	1660.1	1670.21	1670.05
RSS AVG	74.59	69.16	69.17	69.59	69.59
CHAMBER T	-	-	-	-	-
RH	29	29	29	57	57
STATION T	71	69	73	73	73
SONES	2.23	2.55	1.76	5.96	3.94
TYPE	Bath fan	Bath fan	Bath fan	Bath fan	Bath fan

Table 17: ILG RSS data for Quarter four of 2017.

ILG	Q1 2018 1	2	3	4	5
Contract	17-V936BK	17-V936BM	17-V936AK	17-V936BQ	17-V936BU
Model	CG22L500A15	RL613077WC	Broan 512M	UVB30DKBB	ZV36RSFSS
Company	HVI	HVI	HVI	HVI	HVI
Date	1/10/2018	1/10/2018	1/29/2018	3/1/2018	3/9/2018
CFM	436.5	160.5	75.7	398.6	240.1
SP	0.1	0.1	0.031	0.1	0.031
RPM	2237	2986	2658	1530	799
RSS SUM	1795.58	1795.49	1789.66	1799.5	1791.39
RSS AVG	74.82	74.81	74.57	74.98	74.64
CHAMBER T				74	75
RH	46	46	28	57	45
STATION T	76	74	72	72	78
SONES	9.96	7.66	5.68	10.46	1.57
TYPE	RANGE VERT	BATH	BATH	BATH	RANGE VERT

ILG	6	7	8	9	10
Contract	17-V936BN	17-V936AJ3(2)	17-V936BT	17-V936BR	17-V936BV
Model	GI300	EWF180	ZV36RSFSS	IS70036BL	BP124ALN
Company	HVI	HVI	HVI	HVI	HVI
Date	1/7/2018	2/21/2018	3/9/18	3/12/2018	3/13/2018
CFM	235.2	162.5	631.2	584.2	123.7
SP	0.1	0.1	0.1	0.1	0.1
RPM	1090	2321	1819	2208	2916
RSS SUM	1790.76	1796.9	1790.61	1789.16	1789.06
RSS AVG	74.61	74.87	74.61	74.55	74.54
CHAMBER T		72	75	73	73
RH	33	50	46	37	38
STATION T	69	74	78	76	74
SONES	4.12	6.8	7.93	9.06	9.91
TYPE	BATH	OTHER ROOM VENTILATOR	RANGE VERT	RANGE HOR	RANGE HOR

Table 18: ILG RSS data for quarter 1 of 2018.

ILG	Q2 2018 1	2	3	4	5
Contract	18-ES999I	18-ES999H	18-ES999O	18-ES999P	18-ES999AC
Model	Delta: SIG110	Delta: REC80LED	Air King: EL80D	CFM: TF80	Broan: QSE130BL
Company	HVI	HVI	HVI	HVI	HVI
Date	4/18/18	4/18/18	4/19/18	4/23/18	4/26/18
CFM	105.6	73.2	149.4	99.8	225.1
SP	0.1	0.1	0.1	0.1	0.1
RPM	926	1545	897	573	1584
RSS SUM	1666.48	1664.94	1663.23	1672.01	1669.06
RSS AVG	69.44	69.37	69.3	69.67	69.54
CHAMBER T	75	75	75	74	75
RH	53	52	40	46	46
STATION T	78	78	74	78	78
SONES	0.39	2.58	0.62	0.54	5.12
TYPE	Bath Fan	Bath Fan	Bath Fan	Bath Fan	Range Hood

ILG	6	7	8	9	10
Contract	18-1003A	18-V936BX	18-ES999AM	18-ES999AU	18-ES999AT2
Model	Greenheck: SP-A50	Milano: TY-50A	Air King: ECQ243	Reversomatic: SA-90S-2	Reversomatic: QK-180 ES
Company	HVI	HVI	HVI	HVI	HVI
Date	5/1/18	5/14/18	5/21/18	6/7/18	6/7/18
CFM	39.7	59.8	274.2	102.1	149.4
SP	0.25	0.1	0.1	0.1	0.1
RPM	1175	901	1645	1025	1042
RSS SUM	1802.64	1649.02	1662.46	1660.98	1658.79
RSS AVG	75.11	68.71	69.27	69.21	69.12
CHAMBER T	76	78	78	81	82
RH	63	59	60	57	59
STATION T	79	82	77	88	89
SONES	1.02	0.3	4.25	1.05	3.262
TYPE	Ceiling Exhaust Fan	Bath Fan	Rane Hood	Bath Fan	Bath Fan

Table 19: ILG data for quarter 2 of 2018.

ILG	Q3 2018 1	2	3	4	5
Contract	18-1012A1	18-981A	18-996R1	18-996S2	18-1012A1
Model	Rangehood	WA0876	FV-081RQCL1	FV-081RQCL1	Rangehood
Company	Qingdao	CHINABEST	PANASONIC	PANASONIC	Qingdao
Date	7/2/2018	7/12/2018	7/13/2018	7/13/2018	7/17/2018
CFM	257.8	325.3	82.2	111.2	257.8
SP	0.1	0.1	0.1	0.1	0.1
RPM	1633	1628	865	961	1633
RSS SUM	1651.04	1786.96	1649.86	1642.56	1651.11
RSS AVG	68.79	74.46	68.74	68.44	68.8
CHAMBER T	81	78	78	79	79
RH	62	65	63	65	65
STATION T	88	86	86	88	89
SONES	5.284	8.134	0.195	0.864	6.636
TYPE	Rangehood	Rangehood	BATH	BATH	Rangehood

ILG	6	7	8	9	10
Contract	18-1012A2	18-996R2	18-996S3	18-1012A3	18-1012A3
Model	Rangehood	FV-081RQCL1	FV-081RQCL1	Rangehood	Rangehood
Company	Qingdao	PANASONIC	PANASONIC	Qingdao	Qingdao
Date	7/17/2018	7/13/2018	7/13/2018	7/2/2018	7/2/2018
CFM	257.8	82.2	111.2	257.8	257.8
SP	0.1	0.1	0.1	0.1	0.1
RPM	1633	865	961	1633	1633
RSS SUM	1652.46	1651.76	1641.59	1651.4	1650.14
RSS AVG	68.85	68.82	68.4	68.81	68.76
CHAMBER T	79	79	79	81	81
RH	65	65	65	62	62
STATION T	89	88	88	88	88
SONES	6.636	0.273	0.852	6.662	5.353
TYPE	Rangehood	BATH	BATH	Rangehood	Rangehood

Table 20: ILG RSS data for quarter four of 2018.

B&K	Q4 2017 1	2	3	4	5
Contract	17-ES921BC_3_NR	18-963A2_NR	17-V936BH_BK	18_974B_BK	18-974A_BK
Model	Qindao: SES80	7107-05	FRAK 130	BPT14-70CL-2	BPT14-24ALK
Company	HVI	Homewerks	HVI	Zhongshan Aochuange	Zhongshan Aochuange
Date	2017-12-14	2017-12-14	2017-12-15	2017-12-15	2017-12-15
CFM	84.2	113.3	110.5	86.9	113.4
SP	0.1	0.1	0.1	0.1	0.1
RPM	811	830	1312	1072	1113
RSS SUM	1788.28	1788.28	1780.63	1790	1790.04
RSS AVG	74.51	74.51	69.17	74.59	74.38
CHAMBER T	-	-	-	-	-
RH	29	29	29	28	28
STATION T	71	71	69	73	73
SONES	1.73	0.88	2.79	1.86	1.37
TYPE	Bath fan	Bath fan	Bath fan	Bath fan	Bath fan

B&K	6	7	8	9	10
Contract	18-974A_BK	17-V936BD_BK	18-974C	17-V936BF	17-V936BG
Model	BPT18-44A	BPT14-70CL-2	BPT14-24AL-2	Broan 678	Broan 670
Company	Zhongshan Aochuange	Zhongshan Aochuange	Zhongshan Aochuange	HVI	HVI
Date	2017-12-16	2017-12-16	2017-12-17	2017-12-18	2017-12-17
CFM	156.4	52.4	113.6	63.3	49
SP	0.1	0.1	0.1	0.1	0.1
RPM	967	2085	1170	2876	1801
RSS SUM	1788.39	1789.97	1800.53	1801.39	1801.91
RSS AVG	74.52	74.58	75.02	75.06	75.08
CHAMBER T	-	-	-	-	-
RH	29	29	58	57	58
STATION T	71	69	73	73	73
SONES	2.27	2.2	1.48	6.1	4.05
TYPE	Bath fan	Bath fan	Bath fan	Bath fan	Bath fan

Table 21: B&K RSS data for quarter four of 2017.

B&K	Q1 2018 1	2	3	4	5
Contract	18-980G	18-974B(2)	18-979A	18-983B	18-977C
Model	RMDD3604-B	BPT14-70CL-2	CBF 150 DC	SED150L	GXU7130DX51
Company	BROAN	ZHONGSHAN AOCHUANG	VENTS	QINDAO	ELICAMEX
Date	1/17/2018	1/8	1/31/2018	1/31/2018	1/9/2018
CFM	201.5	86.9	151.5	160.4	117.8
SP	0.1	0.1	0.1	0.1	0.1
RPM	1332	1071	1111	774	844
RSS SUM	1781.37	1799.66	1790.74	1792.13	1789.48
RSS AVG	74.22	74.51	74.66	74.67	74.56
CHAMBER T					
RH	29	31	35	35	32
STATION T	66	74	75	76	72
SONES	4.55	1.8	1.78	1.68	2.46
TYPE	Range Hor.	BATH	BATH	BATH	RANGE VERT

B&K	6	7	8	9	10
Contract	18-966A	18-993B	18-993C	18-991A	18-981A
Model	ES36	SP-A50-90	SP-A50-90	SONORA 50	WA0876
Company	FISHER & PAYKEL	GREENHECK	GREENHECK	SIDELL	CHINABEST
Date	1/9/2018	3/8/2018	3/8/2018	3/13/2018	3/13/2018
CFM	578	73.8	95.8	44	325.3
SP	0.1	0.25	0.1	0.1	0.1
RPM	2109	1164	861	2418	1628
RSS SUM	1788.88	1787	1786.63	1789.18	1786.98
RSS AVG	74.59	74.48	74.44	74.55	74.46
CHAMBER T		72	72	73	73
RH	32	33	33	35	35
STATION T	73	73	72	74	75
SONES	11.51	0.62	0.45	1.43	8.13
TYPE	RANGE VERT	BATH	BATH	BATH	RANGE VERT

Table 22: B&K RSS data for quarter one of 2017.

B&K	6	7	8	9	10
Contract	18-1004C	18-1006A(2)	18-1007D	18-1002F	18-995A2
Model	W103B30	Lo-Pro	VFB80-110C6LED3-2	SEP120L	SP-L80-QD
Company	Winslyn	Broan-Nutone	Delta	Qingdao	IAPMO R&T
Date	5/9/18	5/15/18	5/30/18	6/12/18	6/19/18
CFM	211.2	52.2	62.4	106	82.3
SP	0.1	0.25	0.25	0.1	0.1
RPM	1179	904	1140	720	885
RSS SUM	1798.29	1793.26	1792.87	1796.84	1794.07
RSS AVG	74.93	74.72	74.7	74.87	74.75
CHAMBER T	77	78	80	78	78
RH	50	54	56	54	57
STATION T	81	83	83	84	81
SONES	3.45	1.253	0.8	2.09	2.51
TYPE	Range Hood	Bath Fan	Bath Fan	Bath Fan	Bath Fan

Table 23: B&K RSS data for quarter two of 2018.

B&K	Q3 2018 1	2	3	4	5
Contract	18-1012A1	18-1012A2	18-1012A3	18-996R1	18-996R2
Model	Rangehood	Rangehood	Rangehood	FV-081RQCL1	FV-081RQCL1
Company	QINGDAO	QINGDAO	QINGDAO	PANASONIC	PANASONIC
Date	7/17/2018	7/17/2018	7/17/2018	7/13/2018	7/13/2018
CFM	257.8	257.8	257.8	82.2	82.2
SP	0.1	0.1	0.1	0.1	0.1
RPM	1633	1633	1633	865	865
RSS SUM	1781.6	1781.15	1780.83	1785.22	1784.03
RSS AVG	74.23	74.21	74.2	74.38	74.36
CHAMBER T	79	79	79	78	78
RH	65	65	65	63	63
STATION T	89	89	89	84	83
SONES	6.872	6.942	6.966	0.288	0.31
TYPE	Rangehood	Rangehood	Rangehood	Rangehood	Rangehood

B&K	6	7	8	9	10
Contract	18-996R3	18-996S2	18-996S2	18-996S2	18-981A
Model	FV-081RQCL1	FV-081RQCL1	FV-081RQCL1	FV-081RQCL1	WA0876
Company	PANASONIC	PANASONIC	PANASONIC	PANASONIC	CHINABEST
Date	7/13/2018	7/13/2018	7/13/2018	7/13/2018	7/12/2018
CFM	82.2	111.2	111.2	111.2	325.3
SP	0.1	0.1	0.1	0.1	0.1
RPM	865	961	961	961	1628
RSS SUM	1785.5	1784.15	1784.91	1783.67	1784.88
RSS AVG	74.4	74.34	74.37	74.32	74.37
CHAMBER T	78	78	79	79	78
RH	64	64	64	64	66
STATION T	84	84	87	87	82
SONES	0.293	0.874	0.867	0.867	8.179
TYPE	Rangehood	Rangehood	Rangehood	Rangehood	Rangehood

Table 24: B&K RSS data for quarter three of 2018.

APPENDIX C: SPECTRAL RSS DATA

BAND	Q4 2017 1	2	3	4	5	6	7	8	9	10
	17-PROFA2_check1_ILG	18-963A2	17-ES921BC_4_	17-ES921BD2_010	17-ES921BD2__025	17-V936BE	17-V936BH	18-974B	17-V936BF	17-V936BG
50	73.733	73.193	71.61	73.362	72.701	73.562	73.578	74.228	73.796	73.584
63	62.019	62.364	61.949	64.758	64.233	65.381	65.446	64.267	64.414	64.663
80	63.41	63.807	62.882	63.479	63.385	63.476	63.608	63.283	63.699	63.788
100	67.061	68.224	67.891	67.348	67.5	67.229	67.448	67.439	67.753	67.636
125	65.927	66.207	66.042	65.467	65.534	65.445	65.877	65.888	65.998	65.919
160	67.175	67.336	67.279	67.341	67.571	67.598	67.461	67.39	67.74	67.752
200	66.299	66.334	66.077	66.387	66.745	66.396	66.538	66.531	66.78	66.77
250	67.058	66.999	66.975	67.344	67.409	67.378	67.495	67.464	67.599	67.505
315	69.608	69.552	69.274	69.591	69.346	69.62	69.76	69.653	69.644	69.729
400	71.044	71.084	70.987	70.97	70.974	71.083	71.094	71.136	71.217	71.198
500	72.819	72.829	72.721	72.763	72.865	72.854	72.905	73.045	73.133	73.072
630	73.509	73.468	73.531	73.567	73.623	73.672	73.618	73.752	73.852	73.857
800	74.342	74.521	74.325	74.419	74.397	74.502	74.427	74.509	74.607	74.625
1000	74.524	74.585	74.423	74.562	74.657	74.621	74.615	74.703	74.745	74.758
1250	75.224	75.425	75.357	75.328	75.395	75.28	75.38	75.37	75.51	75.52
1600	74.367	74.709	74.484	74.536	74.532	74.489	74.516	74.543	74.768	74.776
2000	73.876	74.249	73.914	74.065	74.033	74	74.014	74.141	74.49	74.498
2500	71.568	72.116	71.751	71.77	71.819	71.801	71.781	71.868	72.344	72.299
3150	70.236	70.76	70.389	70.455	70.462	70.38	70.435	70.535	70.965	70.975
4000	68.689	69.703	68.973	68.983	68.972	68.93	68.956	69.029	69.889	69.881
5000	67.336	68.728	67.789	67.642	67.641	67.578	67.593	67.676	68.752	68.775
6300	64.892	66.657	65.502	65.235	65.235	65.082	65.098	65.261	66.683	66.669
8000	61.569	63.647	62.156	61.864	61.825	61.717	61.729	61.884	63.629	63.599
10000	56.196	58.366	56.727	56.476	56.412	56.401	56.389	56.506	58.201	58.206

Table 25:ILG RSS Spectral Data for quarter four of 2018.

BANDS	Q1 2018 1	2	3	4	5	6	7	8	9	10
	18-ES999B-010	18-ES999B_025	18-ES999C_010	18-ES999C_025	18-ES999D_010	18-ES999D_025	18-ES999E_010	18-ES999E_025	18-ES999E_025_2	18-ES999J_010_3
50	72.28	72.631	72.741	71.768	72.704	71.66	72.689	72.521	71.872	71.995
63	64.36	63.916	64.228	63.64	64.402	64.235	63.934	64.285	63.347	64.154
80	63.60	63.896	63.667	63.846	63.646	63.575	63.641	63.932	63.535	63.433
100	68.12	68.3	68.111	68.162	68.355	68.146	68.335	68.66	67.958	68.121
125	66.91	67.038	66.903	66.387	66.909	66.703	66.66	67.022	66.704	66.832
160	67.10	67.377	67.182	66.987	67.219	66.965	67.197	67.197	66.88	66.912
200	66.19	66.076	66.036	65.822	66.116	65.899	66.307	66.322	65.907	66.093
250	66.79	66.79	66.832	66.382	66.756	66.589	66.778	66.79	66.307	66.585
315	68.60	68.614	68.531	68.32	68.541	68.359	68.626	68.536	68.521	68.512
400	70.64	70.706	70.525	70.411	70.643	70.281	70.628	70.795	70.618	70.6
500	72.50	72.506	72.461	72.269	72.424	72.301	72.448	72.557	72.4	72.455
630	73.48	73.475	73.346	73.207	73.426	73.24	73.489	73.525	73.514	73.371
800	74.22	74.109	74.042	73.949	74.307	74.046	74.238	74.236	74.089	74.174
1000	74.54	74.474	74.49	74.347	74.512	74.346	74.533	74.518	74.285	74.391
1250	75.33	75.254	75.204	75.098	75.217	75.105	75.23	75.27	75.067	75.073
1600	74.67	74.642	74.545	74.366	74.576	74.492	74.641	74.719	74.399	74.409
2000	74.22	74.247	74.133	73.932	74.196	74.05	74.207	74.316	74.075	73.935
2500	72.29	72.293	72.16	72.014	72.21	72.068	72.282	72.37	72.037	71.928
3150	71.08	71.074	70.965	70.822	71.051	70.915	71.102	71.188	70.87	70.777
4000	70.23	70.232	70.134	69.974	70.202	70.057	70.269	70.325	70.072	69.708
5000	69.56	69.571	69.438	69.29	69.528	69.369	69.547	69.652	69.316	68.837
6300	68.26	68.239	68.137	67.983	68.205	68.067	68.254	68.328	67.917	67.221
8000	66.45	66.428	66.338	66.148	66.385	66.247	66.42	66.504	66.046	65.124
10000	62.14	62.118	62.009	61.838	62.066	61.903	62.1	62.167	61.818	60.958

Table 26: ILG RSS Spectral data for quarter one of 2018.

BANDS	Q2 2018 1	2	3	4	5	6	7	8	9	10
	18-ES999I	18-ES999H	18-ES999O	18-ES999P	18-ES999AC	18-ES999L-010	18-V936BX	18-ES999AM	18-ES999AU	18-ES999AT2
50	71.81	71.55	71.55	72.46	71.86	71.62	68.31	71.41	70.77	71.60
63	63.23	63.56	63.67	64.37	63.74	63.39	62.02	63.28	62.87	63.19
80	63.40	63.16	63.41	63.34	63.58	63.68	63.66	62.77	63.06	62.49
100	68.09	68.04	67.94	68.14	68.20	68.17	68.09	67.78	68.31	67.88
125	66.94	66.63	66.54	66.66	66.66	66.56	65.24	66.46	65.99	65.91
160	66.98	66.90	66.84	66.99	66.60	66.76	65.56	67.00	66.66	66.48
200	66.12	66.13	65.79	66.08	65.93	65.92	65.25	66.75	65.76	65.92
250	66.41	66.59	66.45	66.58	66.54	66.38	65.58	66.68	66.04	65.82
315	68.68	68.62	68.46	68.71	68.74	68.53	67.77	67.80	68.32	67.78
400	70.68	70.60	70.49	70.74	70.74	70.54	69.18	69.53	69.93	69.65
500	72.59	72.60	72.36	72.62	72.44	72.29	71.40	71.52	71.88	72.07
630	73.42	73.40	73.36	73.45	73.44	73.24	72.60	72.69	73.00	73.10
800	74.25	74.24	74.04	74.23	74.19	74.08	73.19	73.53	73.57	73.73
1000	74.48	74.44	74.27	74.52	74.42	74.28	73.45	73.94	73.97	73.97
1250	75.27	75.14	74.98	75.21	75.17	75.03	74.33	74.55	74.44	74.39
1600	74.50	74.37	74.31	74.58	74.54	74.39	73.67	74.10	73.98	73.88
2000	74.10	74.01	73.87	74.22	74.15	73.96	73.35	73.78	73.57	73.35
2500	72.05	71.98	71.90	72.19	72.05	71.94	71.53	71.87	71.73	71.53
3150	70.83	70.82	70.68	71.01	70.93	70.73	70.32	70.62	70.46	70.22
4000	69.84	69.75	69.74	70.20	70.07	69.79	69.43	69.89	69.74	69.52
5000	69.00	68.88	68.90	69.43	69.29	68.91	69.04	69.38	69.40	69.20
6300	67.40	67.30	67.36	68.11	67.95	67.41	67.90	68.23	68.35	68.20
8000	65.30	65.22	65.25	66.21	66.03	65.29	66.13	66.46	66.60	66.48
10000	61.13	61.02	61.07	61.97	61.80	61.07	62.03	62.41	62.58	62.45

Table 27: ILG RSS Spectral data for quarter two of 2018.

BANDS	Q3 2018 1	2	3	4	5	6	7	8	9	10
	18-1012A_M1	18-ES999H_025_2	18-996R_M1	18-996S_M1	18-1012A_M2	18-1012A2_M3	18-996R_M2	18-996S_M2	18-1012A_M4	18-1012A_M5
50	70.71	71.73	70.79	71.14	71.03	70.75	69.94	70.79	70.03	70.77
63	63.21	63.49	61.92	61.79	63.98	63.73	64.42	61.92	63.61	63.62
80	62.99	63.55	63.11	62.98	62.70	62.88	63.08	63.11	62.73	62.61
100	68.13	68.15	67.87	68.17	67.82	67.85	67.90	67.87	67.86	67.82
125	66.56	66.50	65.64	65.86	66.56	66.69	66.24	65.64	66.31	66.43
160	66.44	66.90	66.00	65.93	66.43	66.62	66.90	66.00	66.79	66.45
200	66.21	65.85	65.56	65.49	66.19	66.31	66.11	65.56	66.34	66.04
250	66.49	66.34	66.04	66.09	66.40	66.55	66.48	66.04	66.52	66.47
315	68.39	68.56	68.26	68.34	68.27	68.42	68.48	68.26	68.41	68.23
400	70.03	70.48	69.29	69.42	70.10	70.12	70.00	69.29	70.22	70.05
500	71.86	72.55	71.54	71.71	71.97	71.90	71.82	71.54	71.98	71.94
630	72.83	73.46	72.46	72.47	72.77	72.85	72.72	72.46	72.84	72.75
800	73.71	74.16	73.24	73.21	73.59	73.63	73.65	73.24	73.64	73.65
1000	73.92	74.45	73.50	73.57	73.98	74.03	74.03	73.50	74.01	73.85
1250	74.49	75.12	74.28	74.30	74.53	74.57	74.61	74.28	74.57	74.46
1600	73.97	74.38	73.62	73.63	74.04	74.10	74.03	73.62	74.10	73.95
2000	73.58	74.04	73.15	73.14	73.40	73.47	73.58	73.15	73.45	73.52
2500	71.54	72.08	71.17	71.20	71.44	71.49	71.66	71.17	71.49	71.53
3150	70.05	70.93	69.74	69.73	70.01	70.08	70.18	69.74	70.08	70.04
4000	68.93	70.06	68.50	68.51	68.94	69.05	69.04	68.50	69.04	68.95
5000	68.16	69.29	67.85	67.84	68.21	68.33	68.19	67.85	68.29	68.16
6300	66.44	67.93	66.26	66.25	66.56	66.66	66.50	66.26	66.66	66.43
8000	63.86	66.05	63.64	63.65	63.78	63.88	63.84	63.64	63.89	63.86
10000	58.56	61.80	58.18	58.15	58.43	58.53	58.39	58.18	58.54	58.55

Table 28: ILG RSS spectral data for quarter three of 2018.

BANDS	Q4 2017 1	2	3	4	5	6	7	8	9	10
	17-ES921BC_3_NR	18-963A2_NR	17-V936BH_BK	18_974B_BK	18-974A_BK	18-973A_BK	17-V936BD_BK	18-974C	17-V936BF	17-V936BG
50	71.22	71.33	71.00	71.05	71.07	71.25	70.81	71.60	71.39	71.71
63	65.97	65.98	65.98	65.85	65.98	66.00	65.99	66.17	65.87	66.08
80	67.69	67.44	68.19	67.84	67.46	67.73	67.87	67.73	67.83	67.63
100	70.23	70.13	70.69	70.11	70.22	70.85	70.54	70.40	70.76	70.78
125	69.70	69.93	69.83	69.69	69.99	70.15	70.14	69.88	70.09	69.80
160	71.98	71.83	71.69	72.16	71.98	71.72	71.67	71.90	72.10	72.17
200	71.27	71.10	71.04	71.22	71.33	70.68	71.31	71.27	71.35	71.14
250	71.67	71.52	71.67	71.69	71.57	71.77	71.87	71.89	71.89	71.83
315	73.77	73.82	73.68	73.81	73.76	73.72	73.68	73.87	73.77	73.88
400	75.32	75.39	75.40	75.35	75.40	75.32	75.38	75.49	75.45	75.60
500	76.86	76.89	77.07	76.99	76.96	76.83	77.03	77.04	77.09	77.11
630	78.62	78.57	78.77	78.69	78.70	78.65	78.85	78.69	78.88	78.96
800	81.24	81.22	81.34	81.28	81.28	81.37	81.35	81.43	81.38	81.52
1000	82.18	82.12	82.23	82.13	82.19	82.26	82.25	82.29	82.36	82.38
1250	83.16	83.17	83.19	83.15	83.16	83.19	83.20	83.31	83.31	83.40
1600	83.09	83.11	83.17	83.15	83.18	83.27	83.18	83.41	83.45	83.47
2000	82.23	82.31	82.38	82.35	82.38	82.41	82.31	82.77	82.74	82.81
2500	79.47	79.56	79.64	79.60	79.59	79.65	79.56	80.11	80.13	80.12
3150	77.23	77.32	77.42	77.40	77.39	77.44	77.36	77.92	77.95	77.94
4000	76.61	76.69	76.80	76.83	76.83	76.97	76.75	77.68	77.74	77.72
5000	74.92	74.97	75.14	75.21	75.21	75.17	75.06	76.24	76.29	76.31
6300	71.63	71.67	71.81	71.92	71.88	71.95	71.66	73.34	73.39	73.40
8000	68.17	68.21	68.38	68.45	68.40	68.70	68.19	70.12	70.17	70.16
10000	63.93	64.00	64.13	64.18	64.13	64.27	63.98	65.97	66.02	66.00

Table 29: B&K RSS spectral data for quarter four of 2017.

BANDS	Q1 2018 1	2	3	4	5	6	7	8	9	10
	18-980G	18-974B(2)	18-979A	18-983B	18-977C	18-966A	18-993B	18-993C	18-991A	18-981A
50	71.35	71.04	71.44	71.29	71.43	71.71	71.38	71.05	71.32	71.16
63	66.10	65.91	65.80	66.35	65.75	65.94	66.00	65.93	65.94	65.61
80	67.87	67.67	67.60	67.55	67.47	67.42	67.76	67.77	67.92	67.64
100	70.35	70.76	71.38	70.99	70.85	70.60	70.49	70.56	70.42	70.91
125	70.66	70.01	70.21	70.58	70.12	70.27	70.33	70.18	70.20	70.21
160	72.44	71.62	71.85	72.09	71.90	72.18	71.74	71.88	72.02	72.02
200	71.21	70.59	71.09	71.10	70.74	71.51	70.88	70.85	71.09	71.46
250	71.63	71.55	71.69	71.69	71.40	71.60	71.61	71.59	71.57	71.40
315	73.49	73.55	73.43	73.51	73.46	73.01	73.64	73.43	73.69	73.20
400	75.18	75.32	75.26	75.22	75.34	74.78	75.26	75.30	75.22	74.87
500	76.84	76.84	76.75	76.68	76.79	76.53	76.68	76.74	76.78	76.80
630	78.68	78.60	78.51	78.40	78.68	78.38	78.65	78.57	78.65	78.55
800	81.43	81.39	81.23	81.22	81.36	81.17	81.21	81.16	81.41	81.25
1000	82.12	82.24	82.21	82.27	82.13	82.11	82.04	82.00	82.14	82.11
1250	82.85	83.15	83.13	83.14	83.05	83.01	83.00	82.96	83.08	83.03
1600	82.82	83.22	83.13	83.20	83.22	83.14	83.12	83.04	83.15	83.19
2000	81.64	82.34	82.23	82.23	82.29	82.36	82.09	82.08	82.19	82.19
2500	78.66	79.64	79.53	79.47	79.58	79.58	79.31	79.29	79.40	79.30
3150	76.45	77.40	77.33	77.30	77.34	77.39	77.10	77.08	77.26	77.10
4000	75.51	76.91	76.84	76.83	76.90	76.89	76.48	76.47	76.57	76.44
5000	73.67	75.13	75.31	75.28	75.05	74.99	74.79	74.78	74.92	74.78
6300	70.34	71.91	72.23	72.21	71.86	71.74	71.66	71.63	71.75	71.62
8000	67.06	68.66	68.91	68.91	68.61	68.49	68.26	68.25	68.37	68.18
10000	63.03	64.22	64.66	64.64	64.16	64.06	64.04	64.03	64.14	63.94
RSS	81.43	81.39	78.51	83.28	71.40	76.89	71.61	71.59	76.57	77.10
FAN	55.53	44.34	46.23	41.84	48.10	56.66	39.00	39.64	28.53	51.70

Table 30: B&K RSS spectral data for quarter one of 2018.

BANDS	Q2 2018 1	2	3	4	5	6	7	8	9	10
	18-994A	18-996AR	18-1002B	18-1003X	18-1003N	18-1004C	18-1006A(2)	18-1007D	18-1002F	18-995A2
50	70.87	71.25	71.06	71.06	71.34	71.08	70.84	71.51	71.44	70.47
63	65.60	65.75	65.79	65.95	65.90	65.53	65.22	65.99	65.91	65.50
80	67.47	67.37	67.36	67.22	67.24	66.77	66.48	66.50	66.87	66.62
100	71.12	71.45	70.99	71.00	70.60	70.62	70.17	70.44	70.59	70.14
125	70.72	70.70	70.93	70.58	70.63	70.43	70.36	69.94	70.63	70.01
160	71.15	71.45	71.16	71.59	71.59	71.18	71.27	70.86	71.43	70.74
200	70.50	70.82	70.27	71.07	70.74	70.80	70.31	70.15	71.27	70.22
250	70.31	70.25	70.30	70.51	70.60	70.28	70.08	70.03	70.56	70.11
315	72.63	72.72	73.01	72.61	72.82	72.50	72.21	72.49	72.13	72.51
400	74.67	74.68	74.80	74.38	74.42	74.36	74.17	74.18	73.76	74.28
500	76.32	76.24	76.39	76.03	76.12	76.12	75.96	75.89	75.55	75.97
630	78.52	78.29	78.30	78.15	78.17	78.19	77.83	77.81	77.81	77.94
800	81.25	81.05	81.09	80.80	80.77	80.87	80.60	80.40	80.60	80.61
1000	82.00	81.85	81.99	81.68	81.76	81.78	81.51	81.37	81.54	81.49
1250	83.03	83.05	83.01	82.83	82.87	82.72	82.44	82.47	82.51	82.50
1600	83.12	83.21	83.23	83.09	83.12	83.10	82.78	82.78	82.77	82.80
2000	82.17	82.48	82.39	82.40	82.45	82.35	82.09	81.93	82.06	82.07
2500	79.47	79.92	79.83	79.91	80.02	79.76	79.60	79.49	79.48	79.53
3150	77.55	77.99	77.92	77.88	77.95	77.83	77.57	77.42	77.55	77.61
4000	77.26	77.95	77.87	77.99	78.01	77.81	77.58	77.39	77.53	77.55
5000	75.83	76.98	76.73	77.16	77.30	76.90	76.76	76.67	76.76	76.81
6300	73.43	74.86	74.68	75.21	75.35	74.77	74.78	74.98	75.02	75.14
8000	71.19	72.73	72.51	73.20	73.37	72.66	72.68	73.01	72.93	73.08
10000	68.23	69.94	69.64	70.51	70.72	69.87	69.97	70.38	70.14	70.40

Table 31: B&K RSS spectral data for quarter two of 2018.

BANDS	Q3 2018 1	2	3	4	5	6	7	8	9	10
	18- 1012A1	18- 1012A2	18- 1012A3	18- 996R1	18- 996R2	18- 996R3	18- 996S1	18- 996S2	18- 996S3	18- 981A
50	71.33	71.04	70.96	71.10	71.15	71.13	71.34	71.41	71.11	71.16
63	65.79	65.80	65.55	65.72	65.52	66.09	65.89	65.72	65.59	65.61
80	66.61	66.47	66.45	66.71	66.59	66.97	66.57	66.63	66.48	67.64
100	70.31	70.17	70.12	70.87	70.83	71.11	70.61	70.50	70.28	70.91
125	70.19	70.18	70.22	70.56	70.31	70.30	70.28	70.30	70.31	70.21
160	70.77	70.91	70.97	71.06	71.03	70.91	71.03	70.95	70.79	72.02
200	70.35	70.59	70.70	70.69	70.69	70.70	70.75	70.67	70.72	71.46
250	70.13	70.11	70.20	70.30	70.44	70.36	70.33	70.32	70.19	71.40
315	72.52	72.36	72.30	72.43	72.50	72.43	72.43	72.51	72.53	73.20
400	74.07	74.03	73.99	74.28	74.24	74.19	74.11	74.08	74.01	74.87
500	75.71	75.69	75.67	75.93	75.80	75.85	75.73	75.72	75.75	76.80
630	77.77	77.78	77.77	77.98	77.89	77.97	77.84	77.81	77.85	78.55
800	80.53	80.48	80.52	80.61	80.56	80.58	80.60	80.54	80.53	81.25
1000	81.33	81.36	81.33	81.55	81.57	81.50	81.54	81.56	81.51	82.11
1250	82.38	82.36	82.37	82.55	82.54	82.53	82.50	82.53	82.46	83.03
1600	82.62	82.60	82.59	82.75	82.76	82.73	82.78	82.77	82.76	83.19
2000	81.67	81.62	81.62	81.89	81.93	81.86	81.99	82.00	81.96	82.19
2500	79.06	79.07	79.05	79.28	79.33	79.30	79.57	79.56	79.53	79.30
3150	76.87	76.87	76.84	77.06	77.03	77.07	77.57	77.57	77.56	77.10
4000	76.58	76.59	76.57	76.74	76.71	76.72	77.63	77.62	77.64	76.44
5000	75.44	75.46	75.46	75.55	75.55	75.54	76.95	76.95	76.94	74.78
6300	73.29	73.30	73.27	73.21	73.20	73.22	75.37	75.39	75.37	71.62
8000	70.15	70.15	70.16	70.24	70.23	70.26	73.23	73.22	73.22	68.18
10000	66.16	66.17	66.15	66.18	66.18	66.18	70.51	70.52	70.53	63.94

Table 32: B&K RSS spectral data for quarter three of 2018.