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Exploratory Study of Sound Levels for the Kohler Engine Using a Soundbox and Honda V-Twin Engine

Executive Summary
This exploratory study measured sound levels for the Cold Air Drain® #1550 with the currently available Honda V-Twin engine and the discontinued Kohler engine, with and without the soundbox prototype. We measured actual noise using decibels, as well as ratings of perceived noise, in relation to a set point of reference from the engine. Our initial findings suggest that the soundbox reduced sound levels for the Kohler engine, but that the Honda V-Twin engine was the quietest overall. Decibel levels and noise perception ratings for the Honda V-Twin and Kohler engines (with and without the soundbox) generally decreased as the distance from the Cold Air Drain® unit increased. Decibel levels for each engine between 0-50m generally approximate decibel levels for a normal conversation or piano practice. The findings from this exploratory study support Shur Farms Frost Protection's® claims that the current Cold Air Drain® #1550 noise-reduction features are beneficial and that the Honda V-Twin engine is a substantially quieter power option.

The Problem with Noisy Frost Protection
Noise generated by the operation of agricultural frost protection equipment is a contentious issue in many communities. This is especially true with frost protection equipment (e.g., conventional wind machines) that is generally operated during the night when temperatures are lowest.

During calm, quiet nights, the operation of such frost protection equipment may be extremely disruptive to nearby residential areas. Many regions, counties, districts, and cities have already implemented (or are in the process of developing) noise ordinances or best practices to limit noise from activities, such as operating conventional wind machines (e.g., Napa County, California; Marborough, New Zealand).

Growers who use noisy frost protection equipment are trying to protect their crops from frost damage, but potentially to the detriment of their neighbors' health and sanity. Some commonly used frost protection devices, including conventional wind machines, are not just noisy--they are deafening--with decibel levels that have been measured as loud as approximately 90dBA at 38.40m (126ft.) (City of Calistoga 2003: N-17). Regular exposure to noise levels above 80dB may be potentially dangerous to a person's hearing and well-being (American Speech-Language-Hearing Association).

A quieter alternative to noisier frost protection methods (e.g., conventional wind machines) is the Shur Farms Cold Air Drain®. This report provides the findings from an exploratory study that measured sound levels for the Shur Farms Cold Air Drain® #1550 with the currently available Honda V-Twin engine and the discontinued Kohler engine. This sound level test sought to measure actual noise via decibel levels, as well as ratings of perceived noise, in relation to our point of reference from the engine. The discontinued Kohler engine is included in this test, as this engine is still being used with the Cold Air Drain® in the field by customers (the discontinuation of the Kohler engine took place only approximately three years ago). We tested the Honda V-Twin engine to obtain initial sound levels for this engine, as well as to provide a basis for comparison to the Kohler engine. This study also examined the effectiveness of a soundbox prototype built exclusively for use with the Kohler engine as an option to reduce the noise generated by this engine to address noise complaints from a nearby neighbor of a Shur Farms Frost Protection® customer in Napa, California.

Expectations and Hypotheses

We expect that the decibel levels and noise perception ratings will be greater for the Kohler engine than the Honda V-Twin engine, due in part to the noise reduction features for each Cold Air Drain® #1550 model and engine characteristics. Additionally, we expect that the Cold Air Drain® #1550 (older model) with the Kohler engine with the soundbox will be quieter than without the soundbox. We believe that the differences in the decibel levels and perceived noisiness ratings for the unit with the soundbox may be impacted by the side on which the engine is located from our point of reference. When our point of reference is directly facing the engine, we expect perceived noise to be greater than when our point of reference is opposite the engine or when the engine is off to the side from our point of reference. Furthermore, we expect that the further away from the Cold Air Drain® #1550 (with the engine) one is located, the lower the decibel levels measured, since when the distance doubles, the amplitude drops by half for sound in the air when there are no objects that might reflect or block the sound path. We also expect that the further away from the Cold Air Drain® #1550 (with the engine) one is located, the less noisy the unit will be perceived. These expectations for the effects of distance on decibel levels and perceived noise ratings hold for both the Kohler engine (with and without the soundbox) and the Honda V-Twin engine. Based on these expectations, our hypotheses are as follows.

H_0: Decibel levels for the Kohler engine will not be greater than the Honda V-Twin engine.
H_1: Decibel levels for the Kohler engine will be greater than the Honda V-Twin engine.

H_0: Perceived noise ratings for the Kohler engine will not be greater than the Honda V-Twin engine.
H_1: Perceived noise ratings for the Kohler engine will be greater than the Honda V-Twin engine.

H_0: Decibel levels for the Kohler engine with the soundbox will not be lower than the same engine without the soundbox.
H_1: Decibel levels for the Kohler engine with the soundbox will be lower than the same engine without the soundbox.

H_0: Perceived noise ratings for the Kohler engine with the soundbox will not be lower than the same engine without the soundbox.

H_1: Perceived noise ratings for the Kohler engine with the soundbox will be lower than the same engine without the soundbox.

H_0: Decibel levels will be not be greatest for the Kohler and Honda V-Twin engines when the engine is directly facing the point of reference, as compared when the engine is off to the side or opposite from the point of reference.
H_1: Decibel levels will be greatest for the Kohler and Honda V-Twin engines when the engine is directly facing the point of reference, as compared when the engine is off to the side or opposite from the point of reference.

H_0: Perceived noise ratings will be not be greatest for the Kohler and Honda V-Twin engines when the engine is directly facing the point of reference, as compared when the engine is off to the side or opposite from the point of reference.
H_1: Perceived noise ratings will be greatest for the Kohler and Honda V-Twin engines when the engine is directly facing the point of reference, as compared when the engine is off to the side or opposite from the point of reference.

H_0: As the distance from the Kohler and Honda V-Twin engines increases, the decibel levels will not decrease.
H_1: As the distance from the Kohler and Honda V-Twin engines increases, the decibel levels will decrease.

H_0: As the distance from the Kohler and Honda V-Twin engines increases, the perceived noise ratings will not decrease.
H_1: As the distance from the Kohler and Honda V-Twin engines increases, the perceived noise ratings will decrease.

Methods and Data

Measures

We are seeking to measure several major characteristics of sound that contribute to *actual noisiness* and/or the *perception of noisiness*. First, we are measuring *amplitude*, which is the pressure created by sound waves and corresponds to loudness. We use amplitude as our key measure of actual noise. Second, we are evaluating the *intermittence* of the sound, which is the consistency of the loudness and frequency of the sound. We consider the intermittence of sound as a major contributor to the perception of noisiness, as a higher frequency, less consistent sound may be perceived as being louder and more annoying. *Localization* is another component that may contribute to the perception of noisiness, as a sound source that appears to change relative to the listener may be perceived as more annoying. We assume that the sound source is stationary, as we do not expect Cold Air Drains® to be moved regularly during actual use in the field. *Background noise* also may affect the perception of noisiness, as the source noise increases above the background noise will increase annoyance. We assume that the background noise is minimal, as the Cold Air Drain® is used in the field at night during actual use. Finally, the *duration of exposure* to the noise may be a factor in the perception of noisiness, as greater exposure to the noise may increase annoyance. We are primarily interested in amplitude as our measure of actual noise and intermittence for rating noise perception.

Cold Air Drain Models® and Engines

The currently available Cold Air Drain® #1550 model, which includes the newest noise-reducing features, including creased panels and a heavier base, was used for testing the two-cylinder Honda V-Twin engine. An older #1550 model (Figure 1) that included only the noise-reducing creased panels was used with the single-cylinder Kohler engine, as the gearbox on the current Cold Air Drain® #1550 model is not designed to work with the discontinued Kohler engine.

Figure 1: Cold Air Drain® #1550 (older model) with Kohler Engine

Decibel measurements and noise perception ratings were collected from a point of reference, which was located at each distance in 10m increments from the Cold Air Drain® (with the engine), in which the point of reference was the same for the tests of the Kohler engines, with and without the soundbox, as well as the Honda V-Twin engine. Decibel measurements and noise perception ratings were collected when the engine was directly in front of, opposite, and to the side of the point of reference. As the Honda V-Twin is a two-cylinder engine, decibel levels and perceived noise were measured when the engine was both to the right and the left of the point of reference because the exhaust was facing or opposite of the point of reference depending on the side that the engine was located. The Kohler engine is a single cylinder engine, so the exhaust exits straight from the back of the engine; therefore, we only tested this engine to one side of the point of reference because we did not expect any difference in measurements due to the side on which the engine was located.

Soundbox

The soundbox prototype (Figure 2) was made from galvanized metal with an interior layer (3.8cm thickness) of soundproofing material (Super Soundproofing Foam Mat, Super Soundproofing, Co.) to absorb noise generated by the Kohler engine. The soundproofing material is designed for use in cars, boats, airplanes, home, and office. The soundbox was approximately 39.93kg and the dimensions were as follows:

Outer Diameter: 91.44cm L x 83.82cm W x 83.82cm H
Inner Diameter: 88.27cm L x 76.84cm W x 77.47cm H

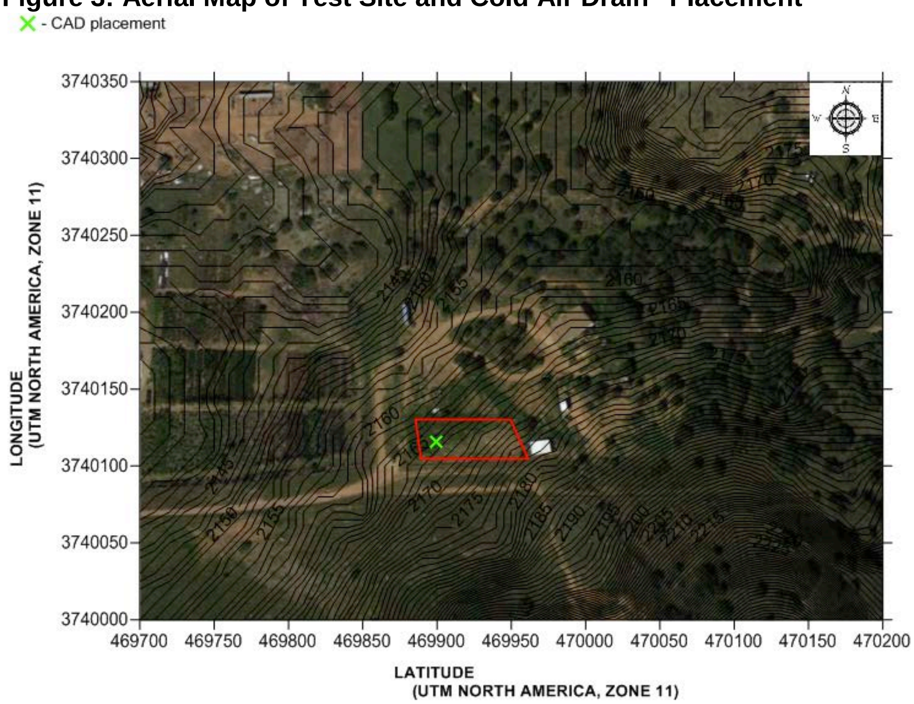
A single panel lined with soundproofing material was placed several centimeters from the front opening to block sound from the engine during the test of the soundbox, while still allowing air to cool the engine to avoid overheating.

Figure 2: Soundbox Prototype

Study Site

Testing was conducted at the Shur Farms® Sustainability Testing and Agricultural Research (STAR) Center in Val Verde, California. The test site was an area with a very small gradient on dry, rocky soil with only a few small bushes around the perimeter of the testing area. No obstructions, such as buildings, cars, or large vegetation, directly surround the testing area; however, a corral was located just east of the test site boundaries and a chain link fence bordered the west and south sides of the site (Figure 3). The test site is bordered in red and the location of the Cold Air Drain® is marked by the green "X".

Figure 3: Aerial Map of Test Site and Cold Air Drain® Placement



By measuring noise levels in this open environment, we hoped to create a situation similar to where the Cold Air Drain® would actually be used, so as to measure realistic sound levels for the Cold Air Drain® during operation. However, during actual use of the Cold Air Drain®, the unit would be placed in the field between crop rows. The area directly surrounding the Cold Air Drain® would be partially or completely surrounded by the bushes, trees, or vines that the unit is protecting, which may dampen the noise generated by the Cold Air Drain®. Additionally, the Cold Air Drain® may be placed in areas that are not completely flat, in which hills in the immediate and/or surrounding area(s) may affect how sound waves travel and are perceived by nearby residents.

Testing was conducted on March 1, 2012 during the daytime. Testing during the daytime presented warmer temperatures, partial cloud cover, and no inversion layer, which differs significantly from recommended operating under radiation frost conditions for the Cold Air Drain®. Though we would have liked to exactly replicate realistic operating conditions for the Cold Air Drain®, we could not reasonably do so, due to the location of the testing facility and reasonable inability to predict ideal weather conditions.

The ambient temperature was 54.4°F when the Honda V-Twin test was started at approximately 11:00AM, which increased to 60.1°F after the Honda V-Twin test was completed. Humidity was 52.2% and there was a light sustained wind with partial cloud cover. Moving clouds covered the sun throughout the day, so the ambient temperature varied quite a bit. The ambient temperature rose to 60.8°F at 12:44PM immediately prior to starting testing of the Kohler engine. Humidity was 42.4% and the sky was overcast with frequent gusts of light wind.

Methods

Actual Noise

Amplitude was measured in decibels using the Checkmate CM-130 at a height of approximately 1.5 meters. The decibel measures sound intensity and is a logarithmic unit, which cannot be added and subtracted like ordinary numbers. An increase of 3dB is a doubling of the "strength" of the sound. An increase of 10dB means the sound is 10 times as loud. For example, 70dB is 10 times as loud as 60dB. Our decibel measurements are based on the A-weighting scale, as this is the most common scale for measuring environmental noise.

Ambient decibel levels were measured at 5m from the Cold Air Drain®. Decibel levels during operation of the Cold Air Drain® were measured from 0m to 70m from the Cold Air Drain® in 10m increments from the point of reference (relative to engine location). Distances from 0m to 50m only had a slight gradient, so it is unlikely that the decibel readings at these distances were significantly skewed by topography; however, the distances of 60m and 70m had a steeper gradient. Three independent readings were taken at each distance were to obtain reasonably consistent measurements. The Cold Air Drain® was run for approximately 10 seconds prior to taking measurements to ensure that the engine was running consistently.

The ambient decibel level was 42dBA. Sustained noise from birds chirping and farm equipment in the distance was present, and there was also the occasional small plane flying overhead, which may have affected decibel levels and noise perception ratings.

Noise Perception

Intermittence was evaluated using a scale rating the perceived loudness, consistency, and perceived pitch of the noise. Ratings were taken at the same distances and points of reference as the measurements of the decibel levels. Our reference for rating perceived noise was based on the noise perception of a normal conversation (approximately 60-70dBA). Noise perception was evaluated by two researchers, in which both researchers had to agree on the rating given at each distance and point of reference.

Ratings were based on an ordinal 4-point scale with “1” being the quietest and “4” being the loudest. We relied on a 4-point scale to force a choice between “loud” and “quiet” to avoid rating noise perception as “normal”, “average” or some other undefinable category inherent in scales with an odd number of categories. The scale is as follows: 1= Quiet; 2= Slightly Quiet; 3= Slightly Loud; 4= Loud. A rating of “Quiet” meant that the researchers could hear each other speaking at a normal volume very easily; the sound from the Cold Air Drain® during operation was insignificant background noise. A rating of “Slightly Quiet” meant that the researchers could still hear each other speaking at a normal volume, but that the Cold Air Drain® noise was more prominent. A rating of “Slightly Loud” meant that the researchers had to strain to hear each other speaking at a normal volume, as the noise from the Cold Air Drain® was prominent. Finally, a “Loud” rating meant that the researchers could not hear each other well speaking at a normal volume, as the noise interference from the Cold Air Drain® was substantial.

Findings

Table 1 shows the decibel levels by distance for the Cold Air Drain® #1550 (older model) with the Kohler engine without the soundbox. Generally, as the distance increased, the decibel levels decreased.

At the distances of 60m and 70m when the engine was located directly in front of the point of reference, the noise perception ratings for the Kohler engine without the soundbox was “Slightly Loud”. At distances from 0m to 50m, the noise perception ratings were “Loud”. Noise perception ratings when the point of reference was opposite the engine were “Slightly Quiet” at 70m, “Slightly Loud” for 40-60m, and “Loud” for 0-30 meters. Ratings of “Slightly Loud” were given at 60-70m when the point of reference was of to the side from the engine, and “Loud” from 0-50 meters.

Table 1: Decibel Levels for Kohler Engine without Soundbox

	Directly Facing	Engine to the Side	Opposite of Engine
0	70.5	64	64.2
10	68.7	60.3	65.5
20	66.3	61.5	63.2
30	64.5	58.2	62.2
40	61.3	60.2	60.2
50	62.5	51.5	59.5
60	62.2	55.7	57.7
70	60.7	52	57.2

Table 2 shows the decibel levels by distance for the Cold Air Drain® #1550 (older model) with the Kohler engine with the soundbox. As compared to the decibel levels for the Kohler engine without the soundbox, the decibel levels for the Kohler engine were generally reduced when the soundbox was used, except for when the point of reference was opposite of the Kohler engine with the soundbox.

When the point of reference was directly facing the engine when the Kohler engine was operating with the soundbox, the following noise perception ratings were given: “Slightly Loud” for 50-70m and “Loud” for 0-40 meters. Ratings for the point of reference opposite the engine were the same as the ratings when the point of reference was directly facing the engine. When the point of reference was off to the side of the engine, the only difference in noise perception ratings was at 50m, which was rated as “Loud”.

Table 2: Decibel Levels for Kohler Engine with Soundbox

	Directly Facing	Engine to the Side	Opposite of Engine
0	65.7	63	65.5
10	64	66.5	65
20	61.8	63.5	64.2
30	60	64	63
40	51.2	58.8	56.7
50	60.8	52.5	61.8
60	61.2	56.7	61.3
70	58.5	51.2	58.7

Table 3 shows the decibel levels by distance for the Cold Air Drain® #1550 (current model) with the Honda V-Twin engine. Although these decibel measurements are not directly comparable to the measurements for the Kohler engine, as a different Cold Air Drain® #1550 model was used for testing the Honda V-Twin engine, these decibel measurements do provide a general indication of how much quieter the newer Cold Air Drain® models are when operated with a Honda V-Twin engine.

Noise perception ratings for the Honda V-Twin engine when the point of reference was directly facing the engine were as follows: “Slightly Quiet” at 60-70m; “Slightly Loud” at 30-50m; and “Loud” only at 0-20 meters. When the point of reference was opposite of the engine, the ratings were “Slightly Quiet” at 70m; “Slightly Loud” at 40-60m; and “Loud” at 0-30 meters. Since the Honda V-Twin is a two-cylinder engine, the noise perception ratings differed from one side to the other when the engine was to the side of the point of reference, depending on whether the exhaust pipe was on the direct or opposite side from the point of reference. Noise perception ratings were louder for 60-70m when the exhaust pipe was facing the point of reference. However, at a distance of 40m, noise perception was rated as “Slightly Loud” when the exhaust pipe was facing the point of reference, but “Loud” when the exhaust pipe was opposite from the point of reference. Other than these few differences, all other noise perception ratings were the same for when the engine was off to the side from point of reference, regardless of which side the exhaust was facing.

Table 3: Decibel Levels for the Honda V-Twin Engine

	Directly Facing	Engine to the East Side	Engine to the West Side	Opposite of Engine
0	67.7	67.7	66.1	66.5
10	62.8	67.7	63.7	66
20	55	65	62.8	62.7
30	59	63.3	62	59.8
40	58	60.8	58.5	56.3
50	53	59.3	57.7	54.5
60	55	57.7	56.7	53.7
70	55	57.2	55.5	52.3

Discussion

The decibel levels at 0m for the Kohler engine, regardless of the engine location from the point of reference, were comparable to the decibel ranges for piano practice or a normal conversation (see Table 4). Each position for the Kohler engine with and without the soundbox generally stayed within the 60-70dB range, although the decibel levels generally did decrease with distance from the Cold Air Drain®. Also consistent with our expectations, the Kohler engine with the soundbox was much quieter than the Kohler engine without the soundbox. Moreover, the Honda V-Twin engine was substantially quieter than the Kohler engine (even with the soundbox). Decibel levels dropped at 40m to slightly more quiet than a TV (home level) at 0.91 meters (3 feet). The noise perception ratings were generally consistent with the decibel level patterns.

Our findings indicate that the soundbox was beneficial for reducing sound levels when the Cold Air Drain® was operated with a Kohler engine, except when the engine was opposite from the point of reference. We are not surprised by this finding, as the soundbox is open on the side that is facing into the Cold Air Drain®, which was a necessary design requirement for the soundbox. The driveline must have been able to connect to the engine inside the soundbox, and air must have been able to flow into the unit (for cold air drainage) and to maintain the engine temperature. Decibel levels for the Kohler engine were greatest when the engine was located directly in front of the point of reference. The placement of the engine to the side of the point of reference for the Kohler engine with and without the soundbox had the lowest decibel levels overall. The placement of the Honda V-Twin engine opposite from the point of reference had the lowest decibel levels overall.

Several factors may have affected the perception of noisiness for the Kohler and Honda V-Twin engines. First, the Honda V-Twin engine is a two-cylinder engine, in which the sound generated by the Honda V-Twin engine may be perceived as being more balanced and consistent than the single-cylinder Kohler engine; therefore, the Honda V-Twin engine may be perceived as being less noisy. Second, we noted that when the Kohler engine was running (with and without the soundbox) the sound was less consistent. The lack of a consistent hum from the Kohler engine made the sound seem more annoying, which may be perceived as being more noisy than the Honda V-Twin engine. Finally, the frequency of the sound (i.e., pitch) generated by each engine may have also affected our ratings of perceptions of noisiness. We noted that the pitch of the Kohler engine seemed much lower than the Honda V-Twin and tended to alternate as the engine cycled; however, we did not measure sound frequency. The less consistent sound, along with the perceived lower pitch, made the Kohler engine seem louder at each distance, regardless of the decibel levels (i.e., actual noise).

Table 4: Decibels (dB) for Common Sounds

Sound	Decibels (dB)
Normal Breathing	10
Rustling Leaves	20
Whisper Quiet Library	30
Refrigerator Humming	40
TV (home level) at 3ft	60
Electric Shaver	60
Piano Practice	60-70
Normal Conversation at 3-5ft	60-70
Vacuum Cleaner	70
Telephone Dial Tone	80
City Traffic (inside car)	85
Train Whistle at 500ft	90
Subway Train at 200ft	95
Power Mower at 3ft	107
Chainsaw at 3ft	110
Pneumatic Riveter at 4ft	125
Shotgun Firing	130
Jet Engine at 150ft	140

Limitations

Several limitations with this exploratory study deserve mention. The most obvious limitation of this study is that our test site did not approximate real environments in which the Cold Air Drain® might generally be operated. The Cold Air Drain® is used to protect crops against frost damage during clear, cold nights with virtually no wind. The outside temperature on the testing day was significantly higher than would be the case during a radiation frost night and wind was present. The Cold Air Drain® generally operates in a relatively open area on an uneven soil surface among plants and vegetation, which may lower the sound levels of the Cold Air Drain® during operation.

Second, despite the overall decrease in decibel levels as the distance from the Cold Air Drain® increased, decibel level readings for the Kohler engine, with and without the soundbox, jumped around at distances of 40-60m. Due to the jumping of the readings by the decibel meter, obtaining consistent readings at these distances for the Kohler engine was very difficult. We are not sure if the characteristics of the sound generated by the Kohler, along with the topography at and around the 40-60m reference points, are what led to the inconsistent readings. The distances of 60m and 70m had a steeper gradient. Sound waves generated by the Kohler engine may have bounced off of the slope between 50-60m, but the issue of jumping decibel level readings for the Kohler engine should be further investigated. Additionally, decibel readings for the Kohler engine with the soundbox at a distance of 10m also were higher than the decibel levels at 0m and 20+ meters. Further investigation is needed to determine if the higher decibel levels at 10m are due to a characteristic of the Kohler engine, soundbox, or both, or if outside noise, such as farm equipment being used in a surrounding area, contributed to the higher decibel level readings at this distance.

Third, although we tried to address the main variables that might affect the results, we cannot reasonably control for all environmental variables. Thus, our findings may have been impacted by environmental variables other than those that we addressed in this study.

Fourth, at distances of 60m and 70m from the Cold Air Drain® the gradient was steeper than the gradient at 0-50 meters. Decibel readings and noise perception ratings may have been affected by the higher elevations at the 60m and 70m distances.

Finally, we relied on the 4-point scale for rating noise perception, which did not contain more refined, detailed categories to rate noise perception. To collect data more appropriate for assessing the degree of perceived noisiness of the Cold Air Drain® with the engines, we would recommend using a 6-point scale, at minimum, for future studies seeking to evaluate noise perception. We also suggest that the concept of perceived noise may be more appropriately measured by parsing out major components that make up "perceived noise" and utilizing objective measures for assessing those components (e.g., pitch would be objectively measured through frequency readings). In addition to the limitations inherent in our scale, our reliance on "normal speaking volume" as the reference for rating noise perception may also be considered a reasonable limitation of this study, as inter-rater reliability was not measured. If using a larger, more refined scale for evaluating noise perception in future studies, a larger number of raters would be necessary, as well as measurements of inter-rater reliability.

This exploratory study was conducted to obtain baseline sound levels for the Cold Air Drain®. Future studies will be designed to more closely approximate the actual operating environment for the Cold Air Drain®, and will address the methodological and measurement limitations identified through this exploratory study.

Conclusion

This exploratory study measured sound levels for the Cold Air Drain® #1550 with the currently available Honda V-Twin engine and the discontinued Kohler engine, with and without the soundbox prototype. We measured actual noise via decibel levels, as well as ratings of perceived noise, in relation to our point of reference from the engine. Our initial findings suggest that the soundbox reduced sound levels for the Kohler engine. Decibel levels and noise perception ratings for the Honda V-Twin and Kohler engines (with and without the soundbox) decreased as the distance from the Cold Air Drain® increased, except at distances of 40-60m for the Kohler engine. Decibel levels for each engine between 0-50m were generally between 60-70dB, which approximates the decibel levels for a normal conversation or piano practice; however, the Honda V-Twin engine was substantially quieter than the Kohler engine (even with the soundbox) overall. The noise perception ratings indicated that the Kohler engine (even with the soundbox) may be perceived by listeners as being much louder than the Honda V-Twin engine, despite decibel levels, due to the Kohler engine's less consistent and lower pitch sound. Several limitations with this study and suggestions for future research were also discussed. The findings from this exploratory study support Shur Farms Frost Protection's® claims that the current Cold Air Drain® #1550 noise-reduction features are beneficial and that the Honda V-Twin engine is a substantially quieter power option.

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*There were some conflicting readings. In many cases the authors did not specify at what distance the readings were taken. When there were several readings, the higher reading was chosen.