ALGORITHMS FOR HVAC ACOUSTICS

About the Authors

This publication was completed as part of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Research Project 556-RP, Algorithms for HVAC Acoustics, by DDR, Inc., Consultants in Acoustics & Vibration, Las Vegas, NV.

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INTRODUCTION

CHAPTER 1

Over the past 10 years ASHRAE Technical Committee TC 2.6, Sound and Vibration Control, has sponsored research that has greatly expanded the available technical data associated with HVAC acoustics. These data, all of which have been included in the ASHRAE Handbook chapter on sound and vibration control, have greatly expanded the ability of designers to make more accurate calculations related to the acoustical characteristics of HVAC systems. However, one of the major difficulties associated with HVAC analyses has been the enormous amount of time that is required to make the many repetitive calculations necessary to examine the sound properties of a specific system. In order for individuals to analyze the sound characteristics of a particular system and to make recommendations that are necessary to ensure a quiet system, the technical data and associated design procedures developed under the sponsorship of TC 2.6 must be presented in a format that is easy to use. As a result, ASHRAE Research Project 556–RP, Algorithms for HVAC Acoustics, was approved for the purpose of developing for the HVAC designer a set of algorithms and related computer programs in the area of HVAC acoustics that are useful and reliable. All algorithms were to be based on currently verifiable published and unpublished test results.

The objectives of this project were to: (1) develop algorithms in English, along with discussions related to the development of the algorithms, references, and other appropriate data; (2) develop computer programs associated with each algorithm programmed in Basic; and (3) produce a final report in a form that can be readily published by ASHRAE.

Algorithms that are presented in this report fall under the following general headings:

Some Basics
Equipment Sound Power
Duct Element Regenerated Sound Power
Duct Element Sound Attenuation
Duct Breakout and Breakin
Sound Transmission in Indoor and Outdoor Spaces

The section on "Some Basics" covers basic terminology, the addition of sound levels, and the determination of NC and RC levels.

The algorithms developed under the general heading of "Equipment Sound Power" are "Fans" and "Chillers." The algorithm for fans is based on the methodology presented in the ASHRAE Handbook for determining the 1/1 octave band sound power levels of fans. The algorithm for chillers is also based on the ASHRAE Handbook. Methods presented here for determining sound pressure levels for chillers should be used for approximations only. Noise problems arising from water–chilling assemblies are dependent upon so many variables that it is impossible to formulate a standard solution. Chiller manufacturers have yet to publish any substantial data due to a lack of an industry–sanctioned, standard method of determining and reporting noise levels.

The algorithms developed under the general heading of "Duct Element Regenerated Sound Power" include: dampers, elbows fitted with turning vanes, junctions and turns, and diffusers. Algorithms for dampers, elbows fitted with turning vanes, and junctions and turns are based on ASHRAE–sponsored research performed by Ver and information in the ASHRAE Handbook (36,44,45,46,47). The algorithm for diffusers is based on material presented in Beranek's book, Noise and Vibration Control (3).

Algorithms developed under the general heading of "Duct Element Sound Attenuation" include: sound plenums, unlined rectangular ducts, acoustically lined rectangular ducts, unlined circular ducts, acoustically lined circular ducts, elbows, acoustically lined circular radiused elbows, duct silencers, duct branch power division, duct end reflection loss, and terminal volume regulation units. The algorithm for plenum chambers is based on work originally completed by Wells (48). Very little research has been undertaken investigating the acoustical properties of plenum chambers since Wells published his paper; thus, further experimental work needs to be performed in this area. Algorithms for unlined rectangular and unlined circular ducts are based on experimental data presented by Chaddock, Sabine, Ver, and Woods Fans (10,14,39,45). The algorithms for lined and rectangular and circular ducts are also based on experimental data. The algorithm for lined rectangular ducts is based on data by Kuntz, Kuntz and Hoover, and Machen and Haines (22,23,24). Multivariable regression analyses were performed on these data to obtain a simple set of equations that can be programmed on a computer. The algorithm for lined circular ducts is based on data obtained from Bodley (8). Similar multivariable regression analyses were performed on this data. The algorithms for unlined and lined square elbows are based on information in the ASHRAE Handbook (4,37,38,40). The algorithm for acoustically lined circular radiused elbows is based on data obtained by Bodley (8). As with lined ducts, a multivariable regression analysis was performed on these data to obtain a set of equations that is easily implemented in a computer program. The algorithm for duct silencers is based solely on product data. This should be kept in mind when using this algorithm, as it would be best to use product data specific to the duct silencers being installed in the ductwork. The algorithm for duct branch sound power division is based on ASHRAE–sponsored work by Ver (44,46). Very little experimental data relative to the low–frequency sound attenuation associated with duct end reflection losses are available in the open literature. The algorithm for duct end reflection loss is based on work completed by Sandbakken, Pande, and Crocker (32). This work resulted in the technical basis for the duct end reflection correction that is part of AMCA Standard 300–85, "Reverberation Room Method for Sound Testing of Fans" (1). The algorithm for terminal volume regulation units is based solely on the 1984 ASHRAE Handbook (38). Most of the available data will be proprietary manufacturers' data. This algorithm should be used only as a general guide. Whenever possible, it is advisable to use manufacturers' data for determining the sound attenuation associated with terminal volume regulation units.

Algorithms that fall under the general heading of "Duct Breakout and Breakin" include: breakout and breakin of rectangular ducts, breakout and breakin of circular ducts, breakout and breakin of flat–oval ducts, and breakout and breakin of externally lagged rectangular ducts. All the algorithms under this general heading are based on work by Cummings, which is also summarized in the ASHRAE handbook (11,12,13,36).

The algorithms that are discussed under the heading "Sound Transmission in Indoor and Outdoor Spaces" include: sound attenuation through ceiling systems; receiver room sound corrections; sound transmission through mechanical equipment room walls, floor and ceiling; and sound transmission in outdoor spaces. The algorithm for the sound attenuation through ceiling systems is based on product data and the ASHRAE handbook (35,36). The coefficients for acoustical leaks and the quality of construction are somewhat subjective and should be used with caution. Algorithms for the receiver room correction are based on work that has been reported by Beranek, Schultz, and Thompson (2,33,42,43). The algorithm for sound transmission through mechanical equipment room walls and through holes in mechanical equipment room walls is based on work completed by Reynolds and Bledsoe (30). As is the case for ceilings, the coefficients for acoustical leaks and the quality of construction are somewhat subjective and should be used with caution. The algorithm for sound attenuation in outdoor environments is presented to give the designer a general idea of outdoor sound attenuation. Approximations are made for barriers and reflecting surfaces. Caution should be exercised in using this information if outdoor noise levels are critical. A more in–depth analysis should be conducted if this is the case.

Computer programs have been developed for each of the algorithms previously mentioned. An outline, a listing, and sample output for each of the programs appear in the appendices of this publication. The programs are programmed in basic. They are examples of how each algorithm can be set up for operation on a computer.

Endless time can be spent in developing computer programs that will contain all of the capabilities and error checking options that their many users desire them to have. The programs listed in the appendices are designed to be reasonably user–friendly and to give accurate results. They are not designed to contain all of the capabilities and error checking options that an integrated, commercial computer program on HVAC acoustics would be expected to have. It was not the intent of ASHRAE Research Project 556–RP to do this. However, the programs are written, so that, subject to the copyright restrictions associated with this publication, a user can incorporate them into an integrated computer program in the area of HVAC acoustics that has all of the capabilities and error checking options he or she desires to add.

2.1 SOUND LEVELS

The most common parameter used to give an indication of "loudness" is the sound pressure level, L_p. The sound pressure level, L_p (dB), is defined as

$$L_p = 10 \log_{10} \left[\frac{p_{rms}^2}{p_{ref}^2} \right] \tag{2.1}$$

where p_{rms} is the root–mean–square value (rms) of acoustic pressure (Pa). p_{ref} is the reference sound pressure and has a value of 2 x 10^{-5} Pa or 0.0002 μbar. This amplitude was selected because it is the amplitude of the sound pressure that roughly corresponds to the threshold of hearing at a frequency of 1000 Hz. The intensity level, L_I (dB), is defined as

$$L_I = 10 \log_{10} \left[\frac{I}{I_{ref}} \right] \tag{2.2}$$

where I is acoustic intensity (W/m^2). I_{ref} is the reference intensity level and has a value of 10^{-12} W/m^2. The sound power level, L_W (dB), is defined as

$$L_W = 10 \log_{10} \left[\frac{W}{W_{ref}} \right] \tag{2.3}$$

where W is sound power (W). W_{ref} is the reference sound power and has a value of 10^{-12} watts.

With respect to HVAC systems, noise reduction, NR (dB), is

$$NR = L_{p(1)} - L_{p(2)} \tag{2.4}$$

where $L_{p(1)}$ is the sound pressure level (dB) of the sound entering a duct element and $L_{p(2)}$ is the sound pressure level (dB) of the sound coming out of the element. Insertion loss, IL (dB), is

$$IL = L_{p(w/o)} - L_{p(w)} \tag{2.5}$$

where $L_{p(w/o)}$ is the sound pressure level (dB) at a point without a specific duct element inserted and $L_{p(w)}$ is the sound pressure level (dB) at the same point with the duct element inserted. Transmission loss, TL (dB), is

$$TL = -10 \log_{10} \left[\frac{W_{out}}{W_{in}} \right] \tag{2.6}$$

where W_{in} is the sound power (W) of sound entering a duct element and W_{out} is the sound power (W) of the sound exiting the duct element.

Often it is necessary to add the sound pressure levels at a point in a room from several sound sources in the room, or it is necessary to add the sound power levels at a specific point in a duct system associated with different duct elements. When adding sound pressure or sound power levels, the total level, L_T (dB), is

$$L_T = 10 \log_{10} [SUM] \tag{2.7}$$

where

$$SUM = 10^{[L_{p1}/10]} + 10^{[L_{p2}/10]} + 10^{[L_{p3}/10]} + \ldots \tag{2.8}$$