HVAC DISPLACEMENT SYSTEM NOISE CONTROL – A NEW METHOD TO QUANTIFY NOISE CONTROL PERFORMANCE

John O'Keefe *[1]
[1]O'Keefe Acoustics, Toronto, Ontario, Canada.

1 Introduction

The only plenum noise control calculation procedures that the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) currently considers are the ones that suit the big box on the exit end of an Air Handling Unit (AHU). In performing arts centres and in modern offices one is confronted with a different problem. Not a chamber at the end of a duct or an AHU but a whole room directly below the noise sensitive space, be it an office or an opera house. When Toronto's new opera house was being designed, there was no method available to measure a plenum's Insertion Loss, let alone a method to predict the anticipated noise levels. This paper will propose methods to do both.

2 Method

2.1 Concept

Top down Heating Ventilation and Air Conditioning (HVAC) systems dump the conditioned air from on high and return it down low. A displacement system reverses this route. A room (the plenum) is located below the audience chamber. It is pressurised with conditioned air, usually with the aid of distribution ducts to get an even distribution of air. Holes in the audience chamber floor allow the air to drift upwards displacing the air that is already there – hence the name. The air flows very slowly, typically at 0.5 m/s (100 fpm) thus virtually eliminating turbulence induced noise. Air is returned through large ducts in the upper reaches of the auditorium. An image of a typical displacement system is shown in Figure 1.

2.2 Analysis

When beginning the analysis of a displacement system's sound field a difficult question is immediately posed. Should one be concerned with the few openings that a listener might have a clear line of sight to? For example, the 4 or 5 openings one might see sitting on the orchestra level. Or should one consider the hundreds of openings that might be seen from a balcony or catwalk? Numerically, it is a difference of at least 25 dB. Ideally one should consider both scenarios but which one is more important?

To do that, the proposed procedure borrows from the early 20th century when sound in a room was first divided into two independent components: Direct and Reverberant. The displacement noise problem does not fit quite so neatly

* john@okeefeacoustics.com

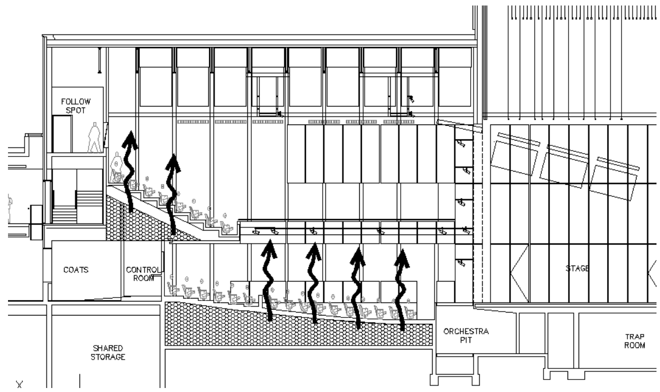

Figure 1: Longitudinal section showing the displacement system at The Esplanade, Medicine Hat, Alberta. Air is supplied through holes in the floor and returns through ductwork located in the ceiling space.

into these categories of Direct and Reverberant sound. But, it was determined that it doesn't have to. A concept of Near and Far Fields was developed both for calculations and measurements. The question still remained though, which field is more important the Near or the Far Field? It's also worth noting that the holes in the floor that the air flows through could be considered as a partially closed pipe. As such, will they display resonances? Only measurements could assist with that question.

But before one moves on to the measurements, a subtle but important refinement of the procedure is required. Up until now the openings in the floor have been considered as individual sound sources, a bit like an array of loudspeakers. Sound starts in one room (the plenum) and propagates into the next as a series of new, smaller sound sources. It's a bit like Huygen's principle. And it's quite difficult to handle either conceptually or through measurements. The solution was to shift the method of confronting the problem; not as a collection of 100s of sound sources but rather as one room (the plenum) separated from the other (the audience chamber) by a barrier. In this case the barrier is a composite of the concrete floor and the openings in it, something very easily calculated with area ratios. Performance is quantified, as one would do with a normal Noise Reduction measurement. One has moved from a complicated 17th century scientific paradigm to an easily understandable mid-20th century noise control engineering solution.

3 Measurements

Measurements were performed in three venues, the Mississauga Living Arts Centre in Mississauga, Ontario (MLAC), The Esplanade Arts and Heritage Centre in

Medicine Hat, Alberta and the Four Seasons Centre for the Performing Arts (FSCPA) in Toronto. Please see the summary in Table 1.

Table 1: List of venues

Building	City	Volume (m^3)	Type of Diffuser	Plenum lining
The Esplanade	Medicine Hat	5,450	Mushroom	None
MLAC	Missis-sauga	approx. 13,000	Seat pedestal	100 mm
FSCPA	Toronto	14,000	Seat pedestal	50 mm

The near field was measured with the loudspeaker resting on top of a duct, close to the hole under examination. Measurements were then performed on either side of the hole, i.e. in the plenum then above in the audience chamber, first at floor level and then at ear level 1 m above the floor. Far field measurements were performed as one would an ASTM E-336 Noise Reduction measurement.

4 Results

4.1 Near field

Results for the Near Field measurements are shown in Figure 2. Note what appears to be resonance effects in the 250 Hz to 500 Hz range. Near Field measurements at ear level (1 m above the floor) show similar results although the suspected resonance effects are not as pronounced. At higher frequencies the attenuation is more pronounced as one might expect for the barrier effect created by the chair.

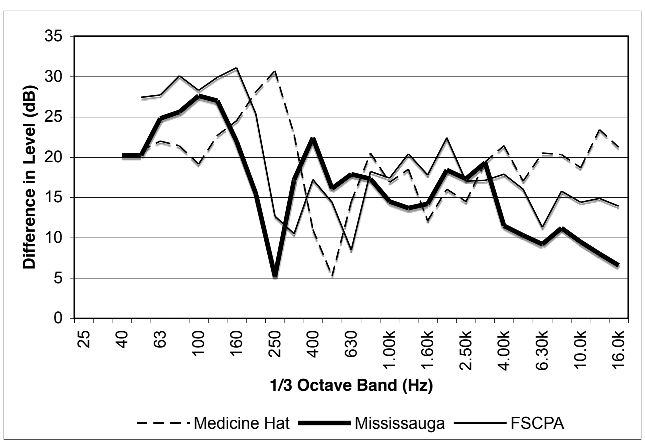

Figure 2: Measured near field noise reduction from the underside of a slab hole to the diffuser at the floor level immediately above.

4.2 Far field

Results from the Far Field measurements are shown in Figure 3. It might be noted that the presence of glass fibre lining had little effect on the Noise Reduction levels. MLAC had the thickest lining (100 mm), FSPAC 50 mm and The Esplanade none. MLAC has slightly higher attenuation but there's little consistent difference between FSCPA and The Esplanade.

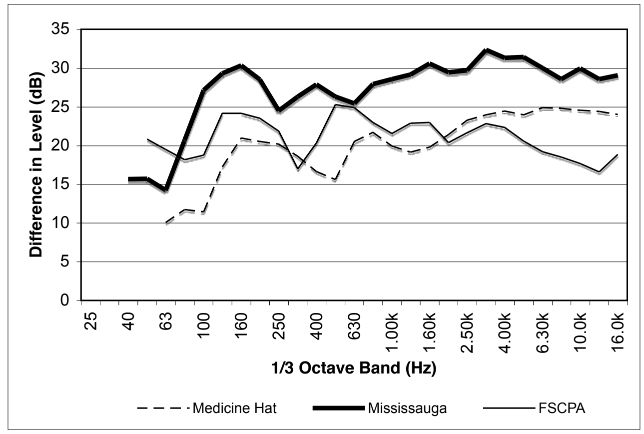

Figure 3: Measured far field noise reduction between the plenum and the orchestra level

4.3 Comparison

So the important question at the beginning was which field is more significant. It turns out it's the Far Field. At most frequencies, the Noise Reduction for the Far Field is lower than the Near Field. This means that the Far Field will be louder inside the auditorium.

5 Validation

Predicted and measured values using the Near and Far Field concept are shown in Figure 4. There is good agreement between the predictions and the measurements, except perhaps at low frequencies.

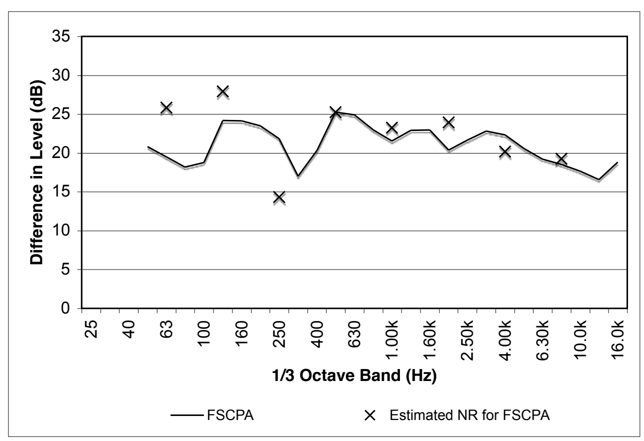

Figure 4: Calculated (X) and measured (–) near field noise reduction at the four seasons centre for the performing arts.