Effects of noise flanking paths on ceiling attenuation class (CAC) ratings of ceiling systems and inter-room speech privacy

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Continuous plenums above suspended, modular ceilings and partial-height walls in buildings can result in inter-room speech privacy and annoyance problems, especially when noise flanking paths via air diffusers, grilles and lights exist. However, testing of the effects of ceiling system noise flanking paths is limited in the industry. Multiple ceiling systems comprised of various noise flanking paths through air diffusers, grilles and lights were tested in an independent, accredited, acoustics laboratory according to ASTM International (ASTM) E-1414 and E-413. Additionally, recorded speech was played back in the test chamber source room and binaurally recorded in the test chamber receiver room. The results show that wideband ceiling attenuation class (CAC) decreases by 10 decibels (dB) and 1/3 octave band normalized ceiling attenuation (Dn,c) decreases by 15 to 22 dB in the higher frequency bands when common noise flanking paths are introduced into a ceiling system with CAC-37 ceiling panels. Subjective listening during the course of these tests shows that a ceiling system comprised of CAC-37 panels and typical noise flanking paths (that drop the system rating down to CAC-27) did not provide speech privacy. Intelligibility of recorded speech transmitting into the receiver room was high.

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1 INTRODUCTION

In some buildings, sound isolation between rooms is important. For example, in patient exam rooms in a medical office building, conversations between patients and their doctors are meant to be private. Even when speech privacy is not a concern, sound transmitting from one room into another can be annoying or distracting and can inhibit productivity, concentration or relaxation. Another example is noise transmitting between adjacent, enclosed offices.

Achieving sound isolation between rooms relates to the construction of the overall envelop of the rooms including the walls, floors, ceilings, windows and doors. The amount of sound isolation often depends on the weakest link in the construction. The wall construction may be adequate, but penetrations through the walls for electrical outlets and light switches may degrade the room-to-room sound isolation substantially.

As a cost savings in some buildings, interior walls are stopped at the height of a suspended, modular ceiling. They do not extend full-height up to the structural floor slab or roof above. This practice does not only save on the construction cost of the walls, it also creates a continuous open plenum above the suspended ceiling that can be used as a return air plenum. Using an open return air plenum saves the cost of rigid, metal, return air ductwork above the ceiling.

When the interior walls do not extend full-height, sound potentially can transmit more easily from room to room via the open plenum above the ceiling. The sound blocking capacity of the ceiling system in each room then becomes an important factor in the overall room-to-room sound isolation. Ceiling manufacturers therefore test the sound blocking capacity of their ceiling systems and report the results as ceiling attenuation class (CAC) ratings. Most modular ceiling systems with bonded fiber panels provide about 20-35 dB of sound isolation at mid frequencies (i.e., 500 Hertz octave band), assuming a double-pass test method as used in this study. Most walls however, provide 40-55 dB of sound isolation at mid frequencies. Ceiling systems can therefore be considered the weaker link in the overall room-to-room sound isolation.

Suspended, modular ceilings typically have recessed light fixtures, open return air grilles, supply air diffusers and other miscellaneous penetrations for sprinkler heads, loudspeakers, security/surveillance devices and Wi-Fi devices. These openings and penetrations in the ceiling system create noise flanking paths whereby noise transmits more easily from room to room. The existence of these noise flanking paths are well known in the architectural acoustics industry.

Although the industry recognizes the impact of noise flanking paths on ceiling system blocking capacity, the literature base lacks studies that quantify the degree of isolation degradation. One study\(^1\) conducted by the Institute for Research in Construction, part of the National Research Council Canada, states that some ceiling systems provide little attenuation, and even if panels with high transmission loss are used, the attenuation commonly is limited by leaks (i.e., flanking paths) such as openings for airflow. That study found that an opening in the ceiling of only 305 millimeters (mm) by 305 mm (1 square foot) decreased room-to-room isolation by up to 10 dB in the 2 kilohertz (kHz) and 4 kHz octave bands.

2 METHOD

A series of CAC tests was performed on various suspended, modular ceiling systems under laboratory conditions in a dual-room chamber with a common plenum above the ceiling. The initial test represented how ceiling manufacturers typically test their ceiling systems. The test specimen comprised just the suspension grid and ceiling panels with no additional noise flanking paths. Subsequent tests had either one or more common noise flanking paths caused by light
fixtures or air distribution devices. After each CAC test, recorded speech was played back in one room of the test chamber and subjective listening tests were conducted in the other room of the test chamber to assess the level of speech privacy provided by each ceiling system. The transmitted speech also was recorded for future assessment and demonstration.

2.1 Test Facility & Procedure

The tests were performed at NGC Testing Services in Buffalo, New York over three consecutive days in late January 2015 by a Senior Test Engineer. The laboratory is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) (Laboratory Code 200291-0). Tests were performed according to ASTM E 1414 and E 413. Figure 1 shows the layout of the CAC test chamber used for the testing.

![Figure 1](image_url)

Fig. 1 - Section showing the configuration and dimensions of the test chamber. Width (not shown) is 15'-5".

2.2 Ceiling System

2.2.1 Ceiling Panels – The ceiling panels used in this study were standard, white, wet-formed, mineral fiber ceiling panels measuring 610 mm (24") (nominal) in length and width and 19 mm (3/4") thick with square, lay-in edges. Their weight was approximately 5 kilograms per square meter (kg/m²) (1 pound per square foot). They have a marketed noise reduction coefficient per ASTM C 423 of NRC 0.70 and a marketed ceiling attenuation class of CAC 35. The measured rating was CAC 37, two points higher than the marketed value.
2.2.2 Suspension System – All of the ceiling systems used a standard 24 mm (15/16") wide, 38 mm (1-1/2") high, steel, tee-bar suspension grid. It was installed in the laboratory test chamber so that a grid member ran along the center of the demising wall in the middle of the test chamber. Ceiling panels did not span across the center wall of the chamber. The grid ran continuously over the center wall of the chamber. It was not disjoined at the center wall.

2.2.3 Air Distribution System – The return air grilles were MetalAire® model CC5-6. They were aluminum, 610 mm (24") (nominal) in length and width and had a 13 mm (1/2") by 13 mm (1/2") open, egg-crate grille. This type of return air grille was selected because of its frequent use in a wide variety of building types. Figure 2 shows the return air grilles used in this study.

![Figure 2 - Return air grilles used in the study.](image)

The supply air diffusers were Price® square plaque diffusers model SPD 40101505. They were 610 mm (24") (nominal) in length and width by 89 mm (3-1/2") high. They were steel with a white powder coat finish and had a 254 mm (10") round duct connection. Square plaque diffusers were selected because they are one of the most commonly used types of air diffuser. Figure 3 shows the supply air diffusers used in this study.

The supply air diffusers positioned in the adjacent sides of the test chamber were connected with supply air ductwork. A rigid metal duct measuring 406 mm (16") wide by 305 mm (12") high by 3658 mm (12’) long and with no internal or external lining ran through the plenum from one side to the other over the demising wall. The supply diffusers were connected to the rigid metal duct above with insulated, round, flexible ducts with a 254 mm (10") inside diameter made by Atco Rubber Products, Inc. There was no main duct that fed air into the supply air system.
The air in the system was therefore not moving. The supply air distribution system is shown in Fig. 4.

2.2.4 Lights – The light fixtures were Lithonia Lighting® general purpose T8 troffer model 2GT8 2 U316 A. They were 610 mm (24") (nominal) in length and width. They had an eggcrate louver with openings that were 19 mm (3/4") by 19 mm (3/4") by 13 mm (1/2") high. No bulbs were installed in the lights and they did not have electrical connections. These were judged to have no effect on the parameters being studied. Lithonia Lighting representatives stated that this model is their most commonly used light fixture. Figure 5 shows the light fixtures used in this study.

2.2.5 Layout – Figure 6 shows the reflected ceiling plan of the last test specimen with the locations of all air distribution devices and light fixtures. Each room of the test chamber had one return air grille, one supply air diffuser and four light fixtures. Licensed mechanical and electrical engineers at Gage Consulting Engineers, Inc. in Oak Brook, Illinois reviewed the light and air distribution systems to ensure that they represented accurately what might appear in standard offices. For heat load, air volume and duct sizing calculations, the engineers were instructed to assume:

- a building located in Kansas City, Missouri,
- one long side of the test chamber was an exterior wall with windows facing South,
- the other long side of the test chamber was adjacent to an open office area,
- and the two short walls of the chamber were adjacent to similar offices.

Fig. 3 – Supply air diffusers used in this study.
Fig. 4 – Supply air ductwork and diffusers that created one of the tested flanking paths.

Fig. 5 – Light fixtures used in this study
2.3 Speech Recordings

Prior to conducting the laboratory measurements, a recording of male speech was made in an anechoic environment. The recording is approximately 22 seconds long and contains the following sensitive content.

“Thanks for coming in today Peter. I’m afraid this is not going to be a pleasant conversation. I was contacted by human resources and legal this morning. We’ve had an employee file a discrimination claim against the company and you. This really is serious now with the incident that occurred last year. I wanted to be the one to break this because we’ve been working together for over twenty years now. But, legal and HR are coming to my office right now.”

This recording was played back through a single loudspeaker in the corner of one side of the dual-room test chamber for each ceiling system tested. The gain of the audio system initially was set to what the authors judged to represent the level of normal dialogue between two people sitting about six to eight feet apart in an enclosed office. The level of the speech then was measured at the receiver location in the source room to be 64 dB, A-weighted (dBA), equivalent continuous sound level (Leq) over the 22 second duration of the speech passage. The speech was recorded binaurally using The Sound Professionals™ model MS-TFB-2-80048 microphones (positioned at the left and right ear canal openings of a human listener sitting in a chair) and a Roland Corporation model R-
09HR digital recorder. The speech was recorded in the source room and then, after each ceiling system test, at the same location in the receiver room. Figure 7 shows the approximate locations and orientations of the loudspeaker and person's head during the recordings.

![Floor plan diagram showing approximate loudspeaker and recording positions and orientations during binaural recordings.](image)

3 RESULTS

A series of five CAC tests was performed by NGC Testing Services. The first ceiling system tested had no additional noise flanking paths; the suspension grid was filled only with ceiling panels. After this baseline test, each of three noise flanking paths (i.e., lights, supply air system and return air grilles) was tested independently. Finally, all noise flanking paths were tested together. Table 1 and Fig. 8 show the test results in both tabular and graphic form.

During listening tests performed after each CAC measurement, subjective impressions were consistent with the quantitative data. The sound that transmitted through the first ceiling system (with only the suspension grid and ceiling panels) was audible and identifiable as a male person speaking. However, the speech was muffled. The intelligibility of each short phrase was 50-75% depending on the speaking rate and enunciation of the person speaking in the recording. While it was not possible to understand fully the conversation, it could not be judged as private or confidential. The sound that was transmitting through the ceiling system could be distracting or annoying to some people.
Table 1 – Normalized ceiling attenuation (transmission loss) values by 1/3 octave band for the various ceiling systems tested.

<table>
<thead>
<tr>
<th>Normalized Ceiling Attenuation (Dn,c) (dB)</th>
<th>Frequency, 1/3 Octave Band Center (Hz)</th>
<th>100</th>
<th>125</th>
<th>160</th>
<th>200</th>
<th>250</th>
<th>315</th>
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<tbody>
<tr>
<td>Ceiling panels only</td>
<td></td>
<td>18</td>
<td>21</td>
<td>26</td>
<td>30</td>
<td>27</td>
<td>26</td>
<td>37</td>
</tr>
<tr>
<td>With supply air system</td>
<td></td>
<td>18</td>
<td>20</td>
<td>26</td>
<td>28</td>
<td>25</td>
<td>26</td>
<td>35</td>
</tr>
<tr>
<td>With light fixtures</td>
<td></td>
<td>17</td>
<td>20</td>
<td>25</td>
<td>29</td>
<td>25</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>With return air grille</td>
<td></td>
<td>16</td>
<td>20</td>
<td>24</td>
<td>28</td>
<td>25</td>
<td>22</td>
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<tr>
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<td>16</td>
<td>18</td>
<td>23</td>
<td>25</td>
<td>22</td>
<td>22</td>
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<tr>
<th></th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>800</th>
<th>1000</th>
<th>1250</th>
<th>CAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling panels only</td>
<td>30</td>
<td>33</td>
<td>33</td>
<td>36</td>
<td>40</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>With supply air system</td>
<td>30</td>
<td>32</td>
<td>33</td>
<td>33</td>
<td>36</td>
<td>37</td>
<td>35</td>
</tr>
<tr>
<td>With light fixtures</td>
<td>28</td>
<td>32</td>
<td>31</td>
<td>34</td>
<td>35</td>
<td>38</td>
<td>35</td>
</tr>
<tr>
<td>With return air grille</td>
<td>26</td>
<td>30</td>
<td>28</td>
<td>30</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>With all noise flanking paths</td>
<td>25</td>
<td>28</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td>26</td>
<td>27</td>
</tr>
</tbody>
</table>

With the return air grilles installed in the ceiling system, intelligibility of the short phrases increased significantly to 75-90%. The transmitted speech was still somewhat muffled, but most words were intelligible, making the conversation plainly understandable. It was not private nor confidential, and there would be a high probability of annoyance and distraction. With the lights and supply air system installed along with the return air grilles, the speech transmitting through the ceiling system was highly intelligible. It was not muffled anymore as the high-frequency sounds were transmitting through the leaks caused by the air distribution devices and lights.

It should be noted that these listening tests were conducted in an acoustics laboratory with low background noise levels. In normally occupied buildings, background noise levels could be higher due to mechanical systems (when cycled on) or noise transmitting from the exterior. In some buildings however, background noise levels could be as low as those experienced in the acoustics laboratory, especially when the mechanical system is cycled off. It also must be considered that in real situations, voice levels vary. Raised voice levels, such as during telephone calls, meetings or an agitated state would increase intelligibility even further.
4 DISCUSSION AND CONCLUSIONS

The results of this study confirm that common noise flanking paths in ceiling systems created by light fixtures, supply air diffusers/ductwork and open return air grilles decrease room-to-room sound isolation compared to a ceiling system of only ceiling panels and suspension grid. The light fixtures and supply air system each degraded the room-to-room sound isolation by two CAC points. The degradation at each 1/3 octave band in the upper frequencies (800 Hz and above) was the largest and averaged 3 dB. At some frequencies, the degradation was as much as 5-6 dB.

The open return air grille resulted in a much greater degradation of room-to-room sound isolation. CAC decreased from 37 dB to 29 dB. The degradation in the upper frequencies averaged 13 dB and at some frequencies was as much as 18-20 dB. This is subjectively equivalent to making the transmitted noise four times louder in the upper frequencies.

Combining all three noise flanking paths simultaneously degraded the room-to-room sound isolation even further. CAC decreased to 27 dB, 10 dB lower than for the ceiling panels without noise flanking paths. The degradation at the upper frequencies averaged 15 dB and at some frequencies was as much as 19-22 dB.
It can be concluded from this study that common elements such as lights, air diffusers and grilles degrade the blocking capacity of the ceiling system and the resulting room-to-room sound isolation. The light fixtures and supply diffusers degraded the isolation to a lesser extent than did the return air grilles. However, the lights and supply diffusers did contribute to further degradation when combined with the return air grilles. Overall, the noise flanking paths in this study degraded wideband isolation 2-10 CAC points. More importantly though, they degraded high frequency isolation (1,000 Hz octave band and above), which is more relevant to whether speech is intelligible or not, by 15-22 dB. This is subjectively equivalent to making the transmitted speech four times louder.

Designers, specifiers, contractors and building owners should be aware of the common noise flanking paths that result from lights and air distribution devices in ceiling systems and the resulting degradation of room-to-room sound isolation and speech privacy. They should not base their expectations of speech privacy on the CAC rating of the ceiling panel alone. Relying on a suspended, modular ceiling system for sound isolation is a risky design approach.

There are a variety of methods to prevent noise flanking paths in ceiling systems. There can be elbow ducts internally treated with sound absorbing, fibrous, linings above the return air grilles to attenuate the noise that would otherwise pass freely through the grille into the plenum. Lights can be suspended instead of recessed. Supply diffusers and light fixtures can be covered with a thick, fibrous matt and mass-loaded vinyl (if heat dissipation upwards is not required). Supply ductwork can be internally lined, rigid metal (no flexible ducts) and routed so as to avoid short, direct paths between adjacent rooms. However, the cost of these preventative measures compared to the cost of extending the walls full-height should be carefully considered by the design team, building owner and occupants early in the planning and budgeting stages.

5 ACKNOWLEDGEMENTS

The authors would like to thank ROCKFON and NGC Testing Services for their support and assistance in conducting this study and disseminating the findings.

6 REFERENCES