REVERBERATION MEASUREMENT AND PREDICTION IN GYMNASIA WITH NON-UNIFORMLY DISTRIBUTED ABSORPTION; THE IMPORTANCE OF DIFFUSION

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1. INTRODUCTION

School gymnasia present several acoustical challenges as the rooms must support a variety of uses, mainly athletic functions, school/community gatherings and performances. Considerations such as user safety, surface durability and impact resistance, ease of maintenance and clean-ability often dictate not only a lack of acoustically absorptive finishes in the occupied portion of the room but also parallel and acoustically reflective floor and lower wall surfaces. In Alberta current government design standards [1] stipulate that reverberation times (RT) in a typical unoccupied gym not exceed RT 2.0 seconds averaged over the frequency range of 500 to 2000 Hz. Design guidelines for acceptable gymnasia finishes are also given in [1].

This paper documents the results of RT measurements conducted in several newly constructed gymnasia as part of a performance verification exercise for the builder. The gymnasia were constructed according to the design guidelines however the initial RT measurements did not meet the performance requirements.

2. ROOM DESCRIPTION

The measured rooms were rectangular in plan with two variations in room size: Type A, 27.8 m x 18.5 m, slightly sloped ceilings 9.3 m to 9.6 m above finished floor (AFF); Type B 24.0 m x 18.0 m, ceilings 9.1 to 9.5 m AFF. The finishes are painted concrete block walls to 3 m above a cushioned wood floor and painted 2-layer 16 mm gwb walls to the underside of a painted acoustic metal deck ceiling. Initially, two 1.2 m high continuous bands of exposed unpainted Tectum/mineral fibre paneling (38 mm mineral fibre behind 25 mm Tectum, edges concealed) extended around the full perimeter of the rooms on the upper walls.

3. EQUIPMENT & PROCEEDURE

A tripod-mounted Brüel & Kjaer 2270 Precision Real Time Sound Level Analyzer equipped with the latest version (3.2) of the BZ7227 Reverberation Time software was used to record archive and evaluate the RT measurements. During the initial measurements sound decays were generated either from amplified interrupted pink noise or by large diameter balloon burst impulses. For later measurements only impulses were used. The decays were measured at at least 5 locations in the rooms with the positions consistent between repeated measurement sessions.

4. INITIAL RT MEASUREMENTS

After the initial RT measurements did not meet the performance requirements a lack of adequate absorption was presumed and the gymnasia were modelled using ODEON room acoustics prediction software to determine the quantity and placement of additional absorption required to bring the RT into compliance. ODEON is based on prediction algorithms (image-source method and ray-tracing) that use scattering due to surface roughness and diffraction. A reflection-based scattering method is used that accounts for frequency-dependent scattering. Like any prediction software, ODEON's accuracy is limited by the validity of the input data, namely the room geometry, surface sound absorption and scattering coefficients. However the geometry for these rooms is not complex and with the exception of the acoustic deck and Tectum panels the absorption coefficients for the various room materials are fairly well established in literature. Both acoustic deck and Tectum panels have been used in enough projects to establish that they provide at least some absorption in the critical mid frequency bands. Scattering coefficients were chosen according to ODEON guidelines [2].

After installation of a third continuous band of panels at a height below the existing panels, the RT were re-measured and found to be significantly higher, particularly in the critical mid-frequencies, contrary to intuition and the predictions. The measurement results seemed to indicate a greater difference from the predicted RT than could be explained by invalid absorption and/or scattering coefficients. Subsequent adjustments to these model inputs confirmed this. The acoustic deck and wall panels in one of the gymanasia were inspected and no obvious problems found. Similar inspections in all of the other gymnasia by the building contractor found no obvious faults.

5. DIFFUSION AND REVERBERATION

Much past work has been done by others exploring the effects of diffusion on reverberation. The requirement for a sufficiently diffuse sound field is established for laboratory measurements in ASTM C423 - 09a [3]. This is typically achieved with fixed and/or rotating sound-reflective panels hung or distributed with random orientations about the volume of the reverberation room. ASTM C423 states that it has been found that in rectangular rooms the area (both sides) of diffusers required to achieve satisfactory diffusion is 15 to 25% of the total surface area of the room.

All of the gymnasia except for the two following cases were measured completely empty except for the measurement equipment and operator: For one Type B gym measurement session a scissor lift was located at one end of the room and a 1.2 m by 2.4 m Tectum board was leaning against a wall. During another measurement session in a different Type B gym with slightly more wall panelling a few boxes of construction materials were present on the floor. In both cases, these objects were judged at the time not to be large enough in area or volume to make a significant difference in the RT. However, the diffusion that they may have provided was not considered. In both cases lower RT were measured with the most dramatic difference in the later case: a mid-frequency average RT of 2.1 seconds, reasonably close to the ODEON prediction of 2.1 seconds.

The third band of wall panels appeared to be having some effect in the Type B gymnasia measured with the additional objects but not in the other (empty) gyms. Further investigation finally lead to the hypothesis of horizontal reflections between the untreated lower walls and a lack of sound diffusion in the lower portion of the rooms contributing to the unexpected results. It was suggested that providing some diffusive objects to break up these reflections might provide results closer to a minimally occupied condition and to the predictions. This hypothesis was tested and the RT re-measured in a Type B gym with some plywood panels and also with a few people.

Five different conditions were measured; an empty gym, addition of people, three levels of diffusion. Diffusion was varied with plywood sheets, 1.2 m x 2.4 m x 12.7 mm thick, stood on end at various locations throughout the gym. Ten of these plywood sheets were fastened together at one end to form five self-supporting A-frame units. The remaining five plywood sheets were leaned against the volleyball net and supporting end poles at the mid point of the gym. Sheets were removed and the measurements repeated. The measurements were also repeated with the room empty and again with the equipment operator plus four other adults.

6. RESULTS AND DISCUSSION

The results for the re-tested Type B gym with and without the third band of wall panels and with and without the additional sound diffusing elements are presented in Figure 1. All plotted measurements were conducted with three bands of wall panels, except as noted, and with the room empty except for the noted fittings or occupants plus the measurement equipment and operator. For the RT with plywood sheets two stepladders were also present.

The addition of as few as four people or five plywood sheets was found to significantly reduce the measured RT, closer to the modeled predictions. This decrease in the measured reverberation times is more than can be accounted for by the sound absorption provided by four additional adult bodies alone. The low frequency RT were not particularly sensitive to the addition of the plywood however the times in the 500 to 4000 Hz bands were significantly reduced.

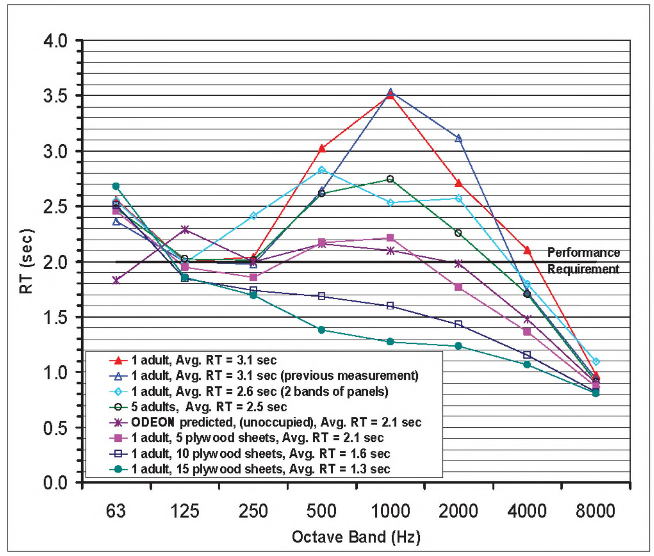

Figure. 1. Measured Reverberation Times RT60 (sec) in a Type B Gymnasium

Similar measurements were repeated by others in both Type B and Type A gymnasia built under the same contract. Their findings were similar with regards to the effect of diffusive elements on the measured RT. The importance of plywood placement was not extensively evaluated but some variations were deliberately introduced to help evaluate any effect this may have. Generally it appeared that the RT were not particularly sensitive to the location of the plywood. The physical variations between the two types of gymnasia did not result in any major differences in RT.

It has been suggested that the plywood panels change the angle of incidence of the sound waves in the lower part of the room and thus of the reflected sound incident on the acoustically absorptive wall panels and acoustic deck and thus may result in more effective absorption by the acoustic treatments. This agrees with the assertion in ASTM C423 that diffusion provides "a rapid and continuous interchange of energy between the directions of sound propagation, thereby increasing the probability that each surface area of the room is exposed to sound of the same intensity." The increase in measured RT with the addition of absorption in the empty rooms requires further study.

REFERENCES

[1] Alberta Infrastructure and Transportation, (2007). Standards and Guidelines for School Facilities. 22-24

[2] Christensen, C. L., (2009) Odeon Room Acoustics Program Version 10 Industrial, Auditorium and Combined Editions (user manual). Odeon A/S.

[3] ASTM C423 – 09a (2009). Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method. ASTM International