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Technical Note

# Effects of varied row spacing and adding cushions, carpet and occupants on pew sound absorption

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ABSTRACT

This work examines how the individual variations of row spacing, as well as the presence of cushions, carpet and occupants, combine to influence the absorption characteristics of church pews as a function of sample perimeter-to-area (*P*/*A*) ratios. Scale models were used to measure the interactive effects of the four test variables on church pew absorption characteristics. The effects of row spacing on frequency-averaged pew absorption coefficients (500–4 kHz) were generally quite small and were smallest for pews without cushions. The variations of absorption increments with varied row spacing tended to be smallest when the pews were less absorptive, i.e. with less cushions, carpet or occupants, similar to the previously studied model theatre chairs. Resonant absorption effects seem to influence the measured absorption of the model pews in the 125 and 250 Hz octave bands and these effects are expected to be modified by the height of the pew backs and the spacing between pews. The incremental absorption coefficients of adding absorptive materials, such as carpet or cushions, to the pews were different than the absorption characteristics of cushions or carpet tested independent of the pews, and these differences varied with frequency. Using the resulting absorption coefficients calculated for each block of pews in a church as input to a room acoustics computer model is expected to provide the best currently possible predictions of acoustical conditions.



## 1. Introduction

The effective absorption coefficients of the chairs in a large auditorium vary with their individual components, such as presence of carpet and occupants, as well as row spacing and the type of chairs [1]. A previous scale model study [2] investigated the interactive effects of these four parameters on the sound absorption of theatre chairs and demonstrated how the absorption coefficients vary with sample size as measured by sample perimeter-to-area (*P*/*A*) ratio. The results showed that the values of each variable influenced the effects of changes to other variables. To accurately predict the sound absorption coefficients of a particular sized sample of theatre chairs, measurements of samples of the chosen chairs with a range of *P*/*A* ratio values and the same values of other variables should be carried out.

The previous results for the eight types of unoccupied theatre chairs showed that the effective absorption coefficients of chairs varied with chair construction details and the specific details influenced the absorption coefficients of unoccupied theatre chairs at particular frequencies [1]. The results indicated that the effects of individual components should not be measured in isolation because the combinations of factors determine the effective absorption coefficients of the chairs. In many cases theatre chairs have more complex construction details than those of church pews. Hence, a simple type of chairs, such as a church pew, should be further investigated to better understand the combined effects of some important test variables on the chair absorption characteristics.

In the present study, the combined effects of all four test variables on the church pew absorption characteristics were experimentally investigated. One-tenth scale model pews were developed to be representative of common types of full scale church pews. First, the predicted absorption coefficients of larger sample blocks of model church pews were compared with those for full scale church pews with and without cushions. Second, the effects of cushions, occupants and carpet as a function of the row spacing were investigated. Next, the effects of added absorption on model pews were compared with the results for model theatre chairs. Finally, the details of how the incremental absorption coefficients vary with frequency are examined and the more important test variables are determined.

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## 2. Measurement procedures

### 2.1. Model pews, carpet, and listener construction

Model church pews were developed that were representative of the absorption characteristics of full scale wooden church pews. The previously reported results for full scale wooden church pews [3] were used as design goals for constructing the model pews. The model pews having dimensions 2.2 m by 0.4 m by 0.74 m high (full scale) were constructed using 1 mm thick expanded PVC (poly vinyl chloride) pieces. A 0.5 mm single layer of felt was added to the seat of all model pews so that the absorption coefficients of the model pews corresponded better with the results for full scale pews. This configuration is referred to as the *no cushions* case. The absorption characteristics of model pews were varied by adding cushions to the *no cushions* case. One cushion added to the seats of the pews is referred to as *Pews with 1 cushion.* When cushions were added to both the seat and the back of the pews, this is referred to as the *Pews with 2 cushions* case. Both cushions were mostly covered when the pews were occupied. Fig. 1 shows a photo of model pews with varied added cushions.

Model carpet was developed to have absorption characteristics similar to those of full scale thick carpet with absorption coefficients that increased with frequency and had significant absorption at higher frequencies [2]. Model carpet was constructed using a 1.0 mm single layer of felt combined with a 0.5 mm thick paper having an embossed pineapple pattern on it.

One-tenth scale model listeners were constructed using 10 mm thick expanded PVC (poly vinyl chloride) pieces. Model listeners with absorption characteristics most similar to those found for the full scale occupants were developed. More details of the model listeners are included in Ref. [4]. Fig. 2 illustrates the 1/10 scale model pews and listeners.

### 2.2. Model reverberation chamber measurements

The volume of the 1/10 scale model reverberation chamber was 300 $m^3$ (full scale) and it was built using 20 mm thick acrylic panels. Fig. 3 illustrates the model reverberation chamber. In the measurements, a 1.37-s logarithmic sine sweep from 1 kHz to 100 kHz was used, which corresponds to full-scale frequencies from 100 Hz to 10 kHz. To eliminate the unwanted effects of air absorption, the model chamber was filled with nitrogen during each test. The reverberation chamber was kept at a constant temperature of 22 °C and a relative humidity of 4%. Six combinations of two source positions and three receiver positions were selected for measuring the absorption coefficients of the unoccupied pews. Twenty dB of each decay, from −5 dB to −25 dB, was used to calculate reverberation times according to the procedures described in ISO 354 [5]. Prior to the measurements, the diffusivity of the sound field in the reverberation room was examined according to ISO 354 [5]. There was no evidence of non-linear decays over this range when the absorption of the chairs was measured. The measurements were made in 1/3-octave bands, but the absorption coefficients were presented as octave band values obtained by averaging the three individual 1/3-octave band sound absorption coefficients in each octave band. A repeatability test of the measurements for the absorption coefficients of the chairs was carried out to check whether the results were consistent for each measurement. The measurements were repeated three times, and the results were presented as the mean absorption coefficients.

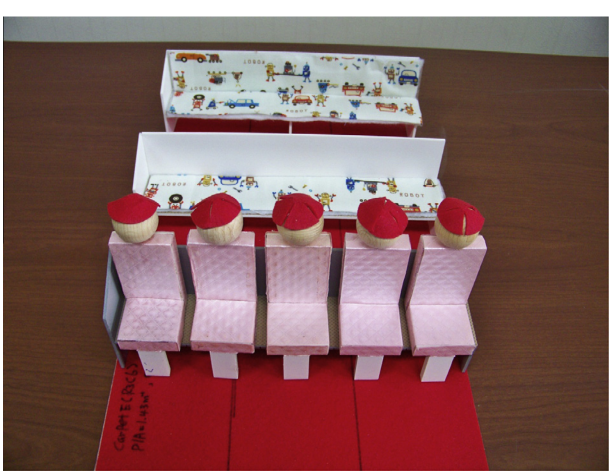

**Fig. 1.** A photo of model pews occupied with model listeners. The first row of pews is *no cushions* case, the second row of pews is *Pews with 1 cushion* case, and the last row of pews is *Pews with 2 cushions* case.

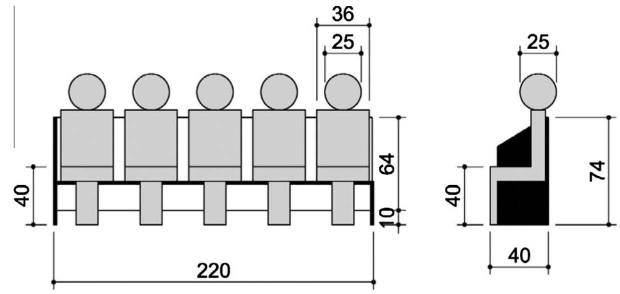


**Fig. 2.** Sketch of front and side views of model pew and listener (unit: mm, 1/10 scale).

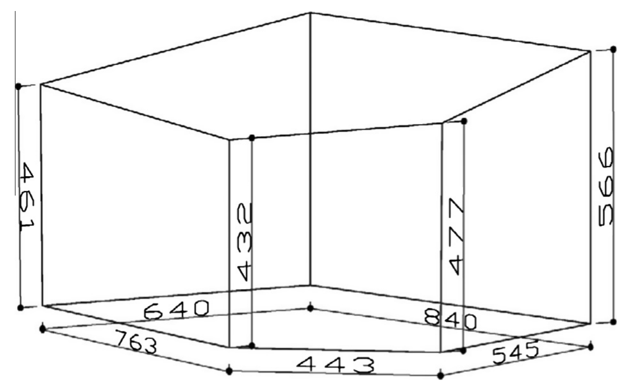


**Fig. 3.** Sketch of model reverberation chamber (unit: mm, 1/10 scale).

Groups of up to 5 rows of model pews were arranged in various-sized rectangular samples having a wide range of *P*/*A* values with varied row spacing. The samples had a range of *P*/*A* values between 1.44 and 2.22 $m^{-1}$ for the pews with a row-to-row spacing of 0.76 m, between 1.35 and 2.01 $m^{-1}$ for the chairs with a row-to-row spacing of 0.91 m, and between 1.24 and 1.74 $m^{-1}$ for the chairs with a row-to-row spacing of 1.2 m (full scale). The measurements were carried out with the pew edges exposed and the absorption coefficients were calculated using floor areas that included the row-to-row space in front of the first row of each block of model pews.

## 3. Results and discussions

### 3.1. Absorption coefficients predicted for larger blocks of model pews

The perimeter-to-area (*P*/*A*) method allows one to predict the absorption coefficients of blocks of pews of a particular *P*/*A* ratio