Applied Acoustics 93 (2015) 65–74

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical Note

Sound quality inside small meeting rooms with different room shape and fine structures

Sipei Zhao [a,b,*], Xiaojun Qiu [b,a], Eva Cheng [b], Ian Burnett [b], Nick Williams [c], Jane Burry [c], Mark Burry [c]

[a] Key Lab of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China
[b] School of Electrical and Computer Engineering, RMIT University, Melbourne 3000, Australia
[c] Design Research Institute, RMIT University, Melbourne 3000, Australia

ARTICLE INFO

Article history:
Received 24 December 2014
Received in revised form 22 January 2015
Accepted 23 January 2015
Available online 14 February 2015

Keywords:
Sound quality
Small room
Room shape
Hyperboloid cells

ABSTRACT

This note is intended to understand relative importance of room shape and fine structures on the sound quality inside small meeting rooms in terms of the reverberation time, the sound field distribution and the speech transmission index with similar room volume, surface area and the absorption coefficients. First, different shaped rooms with smooth walls are modeled and simulated to investigate the effects of room shape on the sound quality, and then hyperboloid cells are made on the walls to examine the influence of fine structural surface on sound quality with both regular and random arrangements. It is found that the reverberation time is affected significantly by the room shape while is not sensitive to the hyperboloid cells. The sound field distribution is affected little by the room shape and the hyperboloid cells and the difference is smaller than the Just-Noticeable-Difference in most cases. The impact of the room shape and fine structural surface on the speech transmission index mainly lies in the transition area between the direct sound and the reverberant sound. The reliability of the simulation remarks is confirmed by the experiments carried out in two different meeting rooms. The main conclusion of the note is that when the room volume, the surface area and the absorption coefficients are kept constant, the room shape and fine structural surface have little impact on the sound field distribution and speech intelligibility inside small rooms with ordinary surface absorption, while the reverberation time is affected significantly by room shape but slightly by the fine structural surface.

1. Introduction

Sound quality inside rooms has been investigated by many researchers, such as proposing objective acoustical parameters to describe sound quality, analyzing factors that affect sound quality and exploring possible solutions to improve the sound quality inside rooms [1–3]. This note concentrates on the effects of room shape on the sound quality inside small rooms, which may provide necessary references for the practitioners when designing small meeting rooms, especially open ceiling meeting rooms in open plan offices.

Previous researches have shown that room features can affect both speech intelligibility and timbre of reproduced sound in small rooms [4,5]. Bradley et al. explored the combined effects of signal-to-noise ratio and room acoustics on speech intelligibility and found that the signal to noise ratio aspect is more important than the room acoustics effects [4]. Bech carried out subjective experiments on the timbre of simulated sound inside small rooms and concluded that only the first-order ceiling and floor reflections are likely to contribute individually to the timbre of a speech signal [5]. However, in these studies, the room effects were simulated as direct sound followed by early reflections and late reverberation that are generated by several loudspeakers in an anechoic room without considering the corresponding relationship between the early reflections with different room shape [4,5]. Therefore, the specific effects of different room shape on speech intelligibility and timbre of sound inside rooms remain unclear.

At low frequencies, modes in small rooms may lead to uneven frequency responses, which often cause unwanted coloration effects that are detrimental to the sound quality [6]. Therefore some research has been devoted to optimizing the room dimensions and aspect ratio, for both the rectangular and polygonal rooms [7,8]. Bolt proposed to determine preferred room ratios by averaging modal spacing to achieve evenly spaced modes [9]. Louden suggested that the standard deviation of the inter-mode spacing is used to judge room ratios [10]. Cox et al. proposed an

* Corresponding author at: Institute of Acoustics, Nanjing University, Nanjing 210093, China.
E-mail address: sipeizhao@sina.com (S. Zhao).

http://dx.doi.org/10.1016/j.apacoust.2015.01.020
0003-682X/

optimization regime to maximize the flatness of modal response while Floody and Venegas proposed to produce equal loudness instead of flat frequency response for rectangular and polygon rooms [6–8]. The above work has mainly focused on the low frequency circumstances (i.e. 20–200 Hz), but the performance of rooms with different shape, i.e. rectangular, polygon and circular, and with fine structure, i.e. both regularly and randomly arranged hyperboloid cells on the walls, have not been explored, so the effects of room shape and fine structure on the sound quality inside small rooms in the whole frequency range are still not clear. This understanding is important for the architects and designers.

In the past decades, sound diffusers have been widely used in architectural acoustics to provide diffuse reflections [3]. Schroder diffusers achieve good diffusion pattern but suffer lob narrowing when they are concatenated or repeatedly used, similar to the periodic-type diffusers that can suppress the echo [11,12]. Jeon et al. measured the scattering coefficients of hemisphere and box-type diffusers and concluded that the scattering coefficients increase with the coverage density until reaching its maximum at 50% for the hemisphere and 30% for the box-type diffusers, respectively and that the scattering coefficients for the regular arrangement are slightly greater than the scattering coefficients for the random arrangement at higher frequencies regarding the box-type diffusers [13]. Although various types of diffusers have been designed and measured, little publications have been found on the hyperboloid cells, and the relative importance of hyperboloid cells and room shape on the sound quality inside small rooms has not been revealed.

Recently, hyperboloids have been integrated into architectural design by architects in different types of buildings [14]. It seems that the hyperboloid surfaces might be effective sound diffusers because the Sagrada Familia Church was reported to have a very diffuse acoustic due to the use of hyperboloids [14]. Burry et al. built a cylindrical wall with hyperbolic cells to investigate the scattering performance of the hyperboloids, and it was found that standing in the acoustic focus of the smooth wall and speaking generated a discernible echo while speaking from the same point in front of the wall made of hyperboloids produced no audible echo [15]. However, the above statement was based on perceptual experience without further measurement. Therefore, an exhaustive study, both theoretically and experimentally, is necessary to confirm the scattering effect of hyperboloids.

This note reports a preliminary investigation on the relative importance of room shape and fine structural surface on the sound quality inside small meeting rooms in terms of reverberation time, sound field distribution and the Speech Transmission Index (STI). First, different shaped rooms with smooth walls are modeled and simulated to investigate the effects of room shape on the sound quality, and then hyperboloid cells are made on the walls to examine the influence of hyperboloid shape on sound quality with both regular and random arrangements. The reliability of the simulation remarks is confirmed by experiments in a normal rectangular meeting room and an open ceiling meeting pod with hyperboloid cells on the curved walls. The purpose of this note is to provide ground of arguments for helping the architects to make right decisions on various acoustics design for small meeting rooms at the design stage, but not for rigorous academic scientific research, which will be carried out in the future and be published as a research paper.

2. Simulations

2.1. Room shape and hyperboloid cells

To investigate the effect of room shape on the sound quality inside rooms, 5 rooms with different shape as shown in Fig. 1 and Table 1 are modeled and simulated. The volume of the rooms is about 36–38 m^3.

To examine the influence of the hyperboloid cells on the sound quality, hyperboloids are made onto the walls of three different rooms (Room 1 through Room 3 in Table 1) as depicted in Fig. 2. For the sake of simplicity, Rooms 4 and 5 are not involved in this note because the hyperboloids are difficult to be configured in the walls of these rooms. The diameter of the opening of all the hyperboloids is 0.5 m and the depth is 0.175 m.

All simulations were conducted with the commercially available room acoustics software ODEON [16]. ODEON is based on a hybrid approach which combines the image source method with a special ray-tracing/radiosity method [17]. For the sake of simplic-

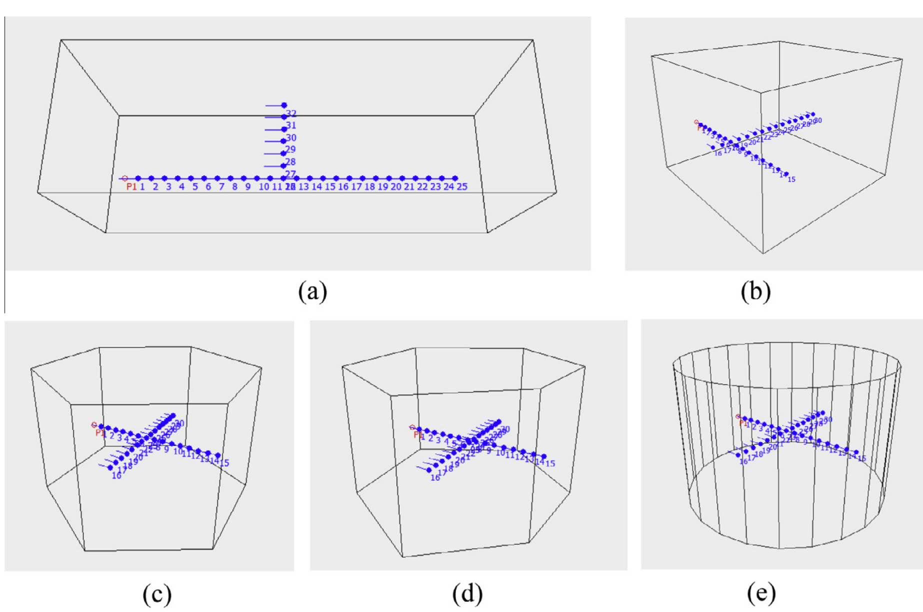

Fig. 1. Rooms with different shapes: (a) rectangular room; (b) square room; (c) regular hexagon room; (d) irregular hexagon room; (e) circular room.