Chapter 6. Acoustic design of rooms

Although any room may have an optimum acoustic environment, depending on the purpose for which it is intended, it is difficult to determine the ultimate goal because the final evaluation still relies on a subjective auditory sensation.

General requirements for the acoustic design of a room are as follows:

- any intrusive noise should be avoided;
- speech intelligibility should be satisfactory;
- music should sound pleasing and have warmth;
- a uniform distribution of sound should be observed throughout the **whole room**;
- there should be no defects such as echoes or flutter.

When all the above conditions are satisfied, the design can be considered successful.

Examples of design goals

- Movie theater

– Hearing the sound track in the way the movie makers have intended it to be heard

- Concert hall

– Good spatial impression (sound surrounds the listener), sense of intimacy, ”warm” sound color, adequate clarity, etc.

- Restaurant

– Peacefull acoustical environment (communication from short distance)

- Open plan office

– Speech sound distract concentration -> speech privacy between work places

- Factory

– Noise level may cause hearing damage -> design of effective sound absorption and noise blocking screens

Design of room shape

A. *Fundamental principles*

- The shape of the room is the most fundamental factor in influencing its acoustics.
- So a building requiring good acoustics needs to be examined at the basic planning stage, with advice from a good acoustic consultant.

- Depending on room size, wave acoustics should be used to assist in the design of small rooms and geometrical acoustics for larger spaces.

Design of room shape

A. *Fundamental principles*

- The shape of the room is the most fundamental factor in influencing its acoustics.
- So a building requiring good acoustics needs to be examined at the basic planning stage, with advice from a good acoustic consultant.

- Depending on room size, wave acoustics should be used to assist in the design of small rooms and geometrical acoustics for larger spaces.

Design of Room shape

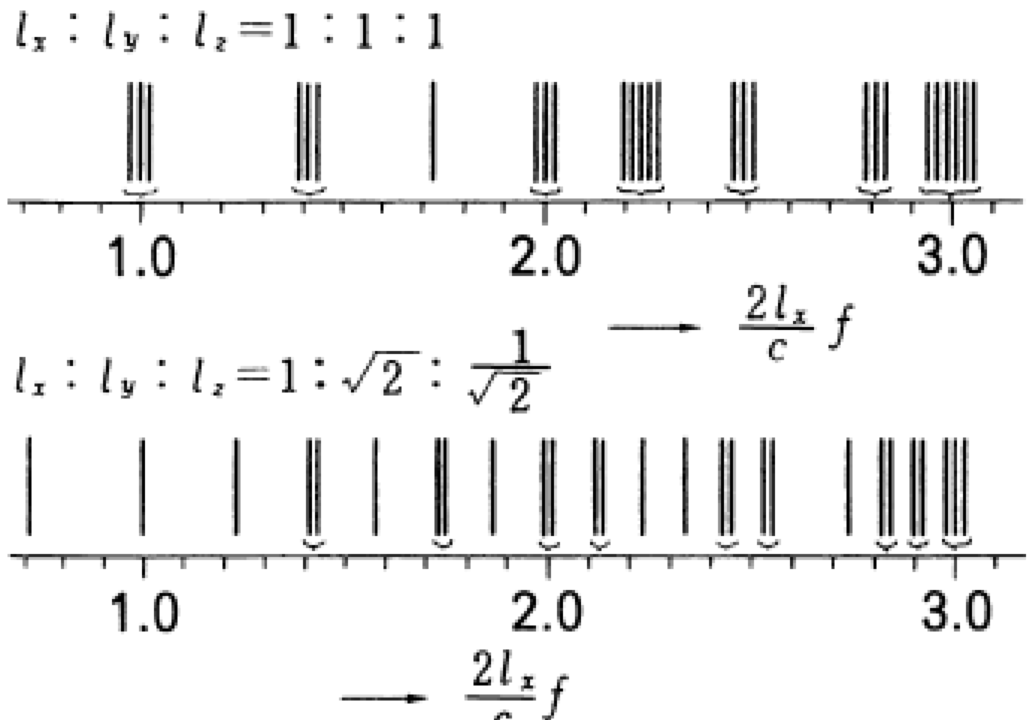
a. Dimensional ratio for a rectangular room

- In a small rectangular room, the natural frequencies should not degenerate and should be uniformly distributed.
- A simple integer ratio of the three edge-lengths must be avoided.

The golden rule, $(\sqrt{5}-1):2:(\sqrt{5}+1)$,

or its approximate ratio such as 2:3:5,

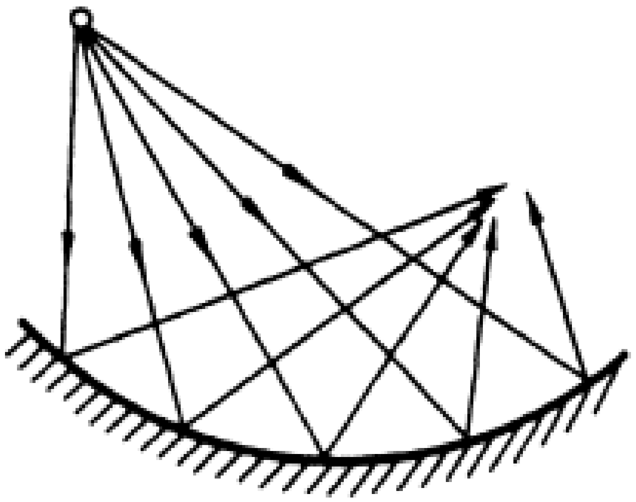
has been recommended over many years.



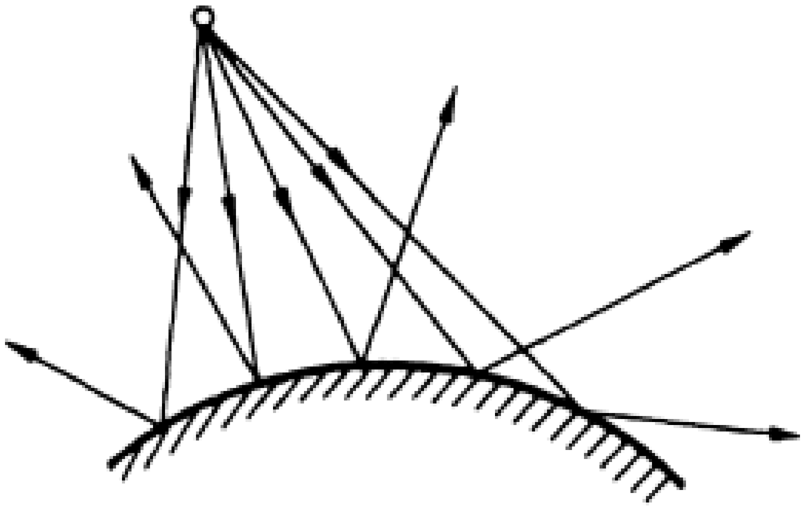
b. Surrounding wall shape and sound reflection

if the wall is concave, the reflected sounds are concentrated; on the other hand, if the wall is convex, they are diffused as shown in Figure.

Therefore, in order to have good diffusion, concave surfaces that are large compared to the wavelengths should not be used. It is no exaggeration to say that almost all concave surfaces are, acoustic, potentially hazardous.



Concave surface



Convex surface

c. Prevention of echo and flutter

At a corner where two planes intercept orthogonally, either indoors or outdoors, sound waves are reflected back in the reverse direction to the incident one, so echoes can arise as shown in Figure 9.2.

(Flutter Echo:When a pair of parallel walls or a ceiling and floor are made of rigid materials a flutter echo can often occur.)

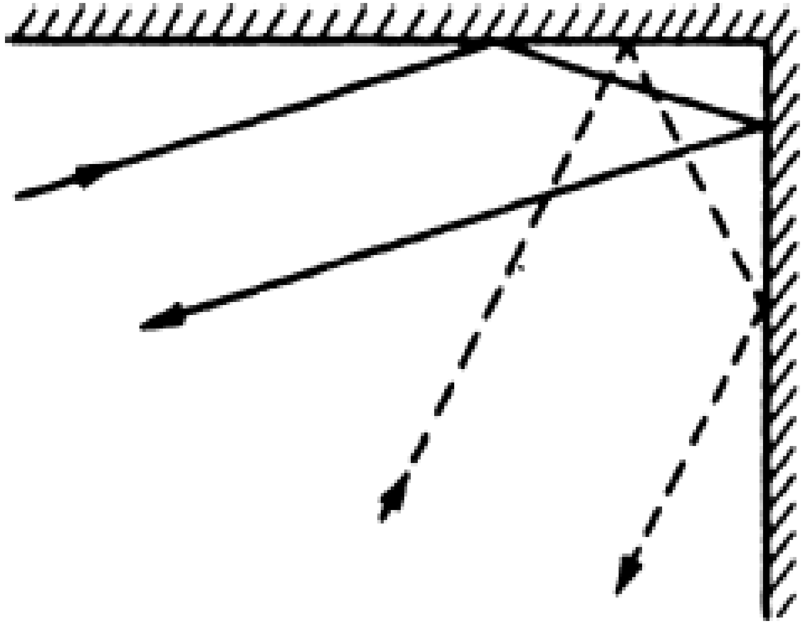


Figure 9.2 Reflection at a corner.

In order to avoid echoes completely, the surface shapes must be created so as to diffuse or absorb the incident sounds as shown in Figures 9.6 and 9.7

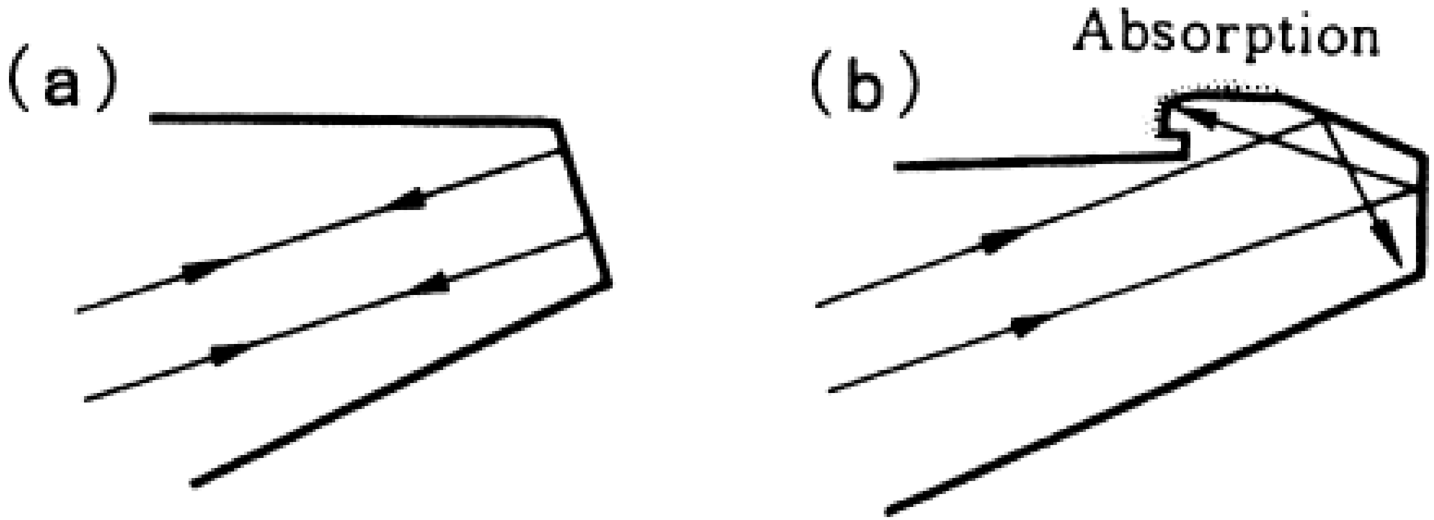


Figure 9.6 Rear wall corner design: (a) poor; and (b) good.

A multiple reflection between two parallel planes may cause flutter echoes. Although it is easy to avoid them by making the two planes non-parallel or the surface undulated.

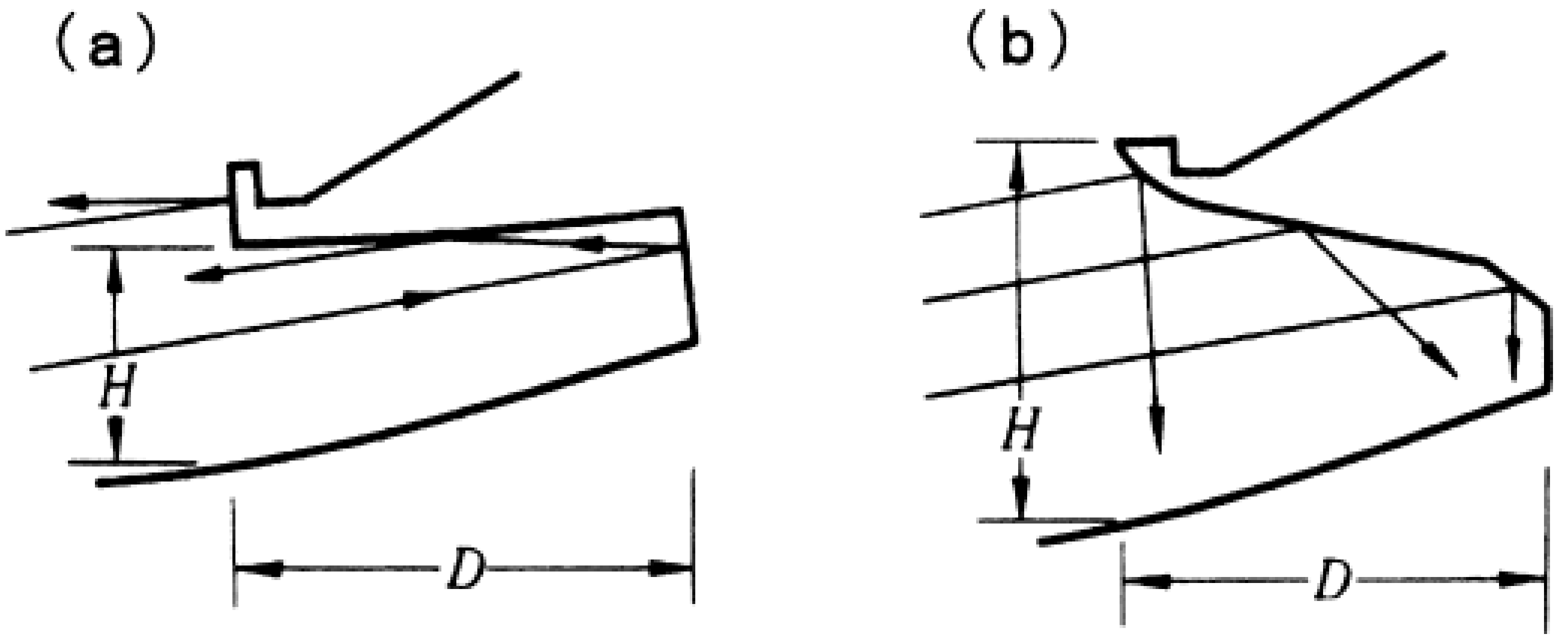


Figure 9.7 Sections of balconies: (a) poor; and (b) good.

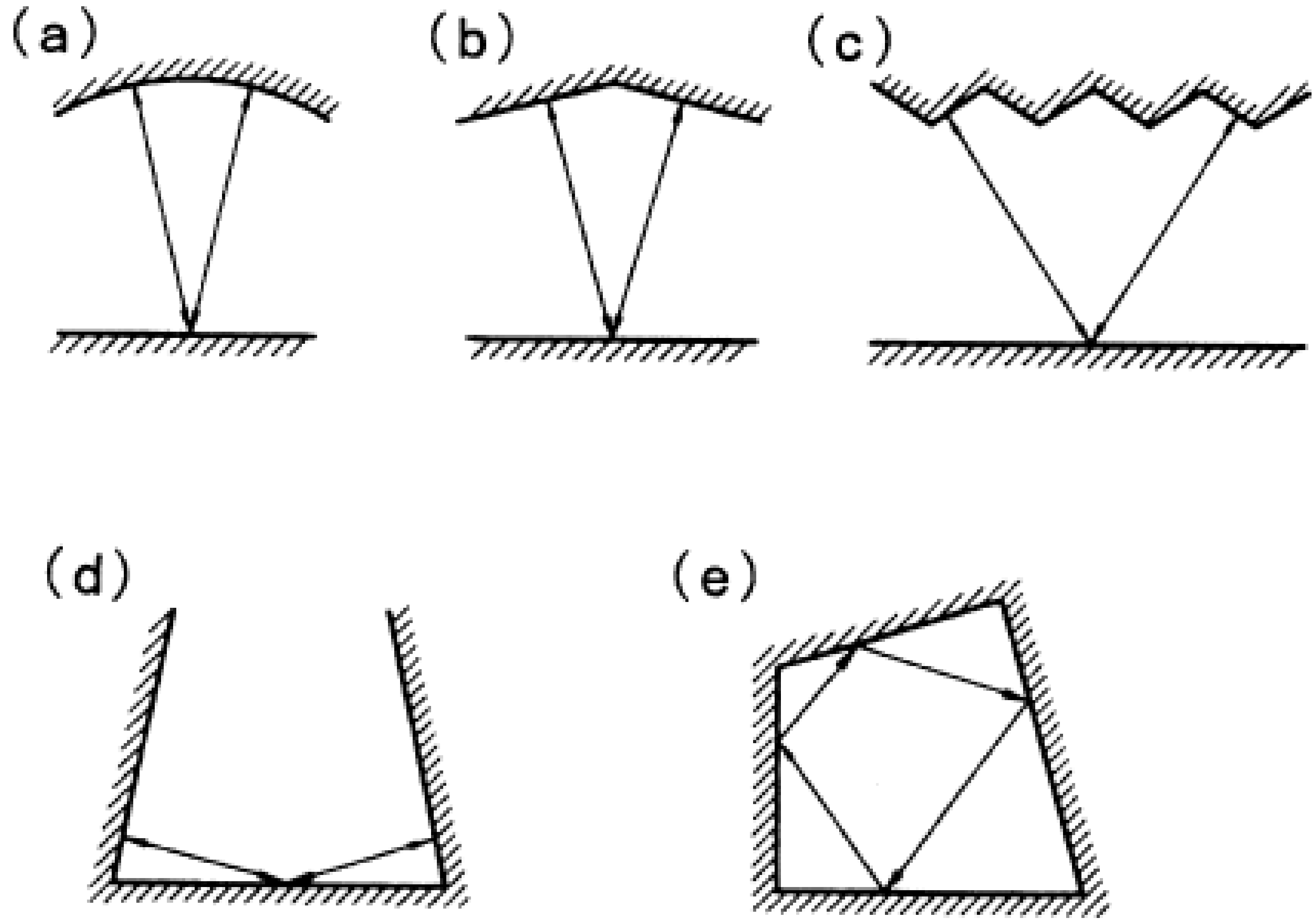


Figure 9.3 Shapes causing flutter echo.

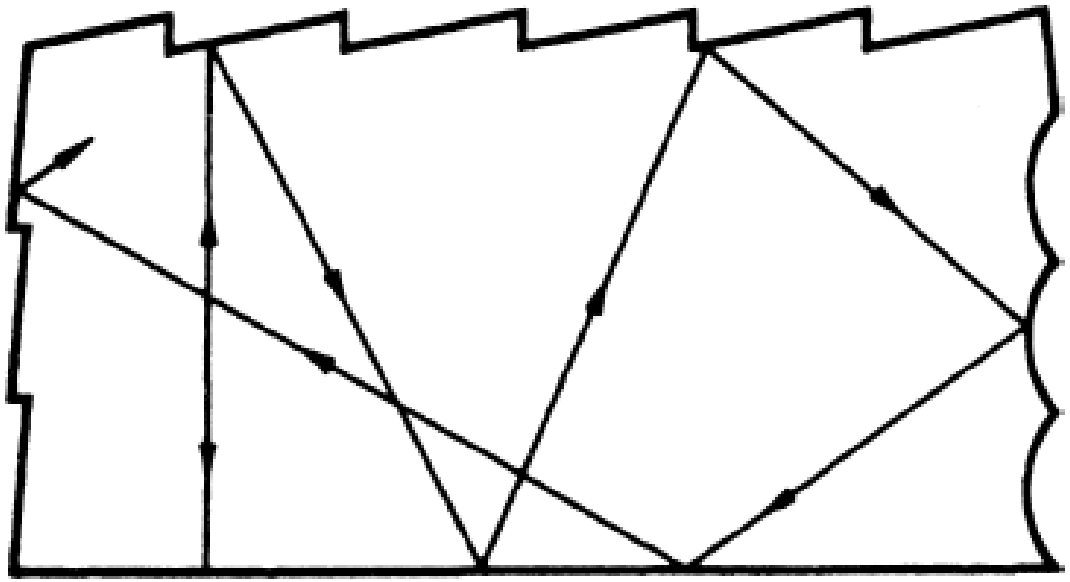


Figure 9.4 Shape causing no flutter echo.

It is essential to diffuse sound waves in the frequency range above 1–2 kHz in order to prevent an audible flutter.

B. Selection of local shapes

a. Profiles of sections

Ceiling: Reflected sound from a ceiling plays a significant role in reinforcing the direct sound, and is particularly important for listeners in rear seats. However, a concave domed ceiling makes the sound distribution worse, as shown in Figure 9.5(a). This situation can be overcome with a combination of convex shapes, as shown in Figure 9.5(b).

When the client insists on a domed ceiling, the radius of curvature should be at least twice as large as the ceiling height.

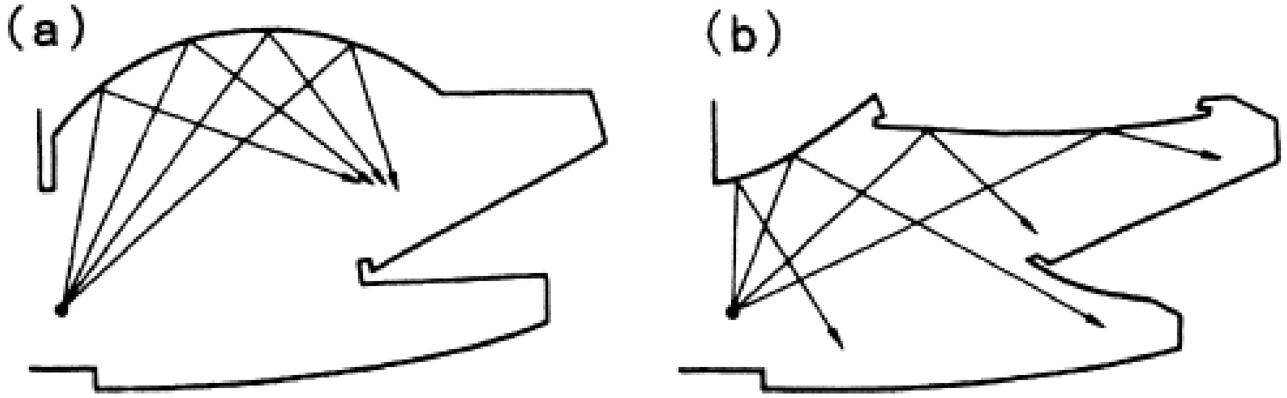


Figure 9.5 Longitudinal sections of auditoria: (a) poor ceiling; and (b) good ceiling.

Since echoes should not occur where the ceiling meets the rear wall, as shown in Figure 9.2, a tilted wall, Figure 9.6(a), may still cause problems; therefore, a design such as the one shown in Figure 9.6(b) is recommended.

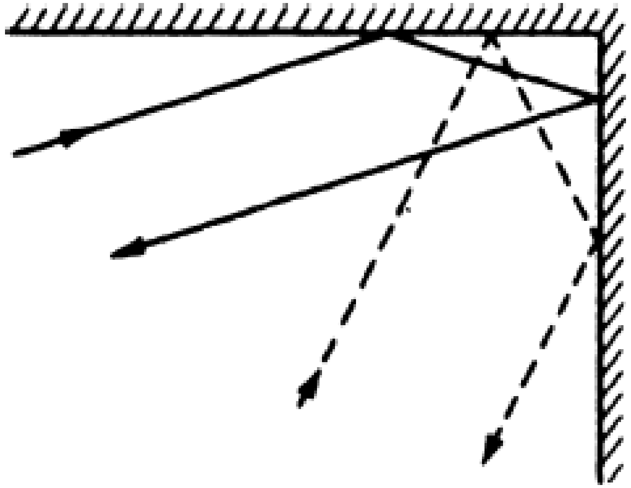


Figure 9.2 Reflection at a corner.

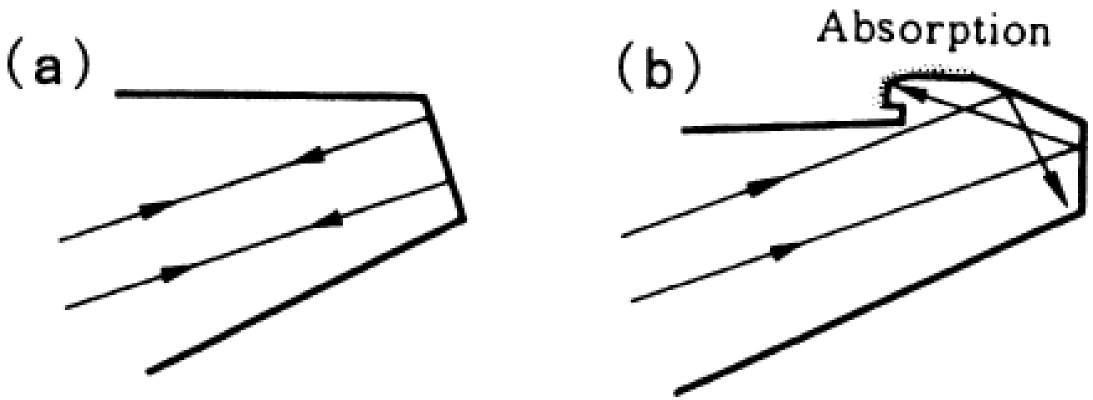


Figure 9.6 Rear wall corner design: (a) poor; and (b) good.

Balcony: *When a balcony is provided in order to increase audience* capacity, the acoustics under the balcony becomes generally worse because the direct sound is attenuated owing to long-distance propagation over the audience, and, hence, the sound pressure levels decay owing to a lack of effective reflection from walls and ceilings.

- Moreover, the reverberation time is shorter due to the smaller volume per audience member and the weak diffused sounds.

- In order to improve this problem, the depth D of the balcony in Figure 9.7 should be as short as possible and less than twice the maximum height H (if possible, equal to the opening height H).

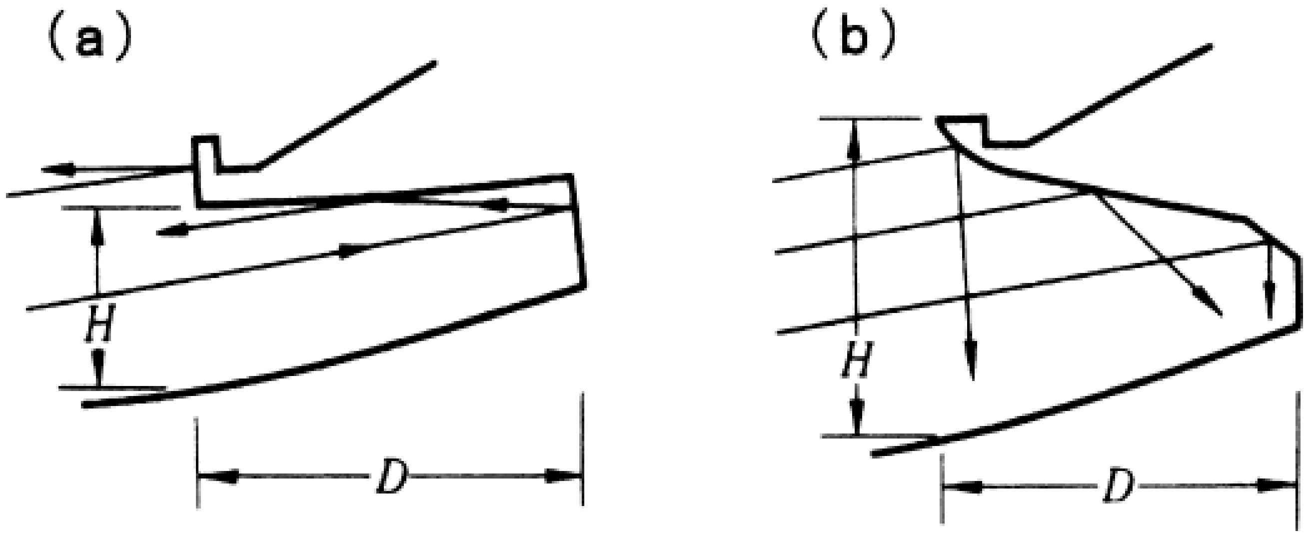


Figure 9.7 Sections of balconies: (a) poor; and (b) good.

- It is also advisable to design the seating under the balcony so that a person sitting in any seat can see as much of the main ceiling as possible.
- The balcony front should be designed so that any echo or focusing may not occur either in plan or in section, while the shape and material of the balcony soffit should be an effective reflecting surface.

Floor:

Since a floor with seating has large absorption, direct sound is rapidly attenuated as it propagates over the absorbing surface because the porous-type absorption provided by chairs and audience is efficient at high frequencies.

In addition, the spaces between rows of seating are found to cause resonance in the low-frequency range from 100 to 200 Hz, which produces remarkable attenuation.

In order to overcome the situation, the floor slope is increased so that the direct sound is not interrupted by the front seats.

The height *H of P from* P_0 *is*

$$H = d_0\gamma + d(\theta - \gamma)$$
$$= \gamma\left[d \cdot \ln\frac{d}{d_0} - (d - d_0)\right]$$

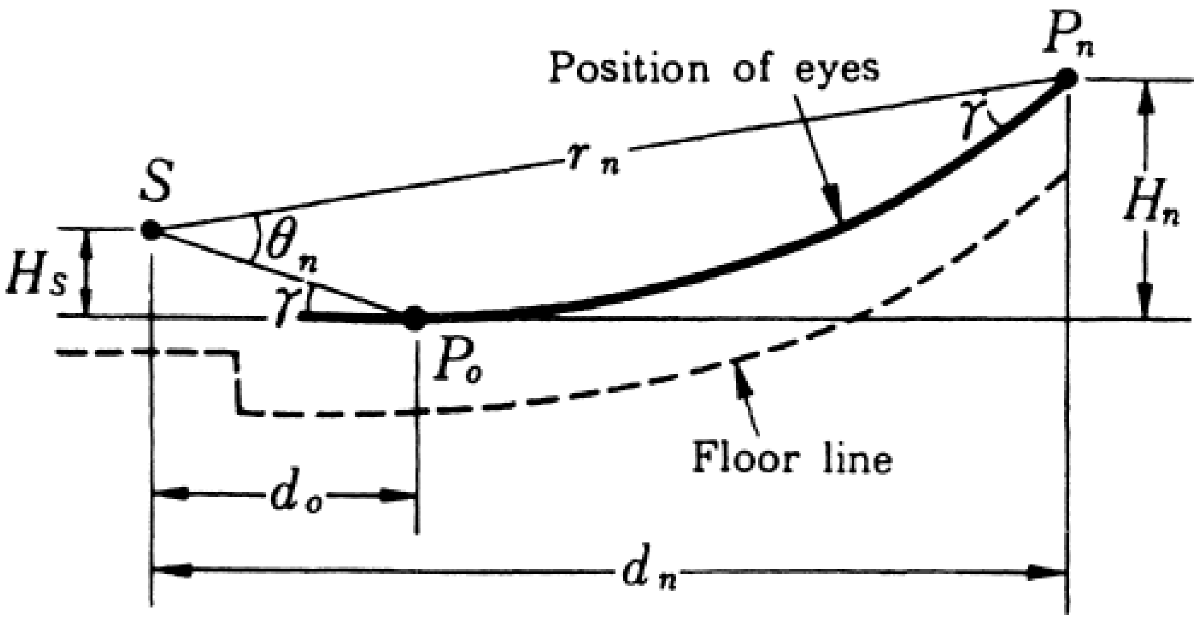


Figure 9.8 Seating floor section (Cremer Lit. B27).

where γ is the angle of elevation of the sound source above P_0*,* the person sitting in the front row, where d_0 *is the distance from the source to the origin* P_0*, the eye position.*

With the requirement that *γ is a* constant, the curve so generated, which starts at P_0 *and continues to a* receiver at P_n *with distance* d_n*,* is *called a logarithmic spiral.*

The condition where the angle γ is larger than 12–15^0 is said to be desirable (Cremer and Müller Lit. B29).

Plan shape

As with the ceiling profile design, it is advisable to obtain the first reflected sound from the wall nearest to the sound source, then gradually change the wall finish towards a surface that diffuses or absorbs.

Concave surfaces should be avoided. Since an elliptical or circular plan, in particular, always creates serious problems, if still required, a combination of convex elements as shown in Figure 9.9(b) should be considered.

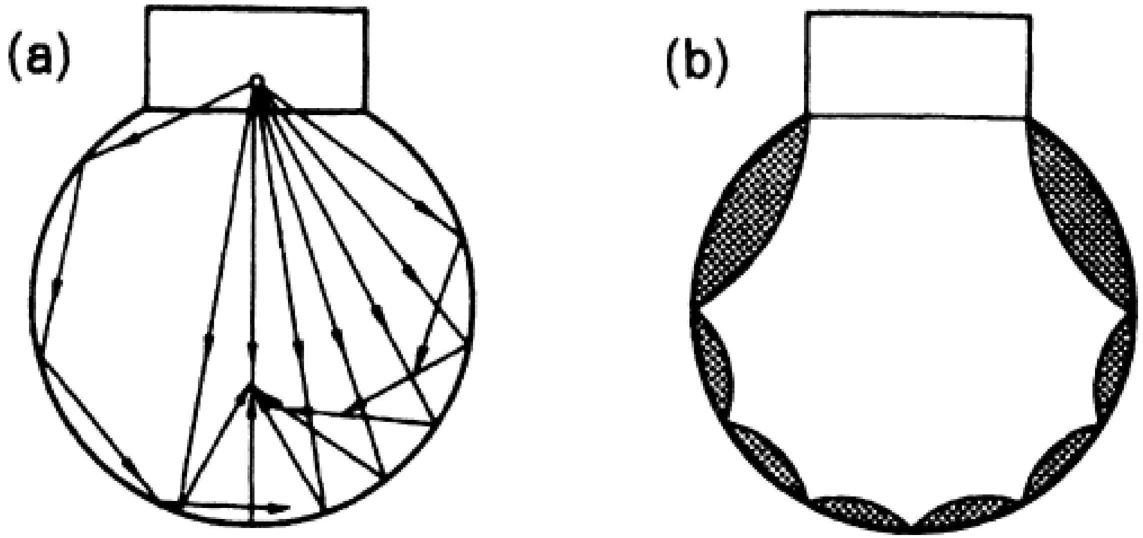


Figure 9.9 Treatment of a circular plan shape: (a) poor; and (b) good (Knudsen & Harris, Lit. Al).

Plan shape

A side-wall plan with a fan shape is often preferred by architects. However, it may produce too few lateral reflections, which play an important role in the subjective acoustic impression and may also give rise to echoes from the rear wall, as shown in Figure 9.10(a). Therefore, adequate diffusion and absorption should be considered, as shown in Figure 9.10(b). Generally, a space that is irregular or asymmetrical in plan is not easy to design, but is desirable from the point of view of sound diffusion and acoustic quality.

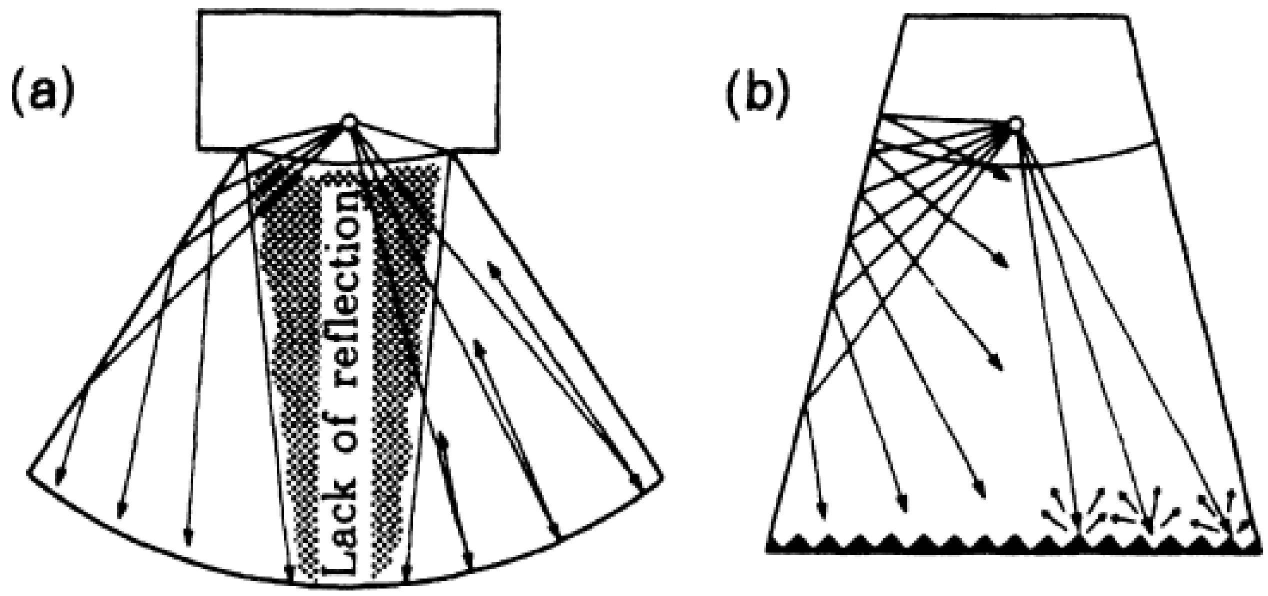


Figure 9.10 Fan shape plan: (a) poor; and (b) good.

Sound-reflecting panels

In multi-purpose halls, movable sound-reflecting walls and ceiling are often installed around the stage as an orchestra shell.

By using these, the sound energy, which would otherwise be absorbed in the space at the rear of the stage, which has high absorption, is reflected back to the players, creating better ensemble, and providing improved listening conditions for the audience.

Although such reflecting panels should be as heavy as possible, a compound laminate-layer construction of plywood and damping rubber sheet has rather good reflection characteristics for low weight.

Sound-reflecting panels

The reflecting surface should consist of flat or convex units whose dimensions are comparable to the sound wavelengths (Figure 9.11). For example, at frequencies lower than 100 Hz, the width required is more than 3.4 m.

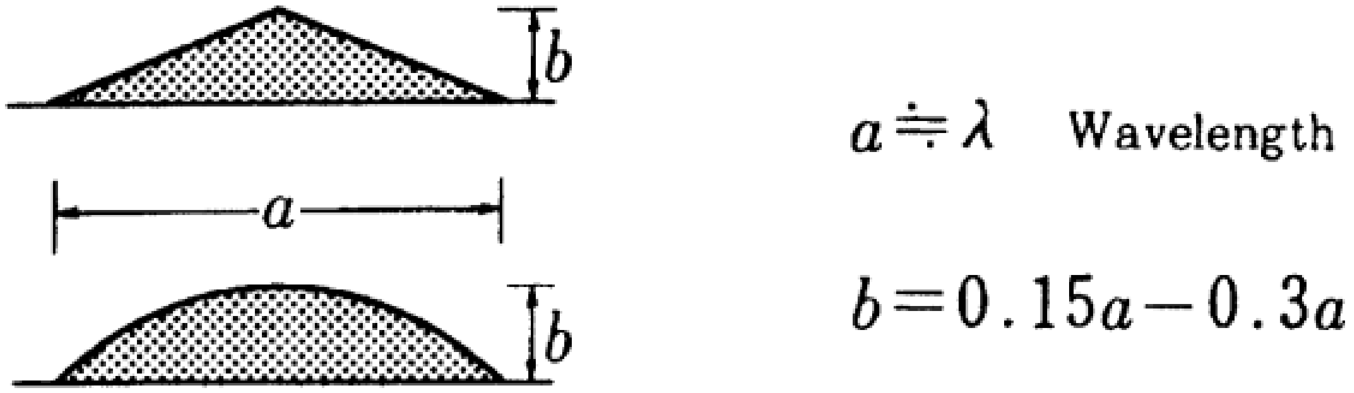


Figure 9.11 Dimensions of a diffusing element.

In large halls, in order to reduce the time delay of reflected sounds, many reflecting panels are often suspended from the ceiling over the stage and audience

Diffusion surface or units

For the purpose of improving sound diffusion in a room, the wall or ceiling can be given a zigzag profile.

Alternatively, cylindrical, spherical, pyramidal modelling or boxes of one sort or another, as well as various uneven irregular-shaped units, can be installed along the boundaries. Figure 9.11 may be a useful reference for designing such a unit. It is advisable to use various types and sizes so that a wide range of frequencies can be diffused. Figure 9.12 shows an example whose effectiveness has been measured by means of a scale model.

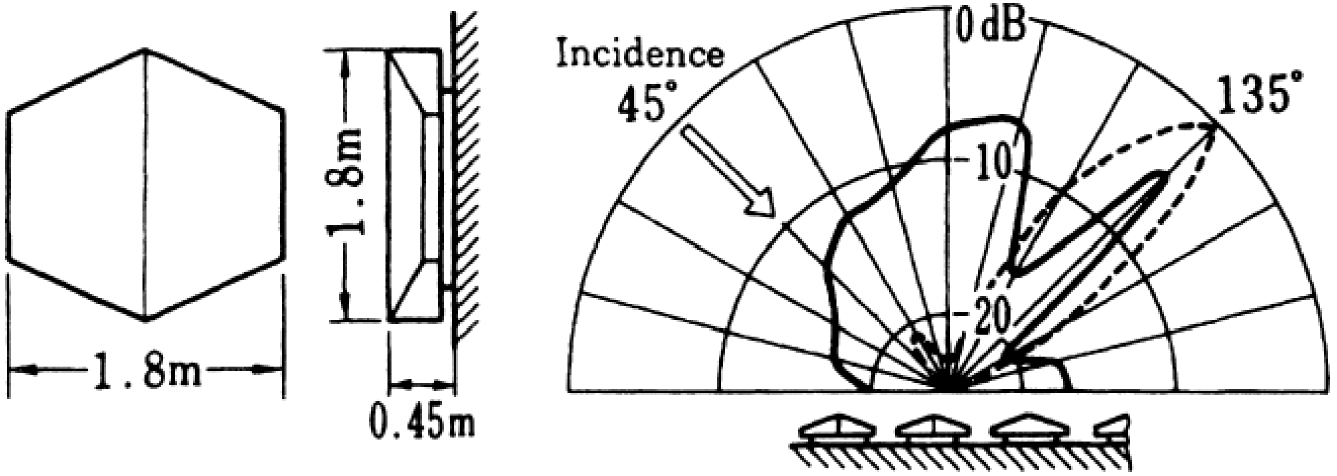


Figure 9.12 Examples of the reflection characteristics of a diffusing element measured by a scale model: (a) actual dimensions of diffusing element; and (b) directivity of reflected sound (actual frequency 250 Hz). Dotted line shows the case without any diffusing element (Maekawa *et al.* 1965).

Diffusion surface or units

Schroeder (1979) proposed a special configuration developed from number theory, Figure 9.13(a), and showed that it reflects diffusely for normal incident sound, such as shown in Figure 9.13(b). This idea is currently being applied to walls and ceilings; however, it must be tested for its absorption, even if it is made from hard material (Fujiwara & Miyajami 1992).

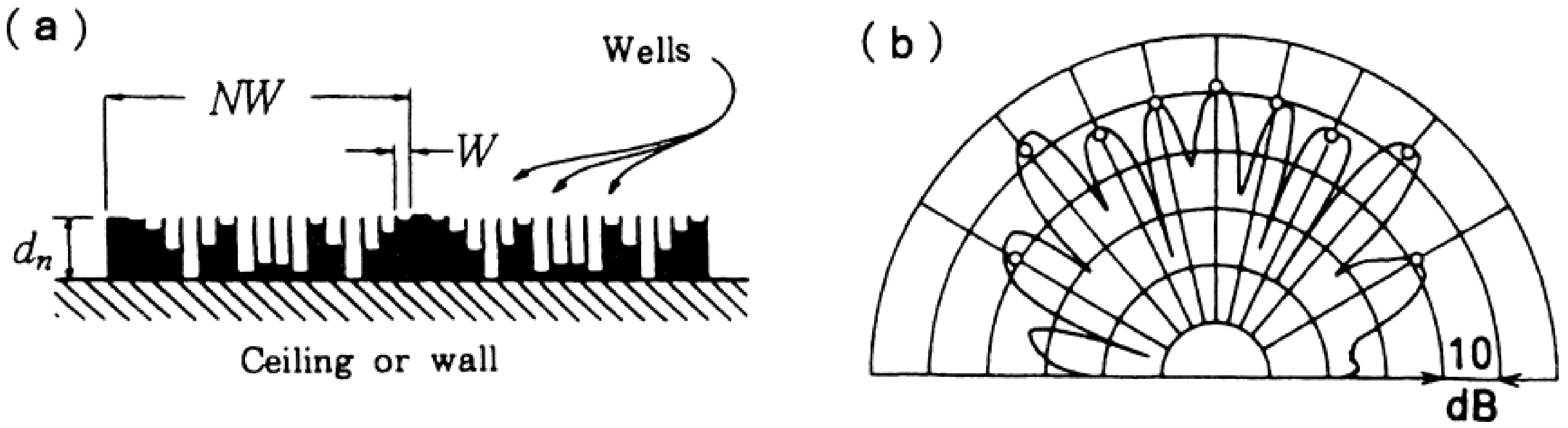


Figure 9.13 Example of diffuse reflection surface based on quadratic residues (Schroeder 1979): (a) section of the surface; and (b) directivity of reflection when the wavelength is $\lambda = \lambda_{max}/2$ (see text).

Diffusion surface or units

The quadratic residue diffuser, shown in Figure 9.13, diffuses over a frequency range that can be characterised by the wavelengths λ_{max} (lowest frequency) and λ_{min} (highest frequency). The well width

$$W < \frac{\lambda_{min}}{2}$$

and the well depth is

$$d_n = \frac{s_n}{N}\frac{\lambda_{max}}{2}$$

where s_n = Res(n^2 mod N) (quadratic residues s_n are numbers taken as the least non-negative residues with modulus N), n = 0, 1, 2, . . ., and N is a prime number. For example, when N = 17, starting with n = 0, the sequence is

s_n =0, 1, 4, 9, 16, 8, 2, 15, 13, 13, 15, 2, 8, 16, 9, 4, 1

so that N is the period.

C. Geometrical drawing study of room shape

- Once a room has been designed with due reference to the components described above, the whole room shape can be developed as a functional acoustic system.

- There is a geometrical method of representing the behaviour of sound transmission and reflection. In order to distribute the prime reflections uniformly over the whole audience area, avoiding undesirable phenomena such as echoes, it is necessary to adjust the positions and angles of the reflecting surfaces.

- Further, in order to avoid the creation of long-path echoes and sound foci, etc., a trial-and-error method is employed to adjust the diffusive and absorptive treatment until an adequate reflected sound distribution is obtained.

- Figure 9.15 shows an example of the investigation of the longitudinal section of the room:

a) with sound rays; and
b) with wave fronts.

- The same analysis should, of course, be applied to the floor plan.

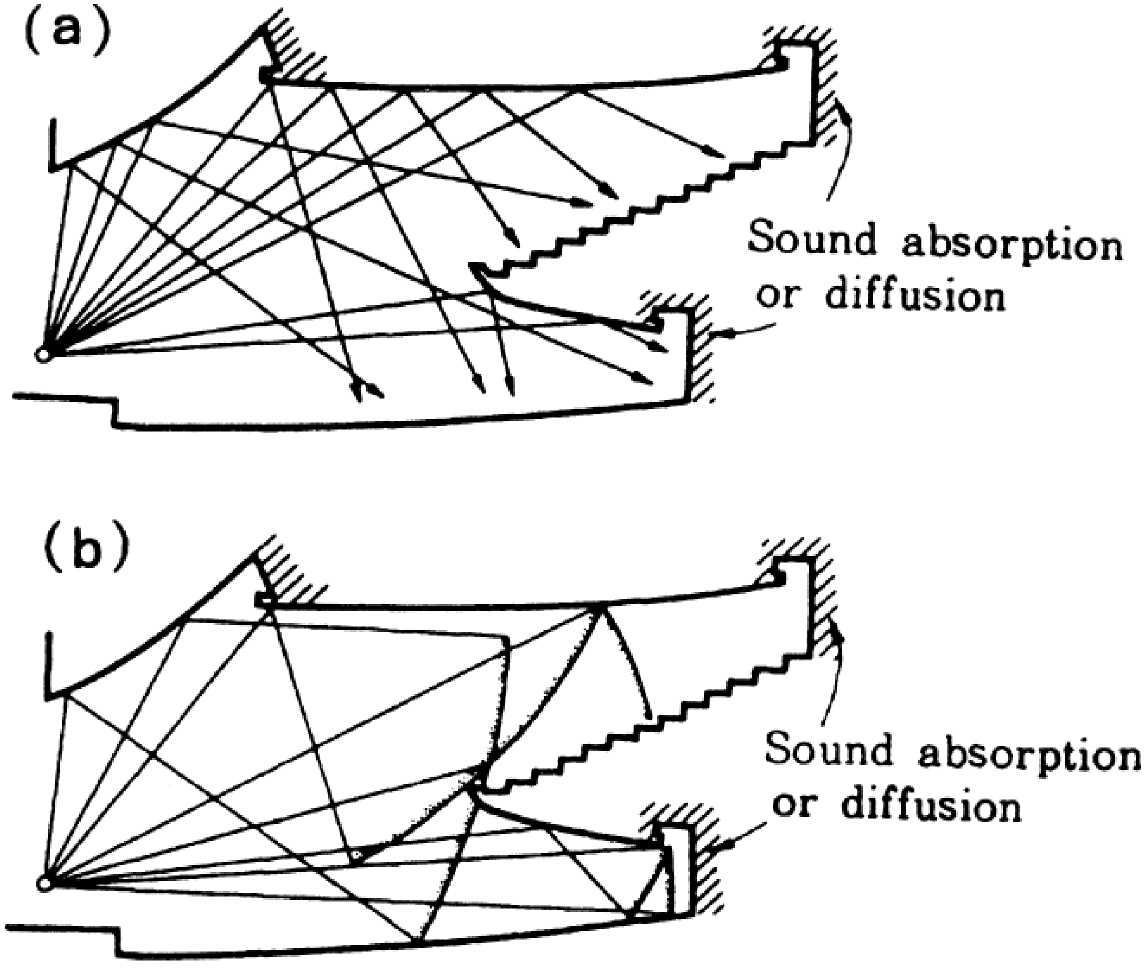
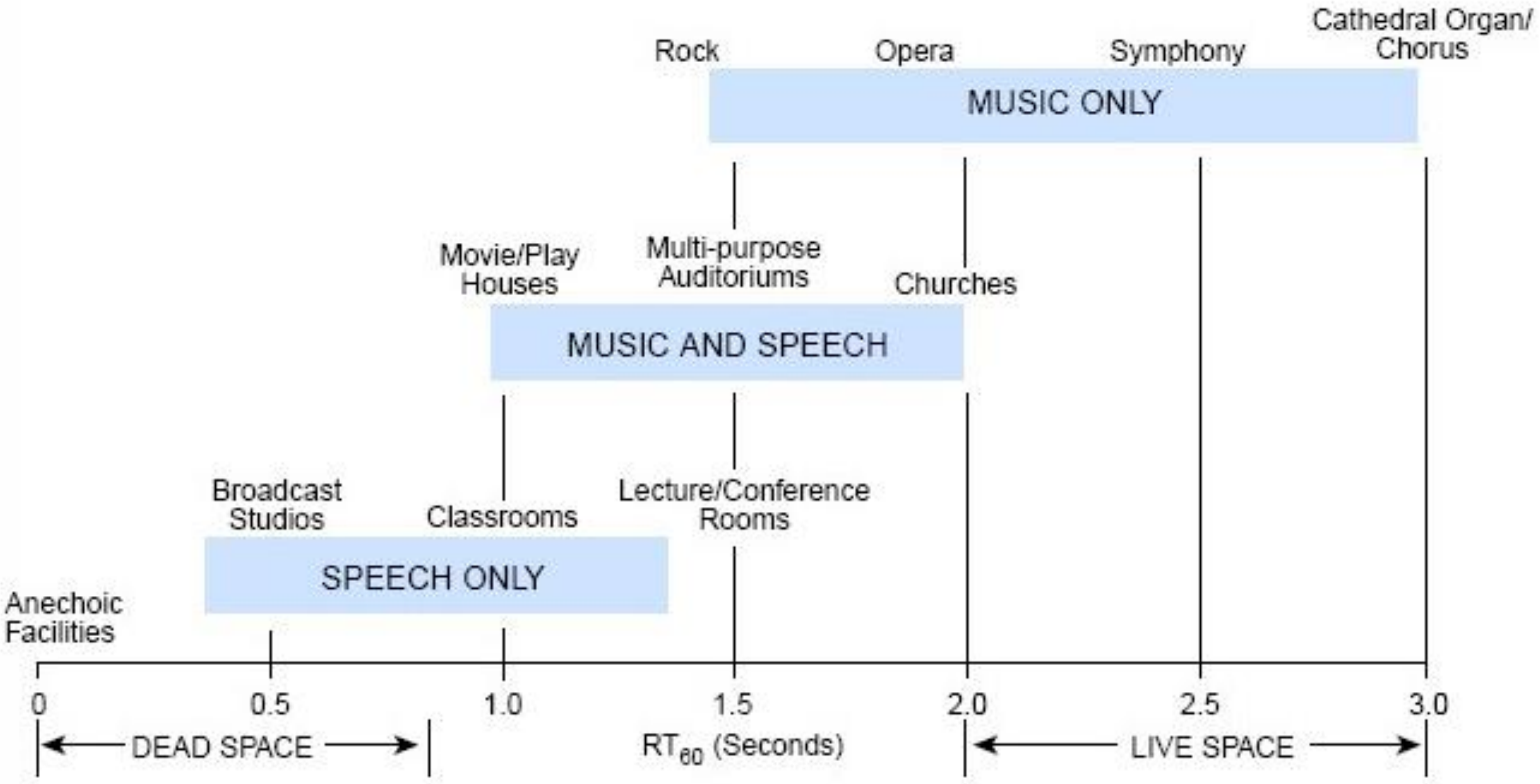


Figure 9.15 Geometrical drawing investigations of room section profiles: (a) sound-ray tracing; and (b) wave-front drawing.

Planning the reverberation

A. Determination of optimum reverberation time

Room volume and purpose: With a knowledge of the major purpose for which a room is to be used and its volume, the optimum reverberation time and its frequency characteristics should be choosen.



Planning the reverberation

Variable reverberation time facilities: In a multi-purpose room, the requirement is for the reverberation to be variable.

- Figure 4.31 shows an example of devices for achieving this flexibility. Further, since the timbre or sonority is also changed by changing the frequency characteristics of absorption or is distorted for unknown reasons, it is difficult to cover the desired range.
- A reasonable approach to the problem is to install a thick curtain with a deep air space behind it.

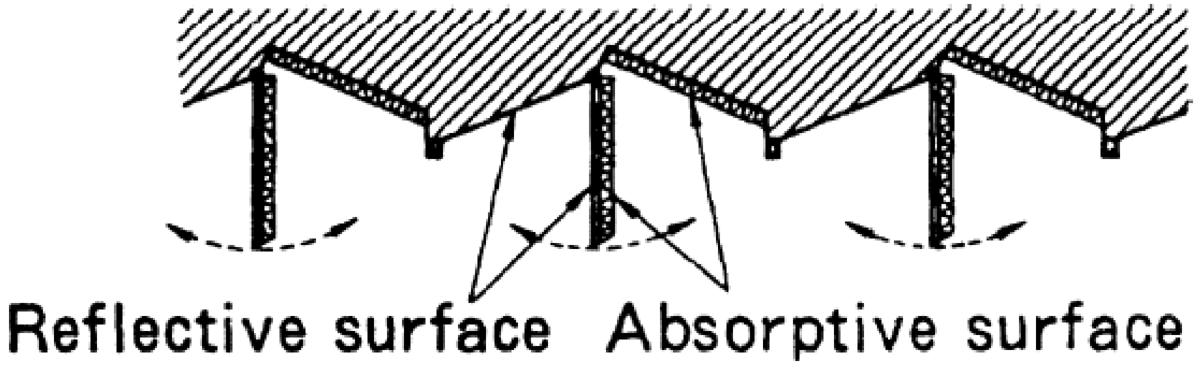


Figure 4.31 Variable sound absorbing panels.

Planning the reverberation

Electro-acoustic systems:

- It is of fundamental importance to note whether an electro-acoustic system acts as the main facility or takes on a subsidiary, supporting role.
- If an electro-acoustic system is to be given priority, then it is advisable to adopt a somewhat shorter reverberation time than the recommended value.
- At the very least the sound absorption surrounding the microphone should be increased.

Table 10.3 Recommended maximum sound pressure levels with electro-acoustic systems (dB)

Lecture room	75–80
Conference room or banquet room	80–85
Sports facilities in open field	85–90
Multi-purpose auditorium (popular music)	90–95
Disco (rock music)	105–110

Average values: equipment must not distort at a peak of more than 10 dB higher.


www.radiomuseum.org

Variable reverberation time facilities:

In a multi-purpose room, the requirement is for the reverberation to be variable.

- The area which can be used for such a variable surface function is often limited, whether it is on the ceiling or walls, resulting in variations up to 10–20%.

- A reasonable approach to the problem is to install a thick curtain with a deep air space behind it.

- In order to make best use of the facilities, a new monitoring system capable of indicating the necessary operating conditions based on objective measurements would be required.

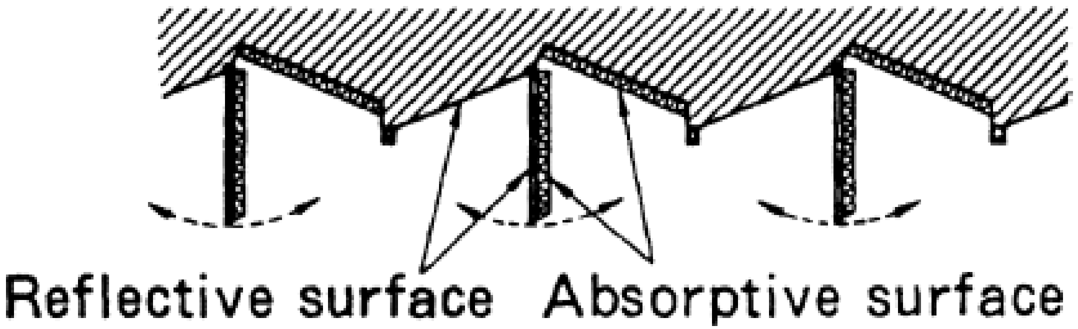


Figure 4.31 Variable sound absorbing panels.

B. Determination of Room volume

- The reverberation time is directly proportional to the room volume and inversely proportional to the total absorption.
- Since an audience has a large absorption, unless the unit volume/person for the space is appropriate, the reverberation time may be inadequate.
- The unit-floor area per seat is about 0.6m^2 including aisles, and, by adjusting the ceiling height, the unit volume should meet the value indicated in Table 9.1, which shows the recommended unit volume for a variety of rooms.

Table 9.1 Recommended room volume per seat

Concert hall	8–10 m^3
Opera, multi-purpose hall	6–8 m^3
Theatre, cinema	4–6 m^3

C. Sound absorption design

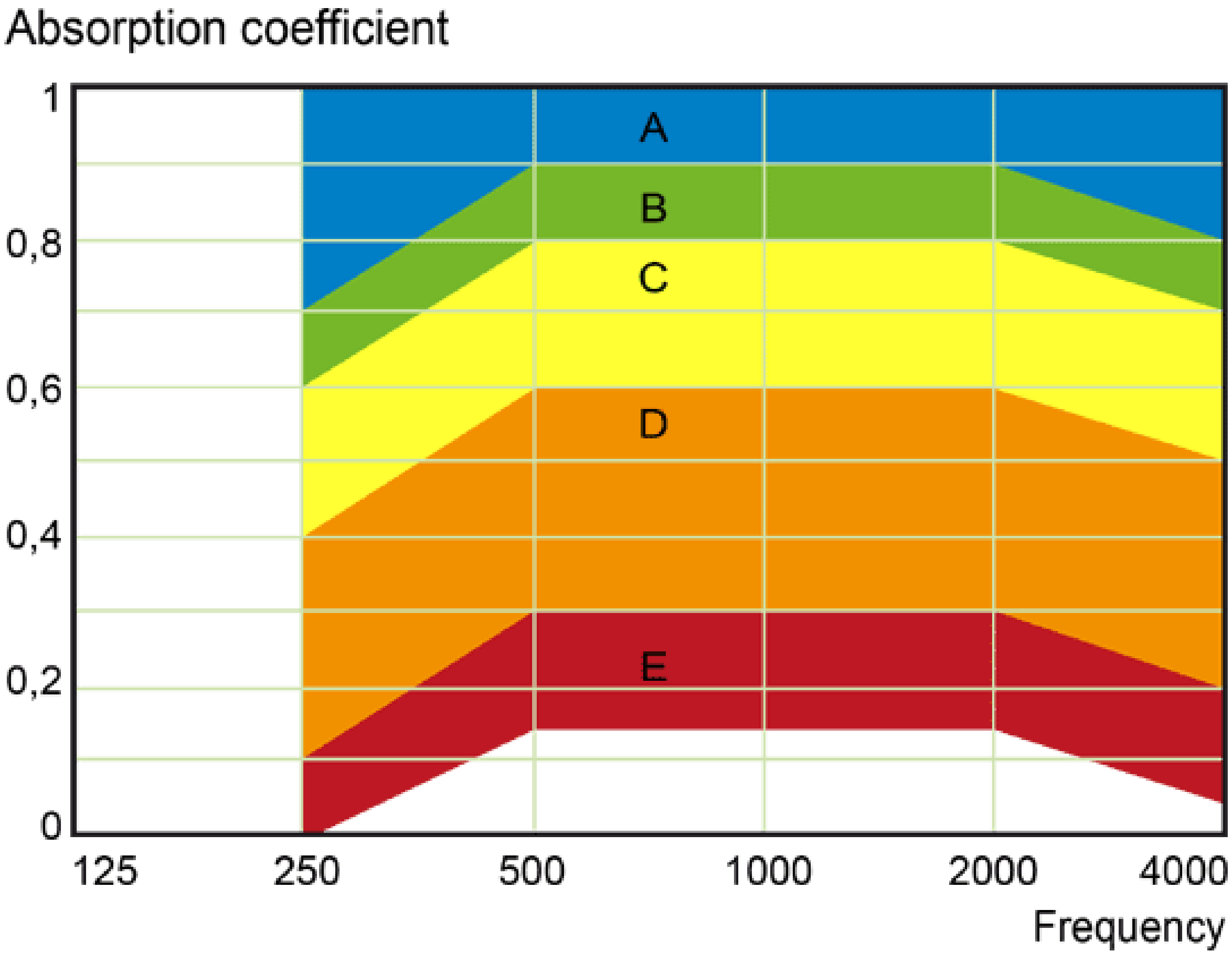
a. Determination of necessary absorption

Once the target values of reverberation time T and room volume V are determined, the necessary absorption A can be obtained from the reverberation time formula, from which the absorption of the audience is subtracted.

This result is then the basis for the design, construction and finishes of walls and ceilings.

Classification of absorption materials

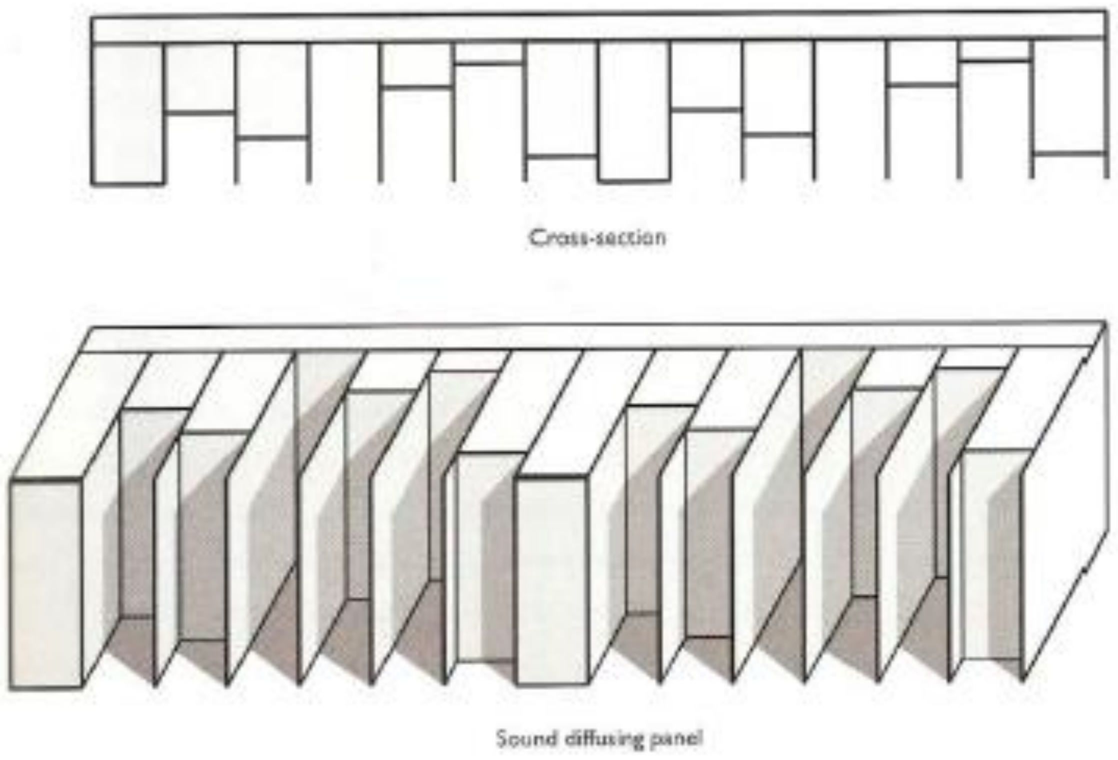
- According to EN 11654 (classes A-E)
- Measured absorption coefficient is compared to a reference curve, the sum of unfavourable deviations ≤ 0,10
- Note: definition of absorption class does not consider frequencies below 200 Hz!

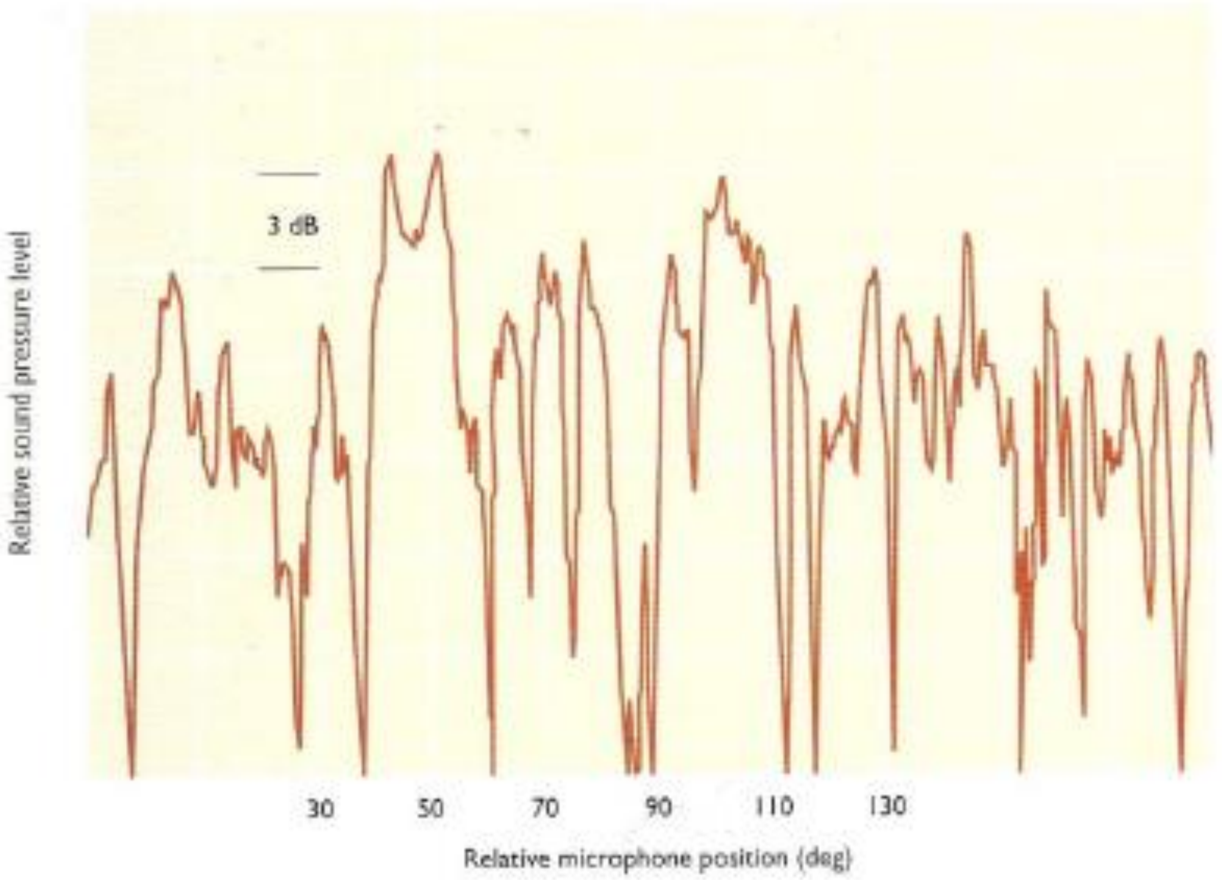


Weighted Sound Absorption Coefficient α_w is provided by EN ISO 11654 with the use of a predetermined curve at 500 Hertz.

Absorption Class	α_w-value [-]
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65; 0.70; 0.75
D	0.30; 0.35; 0.40; 0.45; 0.50; 0.55
E	0.15; 0.20; 0.25
not classified	0.00; 0.05; 0.10

Sound diffusing structures (diffusors)





b. Effect due to variable audience

- For an auditorium whose absorption is largely affected by the audience, the reverberation times, both when fully occupied and empty, should be calculated.

- The seats should provide absorption that is close to that of the full audience, in order to minimise the effect due to the different occupancy.

- However, it should be noted that the seats must not have too much absorption when a member of the audience sits on it.

c. Location of absorbents

Having designed the room shape, the following steps are then followed:

(1) Determine the absorption required for local spot surfaces that need treatment in order to avoid echoes and flutter.

(2) Apply reflective (live) treatment around the stage and absorptive (dead) treatment along the rear wall. These are called the live-end and dead-end methods.

(3) Furnish dead treatment around microphones when they are used as electro-acoustic devices, and

(4) distribute the absorbents in patches of small dimensions, comparable to sound wavelengths, instead of using an absorption treatment over a large extended area, in order to diffuse the sound field in the room and to increase the total absorption by the area effect (Figure 4.10).

d. Remarks on calculation

- Following on from the above guidelines, the frequency range from 125 to 4000 Hz should be investigated and the final reverberation times calculated, satisfying oneself that, by a process of trial and error, the optimum values have been attained by selection from various combinations of materials and construction details.

- Table 9.2 shows an example of this type of calculation.

Table 9.2 Reverberation time calculation for a concert hall

Places	*Finish materials*	*Area S(m²)*	*125 Hz*		*250 Hz*		*500 Hz*		*1 KHz*		*2 KHz*		*4 KHz*	
			α	$S\alpha$	α	$S\alpha$	α	$S\alpha$	α	$S\alpha$	α	$S\alpha$	α	$S\alpha$
Floors	Vinyl chloride tile on concrete	494	0.01	5	0.02	10	0.02	10	0.02	10	0.03	15	0.04	20
	45-mm timber flooring on joists	118	0.15	18	0.10	12	0.08	10	0.07	8	0.05	6	0.05	6
Ceilings	12-mm gypsum board with large air space	431	0.25	108	0.15	65	0.10	43	0.08	34	0.06	26	0.05	22
	Diffuse and absorptive construction	92	0.30	28	0.30	28	0.30	28	0.30	28	0.30	28	0.20	18
Walls	Mortar, paint	403	0.01	4	0.02	8	0.02	8	0.03	12	0.03	12	0.03	12
	24-mm gypsum board with 150 mm air space	60	0.18	11	0.13	8	0.06	4	0.06	4	0.06	4	0.05	3
	Perforated board, 25-mm glasswool, large air space	92	0.55	51	0.80	74	0.75	69	0.48	44	0.33	30	0.15	14
	Reflecting panels on stage	321	0.15	48	0.15	48	0.10	32	0.08	26	0.07	22	0.06	19
Door	Vinyl leather with upholstery	44	0.10	4	0.15	7	0.20	9	0.25	11	0.30	13	0.30	13
Window	Glass panes	16	0.30	5	0.20	3	0.15	2	0.10	2	0.06	1	0.03	0.5
Chairs	Theatre chair upholstered	660	0.15	99	0.20	132	0.28	185	0.30	198	0.30	198	0.30	198
Persons	Adult audiences	660	0.20	132	0.25	165	0.33	218	0.40	264	0.40	264	0.40	264
Surface	$S = 2071\,m^2$													
Volume	$V = 4850\,m^3$													
Total absorption (m²)														
	Unoccupied condition			380		393		399		376		355		325
	With full audiences			413		426		432		442		421		391
Air absorption	(4mV)									17		43		109
Reverberation time (s)														
	Unoccupied			1.86		1.79		1.76		1.80		1.81		1.69
	With full audiences			1.70		1.64		1.61		1.52		1.52		1.44

Computer simulation and acoustic model analysis

Computer-aided design based on geometrical acoustics

For the simulation of sound in large rooms, there are two classical geometrical methods, namely the ray tracing method and the image source method.

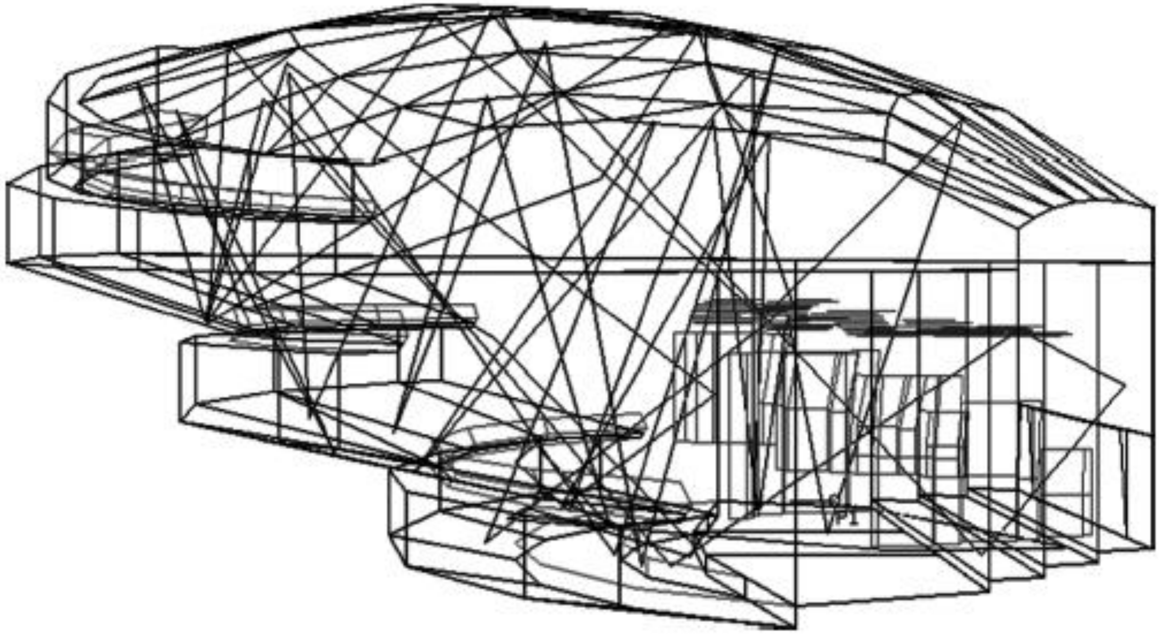


Figure 9.16 Ray tracing from a source position in a computer model of a room. Only one single ray is shown.

The image source method is based on the principle that a specular reflection can be constructed geometrically by mirroring the source in the plane of the reflecting surface.

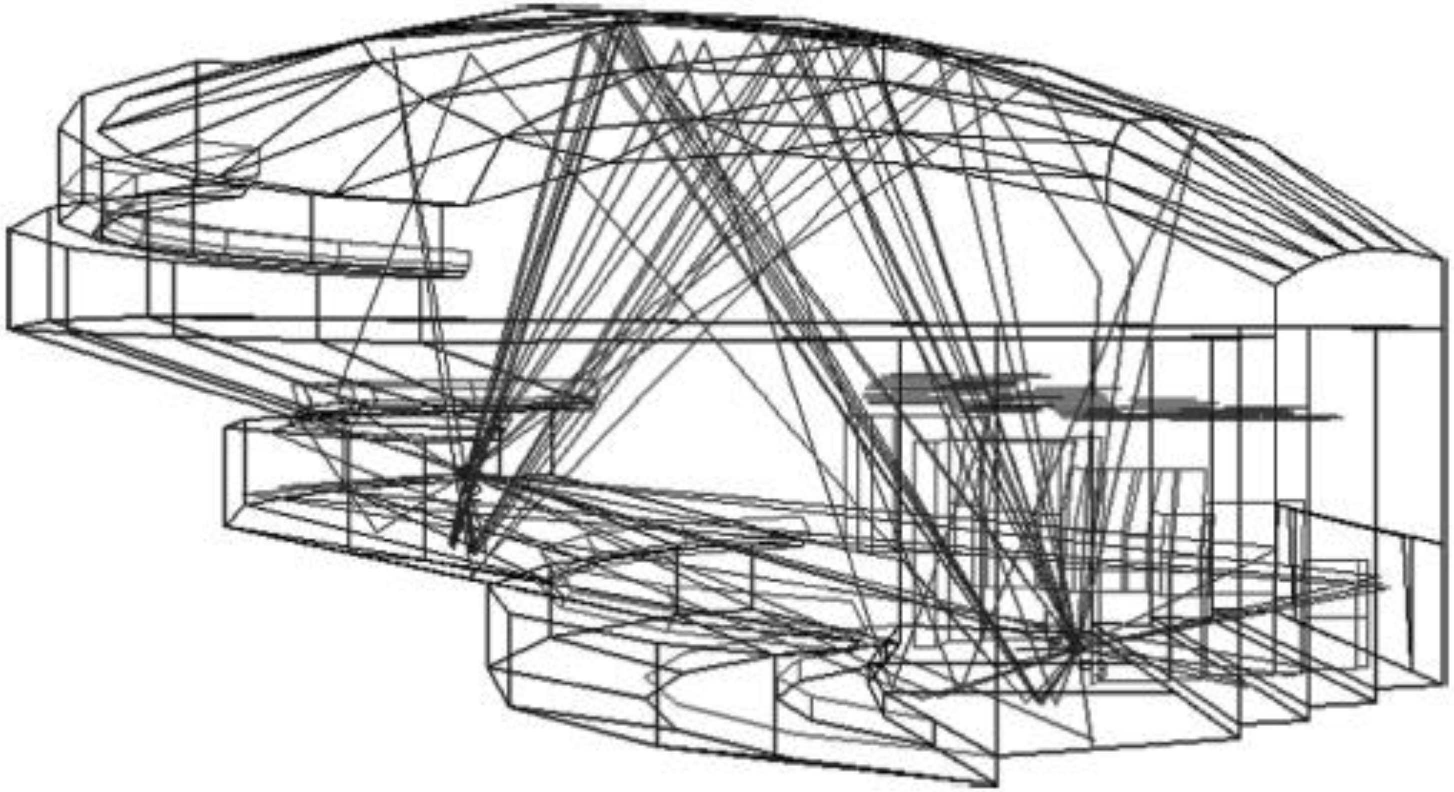


Figure 9.17 Calculated reflections up to the third order between a source point and a receiver point in a room.

- Image source models are only used for simple rectangular rooms or in such cases where low-order reflections are sufficient.

- The disadvantages of the two classical methods have lead to the development of **hybrid models**, which combine the best features of both methods.

- One of the advantages of a room acoustic computer model is the possibility of calculating the response at a large number of receivers distributed in a grid that covers the audience area.

- It can be useful for the acoustic designer to see a mapping of the spatial distribution of acoustic parameters.

- Uneven sound distribution and acoustic weak spots can be localised and appropriate countermeasures can be taken.

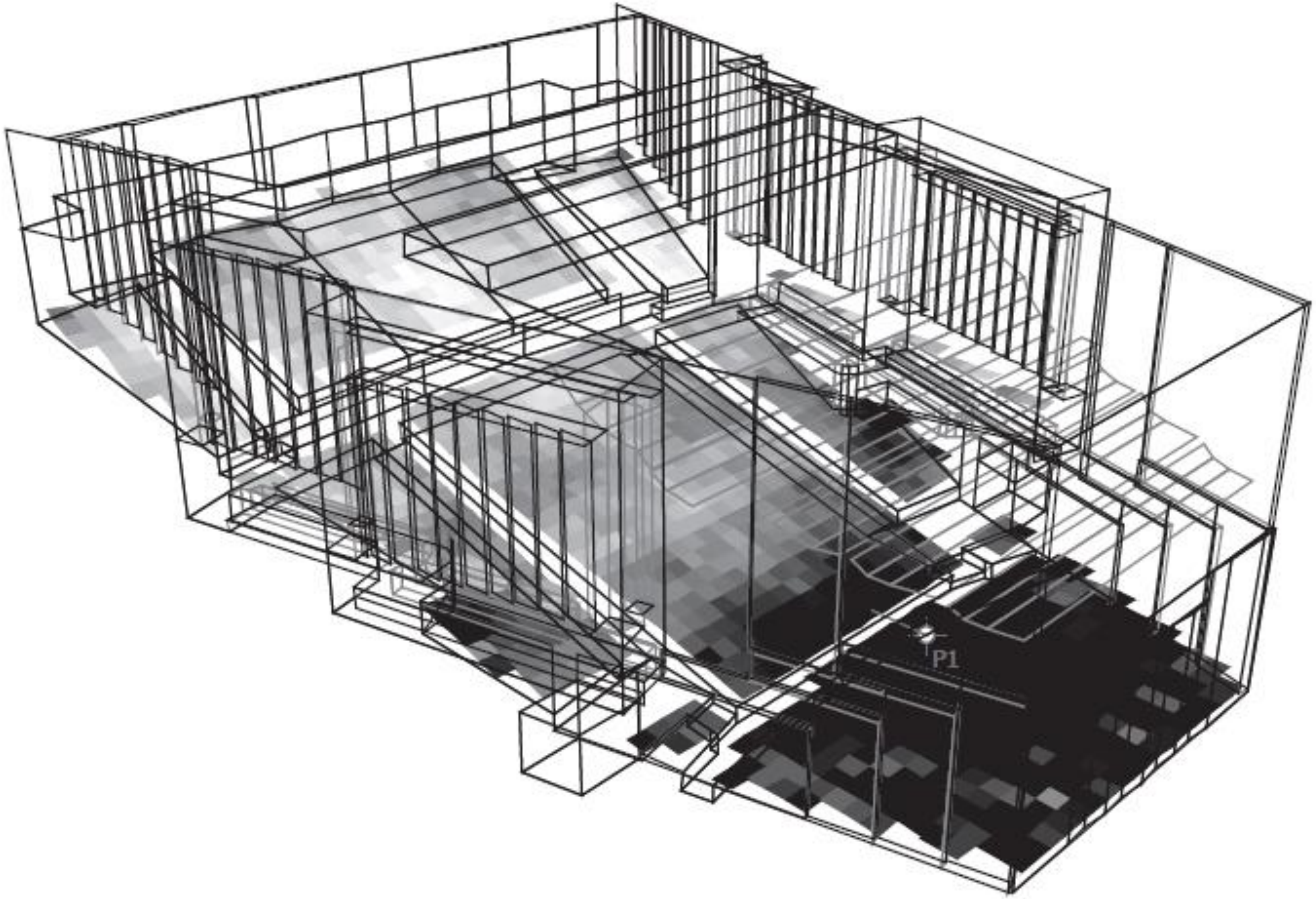


Figure 9.18 Mapping of acoustic parameters calculated in a grid that covers the audience area in a concert hall.

Practical examples of the acoustic design of rooms

- Some examples that present acoustic interesting problems have been selected from the field of architecture and building.

School classroom

- When the number of students is less than 100, a rectangular room shape is acceptable, bearing in mind the three-dimensional proportions.

- If the number is greater than 100 or 150 say, the room section in Figure 9.21 is preferred.

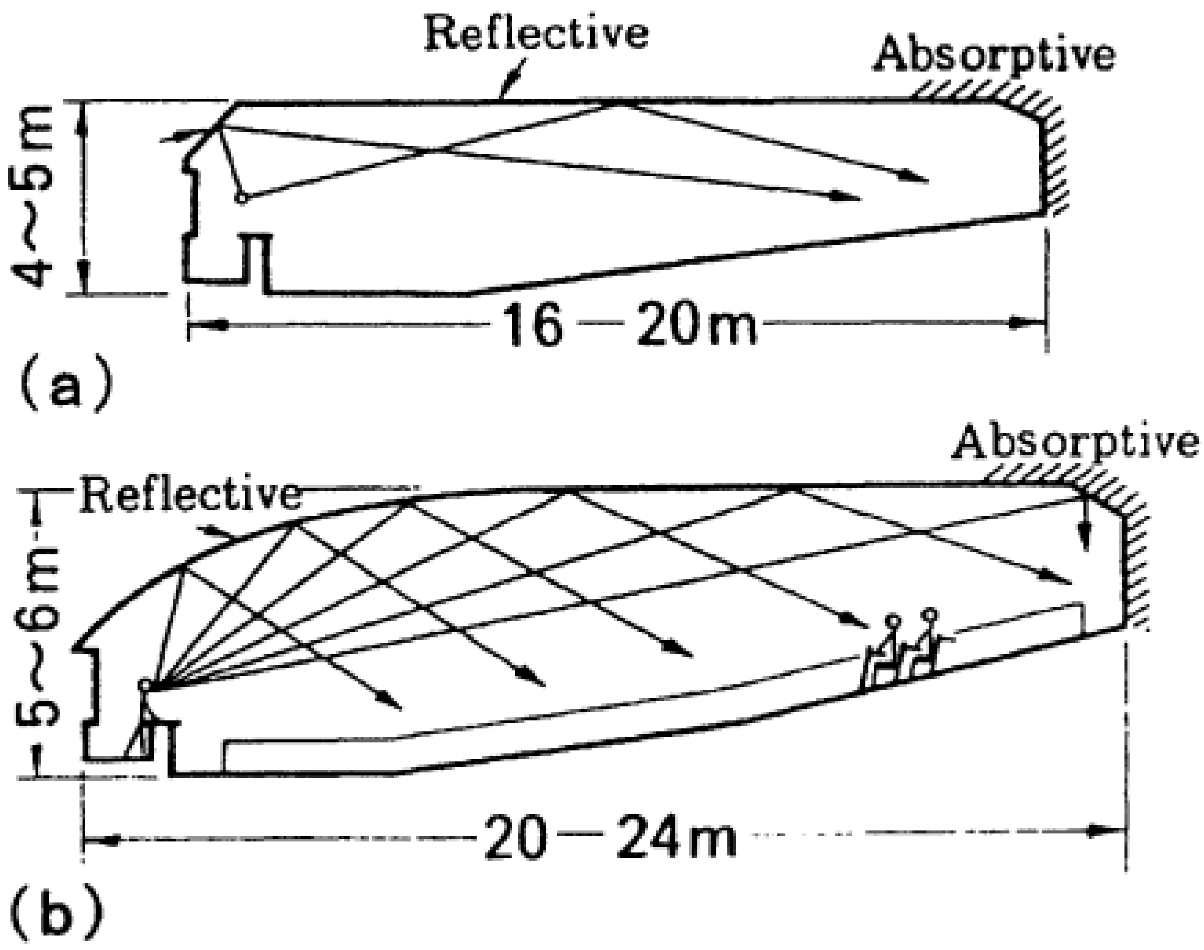
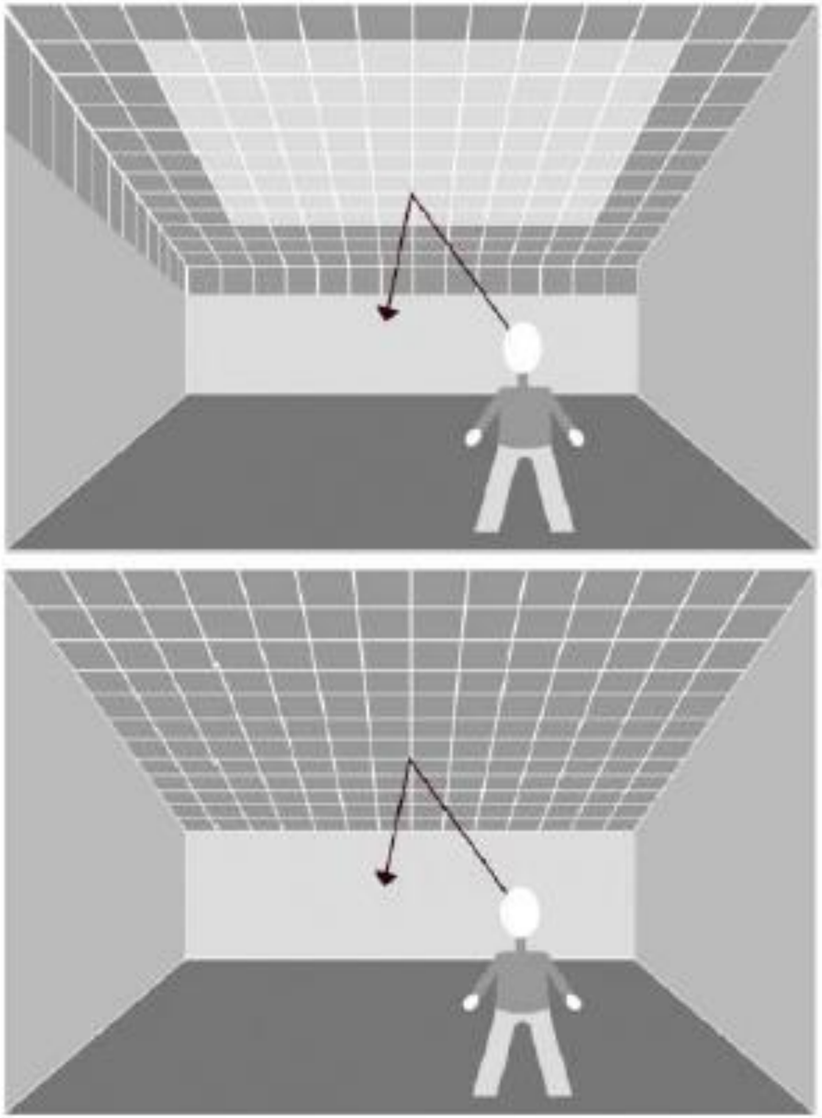


Figure 9.21 Design of longitudinal section of class rooms: (a) for 150–300 seats; and (b) for 300–500 seats.

Optimising speech intelligibility (SFS 5907)

- In classrooms, it is important that speech distinction from the teacher to pupils is good
- Recommended reveberation time 0,5...0,8 s
- When class A sound absorbing material is used (absorption coefficient > 0,9), the centre part of the ceiling should be left sound reflecting (absorption coefficient 0...0.20), from which sound is reflected to the mid and rear part of the room → this improves speech intelligibility
- If class C material is used, the material can be positioned on the whole ceiling surface because the material also reflects sound
- The amount of class A material needed is about 70 % of the floor area and for class C material correspondingly 100 %
- Absorption material should also be placed on the walls to avoid distracting flutter echoes



Gymnasium

Since a gymnasium usually has a large volume with relatively small seating area, the reverberation time tends to be very long and yet the space is frequently used as a multi-purpose hall, thus, it is usually difficult to provide satisfactory acoustics.

Theatre

- There is a wide range of theatre designs possible, depending not only on the type of play or drama, but also on the style of production and direction.
- An overriding influence tends to be the priority given to visual rather than acoustic requirements.
- Therefore, the seating area is limited in distance from the stage and is often extended in a fan shape, so that the shape of walls and ceiling must be treated as an essential acoustic component.
- Although actors require the natural voice to be intelligible, an electroacoustic system will be used for background sound, and because there may be musical performances, it is also important that the reverberation time is chosen from the middle of C and D.

Concert hall

- This is a hall whose main objective is the performance of music. Some plans and sections of historically well-known halls are shown chronologically in Figures 9.22 and 9.23, respectively.

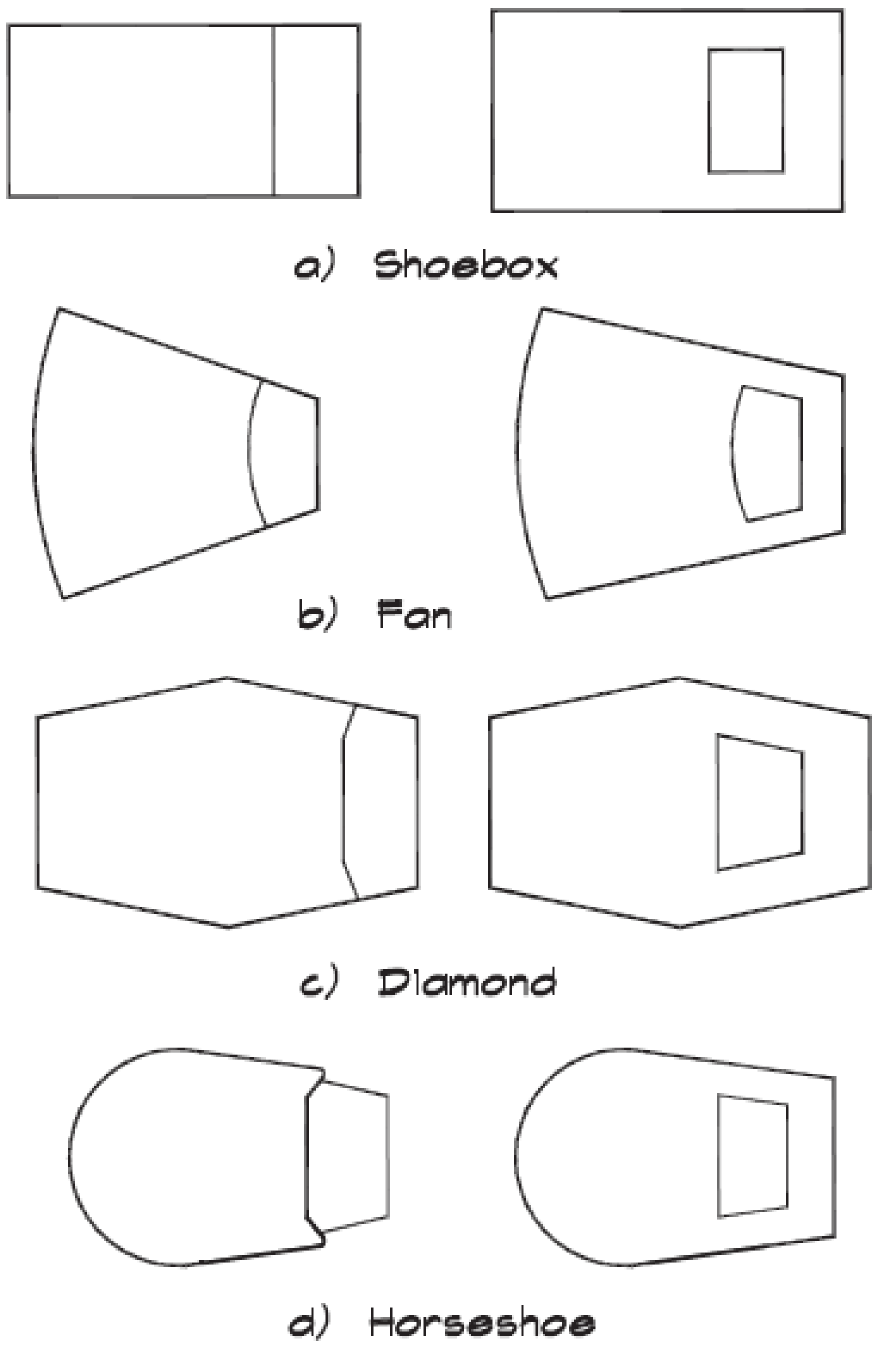
- Part (a) in Figures 9.22, 9.23 and 9.24 shows a representative hall built in the nineteenth century, which, because of its rectangular shape, is referred to as a shoebox, with a rich sonority for many people.

- This basic design has been adopted all over the world; the one shown in Figures 9.20 and 9.22(e) is intended to be a descendant of it.

Simple Plan Forms for Concert Halls in the Normal and Surround Configurations

The best performer is the rectangular or shoebox floor plan. In Beranek's (1996) review of concert halls, the three halls rated Aş and six of the top eight have this basic form.
A rectangular room provides the strong lateral reflections necessary for envelopment as a natural consequence of its shape.

Narrow halls also yield low delay times for early reflected sound.

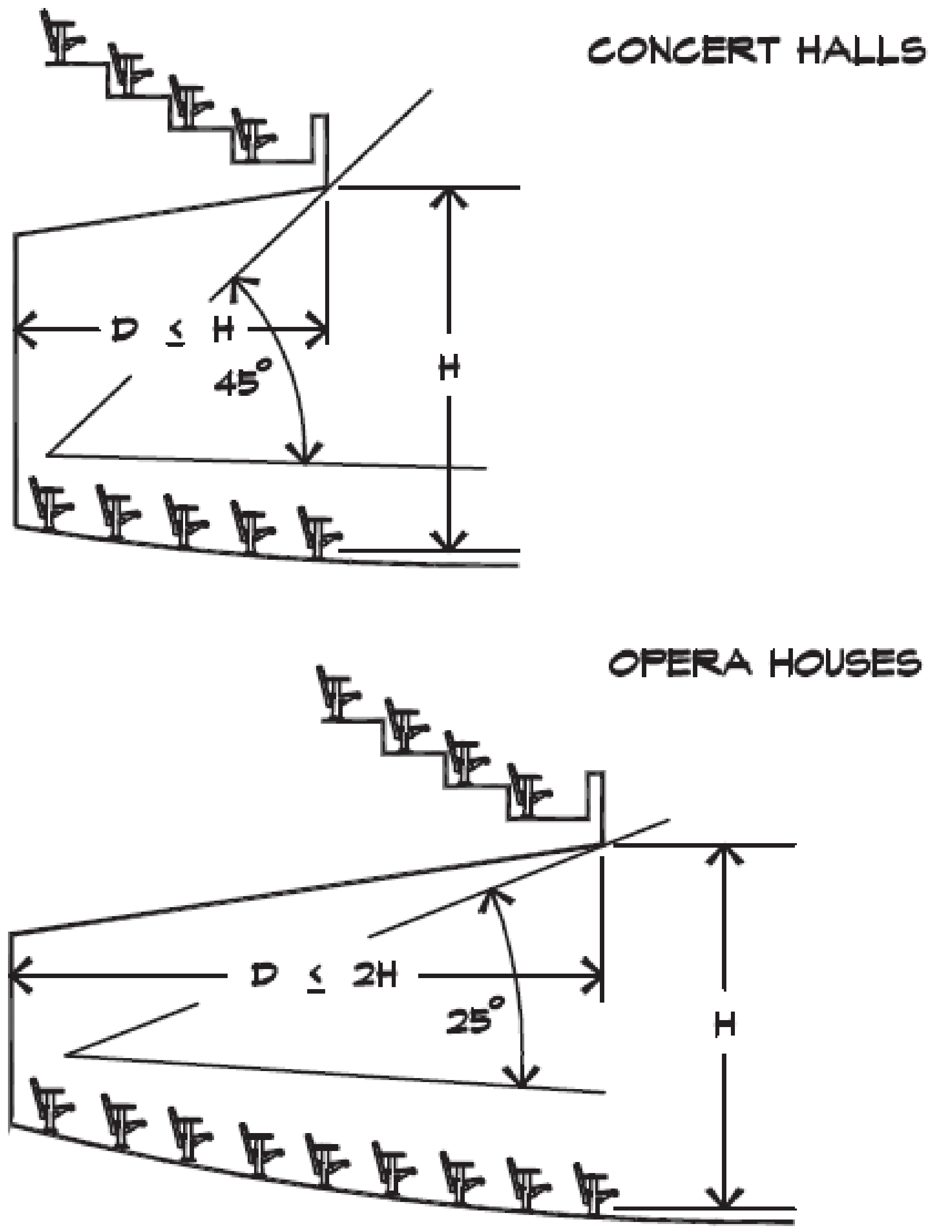


Designs for Balcony Overhangs

Under a deep balcony there is less reverberant energy and the listener below has less sense of envelopment and a lower reverberation time.

As a consequence under-balcony spaces should be shallow and their front openings high.

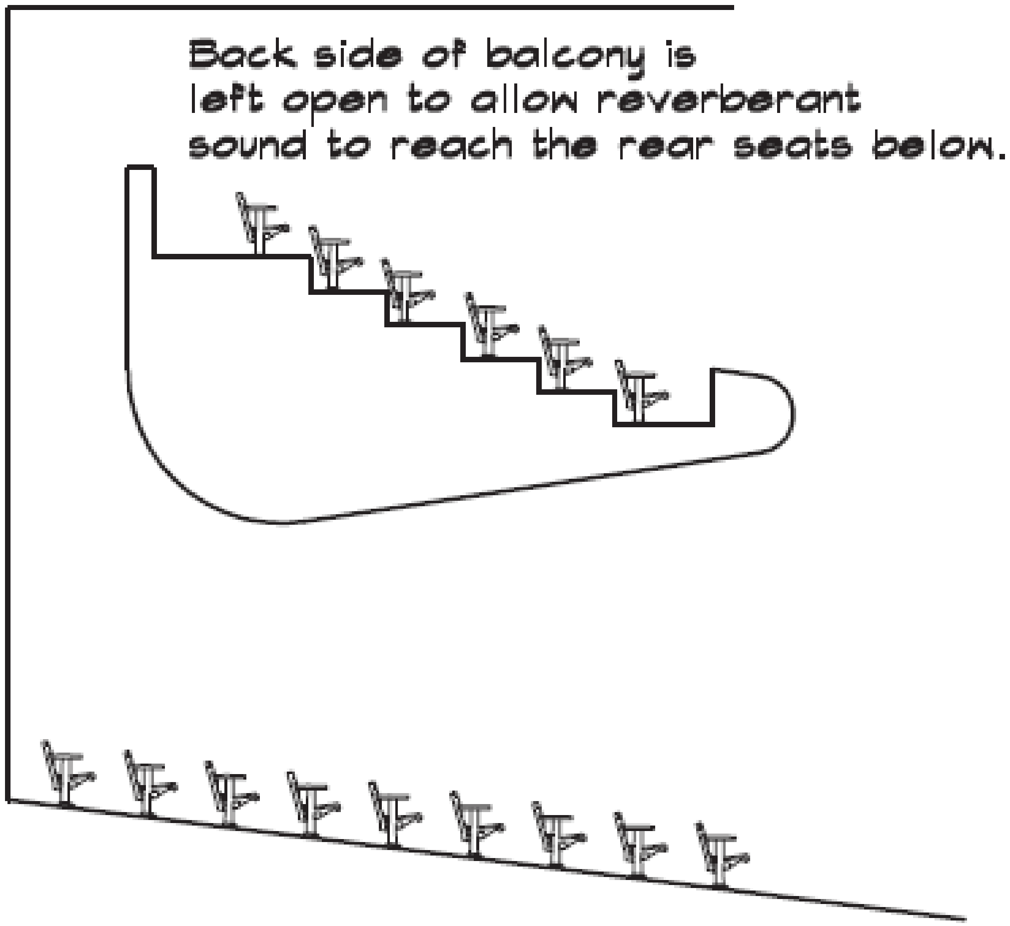
Figure gives recommendations in terms of the depth-to-height Ratio.



Flying Balcony Design

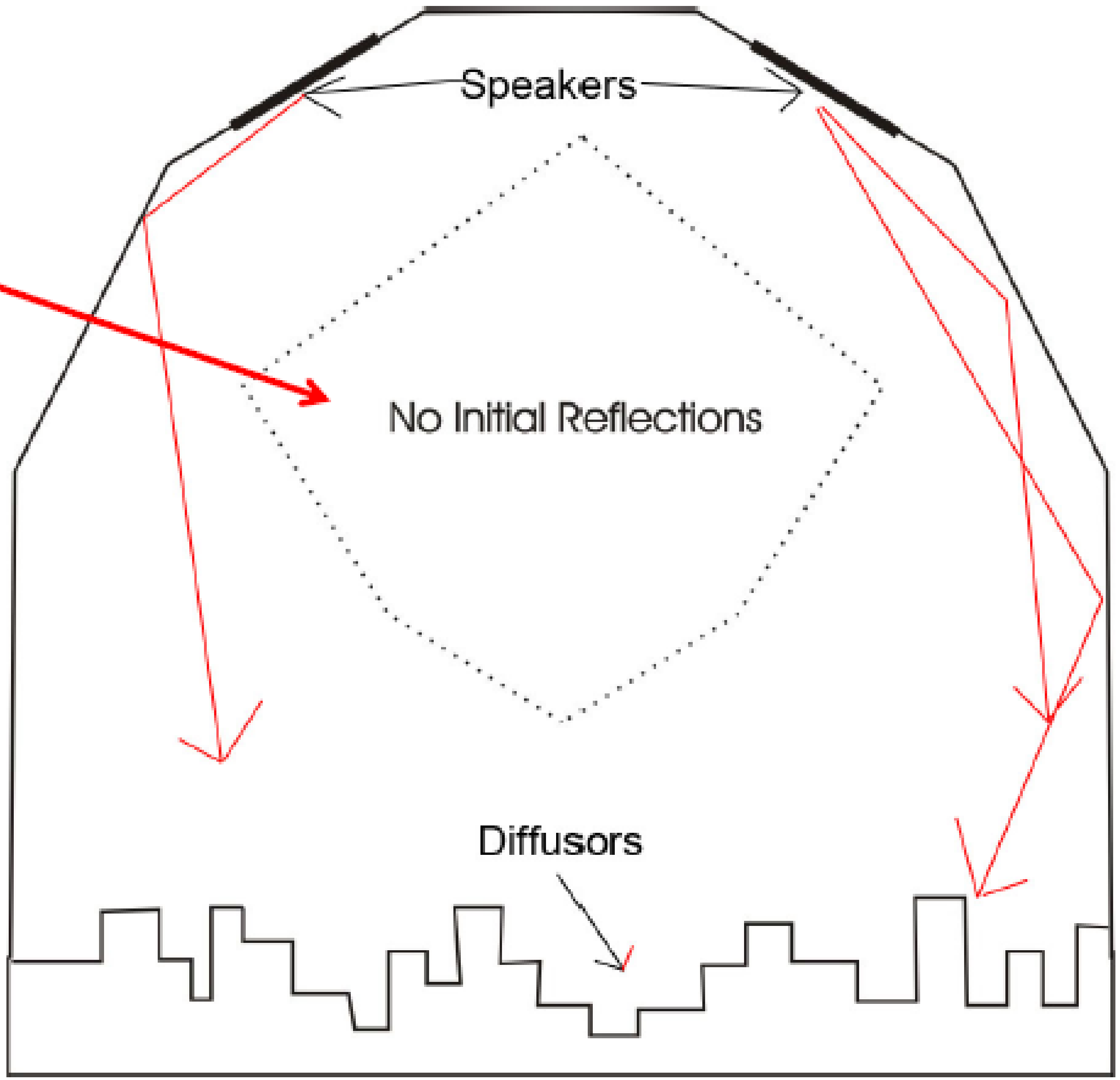
Knudsen (1965), at Grady Gammage Hall in Tempe, Arizona, designed a flying Balcony allow reverberant energy to pass behind the balcony to reach those seated below.

He wrote that, in the rear seats, the audience received the same sense of envelopment as in the orchestra seating areas.
It is an expensive solution, since it presents structural challenges, even when beams support the balcony from the rear.



Studio

Reflection-free zone at the mixer`s position



Parameter		Units/Conditions	Value
Reflected Sound	Early Reflections	0–15 ms (in region 1–8 kHz)	< –10 dB relative to direct sound
	Reverberation Time	T_m[s] = nominal value in region of 200 Hz to 4 kHz V = listening room volume V_0 = reference room volume (100 m^3 [1075 ft^2])	$\approx 0.25(V/V_0)^{1/3}$

Requirements for early reflections and reverberation time

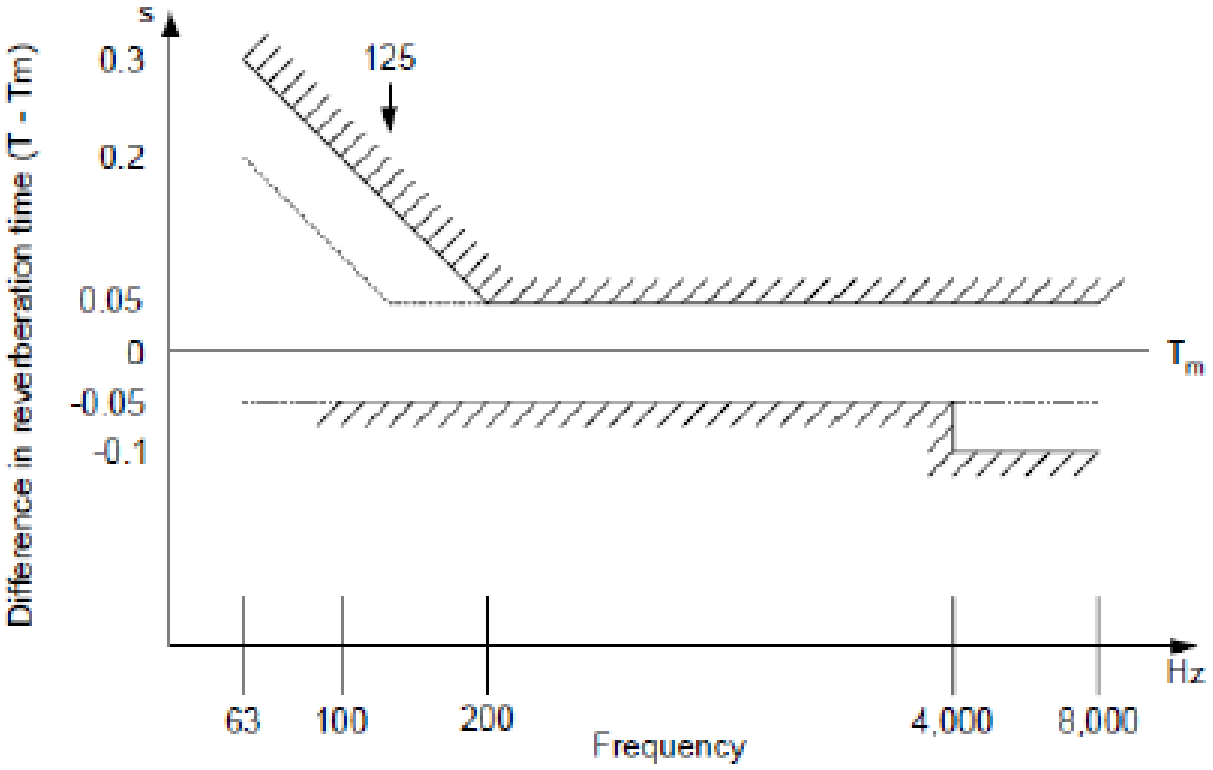


Figure 3-1 Tolerance Limits for Room Reverberation Time

Objective parameters

- Reverberance

– Reverberation time RT60

– Early decay time EDT, has been found to correlate better with subjective impression than RT60)

- Clarity

– Clarity C80 (describes how much of the sound arrives at the listener 0...80 ms after direct sound)

– Definition D50

- Spatial impression

– Lateral Energy Fraction LF (describes hthe amount of reflections reaching the listener from the sides, laterally)

- Loudness or strength of sound

– Strength G

- Warmth, brilliance

– Bass Ratio

– Treble Ratio

- Stage support– Support ST1 (correlates with how the performers are able to hear each other on stage)

Connections between parameters

Reverberance	EDT
Fullness of Tone	RT_{60}
Spaciousness	LF (early), IACC (early), BQI
Liveness	EDT, RT_{60}
Envelopment	LF (late), IACC (late)
Intimacy	LF (early), IACC (late), ITG
Clarity	Clarity C_{80}
Loudness	Total sound pressure level (Strength)
Warmth	Strength at low frequencies, Bass Ratio
Brilliance	Strength at high frequencies, Treble Ratio
Timbre	Frequency dependency of parameters
Blend	Details of the impulse response (initial part)
Stage Support	Support ST (early)
Hall Response	Support ST (late)
Ensemble	Clarity and EDT on stage

Design issues

- Volume and basic shape

– What is performed?
✓ Rock / classical?
✓ Full-sized syphony orchestra / chamber music?
✓ Music theatre / opera?
✓ Multi-functionality?

– Seating capacity (audience, performers)

- Also other than room acoustical issues must be considered!
– Sound insulation to surrounding spaces
– Noise control
    - HVAC
    - Theater equipment, lighting etc.

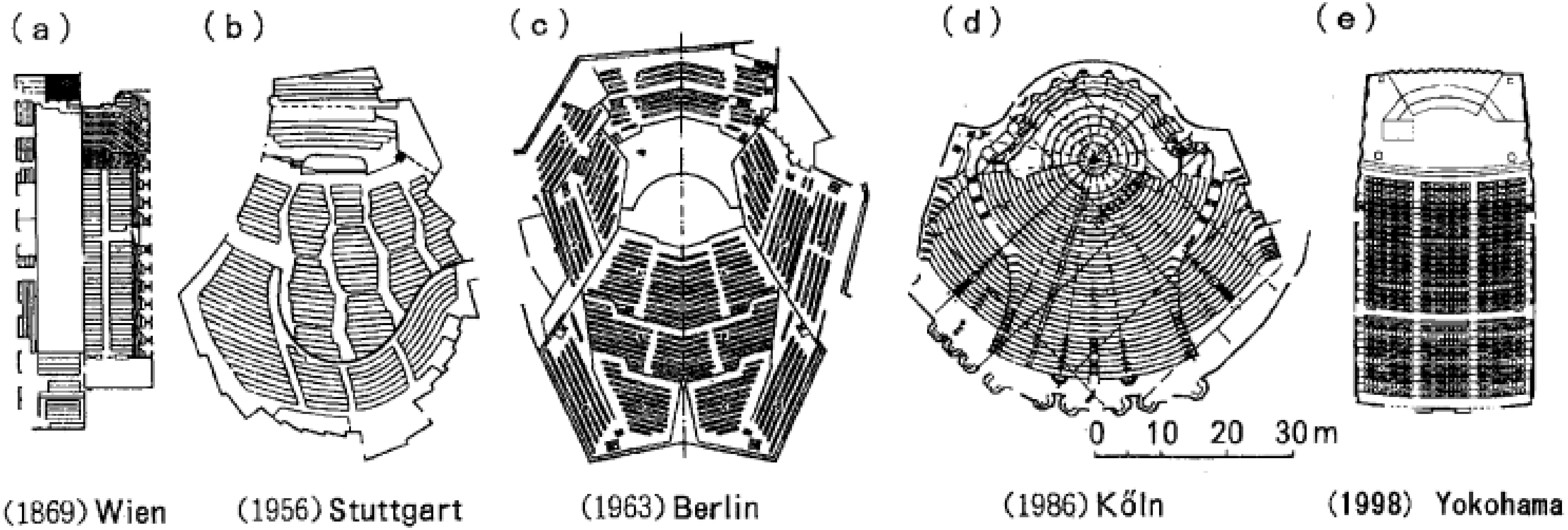


Figure 9.22 Examples of concert-hall plans.

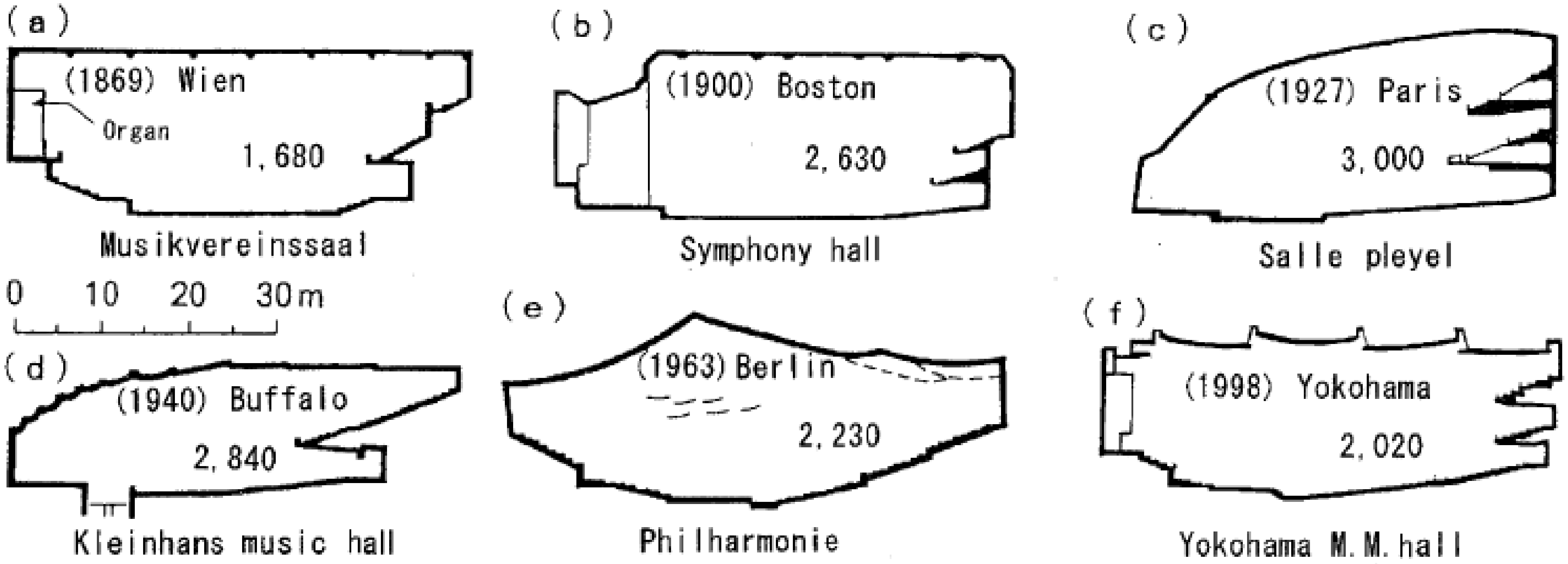


Figure 9.23 History of longitudinal sections of concert halls, showing seating capacity.

Multi-purpose hall

- Public halls, like civic auditoria and most commercial rental halls, are for multi-purpose use, so that the reverberation time has to be adequate for both music and speech, but priority must be given to the requirements of the most frequent performance, although, unfortunately, it is not easy to anticipate the true requirements.

- Once there was an inclination towards shorter reverberation times for the purpose of broadcasting, but nowadays almost everybody in Japan aims at concert hall acoustics.

- This seems to be rather a quirk of fashion, as concerts, especially in the provinces, are rare.

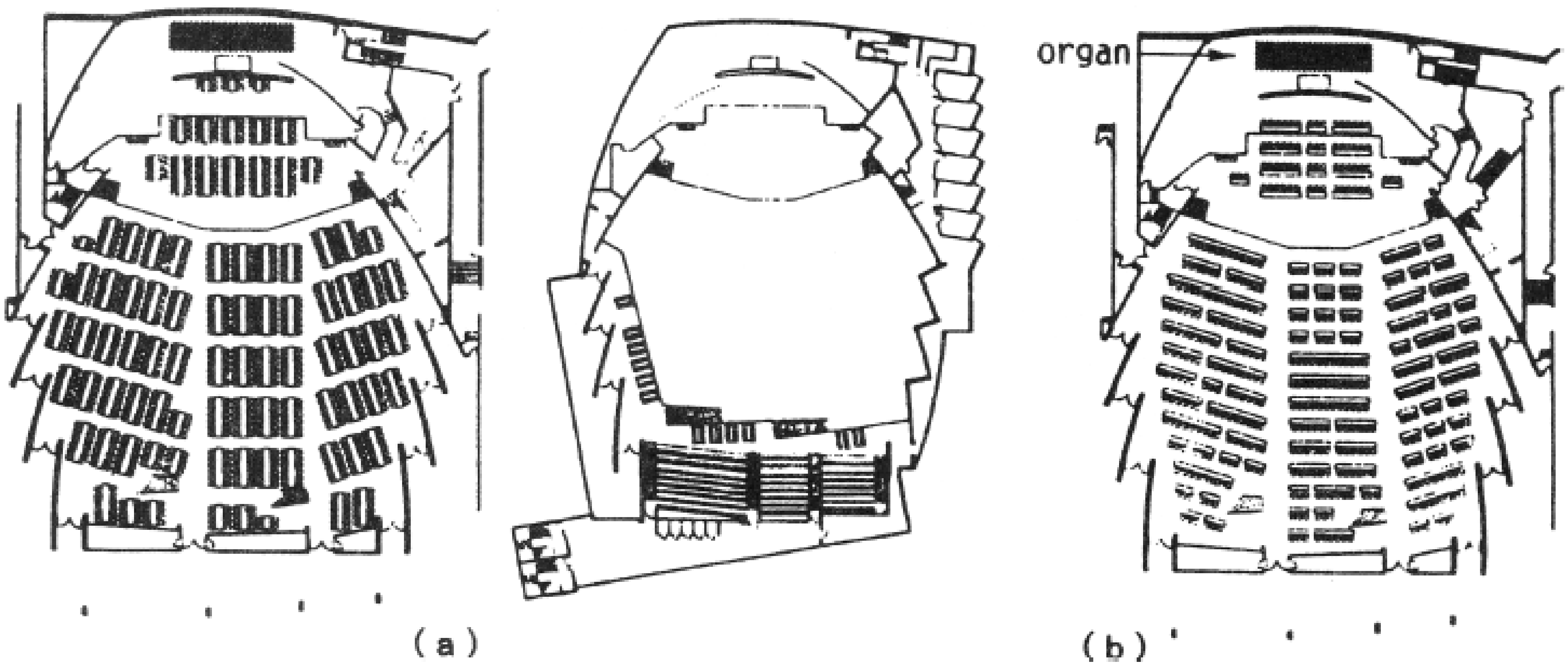


Figure 9.27 Variable seating in Beethovenhalle in Bonn (seating capacity 1407): (a) banquet style with 960 seats; and (b) parliamentary style with 492 seats.

Thank You For Your Attention.

TAKE CARE YOUR SELVES.

References

1. Environmental and Architectural Acoustics, Second edition, Z. Maekawa, J. H. Rindel and P. Lord
2. Architectural Acoustics, Second Edition, Marshall Long.
3. Industrial Noise Control and Acoustics, Randall F. Barron