2003-03-26

Withdrawal of EG 18-1994

Design of Effective Cine Theaters

A document should be Withdrawn only if there is a significant possibility of its use causing harm. A Withdrawn document shall still be made available and offered for sale by the Society, but it shall be prefaced by a cover page explaining its current status including a statement that some or all of the content is no longer endorsed by the Society.

This Engineering Guideline has been withdrawn and its content is no longer endorsed by the Society. This action has been taken because it is judged that there is a significant possibility that use of the document may cause harm.

EG 18-1994 was archived and withdrawn from active status. Though there is a general feeling that the document has value, that value is best served as an archived reference rather than a current document appearing to advocate certain design criteria that may be obsolete in today's world.

SMPTE ENGINEERING GUIDELINE

EG 18-1994
Revision of EG 18-1989

Design of Effective Cine Theaters

1 Introduction

Present-day cinema technology provides the motion-picture theater exhibitor with projection and sound equipment capable of displaying high-quality images with clean, full-frequency sound. Yet, many patrons are denied this fill realization of the film producer's art because the theater designer has failed to provide the proper environment for experiencing the wonderful world of illusion that is the art of cinematography. Good design has often been compromised by practical solutions and the belief that effective cinemas are not economically feasible. Contrary to this belief, many effective cine theaters have been designed for museums, universities, visitor centers, and world's fairs by creative teams of architects, acousticians, and motion-picture engineers at reasonable cost. Similar results could be achieved for the film exhibitor by architects and their consultants based on the parameters and criteria contained in this guideline.

The effective cine theater is a place in which everyone can see and hear well. The summary lists the architectural parameters, which must be addressed by the designers and the criteria recommended here.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this guideline. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this guideline are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below.

ANSI/SMPTE 202M-1991, Motion-Pictures — B-Chain Electroacoustic Response — Dubbing Theaters, Review Rooms, and Indoor Theaters

3 Image size

Although there is validity in discussing image size in terms of visual acuity or camera lens perspective, a criterion in terms of how much of the viewer's field of vision is occupied by the image may be more responsive to the filmmaker's intent and the viewer's subjective impression.

The anthropometric data[1] shown in figure 1 suggests that the screen appears large when it occupies a substantial portion of the viewer's horizontal and vertical field of vision. Experience indicates that the screen image will appear small if the image occupies less than 15° of the viewer's field of vision or approximately 30° of the horizontal field of vision. Geometry for determining the viewer's field of vision is given in figure 2 and an analysis of some selected viewing distances are given in annex A.

4 Viewing angle distortion

It is evident that as the viewer's line of sight to the screen deviates from the perpendicular, circles become ellipses, squares become rhombuses, and all shapes become distorted (figure 3). This subject was treated in detail by Dr. Reubens Meister,[2] who concluded that 45° was the limit of tolerable viewing-angle distortion. He provided a simple geometric construction for outlining the seating area which falls within the prescribed limits (figure 4), which he termed iso-deformation lines.

595 W. Hartsdale Ave., White Plains, NY 10607
(914) 761-1100

Approved March 25, 1994

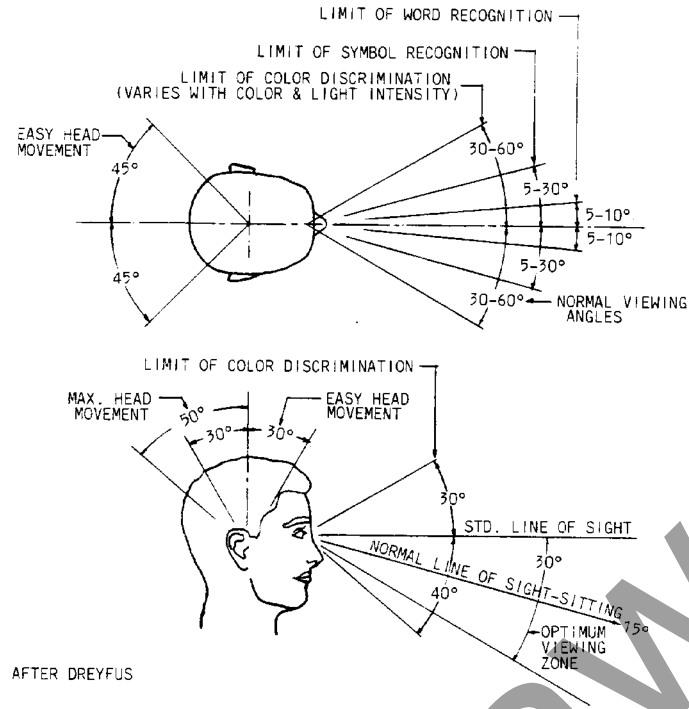
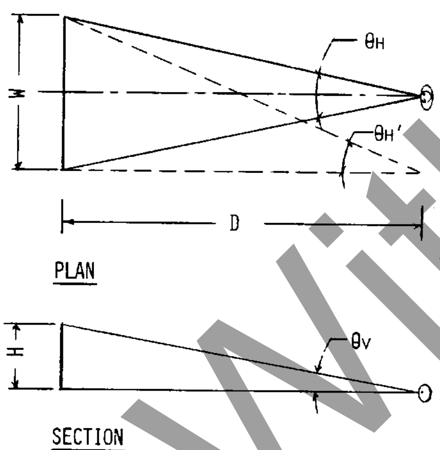
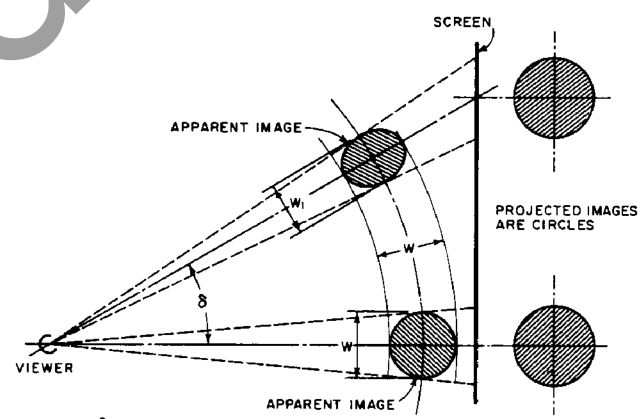


Figure 1 -- Anthropometric data — Field of vision



D	=	Most distant viewer
H	=	Image height (screen height)
W	=	Image width (screen width)
	=	$K \times H$
K	=	Aspect ratio (format
θ_H	=	Horizontal field of vision, degrees
	=	$2 \times \text{ARCTAN}(\frac{1}{2} W \div D)$
θ_V	=	Vertical field of vision, degrees
	=	$\text{ARCTAN}(H \div D)$

Figure 2 -- Geometry for determining viewer's field of vision subtended by the image



δ = VIEWING ANGLE

n = INDEX OF VIEWING ANGLE DISTORTION = $\frac{W}{W_1} = \frac{1}{\cos\delta}$

$0 \geqq n \leqq 1.15$ DESIRABLE

$1.15 \geqq n \leqq 1.41$ ACCEPTABLE

$n > 1.41$ NOT ACCEPTABLE

δ	n
0°	1.00
10°	1.01
20°	1.06
30°	1.15
40°	1.30
45° MAX.	1.41

Figure 3 -- Viewing angle distortion

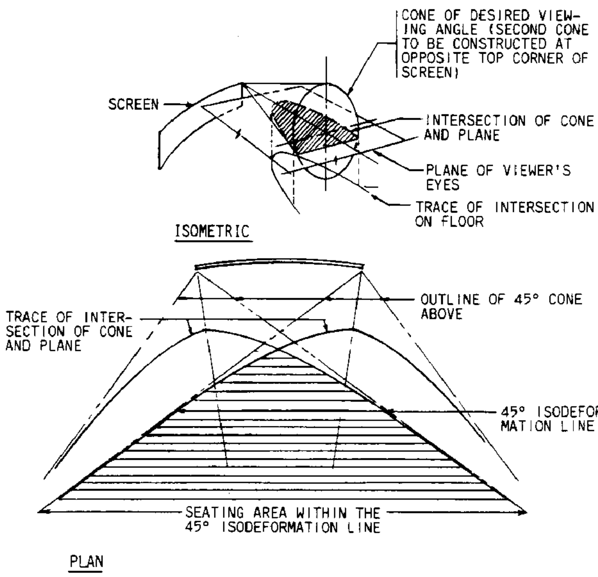
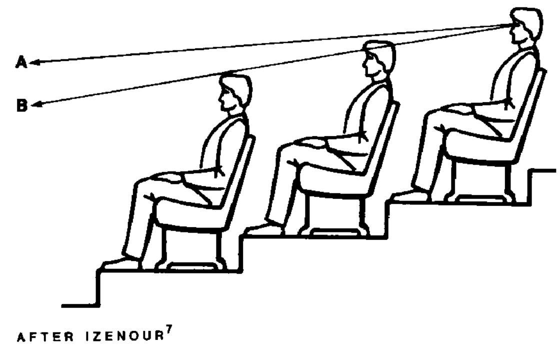


Figure 4 – Construction of the viewing angle iso-deformation line



A: 1-row vision = single-row vision = every-row vision.
Vertical sightline passes over the heads of the persons in the first row ahead.

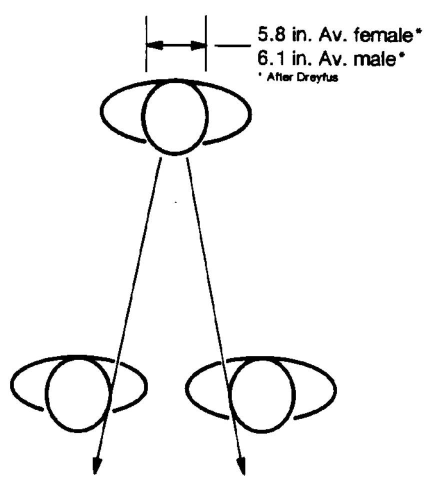
B: 2-row vision = double-row vision = every-other-row vision.
Vertical sightline passes between the heads of the persons in the first row ahead and over the heads of the persons in the second row ahead.

Figure 5 -- Vertical sightlines

5 Visibility

To see well, every viewer should have an unobstructed vertical and horizontal sightline to the image on the screen (figures 5 and 6). If screen images are to fill 30° of the most distant viewer's field of vision and up to 80° of the nearer viewer's, it is evident that looking between the heads of the row immediately ahead, as in 2-row vision, does not permit a view of the entire screen. Thus, 1-row vision is the most desirable for the effective cine theater.

Although the technique for determining the slope of the seating risers, using either drafting or analytical methods, is well known (figure 7), considerable confusion exists with respect to the value given (c), the so-called eye-to-top-of-head dimension. Whereas the actual eye-to-top-of-head distance is fairly constant at 4.3-in average (range = 3.5 in to 4.6 in), the location of a seated person's eye with respect to the top of the head of the person in front differs from the average (figure 8). Thus, if the riser height is to be determined by Yn - K, K = 3 ft 8 in typically, then the value of c must be obtained from c = A -- B (figure 8). It is recommended that c = 9 in to 10 in to be used in the analytical method. Cramer and Booth[3] have shown that when c = 7 in, the probability will be that 80% of the viewers will have satisfactory 1-row vision. It is suggested that c = 7 in as a minimum.



Row Spacing	Seat width 19 in	20 in	21 in
30 in	24.4	26.3	28.1
32 in	23.0	24.7	26.4
34 in	21.6	23.3	24.9
36 in	20.5	22.0	23.5
40 in	18.4	19.9	21.2
42 in	17.5	18.9	20.2

Figure 6 -- Horizontal viewing angles in degrees for 2-row spacing for selected seat widths and row spacings

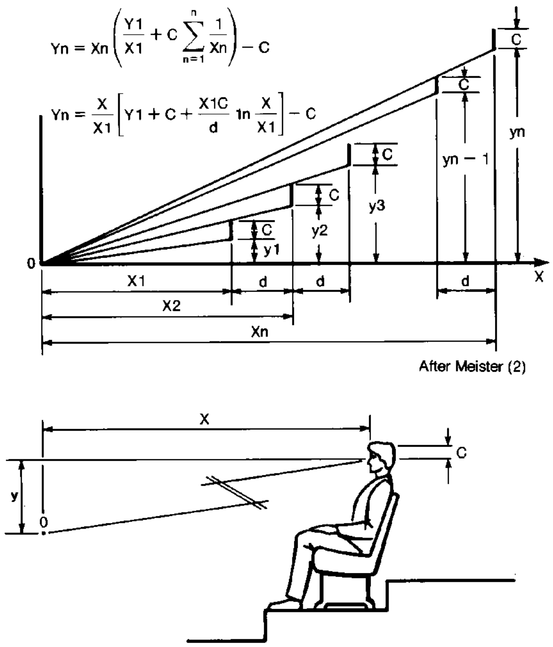
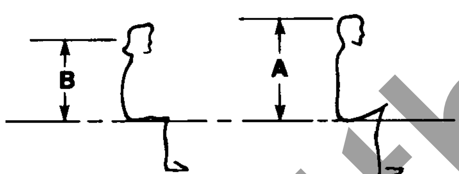


Figure 7 – Analytical method for sighline study



	A* Seat to top of head (Inches)		B* Seat to eye level (Inches)	
	Female	Male	Female	Male
Large	34.9	38.5	30.2	33.9
Average	32.9	36.0	28.8	31.5
Small	29.7	33.4	26.3	29.0

A--B	A = Large male B = Small female	12.2 in without slump 14.2 in with slump
A--B	A = Average male B = Average male	7.2 in without slump 9.2 in with slump
A--B	Per classic texts on theater design	4-5 in (10--12.8 cm)

*After Dreyfus[6] and Jones [8]

Figure 8 -- Anthropometric data for sightline study

Since the floor slope will also be determined by the location of the aiming point (O), and the location of the front row of seats (X1), the placement of the bottom of the screen is important. Experience has shown that 4 ft to 6 ft above the first row of seats is satisfactory, provided a 6-ft standing person does not interrupt the projection beam. If no subtitles are to be used, the aiming point may be placed approximately 10% of the image height above the bottom of the image. This superimposes the heads in front onto the screen, which some viewers find desirable. If subtitles are to be used, the aiming point should be the bottom of the screen image.

The plot of the equation in figure 7 is a parabolic curve whose slope will usually exceed the aisle slopes allowed by local codes. Steps in the aisle should then be used to obtain the required seating levels with appropriate transition segments to join aisles with the seating levels.

Row spacing (d) should not be less than 30 in back-to-back with 36 in to 40 in providing greater comfort. The width of seats should not be less than 19 in with 20 in to 21 in providing greater comfort.

When 1-row vision is not feasible, seats should be offset as determined by a careful sightline study to the screen vertical centerline. The total number of seats in a row will be determined by local codes, nominally 14 or 15, unless wider continental seating is used. If seating layouts are done by the supplier, as is the usual case, the architect should ensure that the work meets these criteria.

6 Comfort

Although it is usually assumed that ventilation, heating, and cooling will provide for human comfort, frequently these conditions are compromised for reasons of economy. Thus, operating costs must be considered during the design phase of the effective cine theater and accepted by the owner as an essential part of the theater's design.

In addition to ensuring that everyone will see well, seating in the effective cine theater must avoid physical discomfort, which occurs when the vertical viewing angle to the top of the screen image is excessive or the lateral viewing angle to the centerline of the screen requires uncomfortable head and/or body position.

Since the normal line of sight is 12° to 15° below the horizontal, seat backs should be tilted to elevate the normal line of sight approximately the same amount. For most viewers, physical discomfort occurs when the vertical viewing angle to the top of the screen exceeds 35°, and when the horizontal line of sight measured between a perpendicular to his seat and the centerline of the screen exceeds 15°. To compensate for excessive lateral viewing angles, the seat rows should be angled or curved as shown in figure 9.

7 Projection angle distortion

When the projector is placed in a position other than normal in relation to the screen, shapes are distorted as shown in figures 10 and 11. Note that the equation shows distortion to be a function of screen size, projection distance, and the projection angle. Experience suggests that 5% is a tolerable maximum limit for projection angle distortion, with 3% preferred.

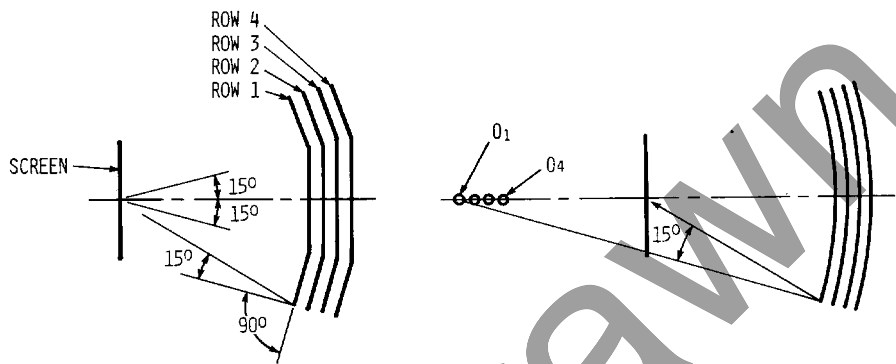


Figure 9 – Construction for seating row angle and seating row radius of curvature

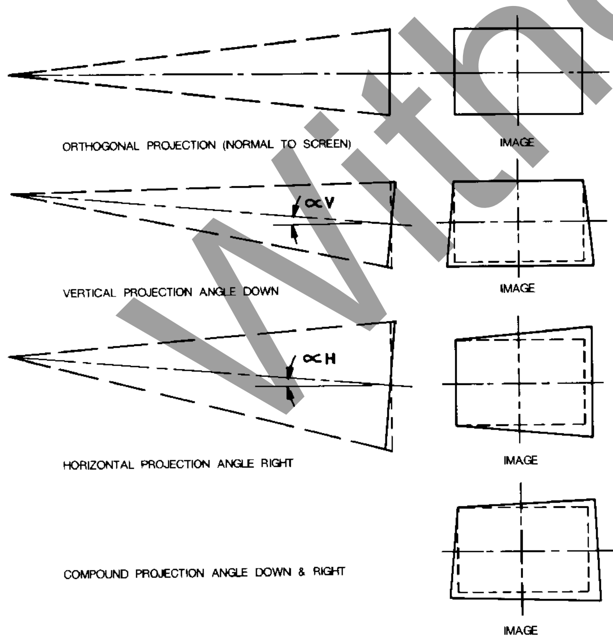
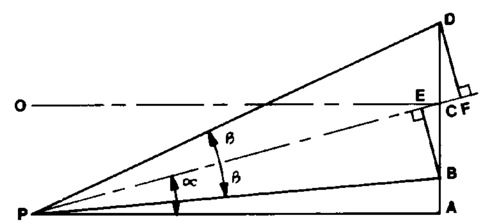


Figure 10 – Projection angle distortion



H = Image height   H′ = Aperture height
W = Image width   W′ = Aperture width
FL = Lens focal length
L = PA = Projection distance
T = PC = Throw distance
CB + CD = H or W   CE + CF = ΔT
α = Projection angle, vertical or horizontal
= ARCTAN (PO ÷ PA)
β = Projection beam half angle, vertical or horizontal
= ARCTAN (½ H′ ÷ FL), or
= ARCTAN (½ W′ ÷ FL)

% distortion = $(\Delta T \div T) \times 100$

For horizontal projection angle:

% distortion = $[(W \times \sin\alpha \times \cos\alpha) \div L] \times 100$
= $[(W \times \sin\alpha) \div T] \times 100$

For vertical projection angle:

% distortion = $[(H \times \sin\alpha \times \cos\alpha) \div L] \times 100$
= $[(H \times \sin\alpha) \div T] \times 100$

Figure 11 – Formulas for determining projection angle distortion

8 Architectural distractions

In 1947, Ben Schlanger, an eminent cinema architect, said, "What we need is a theater in which a person can sit down and look at a picture and not be conscious of the physical shelter in which he is enjoying the picture."[4] That dictum is valid today.

When the picture illuminates the screen, the light from the screen illuminates the walls and ceiling as well as the seating area. Nothing in the room's decor should distract the viewer's attention from the projected image. This does not say that the interior cannot be made to appear attractive and inviting. However, interior finishes should be nonreflective and of low chrominance. Varying the intensity of colors so that the darkest hues are in the vicinity of the screen has proved effective.

The question whether the screen should be masked in black or be free floating is a matter of preference. In theaters using more than one film format, the need for variable masking would lead to the choice of black masking all around. Aisle lights and exit signs required by safety codes can be a serious source of distraction and circulation patterns for patrons entering and leaving may cause undue distractions. These architectural elements must be carefully evaluated in the design of the effective cine theater.

9 Acoustical environment

Technical advances in film sound recording and reproduction make it increasingly apparent that the acoustical environment of the cine theater is critical to the patron's full enjoyment of modern films. Recent research indicates that special consideration must be given to the following:

Freedom from flutter echo, spurious room resonances, and focusing.

Special absorptive treatment of the wall behind the screen loudspeakers and the rear wall of the theater to avoid undesirable reflections and phase cancellations.

Elimination of those elements considered desirable in the live theater, which preferentially support the loudness and "color" the sound of live music.

Background noise: The noise level in the theater due to air conditioning and other mechanical sources must be equal to or less than the Noise Criteria Curve NC30 of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for each octave band. Details of measurement methods and maximum noise levels are given in SMPTE RP 141.

Acoustical isolation: To eliminate objectionable noise from adjacent theaters (in the case of multiples), the projection booth and outside sources, walls, ceilings, floors, and doors must be designed with suitable noise reduction based on industry standard sound transmission class (STC) ratings in the mid-60s and 70s. A table summarizing published information[5] is reproduced in table 1 to guide the acoustician. A local survey of ambient street and overflight noise should also be available.

Table 1 – Recommended noise reduction between adjacent theaters (dB)[5]

31.5 Hz	63 Hz	125 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
38	48	52	66	66	66	66	66

Reverberation: Figure 12 shows preferred reverberation time for the 500-Hz octave band.[5] Ideally, the reverberation time would be equal for all frequencies. Although this is not realizable in most motion-picture theaters, the acoustician should strive to achieve a smooth decay for all frequencies with an absence of bass "overhang."

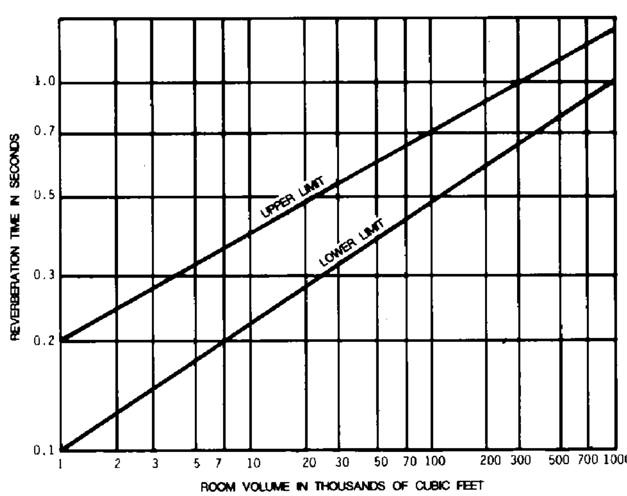


Figure 12 – Recommended reverberation time for motion-picture theaters

Loudspeaker position: For reproduction of multitrack sound records in theaters showing 35-mm 1.85:1 and 2.35:1 formats, it is recommended that when three behind-the-screen speakers are used they be positioned as required for the 2.35:1 format and that acoustically transparent material be used on the trailing edges of the 1.85:1 masking.[5] Alternately, five loudspeakers may be used behind the screen, two of which are positioned for the 2.35 format, and two for the 1.85, with one pair switched off, depending on the format being used.

Equalization: Whether ⅓-octave band equalization will be required in the film sound B chain is a decision to be made by the motion-picture engineer or acoustician. When equalization is required, the house curve characteristic shall be as described by curve X in ANSI/SMPTE 202M, or as specified by the equipment manufacturer.

Summary

A. The effective cine theater is a place where everyone can see and hear well.

1. Image size. How large should the screen image be?

The image on the screen should subtend not less than 15° of the most distant viewer's vertical field of vision and approximately 30° of his horizontal field of vision.

2. Viewing angle distortion. What is the tolerable limit of distortion due to the position of the viewer with respect to the projected image?

All seats should be contained within a 45° iso-deformation line.

3. Visibility (seating risers and sightlines). Does every viewer have an unobstructed horizontal and vertical sightline to the projected image?

Seating slopes and/or seating risers should be designed for 1-row (single-row) vision. If 2-row vision is used, seats should be staggered.

When using the analytical method, the value of c, the so-called eye-to-top-of-head dimension, should be 9 in to 10 in and not less than 7 in; the aiming point should be the bottom of the screen when subtitles are to be used, or 10% of the image height above that point when no subtitles will be used.

Rows should be spaced not less than 30 in back-to-back with 36 in to 40 in preferred unless otherwise required by code (for continental seating).

Seats should not be less than 19 in side-to-side, with 20 in preferred. (For pseudo-staggered seating, use 19, 20, and 21 in.)

4. Comfort. Is the ventilation, heating, and cooling capacity adequate for continuous human comfort? Does the design of seats provide a natural posture for viewing the projected image? Does the vertical viewing angle to the top of the projected image require an uncomfortable head position? Does the lateral viewing angle to the centerline of the screen require an uncomfortable head and/or body position?

HVAC systems should be designed and operated for patrons' comfort whenever the theater is occupied.

Seat backs should be tilted approximately 12° to raise the normal downward line of sight to the horizontal.

The nearest viewer's vertical line of sight should not exceed 35° from the horizontal to the top of the projected image, and preferably should be 15° to the horizontal centerline of the screen image.

For the side seats, the lateral line of sight to the screen centerline, measured from a perpendicular to the seat row, should not exceed 15°.

5. Projection angle distortion. How much is the image distorted due to the position of the projector (projection angle)? What are the tolerable limits of distortion?

Image distortion due to the horizontal or vertical projection angle should not exceed 5%, and 3% maximum is preferred.

6. Architectural distractions. Do any of the theater's interior architectural features distract the viewer's attention from the projected image?

Interior finishes, lighting required for safety, and patron traffic should be designed to minimize distractions for the patrons viewing the screen.

7. Acoustical environment. Do the theater's acoustics ensure that everyone will hear well?

The theater should be free of flutter echo, spurious resonances, focusing, and all elements which will preferentially support loudness or color the sound.

Background noise from all sources should be equal to or less than NC30 in all octave bands.

Acoustical isolation from sound sources in adjacent spaces must be adequate to preserve the noise criteria (NC30) requirements.

Reverberation time at 500 Hz should be optimized for the room volume, with smooth decay at all frequencies and absence of bass "overhang."

Loudspeakers for multichannel sound should optimize the stereo aspects of the sound records.

Equalization, when used, should provide a "house curve" conforming to ANSI/SMPTE 202M.

B. The effective cine theater is a place in which state-of-the-art projection technology is employed.

1. Screen design. Are the screen shape (flat or curve) and material (matte or gain) appropriate for the viewing environment?

2. Screen brightness. Is the picture brightness (screen luminance), contrast ratio, and color balance according to SMPTE standards?

3. Picture steadiness. Do the projectors provide picture steadiness (jump and weave) and freedom from "breathing" and "ghosting" in accordance with SMPTE standards?

4. Picture sharpness. Are lenses and lamphouses of modern design, and have they been properly matched to provide optimum image sharpness (acutance) according to SMPTE standards?

5. Sound system characteristics. Is the "B chain" of the sound system optimized for frequency response, wow and flutter, and distortion according to SMPTE standards?

References

1. Szabo, W. Some comments on the design of large-screen motion-picture theaters. SMPTE Journal 85: 159-163; March 1976.

2. Meister, R. The iso-deformation of images and the criterion for delimitation of the usable areas in cine-auditoriums. Journal of the SMPTE 75: 179-182; March 1966.

3. Cramer, M. and Booth, K. S. The design of audience spaces with predetermined visibility performance. SMPTE Journal 94: 578-584; May 1985.

4. Schlanger, B. Increasing the effectiveness of motion picture presentation. The Motion Picture Theater, pp. 72-78, New York: SMPTE; 1948.

5. Holman, T. Room acoustics of motion picture theaters. National Association of Theatre Owners 1984 Encyclopedia.

6. Dreyfus, H. The measure of man, passim, Whitney Library of Design, New York, 1960.

7. Izenour, G. C. Theater design. New York: McGraw Hill; 1977.

8. Jones, J. C. Seating in the lecture theater... pp. 110-116, Modern Lecture Theaters. London: Oriel Press Ltd., 1966.

9. Komar, V. G. Techniques of large-capacity motion-picture theaters. Journal of the SMPTE 75: 167-172; March 1966.

10. Planning a cinema, Philips Electro-Acoustics Div., Eindhoven, The Netherlands; 1964.

11. Vivié, J. From the cinema to the cinema theater. Journal of the SMPTE 75: 175-179; March 1966.

12. Soulé, C. Technical quality control of motion-picture theaters. SMPTE Journal 90: 255-261; April 1981.

13. Guide and data book — Applications. American Society of Heating, Refrigerating and Air Conditioning Engineers. Atlanta; 1982.

14. Holman, T. THX sound systems manual. Lucasfilm Ltd. San Rafael, CA; 1988.

15. Winchell, W. H. and Gourgon, M. Design considerations for television film review rooms. SMPTE Journal 91: 365-371; April 1982.

Annex A (informative)
Representative fields of vision

Some representative fields of vision for selected viewing distances normalized for 2.35, 1.85, and 1.37 aspect ratios are given in table A.1.

Table A.1 – Some representative fields of vision for selected viewing distances normalized for 2.35, 1.85, and 1.37 aspect ratios

Format	θ_H	θ_V	D		Remarks
2.35	37.6	16.1	3.45H	1.46W	Szabo, 1984
1.85	30.0	16.1	3.45H	1.86W	
1.37	22.5	16.1	3.45H	2.50W	
2.35	35.9	15.0	3.73H	1.59W	NIFKI, 1961[9]
1.85	27.8	15.0	3.73H	2.01W	
1.37	20.8	15.0	3.73H	2.72W	
2.35	28.0	12.0	4.70H	2.00W	Meister[2] and
1.85	22.3	12.0	4.70H	3.43W	Philips[10]
1.37	16.5	12.0	4.70H	3.43W	
2.35	26.4	11.3	5.00H	2.12W	Vivié, 1965[11]
1.85	21.0	11.3	5.00H	2.70W	
1.37	15.6	11.3	5.00H	3.65W	
2.35	19.5	8.35	6.81H	2.90W	Soulé, 1980[12]
1.85	15.5	8.35	6.81H	3.70W	
1.37	11.5	8.35	6.81H	5.00W	

Annex B (informative)
Bibliography

SMPTE RP 141-1990, Background Acoustic Noise Levels in Theaters and Review Rooms