Information

Screen Size
The Impact on Picture & Sound

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Over the years, the film industry has seen cyclical changes in the range of screen sizes, some dictated by film format, and some by exhibition economics. The small screens of the 1930s were eclipsed by the large-format screens of the 1950s; today, the “pillbox” screens of the 1970s are being supplanted by relatively huge screens for 35 mm film projection. The impact of large screens for audience involvement is obviously beneficial, but there can be significant technical trade-offs. Perhaps surprisingly, not only picture but also sound quality can be affected by screen size; the following material discusses the impact of screen size on various presentation parameters including acoustics and image contrast.

What Does “Screen Size” Mean?

Theatre designers frequently refer to screen size by linear width—for example: “the Bijou 9 has a 50-foot screen.” But this definition has no meaning without reference to theatre size. A 4,000-seat auditorium with a 50-foot screen would provide a picture to someone in the back row little better than a 19-inch TV in a large living room—but the same screen in a 50-seat screening room would seem as large as the Grand Canyon when viewed by a flea!

The best measure of screen size as perceived by the audience is that of subtended angle. Folk legend has it that the first person walking into an empty theatre will choose a seat two-thirds of the way back from the screen, possibly half of the way back in the seated area, depending on the clear space between the screen and the front row of seats. The best measure of *perceived* screen size is that of *subtended angle*. The audience is conscious of screen size not by absolute dimension, but by angular percentage of vision. “Rational man” sitting in the prime seat two-thirds of the way back will see a screen which subtends a horizontal width of 35, 40, 45, 50, or 55 degrees (Figure 1).

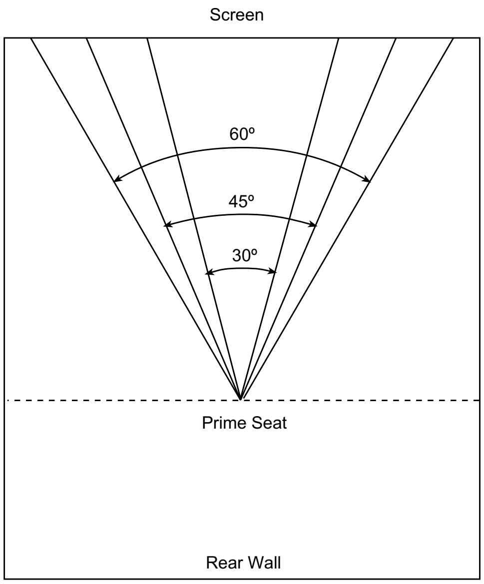

Figure 1: Subtended screen angles

From a projector's point of view, the most obvious significance of increased screen size is the need for more projection illumination, if the standard 16 foot-lambert illumination is to be maintained; the implications of this will be discussed further.

First-Order Effects

There are obvious relationships between subtended screen angle and the filmgoer's experience. As the screen angle gets larger, the story impact gets greater (Figure 2)—the audience feels less like TV watchers, and more like participants in the action on the screen. The eye's theoretical field-of-view is 110 degrees—a movie screen subtending such an angle is hard to ignore! All the connections between eye and brain are derived from the film, and the observer is potentially completely involved in the film.

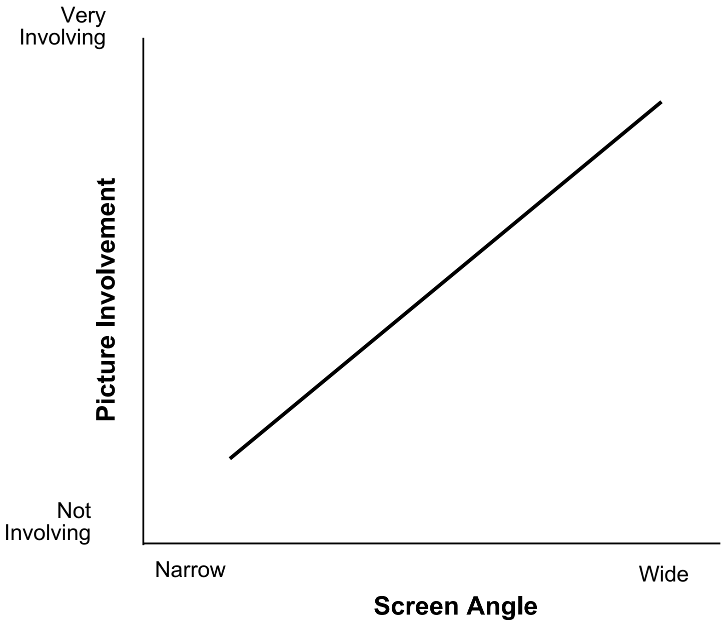

Figure 2: Subtended screen angle and picture involvement

But as the perceived picture size increases, so do the picture flaws become more apparent, whether we are looking at film or TV (Figure 3). As a TV image is blown up, the flaws become glaringly apparent—the line structure, lack of definition, convergence problems, etc. A TV image (even from HDTV) is far inferior to 35 mm film, but even film has technical flaws when the picture is examined closely, or indeed, blown up too large.

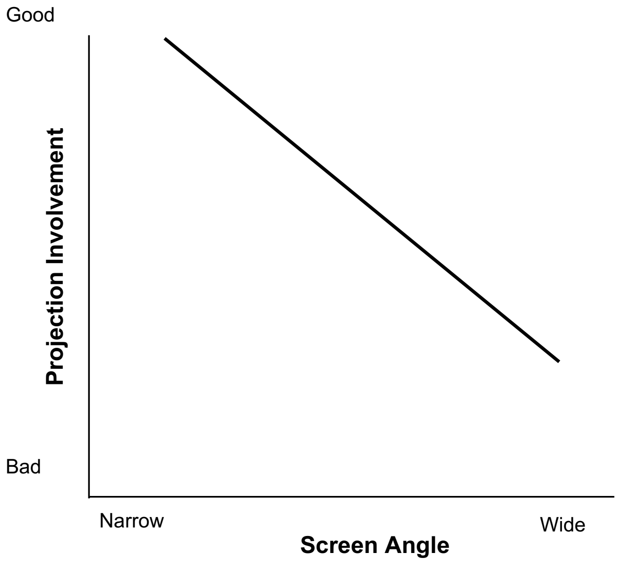

Figure 3: Screen angles and picture flaws

There are three most obvious problems visible when a film image is examined closely, or blown up large, as on an excessively big screen. The first is the grain, which can be paralleled with the line structure of a TV image. Even though camera negative stock, interpositive and internegative stocks, and release print stocks have been improved over the years, granularity is still visible, and the greater the enlargement (or subtended picture angle), the more visible the grain will become.

Next, the film in a projector gate is never held perfectly steady. Jump (vertical irregularities) and weave (horizontal irregularities) seem unavoidable in conventional 35 mm projection, and the greater the subtended screen angle, the more obvious the unsteadiness. Furthermore with a steady projector, image unsteadiness can be caused in the laboratory printer or during the generational process—sometimes clearly visible, with titles superimposed over static images. Again, the greater the enlargement, the more apparent the unsteadiness.

The third result of increased subtended screen size is the difficulty of maintaining focus. The problem at first seems not to be so much that of maintaining focus, but more that the increased subtended screen size makes soft focus more obvious.

So, as the perceived screen size increases, first-order effects lead to several apparent picture flaws. Too large a picture leads to excessive grain visibility, picture jump and weave visibility, and soft focus.

Now, consider the effect of an increased screen size on the demand for illumination. If the same illumination at the screen is to be maintained, increasing screen size (and consequently illuminated area) will demand increasing lamp power. As this lamp power is increased, the heat at the film plane will also increase. Two problems result: first, the film will flex in the film gate, making accurate focus more difficult to achieve, and second, the heat may cause permanent deformation of the film, resulting in the impossibility of ever achieving precise focus over the entire film field.

An ideal screen size?

The varying compromise between screen size (subtended angle) and picture quality has been ongoing for as long as there have been movies. Back in 1953, Twentieth Century Fox introduced Cinemascope[1]. The wider aspect ratio (originally 2.55:1, then 2.35:1, and now standardized as 2.39:1) obviously provided a significantly greater picture involvement than a 1.33:1 image at the same height. But Fox evaluated the ideal subtended screen angle as 45 degrees[2], as this proved to be the point where the subjective curve of image involvement crossed the curve of visual technical flaws (Figure 4).

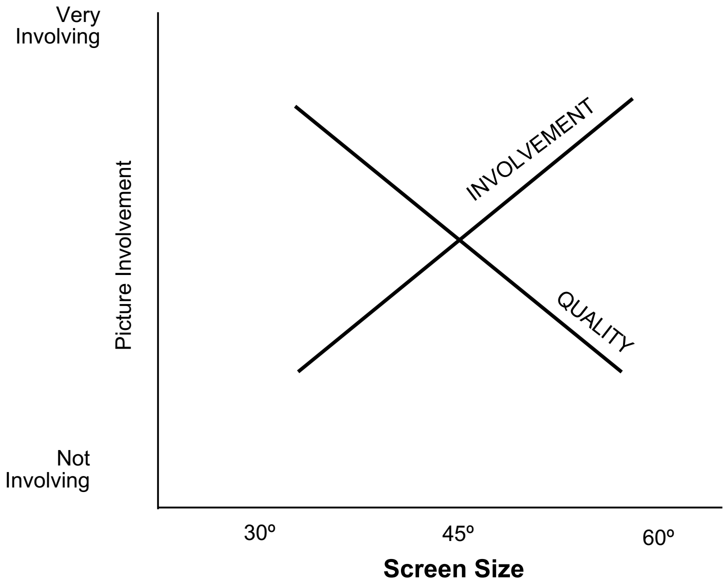

Figure 4: Optimum "screen size"–1953 Cinemascope

Quality Improvements

There is no doubt that some issues relating to film performance have improved since 1953. Release print stock, in particular, now has much finer grain than 40 years ago. On the other hand, jump and weave in many modern projectors are probably no better than they used to be—and the lack of permanent projectionists assigned to each screen means that focus is less accurately maintained than used to be the case. It probably would be optimistic to think that the optimum screen angle for Cinemascope has progressed much above 45 degrees. Perhaps the same evaluation carried out today would lead to a number no greater than 50 degrees.

1.85 v Scope

The 1.85:1 aspect ratio is extremely inefficient, in that approximately 35 percent of the film frame area is thrown away (Figure 5). Eighty percent of US movies are shot with this aspect ratio. (This ratio was not chosen for image quality, but for image shape—a cheaper alternative than Cinemascope, providing a "wide-angle" image, but using spherical, non-anamorphic lenses.)

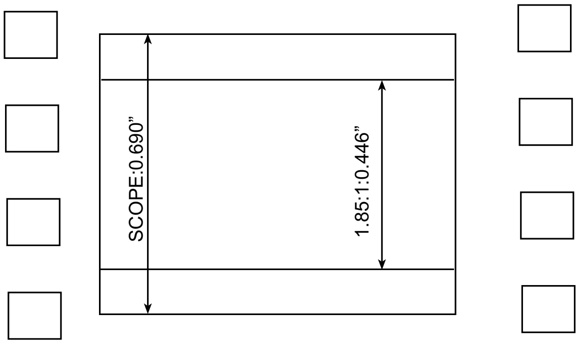

Figure 5: Film image heights

Now, to maintain a constant image quality with 1.85:1 and 2.39:1, the two most common aspect ratios (at least in the US), the screen sizes should take account of the actual film image size. As the “scope” film frame uses most of the available space, and the 1.85:1 frame uses only 65 percent of the frame, the scope screen should exhibit 35 percent more area to show the same image quality.

Some simple mathematics shows that equal image quality with 1.85:1 and 2.39:1 can only be achieved with a screen height actually slightly higher with scope than 1.85:1. In fact, a result close to optimum is achieved when the scope image is arrived at by expanding the left and right horizontal masking (Figure 6). Certainly the practice of common width (i.e., a 1.85:1 image 35 percent higher than scope) is the wrong way around, and provides a great disservice to the projected image.

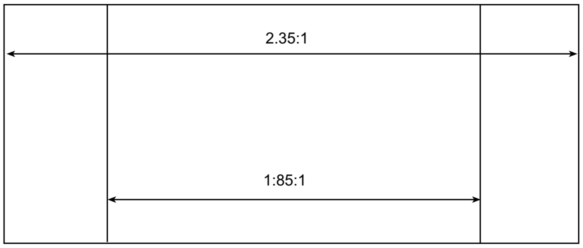

Figure 6: Common height, scope and 1.85:1

Limiting Contrast – a New Concept

The maximum contrast that can be achieved with a motion picture presentation depends on several factors—lens flare, port-glass design, ambient light, etc. A less obvious effect that reduces contrast is that of reflected light coming back onto the screen after hitting side walls, ceiling, or back walls. The film itself has a potential contrast of at least 300:1, the range from bright to dark. But, for a worst case, consider a screen that is illuminated with a picture that is 90 percent white, with just a small black patch. All the white light bounces off the walls, and depending on the surface reflectivity, a certain percentage will bounce back to the screen. The small black patch will now turn dark gray, and the potential contrast is now much reduced—a reduction to 50:1 is not uncommon. This much worse number we shall call "limiting contrast."

What may seem surprising is that limiting contrast is not only affected by the surface reflectivity of the walls and ceiling, but is also significantly affected by screen size. The greater the screen size, with a constant illumination level, the smaller the limiting contrast. A simple model can be visualized by considering a sphere, and internal visual conditions varied according to light source areas and reflective materials.

First, consider a sphere which has a uniform internal surface with a reflectivity of (for the sake of this example) 0.25 or, in subjective terms, dark gray. At some point in the sphere, a hole is made to allow light in; alongside this minimal-sized hole, there is a test patch of the same dark gray, of a size comparable to the light source, certainly a trivial percentage of the total internal surface of the sphere. A light source outside the sphere is switched on, visible through the small hole. A viewer at the center of the sphere uses a light meter with a narrow acceptance angle to read the light level at the test patch. With the minimal amount of light passing through the small hole being reflected from the gray internal surface back at the test patch, the measured luminance is very low.

Now consider the case where the small hole to allow light in is expanded, until half the internal surface of the sphere is open. In the middle, the same small test patch remains unchanged. This time, the reflected light from the 25 percent gray surface has a major impact on the luminance measured of the small gray test patch. In essence, a secondary light source has been created by reflection from the increased total light being reflected from the sphere's internal surface.

In practical terms, this spherical model translates to a real theatre as follows:

a) As the reflectivity of surfaces facing the screen increases (the material becomes lighter), the more the screen limiting contrast will be reduced.

b) As the screen size increases (as a percentage of the total theatre surface area), and with the same constant spot luminance (for example, the standard 16 foot-lamberts), the more the screen limiting contrast will be reduced.

In effect, only matte black walls and ceilings will allow the full contrast ratio of the film to be revealed. If the walls and ceilings are not matte black (a more typical case!), then the larger the screen, the more the limiting contrast is reduced.

Practical Tests

To determine the relationship between limiting contrast and screen size for a given set of wall and ceiling surfaces, a test was set up with a 70 mm-sized screen, and then an Academy 1.33:1-sized screen of approximately common height. Actual screen sizes are 23.3 by 10.6 feet, and 13.5 by 9.5 feet. Illumination was measured at screen left, center, and right, and was matched as close as possible between the large and small screens. A matte black square was then inserted about six feet from the screen, which created a shadow approximately two square feet at sequentiallyscreen left, center, and right. The screen illumination and illumination in the shadow area are shown in Table 1.

Table 1: Effect on Limiting Contrast of Changed Screen Size

		70mm	
	Left	Centre	Right
Screen illumination (ft lamberts):	12.3	13.7	13.5
Shadow illumination (ft lamberts):	0.22	0.27	0.25
Ratio:	55.9	50.74	54.0

Average Ratio (limiting contrast): 53.54

	“Academy” 1.33:1		
	Left	Centre	Right
Screen illumination (ft lamberts):	11.2	13.3	11.0
Shadow illumination (ft lamberts):	0.11	0.14	0.10
Ratio:	101.8	95.0	110.0

Average Ratio (limiting contrast): 102.26

Ratio of limiting contrasts 102.26 : 53.54 = 1.92

70mm screen area: 23.3 feet x 10.58 feet = 246.9 sq feet
1.33:1 screen area: 13.5 feet x 9.5 feet = 128.25 sq feet

Ratio of screen sizes 70 mm : 1.33:1 = 246.9/128.25 = 1.91

This example showed a correlation far more precise than the author anticipated, and it is doubtful that such a precise proportionality would be found in every case! Nevertheless, the relationship clearly shows that as the screen gets bigger, the limiting contrast goes down.

Not shown in the table is a further test with only a small illuminated area, approximately two square feet—here the limiting contrast was in excess of 800:1, presumably greater than the film's own contrast capability.

A simple procedure is described in the addendum at the end of this article, which gives an approximate method of calculating anticipated limiting contrast, taking into account room and screen dimensions and material reflectivity.

Acoustic Issues

It may seem surprising that screen size also has a significant effect on auditorium acoustics.

One of the major challenges for the design of any performance room is to avoid pronounced room resonances. These are particular frequencies which "ring." The effect can best be imagined by a scale played on the low-frequency notes of a church organ—in a badly designed space, certain notes will sound much louder than others.

The best way to avoid these effects is to avoid repetition of a single dimension, or a multiple of a single dimension. For example, a sphere is a very bad shape, having a single dimension repeating. A cube is a bad shape, with the same length, breadth, and height dimension. A square room with a height half of the length would also be bad, as again, a certain note would be emphasized.

Now, acousticians analyzing the best-sounding concert halls find that there are some standard ratios that minimize the number of standing waves or resonances. The best ratio of length to breadth is about 1.55 to 1, and a height-to-width ratio of about 0.67, as shown in Figure 7. It is interesting that both these numbers (1.55 and 1/0.67) are close to (1.55)/2, 1.62, which is known as the Golden Ratio[3]. The Golden Ratio has been a fundamental principle of architecture and design for thousands of years.

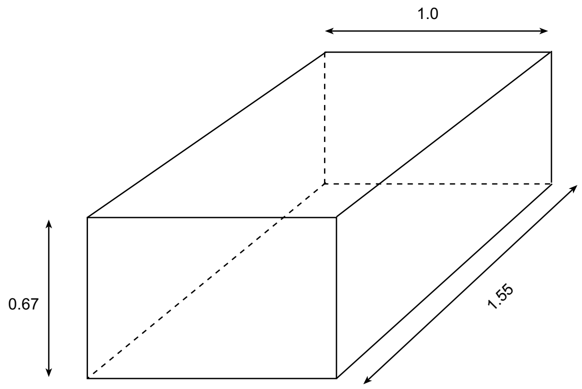

Figure 7: An acoustically optimum shape

As a room shape deviates further and further from these ratios, certain room resonances will begin to dominate. Let us now go back to the hypothetical picture ideal of a 45-degree subtended screen angle two-thirds of the way back in the auditorium. Suppose that the screen is 85 percent of the width of the auditorium (allowing some room for black masking). Figure 8 shows that the length of the room will now be 1.54 times the width, or almost exactly the acoustic ideal of 1.55:1.

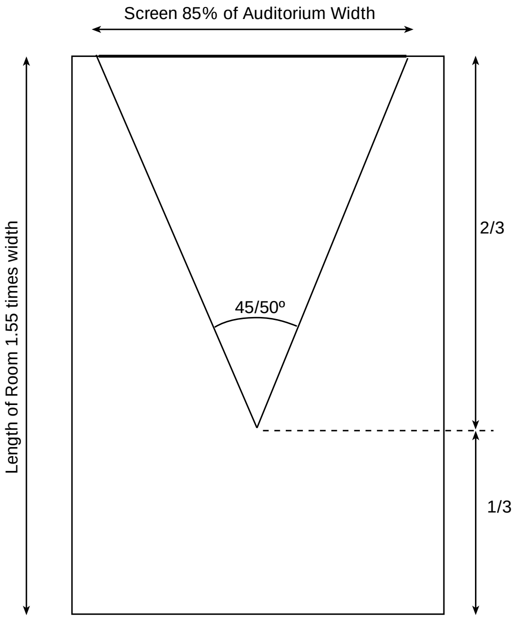

Figure 8: Ideal room geometry

To translate this into lens focal length, look at Figure 9. A subtended screen angle of 45 degrees requires a lens with a focal length of around 38 mm. Five years ago, a typical theatre lens had a focal length of around 45 mm, suggesting a screen angle of 38 degrees. Today, the average theatre lens has a focal length of around 35 mm, suggesting a screen angle of around 50 degrees. Some new theatres are now being planned with lenses as short as 28, 26, or even 24 mm[4].

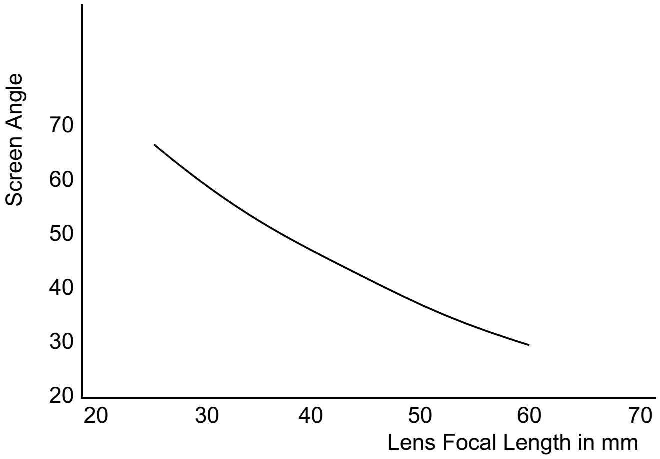

Figure 9: Lens focal length and subtended screen angle

Now look at Figure 10, which shows the likely room ratio (length to breadth) plotted against lens focal length. Maintaining the assumption of the screen being 85 percent of the auditorium width, it can be seen that short focal length lenses in the area of 26 mm are likely to mean a room ratio close to 1:1, i.e., close to square, with all the attendant likelihood of bad sound.

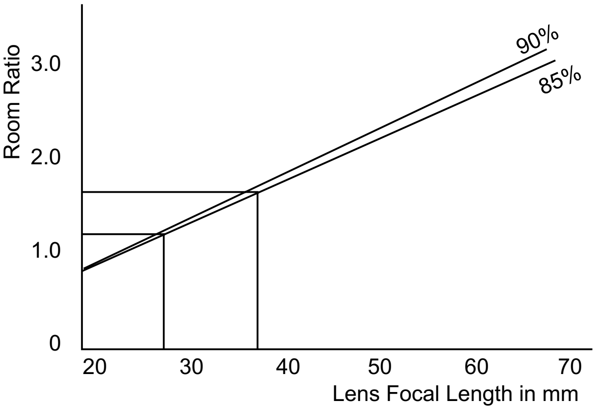

Figure 10: Lens focal length and room ratio

Cinematography

There is another issue that should be addressed briefly—the intention of the cinematographer. It seems apparent that a cinematographer will frame a shot differently, depending on whether it is intended for theatrical projection or only television. The television version will have more close-ups, and less background detail, which would not resolve on the small screen. In the same way, a cinematographer presumably imagines a certain theatrical projection angle when shooting a movie for cinema. Much larger projection angles than he is framing for will result in overly large close-up images, which in an extreme case can be contrary to the intent of the storytelling process.

Conclusion

The trend to larger and larger screens may at first sight seem attractive in terms of audience appeal. But as the screen size becomes excessively large, there is a significant impact in terms of presentation quality, both picture and sound. While subtle variations in room shapes may be possible to avoid some acoustic problems, and matte black walls may help the contrast, it seems probable that any theatre design requiring a prime lens focal length of 30 mm or less has a less than optimum presentation quality.

[1] Twentieth Century Fox articles on Cinemascope, *SMPTE Journal,* January 1954.

[2] Author’s conversation with Alex Alden, supervisor of Cinemascope installations for Twentieth Century Fox, and later engineering director for SMPTE.

[3] M.R. Schroeder, *Number Theory in Science and Communication,* Springer Verlag 1990.

[4] The author is indebted to Mr. Dwight Lindsey of Schneider Lenses for this information.

ADDENDUM

Calculation of Anticipated Limiting Contrast

The technique described here is very approximate; a more sophisticated version would take account of varying screen gain, curved or flat screens, etc. In addition, the technique assumes matte materials, with no specular reflections. Nevertheless, it can be a useful tool to show the effect of differing wall material surfaces, variations in screen sizes, etc.

Figure 11 shows an isometric of the view as seen from the screen. The ordinates are degrees. Calculate the percentage areas represented by each material, such that the total is 1.0. For example:

Ceiling	0.4
Seats	0.2
Rear wall	0.2
Carpets	0.1
Side Walls	0.1
	1.0

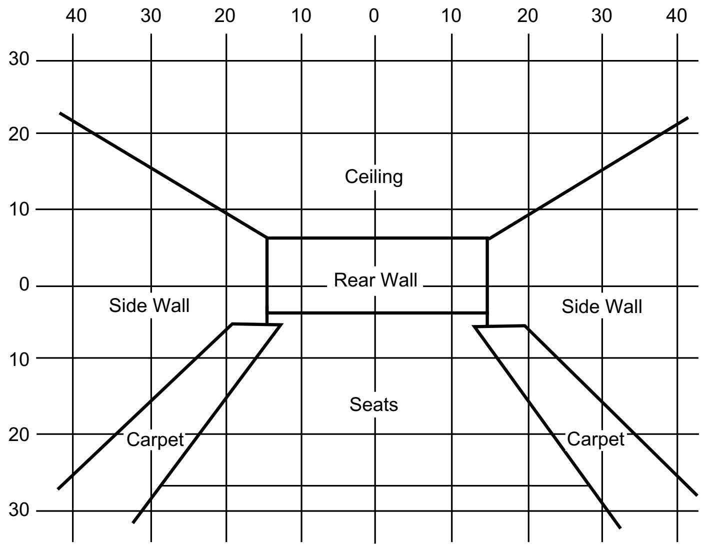

Figure 11: Isometric to calculate material/surface percentages

Measure the reflectivity of each sample material as shown in Figure 12. A 35 mm slide projector with a clear slide in the gate provides a convenient light source. Project the light onto a sheet of matte white card about six to eight feet away. Use a spot light meter to measure the light on the white card. Cover the card with a sample of each material to be tested, and measure the light value. The sample light reading divided by the reference light reading provides an approximate number for the reflectivity.

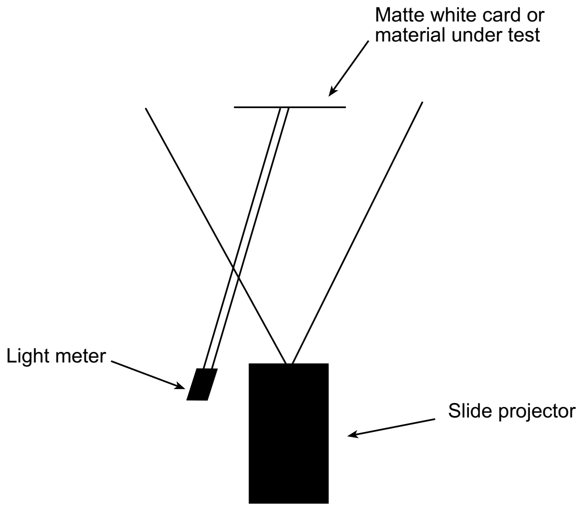

Figure 12: Measuring material reflectivity

Create a simple spread sheet which first of all finds the sum of the products of surface area and reflectivity, i.e.:

	Area	Reflectivity	Product
Material A	0.4	0.1	0.04
Material B	0.2	0.2	0.04
Material C	0.2	0.1	0.02
Material D	0.1	0.3	0.03
Material E	0.1	0.1	0.01
Product Sum:			0.14

Next calculate the proportion of total cinema surface area represented by the screen, i.e.:

Screen Area: 300 sq. feet
Total Surface Area: 5000 sq. feet

Ratio Screen to Total Surface Area: 0.06

Finally total reflectivity is (0.14 x 0.06 x 100) = 0.84%
And the limiting contrast = 100/0.84 = 119