The following document is the original best practice document from which the PISCR (and ISCR) Standards were developed.

It goes into substantially more detail into the entire subject of projected image quality, although the contrast ratios here have been superseded by PISCR and ISCR, which you can download from https://www.avixa.org/standards/image-system-contrast-ratio.

Any mistakes are entirely mine! However I trust you find it useful. Please use as you wish, but please credit it if you do.

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13 December 2019

SPECIFYING AND ASSESSING PROJECTED IMAGE QUALITY

Best practice paper – June 2005 (rev. October 2006)

Dear colleague

In the following pages you will find the latest version of our best practice paper. This comes from a larger project to create a full quality standard, a committee for which was founded at the beginning of 2004. The founding committee members, present at the inaugural meeting at dnp's factory in Karlslunde, Denmark were:

Jason Brameld, Mark Johnson Consultants, UK
Jacob Christensen, dnp denmark A/S, Denmark
John Eden-Green, Arup Communications, UK
Terry Friesenborg, International Communications Industries Association (ICIA) – [now renamed as InfoComm], USA
Greg Jeffreys, Paradigm Audio Visual Ltd, UK
Søren Weis Lindegaard [now Jacob Christensen], dnp denmark A/S, Denmark
Marcus Schoenrich, Mediascreen, Germany
Hans Struwe, STRUWE, Denmark

The inaugural meeting took place over two days in January 2004, where we had detailed discussions, took detailed measurements, and generally exploited the opportunity to try as many ideas and configurations as we could using the superb facilities and instruments available at dnp. This meeting was very successful and our project was truly underway.

At a review meeting at InfoComm 2004 in Atlanta, we had to recognize that acceptance and publication of a quality standard can take years – but the need for the project was immediate. Therefore we agreed the next step would be to produce some kind of 'white paper', which is what you see here. Having agreed to write this for the committee, when I sat down to start I realized the project was more extensive that first foreseen. We had indeed achieved a high level of unanimity and agreement in our committee work. But if this draft did not provide sufficient background and workings, it could prove insufficiently convincing for the professional specifier.

The balance between scientific rigour and day-to-practicality is a tough call. But this has been our guiding principle here. A full reading of the text should provide a reasonable explanation for the decisions taken.

Now this lengthy version is in the public domain – waiting for comments and suggestions from you fellow professionals – the next step will be to produce a concise version, omitting so much supporting detail and relying more on the spreadsheets. These spreadsheets, being concurrently released with this document, also need peer review.

To paraphrase the Irish writer George Bernard Shaw: the English and Americans are divided by a common language. The world is hopefully small enough now to cope with color/colour etc, but we do tend to use different units of measurement from one side of the world to another (specifically foot-candles/lumens and foot-Lamberts/nit [cd/m^2]). However since InfoComm's has decided to use SI units, you will therefore see lumens and nit [cd/m^2] here.

But finally I would like to thank my colleagues. Apart from the work of the committee – some members travelling across oceans to take part – I have to declare some specific debts. To my colleagues Søren Weis Lindegaard and Jacob Christensen of dnp, whose patient professionalism and scientific rigour have provided a backbone for our enterprise: thank you very much

To Professor Geoff Levermore of UMIST, who invited me to contribute to UMIST's Sustainable Electrical Building Services Engineering MSc, special thanks are due. His wry and strategic questioning of me was arguably the true progenitor of this work!

But the real engine for getting this actually finished and into circulation is InfoComm, of course. In recent years we Europeans have really begun to understand the 'International' part of the remit. Terry Friesenborg was not only an active committee member, but provided continuous and invaluable support from the first day. Scott Wills has provided great support too (and has been kind enough to continue to help with positive comments and editing input). My sincere thanks to you all.

We hope you find this paper of interest and benefit. However, what we're really hoping for is feedback. In the first instance please direct this to me via greg@rearpro.com.

Please contact me at greg@rearpro.com to receive the associated spreadsheets and updated drafts.

Greg Jeffreys

Bromham,UK, 17 June 2007

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Introduction

When we point a projector at a screen – or even a wall – we create a projected display. Other parts of the installation might include plasma or LCD panels. But the deliverable is the same: an image quality suitable for the location and application. The problem for the installer lies in this aspect of combination: combining projector and screen – plus ensuring it is suited to its location and application, which might vary from store window to meeting rooms, from exhibition hall to control room displays. And let's not forget the 'killer variable': the impact of ambient light.

Although the projected 'big picture' comprises the focal point of in many installations, until recently relatively little science was ever used in its specification or assessment. This contrasts with the quite elevated appliance of science often used for specifying and assessing audio, control systems, matrix switchers etc. On the basis that consultants and specifiers would prefer to use similar disciplines and processes for the projected image – and be seen to have done so by the client – this project was founded.

Our objective here, therefore, is to produce a guide to best practice in the specification and assessment of projected images. Let us start with a brief background.

Background

A review of available guidelines and quality standards revealed that there were good science and methodologies available both for specifying the projected image and for assessing it after installation. Also, it is perfectly possible to compare all projection screens – front and rear – on a true like for like basis. But the obstacles that had prevented universal adoption and use by specifiers included:

- Existing quality standards only addressed components in the system (e.g. the projector or certain screen types).
- Although it's very easy to calculate image luminance, contrast etc, a lot of data provided by manufacturers is too inaccurate for use in calculation. For example, knowing the projector lumens, the screen area and the screen gain allows us to calculate the image luminance using a simple formula in an Excel spreadsheet. But unless we can be confident the input data is accurate, the output data is not useable.
- Some commercial data, such as projector contrast ratios, have little correlation to actual achievable onscreen contrast ratios. This is of sufficient magnitude to require a wholesale 'reality check' or recalibration of our expectations. If we are going to be more scientific, we need to set realistic expectation levels in terms of what calculations or meter readings might reveal.
- As good as the science and methodology are within existing quality standards, they are laboratory-based and require the use of expensive specialist measurement tools.

How can we balance the requirement for straightforward guidelines and calculators with sufficient scientific rigour? Reading the above checklist of negatives might imply that it was an impossible task. But one point of science has been central to the project, and has provided the key. Our general perception of light is logarithmic: normally we only perceive a change in light levels when they either double or halve. Therefore, for example, using a cheap illuminance meter with a cost of around $100 and a tolerance of +/- 5%, would remain acceptable, even though the laboratory equivalent might cost over $1000 yet have a tolerance better than +/- 1%. Indeed this logarithmic principle is central to the use of decibels in audio specification, and has universal acceptance. We might also call it the 'common sense factor'!

Finding useable data from manufacturers

In theory, using this document, you can obtain all the data you would need – by measurement – on both projector and screen, without even asking the manufacturer. But why should you do all the work every time?

As you work through this document, you will find that in most cases the actual measurements you need to carry out will be minimal. But knowing how to measure – and how incredibly easy it is to do – will mean you can both use manufacturers' data more critically and also ask more qualified and accurate questions.

Much of the data you need will be readily available internally within manufacturers. Just because you can't see what you need in the brochure or on their web site, doesn't mean it's not there for the asking. 'If you don't ask, you don't get!'

How to use this document

This document is designed to take you through the main elements of projected displays, in a logical order. Now it might be, for example, that you don't end up carrying out all – or even any– of the tests described here. But they remain important for you to understand their significance in terms of you making decisions on system components and priorities. Also, it's important to realise just how simple and easy most of these tests really are.

Although there are several pages here, in terms of your professional work, there is one positive aspect to cheer you. All of the science, tests, methodologies and guidelines can be held in the form of a series of simple interlinked spreadsheets. Moreover, using these spreadsheets can make the specification and assessment processes swift and simple.

IMAGE QUALITY PAPER

Introduction – important points about vocabulary

The most common term used in connection with projected image quality is 'brightness'. But this word does not have scientific or objective status. The word we should use more often is 'luminance'. And the other word is 'illuminance'. Let's define these words in the context of this paper.

Luminance. Light emitted or reflected from any object ('a photometric measure of the density of luminous intensity in a given direction'). This includes any objects such as walls and furniture around you, as well as projection screens, plasma displays etc. We measure luminance in candela/m^2 (also known as cd/m^2 and 'nit') or foot-Lambert (fL). [1 nit = 0.292 fL.]

Illuminance. Light falling on any surface ('the total luminous flux incident on a surface, per unit area'). In A-V and architectural circles, also called ambient light, referring to the illuminance encountered in a given location. Paradoxically, illuminance is invisible. It describes light passing through free space. We only see luminance, one source being reflected illuminance. We measure it in lux (lx) or foot-candle (ft-c or fc). [1 lux = 0.09 ft-c.]

Brightness. The way we perceive light; it refers to our experience and impression of light; it not a metric of its magnitude.

Component elements

Let's make an initial review of the component elements in terms of their contribution to the projected image.

Projector

- Luminance. How much light does it really generate? Is the published ANSI lumens data a useable figure?
- Lamp decay factor. The life of a standard UHP lamp used in most projectors is usually defined as the time it takes to fall to 50% of its luminance. If used to point of failure the luminance decay can be even more significant. We need to factor this into our specification.
- Luminance uniformity. If the projector's luminance is not consistent over its entire area the screen will not be able to correct it. Uniformity is fundamental to image quality, yet is often overlooked.
- Contrast. The massive contrast ratios, such as 1000:1, quoted by manufacturers are normally for full white field compared with the projector full off! A more usable figure is the ANSI sixteen square checkerboard contrast test, which is always a fraction of this full on/full off figure. (The onscreen contrast figure reduces even further.)
- Lens. Luminance, uniformity and contrast figures quoted are for standard lenses. If you use a wide-angle or long throw lens, the performance will

change – often significantly. Expressed another way: if you specify another lens, you have effectively specified a completely different projector!

Screen

- The measurements, methods and calculations are the same for front projection and rear projection. So we really can create the so-called 'level playing field' where all screens can be compared on a true like-for-like basis.
- Gain. The luminance of a screen relative to the light falling on it, as a multiple against a reference plain white surface (also known as 'Lambertian' in respect of the absolute uniformity of the viewing angles of all reflected light – no matter at which angle light strikes it from). Knowing this figure accurately makes it simple to predict the image luminance if we also know the true projector luminance (ANSI lumens) figure.
- Luminance uniformity. Poor uniformity can be an issue with many screens. Coupled with poor uniformity from the projector, this can create images with severe 'hot spot'.
- Contrast. In practice all screens reduce the projector's contrast ratio, but the issue is by how much and in what way (i.e. whether more on the black or the white levels).
- Ambient light. To further complicate the issue of contrast, the actual delivered image contrast ratio is also a product of the ambient light falling on the screen. So we need to know what the impact of ambient light will be.

Image

- Using data from the above elements – if reliable – allows us to make accurate calculated predictions concerning the image quality.
- Very simple measurements allow us to check and confirm actual on-screen image performance, for example. So it's possible for specifiers and consultants to specify image quality and to check it before signing off the system.
- What numbers should we actually use when we specify a system? Guidelines, such as those detailed below, offer no more than benchmarks. You, the professional, can change these according to your experience and opinions.

Environment

- In fact this is often the starting point for the exercise. As professionals we are given a specific room (planned or existing) and then have to design a system to match. There are good existing tools and methods to determine image size, type size and so forth, but here we will look at setting image quality parameters to match the given environment – and its application.

Isolating the subjective elements

You may have noticed the potential tensions between hard facts and value judgement. After all, image quality assessment is notoriously subjective. (Indeed we often have a problem with the vocabulary itself in describing what we like and dislike.) Therefore the quality standard project, from which this document emanates, breaks down into three sections, reflected in the structure of this document:

1. The **Standard** itself, containing the methodology and science in obtaining useable figures, using available test devices and under realistically achievable test conditions.
2. **Appendices** to record test data and scientific footnotes.
3. A **Guidelines** section, separated to avoid the possibility of subjective judgements inappropriate to a scientific standard. It will include a sequence of Excel spreadsheets with the option for the individual to adjust and amend performance criteria, as required. (The guidelines referred to in this paper are mostly taken from CIBSE Lighting Guide 1 [Chartered Institute of Building Service Engineers, UK. http://www.cibse.org/].)

Exclusions – what you won't find here

There are useful standards and methodologies for determining image size, text size, image definition etc – as evidenced by their widespread use. Such material is freely available in reference works, ICIA training materials and, of course, the internet. Therefore it is not covered in this document.

Practical issues – keep it simple & don't reinvent the wheel

In practice, there are two main requirements for the professional specifier:

1. To start with a brief, establish the system specifications, then to drill down on component requirements. Often the environment (e.g. meeting room) is pre-determined by the architect and the builder – 'here is a room, now design something for it'. In this given room, you might say 'I want an image of a certain luminance, uniformity and contrast ratio'. Having reached that point, you then need to know what projector and screen to specify in order to achieve these deliverables. Of course, sometimes you can exercise some control over elements such as the ambient light.
2. To be able to calculate and also measure actual performance elements for projector, screen – and the projected image itself.

This is all very well, but how can we minimise the workload and still do a thorough job? What data can we take and trust from manufacturers? What data can we use repeatedly? These practical issues have informed our work here. Therefore we start with a description of the 'building blocks' of the system: the projector, screen and the environment – and how we assess them. We describe how we reached our recommendations we include here.

Once the project is understood, simple yet powerful specification and assessment tools can be used in the form of Excel spreadsheets. This is both quick and effective. The spreadsheets we are providing have default figures and factors in line with this document; you can change these according to your own experience and opinion.

How do we see? The eye: our main tool.

Before we look at the component elements, let's consider our main viewing apparatus, the eye itself.

Our eyes have to operate under a dramatic range of lighting levels. We can read newspaper headlines by the light of the full moon (approx 0.2 lux). Outdoors, in direct sunlight, illuminance levels might reach 120,000 lux. Therefore our eyes have to work in a dynamic range of greater than 1,000,000:1. This demonstrates the compression our eyes and optical perception system have to undertake. (If this did not happen we would be blinded, for example, walking from inside the house onto the street.) It also helps explain the logarithmic principle: why we generally only perceive difference in lighting levels when they either double or halve.

This logarithmic perception of light is important in keeping a common-sense balance between maintaining scientific rigour and in-the-field practicality. This principle gives us the opportunity to take specification and assessment out of the lab and into real life situations – and to absorb it into our daily working lives.

When we experience a change in lighting level the iris of our eye contracts or expands to control the light falling on the retina at the back of the eye. This happens involuntarily; there is no conscious intervention on our part.

The level of light our eye is currently adjusted to is known as the *adaptation level*. If the eye suddenly experiences a dramatic increase in light, this is known as *disability glare*. We know this from the temporary discomfort we feel if we switch on the light in the middle of the night. Another example is if we use a laptop in a dark room: when the screen is too bright, we cannot see the keyboard if we just glance at it to locate a particular key; the screen luminance has to be adjusted down accordingly.

These principles and the whole subject of visual acuity have been the subject of detailed research by scientists involved with the lighting industries. They have produced useful and practical specification guidelines that we can utilise and adopt for the purposes of projected images – particularly in the case of setting performance parameters relative to the actual environment where the image is to be placed.

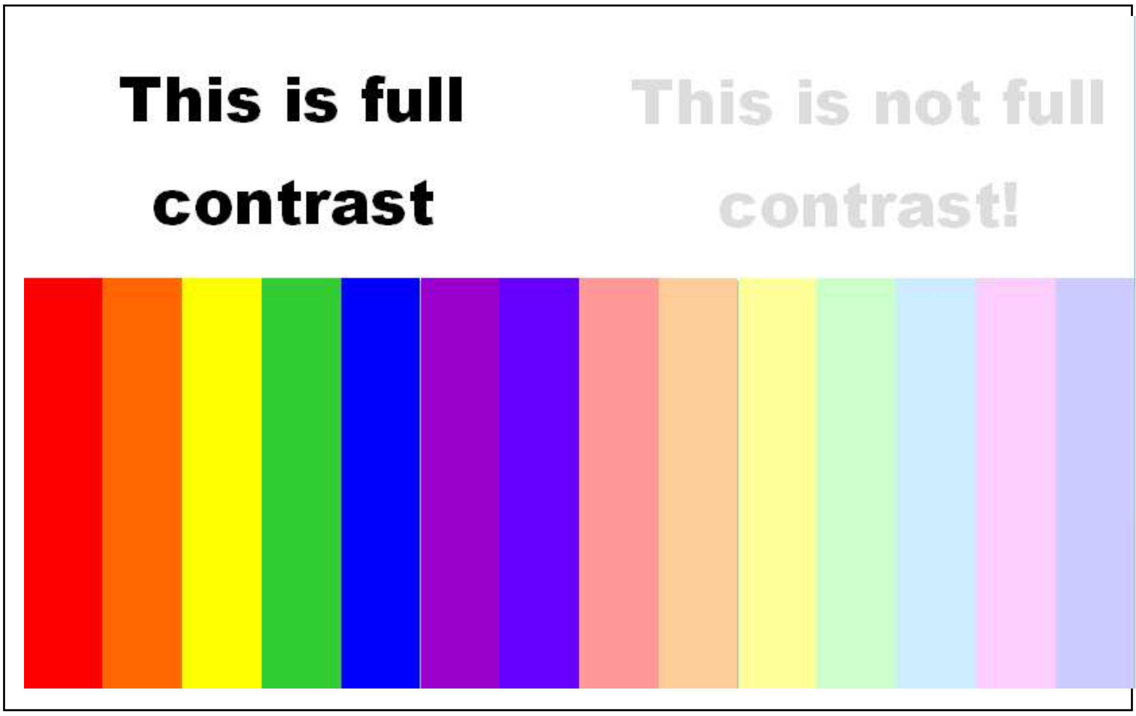
The importance of contrast

This cannot be overstated. Contrast is central to our project. It's sufficiently important to be worth taking a section to discuss it.

Without contrast we cannot see. Look at this example, imagining it to be a projected image.

Although the contrast is less on the right side of the above, there's one really important point. The overall image is at the same luminance. Luminance is not the same thing as contrast. We'll often witness a user say 'that image is not so bright' when they really mean the contrast is poor – usually in the case of being 'washed out' by high ambient light levels.

Now check the expanded version of the same illustration.



This illustration demonstrates the impact on colour saturation when contrast is reduced.

Contrast in the projected image is a product of three connected properties:

1. The true ANSI (checker board) contrast ratio of the projector
2. The impact of the screen. Screens reduce projector contrast. The nature of this impact varies: a projected image will have a given contrast ratio (e.g. 25:1, 10:1 etc) but this is relative to a 'baseline' determined by the luminance of the projected black levels.
3. The impact of ambient light. This can deal a real killer blow to any installation – and is why considering the exact location/environment of individual installations is so important.

Before we go into more detail, let's consider a very useful benchmark, namely this piece of printed paper. Crisp black print on clean white paper is an effective benchmark for image acuity. Its properties are low luminance, but high black levels: the black really is black!

Contrast is the most important attribute of projected image quality. In practice, achieving good black levels in the installed projected image is our main objective.

Contrast levels in practice

The committee involved in developing this paper reached consensus about minimum – and practicable – contrast levels. This is not a 'law': these are guidelines. You may well amend them having made some tests yourselves.

There is good news and bad news here. The good news is that the minimum recommended contrast levels are much lower than you might have predicted. The bad news is that it's actually much harder to achieve these levels than you might predict – particularly front projection.

Front projection contrast

We found that even if projectors had the kind of contrast figures the brochures claim, then in a typical meeting room, the best on-screen contrast levels achievable will only be in the approximate range of 3:1 to 12:1!

Front projection contrast is, in practice, entirely a function of ambient light. Only in true blackout conditions does the projector's contrast (i.e. black levels) have any relevant impact. You can validate this by entering some sample figures in the supplied Excel sheets.

We found that for normal PowerPoint and non-detailed content, 10:1 contrast produced a reasonable minimum level of acceptability. For detailed content and photographic images, 15:1 proved an acceptable minimum. At 20:1 we all agreed the image quality was good.

We will show here that the main driver for contrast levels in front projection is ambient light. If you can control ambient light effectively, you're in good form. Generally, front projection screens cannot distinguish between ambient and projected light. However, at the time of writing advanced optical front projection screens are being launched with much enhanced contrast performance.

(We also discovered that there is no measurable difference in performance between a matt white painted surface and a standard front projection screen with unity gain [i.e. 1].)

Rear projection

Unsurprisingly, rear projection can achieve much higher contrast levels than front projection. The downside being its greater expense and room depth requirements. In practice it's possible to achieve from 20:1 to > 200:1 contrast ratios.

Taking measurements – meters required

In order to measure all possible elements, two kinds of light meters and readings are required.

Illuminance meter. In our case, this effectively means 'ambient light'. This is measured in lumens (and sometimes in foot candles in US). We use this meter to measure ambient light and for projector readings facing towards the lens. This is the most essential meter for day-to-day use and for site surveys. Reasonable models cost from approx $100 (€100 or £60).

Luminance meter. This refers to light emanating (i.e. radiating or reflecting) from an object, such as laptop screen, computer monitor – or projector screen. It is measured in foot Lamberts (US) or cd/m^2 (candelas per square metre, also referred to as 'nit') outside the US. Its benefit is that it measures what the eye looks at – the actual delivered image quality. (If we looked at the projector lens, in the way an illuminance meter does, we'd be blinded!) These can vary dramatically in cost. However for the most part we are looking for a relative reading (which is what a contrast ratio is) rather than calibrated absolute readings. You can use a standard photographic spot meter and then apply a simple conversion factor. You can use an entry level meter from approx $400. The industry-standard lab unit is a mere $3000!

At time of this revision (October 2006) we have found that illuminance meters, giving readings in lux or foot-candle, are widely available, starting at approx $100 (£60, €100). We have also tested a number of luminance meters, with mixed results. Currently the most promising lead seems to be to source a used professional photography meter, such as the Minolta Spot Meter F through eBay.

METHODOLOGY AND SCIENCE

Testing and evaluating the projector

The projector is the engine of the system. Its selection is vital to the quality of the projected image. But we are only concerning ourselves here with the aspects that relate to image quality. There are elements, not covered here, that you will have to consider separately, which might include:

- image resolution;
- integration with control systems;
- networking;
- mechanical issues (e.g. whether it is warranted to work vertically, if rear projected);
- hours warranted to work per day;
- lamp life;
- relevant exclusions in the manufacturer's warranty.

Test conditions

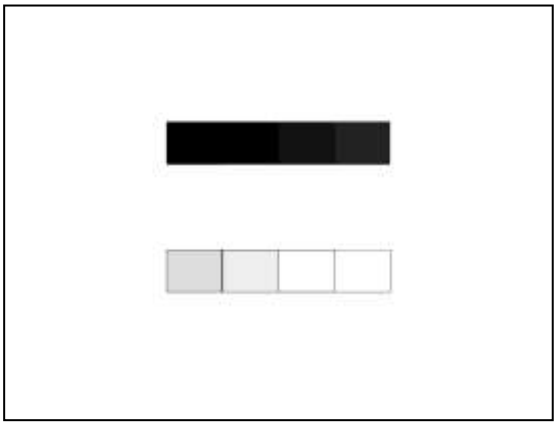
In the lab, you'd be expected to have blackout conditions available (although reflected light can bounce back and affect the test results to some extent). In any case ambient light is factored out, as you'll see below.

If you're going to test a projector out of the lab, the most important thing is to remove all impact of daylight, because daylight levels vary constantly and imperceptibly, which means they can't be factored out accurately. You can either stick cardboard (or other opaque material) over the windows, or simply wait for night. Try and get the levels below 20 lux if you can. But the most important thing is to ensure that the ambient light is falling uniformly across the entire image area.

Setting up the projector.

Note projector and lens type and serial number. Allow projector to warm up for at least the manufacturer-recommended period.

The next step is to set up the projector to a valid source. For that reason, we recommend a laptop displaying this PowerPoint grey scale slide (available as a free download as part of this project – or can be made easily yourself):



The top line comprises a 0% (black) square on the left, with squares moving to white in 5% increments (95%, 90% etc). The bottom line shows full white on the right square, descending to black in 5% increments (95%, 90% etc).

Step one is to set the projector luminance to the ‘clipping’ point i.e. the point before which the black square begins to lighten.

Step two is to use the contrast control to adjust the grey levels to their ‘clipping’ point i.e. the point at which the greys and their graduations are even and easily distinguishable.

You may need to repeat both steps a couple of times before you are happy with the result.

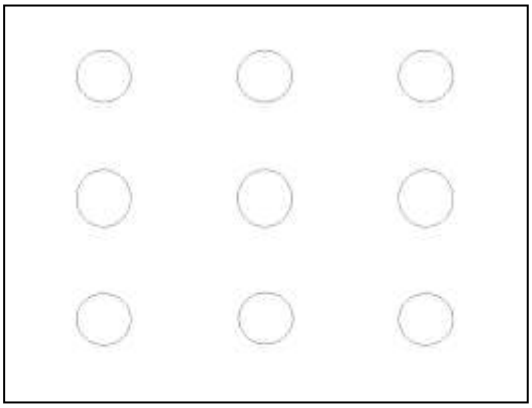
In the tests we carried out as a committee, we agreed that when adjusted in this way, all sources we then displayed looked acceptable (computer, video, photos etc). Try it yourself and see what you think.

Remember that the grey scale will appear differently at different levels of ambient light – especially with front projection.

Projector luminance measurement

Very few realise just how easy this is to do!

Using a blank white PowerPoint slide or this slide (which we’ll be using shortly anyway) which is a white field, but with guides for where to measure:



1 Measure the screen size and determine the surface area of the image (e.g. 2m x 1.5m = $3m^2$)
2 Put a lens cap on the projector, or otherwise block any projected light from falling on the screen.
3 Using the illuminance meter, placed flat against the centre of the image area, facing the projector, measure the ambient light (lux)
4 Remove the lens cap and with the illuminance meter, measure the light again (lux)
5 Subtract the ambient light reading from the projected light (this factors out the impact of ambient light)
6 Multiply the adjusted light level by the screen area – this is your answer! (lux = lumens/m^2).

The formula looks like this:
(projected light [lux] – ambient light [lux]) x screen area [m^2] = projector lumens

Example:
([projected light = 1100 lux] – [ambient light = 100 lux]) x [screen area = $3m^2$] = 3000 lumens

Projector uniformity measurement
(Assuming you are continuing from the previous test.)

Here we compare the projector's average light output in the corner of the images with its centre luminance. The above slide is used to indicate the centre spot of the nine individual rectangles, with the image broken down into a 3 x 3 matrix.

1 Measure the projected light in the centre of each of the nine target areas, subtracting the ambient light figure from each.
2 Make an average of the eight figures (i.e. excluding the centre spot)
3 Express this average figure as a percentage figure relative to the ambient-adjusted centre reading (1000 lux in our example).

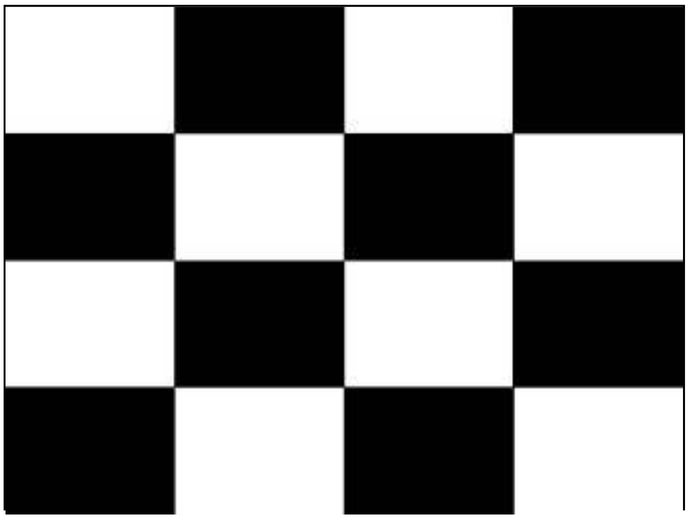
a. Example, if the average of the eight peripheral locations, adjusted for ambient light, is 817.5, then: 817.5 ÷ 1000 = 0.8175 (= 82%). So in this example, we would express this projector's uniformity as being 82%.

In practice we would recommend:

- 90% or better uniformity is 'good'
- 85% is acceptable
- 80% at the lower end of acceptability (but be prepared to witness much lower than this).

Projector contrast measurement
(Assuming you are continuing from the previous test.)

We use the same set-up as before, but changing the slide to this checkerboard pattern:



1 Measure all the white squares, subtracting the ambient light reading for each reading.
    a. Example: let’s assume average of these eight – ambient-adjusted – readings is 1000 lux.
2 Measure all the black squares, subtracting the ambient light reading for each reading.
    a. Example: let’s assume average of these eight – ambient-adjusted – readings is 20 lux.
3 The projector contrast ratio is the ambient-adjusted white average figure divided by the ambient-adjusted black figure
    a. Example: 1000 ÷ 20 = 50. Therefore projector contrast = 50:1.

In all cases, the figure you measure will be significantly less than the on/off contrast figures you will find in commercial brochures.

Onscreen image contrast measurement
(Assuming you are continuing from the previous test.)

This is actually the most useful figure we'll get. It tells us what we are actually seeing!

We use the same checker board pattern as above. But this time we include the use of the **luminance meter**.

1. Set the meter up on a tripod, perpendicular to the screen centre, at a distance of three times the image width. (This is because only the screen centre reading is completely on-axis, but means all the other readings will be taken at a consistent angle, no matter what the image size may be.)
2. Measure all the white squares (in nit, which is the same as cd/m^2), noting each.
3. Measure all the black squares (in nit, which is the same as cd/m^2), noting each.
4. The projector contrast ratio is the average white figure divided by the average black figure.
5. Do not subtract the noted ambient light figure – what we seek here is the contrast ratio relative to specific ambient light levels. You have two options:
    a. If you can control ambient light, bring it up to the level you know will exist in your project, then test the on-screen contrast again.
    b. Take contrast measurements at two ambient lighting levels (ideally with one at 0 lux). With these figures you can calculate the image's contrast levels at any given ambient light level. This can also be plotted onto a graph with image contrast on one axis and the ambient light on another – the relationship between the two data is linear and will create a straight line on the graph.

+++

Practical points:

- At best, the screen can only do as well as the projected light it receives (remember the old computer programming expression GIGO, 'garbage in, garbage out'?). This applies particularly to luminance uniformity.
- The reading you take is only valid for the particular projector and lens combination you have tested
    - If you specify another lens, you have effectively specified another projector. You need to test (or get accurate figures for) the exact projector and lens you are specifying
- Wide angle lenses are often much slower (i.e. dimmer, less transmissive) than standard lenses – sometimes up to 50% or more
    - Wide angle lenses often have much worse uniformity than standard lenses (e.g. worse than 70%). Often used for rearpro (rear projection), this can be a major cause of 'hot-spot' (i.e. very poor final image uniformity)
- If the image is very bright relative to its environment, the perceived visibility of hotspots can be less than if the image is not bright – or even dim – relative to its environment. However where the image is not relatively bright, the hotspot can be painfully apparent! It's not just a question of how bad a hot-spot is according to the meter, it's a question of how the eye sees it.
- There is another significant phenomenon connected to viewing screens with poor uniformity. As noted above, screens with poor uniformity can actually look acceptable under certain circumstances – when viewed in isolation. However when positioned hard up against other screens (e.g. in an array or video-wall), the eye adopts into a more critical mode and poor uniformity is much more evident. This usually leads to the use of low gain screens for front projection, and optical (Fresnel lensed) screens with rear projection – together with projectors and lenses that have been rigorously selected.

Testing and evaluating the screen
We will be using the same meters we used for the projector: luminance and illuminance meters.

All tests and methodologies described here apply equally to front and rear projection. All projection screens can be compared on a true like-for-like basis.

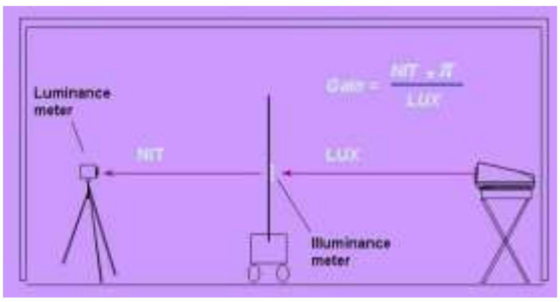
- **The illuminance (lux) meter always faces the projector. Therefore in front projection it is placed on the screen, facing the projector; in rear projection tests it is placed behind the screen, facing the projector.**
- **The luminance (nit) meter is always on the side of the viewer – i.e. in front of the screen. To make a consistent analogue to the viewing experience, it is recommended that it is positioned on-axis to the screen centre, at a distance of three times the image width.**

Screen gain measurement
In fact, to get an accurate figure, completely controlled conditions are required (e.g. a laboratory) and calibrated meters. However we will still describe the process because:

1. It is easy.
2. If you are getting bizarre results elsewhere, you can at least make a rough test as indicator.
3. This is probably a good practical demonstration of how some of the more inaccurate figures quoted by some manufacturers are arrived at!

The tests should be made at 0 lux, or very low ambient levels. Any ambient light should be measured and factored out, as per the projection tests.

1. Measure the light from the projector, by placing the illuminance meter in the centre of the screen facing the projector. (In the case of front projection, this means with the meter in front of the screen. In the case of rear projection this means with the meter at the rear of the screen.)
2. Measure the light at the centre of the screen using the luminance meter. The meter should be perpendicular to screen centre, positioned at three times the image width. The meter remains in this relative position to reflect that your eye can only view from a single position at any given moment.
3. The screen gain = (luminance [nit] x 3.14159 [π] ÷ illuminance [lux]

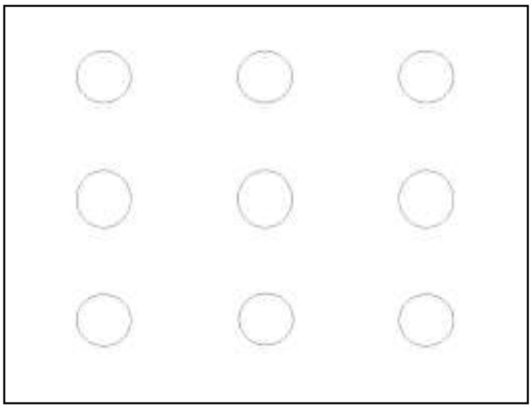


PLEASE NOTE: This is one case where the outputs from the meters are significant for needing to be actual, rather than relative. If you don't use high quality meters – and meters that have been recently tested and ascribed an accurate calibration factor – your results will be inaccurate.

Screen uniformity measurement

In fact this test process is identical to the projector uniformity test. However in this case we will be factoring out the projector's uniformity. The question effectively asked here is 'what is the screen uniformity assuming the projector uniformity is perfect'?

These tests are of significance for all rear projection screens and for high gain (i.e. relatively reflective) front projection screens. Standard front projection screens (i.e. gain close to 1) tend to exhibit good uniformity.



As in the projector uniformity tests, we measure the uniformity of the screen in the eight peripheral positions.

1 The test should be carried out in a darkened environment.

2 Measure the luminance of each position, in nit, (L^1, L^2, L^3, $L^{4,}$ L^5, L^6, L^7, L^8) – remember that the luminance meter should be on axis, at a distance of three times the image width.

3 Measure the illuminance of each position, in lux, (I^1, I^2, I^3, I^4 I^5, I^6, I^7, I^8)

4 Measure the luminance of the centre, in nit (L^C)

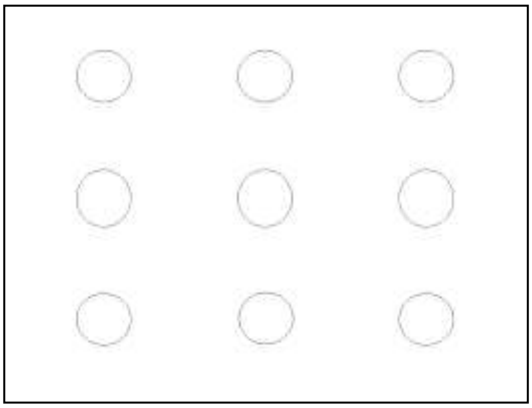
5 Measure the illuminance of the centre (I^C)

The screen uniformity, corrected for projector uniformity, is calculated by using the above data in the following formula.

$$((((L^1/ I^1) + (L^2/ I^2) + (L^3/ I^3) + (L^4/ I^4) + (L^5/ I^5) + (L^6/ I^6) + (L^7/ I^7) + (L^8/ I^8)) \div 8) \div (L^C / I^C)) \times 100$$

System uniformity measurement – the projector and lens combined (i.e. 'the display')

In the above cases, we have looked at the relatively academic questions of the component element uniformities, namely the projector and screen. However the deliverable as far as this project is concerned is the actual image quality. Describing the previous tests shows how easy it is to take these measurements. Measuring the uniformity of the system is an even simpler process than the screen, as there is nothing to factor out.



As in the projector uniformity tests, we measure the uniformity of the screen in the eight peripheral positions.

1. Measure the luminance of each position, in nit, (L^1, L^2, L^3, L^4, L^5, L^6, L^7, L^8)
2. Measure the luminance of the centre, in nit (L^C)

The formula is correspondingly simpler.

$$(((L^1 + L^2 + L^3 + L^4 + L^5 + L^6 + L^7 + L^8) \div 8) \div L^C) \times 100$$

You may have noticed there is no reference to taking these measurements in darkness. Although it is useful to take this figure in darkness – if indeed this is possible with your installed system – you will probably be more interested to know what the uniformity is under normal viewing conditions. However if you can take both, this will be ideal for your system records.

Practical points:

- **Uniformity is important. Apart from general image problems, users seeing 'hot spot' in their image regard this as a major problem – one that is hard to address after system installation.**
- The image uniformity is a combined product of both projector and screen uniformity.
- If the projector has poor uniformity the screen cannot correct it.
- A screen with poor uniformity will produce an image of poor uniformity, no matter how good the projector uniformity is.
- Using wide angle lenses is often where the issue of uniformity becomes a problem – particularly if combined with high gain (transmissive) diffusion screens.
    - Wide angle lenses used for rear projection should be combined with optical (i.e. Fresnel-lensed) screens – or low gain diffusion screens if budget forces their use.
    - Wide angle lenses used for front projection should be combined with low gain screens.
- Image uniformity in practice means **perceived** uniformity: uniformity will often appear worse to the eye at higher ambient light levels.

Image calculations and predictions

If:

1. You have screen and data you feel are of sufficient accuracy, or
2. You have data to which you can apply 'reality check' calibration factors, then…

… You can use simple formulae – usually pre-entered in an Excel spreadsheet – to calculate actual image performance. If the figures you enter are accurate, then your answers will be accurate too. But remember: 'garbage in, garbage out'!

Image luminance

The formulae used are simple:

- **Image brightness:**

$$cd/m^2 = \frac{Pg \times (lumen / ScreenArea)}{\pi}$$

- **Required projector lumens:**

$$\frac{\pi \times nit \times ScreenArea}{Pg} = lumens$$

The first formula we use to calculate the luminance of the image in cd/m^2 (i.e. nit), using the screen gain (Pg), the projector luminance (in lumens), the screen area (in m^2) and π (3.14159). In Excel, it would look like this:

= (screen gain x (lumens / screen area)) / 3.14159

The second formula we use to calculate how bright the projector needs to be (in lumens) if you want to achieve a certain screen luminance (i.e. luminance, in nit). In Excel, it would look like this:

= (3.14159 x required nit x screen area) / screen gain

In practice, these formulae only need to be entered once, or even just copy/pasted from another spreadsheet.

Image contrast – front & rear projection – including effects of ambient light

Calculating front projection contrast and rear projection contrast is very straightforward. But they use different methods. If we are to create a level playing field, where both can be compared on a like-for-like basis, then we have to take these formulae further. But let's start with the basics first.

Front projection image contrast

Front projection contrast, factoring in the effects of ambient light, is very simple to calculate. Consider the following example from the accompanying Excel sheet *front projection contrast calculator* (which also has the same calculations, using foot-candle and foot-Lambert). We need to input the figures in red: illuminance (i.e. ambient light, in lux); screen gain; projector lumens (true projector lumens!); screen area (which the sheet calculates from the diagonal measurement).

Image contrast calculator. Front screen black levels are limited by ambient light falling on screen. (This calculator assumes projector black levels are perfect!)			Conversion to US
If ambient light on screen is	100	lux	**9.0** foot-candle (ft-c)
If the screen is	1	gain	
resulting max screen black level	32	nit	**9.3** foot-lambert (fL)
so…			
If projector has	2000	ANSI lumens	
& screen size is	100	inches diagonal	
(so screen width is	2032	mm	
…and screen height is)	1524	mm	
so screen area is	3.10	m^2	
Then screen max white can be	206	nit	**60.0** foot-lambert (fL)
So max possible contrast ratio :	**7.5**	**:1**	

Contrast ratio = nit1 + nit2 / nit2 [you have to add the ambient light to the projected light to get a true ratio]
Screen luminance from ambient light = (ambient light [lux] / 3.14 [*pi*]) x screen gain
Screen luminance from projector = (projector lumens / (screen area [m^2]) x screen gain / 3.14 [*pi*])

This is very simple because the screen reflects ambient light in the same way as projected light; we just use the gain figure in both cases.

Note that in this case there is no input for projector contrast (i.e. true ANSI contrast ratio). Looking at this example and experimenting with the spreadsheet, you will find that all cases other than complete blackout, final image contrast in practice is entirely a function of ambient light.

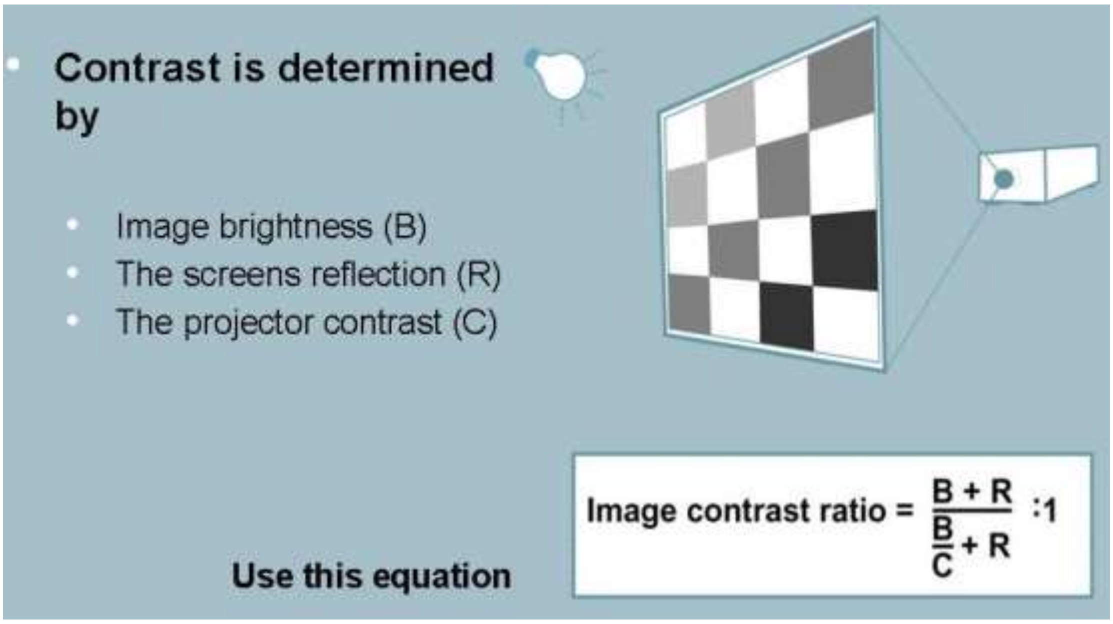
If you did want to add in the factor of projector contrast, this can be done easily. If you knew, for example, your projector had a contrast ratio of 100:1, another way of expressing this is that the black area level would be 1% of the peak white. This output can then be added to the black level generated by ambient light before making the net contrast calculation. This has been done in the Excel sheet *front vs rear projection contrast calculator*. Using this example of projector contrast of 100:1 together with the inputs in the above sheet, it further reduces the image contrast from 7.5:1 to 7:1, in this case.

Using these two Excel sheets you can confirm three significant facts:

1. Front projection contrast is effectively generated by ambient light – except in situations such as blacked-out cinemas
2. Projector contrast – which must be ANSI contrast, not the usual on/off variants – has little significant effect on front projection contrast (with the same exception of blacked-out rooms)
3. However projector contrast has significant impact on rear projected image contrast, as we'll see below.

Rear projection image contrast

The calculation for rear projection contrast is also simple.



B = image luminance, in nit (cd/m^2)
R = ambient light reflected from screen, also in nit
C = projector contrast ratio (using ANSI checker board measurement)

In Excel the above contrast calculation formula would look like this:

= (B+R) / ((B/C) + R)

In this example, let us assume the following:

- Image luminance is 600 nit
- Ambient light falling on screen is 200 lux
- The screen is reflecting 3 nit.
- The projector contrast ratio is 50:1

In this case the actual figures would look like this:

= (600 + 3) / ((600 / 50) + 3)

which equals 40.2 : 1.

This is relatively simple, but leaves us with two residual problems:

1 In practice we would want to be able to calculate the reflected light from the screen (in nit or foot-Lamberts) from taking ambient light measurements (in lux or foot-candles)

2 Our stated aim is to be able to compare front and rear projection screens – specifically contrast in this case – on a like-for-like basis.

In front projection, the gain of the screen is used to calculate the effect of ambient light. We cannot use the gain figure of a rear projection screen here, because its gain is a function of its transmissive properties, and not its reflective properties (as is the case with front screen gain). Therefore what we need to know for this exercise is this: how does a rear screen behave like a front projection screen in terms of reflecting ambient light?

This is a simple question, but not normally asked. Before we proceed further, let us consider the nature of reflection for a moment. There are two types of reflection:

1 Specular reflection. Where light from a single incoming direction is reflected in a single outgoing direction. We might think of this as a mirror-like reflection. Example, a focused beam of light will reflect from a mirror at the same angle it strikes at (the basic law of reflection).

2 Diffused reflection. Where light is reflected from a surface in a number of directions. A projection example is a matt white screen, gain 1, effectively a Lambertian surface, where no matter which direction any beam of light strikes it from, it will be radiated out in a uniform hemispherical pattern.

Now this opens up all kinds of potential complications for a project whose stated aims are simplicity and practicality. In the discipline of lighting this is normally considered using the complex formulae associated with *Contrast Rendering Factor* (CRF).

The proposal in this paper is to use an existing methodology: the dnp reflectance factor. This is an internal standard. It involves taking light sources (above, at 45°, and to one side at 45° of the screen) emitting a given luminance, directed at the test surface (viewer side), taking a reading with meter perpendicular to screen centre, then generating the output as a percentile. Example: 100 lux on the screen produces a reflected luminance of 1.5 nit; this equals a reflectance factor of 1.5%.

Taking this reflectance factor further, we can observe that it has similarities to front projection screen gain: it is an operand we can use to calculate screen luminance from a given illuminance falling upon it. This reflectance factor therefore has a relationship to screen gain: in this case if you divide reflectance factor by screen gain, the result is 0.3183. Therefore we can use this factor to convert reflectance factor into gain – **but we must be clear about its limitations.**

Comment. There are some obvious pitfalls here. The dnp standard is not used universally. But to the knowledge of this writer, there is nothing else existing that fulfils the stated needs of this exercise. Furthermore, it is both simple and an 'open access' standard: anyone can use, check and even modify it. It provides a datum to convert rear projection screen reflectance into gain. This figure is in the spreadsheets and can be changed by any user. The spreadsheets also provide dnp's laboratory measurements of a range of non-dnp screens for users to compare and validate as they wish.

The main potential complexity generated by considering reflectance, *Contrast Rendering Factors* etc concerns angles: angles of view, angles of ambient light (directions from which it emanates), angles of projection – and so forth. There are two points to be made. Firstly, reputable screen manufacturers provide peak gain charts, from which one can discern the % reduction in performance at relative angles (which can be converted into reflectance factors as required). Secondly, there's the commonsense factor: these methodologies are sufficient to be able to validate predictions by using meters, within reason; and the requirement is to be thinking on behalf of the user, not to generate numbers in a spreadsheet that would be meaningless to the user. It's our job as professionals to interpret the figures using experience and commonsense and give clients level-headed and reasonable advice.

Now let's revisit the rear projection contrast formula introduced above, using the reflectance factor, but calculating screen reflection from a given or measured ambient light level.

- Image luminance is 600 nit
- Ambient light falling on screen is 200 lux
    - Screen reflectance factor is 1.5%
    - Therefore the screen is reflecting 3 nit
- The projector contrast ratio is 50:1

In Excel the above contrast calculation formula looks like this:

= (B+R) / ((B/C) + R)

And again, the actual figures look like this:

= (600 + 3) / ((600 / 50) + 3)

which equals 40.2 : 1.

Comparing front and rear projection screen contrast on a like-for-like basis

The foregoing text explains the thinking behind the more complex spreadsheet *front vs rear projection contrast calculator*. Using the reflectance factor, we can now expand the original sheet to compare the impact of ambient light on front and rear projected images – on a like-for-like basis. Here's the same front projection example, compared with a typical optical (i.e. lensed) rear projection screen.

Change numbers in *blue italics* to compare front & rear projection	**FRONT PROJECTION**		**REAR PROJECTION**	reflectance factor
If ambient light on screen is	***100***	lux	100	
If the front screen gain is	***1***	gain	0.047	***1.50%***
Reflectance factor	32%	)		
best black level (before projection)	31.83	nit	1.50	
If the rear screen gain is	***3***		3	
If projector has	***2000***	ANSI lumens	2000	
& screen size is	***100***	inches diagonal	100	
(so screen width is	2032	mm	2032	
...and screen height is)	1524	mm	1524	
so screen area is	3.10	m2	3.10	
Then screen max white can be	206	nit	617	
So max theoretical contrast ratio	**7.5**	**:1**	**412.1**	**:1**
If **true** projector contrast =	***100***	:1	100	:1
then max actual contrast will be	**7.0**		**80.6**	
Contrast ratio = nit1 + nit2 / nit2				
Screen luminance from ambient light = (ambient light [lux] / 3.14 [*pi*]) x screen gain				
Screen luminance from projector = (projector lumens / (screen area [m^2]) x screen gain / 3.14 [*pi*])				

The main points to note in this example are:

- The projector contrast of 100:1 (ANSI) is at the top end of realistic expectations.
- Although relatively unimportant to front projection, you'll see it's very important to use projector contrast to get a realistic prediction of rear projection image contrast (i.e. a figure that would be confirmed by taking readings).
- There are limitations to the use of the screen reflectance factor (a metric which effectively determines to what extent a rear projection screen reflects ambient light in the way a front projection screen does) which are detailed in the notes contained within the spreadsheet.
- Older versions of these sheets are available for download from www.infocomm.org/ and then search 'white papers'. Please email me on

greg@rearpro.com for the latest versions. You are recommended to experiment with different inputs to see the kinds of results you might expect

GUIDELINES

Introduction

So far we have considered the main elements of the system. But here we have to add another element: the environment. Where will the system be installed and what will it be used for?

There's a kind of paradox here. Obviously it's very important to understand all the key issues of evaluating and testing the main system components – namely the projector and screen. However our most usual professional task is to be presented with an environment and a brief on the intended application, then to be tasked with designing and installing a system accordingly. The environment and application determines the display specification.

There is a sequence of paradoxes here. The projector is usually regarded as the main element in the projected display, yet we don't look at the projector, we look at the screen. As far as the user is concerned, they look at neither: they look at the image. Often the biggest single impact on the image quality is the ambient light.

On the basis that the environment and application are the defining factors, it's worth recalling how we discovered above that front projection contrast is primarily a function of ambient light, rather than the projector. So if we use a light meter anywhere, it should at least be to measure and accurately define the environment in which our system is to be installed.

It's worth thinking of projected displays as 'organised light'. And of course the main environmental impact on our system will also be light: ambient light. Therefore we can express our task as including setting the parameters of the 'organised light' system (image luminance, contrast etc) relative to the 'environmental light' factors in the room or location (ambient light levels etc).

From the above comments, and against the background of quality standards that – so far anyway – have addressed component elements rather than the overall system, it's easy to see why it can be a confusing subject. Therefore this paper is informed by the need to have an organised view on system elements and their interaction – plus the commonsense requirement to have methodologies and guidelines we really can use in a day to day context.

Defining the environment

Here we look at two examples, firstly as one way of evaluating the environment before specifying the image, but secondly to utilise the materials we have explored in this paper.

1 Meeting rooms, training rooms and boardrooms

This sector is the largest into which projectors are used and which can benefit from the kind of analysis detailed here.

- These are the environments we work in.
- We tend to use MS PowerPoint, Word and Excel.
- Work sessions can last hours or all day.
- We tend to use paper and pen, plus printed materials.

Let’s focus on the paper. Printed material provides a useful benchmark in these environments for acuity and reading comfort:

- It is low luminance
- It is high contrast
- It is high definition
- It is dynamic: its luminance is always set by the illuminance [ambient light].

Paper provides another benchmark. Plain white paper has a gain of around 1. In a meeting room with light levels at the recommended minimum level of 500 lux, the paper will have a luminance of around 159 nit (luminance [nit] = gain ÷ 3.14159 [π] x illuminance [lux]). This is not high luminance.

If our eyes have to adjust from one *adaptation level* to a substantially higher level, this is described as *disability glare*. (It hurts when we switch on the light in the middle of the night!) Therefore if there is too great a variation in task luminances [the *task* being defined as the object you are looking at] you will effectively design eye strain into the room’s system.

In the UK, the Chartered Institute of Building Services Engineers (CIBSE) has set some environmental guidelines, based on academic research and practical experience. We have extracted some key elements:

- Meeting room illuminance levels should be at least 500 lux (they also define recommended levels for virtually every conceivable environment)
- General illuminance levels in the room should be less than 10:1 from brightest to darkest zone
- Core area (i.e. the main working zones) illuminance levels should be less than 5:1.

- Task luminance ratio should be no greater than 3:1. The brightest object the eye looks at in the course of normal work should be no more than three times brighter than the darkest object. If the paper, for example, has a luminance of 159, then the projected display should be no more than three times this (e.g. 477 nit).

Task luminance ratio **is therefore central to the specification process.** If the eye is constantly adjusting to different adaptation levels, it will obviously lead to eye fatigue. One can now routinely witness installations where the image is set too bright – particularly with front projection where often the only way to achieve any minimal contrast level is to raise the image luminance. There was once a time when projectors were not bright enough. Those days are past. There can be no debate as to whether a screen can be too bright, relative to its environment and application. The only question is what the task luminance ratio should be set at. In the spreadsheets we have used the CIBSE recommendation of 3:1; this can be changed according to your own views and experience.

2 Public display environments

Here we consider environments such as exhibitions, shopping malls and screens facing the street (i.e. direct daylight). This example is selected by way of striking juxtaposition with the previous example.

- There's usually a very limited viewing and dwell time
- The viewing period is determined by the viewer – usually they can just walk away
    - Issues of eyestrain are thus rendered relatively unimportant
- The image itself has to create an impact to stimulate desire for the viewer to focus on its content
    - High luminance levels are usually required to make this impact
- Using the same white paper idea explored above, in these higher ambient light levels we witness correspondingly higher reference luminances from all surfaces.
    - White paper (gain 1) at illuminance level 1,000 lux (93 foot-candle) will generate 320 nit (93 foot-lambert)
    - White paper (gain 1) at illuminance level 10,000 lux (929 foot-candle) will generate 3,200 nit (929 foot-lambert)
- Under very high levels, meaningful contrast levels using conventional front projection screens are not attainable
- Even using rear projection we can see there are some steep demands to create image luminance that are even visible – let alone attract the viewer's eye.
- Even using rear projection, in elevated ambient light levels diffusion screens will also suffer from poor contrast. This means that screens with contrast filter technologies (so called 'optical' screens) may need to be considered.

This category may indeed be too broad, but nevertheless provides a useful contrast with the more easily defined meeting room environments. It also provides an example of a methodology that can be refined and developed by the individual consultant.

Using spreadsheets

But perhaps most importantly of all, such methodologies can be transcribed simple and interlinked spreadsheets, so these critical decisions can be explored and decided almost in a matter of seconds by entering actual or possible data into your Excel workbooks.

With the document, we are distributing example spreadsheets putting these ideas, formulae and methodologies into practice. As with this document, it is for the purpose of peer review – so please let us have your feedback!

Setting measurable deliverables

From the above, it can also be observed that it's quite possible to set measurable image quality deliverables for the installer to work to, and for the consultant to sign off by using a meter quickly and easily on site.

For example, a specification might state: 'In Room A, where the measured ambient illuminance level is at *x* lux/foot-candle, the contractor will be required to provide an image luminance within the range of *a* to *b* nit/foot-lamberts and a measured image checkerboard contrast of at least 15:1.' The spreadsheets can be used so that the deliverables can be tested at different ambient light levels (i.e. those available at time of testing) to give equivalent performance criteria – and to be fair to the installer!

+++

CONCLUSION

This paper – and the related materials and documents – are very much in the public domain. We hope you find this of value. However this is an ongoing project which we hope to develop organically, with your assistance.

If you have any comments or suggestions, we would be delighted to hear them with a view to incorporation in future versions. In the first instance please email me at greg@rearpro.com.

Greg Jeffreys
Bromham, UK
November 2006