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ABSTRACT

Eighteen significantly different classroom lighting systems were measured and analyzed in order to determine how contrasts from different light sources affect the ability to see visual tasks in the school room. Using criteria and techniques established from previous lighting research, the lighting systems are evaluated according to their characteristics regarding contrast rendition of pencil handwriting. The comparisons and conclusions presented should be helpful in selecting classroom lighting systems. (JD)

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Contrast Rendition in School Lighting

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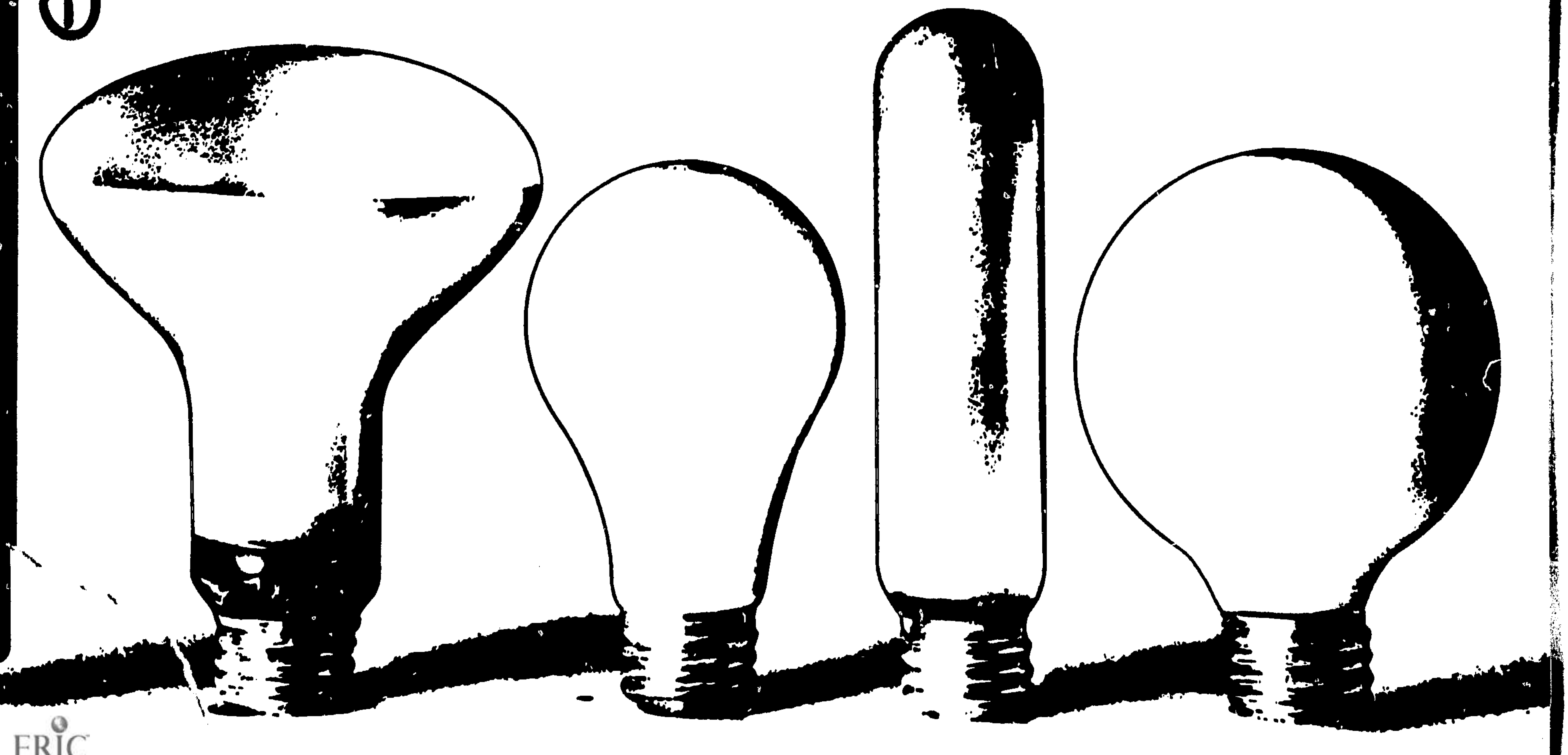

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Contrast Rendition in School Lighting

by Foster K. Sampson

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I would also like to express my appreciation to the many school district officials, principals, and teachers, all of whom went out of their way to cooperate and provide facilities to make the survey possible.

Foster K. Sampson

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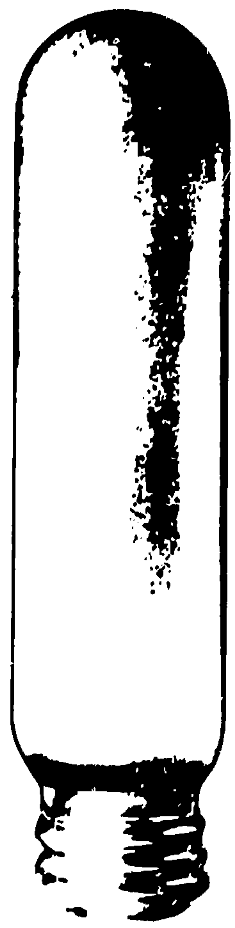
foreword



Most lighting research is done in laboratories where hypotheses are drawn, theories developed, and reports written. Some of the theories are applied to design practice, but few are checked or challenged by field research conducted with the same competence, instrumentation, and sophisticated procedures as those used in the laboratory. Fortunately, Foster Sampson's work, which he describes in this publication, is one of the rare exceptions to this rule. His field research on the basic elements of lighting for effective seeing should be the forerunner of more field investigations to check the performance of lab-born theories.

The organization of the study reflects meticulous care in data gathering. Scientists and research-minded engineers will find detailed reporting of lighting levels and distribution, luminance patterns, contrast rendition factors indicating the lighting effectiveness of the various installations studied, and other information of interest. They will also find relatively new research terminology explained and applied. Architects, application engineers, and facilities planners will find comparative data on the lighting effectiveness of a wide variety of luminaire installations. From such data they will be able to evaluate the effectiveness of their favorite light sources and installations better. It is to be hoped they also will find the information they need to improve their future lighting designs.

There has always been a concerned interest inside and outside of laboratories about how light could both help and hinder seeing. By far the greatest research and application thrust has been toward the positive aspects of light and seeing—"the more the better." Foster Sampson investigates the possible negative aspects of light and seeing. Is the amount of light on the task the real answer to effective seeing? Are there such things as *good* and *bad* footcandles? Can visual performance be adversely affected by large or small amounts of the wrong kind of light? If so, what is the wrong light? How can it be controlled or eliminated? He also poses other questions such as: Is it possible, with proper competence and instrumentation, to discover more about the positive and negative relationships of light and seeing in classrooms with a wide variety of light sources and installation patterns? Are there a number of factors that must be determined, measured, and interrelated before a valid judgment can be made about the effectiveness of any given lighting installation? How valid are some of the older theories used to evaluate lighting installations, such as the brightness ratio formulas espoused by the National Council on Schoolhouse Construction (now Council of Educational Facility Planners) some 25 years ago? Can research findings reported in proper and acceptable scientific language be made understandable to the lay public concerned with the results?

Everyone knows by experience that words or illustrations in books or magazines sometimes are much more easily seen when the top of the book or magazine is tilted upwards. They may or may not know that by tilting the reading task they are redirecting the reflections of light sources, increasing the contrast between the print and the background page and making the task easier to see. In its simplest terms, this study investigated the same seeing problem.

This investigation was carried on in 18 classrooms located in Washington and California. Each classroom laboratory was selected to add to the variety of luminaire types and installation patterns. The overall selection represents a high quality of school lighting as it would be found across the United States today. The finest available laboratory-refined instrumentation was used by a researcher who understood thoroughly both the problem and the process.

The data in this report could be used to change the order of priorities in many educational facilities budgets. We can deduce that the cost of a lighting system does not indicate its effectiveness in terms of seeing a task accurately, comfortably, and quickly. Also, we can infer that the extra lights in an inefficient lighting system will raise operating costs through consuming more electrical power and raising the room temperature which in turn increases the air-conditioning load.

When architects and engineers begin applying the information gathered in this study to the design of lighting systems for educational facilities, they may discover the happy fact that they can produce better seeing conditions for less money. After recovering from shock, all the people concerned with a building project might spend some pleasant moments redistributing some of the electrical and mechanical budget into such features as air conditioning and individualized audio-visual teaching aids.

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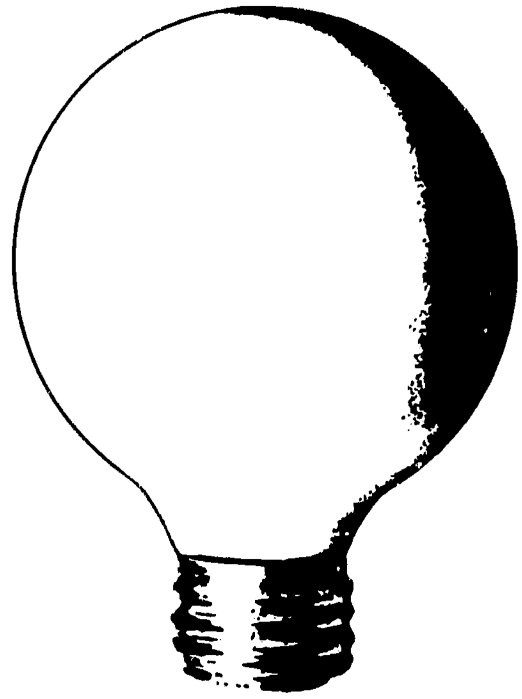
Illuminating Engineering
Research Institute

introduction



The purpose of this study was to determine how the contrasts in light from different sources affect the ability to see visual tasks in schoolrooms. How well the contrast on a visual task is rendered is called contrast rendition, and by comparing it with a controlled lighting situation we can assign a numerical Contrast Rendition Factor. So far, no one has developed the science of lighting far enough to calculate contrast rendition factors during the design of a building. But it is hoped that this report will help to establish guidelines that will eventually enable designers to compute the effectiveness of lighting in a school before it is built.

For many years, school authorities, architects, and engineers have made every effort to provide adequate and comfortable electric lighting in the most efficient manner which would be in keeping with the architecture and the budget for new construction. In almost all new installations, the levels of illumination are adequate to meet current standards, interior color selections took brightness ratios into consideration, and glare from unshielded windows was recognized and treated in one way or another. The loss of visibility due to veiling reflections was also recognized as a problem, but there were no methods to evaluate these losses accurately in actual installations, and consequently the problem was not given the importance that is now evident as the result of this study. It can now be shown that many systems in common use are less than 20% effective in terms of adequate "glare-free" illumination.

The amount of light directed toward the side walls by many systems provides less than good chalkboard lighting, and the resultant dark walls seriously reduce the visibility of pencil handwriting by not reflecting light to the task. Although there are advantages in the use of carpeting, the dark colors being used often exaggerate an already poor situation. Where recessed luminaires are used, the ceiling brightness depends almost entirely upon light reflected from the floor, and dark carpets often cut ceiling brightness by 50% when compared with similar rooms with light-colored tile floors. Dark ceilings are not desirable because of the discomfort due to high brightness differences between the ceiling and lighting fixtures and the bad effect on the visibility of pencil handwriting. In most of the rooms tested, the level of illumination four feet from the side walls was less than 50% of that found in the center of the room, and at least three benefits accrue for the systems where more light was placed around the periphery of the room:

1 The level of illumination was much more uniform.
2 The side wall and chalkboard lighting was much better.
3 The increase of light reflected from the sides of the room made a marked increase in the visibility of pencil handwriting.

The early recommendations for school lighting stressed the need for adequate levels of illumination for safety and ease of seeing. Even as late as 1930, the prime consideration was the level of illumination, and at that time only 15 to 20 footcandles was being suggested. The importance of quality was recognized by some broad guidelines which were provided to assure "comfort."

New light sources were developed and installed in systems which produced much higher levels of illumination. Usually the new systems used more fixtures, of higher brightness than in previous installations, and many occupants of these rooms became highly conscious of the discomfort and distraction from these glaring luminaires, particularly those near the line of sight. As a result, there was considerable discussion and study of this problem, and several similar but slightly different concepts of limitations were expressed in terms of brightness values for luminaires and brightness ratios based upon task and surrounding brightnesses.

Many architects, educators, and engineers came to recognize the value of brightness control for all areas in which critical seeing was done, and there were many who considered this aspect of "quality" to be more important than quantity. The need for flexibility in both quantity and quality was also recognized for those situations in which "seeing" was not critical.

In 1959, Dr. H. Richard Blackwell, an independent researcher in the field of light and vision, presented the results of his years of study at the University of Michigan under grants from the Illuminating Engineering Research Institute. Although it took time for the people concerned with illumination design to understand the completely new research techniques and to accept his work, it was finally recognized as being more important than all previous work in this field. In order to apply his findings to the practical problems of how much light was necessary for critical seeing, Dr. Blackwell developed the "Visual Task Evaluator" to make visual assessments of specific "tasks" and relate them directly to his research findings. From this information, Blackwell could determine a positive level of footcandles.

Many of the findings came as a surprise because of the wide differences in required levels for common school and office tasks.

For example:

Task	Footcandles
Ink handwriting	1.4
8-point Bodoni type	1.9
8-point Textype	1.1
Typed original, good ribbon	1.0
Transcribing #3 pencil shorthand	76.5
Typed carbon, fifth copy	133.0
Thermal reproduced copy, poor quality	589.0

Samples of pencil handwriting were taken from a group of schoolchildren. It was found that they illustrated a wide variety of characteristics from large to small in size and from dark to light in contrast, and the average sample required 63 footcandles of glare-free illumination. By definition, glare-free illumination results from a uniformly lighted hemisphere over the task. Because pencil handwriting is a commonly found, difficult seeing task in a classroom, it has been accepted by many as the basis for recommending 70 footcandles for classroom lighting.

At about this time, a task committee was made up of representatives of the American Institute of Architects, The National Council on Schoolhouse Construction, and the Illuminating Engineering Society. This committee was engaged in gathering information and rewriting the Illuminating Engineering Society "Recommended Practice on School Lighting," and one team working with John Chorlton of Toronto, Canada, made tedious and painstaking measurements of the loss of contrast in pencil handwriting under different lighting systems. The purpose of this study was to find a way to make these measurements and report on visibility losses due to veiling reflections. It was found that the basic research data was clear in showing that each 1% loss in contrast required a 15% increase in illumination, if the characteristics of visibility were to be maintained equal.

Precise laboratory measurements were made, using pencil dots as the target, and these studies indicated that losses of contrast might easily exceed 20% under some lighting systems. Interpreting these facts into the required levels of illumination for different systems meant that even the best lighting systems would have to produce much more than 70 footcandles, and the poor ones would require several times the glare-free requirement, just to compensate for the contrast losses due to veiling reflections caused by the lighting system.

This development created a stir within the lighting and design industry. Other men in the design and engineering field made crude measurements and presented papers proving the importance of this consideration. The photographs in Figure 1 illustrate the losses in contrast for several visual tasks under three distinctly different and extreme conditions of lighting. Through the process of preparing pencil targets and making gross measurements, it was soon recognized that commercial photometers available at that time were not capable of making accurate measurements using the Visual Task Evaluator under the same lighting system.

These findings made three major advancements mandatory before accurate testing of existing systems could begin. A photometer and the mechanical devices had to be developed which would allow and provide accurate readings of the "background" paper and the "target" area at several viewing angles. Second, the large, heavy, and complex Visual Task Evaluator had to be simplified and made portable if it was to be a useful field instrument. Third, a standard pencil target had

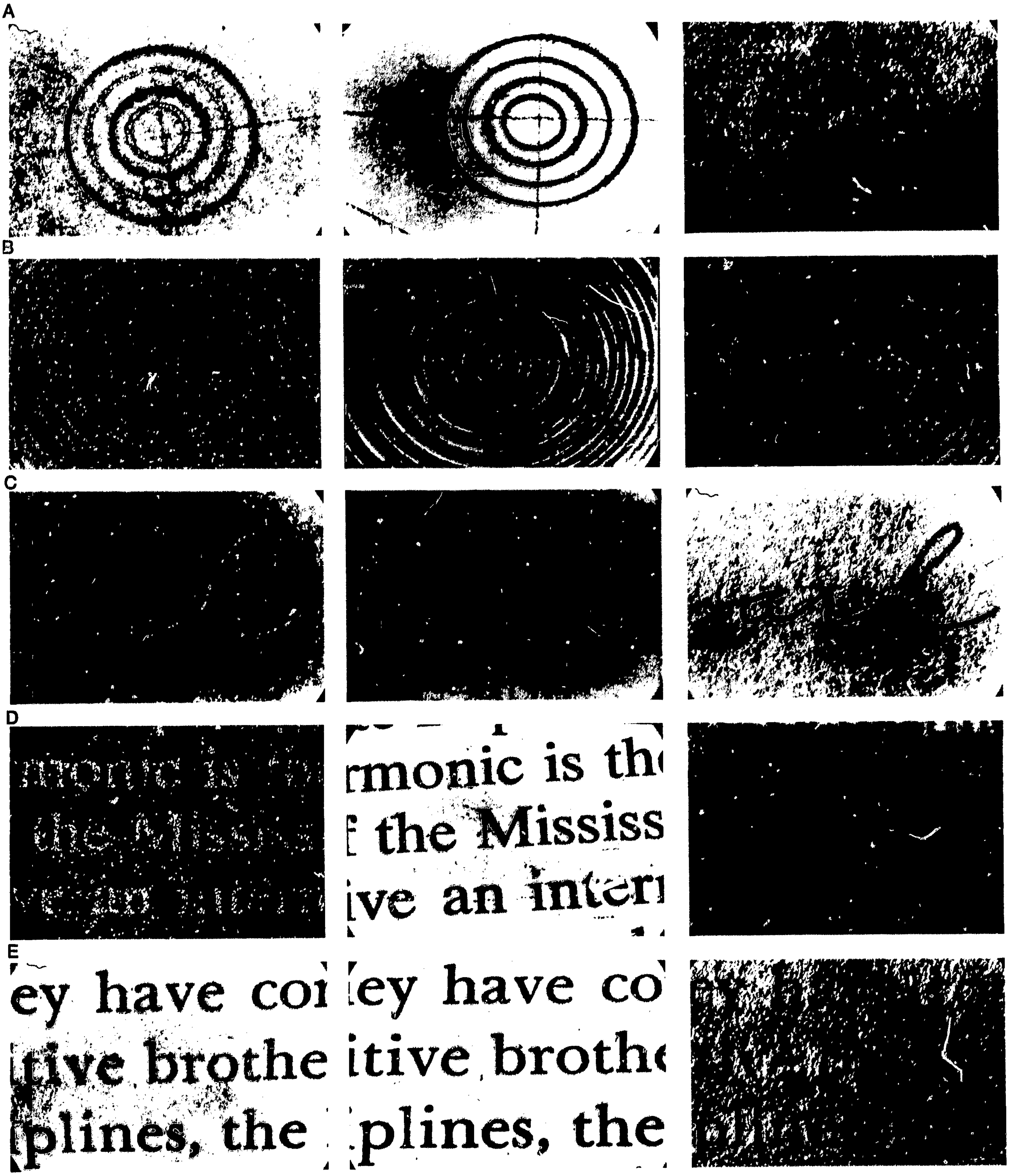


Figure 1
The five samples were photographed under three distinctly different lighting systems. The left hand column had a single light source at the critical angle over the task; the center column was under the glare-free lighting of a uniformly bright hemisphere placed over the task; and the right hand column was lighted from a single lamp located behind the line of sight of the camera. The target on line A has two circles made with a nylon tip pen and two circles of #2 pencil on soft paper. Line B is the actual target used in the photometric equipment for the contrast rendition values. These are very carefully and accurately made pencil lines in concentric circles. The target on line C is a pencil handwriting sample with the same contrast and specularity characteristic as the target immediately above. The printed target on line D is glossy ink on glossy paper, and the target on line E is reasonably matte in all respects.

The following observations can be made. The apparent visibility of all tasks in the center column is very good, and there are no serious losses due to the uniform overhead light source. The right hand column clearly shows that pencil lines in particular are made easier to see by concentrating the light from the sides and behind instead of from overhead. The left hand column accentuates the losses from light at the critical angle. The only two target elements that show no serious loss are lines A and E. The nylon tip pen target and the matte black ink on soft paper show very little loss of visibility. All the pencil targets and the glossy printing sample have virtually disappeared. In fact the black glossy ink actually appears brighter than the paper.

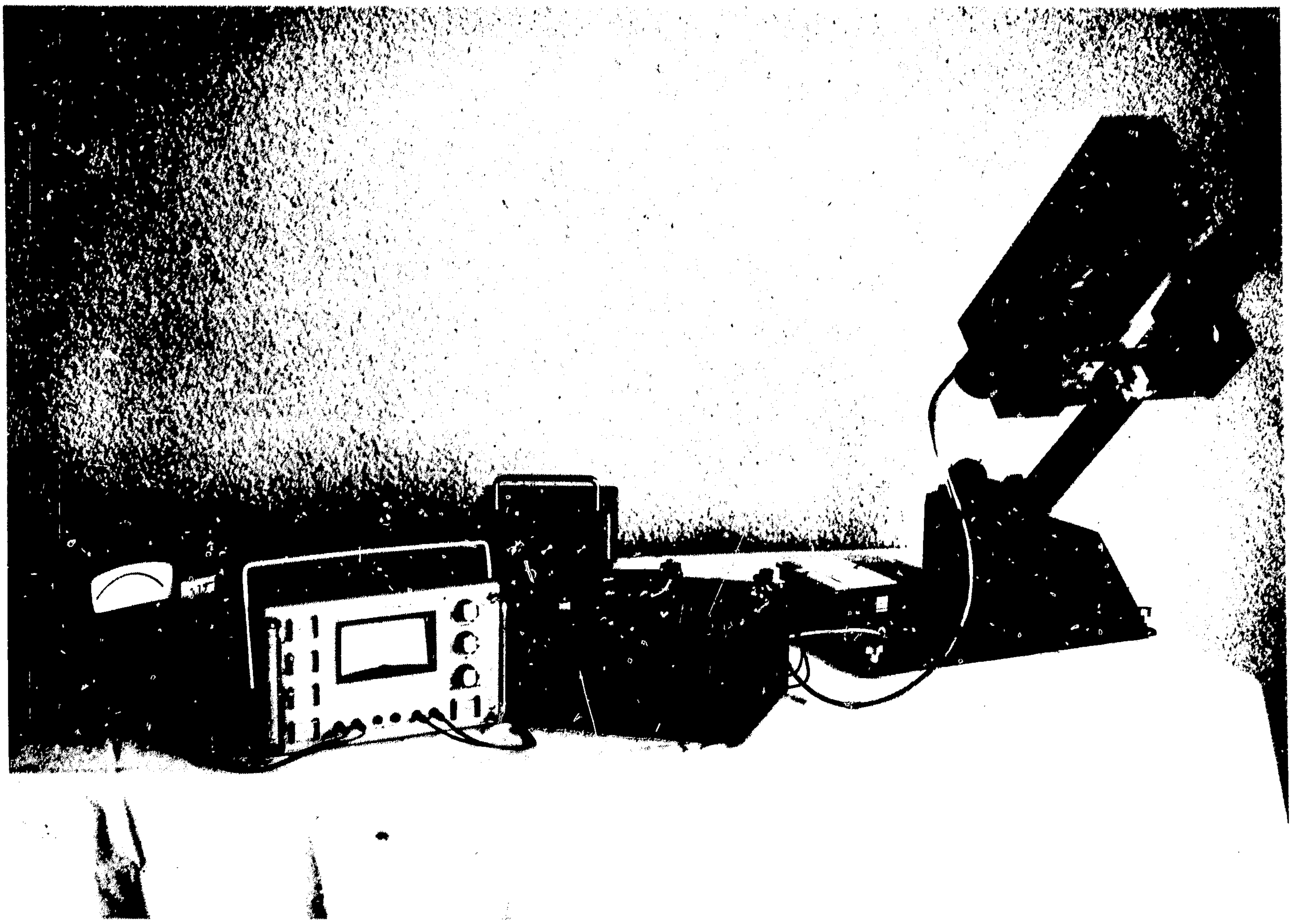


Figure 2—Visual Task Photometer

to be developed which would have the same contrast and reflective characteristics as handwriting, and a method had to be devised by which this standard could be reproduced so that more than one could be made available for other researchers.

The difficulties encountered in developing all of the instruments and target samples were numerous; however, the devices and refinements were in a continuing state of improvement, and laboratory reports and research findings kept the industry informed of the progress. As the instruments and targets were refined, visual evaluations using the Visual Task Evaluator and contrast measurements using the Visual Task Photometer were made under different lighting systems, and it has very recently been established by Dr. Blackwell that the contrast measurements *do* agree with the findings of studies made with the portable Visual Task Evaluator.

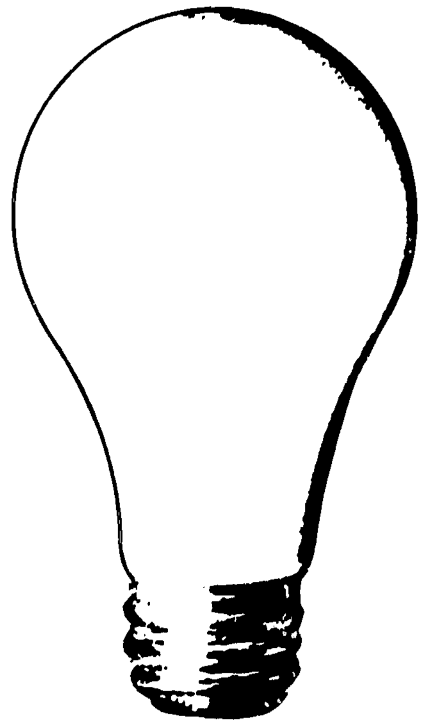
The Visual Task Photometer, Figure 2, is a sophisticated combination of a photometer, with meters, balancing electrical circuits, and a mechanical support for the photometer, and "task" target. The photometer is supported on a pivoted arm which can be moved in a vertical plane, and a scale is built in to indicate the "viewing angle" which can be established from 0°, or straight down, to 60° from the vertical. At all viewing angles, the photometer is directed at the same small area on the task carriage. The task is a pattern of concentric circles drawn with a pencil on white paper mounted on a rigid plastic backing which can be carefully protected when not in use but which can be secured to the carriage for making measurements. When the "background" button is activated on the meter turret, the carriage positions the task so that the background paper is exposed to the photometer. When the task button is activated, the carriage moves automatically to expose the pencil task to the photometer. In making an evaluation, the entire meter with all of its components is set in the desired location in the room, and all the circuits are checked and balanced. By careful operation of the meter complex, a direct reading of the flux contrast is obtained. At least five readings are made for each condition, and these values are then averaged. The Contrast Rendition Factor (CRF) is determined by dividing the flux contrast for the test condition by the flux contrast found at the same angle of viewing when lighted by a hemisphere of uniform brightness. In other words, if the flux contrast under glare-free lighting is considered to be 100%, then the CRF is the percentage of glare-free lighting developed under the test condition.

The author has had a continuing interest in the subject of school lighting in general and contrast rendition in particular, so, when it appeared that equipment would be available for field use, application was made to Educational Facilities Laboratories for assistance in conducting a field study and publishing the results. Fortunately, the project was accepted.

At this time there were only five Visual Task Photometers in existence, and again the author was fortunate in having one made available from Dr. Blackwell. The Illuminating Engineering Research Institute has been the prime supporter of research and development of instruments for this phase of illumination, and it was from this organization that funds were made available for the rental of the instrument.

It is the purpose of this survey to make measurements of contrast rendition under a wide variety of classroom lighting systems in order that comparisons can be made and conclusions drawn which will be helpful to educators and engineers in their selection of future classroom lighting systems.

procedure



The prime objective of this survey is the evaluation of significantly different classroom lighting systems to determine their characteristics regarding contrast rendition of pencil handwriting. In order that the recorded information can be studied in detail and comparisons made, several related aspects of the total environment were considered essential. For this purpose drawings, tables of illumination levels, tables of brightnesses, and photographs, as well as Contrast Rendition Factors are provided for each project, starting on page 17.

The classrooms studied are identified by a project number and the basic lighting systems are as follows:

Project 1	Single-lamp, surface-mounted diffusers, 12″ wide in continuous rows, 5′-0″ on center.
Project 2	Polarizing luminous ceiling.
Project 3	Four-lamp, surface-mounted, lens wraparound, 16″ wide in continuous rows, 10′-0″ on center.
Project 4	Semi-indirect, perimeter type, suspended, using very high output lamps.
Project 5	Wall-mounted coves, using very high output lamps.
Project 6	Luminous coffers, 5′-0″ square, each using two lamps, shielded by plastic diffuser.
Project 7	Single-lamp troffers, 24″ wide, diffusing panels, continuous rows 4′-0″ on center.
Project 8	Six-lamp, 48″ square, surface-mounted, lens bottom units, 10′-0″ on center, both ways.
Project 9	Luminous ceiling with vinyl plastic diffusers.
Project 10	Four 11′-6″ square coffers, indirectly lighted by coves on the side of each coffer.
Project 11	Two-lamp, surface-mounted, 13″ wide, lens wraparound in continuous rows, 7′-0″ on center.
Project 12	Two-lamp troffers, 24″ wide lens panels, continuous rows, 6′-0″ on center.
Project 13	Two-lamp, semi-indirect 13″ wide, plastic wraparound lens, in continuous rows, 7′-0″ on center.
Project 14	Four-lamp, recessed, 5′-0″ square diffusing panels in checkerboard arrangement.
Project 15	Two-lamp, recessed, 24″ wide, lens panels in a continuous perimeter pattern with a single group of units in the center of the rectangle.
Project 16	Two-lamp, recessed, 12″ wide, lens panels, in continuous rows, 7′-0″ on center.
Project 17	Two-lamp, surface-mounted, 13″ wide, lens wraparound, in continuous rows, 10′-0″ on center.
Project 18	Two-lamp, high output, suspended, semi-indirect, in continuous rows 10′-0″ on center.

A scale drawing of each project classroom shows the floor plan, each of the four side walls laid flat beside the related side of the plan, and the reflected ceiling plan. Each location at which a measurement was made is shown by a dot on the drawings, and each dot is identified by a number. Numerals from 1 to 24 are enclosed in circles, and these establish the positions at which levels of illumination are recorded. Numerals 25 and above are enclosed in hexagons and indicate the locations of brightness readings. Positions of the Visual Task Photometer are shown as M1, M2, etc. They are enclosed in triangles with the apexes pointing to the direction of viewing. The meter position and direction of viewing is shown on the ceiling plan to show the relationship with the luminaires.

Levels of illumination were recorded for 13 locations within the normal seating area of the classroom and in two or more locations on chalkboards. Three sets of readings are reported across the room, the first set is 4′-0″ from the front of the room, the second is across the center of the room, and the third is 4′-0″ forward of the rear wall. Each of the three sets has three locations, one at the center of that group and one at each end, 4′-0″ in from the side walls. These are numbered 1 through 9. Another set of four readings, numbered 10 through 13, are located on the quarter points of the diagonals of the room. These 13 readings were taken 30″ above the floor and with the meter placed horizontally on a tripod. Readings on chalk-and tackboard were 5′-0″ above the floor and in a vertical plane.

In some projects, the quantity of daylight was so low that all readings were taken including the daylight, but this small contribution was ignored because it did not affect the basic results of this survey. Some rooms had relatively large window areas, but were so shielded by arcades and adjacent buildings that the blackout curtains were closed and the results shown only for the electric system. Where daylight was available to provide a reasonable level in itself, readings were made under three situations; daylight only, electric light only, and with a combination of the two. Where multiple conditions of lighting levels are reported, readings were usually made under the same circumstances for brightness and contrast rendition.

Brightness readings were taken with a Spectra Spot meter which covers an area of 3″ at 10′-0″, and the brightness is read directly in footlamberts. The meter was mounted on a tripod at seated eye height, and all readings were taken from a location in the center of the room and about 6′-0″ from the rear wall. The number of locations at which readings are recorded vary, depending upon the character of the room and lighting conditions. In the table of "Brightness Distribution" for each project, the location of each reading is further described with the character of the surface, its color, reflection factor, and actual brightness in footlamberts. In each case, the reflection factor was computed from a direct brightness reading taken on a surface of known reflection factor, and the direct reading from the surface itself. Although this is not considered "accurate laboratory practice," the error is not significant so long as values are recognized as approximate rather than absolute.

Readings with the Visual Task Photometer were taken near the center rear of the room. The meter position "M1" was from 6′-0″ to 9′-0″ feet from the rear wall in the approximate center of the room, and the photometer was located so that the "mirror image" of a lighting element fell directly on the task when being viewed at 25°. Meter position "M2" was at the same distance from the rear wall, but the meter was moved sideways to a point where the mirror image falling on the task, when viewed at 25°, was a point on the ceiling area halfway between rows of fixtures or lighting elements. Where unusual circumstances required a variation in this procedure, or additional locations are reported, a description of the meter position is given as well as the reason for the variation.

Many studies have been made to establish the most commonly found viewing angle for tasks on a desk or table top. These angles are found to vary with individuals and with the nature of the work being performed. However, the most common angle is very close to 25°, and for this reason 25° has been chosen for the prime angle of consideration. On the other hand, viewing angles as low as 40° from the vertical are not uncommon, and these were measured and reported for the benefit of anyone who might want to extend the computations. Viewing angles of 60° are sometimes found, but the general consensus is that the factors of visual distortion of the task, and the greatly increased viewing distance, are far more important than the loss of contrast at this low angle.

Photographs were made from at least two locations to show the basic character of the room and to give an approximate idea of the ranges of brightness found in the space. By studying the drawings, photographs, and tables of "Brightness Distribution," a good idea can be developed of the total visual environment.

A photograph into a spherical mirror is presented to give an idea of the brightness distribution in the entire space in one exposure. For this picture, the camera was placed about 5′-6″ above the mirror, which was on a horizontal table top in the center of the room. The image is distorted but the range of brightness and relative positions and sizes can be approximated.

To show the quality of shadow and form rendition by each system, a group of geometric forms was photographed on a desk located in the center of the room. The cube is 1½″ on each side, the cylinder is 1½″ diameter and 1½″ long, the hemisphere is 2″ diameter, and the 1/4″ dowels are 7″ long. All are painted gloss white. The minimum shadow is shown to exist under systems of luminous ceilings and indirect lighting, and the maximum shadow is formed where luminaires are small or widely spaced, or both. Shadows do form under the dowel rods when they lie parallel to continuous rows of direct type fixtures, yet the shadow is not apparent where rows of fixtures are at right angles.

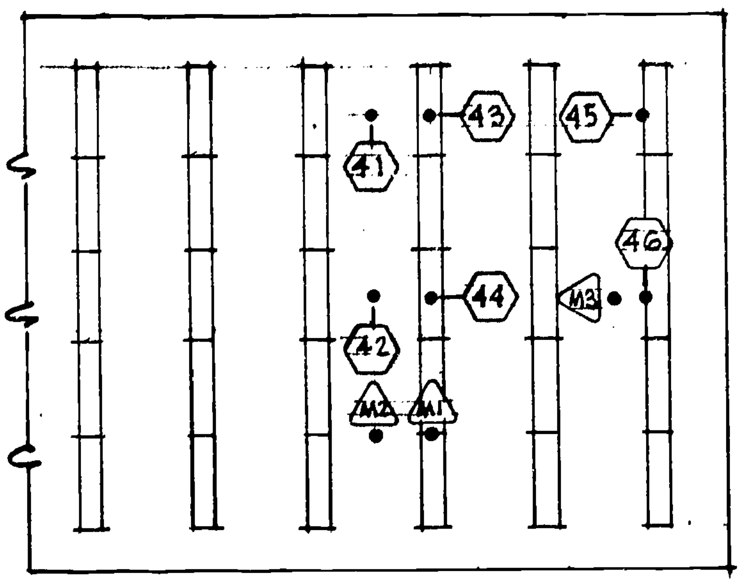
In each room, the pencil handwriting sample "ark" was photographed at a 25° viewing angle at the M1 meter position. This is probably one of the poorer locations in the room except possibly for locations on the extreme edge or in corners. The M1 position is selected so that reasonable comparisons can be made between systems. The same task has been photographed under a luminous hemisphere, and a print is shown beside each project photo for visual comparison. The problems of making accurate comparisons of contrast rendition by photographic procedures in the field are too numerous; however, this might be possible under the extreme controls which are possible in the laboratory. The difference in contrast rendition in the photographs may not be immediately seen in all of the examples; however, the gross losses developed by the poor systems are immediately obvious.

Three values are shown with each project, for each meter position, with electric light, and in some cases additional values are shown for other combinations of daylight and electric light. Task Illuminance (TI) is the actual level of illumination in footcandles measured at each position and under each lighting condition. Contrast Rendition Factor (CRF) is the value established by the Visual Task Photometer, shown in Figure 2, and this value is the measure of capability of the installation to render contrast as compared with the quality of illumination within a uniformly illuminated sphere. The CRF depends upon several variables, such as the physical size of the light source, the character of light distribution, and the location of the sources in relation to the task. The third factor, Equivalent Sphere Illuminance (ESI) is the level of glare-free or sphere illumination which would provide the same degree of visual accuracy as that developed by the installation being surveyed. In Project 1 for example, at the M1 position the system provided a T1 of 62 footcandles under the electric lighting, the CRF was found to be .882 and the ESI was equal to only 27.6 footcandles of sphere illuminance. These three values, when taken together, allow several basic comparisons between installations.

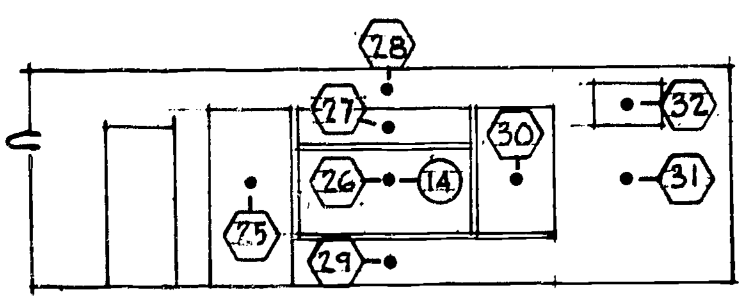
The measurements were all made with care and precision, and they are correct for each particular test room. The same lighting system in another room will produce very nearly, but not necessarily exactly, the same effects. The differences would result from variations in the room size, and the reflectance of walls, ceiling, floor, and furniture. The extreme differences found in the ESI values show the wide variations in basically different systems. However, care should be taken not to draw too fine a line between installations which produce nearly comparable values.

project 1 description

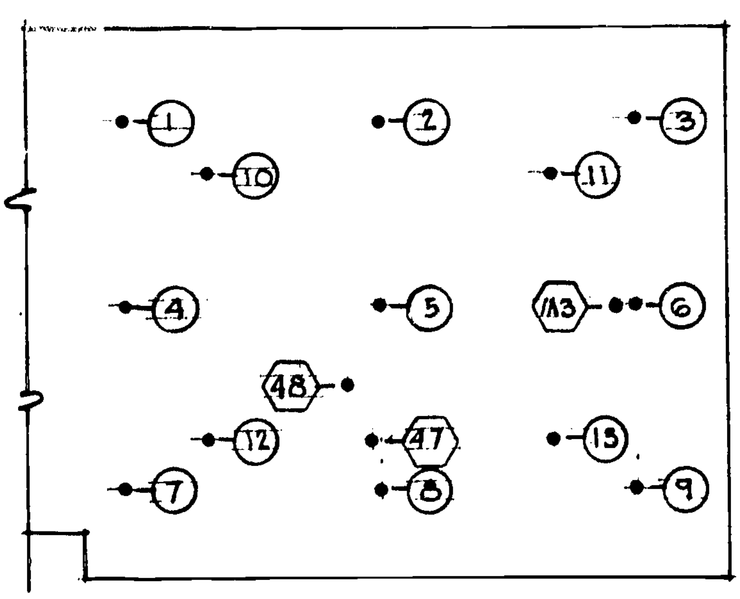
The room is 24′-0″ wide, in excess of 36′-0″ long, and the ceiling height is 9′-6″. The drawing includes one end of the room, and the test locations were selected to simulate a 30′-0″ long room. The lighting consists of continuous rows of five 12″ wide, surface-mounted diffusers, with rows spaced 5′-0″ on center. Each luminaire has one 40-watt rapid-start lamp. There are large, clear glass windows facing north and equipped with blackout curtains. The levels of illumination are given for the electric lighting, day lighting, and the combination of the two.



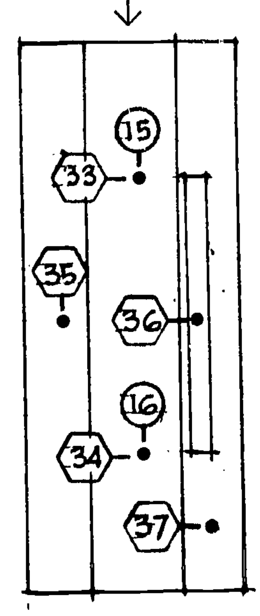
Reflected Ceiling Plan



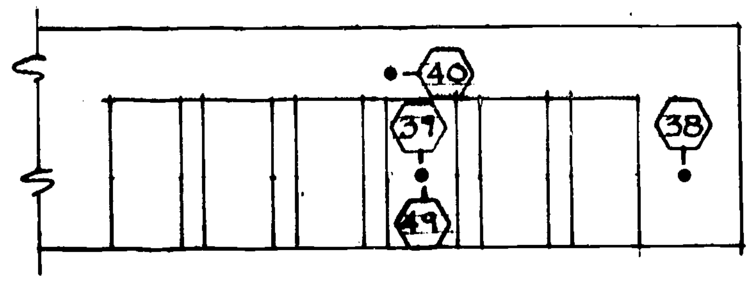
Wall Elevations



Floor Plan



Wall Elevation



The uniformity of electric lighting levels in this space is excellent, and probably results from the relatively large number of sources and the fact that they cover well toward the side walls.

The environment brightnesses are quite acceptable except for the unusually dark tackboards, chalkboards, and blackout curtains. The contribution of daylighting improves the brightness balance except for the extreme brightness of the unshielded window exposure to the north sky.

lighting levels

Location	Footcandles		
	Electric	Daylight	Combination
1	69	24	93
2	66	28	94
3	57	25	82
4	75	37	112
5	74	63	137
6	69	37	106
7	66	90	156
8	60	160	220
9	51	46	97
10	78	30	108
11	72	29	101
12	72	105	177
13	66	90	156
14	45	66	111
15	51	36	87
16	51	45	96


brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness Elec.	Day	Comb.
25	Tackboard	Tan Burlap	31%	15	18	33
26	Chalkboard	Green	15%	7	16	23
27	Tackboard	Slate Green	13%	6	8	14
28	Paint	Cream	55%	20	30	50
29	Paint	Cream	55%	20	35	55
30	Tackboard	Tan Burlap	31%	14	17	31
31	Paint	Cream	55%	25	26	51
32	Window to corridor		—	25	25	50
33	Tackboard	Tan Burlap	31%	20	12	32
34	Tackboard	Tan Burlap	31%	20	15	35
35	Paint	Cream	55%	19	22	41
36	Tackboard	Slate Green	13%	10	6	16
37	Paint	Cream	55%	34	17	51
38	Paint	Cream	55%	21	10	31
39	Blackout Curtain	Green	6%	25	—	—
40	Paint	Cream	55%	22	19	41
41	Acoustic Tile	White	80%	17	19	36
42	Acoustic Tile	White	80%	20	28	48
43	Fixture Diffuser		—	280	—	300
44	Fixture Diffuser		—	390	—	410
45	Fixture Diffuser		—	350	—	370
46	Fixture Diffuser		—	360	—	380
47	Desk Top	Birch Formica	37%	22	51	73
48	Floor	Oak Wood	38%	10	20	30
49	Window		—	—	1750	1750

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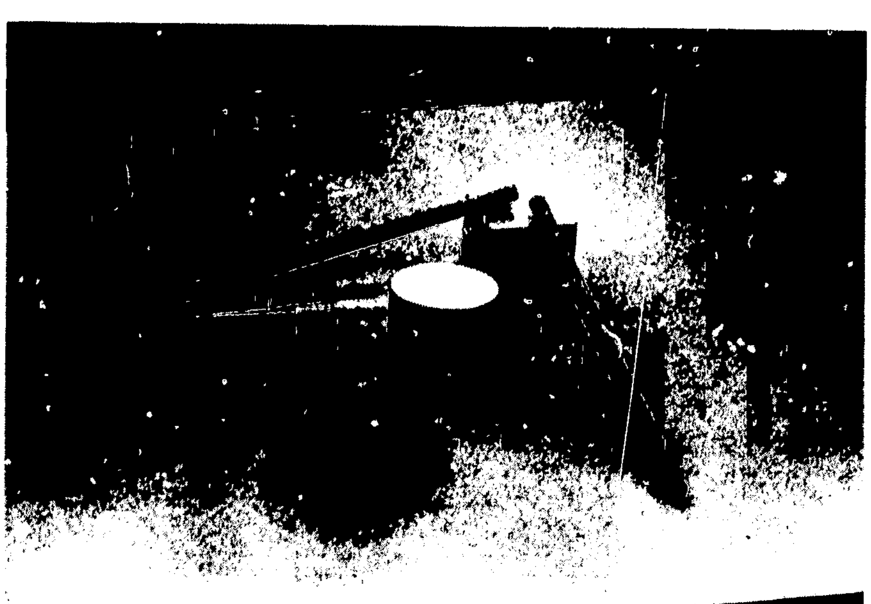
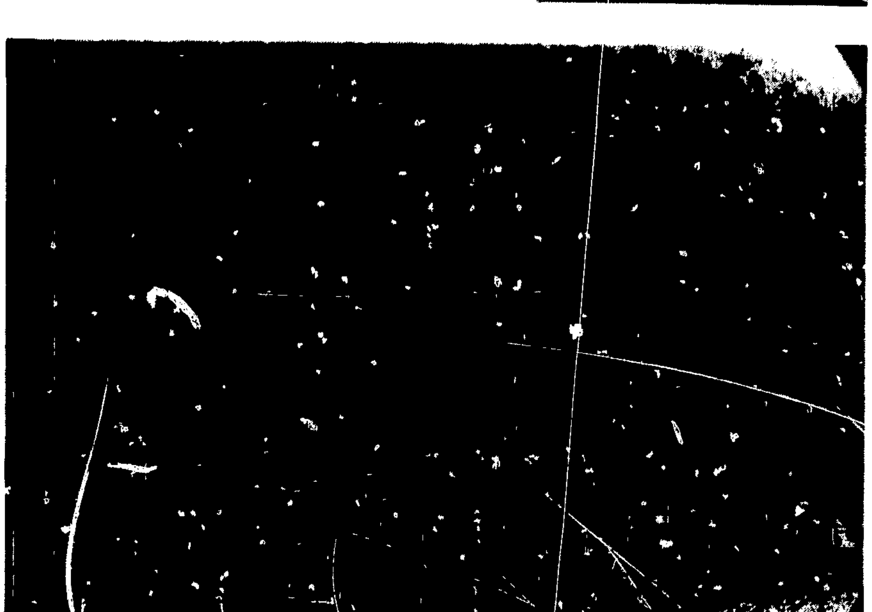
project 1 evaluations

Quality	Location M1	M2	M3
TI (electric only)	62	61	69
CRF	.882	.925	.892
ESI	27.6	35.8	32.1
TI (electric & daylight)	172	188	106
CRF	1.03	1.05	1.00
ESI	220.8	279.2	106.1

The ESI values are all fairly low in spite of good CRF, and this is due to the low level of the general lighting. The difference between M1 and M2 is reasonably small, no doubt due to the relatively close spacing of the rows. Although the difference between M1 and M3 is very small, this is some indication that rows of luminaires transverse to the line of sight cause somewhat less loss than those in line. This is also verified in Project 3.

The addition of daylight makes a remarkable improvement in the ESI where the line of sight is away from, or at right angles to, the direction of the windows. No readings were taken to simulate children looking towards windows because the veiling reflectances would be bad and the discomfort even worse.

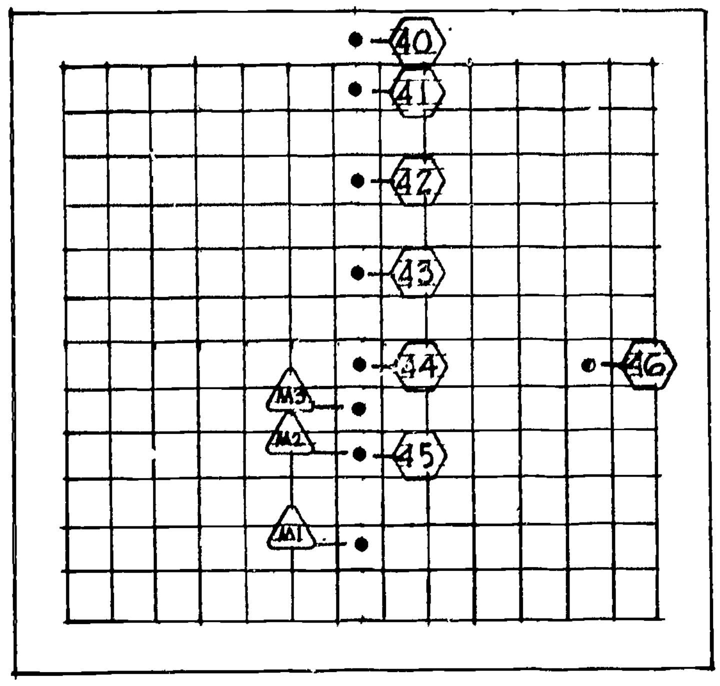



Sphere Quality

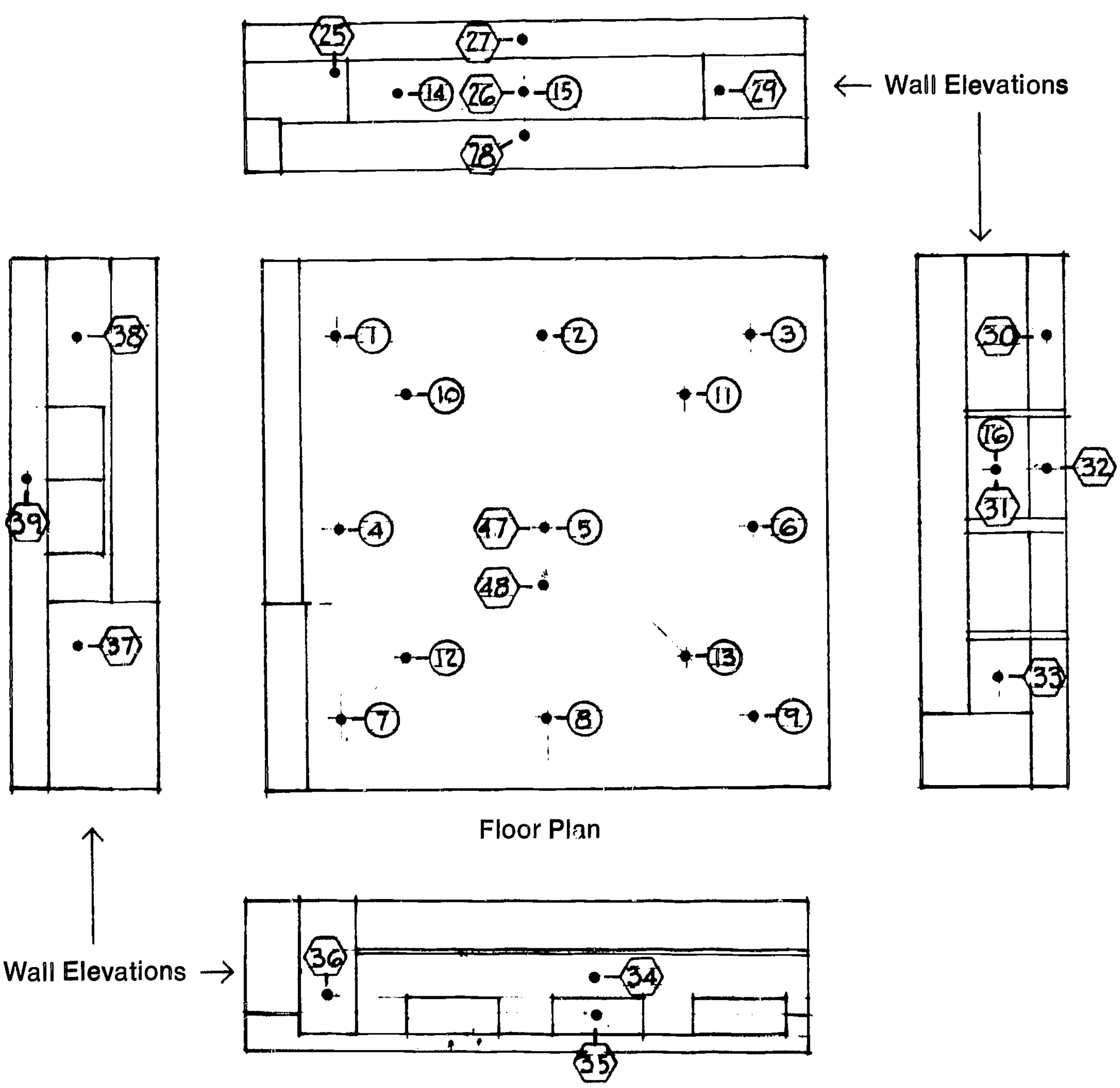

Project Quality

project 2 description

The room is 28'-6" x 31'-0" and the ceiling is 8'-0". The lighting system is a luminous ceiling of polarizing plastic. The luminous area is 24'-0" x 26'-0" made up of 2'-0" square panels on T bars. There are 12 strips of 3, 96", 430 m.a. cool white, slimline lamps mounted 16" above the diffusers. The plenum space immediately above the lamps is lined with aluminum foil-faced kraft paper. Two sets of illumination levels are shown here, one with daylight only, and this is supplied through the three 2'-0" high x 5'-0" wide windows set high in the north wall. Each window is glazed with low transmission glass to reduce the direct glare from adjacent buildings. The quantity of daylight is so small that it has little or no effect on contrast rendition.



Reflected Ceiling Plan



Floor Plan

ERIC

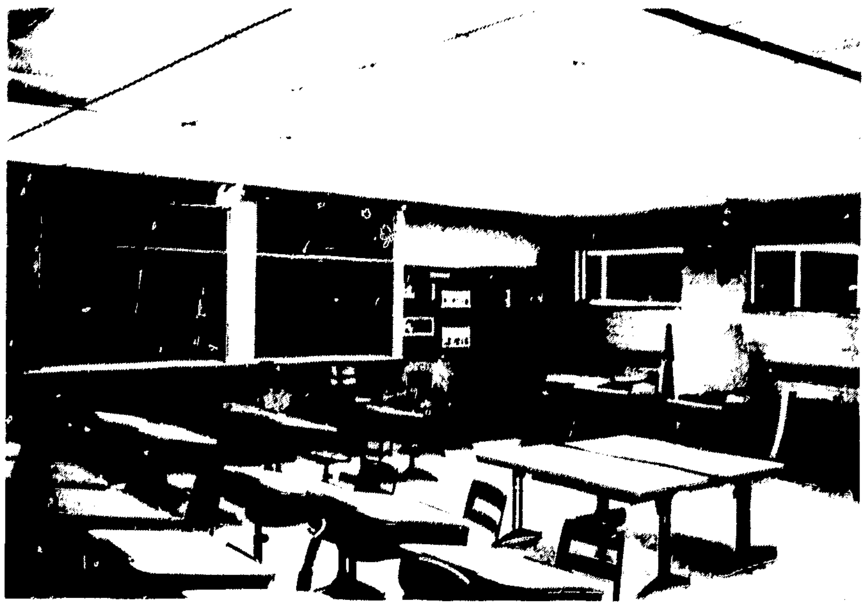
The uniformity of lighting levels in this room is not particularly good in that the four corners are only about 55% of maximum. Had the luminous area been run closer to the side walls, and had the side walls been finished in colors of higher reflectance, the lighting around the periphery would have been better. The front wall in particular has dark chalk- and tackboard over the entire surface above the 30"-high chalk rail.

The fact that so little light falls upon the walls makes the entire room appear to have low levels of illumination. Even those surfaces with light-colored finishes barely meet the minimum brightness recommendation, based upon task brightness at the M1 position.

The use of low transmission glass in the small windows was good in that the windows would have been a glare source had clear glass been used. Also, the floors are particularly good, and the high reflectance here was of considerable value in brightening the room. The large luminous ceiling area was exceptionally comfortable. The most restrictive of current "recommendations" will accept a large area source of high brightness which does not exceed three times task brightness. In this project, the maximum brightness occurs directly overhead and, even at this extreme angle, it is considerably below the allowable brightness limit.

lighting levels

	Footcandles	
Location	Daylight	Day and Electric
1	.4	69
2	.8	79
3	.8	66
4	.6	105
5	1.6	120
6	1.5	96
7	.4	66
8	1.6	85
9	2.4	69
10	.6	102
11	.9	99
12	1.0	111
13	2.2	105
14	—	42
15	—	45
16	—	42



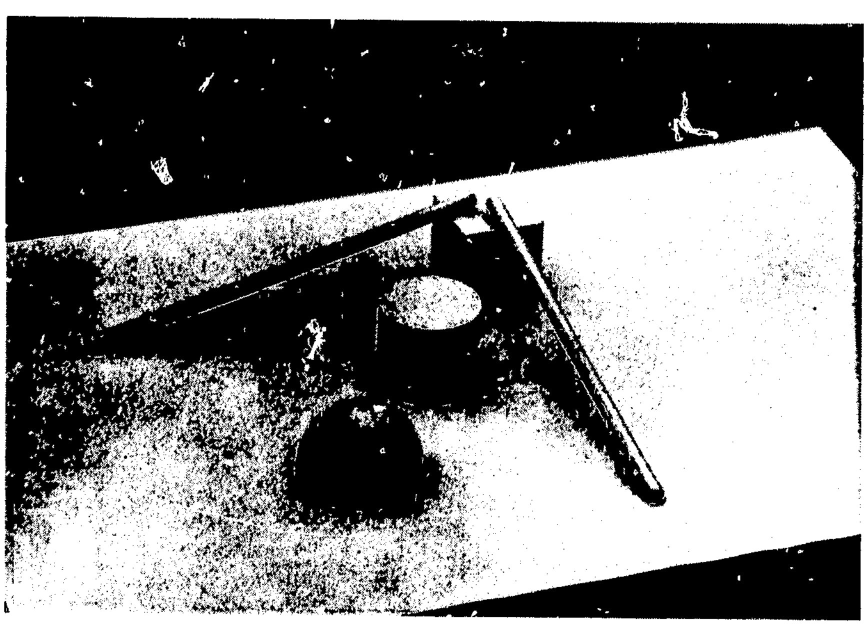
brightness distribution

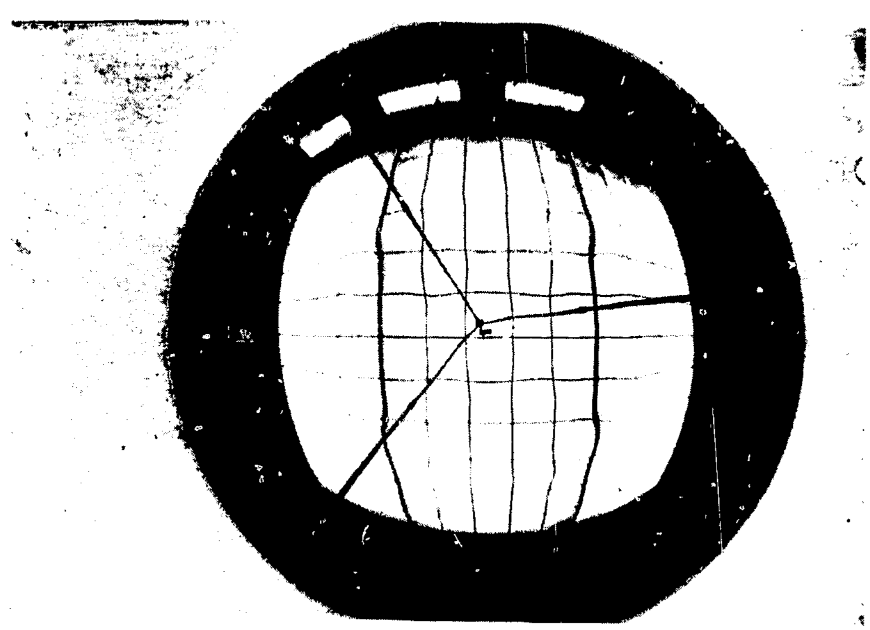
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Vinyl Tackboard	Blue Grey	22%	8
26	Chalkboard	Slate Blue	19%	8
27	Vinyl Tackboard	Blue Grey	22%	7
28	Vinyl Wall	Blue	45%	18
29	Vinyl Tackboard	Blue Grey	22%	9
30	Acoustic Tile	White	75%	21
31	Chalkboard	Slate Blue	19%	9
32	Chalkboard	Slate Blue	19%	8
33	Vinyl Tackboard	Blue Grey	22%	10
34	Painted Brick	Green	65%	29
35	Sky thru Glass	(14% transmission)		225
36	Painted Door	Green	62%	20
37	Wood Cabinet	Natural Birch	22%	15
38	Vinyl Tackboard	Blue Grey	22%	9
39	Acoustic Tile	White	75%	30
40	Acoustic Tile	White	75%	30
41	Light Polarizer	White	—	45
42	Light Polarizer	White	—	55
43	Light Polarizer	White	—	63
44	Light Polarizer	White	—	100
45	Light Polarizer	White	—	145
46	Light Polarizer	White	—	85
47	Vinyl Floor	Grey	43%	33
48	Desk Top	Birch	46%	41

project 2 evaluations

Quality	Location		
	M1	M2	M3
TI	100	115	118
CRF	.900	.939	.932
ESI	46.1	72.6	70.0

Only four projects had higher ESI values at the M1 position, and this project would have had a much better rating if three factors were different. The luminous portion of the ceiling should have been extended to the wall to provide light on the wall. Also the wall colors above the chalkboard line should be nearly white, and all tackboards should have been as high in reflectance as possible. The effect of the extremely dark front wall is seen by the reduction of ESI value at M3 as compared with M2.



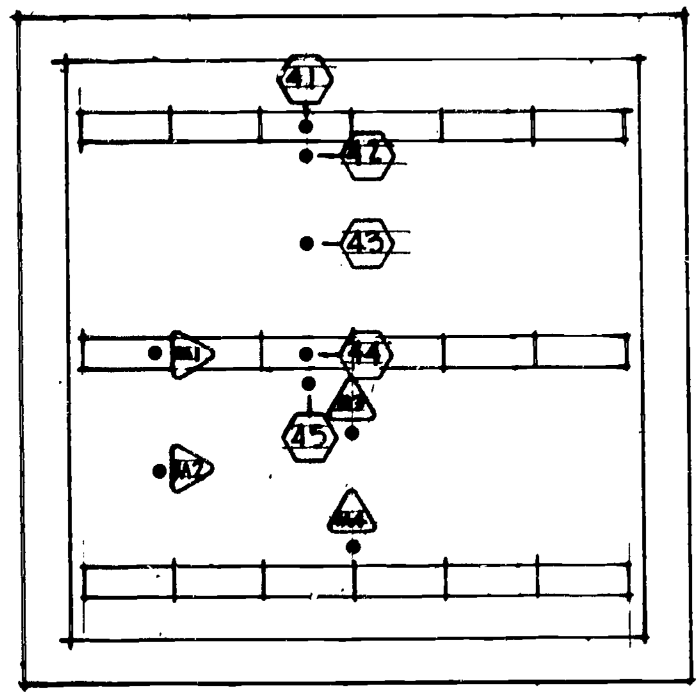


here Quality

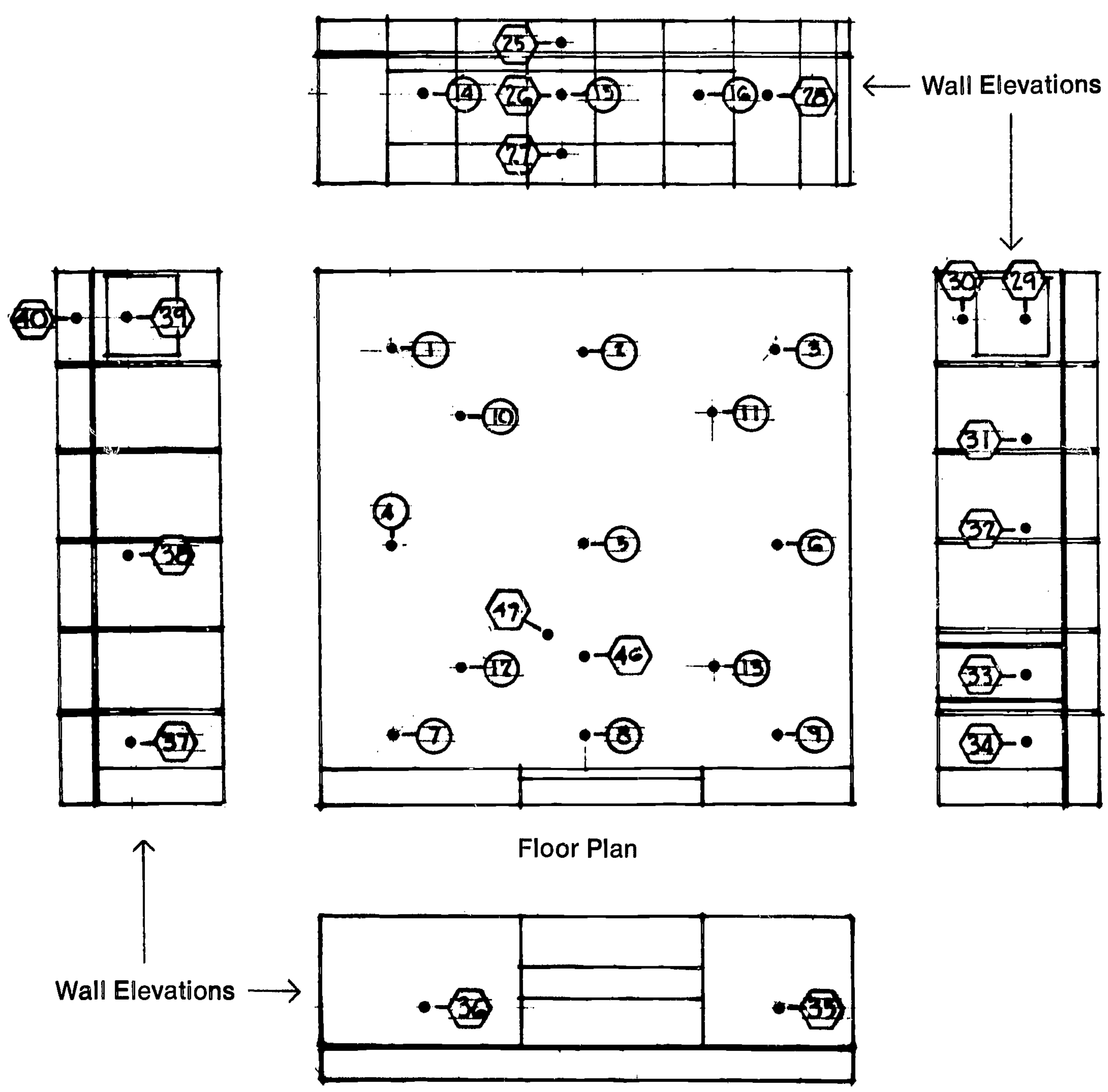
Project Quality

project 3 description

The classroom is 29′-0″ x 29′-6″, and the ceiling height is 9′-0″. The lighting system consists of three rows of six, 4′-0″ plastic, lens-type wraparound units, surface mounted. Each luminaire has four lamps; all of the outside pairs of lamps in each luminaire are switched together, and all of the center pairs of lamps are separately switched. The large windows are covered with Venetian blinds. The only daylight in the room comes through two small transom windows close up under a projecting eave. There are small glass areas high on the opposite side which look into the central corridor of the building. Daylight readings shown in the table have all room lights "off," but this does not include the contribution of the corridor lighting. The illumination in this room from any source other than the electric system is so low as to have no effect on the contrast readings.



Reflected Ceiling Plan



From the table of illumination levels it can be seen that there is little or no difference in the quantity of illumination produced on the horizontal by the inner and outer pairs of lamps. However, the outer pair should, and does, produce a somewhat higher level on the chalkboard. This room has only 856 square feet, therefore the degree of uniformity is somewhat higher than it would have been with the same number of luminaires in a larger room of 960 square feet. Four lamp units were used to provide added heating when required, and only two lamps are normally used during "warm" weather.

The chalkboards and tackboards have low reflection factors, and together they add up to quite large areas of too dark space. The natural brick surfaces add to the already dark surround. Any one of these surfaces, taken alone, might not be objectionable; however, the three together develop a dark environment for the bright lens luminaires which are in themselves quite bright, particularly the sides of the units when the outside lamps are used. All brightness readings in this room were taken from the M4 position. This room demonstrates the need for lower brightness ratios at higher levels of illumination because it is said that the system is seldom used with all four lamps because of the high luminaire brightness. A look at the Brightness Distribution table shows that the luminaire brightness is somewhat less than double with all four lamps, and the level of illumination is double.

lighting levels

		Footcandles		
Station	Daylight Only	Center Rows of Lamps	Outer Rows of Lamps	Daylight plus All Four Lamps
1	4	81	84	169
2	1	114	117	232
3	1	81	81	163
4	2	98	99	199
5	1	129	128	258
6	1	93	93	187
7	3	88	86	177
8	1	114	114	229
9	1	78	75	154
10	3	105	102	210
11	1	102	99	202
12	3	99	99	201
13	1	96	91	188
14	4	47	47	98
15	2	54	59	115
16	2	47	52	101

brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness Ctr. Pair	Outer Pair	Both Pairs
25	Painted	Ivory	80%	32	43	72
26	Chalkboard	Grey	24%	13	14	25
27	Painted	Ivory	80%	42	45	82
28	Tackboard	Tan	34%	15	18	30
29	Chalkboard	Green	32%	10	11	19
30	Brick	Umber	18%	7	7	14
31	Tackboard	Tan	34%	10	12	21
32	Tackboard	Tan	34%	15	15	28
33	Door	Natural Birch	26%	9	10	15
34	Brick	Umber	18%	7	8	13
35	Cabinet	Natural Birch	26%	15	15	26
36	Cabinet	Natural Birch	26%	19	19	32
37	Brick	Umber	18%	8	9	14
38	Venetian Blind	Cream	57%	22	25	42
39	Chalkboard	Green	32%	13	14	21
40	Plaster Soffit seen through window			—	—	70
41	Luminaire	—	—	350	500	800
42	Acoustic Tile	White	80%	37	68	120
43	Acoustic Tile	White	80%	25	28	48
44	Luminaire (Bottom)		—	750	610	1100
45	Acoustic Tile	White	80%	80	140	170
46	Desk Top	Natural Maple	35%	40	40	70
47	Vinyl Floor	Green Grey	35%	32	35	62

project 3 evaluations

In this project, four task positions were studied. At M1 the task was located directly under and in line with a row of luminaires, and M2 was halfway between rows. M3 was located so that the line of sight to the task was at right angles to the center row of luminaires, and the luminaires were 25° forward of the task. M4 was in the same relative position with regard to the direction of rows; however, the task was moved back so that the ceiling halfway between rows was 25° forward of the task.

The M1 position does not follow the usual pattern in that it is to one side of the room instead of to the rear. This change

Quality	Location M1	M2	M3	M4
(inside pair lamps)				
TI	108	92	125	118
CRF	.749	1.00	.822	1.01
ESI	17.8	91.9	31.5	127.8
(both pair lamps)				
TI	215	185	250	235
CRF	.758	1.00	.831	1.03
ESI	28.4	185.3	58.1	308.3
(outside pair lamps)				
TI	107	—	125	—
CRF	.764	—	.830	—
ESI	18.5	—	33.4	—

project 3 evaluations

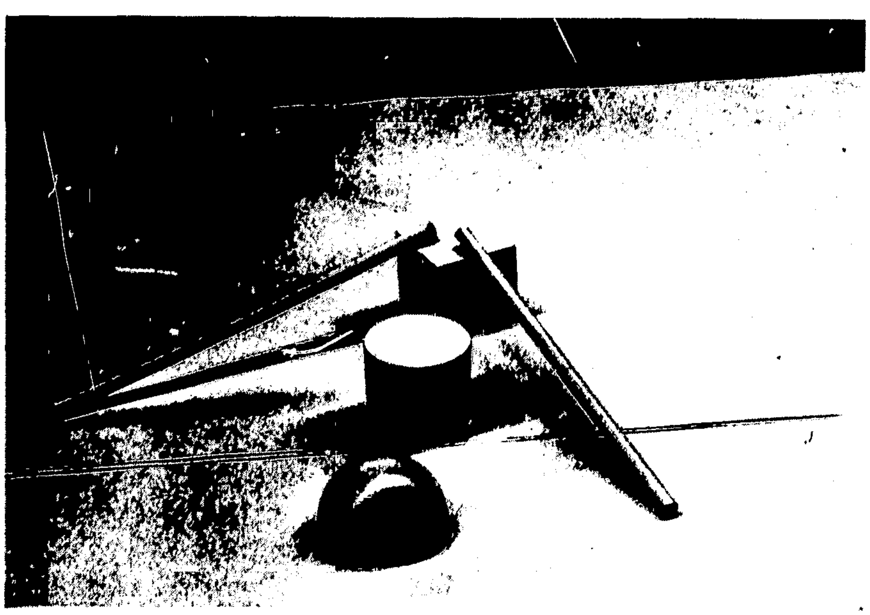
was made because other rooms with rows of luminaires almost invariably run from front to back. Also, because of the spacing of the rows, it was not possible to get back far enough behind the rear row to place it in the desired location in relationship to the Visual Task Photometer. M3 is the closest approach possible to the "standard" M1 position; however, this M3 is much farther into the center of the room.

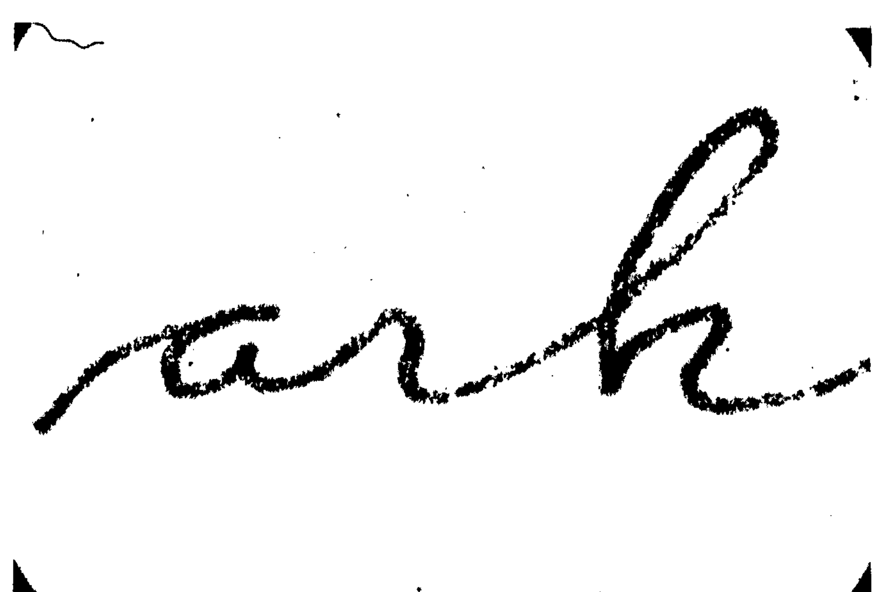
The results are reported here for all four meter locations, both angles of viewing, *and* for the inside pair of lamps as well as all four lamps. A close study of these values shows that contrast rendition is not a function of lighting level. The CRF for M1 at 25° is slightly less with the center pair only than with all four lamps. The same trend shows for M3 at 25°, and these differences, although slight, are probably due to the slightly larger area of brightness of the luminaire and the ceiling in the case of the four-lamp rendition. The CRF and ESI values shown for the outside pair of lamps are in each location higher than those for the inside pair. This follows the same basic reasoning as for the four-lamp situation; namely, the larger area provides a source of lower average brightness.

This project is a good example of what happens with luminaires in widely separated rows. The contrast rendition in the critical locations M1 and M3 is much poorer than the M2 and M4 positions. M1 and M3 are much poorer than comparable locations in rooms with more closely spaced rows.

Here, as in Project 1, the CRF values show that there is less loss when the normal line of sight is at right angles to the line of luminaires. At the same time, care should be taken to avoid high brightness on the sides of luminaires, if they are to run in this direction, because the side brightness will be critical from a direct glare standpoint.

This project is one of the poorest of those measured, and demonstrates conclusively that the use of a relatively narrow luminaire in widely spaced rows will result in high loss of contrast. Even though this system produces 108 footcandles with two lamps per luminaire and 215 with four lamps, the CRF is poor in either case. This system demonstrates that the CRF is a function of the manner in which the light is directed to the task, not the level of illumination. The outside pair of lamps produce a slightly higher CRF than the inside pair for two reasons: the inside pair results in a narrow light source when compared with the wider spacing of the outside pair plus the light on the ceiling, which is not present with the inside pair.



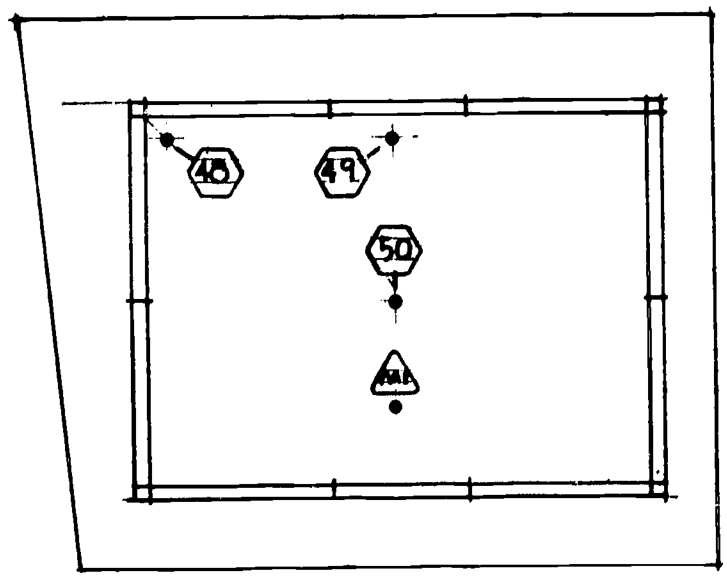


Sphere Quality

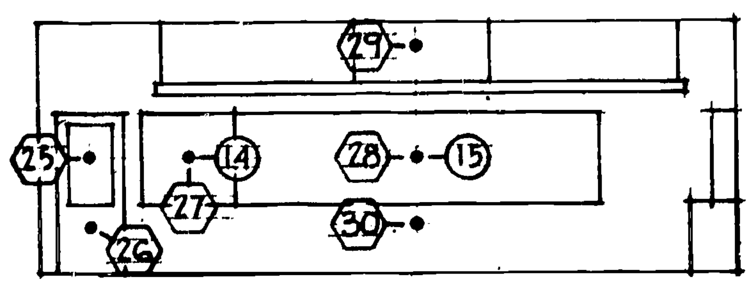
Project Quality

project 4 description

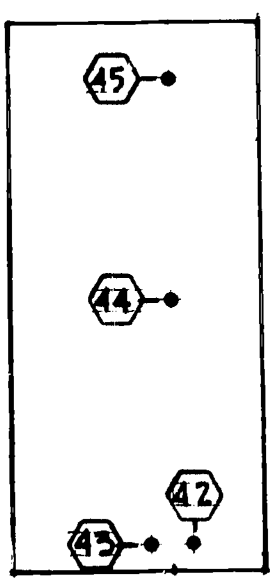
This room is 24′-0″ wide, the window wall, facing east, is 28′-0″, and the inside wall is 31″-0′. The three-foot differential is due to the angle of the south wall The ceiling height is 11′-0″. A wide arcade roof shields the east windows. The lighting system consists of an open rectangle, approximately 17′-0″ x 23′-0″, formed by single-lamp, semi-indirect units using 1500 m.a. power groove lamps. There are eight 8′-0″ lamps and two 6′-0″ lamps. The units have a plastic lens bottom panel with a thin diffusing panel directly on top of the lens. This combination provides a lower brightness when viewed directly than either the lens or the diffuser when viewed separately.

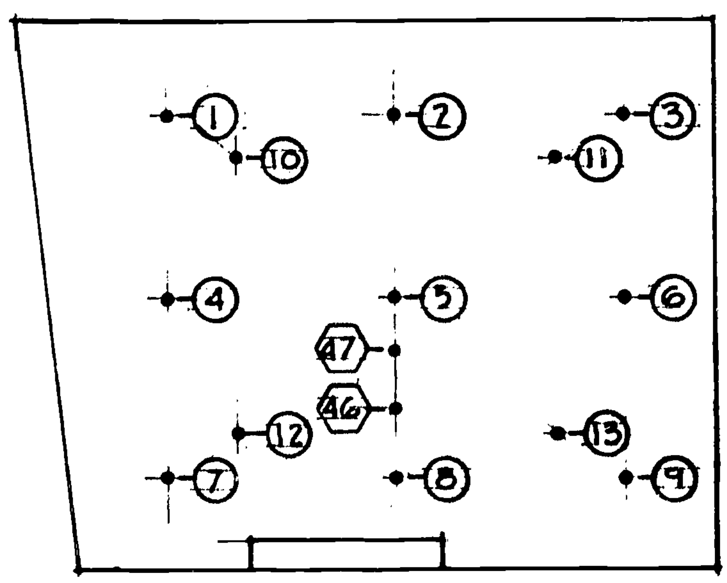


Reflected Ceiling Plan

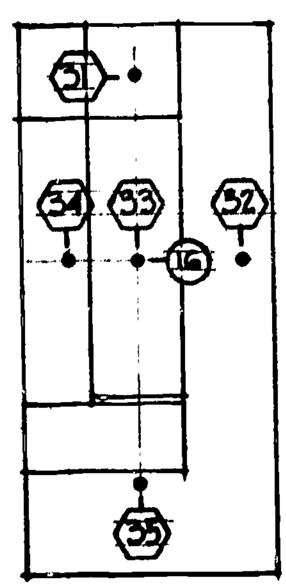


Wall Elevations

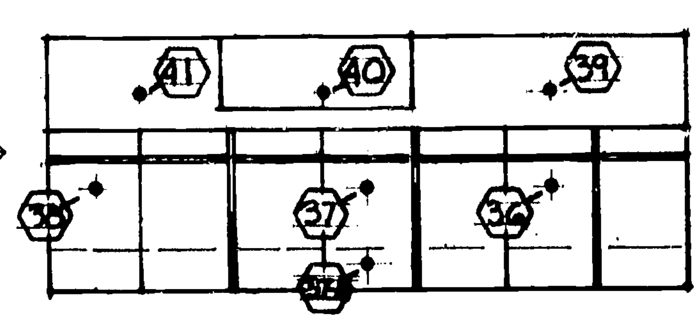




Floor Plan



Wall Elevations



This room is smaller than most of the other rooms and has a total of about 680 square feet, and the ceiling is higher than most of the others. The perimeter system provides an unusually uniform distribution with the minimum of 54 footcandles at the center of the room only 27% lower than the maximum of 74 footcandles. The photograph into the convex mirror shows the concentration of light around the perimeter and the dark area in the center of the ceiling. The general level of illumination is on the low side; however, it would have been materially better had the large wall areas been finished in colors with much higher reflectance.

The luminaire and ceiling brightness is exceptionally low and well within recommended brightness ratios. Again, the wall colors were much darker than is suggested, and a choice of lighter colors would have improved the general quality of the room. Unfortunately, no record was made of the brightness, color, or reflection factor of the blackout curtains; however, the photographs show them to be about the same brightness as the plywood walls, or 36% reflectance. The clear glass window in the door to the adjoining classroom is exposed directly to the western sky and creates a problem which could be cured quite easily.

lighting levels

Location	Footcandles Daylight	Electric	Combination
1	17	68	85
2	20	69	89
3	14	73	87
4	26	69	95
5	28	54	82
6	20	74	94
7	39	65	104
8	43	63	106
9	31	72	103
10	21	72	93
11	18	72	90
12	39	66	105
13	35	72	107
14	43	34	77
15	48	37	85
16	33	44	77

ERIC

brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness Day	Elec.	Comb.
25	Glass in Door	Clear	—	1750	1750	1750
26	Door	Natural Maple	32%	18	8	26
27	Tackboard	Warm Tan	37%	17	14	31
28	Chalkboard	Brown	17%	14	7	21
29	Plywood Wall	Yellow Green Stain	36%	15	36	54
30	Plywood Wall	Yellow Green Stain	36%	19	10	27
31	Cabinet	Natural Maple	32%	9	13	23
32	Plywood	Yellow Green	36%	10	58	75
33	Chalkboard	Brown	17%	5	7	15
34	Plywood	Yellow Green	36%	9	13	20
35	Plywood	Yellow Green	36%	16	13	30
36	Window	To Sky	—	1900	—	1900
37	Window	To Sky	—	1900	—	1900
37A	Window	To Arcade Soffit	—	72	—	72
38	Window	To Sky	—	1900	—	1900
39	Plywood	Yellow Green	36%	15	13	30
40	Air Conditioner	Buff	25%	9	9	18
41	Plywood	Yellow Green	36%	9	12	21
42	Plywood	Yellow Green	36%	11	10	21
43	Plywood	Yellow Green	36%	55	9	64
44	Plywood	Yellow Green	36%	11	15	25
45	Plywood	Yellow Green	36%	9	14	23
46	Desk Top	Maple	44%	12	25	37
47	Vinyl Floor	Grey	50%	9	22	32
48	Acoustic Tile	White	80%	15	105	120
49	Acoustic Tile	White	80%	15	110	125
50	Acoustic Tile	White	80%	20	29	49

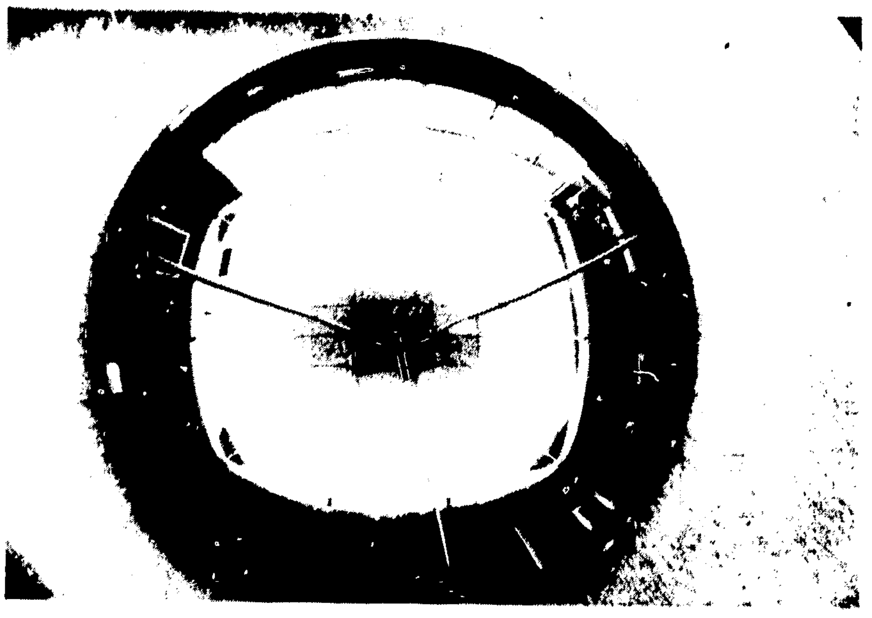
project 4 evaluations

Quality	Location M1
(electric only)	
TI	59
CRF	1.02
ESI	68.5
(daylight only)	
TI	36
CRF	1.18
ESI	117.8
(combination)	
TI	95
CRF	1.12
ESI	235.8

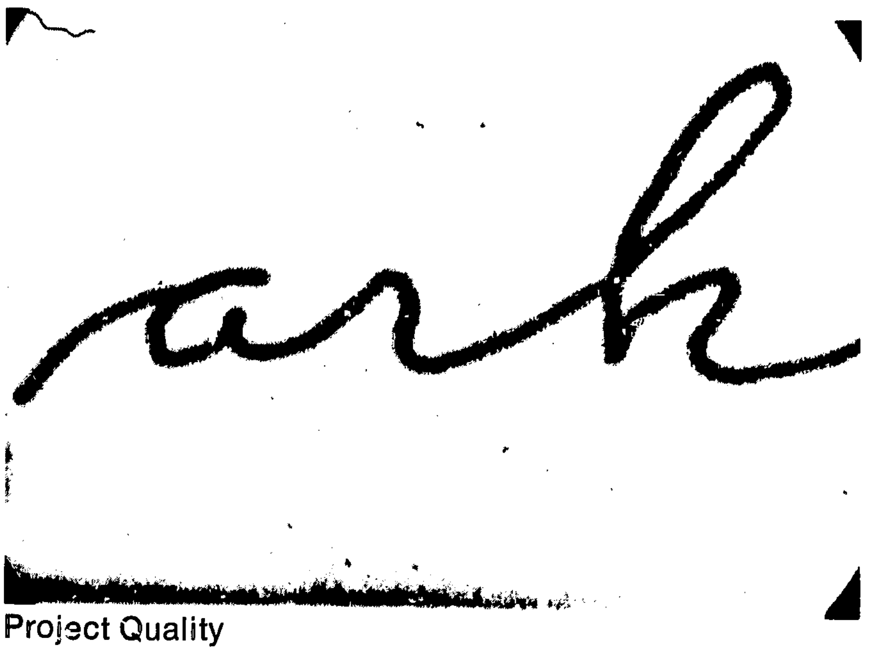
The CRF of 1.02 is excellent when compared with all of the other projects, with the exception of Project 5. It would appear that good CRF values would be obtained in the entire seating area regardless of the direction of viewing, with the exception of those locations directly under the luminaire, close to the side walls, when looking in the same direction as the luminaire orientation.

The large windows are under a high corridor roof about 10′-0″ wide. As a result, the afternoon sky provided a rather low level of added light in the room, but the CRF values were exceptionally good. At M1, daylight alone provided a CRF of 18% better than glare-free. If all students faced away from the windows, only the teacher would suffer from the extreme brightness.

CRF and ESI values are given for each of three lighting combinations, first electric, then daylight alone, and then a combination. The electric system is the number two system of all those surveyed in that it shows a 1.02 CRF and with only 59 footcandles the results are equivalent to 68.5 footcandles. This is of course due to the fact that the major percentage of the light to the task comes from an area outside the critical zone for veiling reflectances. The daylight alone produces an excellent CRF of 1.18 and an equivalent of 117.8 footcandles with only 36 footcandles. Here again most of the light reaches the task from the sides and behind; a small portion of the total originates from areas forward of the task. Where students can be placed with their backs to the windows, the CRF will be excellent, but the teacher will have a constant major glare source from the windows as she faces the class.



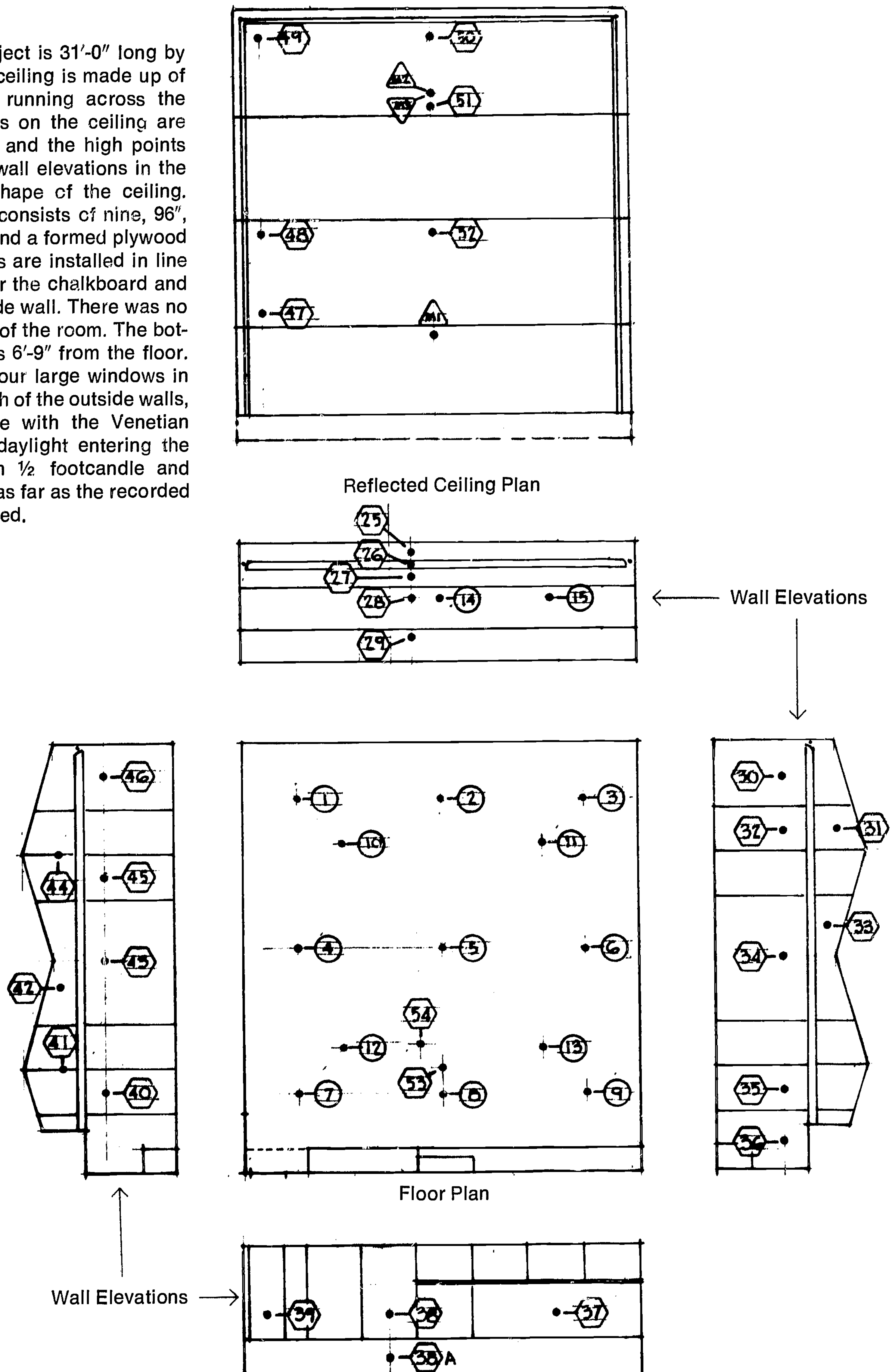
Sphere Quality



Project Quality

project 5 description

The room in this project is 31′-0″ long by 29′-0″ wide, and the ceiling is made up of four sloping planes running across the room. The low points on the ceiling are 8′-9″ above the floor and the high points are 11′-0″. The side wall elevations in the drawing show the shape of the ceiling. The lighting system consists of nine, 96″, 1500 m.a. lamps behind a formed plywood valance. Three lamps are installed in line on the front wall over the chalkboard and the same on each side wall. There was no light across the rear of the room. The bottom of the valance is 6′-9″ from the floor. Although there are four large windows in the room, two on each of the outside walls, all testing was done with the Venetian blinds closed. The daylight entering the room was less than ½ footcandle and therefore negligible as far as the recorded findings are concerned.



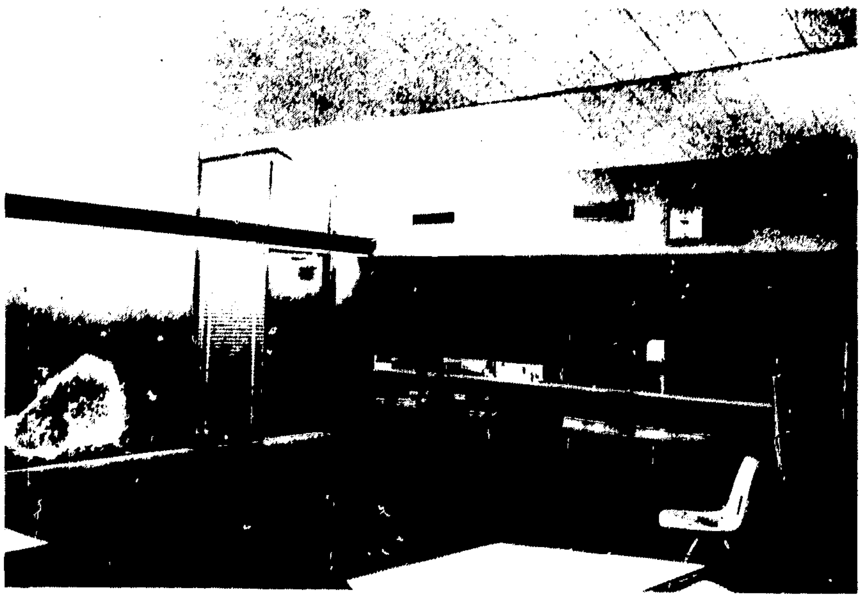
This is the only example of a cove lighting system in the western United States to the knowledge of the author. This sample should not be considered the best of its kind; however, there is much that can be learned from the study.

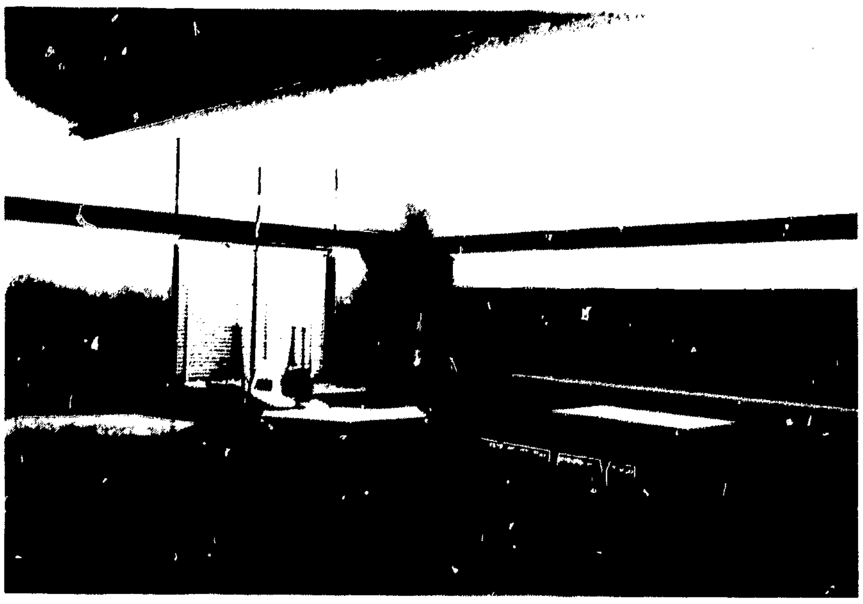
The levels of illumination are far less than any other project surveyed. The omission of the valance on the rear wall is unfortunate, and although the ceiling color was good, the shape may have a slight effect on the over-all efficiency. A lighting valance on the rear wall would have provided levels at the rear of the room comparable with those at the front, and the center location (#5) would probably have had 30 instead of only 23 footcandles. The large areas of wall surfaces with a fabric finish of only 24% reflection factor caused an added loss in the lighting levels.

From a brightness standpoint, the highest values are directly related to the valance unit, and they exceed the 10 to 1 ratio allowed for the low task brightness of only 11.5 footlamberts resulting from 16 footcandles at the M1 position. On the other hand, the task would have had 30 footlamberts if the fourth valance had been installed, and this would have allowed the wall and ceiling brightnesses to come within the desired ratios. The general brightness of the room would have been much better if the wall covering had been chosen with much lighter colors.

lighting levels

Location	Footcandles Electric
1	44
2	45
3	43
4	37
5	23
6	41
7	26
8	14
9	26
10	40
11	42
12	24
13	27
14	50
15	43





brightness distribution

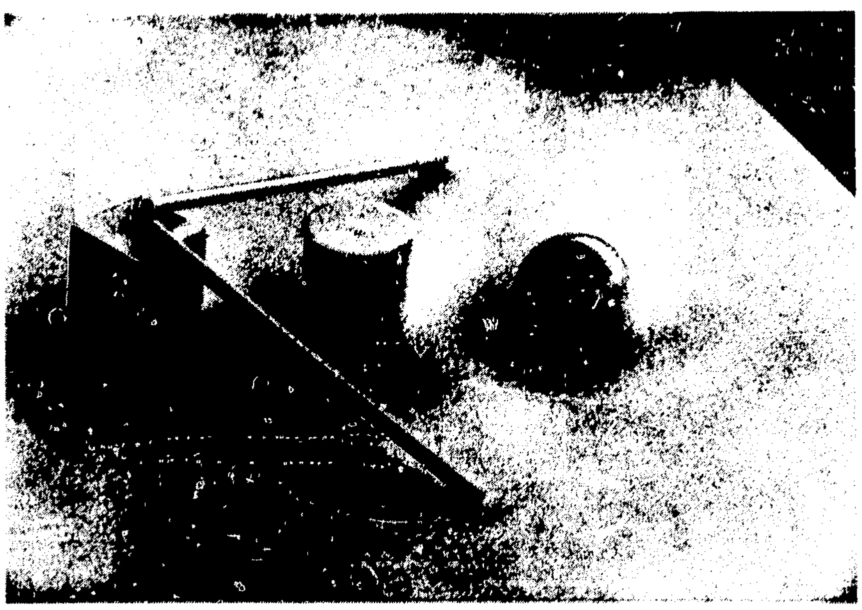
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Front Wall	Mustard	45%	110
26	Valance Baffle	Walnut	25%	5
27	Wall Fabric	Yellow Green	24%	45
28	Chalkboard	Brown	15%	9
29	Wall Fabric	Yellow Green	24%	5
30	Wall Fabric	Yellow Green	24%	8
31	Vertical Venetian Blind	Grey	—	70
32	Horizontal Venetian Blind	Grey	—	35
33	Wall Fabric	Yellow Green	24%	50
34	Wall Fabric	Yellow Green	24%	20
35	Wood Door	Grey	12%	8
36	Wall Fabric	Yellow Green	24%	4
37	Wall Fabric	Yellow Green	24%	4
38	Wood Cabinet	Natural Birch	29%	5
38A	Painted Wall	Mustard	45%	7
39	Painted Door	Grey	12%	1
40	Painted Door	Grey	12%	9
41	Painted Wall	Mustard	45%	72
42	Wall Fabric	Yellow Green	24%	48
43	Wall Fabric	Yellow Green	24%	20
44	Painted Wall	Mustard	45%	72
45	Horizontal Venetian Blind	Grey	—	29
46	Wall Fabric	Yellow Green	24%	9
47	Acoustic Tile	White	80%	95
48	Acoustic Tile	White	80%	165
49	Acoustic Tile	White	80%	42
50	Acoustic Tile	White	80%	200
51	Acoustic Tile	White	80%	18
52	Acoustic Tile	White	80%	6
53	Desk Top	Maple	49%	8
54	Floor Tile	Grey	28%	5

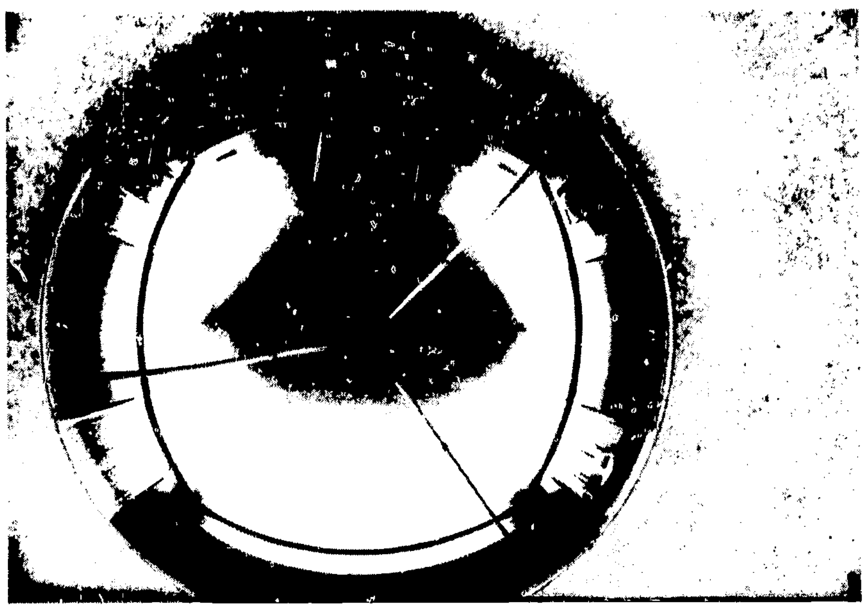
project 5 evaluations

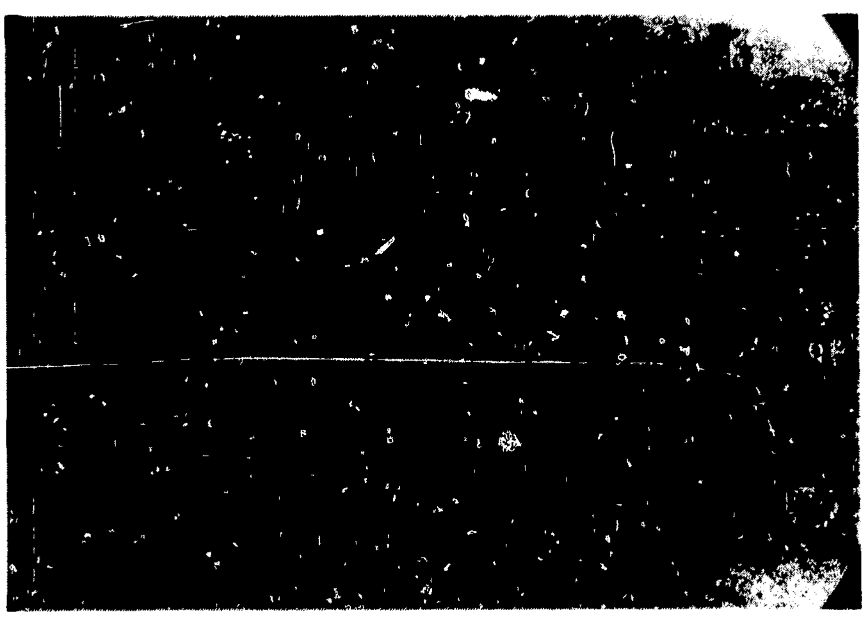
Quality	Location		
	M1	M2	M3
TI	16	42	42
CRF	1.12	.915	1.07
ESI	29.9	24.7	68.5

The CRF value at M1 in this room is outstanding in that it produces a value 12% greater than sphere quality and with only 16 actual footcandles, the equivalent in the sphere would be 29.9 footcandles. If the fourth valance had been installed on the rear wall, the TI would have been about 45 footcandles, the CRF about 1.06, and the ESI would have been 69.4 footcandles. Even with 39 actual footcandles, the ESI would have been 63 footcandles.

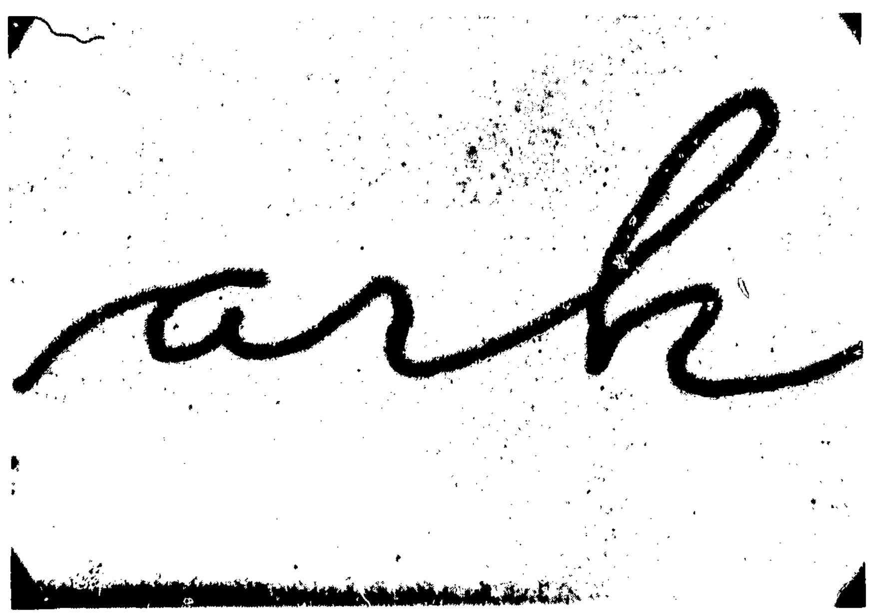
The excellent results shown in this project, in spite of several unfavorable conditions, would indicate that designers should recognize desirable aspects and work out cove systems to utilize their advantages. It appears that with proper ceiling shape and color, better wall reflectance, and a little more light, the CRF and ESI could be developed economically in spite of the inherent low lighting efficiency of cove systems.







Sphere Quality

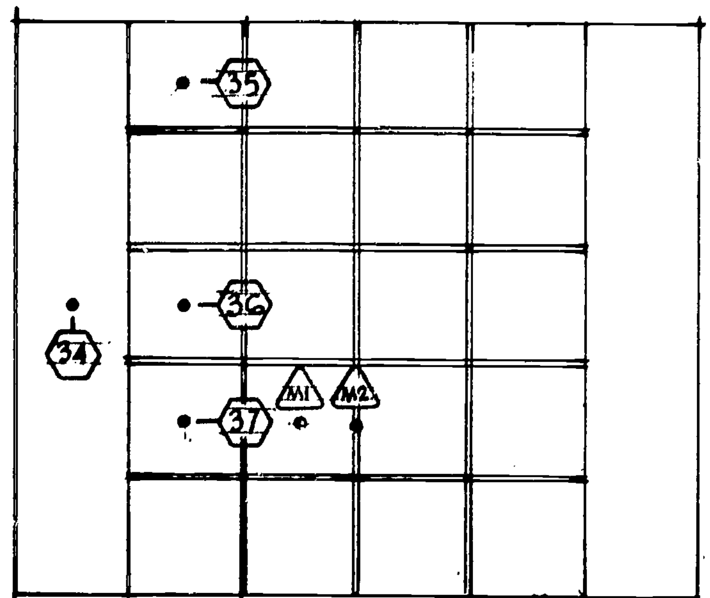


Project Quality

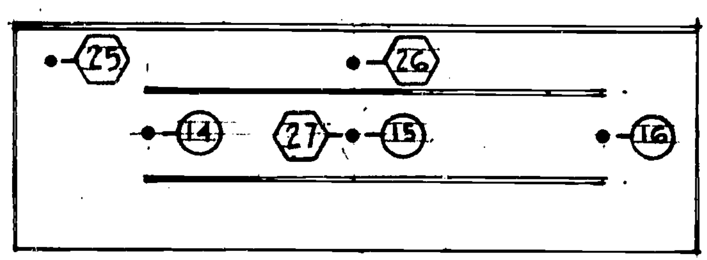
ERIC

project 6 description

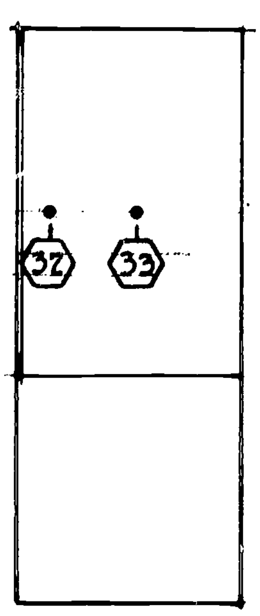
The room is 25′-0″ x 30′-0″, and the ceiling height is 10′-0″. The lighting system consists of 20, 5′-0″ square elements arranged as shown on the drawing. Each element of the ceiling system consists of a metal coffer in which a plastic diffuser conceals two 40-watt, rapid-start fluorescent lamps.

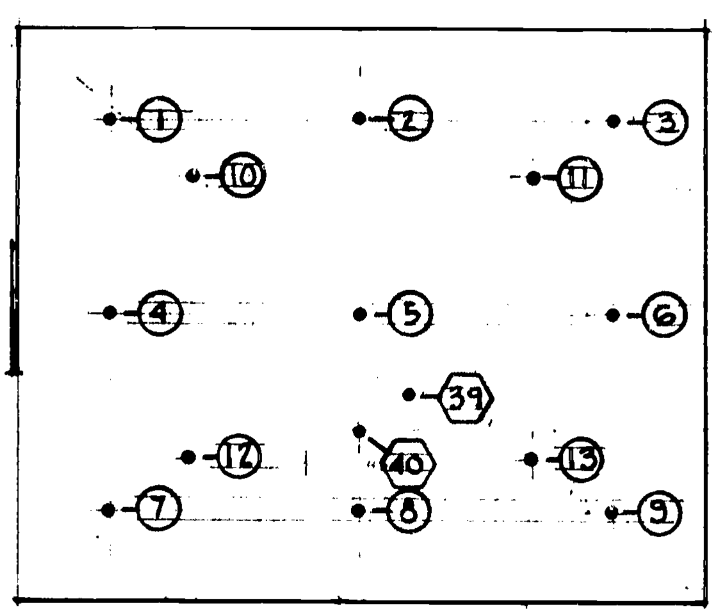


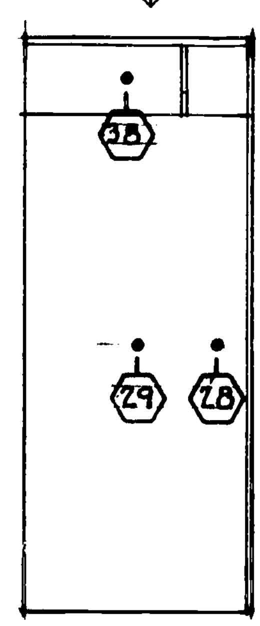
Reflected Ceiling Plan



Wall Elevations

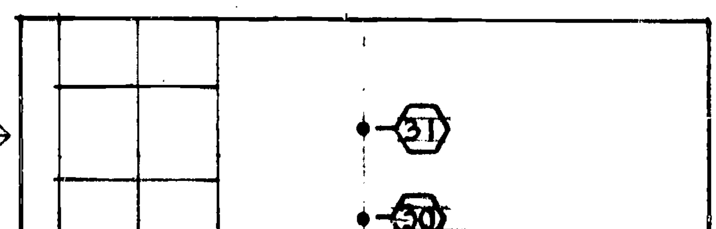






Floor Plan

Wall Elevations



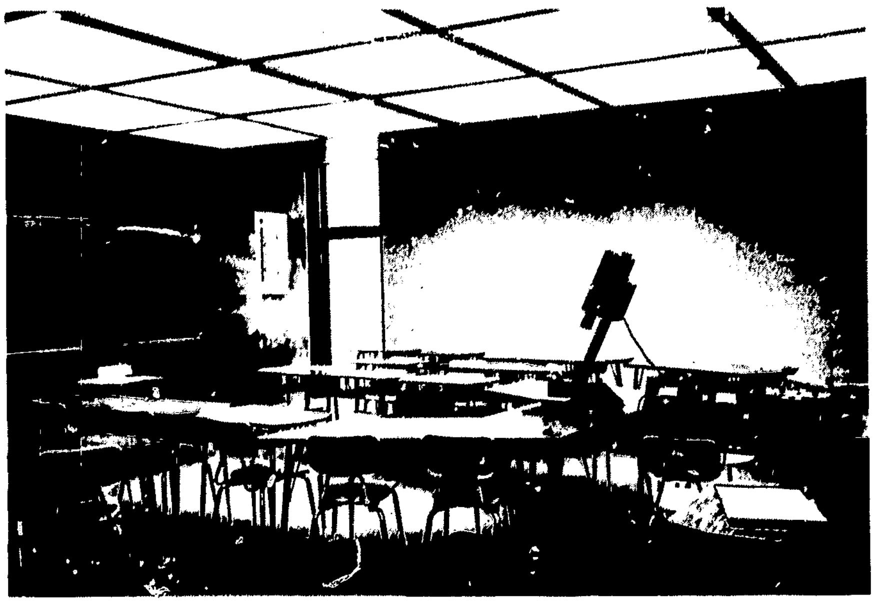
The only daylight in the room comes through the glass door and transom, both of which are of a low transmission glass. The added illumination was insignificant in relationship to the lighting from the electric system. Access to the interior of the building is through the 10'-0" opening in the wall for which there is no closure. Light entering the test room through this opening is not a factor which could upset the accuracy of the contrast rendition study.

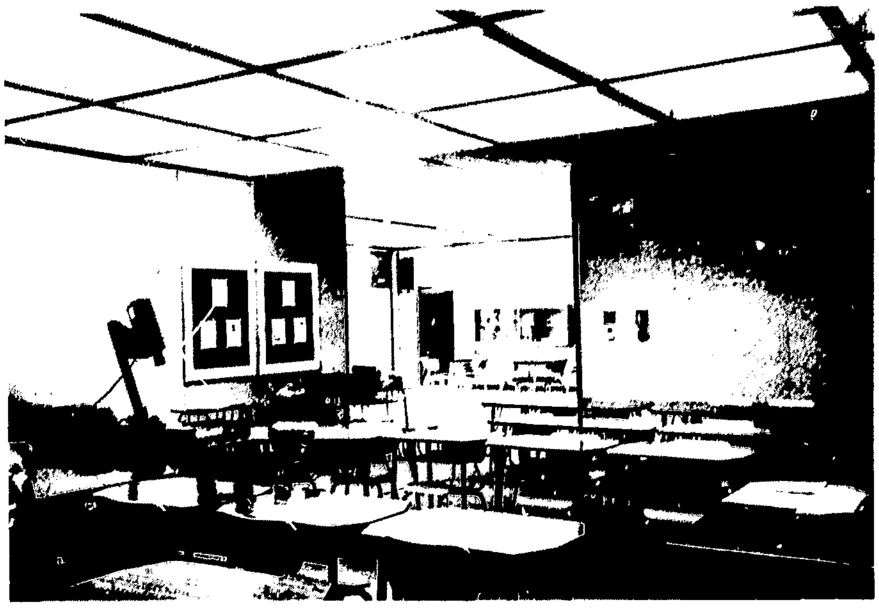
The over-all effect of this system is similar to that of a luminous ceiling with a 5'-0" wide unlighted ceiling space on each side. This wide dark area leaves the two sides of the room with considerably less light than in the center. The south side and rear wall color are fairly light, and this helps materially in reflecting light back to the room. The front and the north walls, on the other hand, are dark, and give the room a very low key. The lighting ceiling is carried all the way to the front and rear walls, and this is very good. The only light to reach the upper portion of the north wall is that bounced from the furniture and carpet, and unfortunately the carpet is very dark. The entire character of this room would have been improved if only four more lighting modules had been used. By omitting six modules in the center of the room and installing modules to cover the ceiling on each side, the walls would all have been very well lighted, and the sides and corners of the room would have had much more light on the desks.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	45	9	45
2	78	10	69
3	51	11	69
4	54	12	69
5	90	13	69
6	54	14	41
7	51	15	48
8	81	16	42

ERIC





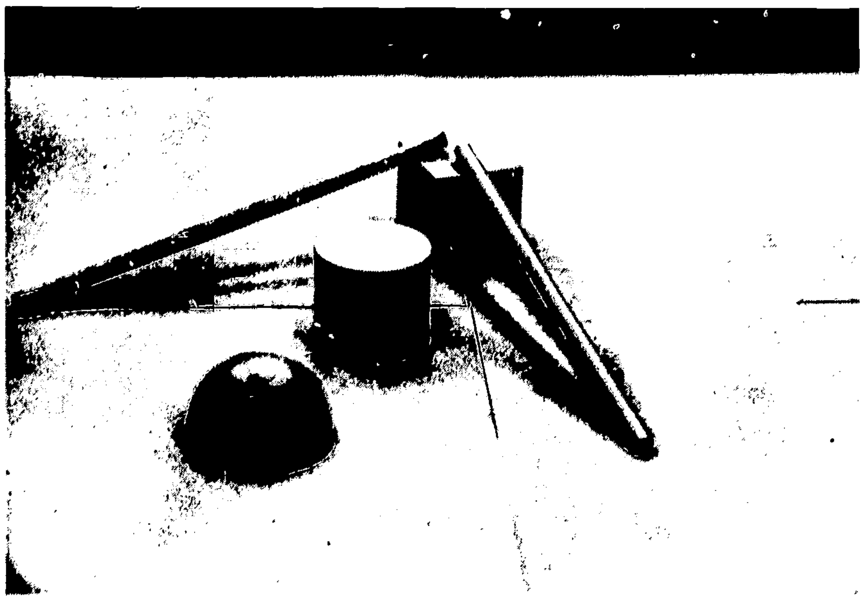
brightness distribution

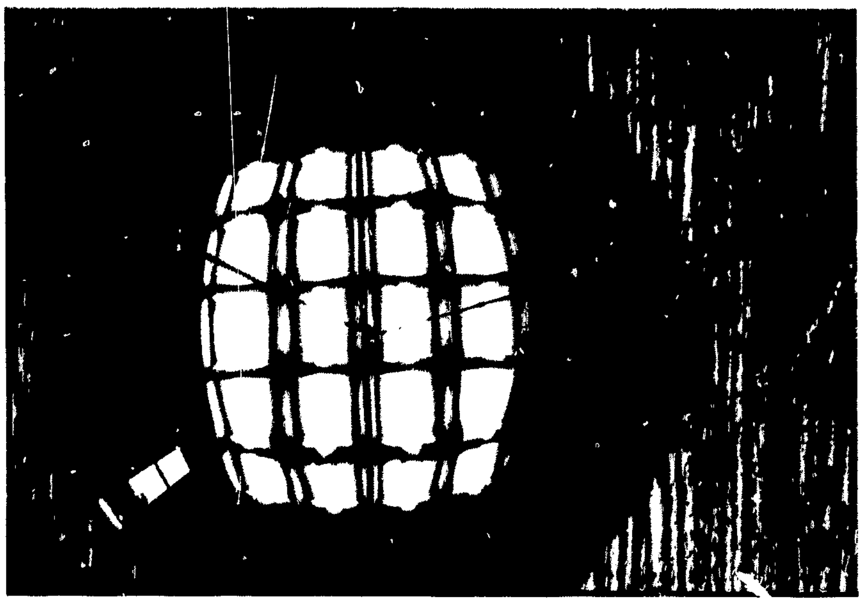
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Chalkboard Wall	Olive Green	23%	4.5
26	Chalkboard Wall	Olive Green	23%	11
27	Chalkboard Wall	Olive Green	23%	9
28	Painted Wall	Grey Green	53%	9
29	Painted Wall	Grey Green	53%	20
30	Metal Partition	Grey Green	53%	31
31	Metal Partition	Grey Green	53%	22
32	Metal Partition	Grey Green	53%	10
33	Metal Partition	Grey Green	53%	18
34	Metal Acoustic Ceiling	White	80%	11
35	Light Diffuser	—	—	260
36	Light Diffuser	—	—	310
37	Light Diffuser	—	—	310
38	Glass Door	—	—	180
39	Carpet	Olive Green	22%	13
40	Desk Top	Pecan Formica	25%	20

project 6 evaluations

Quality	Location M1	M2
TI	83	80
CRF	.886	.911
ESI	35.6	40.8

This system is only fair in its qualities for contrast rendition. Much of the reason for this is in the fact that practically no light reaches the task from low angles. Even though the source of light is a large, low brightness area, the lack of light from the sides really shows. Had the previous suggestions been followed and light colors been used on the walls and carpeting, the over-all contrast rendition would have been much better. Obviously, the architecture of the room would be entirely different, and it is here that the architects have the right and duty to make decisions.



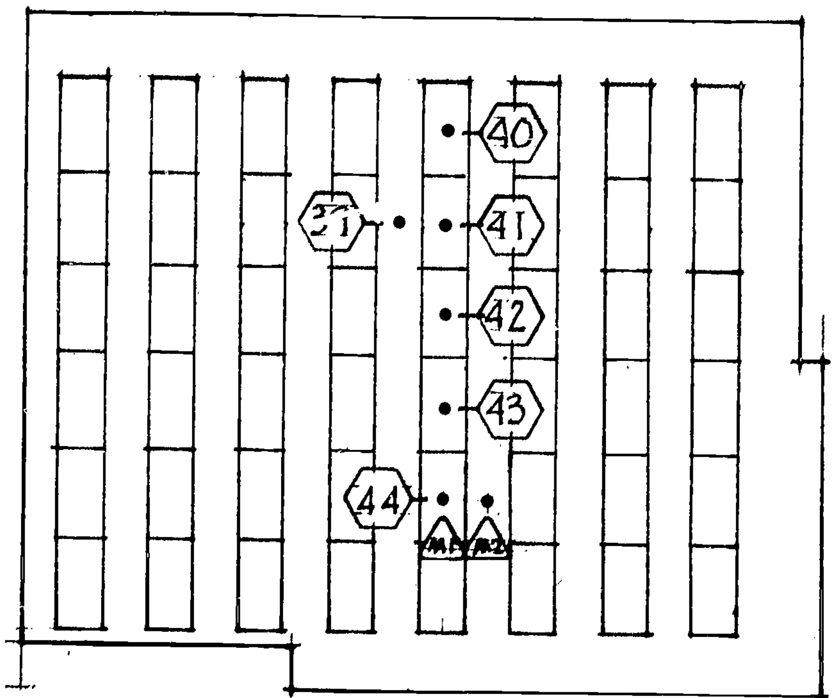


Sphere Quality

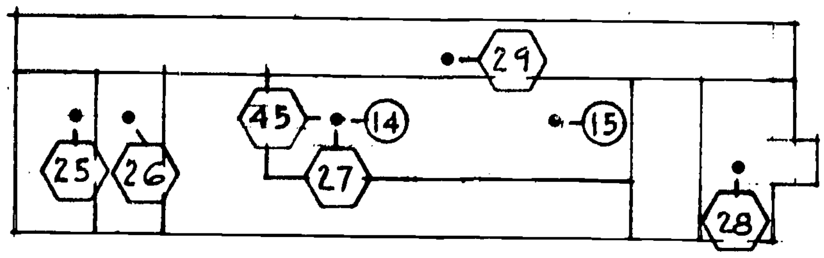
Project Quality

project 7 description

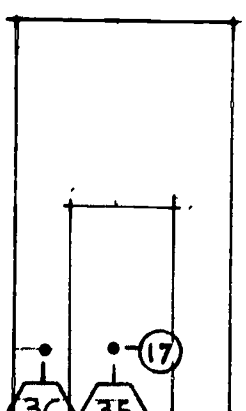
The room is about 29′-0″ by 35′-0″, and the ceiling height is 9′-6″. The lighting system consists of eight rows of 2′-0″ wide recessed units with the rows 4′-0″ on center. There are two 90-watt, rapid-start lamps in each 8′-0″ long unit, and each row is 24′-0″ long. This system uses a total of 48 lamps. The troffers are deep, and the acrylic diffusers are almost uniformly lighted. Daylight light levels are recorded for information only. Daylight enters the room from windows located behind one chalkboard which may be slid sideways over the other board when this is desired. In the closed position, no daylight enters the room, and this is the condition used for drawings and light measurements.

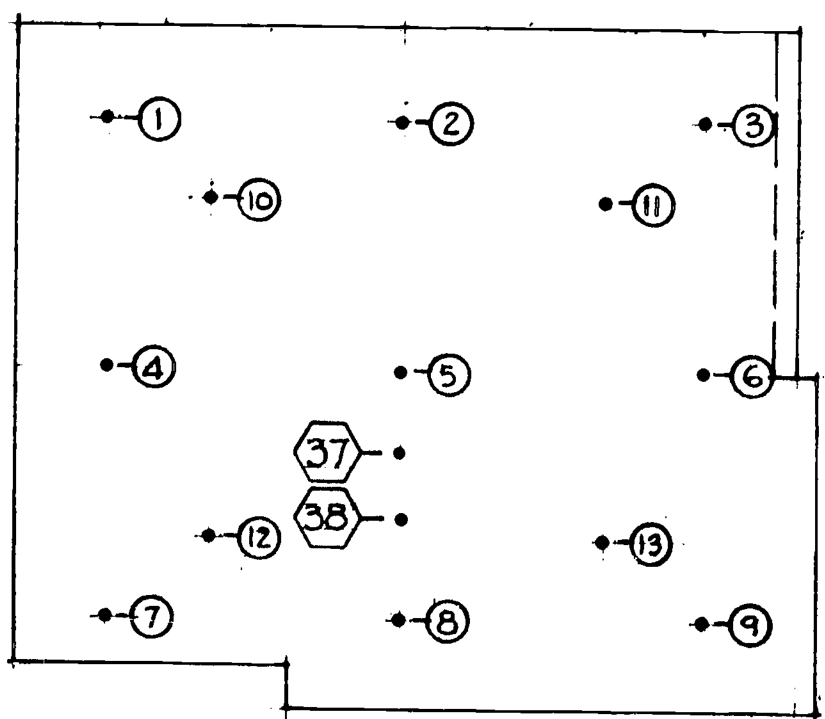


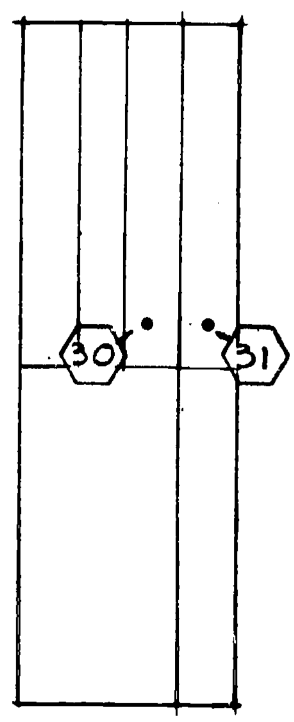
Reflected Ceiling Plan



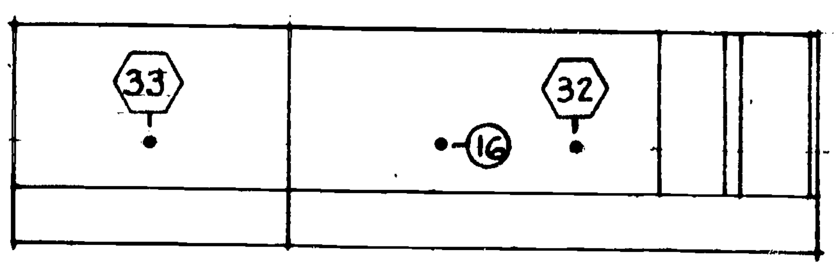
← Wall Elevations







Floor Plan



Wall Elevations →

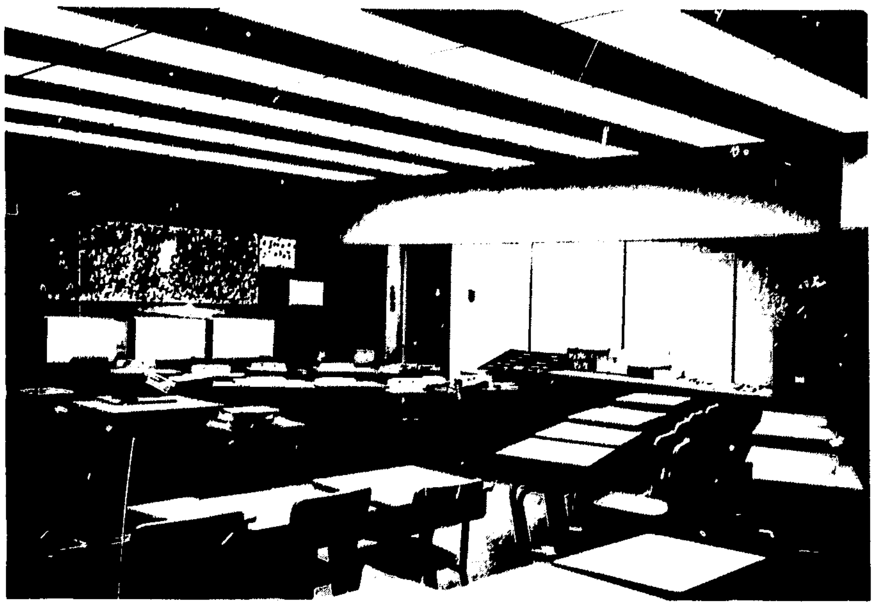
This system covers virtually one half the ceiling with luminaires and develops a degree of uniformity similar to the better luminous ceilings, but with a much higher over-all efficiency. For example, Project 2 produces an average of 104 footcandles with 4 watts per square foot or 26 footcandles per watt per square foot. This project has an average of 92 footcandles from 2.4 watts per square foot, or 38 footcandles per watt per square foot. The high reflectances of the side wall and cabinet finishes help materially in the over-all efficiency.

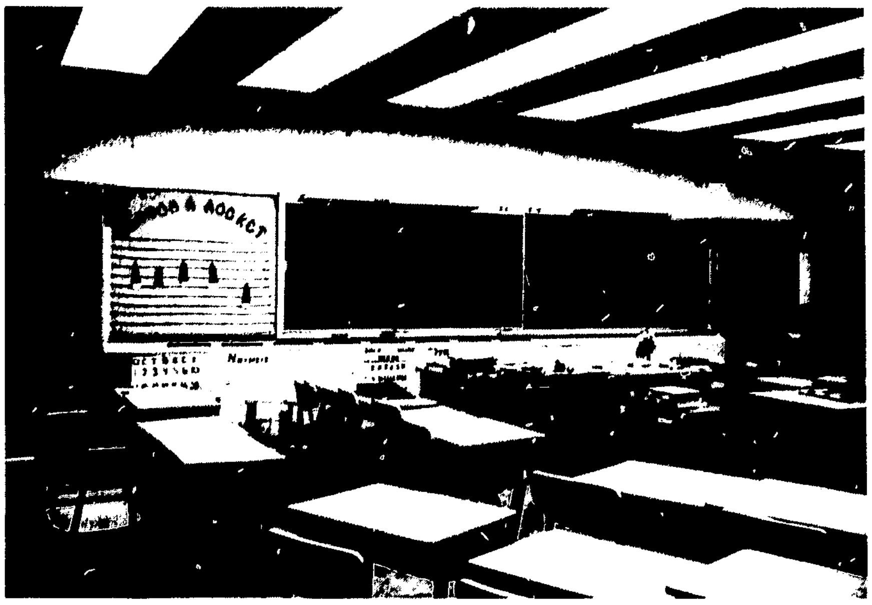
An interesting improvement in this room would be to remove the two center luminaires from the four center rows and to put two more luminaires in each of the four corners between the existing end luminaires. This would decrease the level in the center of the room and boost the four corners, making the system even more uniform, and still providing a satisfactory level in the center.

The brightness balance in this project is excellent. The chalkboard is the only large dark area, while most of the wall finishes, tackboards, and cabinets are of high reflectances. The use of white acoustic tile on the upper side walls helps greatly in removing the feeling of darkness often found in projects with recessed lighting. Also, the use of diffusing panels instead of lenses provides more light to the side walls. Only one lamp is shielded by the 24″ wide panel, and consequently the brightness is maintained well within the allowable ratios.

lighting levels

Location	Footcandles Day	Footcandles Electric Only	Location	Footcandles Day	Footcandles Electric Only
1	.9	65	10	3.0	93
2	11.0	75	11	1.9	89
3	.7	59	12	1.3	95
4	1.4	89	13	1.2	90
5	2.5	108	14	—	47
6	1.2	81	15	—	47
7	.9	66	16	—	57
8	1.7	81	17	—	51
9	.7	60			





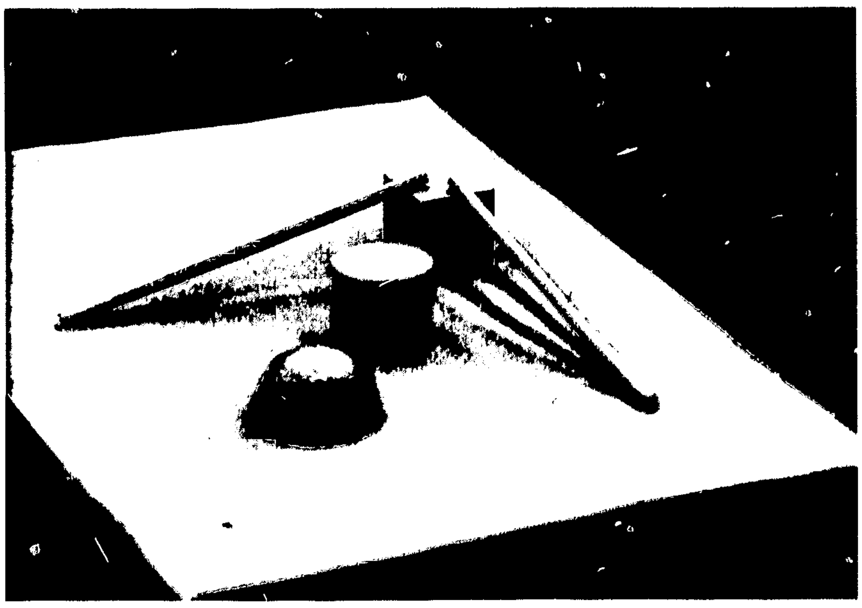
brightness distribution

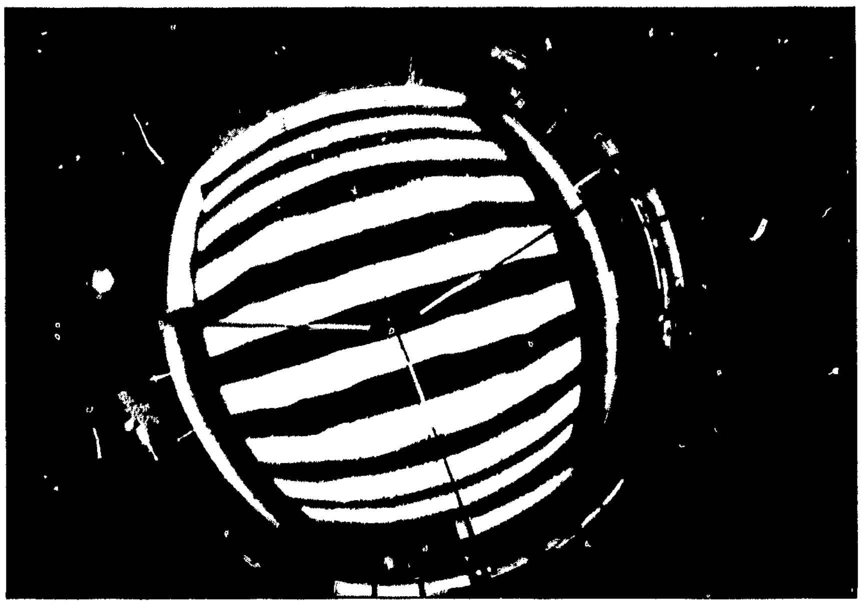
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Warm Grey	52%	19
26	Painted Door	Burnt Orange	25%	10
27	Chalkboard	Grey Green	19%	9
28	Tackboard	Grey	52%	17
29	Acoustic Tile (Wall)	White	80%	33
30	Wood Cabinet	Natural Birch	32%	12
31	Acoustic Tile (Wall)	White	80%	36
32	Tackboard	Grey	52%	21
33	Wood Cabinet	Natural Birch	32%	45
34	Tackboard	Grey	52%	25
35	Chalkboard	Grey Green	19%	10
36	Acoustic Tile	White	80%	46
37	Asphalt Tile Floor	Grey	29%	20
38	Desk Top	Maple	45%	40
39	Ceiling Tile	White	80%	19
40	Lighting Diffuser	White	—	250
41	Lighting Diffuser	White	—	275
42	Lighting Diffuser	White	—	275
43	Lighting Diffuser	White	—	250
44	Lighting Diffuser	White	—	275
45	Window with Chalkboard open (low transmission glass)		—	325

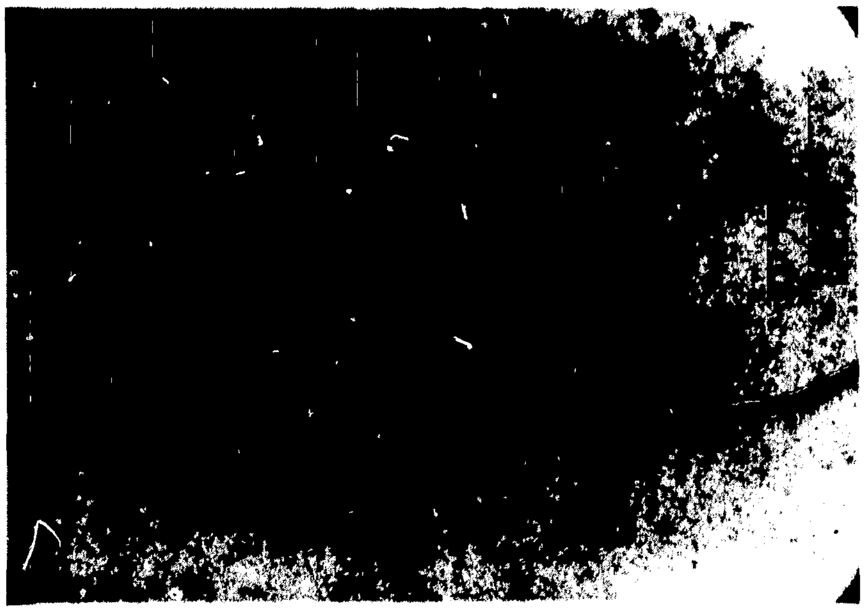
project 7 evaluations

Quality	Location	
	M1	M2
TI	90	90
CRF	.915	.942
ESI	46.7	57.4

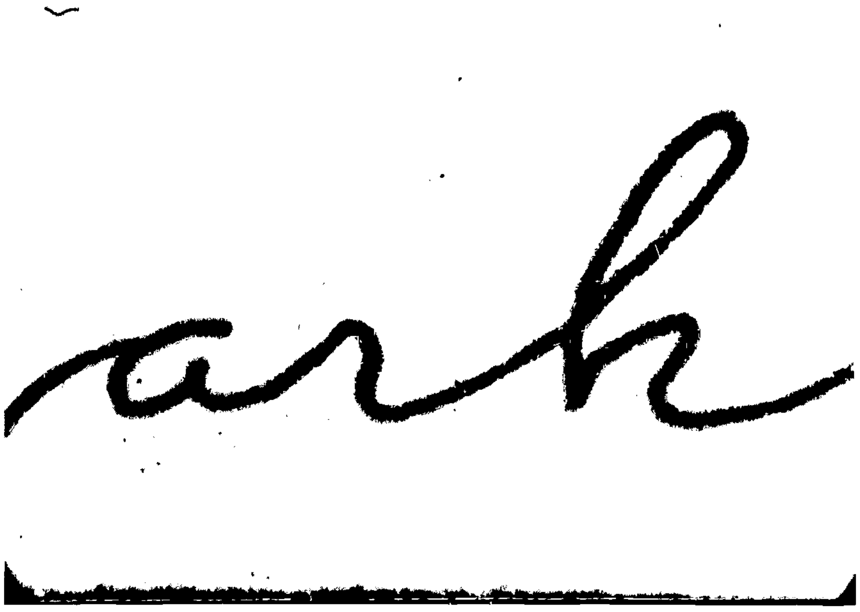
The CRF in this project is very good when compared with other systems using conventional luminaires in conventional patterns, but is not so good as those systems which provide light from the perimeter of the room. The choice of diffusing panels instead of lenses improves the contrast rendition because of the larger percentage of light at wide angles with the diffuser. Currently available lenses tend to concentrate light into the offending zone. Manufacturers are now working on lens designs which will concentrate most of the light between 30° and 45°, with a smaller percentage between 0° and 30°. When this is available, the CRF will be improved, *but* care will be required to avoid direct glare from the higher lens brightness.







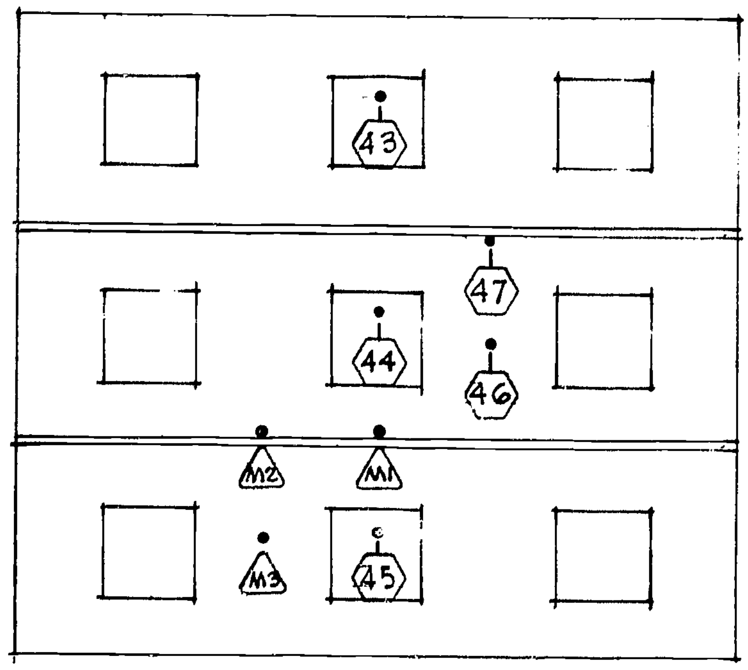
Sphere Quality



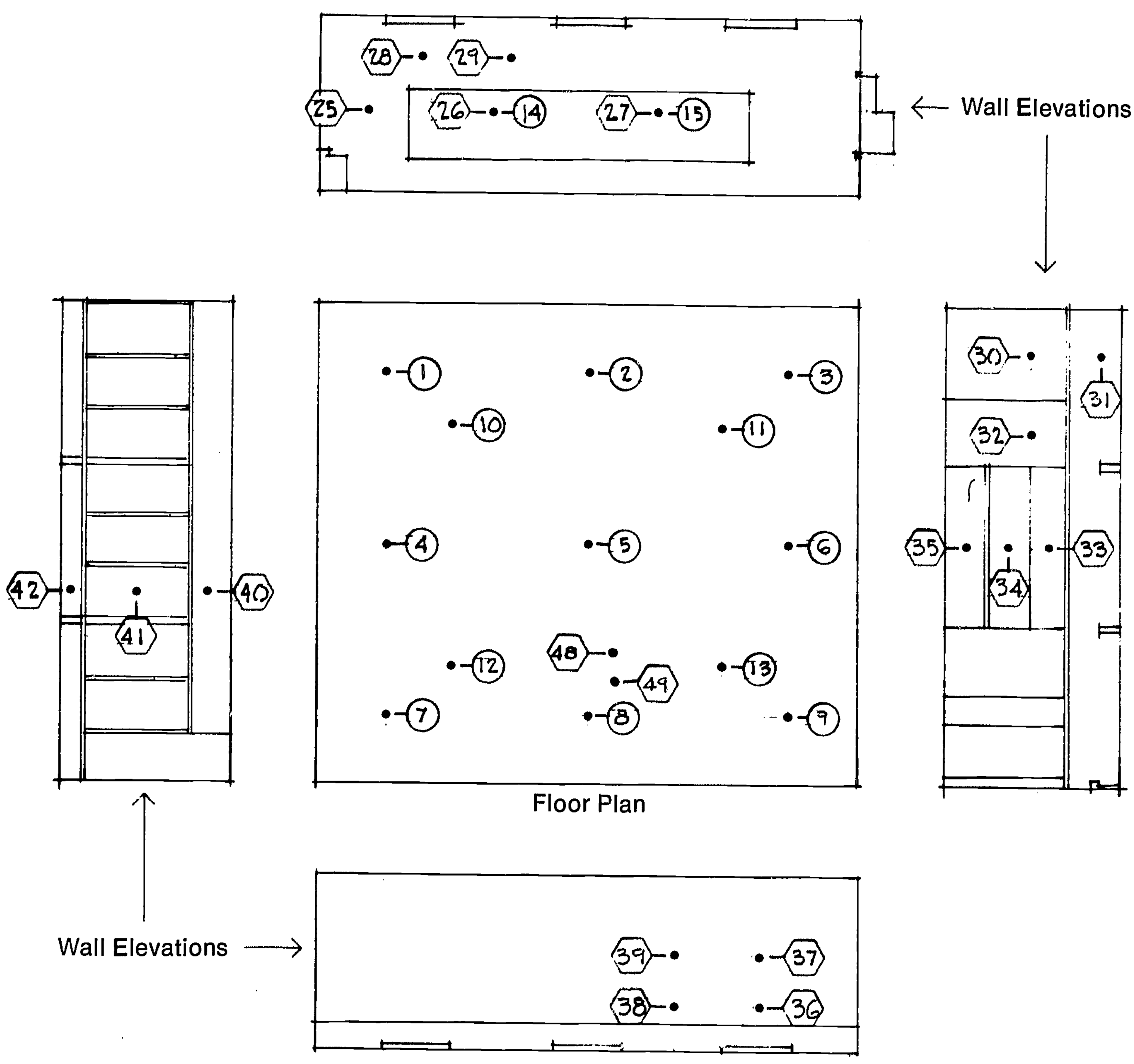
Project Quality

project 8 description

This room is 32′-0″ wide and 29′-0″ long, and the ceiling is 10′-3″. The wall opposite the chalkboard is of the accordion type, opening into an adjacent classroom; however, the wall was closed during this survey. There are two 15″ deep beams which divide the ceiling into three panels. The north window wall has operable shutters which are lighttight, and these were closed during the survey. The electric lighting system consists of nine 48″ square, surface-mounted, lens bottom luminaires, each with six 48″, rapid-start fluorescent lamps.



Reflected Ceiling Plan



Floor Plan

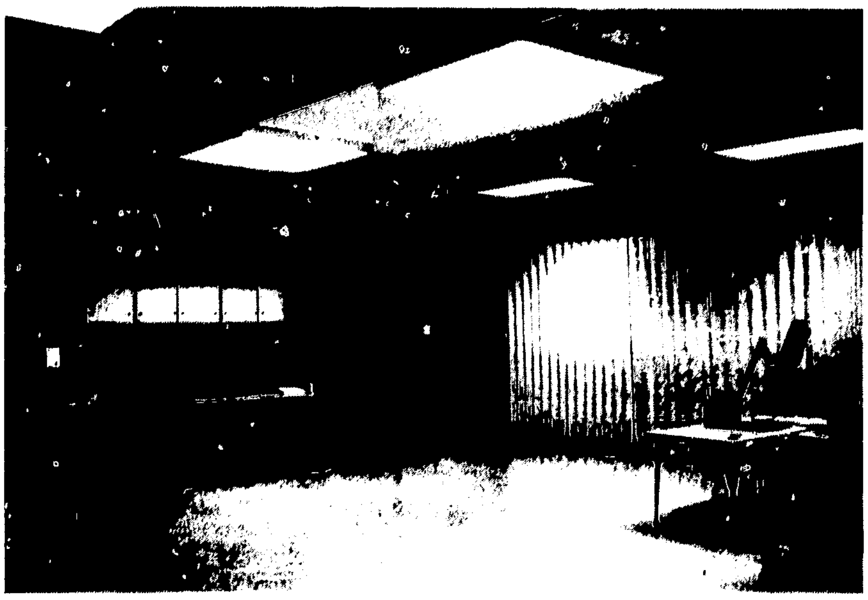
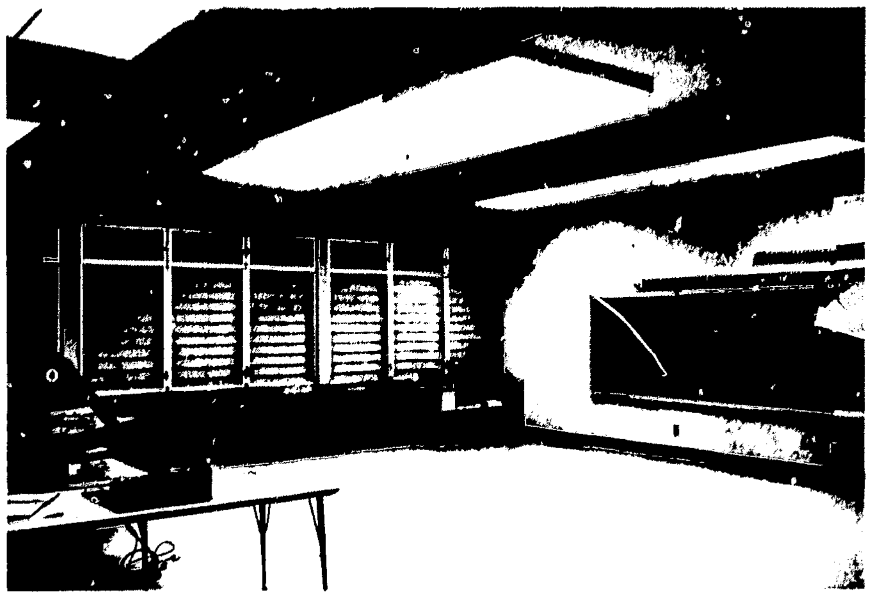
This is one of the more efficient systems with regard to lighting level, producing an average of 127 footcandles with 2.9 watts per square foot, or about 44 footcandles per watt per square foot. The degree of uniformity is normal for conventionally arranged luminaires. The minimum level of illumination is 67% of the maximum. This is not so good as those systems which place the light toward the perimeter of the room. With only nine large units, relocating them to provide more light into the corners of the room would run the danger of leaving areas of low level between fixtures. The ratio of spacing width to mounting height must be watched carefully to avoid dark areas. The light colors used on the side walls helped maintain a high room efficiency. The unusually light floor was a great help in bouncing light back to the ceiling and upper side walls.

The brightnesses within this environment were very good except for the unusually high brightness from the large lens panels.

The brightness balance within the room is on the edge of being poor. In all systems using conventional recessed lenses, little or no direct light falls on the upper side walls or ceiling, and the floor is the primary source of reflected light to these areas. In this project, the floor has a reflectance of 40%, one of the highest of all those surveyed, and, as a result, the 80% ceiling has a brightness of 35 footlamberts. The room would have been better if the large areas of stained plywood had been of higher reflectance. The direct brightness from the lens was extremely high, and the brightness difference between the lenses and the adjacent ceiling was far above normal comfort limits.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	111	9	102
2	126	10	130
3	105	11	126
4	132	12	126
5	147	13	126
6	117	14	72
7	99	15	72
8	129		

brightness distribution

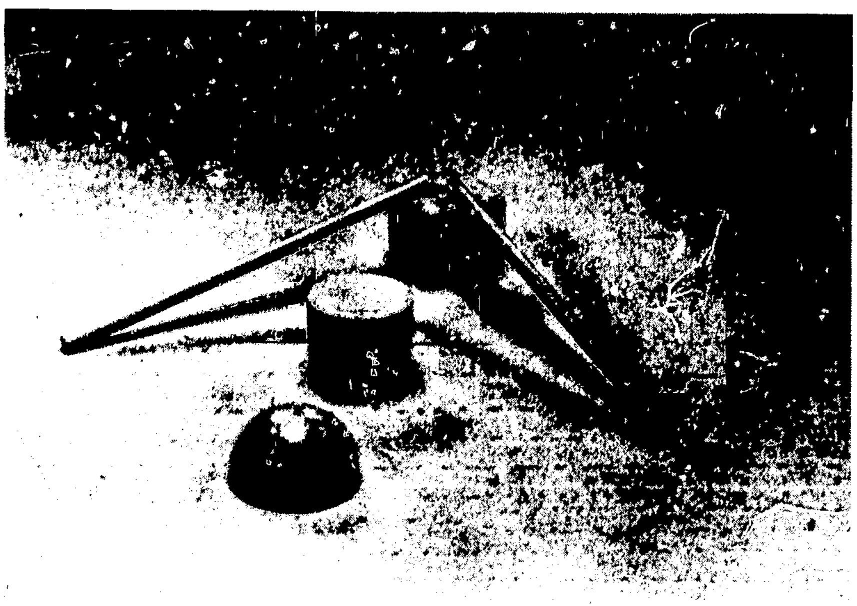
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Vinyl Tackboard	Beige	48%	30
26	Chalkboard	Brown	20%	15
27	Chalkboard	Brown	20%	15
28	Tackboard	Beige	48%	33
29	Tackboard	Beige	48%	19
30	Stained Plywood	Warm Green	27%	18
31	Stained Plywood	Warm Green	27%	10
32	Drape	Orange	24%	16
33	Formica Cabinet	White	55%	49
34	Tackboard	Beige	48%	21
35	Stained Plywood	Warm Green	27%	18
36	Vinyl Accordion Door	Beige	54%	35
37	Vinyl Accordion Door	Beige	54%	47
38	Vinyl Accordion Door	Beige	54%	19
39	Vinyl Accordion Door	Beige	54%	30
40	Stained Plywood	Warm Green	27%	17
41	Metal Shutter	Cream	27%	20
42	Stained Plywood	Warm Green	27%	10
43	Fixture Lens		—	475
44	Fixture Lens		—	1000
45	Fixture Lens		—	1700
46	Acoustic Tile	White	80%	35
47	Side of Beam	Warm Green	27%	13
48	Vinyl Floor	Cream	40%	46
49	Desk Top	Grey	43%	58

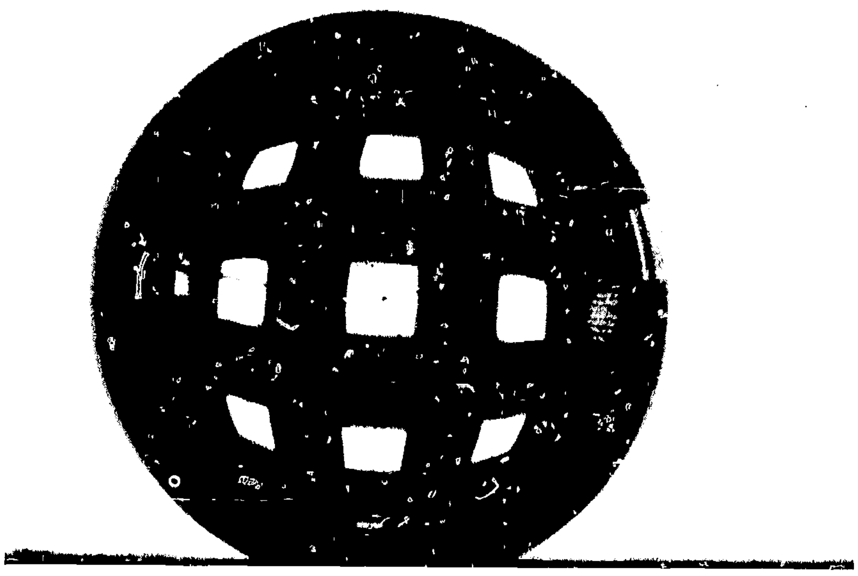
project 8 evaluations

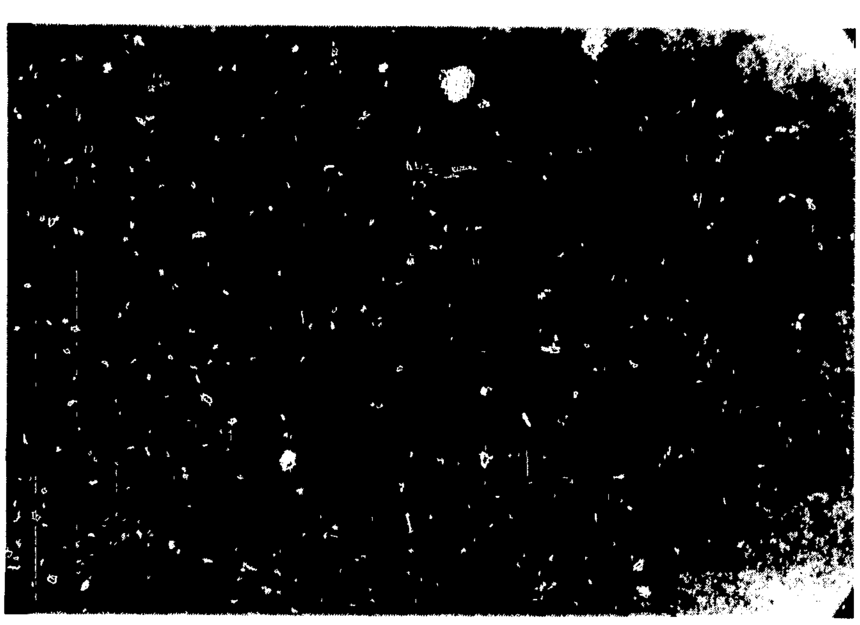
Quality	Location		
	M1	M2	M3
TI	135	135	120
CRF	.742	.908	.987
ESI	18.3	64.4	109.3

As might be expected with such concentrated sources of direct illumination, the CRF value at the M1 position was the worst of those surveyed even though this position was nearer the center of the room than in most of the other projects. The M2 position was to the left, far enough to put the mirror image halfway between luminaires, and the CRF at this point was much better. Meter position M3 was chosen to locate the mirror image on the diagonal between four luminaires, and this location has the highest CRF for this project.

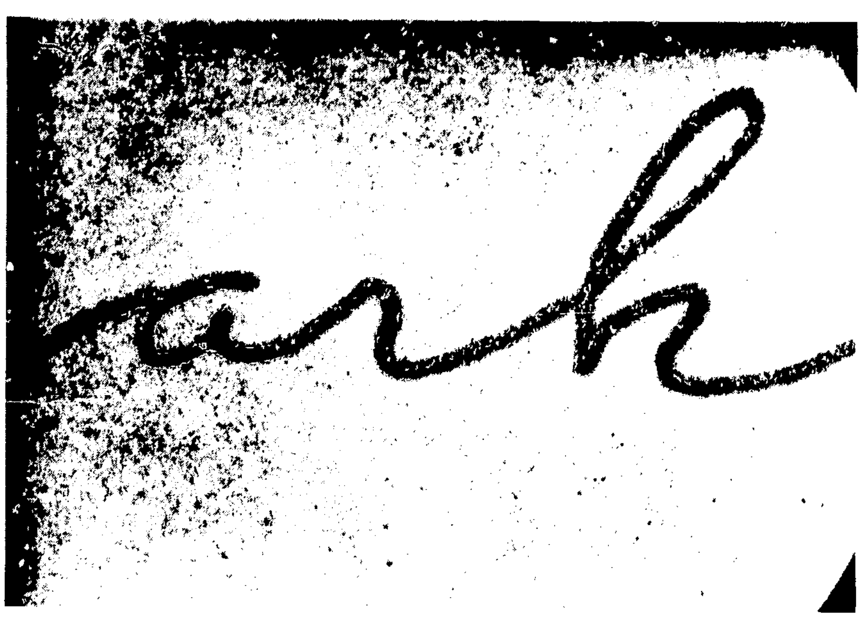
The CRF in this project is the poorest of all those surveyed, only 13.6% of the total light delivered was effective. Even though the system produced 135 footcandles at M1 position, the quality was so poor that the resultant visibility was the same as that produced by only 18.3 footcandles of sphere quality light. The CRF value at M2 is very high because little light comes from the ceiling at the critical area, and M3 is even higher because light is coming from even better angles. As in most all of the projects, the M2 position is good for CRF.







Sphere Quality



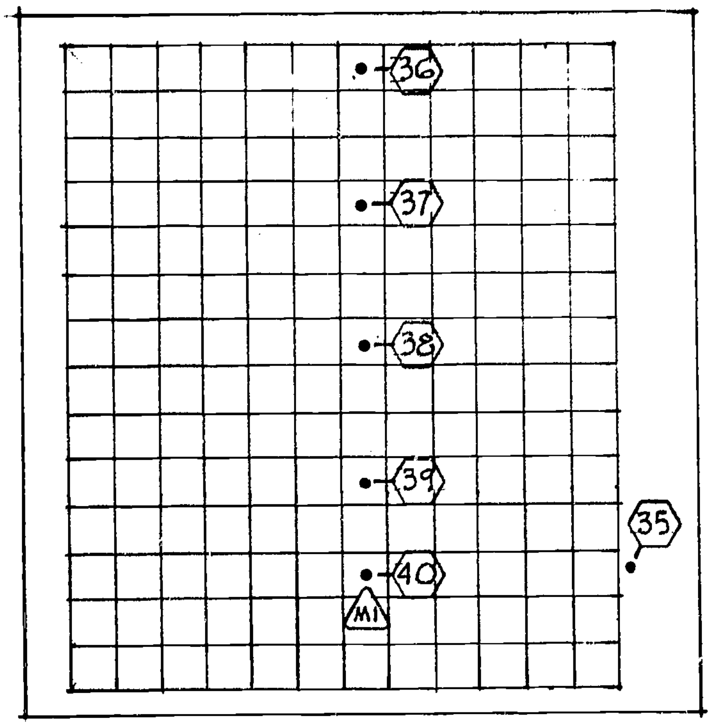
Project Quality

ERIC

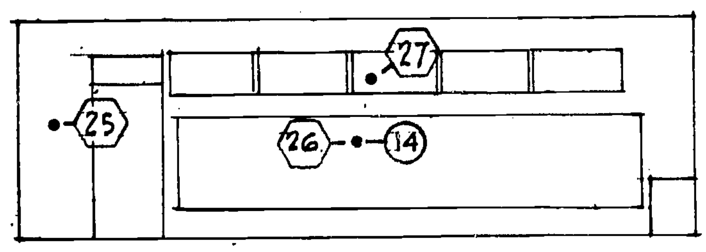
project 9 description

The room is 30′-0″ square with a 9′-6″ ceiling height. The lighting system is a luminous ceiling 24′-0″ x 28′-0″ made up of 2′-0″ square diffusers on suspended T bars. There are 12 rows of seven 48″, rapid-start cool white lamps mounted 12″ above the diffusers. The plenum is lined with aluminum foil to act as a reflecting surface.

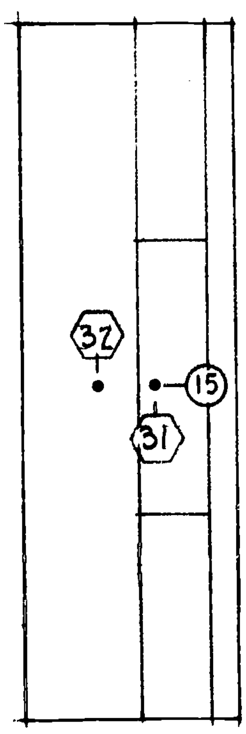
Levels of illumination are shown for both daylight and electric light alone. The large windows face east under an arcade roof and are glazed with low transmission glass. They were covered by a heavy drape during the survey. The interior photographs were taken late in the afternoon and show the windows undraped. On the opposite, or west, wall, there are five 2′-0″ high windows which were also covered with drapes during the survey.

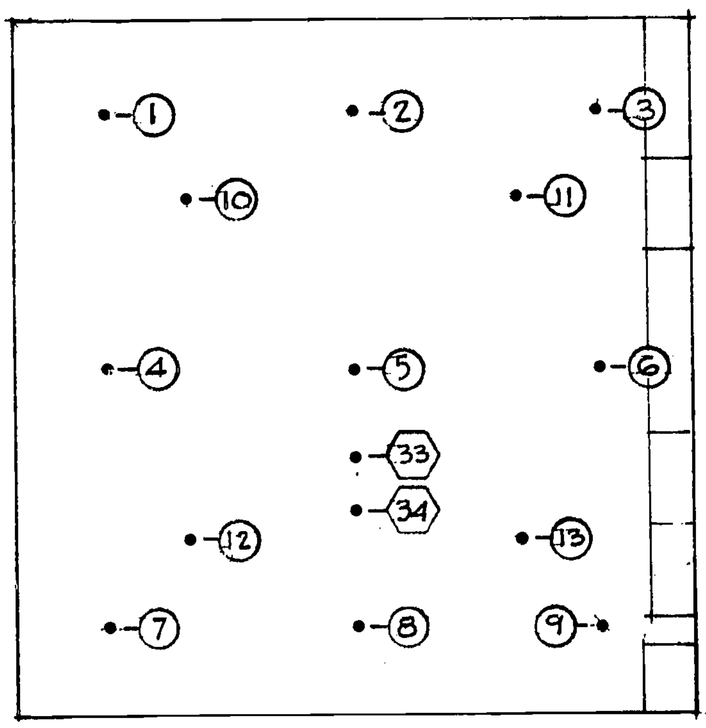


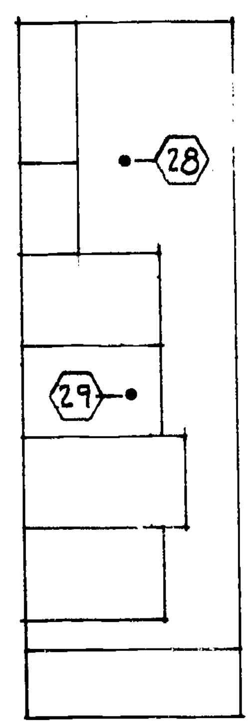
Reflected Ceiling Plan



Wall Elevations

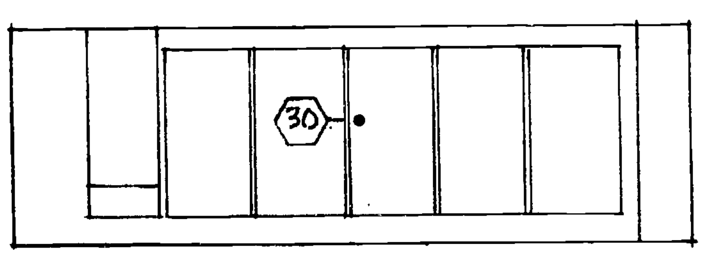






Floor Plan

Wall Elevations



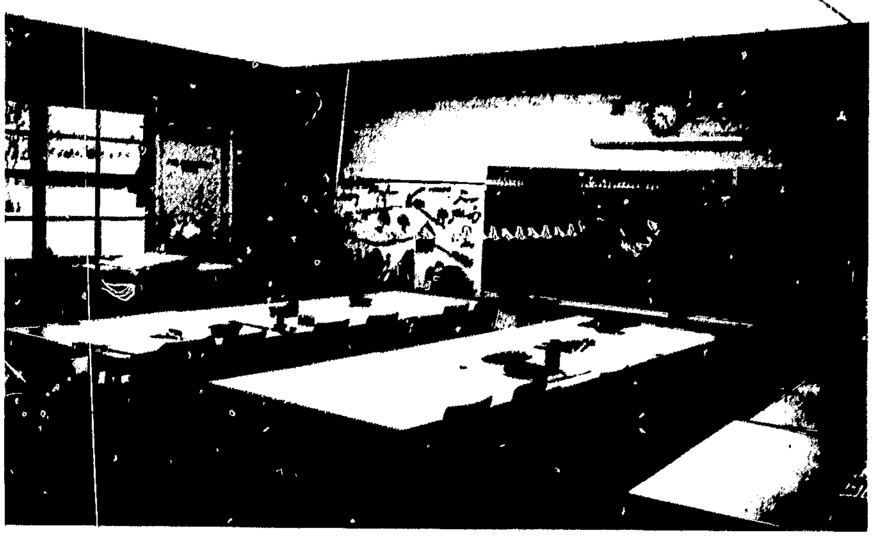
The brightness ratios in the space are very good. Although the wall colors were not high in reflectance, they did not produce a dark-appearing room. The chalkboards were dark, but the only other area of low brightness was the white ceiling, adjacent to the luminous ceiling. The only cure for this problem is to use much lighter floor colors and white or nearly white on the upper side walls. Also, in this particular room, the luminous area was stopped more than 42″ from the wall near which this reading was taken.

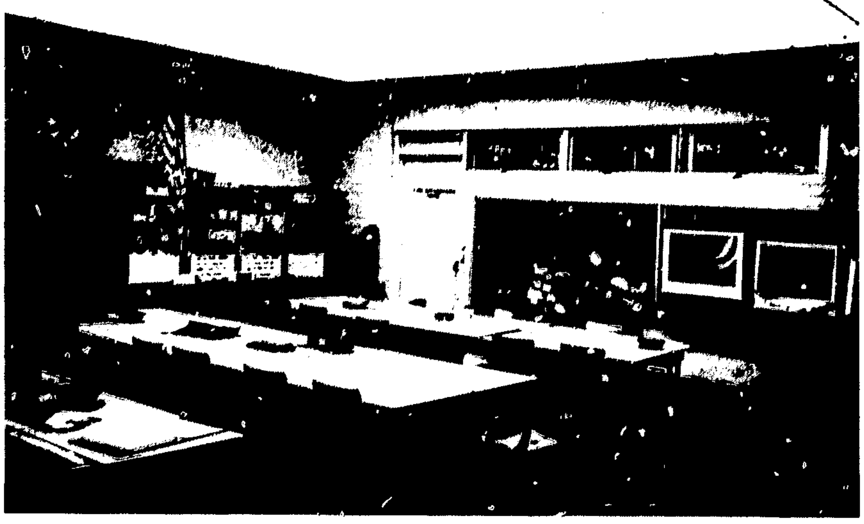
The room, even with the windows unshielded, was very comfortable because of the use of low transmission glass in the large windows which face east. Even though the exposure was correct for the interior brightnesses, and no supplementary light was used, the buildings and trees outside the classroom are also well exposed. Had the window glass been clear, the outdoor brightness would have been excessive, and the entire view through the window would have been badly over-exposed. Discomfort from window brightness follows to a degree the over-exposure shown on unretouched photos. It will usually be comfortable in a room where a well-exposed photo of the room interior also shows the exterior in good exposure.

This room has 900 square feet, used 4200 watts, and produced an average of 61 footcandles, or 13 footcandles per watt per square foot. This efficiency is very low, particularly when compared with Project 2 which is comparable construction and developed 25 footcandles per watt per square foot. Although no test was made, it is very possible that the diffusing material is of too low a transmission factor. The degree of uniformity is less than should be expected from a uniformly lighted ceiling that goes well over toward the side walls. The side wall colors are not as high in reflectance as they might be; however, they are not so low as to cause the over-all low efficiency in the system.

lighting levels

	Footcandles			Footcandles	
Location	Daylight	Electric	Location	Daylight	Electric
1	1.3	45	9	2.4	36
2	1.9	60	10	1.4	61
3	1.3	38	11	1.4	60
4	1.2	59	12	2.3	64
5	1.8	80	13	2.4	59
6	1.5	51	14	—	42
7	1.6	44	15	—	36
8	5.6	60			





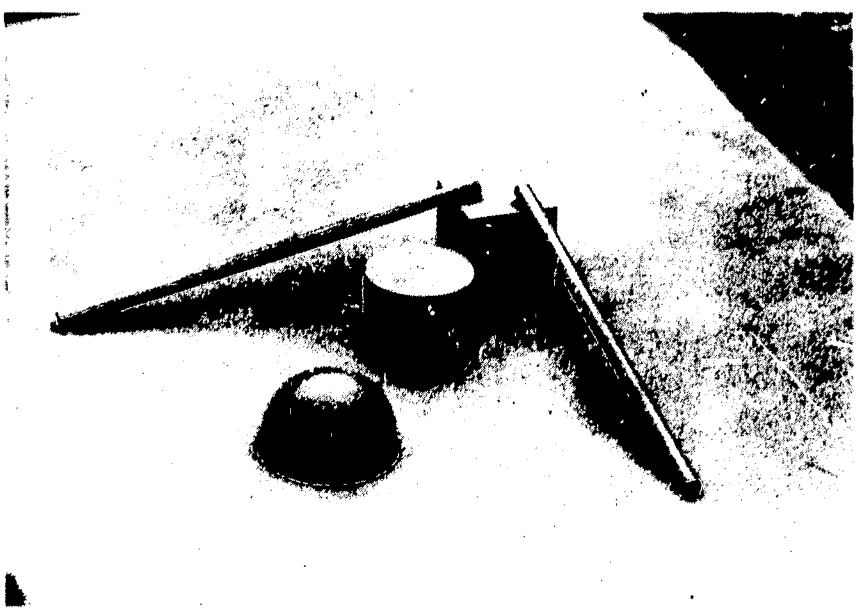
brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Painted Brick	Soft Yellow	65%	15
26	Chalkboard	Green	21%	8
27	Curtain	Tan Gold	43%	17
28	Painted Plaster	Grey	46%	13
29	Wood Cabinet	Oak Color	25%	10
30	Curtain	Tan Gold	43%	16
31	Chalkboard	Green	19%	7
32	Painted Brick	Grey	46%	18
33	Table Top	Tan Formica	45%	33
34	Asphalt Tile	Tan	27%	15
35	Acoustic Tile	White	80%	7
36	Light Diffusers	White	—	70
37	Light Diffusers	White	—	70
38	Light Diffusers	White	—	88
39	Light Diffusers	White	—	92
40	Light Diffusers	White	—	100

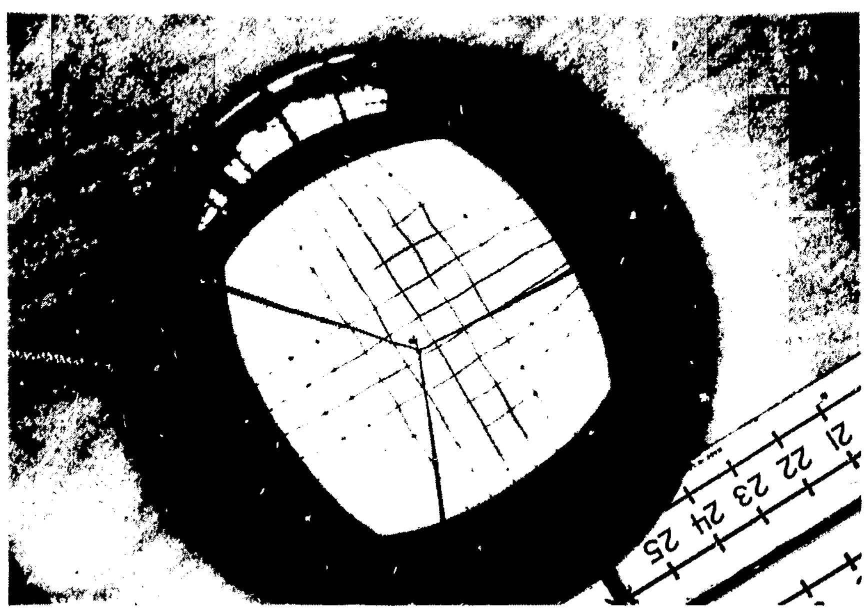
project 9 evaluations

Quality	Location M1
TI	65
CRF	.886
ESI	29.3

The CRF developed in this project would be the same for any nonpolarizing, diffusing material. The density of the diffuser may be high or low, but as long as the distribution characteristics are the same, the CRF will be the same. Although luminous ceilings were considered the ultimate in quality, this and the one in Project 2 do not prove the point. What this and other projects do prove is that, from the standpoint of contrast rendition, light from directly overhead is detrimental, regardless of brightness. The problem is how to direct light to the task from wide, low angles, rather than from directly overhead, and to do this without creating direct glare.



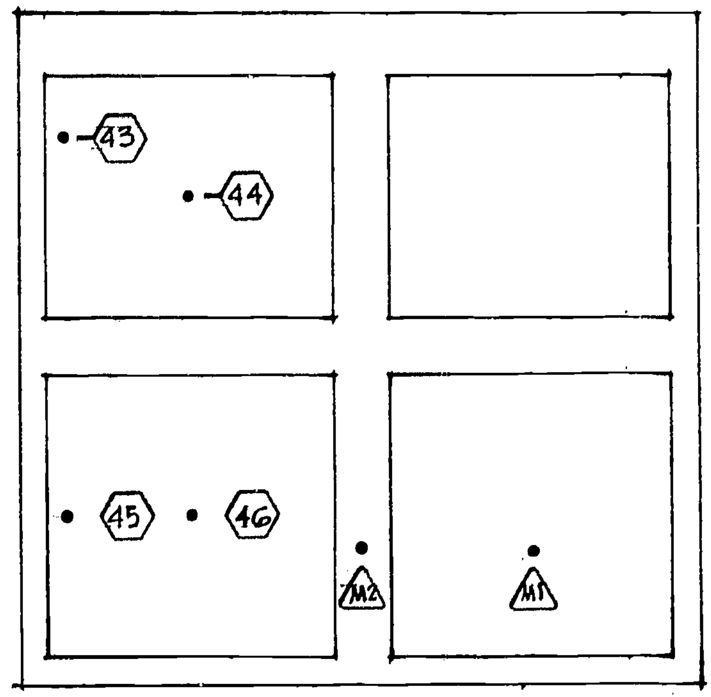
Sphere Quality



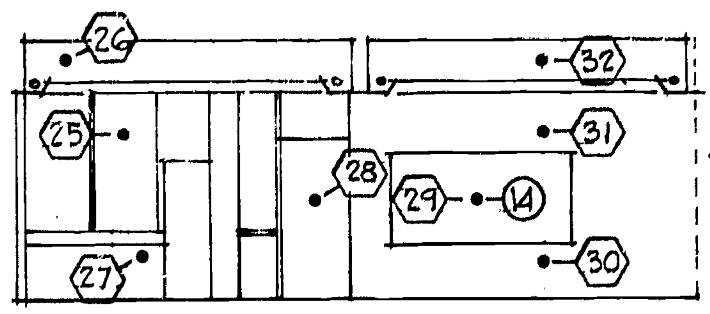
Project Quality

project 10 description

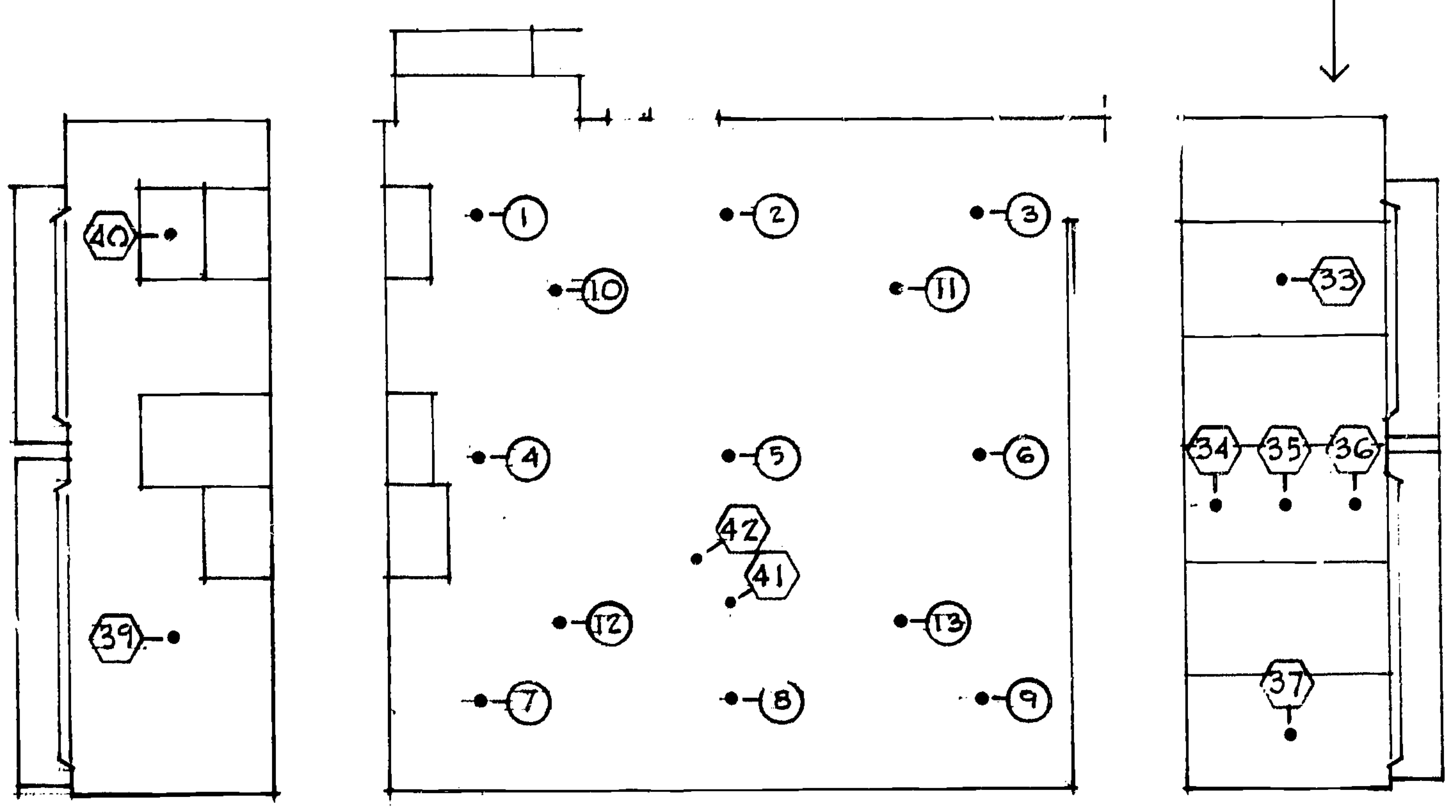
This classroom building is made up of 15′-0″ square bays and the building is basically 4 bays wide and more than 10 bays long. There are no fixed partitions; however, movable partitions may be placed on any 30′-0″ module. During the test, partitions were placed to provide a 30′-0″ square room in one corner of the building. The electric lighting is from 4 bays, each with an opening 11′-6″ square in which coves on all four sides light the 28″ deep coffer. On each of the four sides of each lighting coffer, there are two 72″ long, 1500 m.a., fluorescent lamps. Daylight enters the room only through a corner alcove window, glazed with 15% transmission factor, neutral grey glass. The quantity and distribution of daylight were not significant factors in the contrast rendition study.



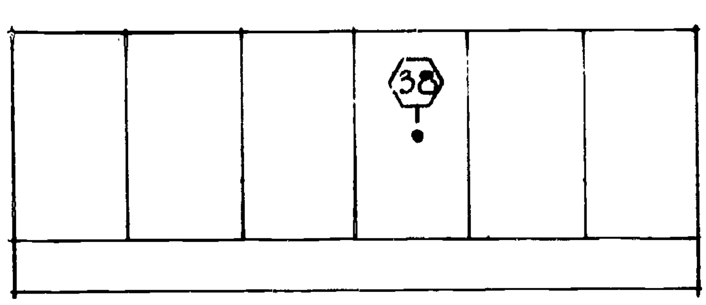
Reflected Ceiling Plan



Wall Elevations



Floor Plan



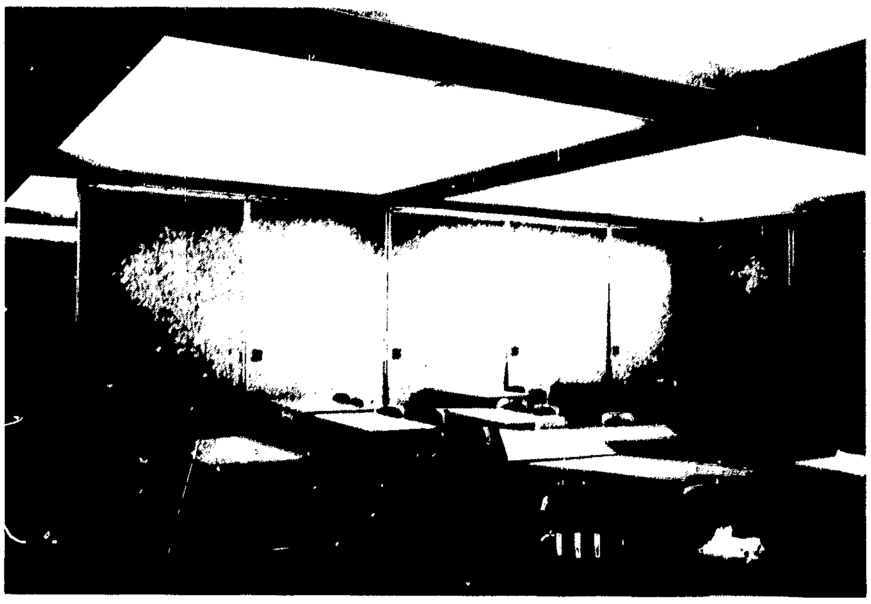
Wall Elevations

The degree of uniformity of light within the seating area of this project is quite unusual in that the minimum level is only 32% lower than the maximum. The highest level is not at the center of the room, but it is nearly equal under the center of each of the lighting coffers.

The brightness balance is very good as far as high brightnesses are concerned. The small corner window is glazed with a 15% transmission, neutral grey glass which produced a brightness of only 300 footlamberts. The brightest areas within the coffers were all less than 300 footlamberts. The chalkboards are of lower reflectance than many found in other schools, and even though the areas are reasonably small, it would be an improvement to have them lighter. The sage green carpeting was only 13% reflectance, and consequently the floor brightness was well below the recommended minimum of one third task brightness. Also, had the carpeting been lighter, the added reflected light would have increased the brightness of the 28″ wide ceiling surfaces between coffers. The vinyl wall coverings and painted walls are excellently chosen with relatively high reflection.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	84	8	96
2	75	9	96
3	78	10	108
4	90	11	105
5	99	12	108
6	93	13	111
7	96	14	57

brightness distribution

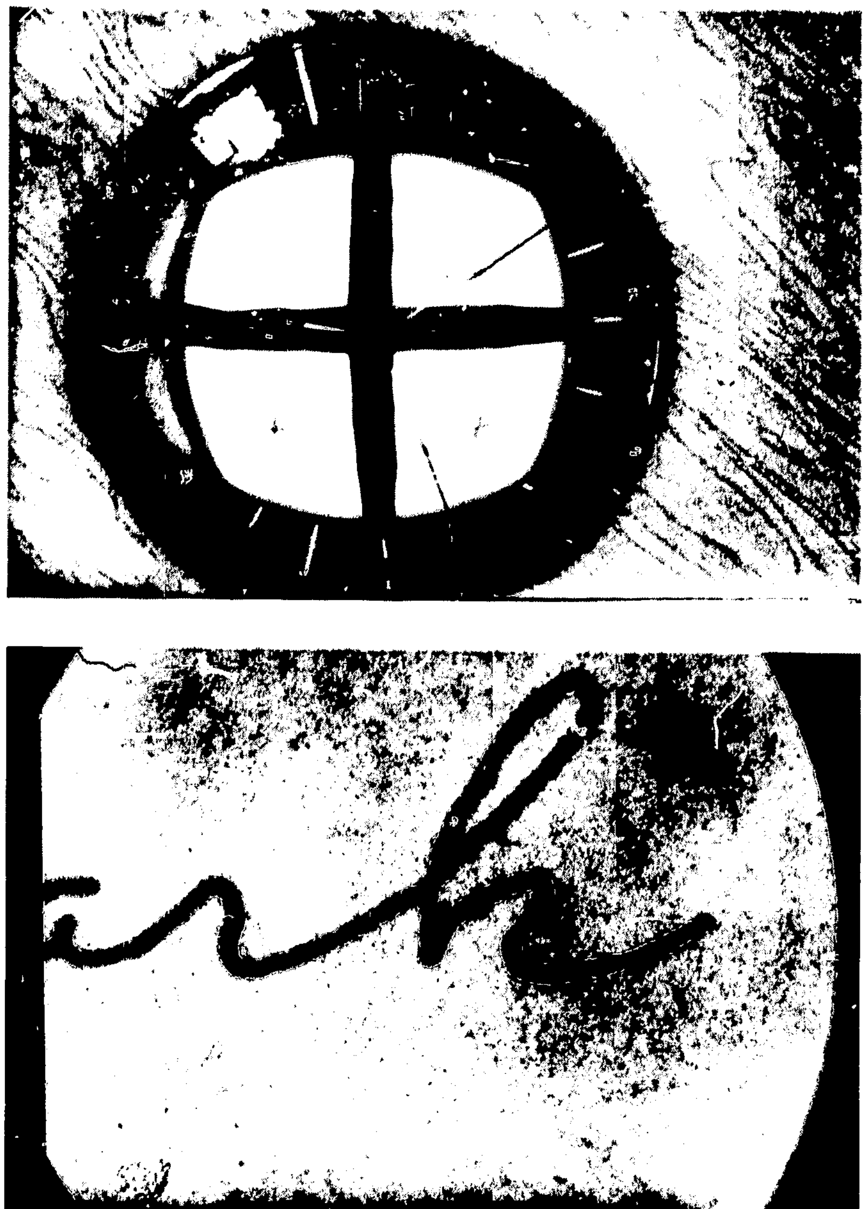
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Lo-Tran Glass	15% Trans.-Neutral		300
26	Painted Plaster	White	80%	230
27	Stained Wood	Brown	21%	9
28	Painted Door	Green	35%	19
29	Chalkboard	Brown	16%	9
30	Vinyl Wall	Warm Green	53%	25
31	Vinyl Wall	Warm Green	53%	27
32	Painted Plaster	White	80%	200
33	Vinyl Wall	Warm Green	53%	35
34	Vinyl Wall	Warm Green	53%	30
35	Vinyl Wall	Warm Green	53%	40
36	Vinyl Wall	Warm Green	53%	35
37	Vinyl Wall	Warm Green	53%	35
38	Vinyl Wall	Warm Green	53%	40
39	Painted Plaster	Green	58%	40
40	Chalkboard	Green	19%	9
41	Table Top	Maple	35%	42
42	Carpet	Sage Green	13%	11
43	Acoustic Tile	White	80%	290
44	Acoustic Tile	White	80%	80
45	Acoustic Tile	White	80%	275
46	Acoustic Tile	White	80%	41

project 10 evaluations

Quality	Location M1	Location M2
TI	110	97
CRF	.956	.972
ESI	79.4	78.6

As would be expected, the CRF values in this project rate very well. The large areas of low over-all brightness produce diffuse light which minimizes veiling reflections. The side walls were all of high reflectivity, and this added to the low angle light which is so advantageous. The normal practice of selecting the M1 meter position to reflect the center of a lighting panel produced the maximum brightness at the offending area. In this project, the center of the coffer has the lowest brightness, and for this reason the M1 position was moved forward three feet so that the ceiling area reflected in the task was about halfway toward the far side of the coffer. M2 was chosen at the same distance from the rear wall as M1, but on the center line of the room, under the 28″ wide panel of ceiling, between coffers. This project has the third best CRF of those tested and should certainly arouse interest.

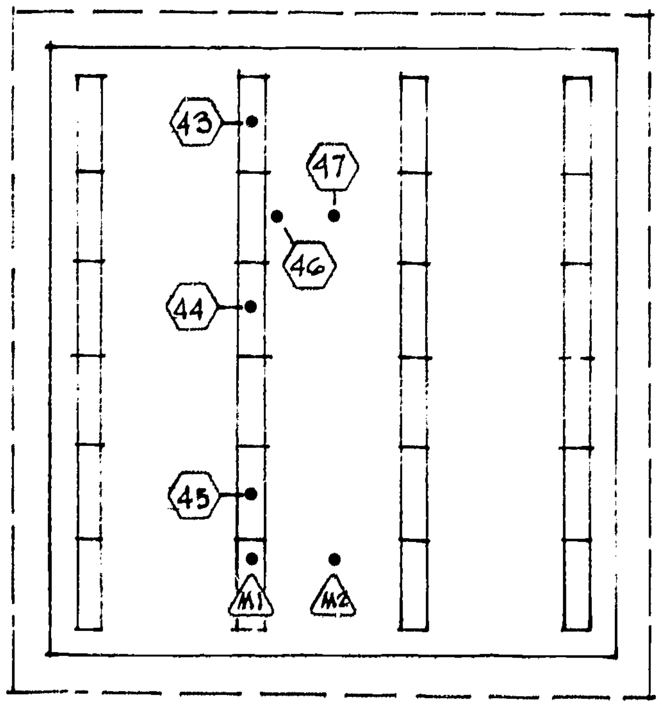
Sphere Quality



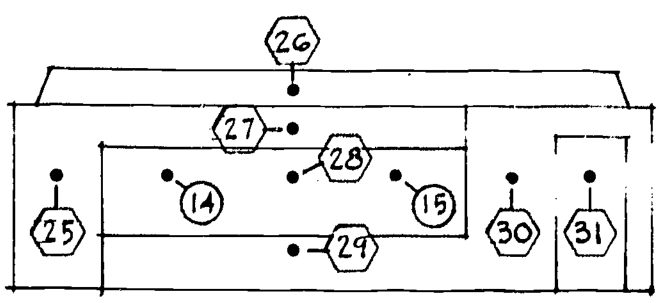
Project Quality

project description 11

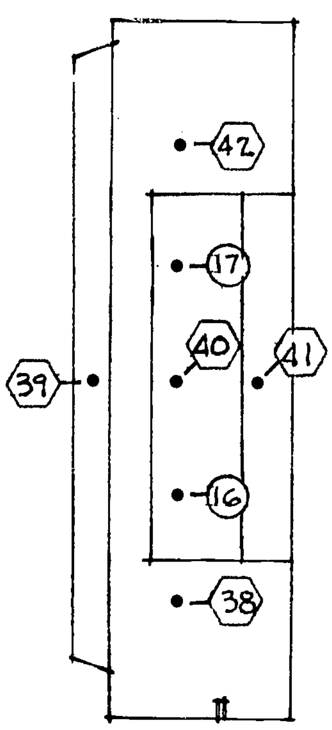
This room is 28'-0" by 30'-0" with a 9'-6" ceiling. The ceiling is dropped 20" around all four walls as shown on the drawings of the wall elevations. The electric system consists of four continuous rows of six luminaires each. The units are surface mounted, 4½" deep and 13" wide, with plastic lens sides and bottom, and with two 48" rapid-start fluorescent lamps. The windows on the north wall are covered with Venetian blinds which were kept closed during the survey.

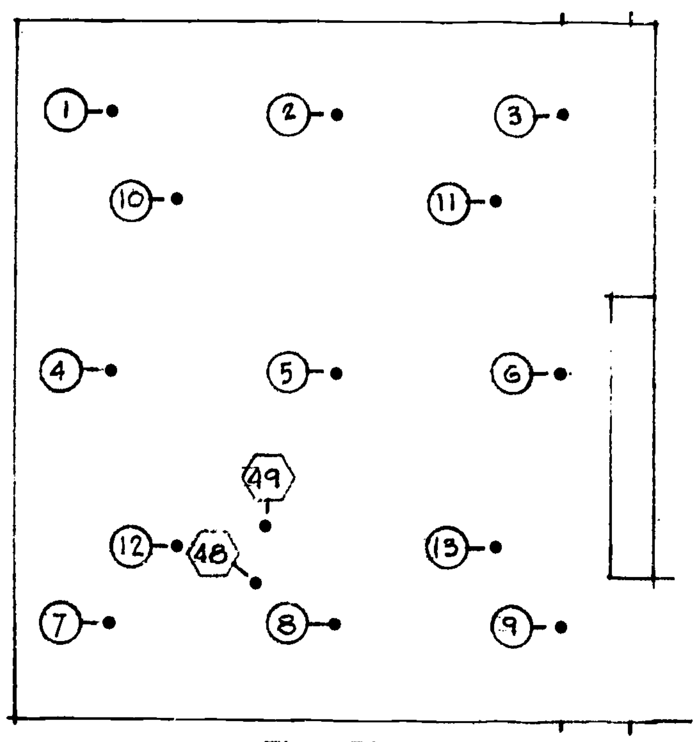


Reflected Ceiling Plan

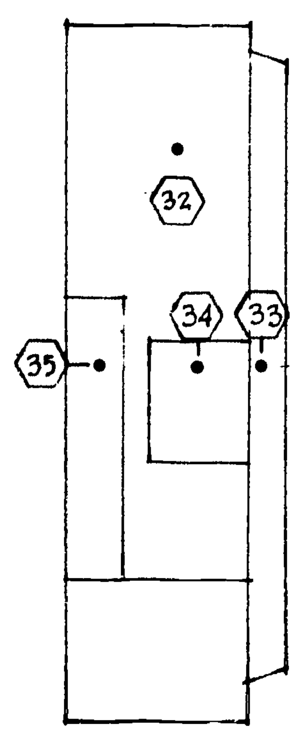


← Wall Elevations

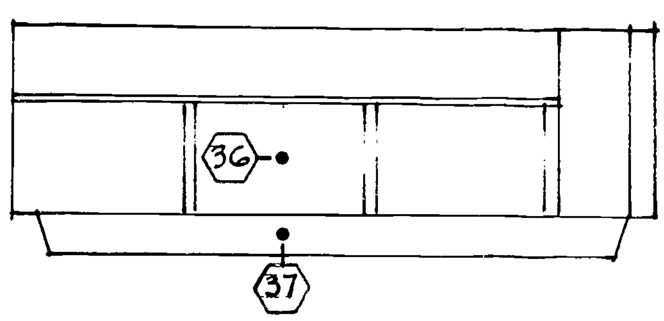




Floor Plan



Wall Elevations →

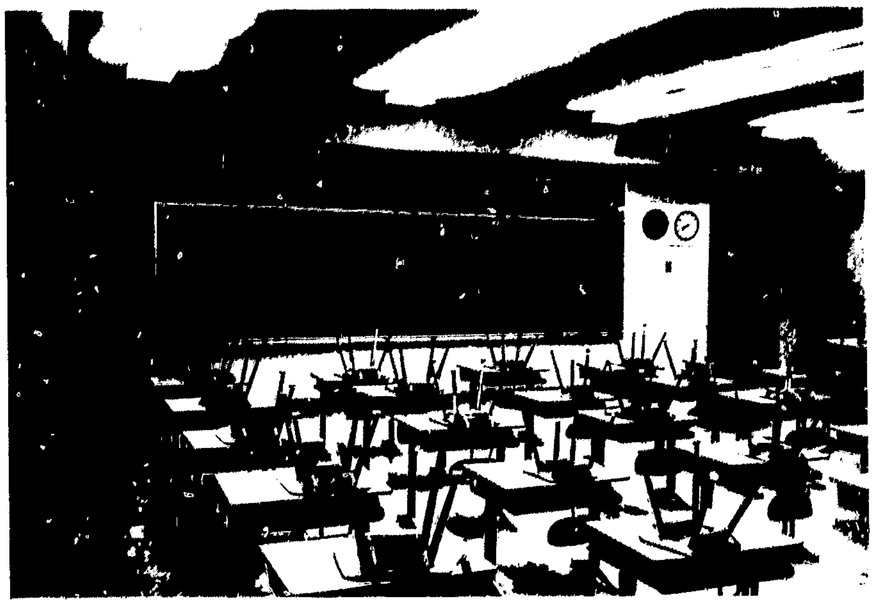


The lighting levels are very good and the minimum level was 59% that of the highest. In determining this value, the author used the low level at station 7 rather than that at station 9 because the wall opening adjacent to station 9 was an unusual situation. The high reflectance values of the walls and floor added materially to the over-all efficiency of the lighting system.

The brightness balance in this project was excellent except for the extreme luminaire brightness when viewed at a rather high angle. The painted walls had a reflectance of 60% and the floor was 39%, and together these two surfaces reflected a very good percentage back to the ceiling. At station 47, on the ceiling halfway between rows, the brightness was 36 footlamberts. This is excellent when compared with 11 footlamberts on the ceiling for Project 6, and 10 footlamberts for Project 16. The levels of illumination are different in each case so the ceiling brightness comparisons must be made with this fact in mind. If the room is used with the Venetion blinds in the open position, the brightness of the exterior on sunny or bright days will be uncomfortable. The glare on dark overcast days will not be a problem nor will the added light be a factor to consider. There is much to be said in favor of windows that allow vision to the outside with proper control of the shielding devices.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	93	10	129
2	108	11	129
3	102	12	120
4	132	13	123
5	147	14	54
6	132	15	60
7	87	16	81
8	93	17	81
9	84		

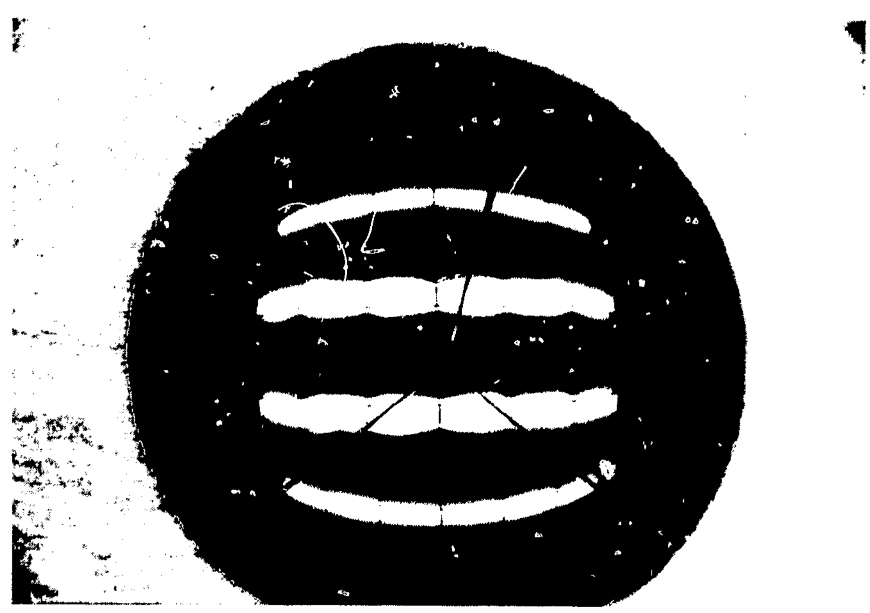
brightness distribution

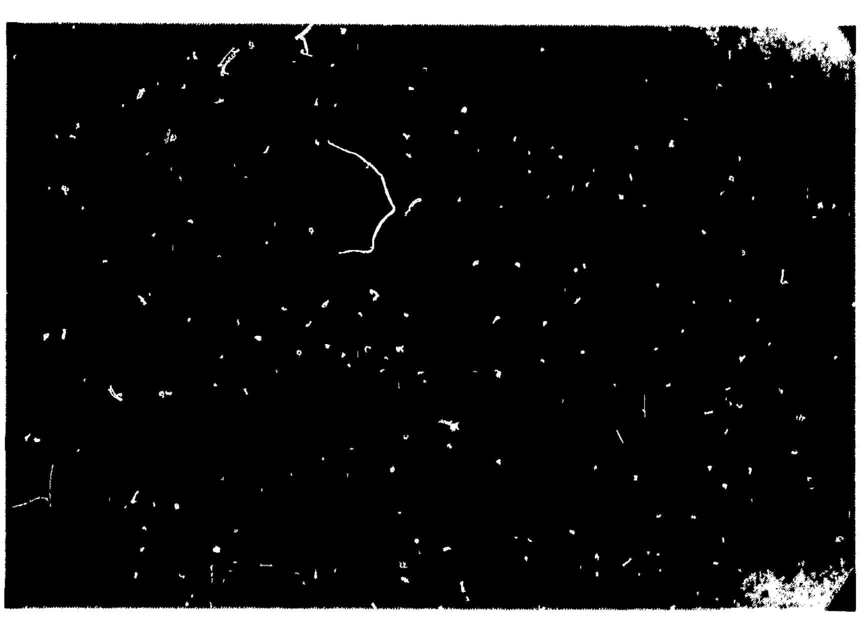
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Tan	37%	18
26	Painted Plaster	Off-White	60%	35
27	Tackboard	Tan	37%	20
28	Chalkboard	Blue Green	16%	10
29	Painted Plaster	Yellow Green	52%	28
30	Painted Plaster	Off-White	60%	36
31	Birch Door	Natural	30%	16
32	Painted Plaster	Off-White	60%	48
33	Painted Plaster	Off-White	60%	56
34	Tackboard	Tan	37%	37
35	Cabinet Door	Tan	27%	12
36	Venetian Blind	White	—	33
37	Painted Plaster	Off-White	60%	34
38	Tackboard	Tan	37%	24
39	Painted Plaster	Off-White	60%	53
40	Chalkboard	Blue Green	16%	15
41	Painted Plaster	Yellow Green	52%	35
42	Tackboard	Tan	37%	26
43	Fixtures		—	290
44	Fixtures		—	450
45	Fixtures		—	1200
46	Acoustic Tile	White	80%	100
47	Acoustic Tile	White	80%	36
48	Desk Top	Maple	47%	52
49	Vinyl Floor	Grey Green	39%	36

project 11 evaluations

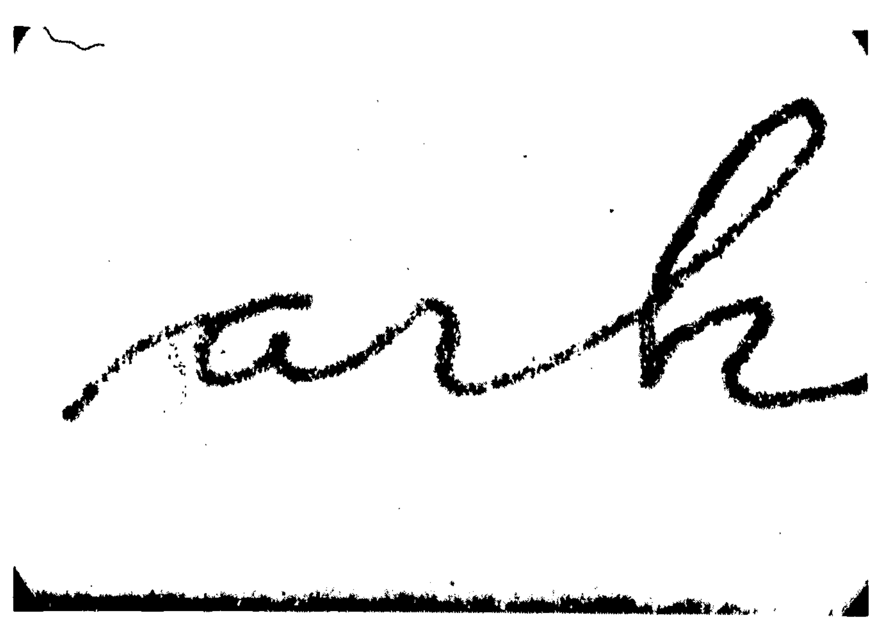
Quality	Location M1	Location M2
(electric only)		
TI	111	110
CRF	.845	.943
ESI	33.8	70.8
(electric & daylight)		
TI	147	146
CRF	.905	1.01
ESI	68.5	157.6

The CRF values are typical for continuous row systems, with narrow units. The CRF at M1 was poor, and 11 of the 18 projects had higher ratings. Added readings for 25° at M1 and M2 indicated the improvement in CRF by adding 36 footcandles of daylight. The windows were directly behind the meter positions, and as long as all students face away from the windows, there would be a major benefit to those near the windows. Students farther from the windows would receive less benefit because of the smaller contribution of daylight. The direct glare problem has already been discussed in other projects.





Sphere Quality

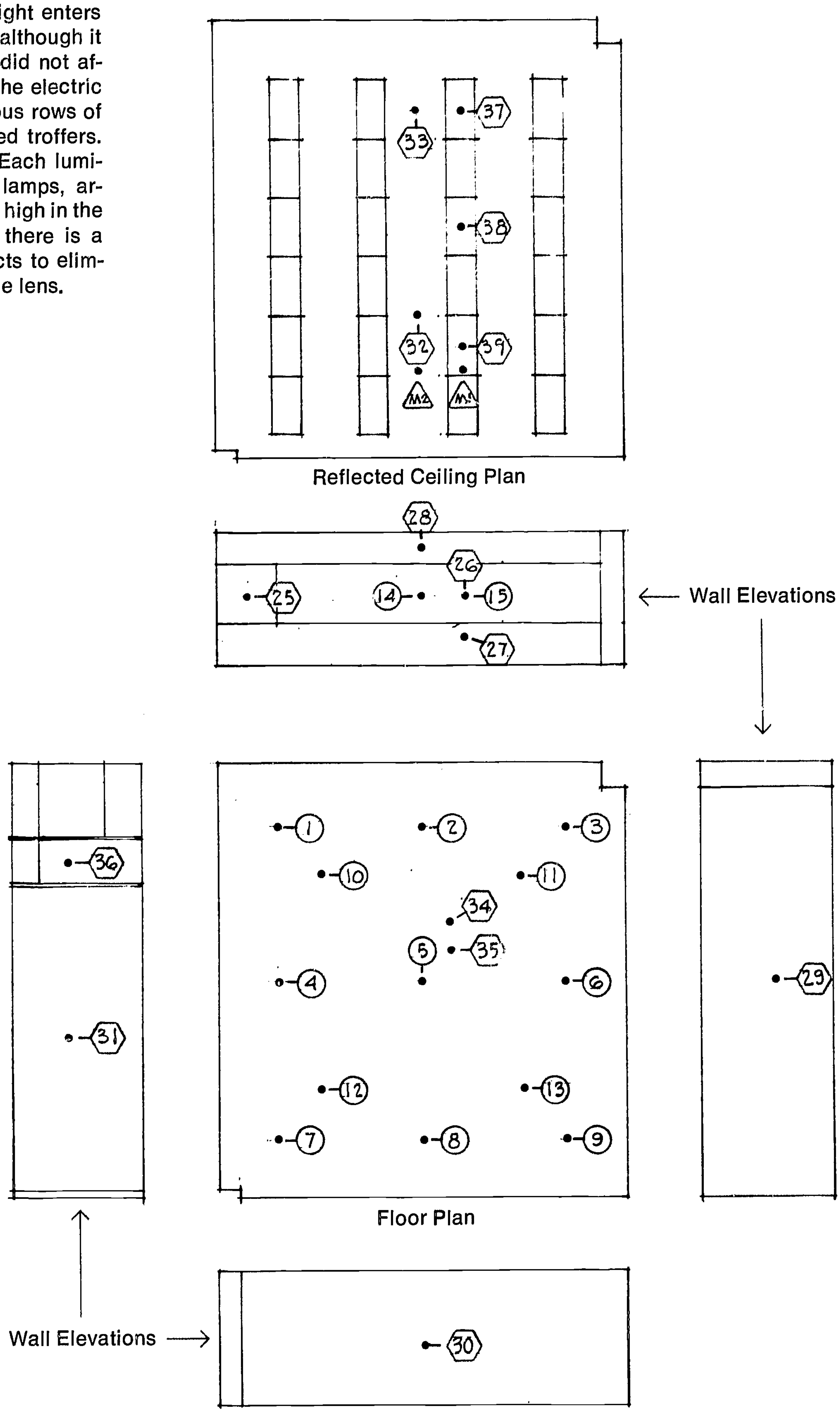


Project Quality

ERIC

project 12 description

The room is 27′-6″ wide, 29′-6″ long, and the ceiling height is 9′-0″. Daylight enters through one window only, and, although it was not covered, the daylight did not affect the results of the survey. The electric lighting system is four continuous rows of six 2′-0″ x 4′-0″ recessed, lensed troffers. The rows are 6′-0″ on center. Each luminaire has two 48″ rapid-start lamps, arranged one above the other and high in the unit. Under the pair of lamps there is a V-shaped plastic lens which acts to eliminate lamp image in the 24″ wide lens.



The lack of uniformity in the lighting levels for this project show very clearly that the placement of luminaires in a room must be thought out very carefully. In this instance, the ceiling is formed by suspended "T" bars with luminaires and acoustic panels fitted into the pattern of T bars. The total number of units produced quite high levels in the center of the room, but rather low values in the corners. A change in the pattern of T bars could have allowed a 6′-0″ space in the center of the room instead of the 4′-0″ space, and the six luminaires in each row could have been split into two groups of three luminaires with a 4′-0″ space between. This would have reduced the level of light in the center of the room and added light into the corners, and the chalkboard on the end wall would have been much better lighted. Other luminaire patterns could have been worked out in the T bar ceiling to provide a more uniform distribution. In this particular case, the low level is only 42% that of the maximum.

At M1, the level of illumination is 137 footcandles, and on this basis, the reference brightness for the task would be 96 footlamberts. Most of the large wall spaces have very good reflection factors and contribute to a comfortable and efficient environment The only large area of low reflectance is the folding wall, and a much lighter color would have been beneficial if students had this surface in their normal line of sight. In this case, however, it is a rear wall. The design of the lighting unit is very efficient, and yet, by the interior design of the fixture, the lamp image is removed entirely. The maximum reading even at a high angle of viewing was only 370 footlamberts, which is less than four times task brightness. It is true that if the spacing of rows of luminaires were made wider to provide greater uniformity of lighting level, the task brightness at the M1 position would have gone down slightly.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	71	9	95
2	105	10	138
3	83	11	124
4	135	12	150
5	171	13	147
6	134	14	48
7	96	15	48
8	129		

brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Beige	56%	25
26	Chalkboard	Grey Green	19%	10
27	Vinyl Wall	Grey	55%	31
28	Vinyl Wall	Grey	55%	22
29	Vinyl Wall	Grey	55%	36
30	Vinyl Folding Wall	Blue Grey	21%	13
31	Vinyl Wall	Grey	55%	35
32	Acoustic Tile	White	80%	35
33	Acoustic Tile	White	80%	27
34	Floor Tile	Beige	37%	37
35	Desk Top	Maple	38%	52
36	Wood Door	Maple	36%	19
37	Luminaire		—	260
38	Luminaire		—	280
39	Luminaire		—	370

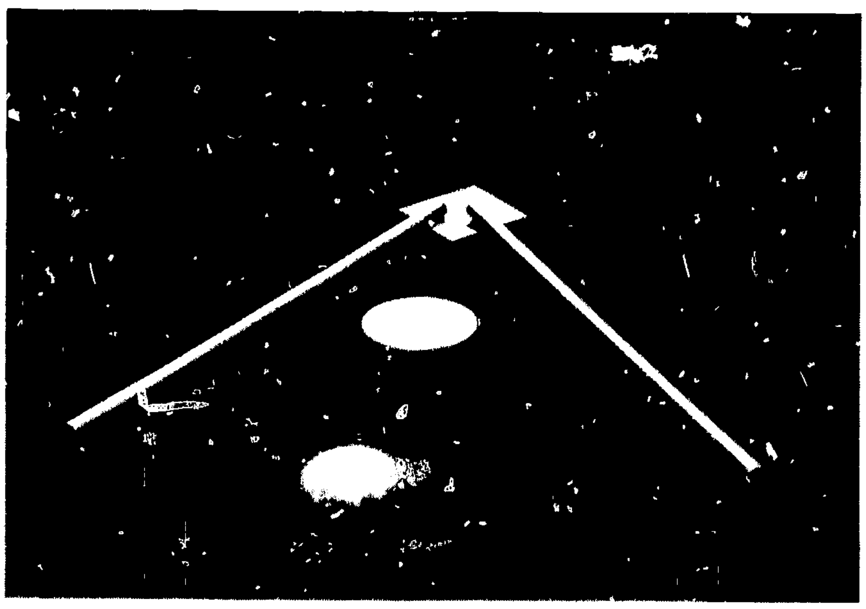
project 12 evaluations

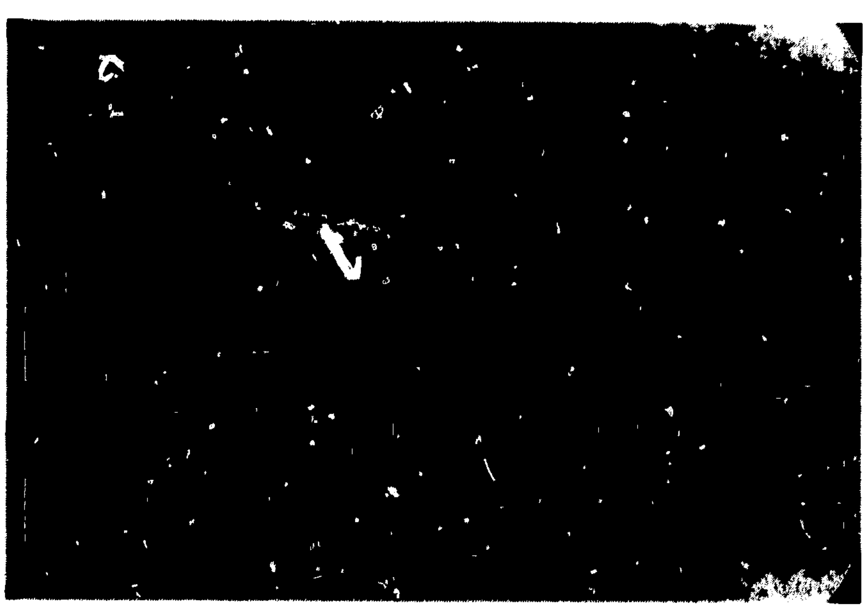
Quality	Location	
	M1	M2
TI	137	140
CRF	.832	.910
ESI	36.1	68.5

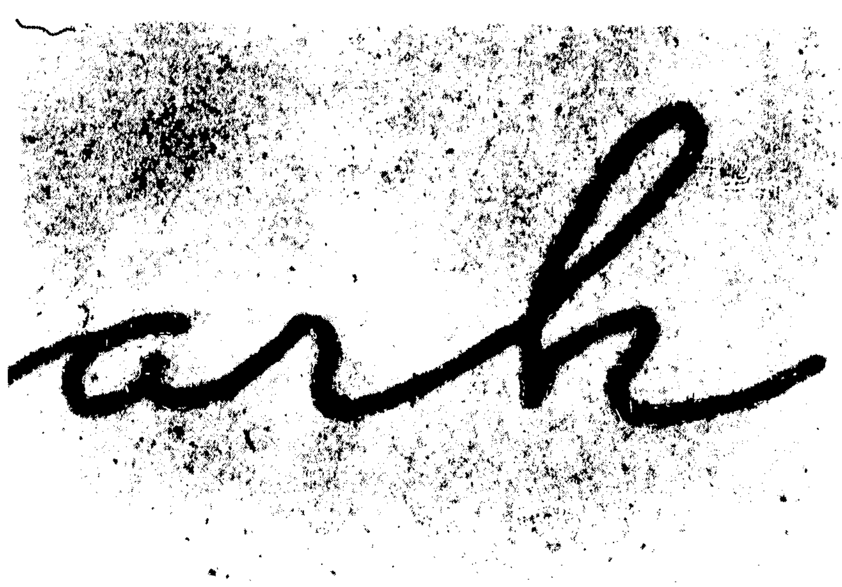
The CRF values for this project are a little surprising, the spacing of rows is 6′-0″ on center, and the units are recessed and 24″ wide. In Project 11, the rows are 7′-0″ on center, the units are surface mounted, and only 13″ wide. On the basis of luminaire spacing and width, the CRF values for Project 12 should be better; however, the distribution characteristics of the surface-mounted unit are wider, and this quality was more than enough to prove slightly better than the recessed system. On the other hand, Project 17 has 13″ wide, surface-mounted units in continuous rows 9′-0″ on center and the CRF was only .798, considerably lower than this project. These results point out the importance of luminaire spacing, apparent size, and the distribution characteristics of the lighting elements.

At a previous testing period, two other lens patterns were tested in these same luminaires in this same room, but with a different test pattern for the task. With that pattern, it was established that, with the "V" lens removed from the interior of the lighting unit, the lamp image became apparent; however, the CRF decreased only slightly. With a diffusing plastic instead of the lens, the system provided CRF values only slightly higher than the lens with the "V" shield.

The CRF for this project is considerably better than Project 16 which used the 12″ wide lens troffer.







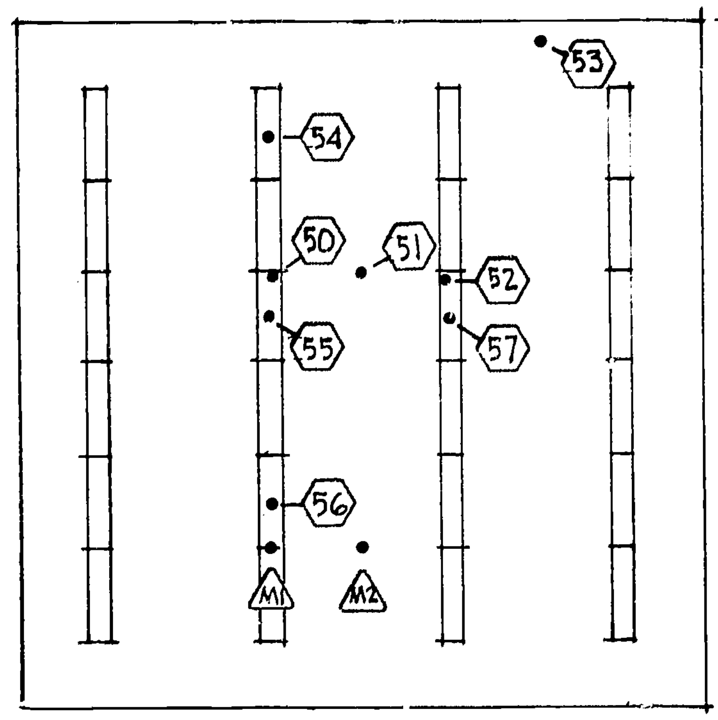
Sphere Quality

Project Quality

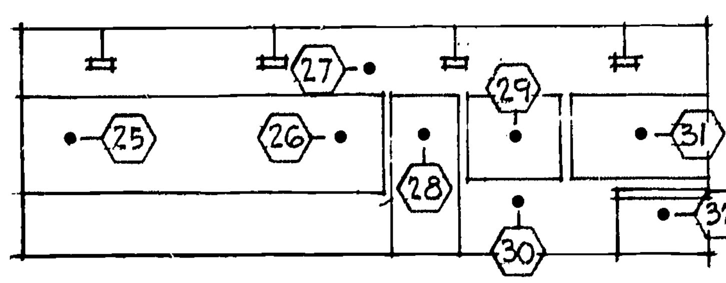
project description 13

This room is 30′-0″ square and has a 10′-0″ ceiling. It is lighted by four rows of six luminaires, each with two 40-watt rapid-start lamps. The units are suspended 1′-8½″ from the ceiling to the bottom of the luminaire, which is 13″ wide, with an open top, and the shield is a one-piece wraparound clear plastic lens. According to the manufacturer's information, the upward component accounts for 53% of the total light output, and the balance is downward, with 57% of the downlight in the 0°-40° zone and 43% in the 40°-90° zone. The maximum candlepower at nadir is 1040 and 500 at 45° which makes the downward component quite strong in the angles near nadir.

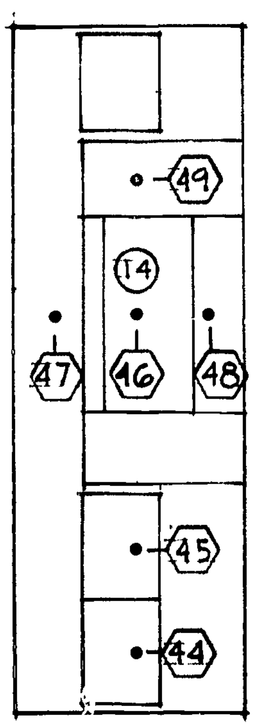
Although the windows are large, they are under an extremely wide porch area which reduces the brightness and illumination far below what would be considered normal for windows of equal size. There were blackout drapes available, and for the entire survey the drapes were closed to eliminate practically all daylight.

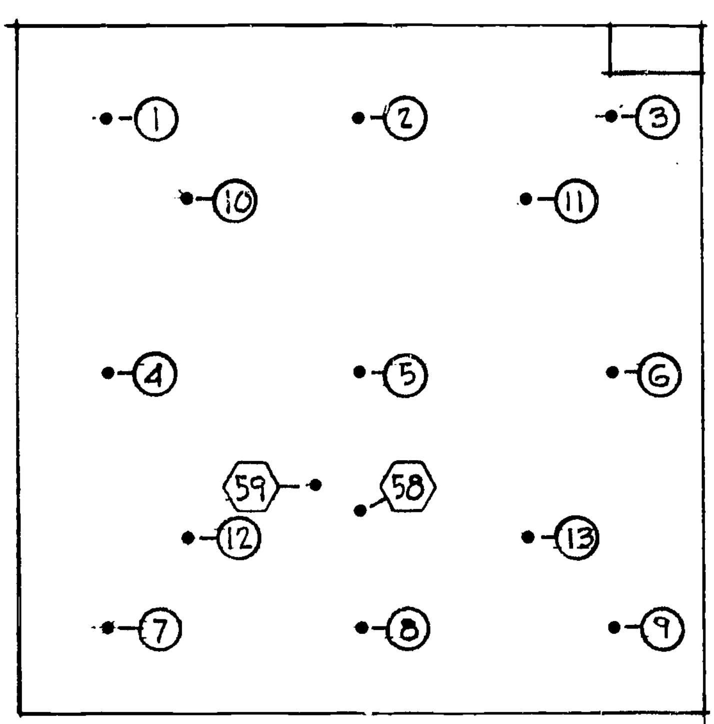


Reflected Ceiling Plan

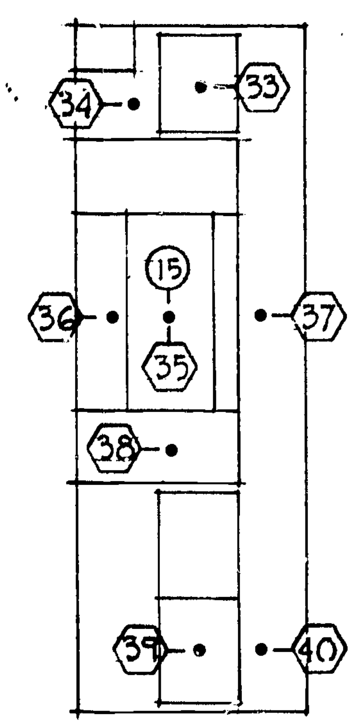


Wall Elevations

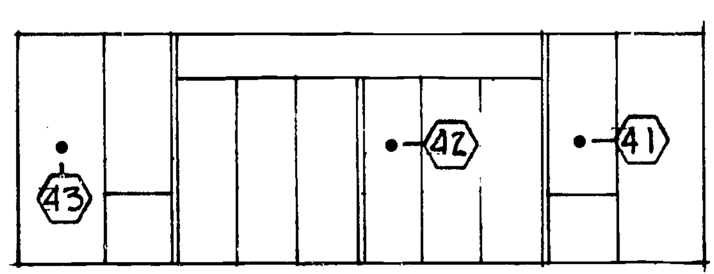




Floor Plan



Wall Elevations



The levels of illumination shown on the table are a clear example of the desirability of splitting the six luminaires in each row, leaving at least four feet open, and thereby providing a higher level near the walls. The average would remain about the same, but the minimum level would be increased and the maximum reduced. The side wall colors are quite dark as compared to other projects, and this feature causes a loss in the over-all efficiency. This is more important in this project than in some of the direct systems, because a large portion of the light from the luminaires is directed to the ceiling and is in turn reflected to the work area. A large portion of the reflected ceiling light falls on the side walls and is absorbed by the dark colors.

At position M1, the task brightness was found to be 82 footlamberts, and, on this basis, 27 footlamberts should be the lowest acceptable brightness in any dark area. With the exception of the ceiling and lighting elements, there are very few areas, large or small, that come up to the desired minimum. Fortunately, the floors are exceptionally light, and this helped. In actual use, the room will have lower brightnesses because tables and chairs will cover a large portion of the floor, which was practically clear during the survey. The suspended luminaires provide a high component of light to the ceiling, and this tends to ease the discomfort from rather high fixture brightness.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	93	9	90
2	93	10	120
3	93	11	123
4	129	12	114
5	129	13	117
6	132	14	84
7	87	15	84
8	87		

brightness distribution

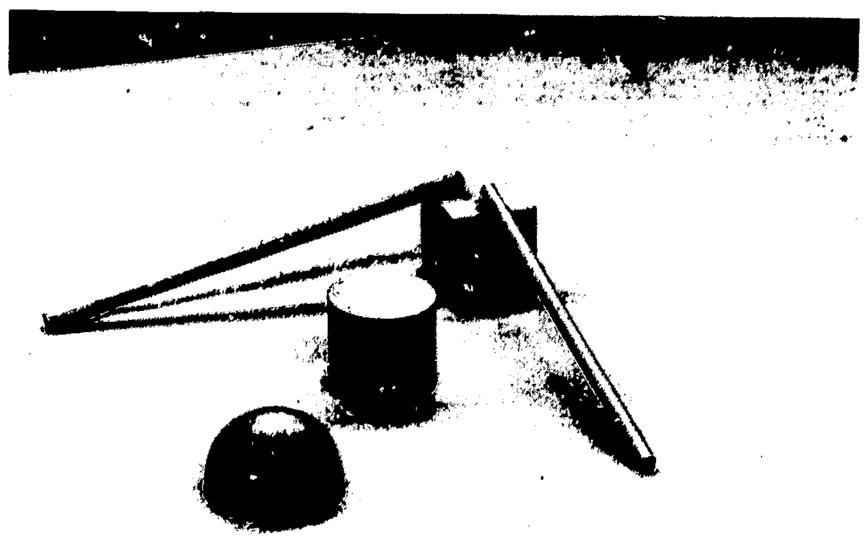
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Brown	25%	9
26	Tackboard	Brown	25%	16
27	Grasscloth	Tan	22%	17
28	Curtain behind interior window		—	7
29	Curtain behind interior window		—	7
30	Grasscloth	Tan	22%	22
31	Tackboard	Brown	25%	14
32	Wood Cabinet	Maple	25%	14
33	Tackboard	Brown	25%	6
34	Grasscloth	Tan	22%	21
35	Chalkboard		20%	19
36	Grasscloth	Tan	22%	25
37	Grasscloth	Tan	22%	22
38	Painted Door	White	66%	57
39	Tackboard	Brown	25%	12
40	Grasscloth	Tan	22%	17
41	Painted Door	White	66%	35
42	Curtain	Dark Brown	10%	7
43	Grasscloth	Tan	22%	17
44	Tackboard	Brown	25%	13
45	Curtain behind interior window		—	6
46	Chalkboard		20%	17
47	Grasscloth	Tan	22%	27
48	Grasscloth	Tan	22%	20
49	Painted Door	White	66%	50
50	Ceiling Tile	White	80%	190
51	Ceiling Tile	White	80%	46
52	Ceiling Tile	White	80%	190
53	Ceiling Tile	White	80%	30
54	Luminaire (from M1 position)		—	350
55	Luminaire (from M1 position)		—	475
56	Luminaire (from M1 position)		—	700
57	Luminaire (from M1 position)		—	240
58	Desk Top	Maple Formica	28%	32
59	Vinyl Floor Tile	Tan	45%	40

project 13 evaluations

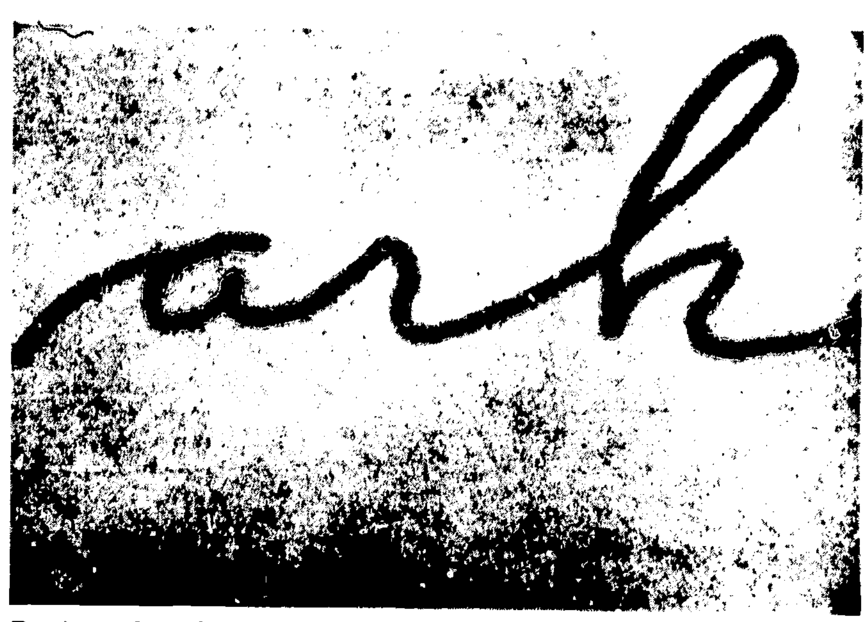
Quality	Location		
	M1	M2	M3
TI	114	108	87
CRF	.798	.973	.785
ESI	24.9	89.3	18.2

The CRF value of .798 for this project is disappointing when compared with the .845 CRF found in Project 11 because the reverse condition might easily be anticipated. In Project 11, the room size is only slightly smaller, the walls are brighter, and the rows of luminaires are slightly closer together. In Project 13, the relatively low luminaire brightness and the somewhat higher ceiling brightness (between rows) should result in a higher contrast rendition. The larger areas of relatively bright walls in Project 11 seem to be the prime factor which should make that system better than Project 13. A detailed study of the effect of wall brightness on contrast rendition should be made as soon as possible.

The M3 position in this project was taken directly under the side row of luminaires and shows that there is a poorer CRF at this point than in the areas closer to the center of the room. Particularly at this point, lighter side wall colors would have been much better than the dark ones. The light reflected from the walls would have helped reduce the contrast losses.



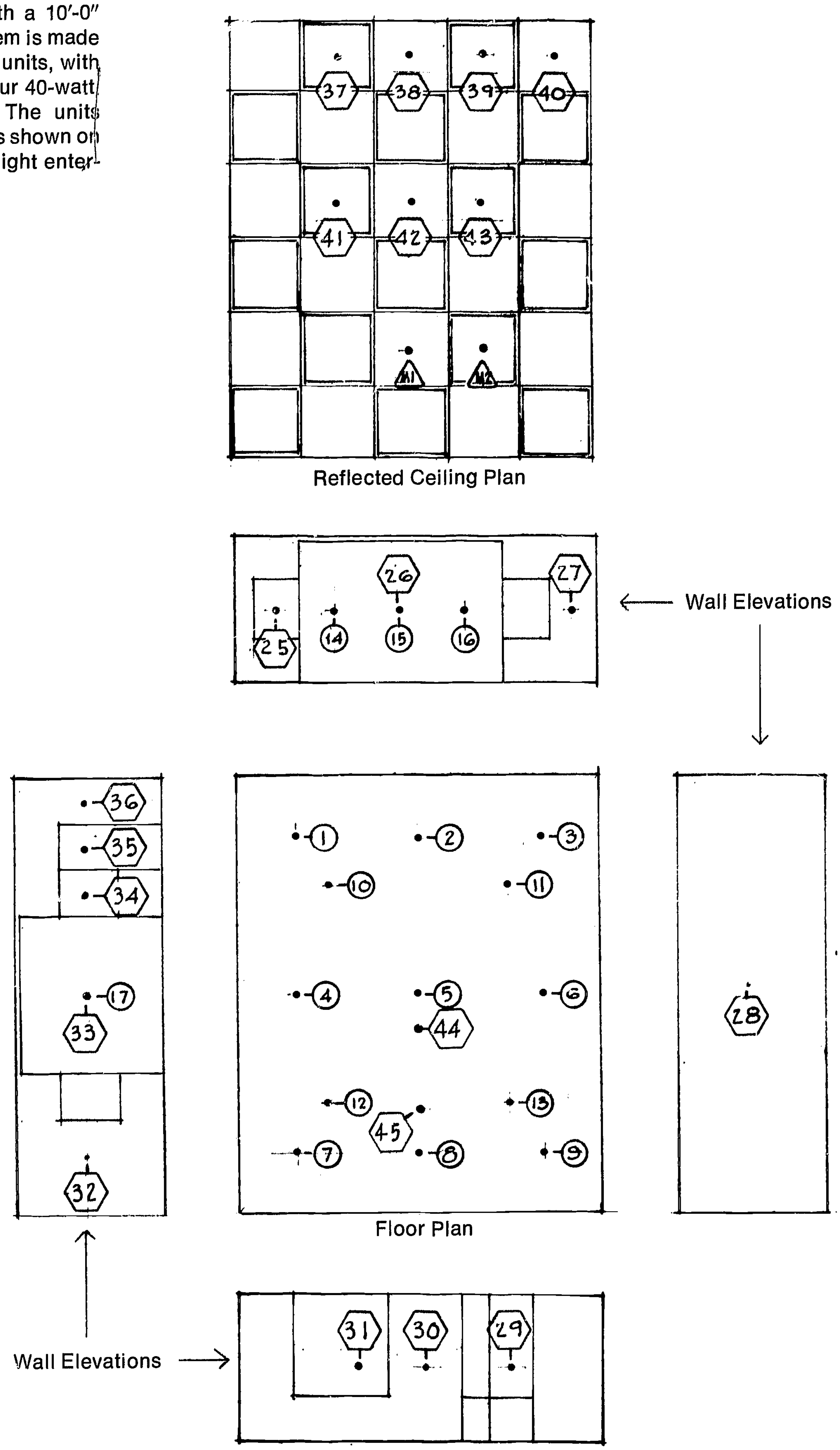
Sphere Quality



Project Quality

project 14 description

The room is 25'-0" x 30'-0" with a 10'-0" ceiling height. The lighting system is made up of 15 5'-0" square, recessed units, with vinyl diffusers. Each unit has four 40-watt rapid-start fluorescent lamps. The units are in a checkerboard pattern as shown on the drawing. There was no daylight entering the room during the survey.

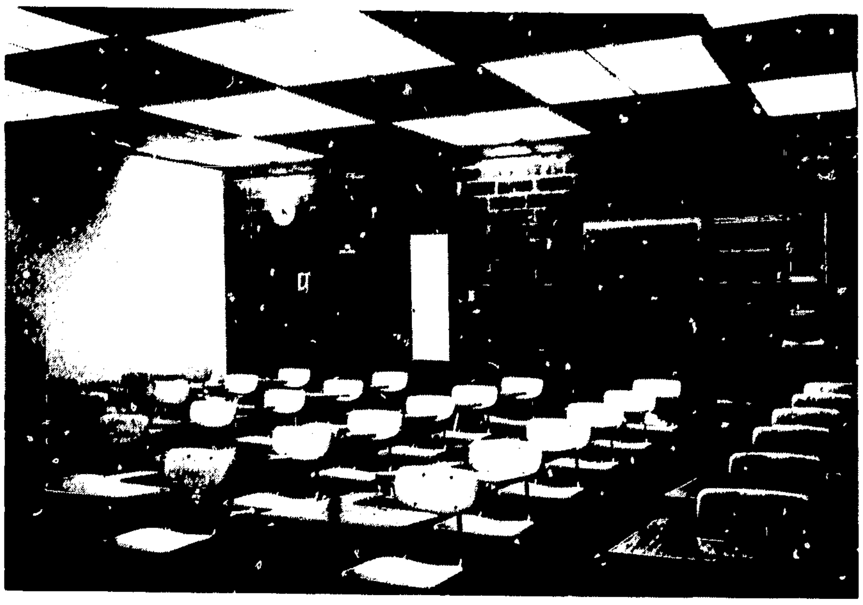


The degree of uniformity in this system is well above the average in that the lowest level is 70% of the maximum and only 20% below the average. In this project, all of the interior walls are movable, and the checkerboard pattern of the fixtures was chosen to allow a nearly uniform distribution of light into any space, regardless of the room size, without the need for moving lighting elements.

Task brightness at the M1 position was determined to be 76 footlamberts, thereby allowing a minimum of 25 for reasonable comfort. Unfortunately, the carpet is quite dark, and this provides a large area of low brightness. On the front wall, the chalkboard is from floor to ceiling, and the reflection factor is quite low. The rear wall of natural brick is also quite low in reflectance. The warm grey partitions and the tackboards are of high reflectance and assist in producing a light environment. The dark carpet absorbs light which might otherwise be reflected back to the ceiling, and, even though the ceiling color is good, the total light coming to this surface is only enough to provide a 15 footlambert brightness, which is too little for the room in general and is particularly noticeable when seen immediately adjacent to the lighting diffuser. The only area of brightness brighter than the task is the luminaire itself, and this is only 4.7 times task brightness, which is very good for this level of task brightness.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	83	10	102
2	95	11	96
3	84	12	108
4	102	13	111
5	119	14	60
6	111	15	57
7	96	16	60
8	105	17	63
9	96		

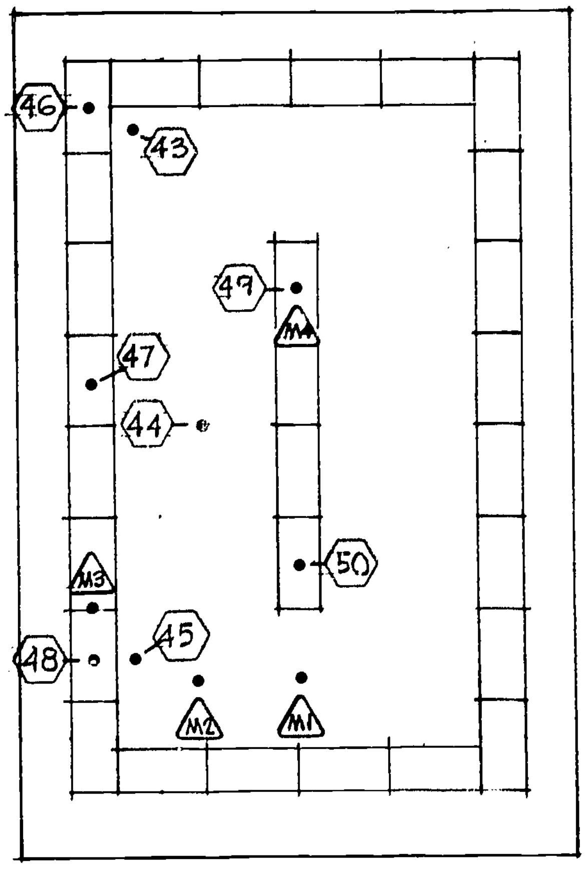


brightness distribution

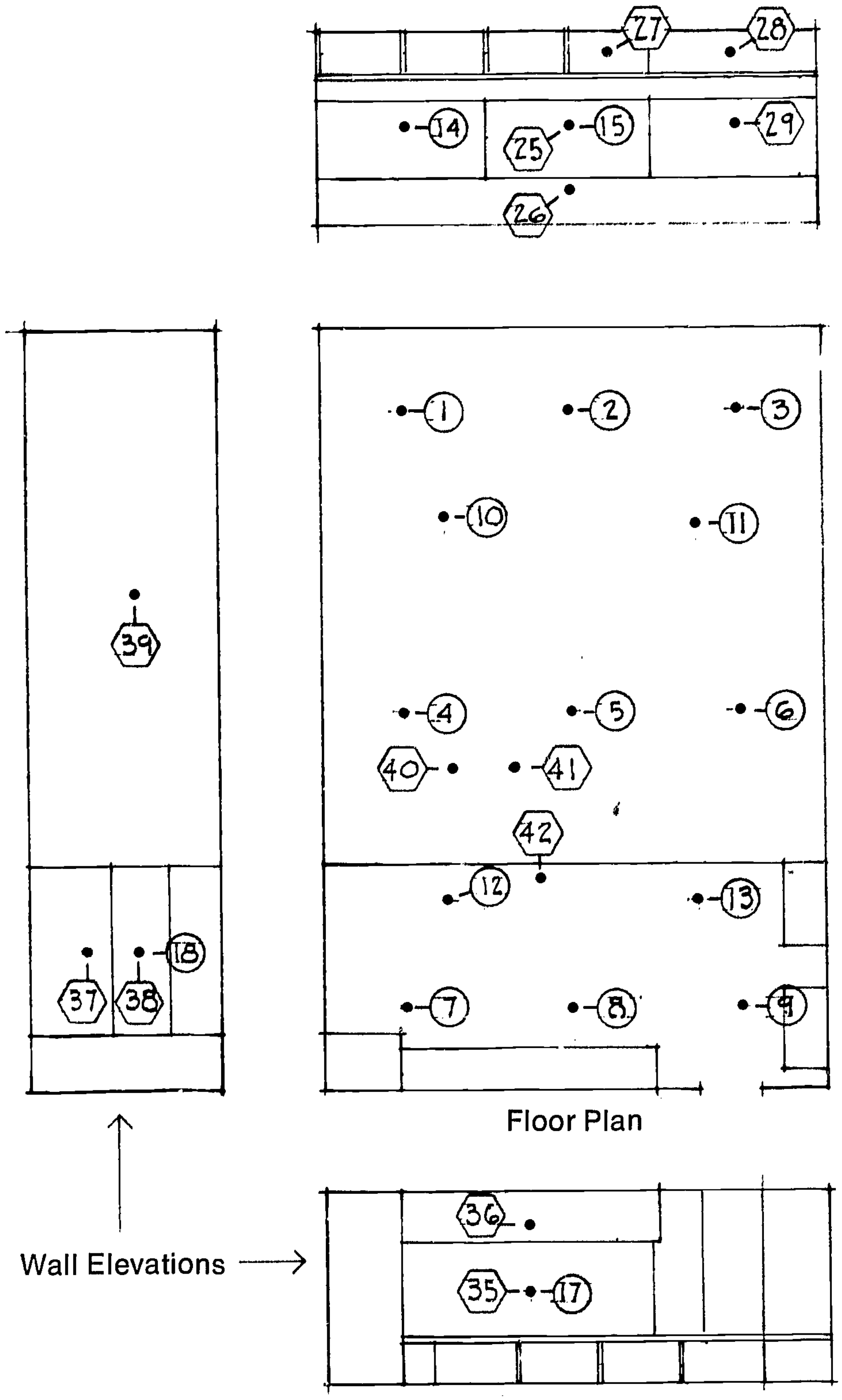
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Vinyl Tackboard	Grey	42%	22
26	Metal Chalkboard	Blue	11%	7
27	Metal Wall	Warm Grey	57%	25
28	Metal Wall	Warm Grey	57%	35
29	Painted Door	Blue	21%	11
30	Brick Wall	Red	25%	14
31	Cabinet Door	Blue	21%	13
32	Metal Wall	Warm Grey	57%	32
33	Metal Chalkboard	Blue	11%	9
34	Tackboard	Grey	42%	27
35	Painted Door	Blue	21%	11
36	Metal Wall	Warm Grey	57%	28
37	Lighting Diffuser	White	—	270
38	Metal Acoustical Ceiling	White	80%	15
39	Lighting Diffuser	White	—	275
40	Metal Ceiling	White	80%	18
41	Lighting Diffuser	White	—	290
42	Metal Ceiling	White	80%	15
43	Lighting Diffuser	White	—	360
44	Carpet	Blue Green	10%	9
45	Desk Top	Light Oak	24%	26

project 15 description

This room is 24′-6″ x 37′-0″ and the ceiling height is 9′-4″. There are 28 2′-0″ x 4′-0″ recessed luminaires with low brightness lenses. Each unit has two 40-watt, rapid-start lamps. The layout is unusual, as the drawing shows. The daylight in this room enters through four 18″ high by 48″ wide windows glazed with low transmission glass. The illumination contributed was negligible.



Reflected Ceiling Plan



Floor Plan

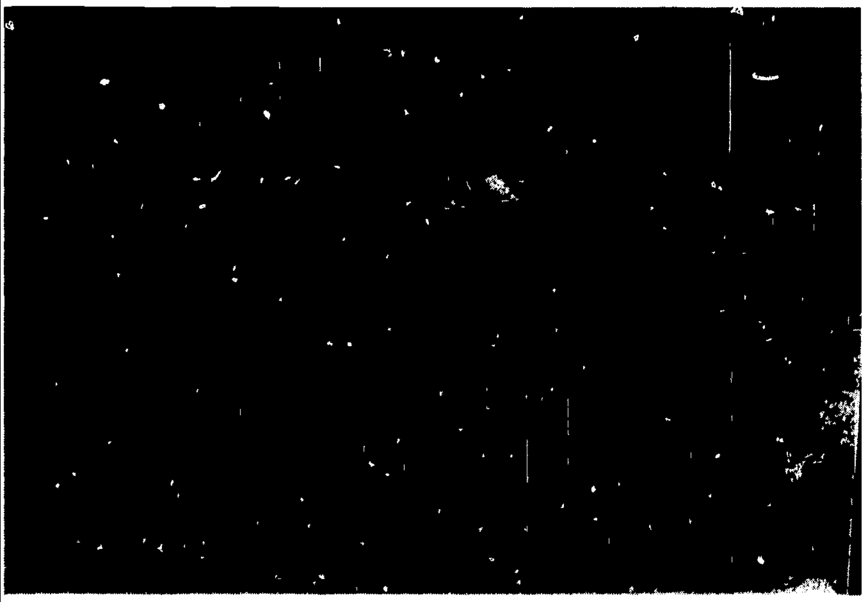
ERIC

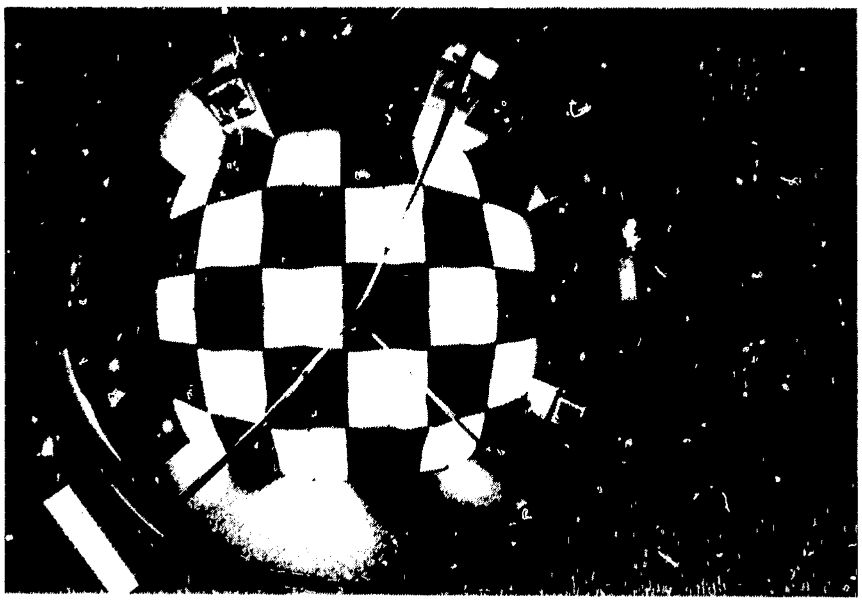
project 14 evaluations

Quality	Location M1	M2
TI	106	100
CRF	.887	.962
ESI	44.2	75.1

The CRF value for this project rates 8th in the total group; however, Projects 1, 6, 9, and 18 are all very close, and it is unreasonable to say that any one of the five systems is markedly superior to another as far as CRF is concerned. The good and bad features in each project seem to balance out to obtain the same general quality. Although Project 14 has the highest TI and ESI values, it has the lowest LEF, whereas Project 9 has the next to the lowest ESI and the best LEF. It is apparent, from a close study of these characteristics in these and other projects, that due consideration must be given to each of the many qualities of each project.

The dark walls, floors, and ceiling all worked against good contrast rendition, as well as good brightness balance.





Sp[illegible] Quality

Project Quality

ERIC

The uniformity of the lighting level in the seating area of this project is outstanding because the low reading at station 1 is 114 footcandles which is 89% of the high reading of 128 footcandles at station 12. This unusual pattern of luminaires also provides excellent light to the side walls including the chalk- and tackboards.

The brightness pattern is also very good. The minimum brightness should be not less than 29 footlamberts for the task, which was found to be 86 footlamberts. The green chalkboard, with only a 12% RF is too dark; however, the white chalkboard at station 32 is very good. The only other large, permanently installed surface which is too dark is the carpet, which has 10% reflectance. The desk top is one of very few locations which is too dark to meet these brightness recommendations. Paper on the tackboards was dark; however, the board itself was satisfactory, and certainly the material on the board should be chosen for its purpose rather than to meet "brightness recommendations."

It is interesting to note the three readings on ceiling brightness, for in two cases they are 17 and 18 footlamberts, and in the third case it is 30. The ceiling color is constant; however, the difference is the result of much higher floor brightness in the rear of the room where light green vinyl tile was used in lieu of dark carpeting.

The luminaires in this project meet the "scissors curve" specification of the Illuminating Engineering Society, and the brightness, as measured with the Spectra meter, shows them to be reasonable at the low angles, and undoubtedly they average correctly. At high angles, above 45°, the lens has a degree of nonuniformity which allows the lamp image to show up.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	114	10	119
2	119	11	126
3	125	12	128
4	120	13	126
5	123	14	69
6	123	15	78
7	120	16	78
8	125	17	84
9	123	18	84

brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Chalkboard	Green	12%	9
26	Painted Plaster	Cream	68%	22
27	Soffit of Eave through lo-tran glass		—	10
28	Painted Plaster	Cream	68%	47
29	Paper on Tackboard	Tan	42%	27
30	Paper on Tackboard	Green	—	19
31	Painted Plaster	Tan	73%	50
32	Chalkboard	White	68%	55
33	Tackboard	Tan	44%	42
34	Painted Plaster	Tan	65%	60
35	Tackboard	Tan	48%	38
36	Formica Cabinet	Grey Green	27%	15
37	Painted Plaster	Grey Green	28%	25
38	Vinyl Linoleum	Grey	62%	56
39	Wood Folding Curtain	Natural Birch	37%	28
40	Carpet	Olive	15%	18
41	Desk Top	Pecan Formica	17%	21
42	Vinyl Linoleum	Green	41%	46
43	Acoustic Tile Clg.	White	80%	18
44	Acoustic Tile Clg.	White	80%	17
45	Acoustic Tile Clg.	White	80%	30
46	Luminaire Lens	White	—	310
47	Luminaire Lens	White	—	325
48	Luminaire Lens	White	—	750
49	Luminaire Lens	White	—	300
50	Luminaire Lens	White	—	900 on lamp 450 between lamps

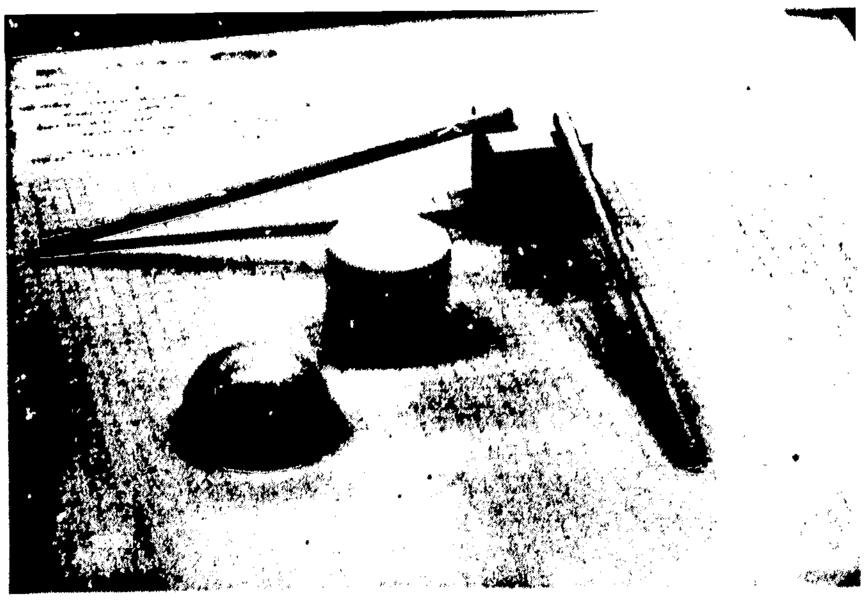
project 15 evaluations

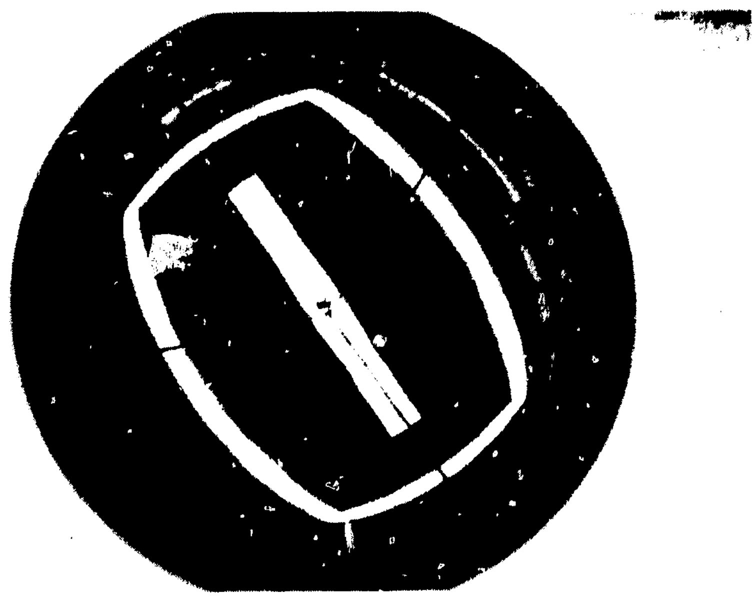
Quality	Location		
	M1	M2	M3
TI	120	126	120
CRF	.919	.985	.789
ESI	63.6	111.8	24.0

The M1 position was chosen to reflect the first fixture in the center row, to be comparable with other rooms as far as the distance from the rear wall was concerned. The resultant CRF is probably higher than it would have been had the location been 6′-0″ farther into the center of the room. The lens characteristic provides for a reasonably wide distribution of light, and consequently the M2 position has a very high CRF. This was not achieved at a loss of illumination, because 126 footcandles were delivered at M2 as opposed to 120 at M1.

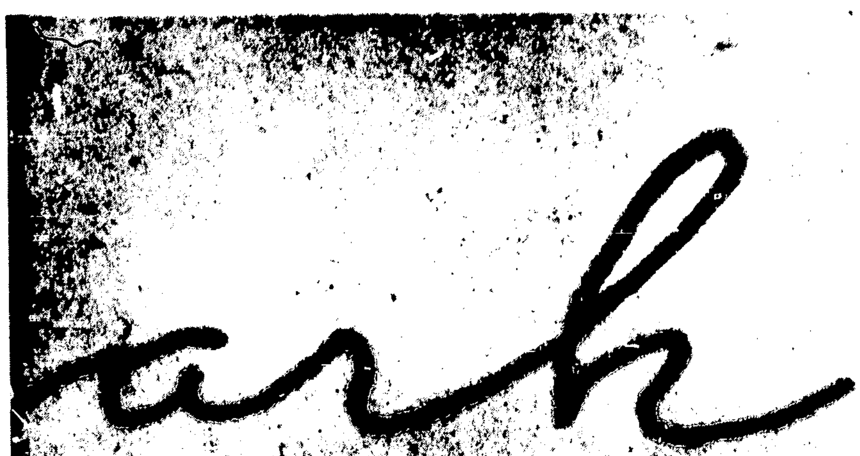
At M3 we find again that under a continuous row, particularly at one side of the room, the CRF values are poorer. Only a few other projects have CRF values for comparable positions; however, it would appear that in most cases the sides of rooms will be poorer than in the center areas.

This is one of three projects where the light delivered to M1 was adequate to be equivalent to at least 63 footcandles of glare-free illumination. Although Project 5 has a much higher CRF, the actual illumination level was far too low. Had Project 5 been completed, the total wattage would have been over 3300 watts to provide 45 footcandles at the task; however, in this Project 15, a total of 2800 watts produced 120 footcandles at the task.





Sphere Quality

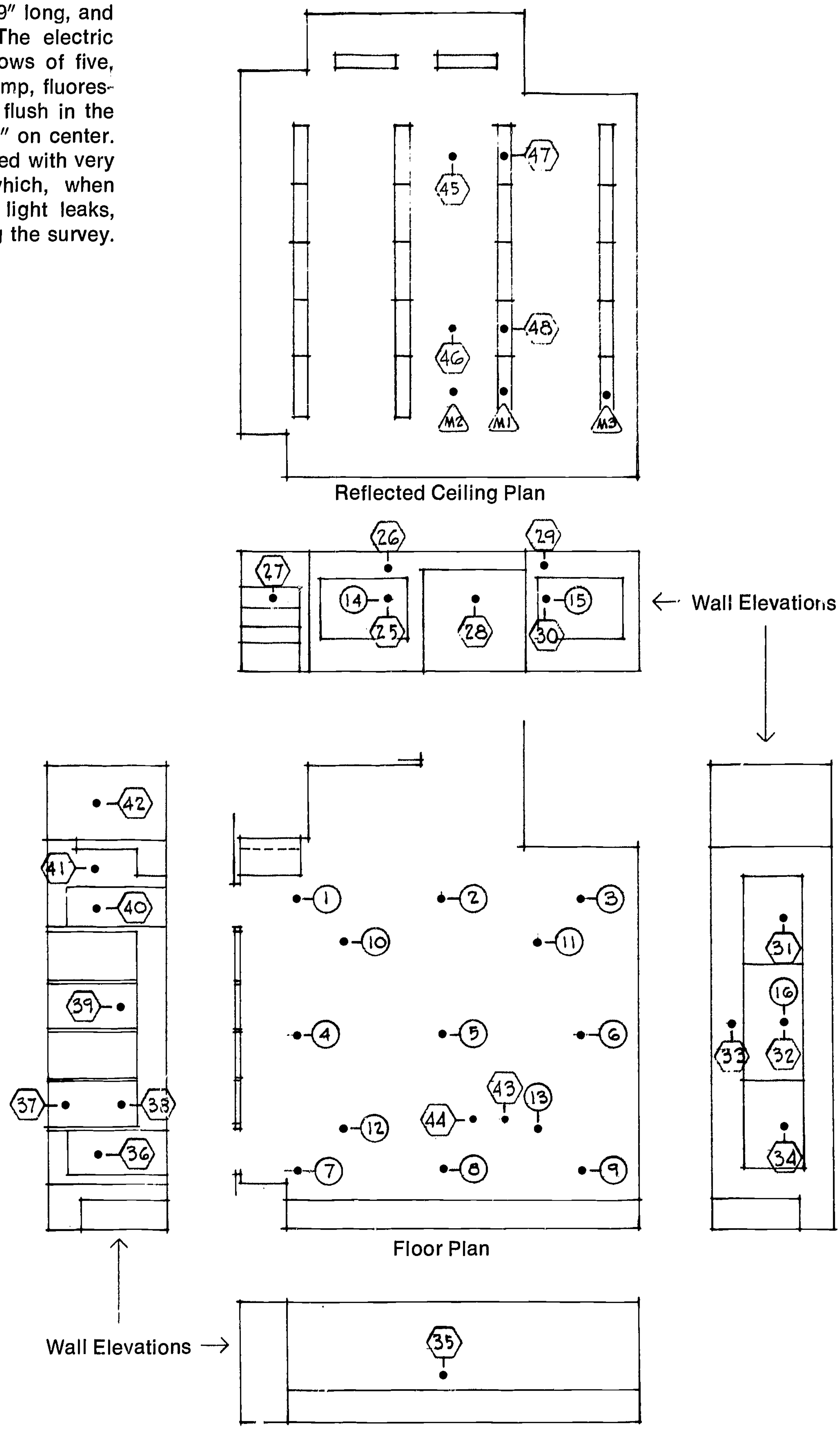


Project Quality

ERIC

project description 16

This room is 27′-3″ wide, 31′-9″ long, and the ceiling height is 8′-3″. The electric lighting is four continuous rows of five, 4′-0″ long x 1′-0″ wide, two-lamp, fluorescent luminaires, with lenses, flush in the ceiling, and the rows are 7′-0″ on center. The four windows are equipped with very efficient Venetian blinds, which, when closed, allow practically no light leaks, and these were closed during the survey.



ERIC

The uniformity of lighting levels is relatively good, and the low ceiling height of only 8'-3" required a maximum spacing of 7'-0" for the fixture used. Here the designer placed the row of luminaires on the chalkboard side, only 20" from the side wall. This provided an accent on the chalkboard which was desirable. The row adjacent to the windows was moved in 3'-6", which allowed the windows to light the outer edge of the room, and the luminaires to provide higher levels in the class area. This off-center arrangement is not symmetrical with the 13 stations for measuring illumination, and this should be noted if comparisons of illumination levels are being made.

The distribution of light from the narrow lens unit provides little or no direct light on the side walls, except for the chalkboard wall. As a result, the walls barely meet the minimum brightness requirements. It is indeed fortunate that unusually high reflectances were used on the walls, otherwise the interior would have been very poor. The dark carpet provides a large area which is materially below the recommended minimum. Also, the dark carpet reflects so little light to the ceiling that the whole ceiling is also too dark. The dark carpets are unfortunate, and designers and owners should be encouraging carpet manufacturers to make lighter colors available.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	72	9	66
2	81	10	96
3	72	11	99
4	111	12	93
5	108	13	93
6	106	14	42
7	69	15	39
8	72	16	63

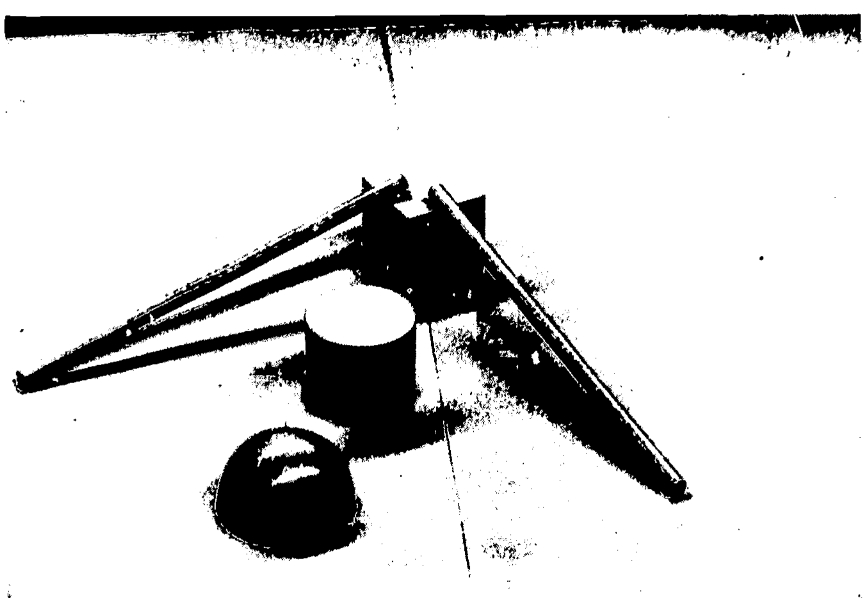
brightness distribution

Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Olive Green	22%	9
26	Paint	Ivory	67%	21
27	Paint	Ivory	65%	17
28	Accordion Door	Maple	38%	15
29	Paint	Ivory	67%	17
30	Tackboard	Olive Green	22%	8
31	Tackboard	Olive Green	22%	17
32	Chalkboard	Green	22%	15
33	Paint	Ivory	67%	15
34	Tackboard	Black Paper	6%	4
35	Wood Cabinet	Birch	32%	14
36	Painted Door	Ivory	67%	20
37	Venetian Blind	Grey	52%	13
38	Venetian Blind	Grey	52%	20
39	Venetian Blind	Grey	52%	20
40	Painted Door	Ivory	67%	23
41	Paint	Ivory	67%	16
42	Paint	Ivory	67%	19
43	Table Top	Birch	38%	37
44	Carpet	Olive Green	10%	11
45	Acoustic Tile	White	80%	11
46	Acoustic Tile	White	80%	10
47	Lens		—	350
48	Lens		—	1300

project 16 evaluations

Quality	Location		
	M1	M2	M3
TI	90	84	70
CRF	.766	.977	.690
ESI	16.4	111.8	9.2

CRF readings were taken at three locations to show the extreme variation under this system. In the M1 position, under a row of luminaires, the CRF is quite poor; however, at M2, between rows the CRF is excellent. The low value under the luminaires results from the relatively small and bright source in a ceiling of low brightness. Very little light reaches the task from low angles, and most of the light originates in the offending zone. The extremely high CRF found at M2 results from the fact that the dark ceiling provides very little light on the task from the offending zone. The two rows of lights providing the illumination are well to the side and provide a minimum of veiling action. At M3, the task was immediately adjacent to a large area of black paper on a tackboard. The CRF at this location is lower than any other point found in the entire survey, but it must be said that the location, 24" from the wall, is not a normal desk location, and the black paper is not a normal wall color. The reading was taken to show the cumulative effect of a small bright source on a dark ceiling and with a dark wall, all aspects being very poor for good contrast rendition.

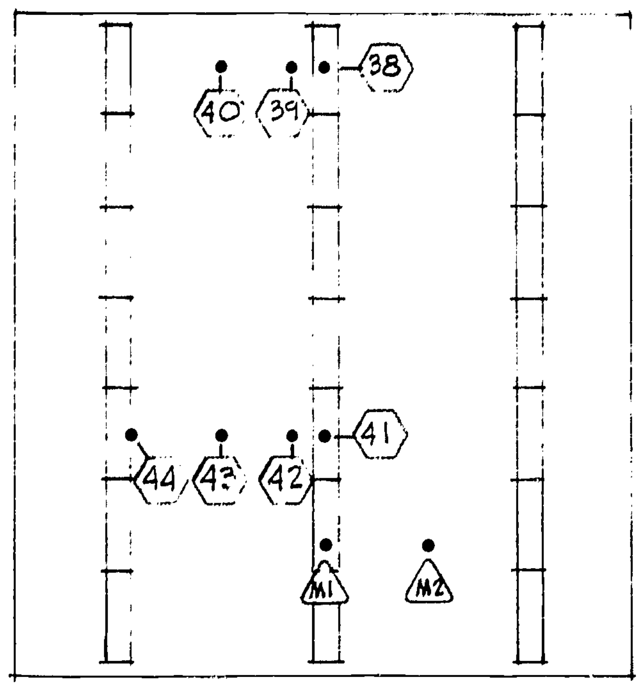


Sphere Quality

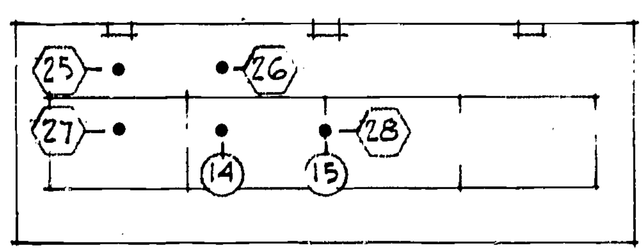
Project Quality

project description 17

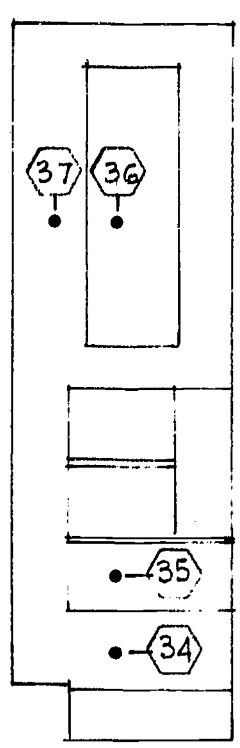
The room is 29′-0″ long, 27′-0″ wide, and the ceiling height is 9′-6″. The lighting system consists of three continuous rows of 13″ wide, surface-mounted luminaires, wraparound, with lens side and bottom. In each row there are three 8′-0″ units and one 4′-0″, each with two 430 m.a. lamps. The rows are 9′-0″ on center. The two small windows are glazed with low transmission glass, and they face a nearby building. The test was conducted in the late afternoon and evening, so there was no daylight contribution.

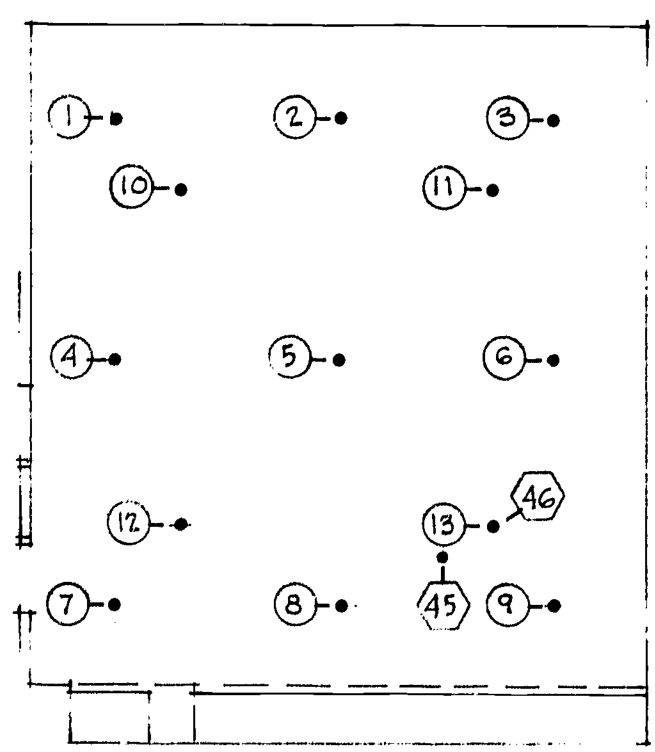


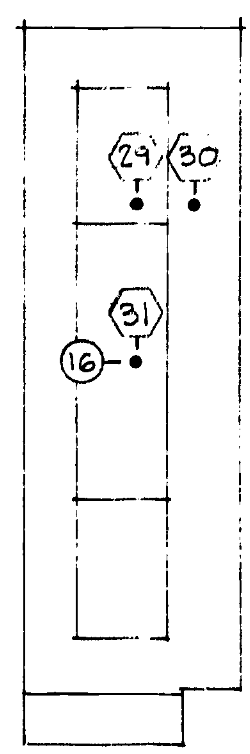
Reflected Ceiling Plan



← Wall Elevations

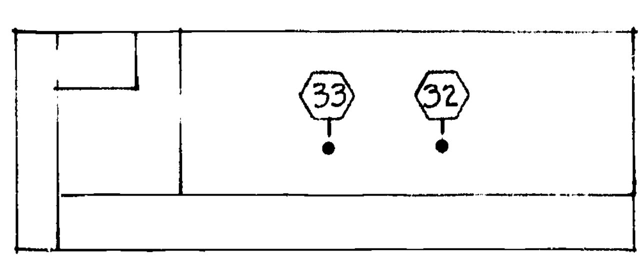






Floor Plan

Wall Elevations →



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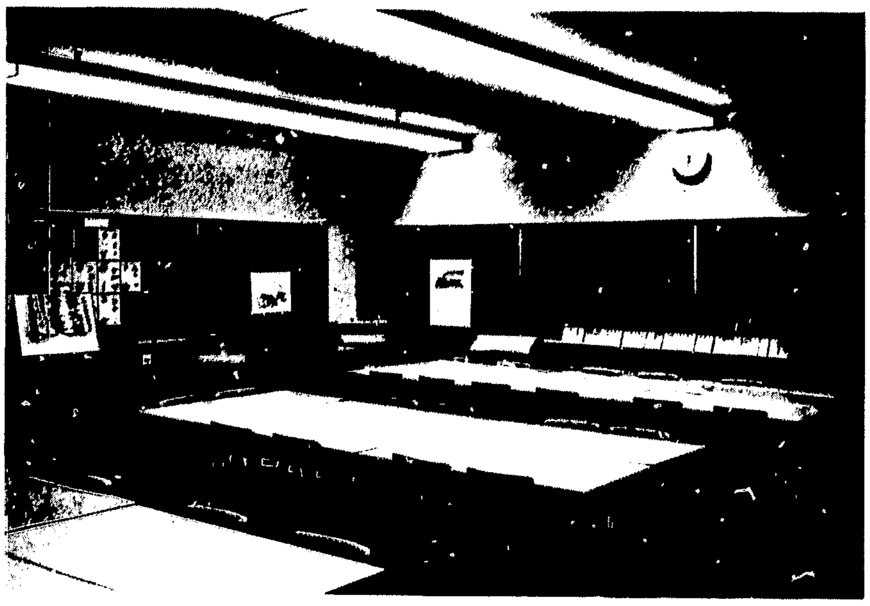
The level of illumination is surprisingly good for the relatively wide spacing. The ends of the room were well lighted because the rows were extended to within 6″ of the wall. If one luminaire had been omitted from each end of each row, the ends of the room would have been poor by comparison. Also, the chalkboard at the end of the room has much better light because the luminaires run to the end of the room.

The environment brightness is good because the side wall colors are unusually light and sufficient light was put on the walls by the luminaires themselves to provide acceptable brightness. The chalkboards and tackboards fall below a desirable minimum, and the tackboards at least could have been of lighter color without sacrificing utility. The carpet was better than some, but still too dark to meet the minimum brightness goal.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	108	9	99
2	117	10	123
3	105	11	120
4	120	12	117
5	129	13	117
6	117	14	54
7	99	15	72
8	108	16	69



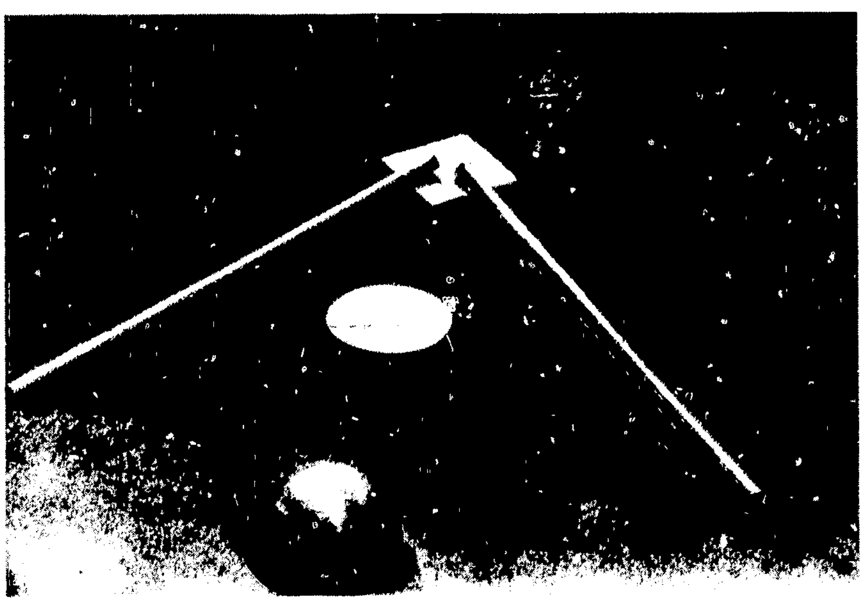
brightness distribution

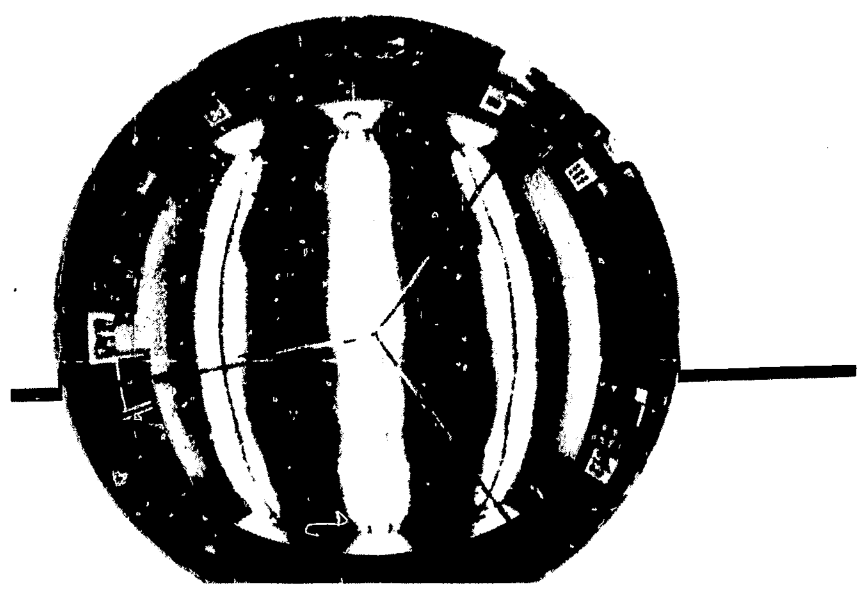
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Painted Wall	Blue	68%	60
26	Painted Wall	Blue	68%	28
27	Tackboard	Slate Green	17%	14
28	Chalkboard	Blue Green	24%	13
29	Tackboard	Slate Green	17%	14
30	Painted Wall	Cream	68%	47
31	Chalkboard	Blue Green	24%	17
32	Cabinet Door	Birch	29%	15
33	Cabinet Door	Birch	29%	20
34	Painted Wall	Blue	68%	31
35	Painted Door	Blue	28%	16
36	Tackboard	Slate Green	17%	11
37	Painted Wall	Blue	68%	33
38	Luminaire		—	500
39	Ceiling	White	79%	55
40	Ceiling	White	79%	28
41	Luminaire		—	680
42	Ceiling	White	79%	55
43	Ceiling	White	79%	27
44	Luminaire		—	560
45	Desk Top	Birch	35%	45
46	Carpet	Gold	16%	15

project 17 evaluations

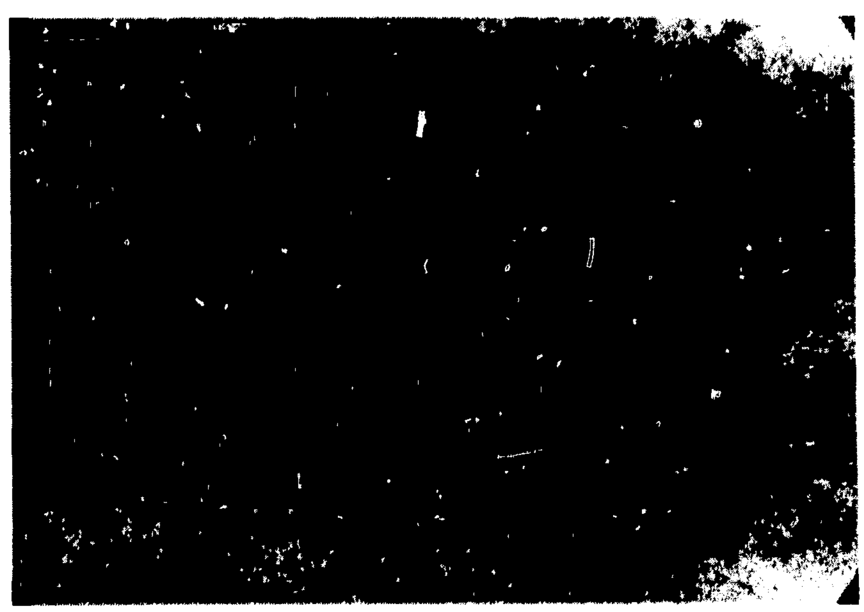
Quality	Location M1	Location M2
TI	112	115
CRF	.798	.996
ESI	24.2	111.8

The M1 and M2 meter positions were chosen to view along the rows of luminaires because this gave a better comparison with other similar systems. Also the tables were arranged so that the children faced in the same way the meter was directed. An interesting comparison can be made with Project 3. There the spacing was 10′-0″ o.c. and the CRF at M1 was poorer and at M2 it was better. This supports the concept that, as direct-type luminaires are spaced wider apart, the contrast rendition directly under the luminaires is reduced. This same thesis is supported again by comparing the CRF values for Project 11. All three of these projects have similar lighting units, and the only major difference is in the spacing which is 7′-0″ at Project 11, 9′-0″ at Project 17, and 10′-0″ at Project 3. The lighting effectiveness in this system is only 26.7% and even though there are 112 footcandles on the task the results are only equal to 24.2 footcandles of sphere quality. The CRF for this lighting geometry is so low that it would require 402 footcandles to be equivalent to 63 footcandles of sphere quality light.





Sphere Quality

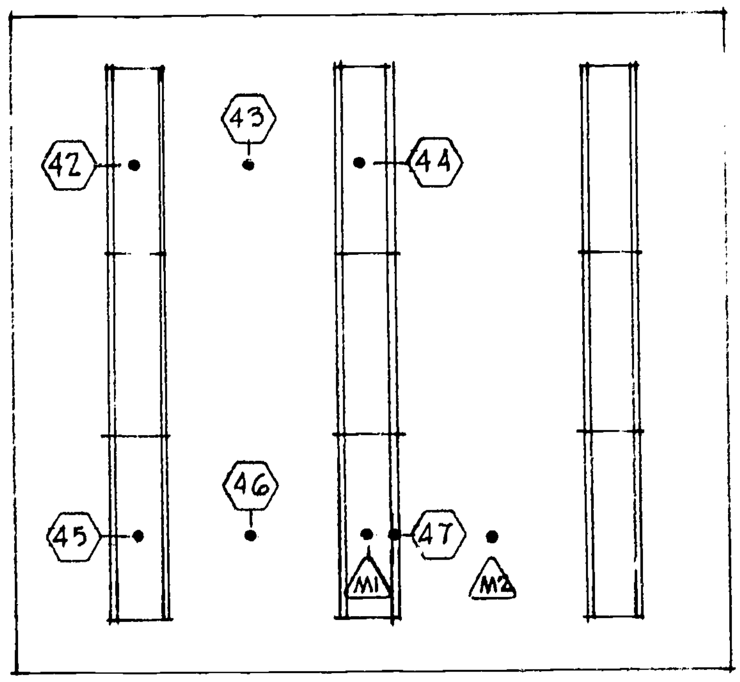


Project Quality

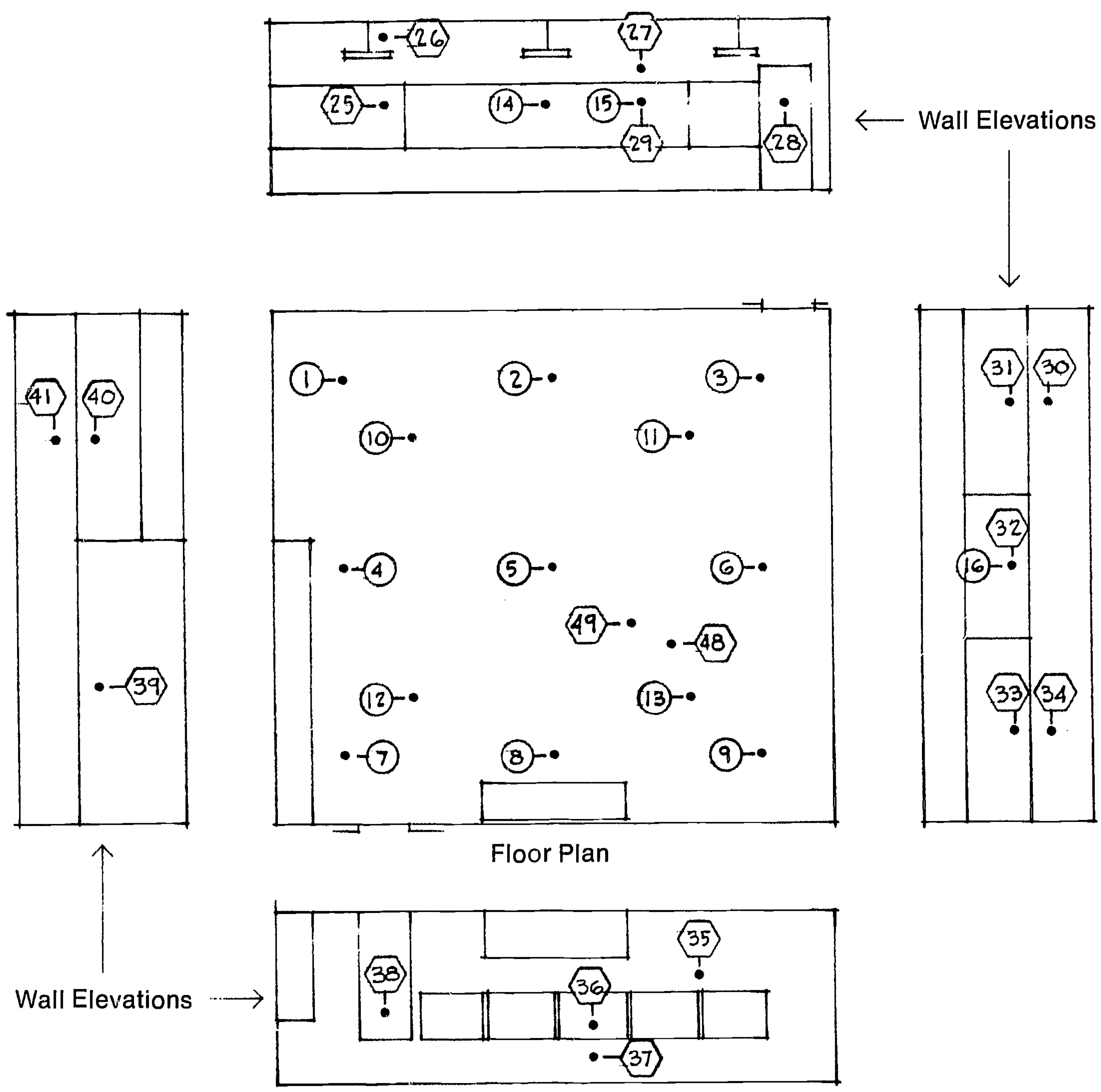
ERIC

project 18 description

The room is approximately 31′-6″ x 29′-0″, and the ceiling is 9′-6″. The lighting system is three rows of semi-indirect units with the 24′-0″ rows 10′-0″ on center. The units are suspended 24″ from the ceiling, and each contains two 96″, 800 m.a. fluorescent lamps. The photographs of the room interior show the character of the fixture. The narrow lens panel under each lamp has a lay-in diffusing panel over the lens to reduce brightness and eliminate lamp image. The windows in the wall behind the M1 position are small and use 15% transmission glass. For this reason, the daylight component is small. The rooms have been occupied two years, and one lamp has been replaced in the fixture over the number 3 location for reporting lighting levels. The balance of the system is probably ready for relamping, and the reported levels are minimum, not average.



Reflected Ceiling Plan



Floor Plan

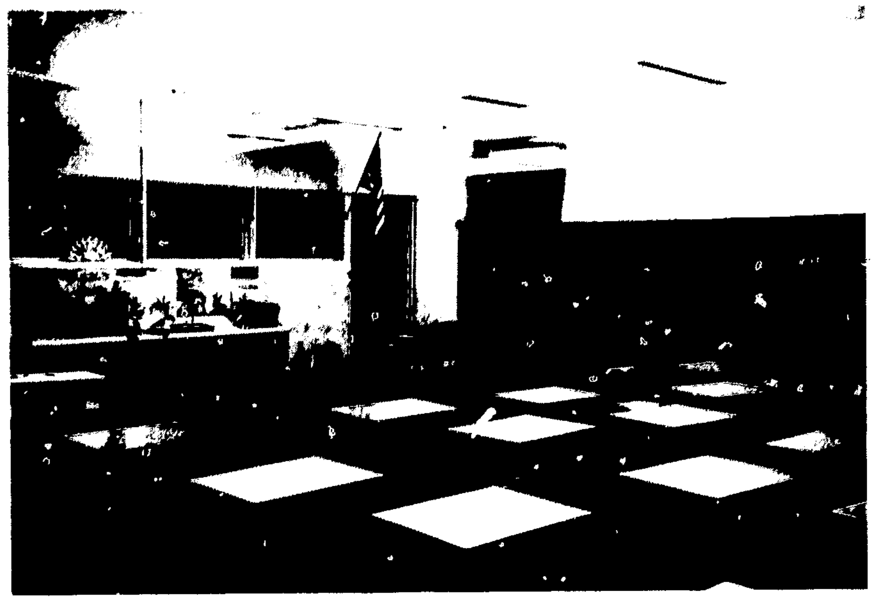
ERIC

The uniformity of the lighting levels in this room is relatively good in that the minimum at station 7 is 75 footcandles or 68% of the maximum of 111 at station 5. The high reflection factor on the upper side walls helps materially in maintaining a fair level around the periphery of the room. Dark upper side wall colors would have caused the level near the walls to be measurably lower. The over-all efficiency is remarkably high for a semi-indirect system. With a total of 2340 watts in a space with 914 square feet, the average level of illumination is about 96 footcandles or better than 35 footcandles per watt per square foot Had the carpet material been of a higher reflectance, the level would have been even higher. Also, it should be noted that the system was two years old, and the lamps were nearing their end of life.

As would be expected in a room using semi-indirect lighting and light wall and ceiling colors, the brightness ratios are very good. The minimum brightness recommended for this environment would be ⅓ of 68 footlamberts or 23 footlamberts. Except for the carpeting and chalkboards, there are no large areas of excessively low brightness. The low readings of 40 footlamberts on the ceiling are not too bad; however, a better carpet color would have helped materially in adding to the brightness of the ceiling. The distribution of brightness on the ceiling is helped in this installation by suspending the luminaires on longer than normal stems. Had the luminaires been mounted closer to the ceiling, the brightness would have been greater directly over the luminaires and somewhat lower between rows.

lighting levels

Location	Footcandles Electric	Location	Footcandles Electric
1	78	9	80
2	87	10	96
3	94	11	99
4	102	12	96
5	111	13	96
6	105	14	57
7	75	15	54
8	90	16	72

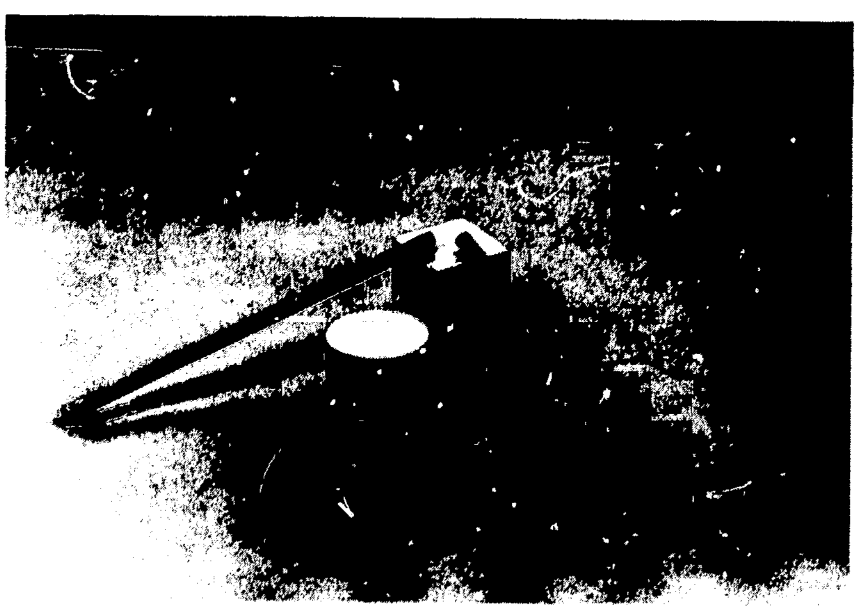
brightness distribution

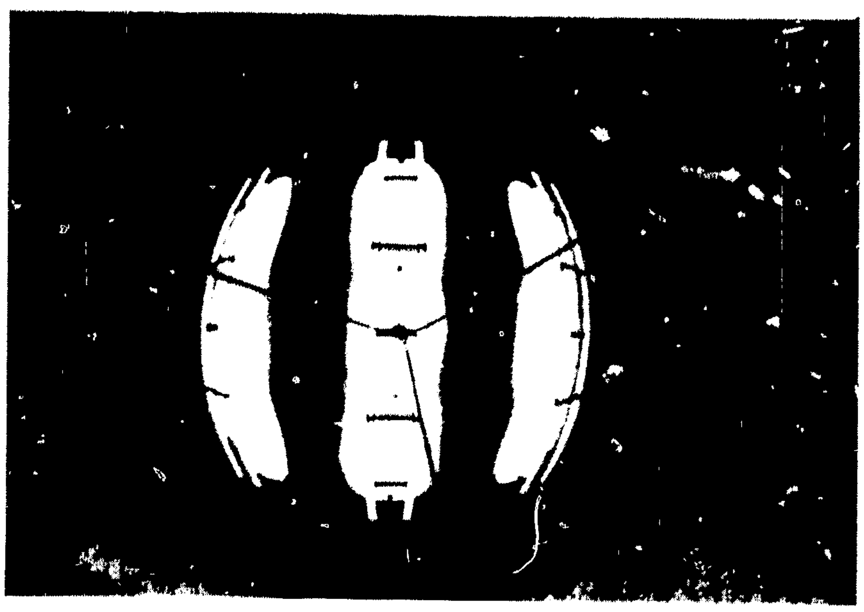
Location	Surface	Color	Reflection Factor	Footlambert Brightness
25	Tackboard	Beige	57%	35
26	Paint	Cream	63%	50
27	Paint	Cream	63%	37
28	Door	Gumwood	43%	22
29	Chalkboard	Brown	25%	16
30	Paint	Cream	63%	45
31	Tackboard	Beige	57%	20
32	Chalkboard	Brown	25%	21
33	Tackboard	Beige	57%	35
34	Paint	Cream	63%	45
35	Paint	Cream	63%	35
36	Window	15% trans. glass	—	33
37	Paint	Cream	63%	32
38	Door	Umber	30%	15
39	Cabinet	Birch	20%	18
40	Tackboard	Green Painting	—	40
41	Paint	Cream	63%	51
42	Ceiling Tile	White	80%	250
43	Ceiling Tile	White	80%	40
44	Ceiling Tile	White	80%	250
45	Ceiling Tile	White	80%	250
46	Ceiling Tile	White	80%	40
47	Luminaire		—	260
48	Desk Top	Formica	34%	37
49	Carpet	Cinnamon	11%	11

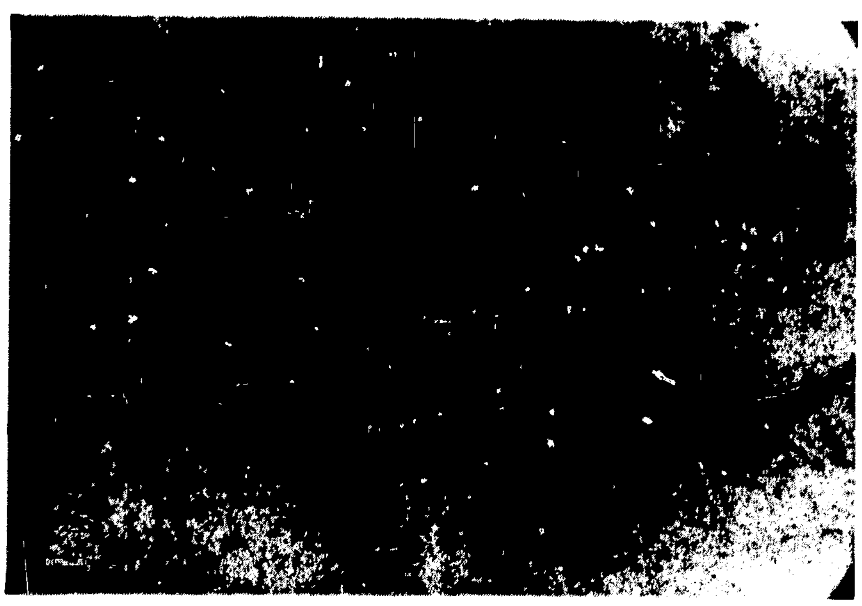
project 18 evaluations

Quality	Location	
	M1	M2
TI	95	90
CRF	.889	1.00
ESI	40.4	90.0

The basic CRF value for this project rates seventh and the ESI is also seventh. In each case, these values are better than the nonpolarized luminous ceiling and only slightly less than the polarized ceiling. The high side wall brightness made the difference. The contribution of light from the high walls helps materially in contrast rendition. The recessed luminous ceilings, particularly when they stop several feet from the side walls, leave the high portions of the walls almost completely dark, and this is detrimental to contrast rendition on the pencil task.



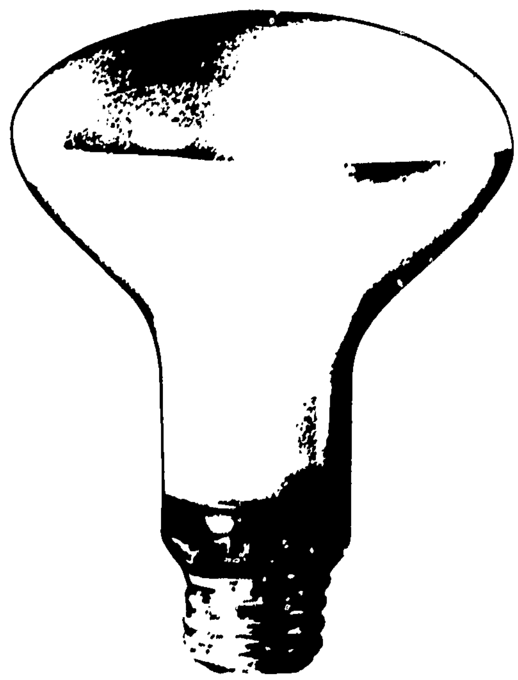




Sphere Quality

Project Quality

conclusion

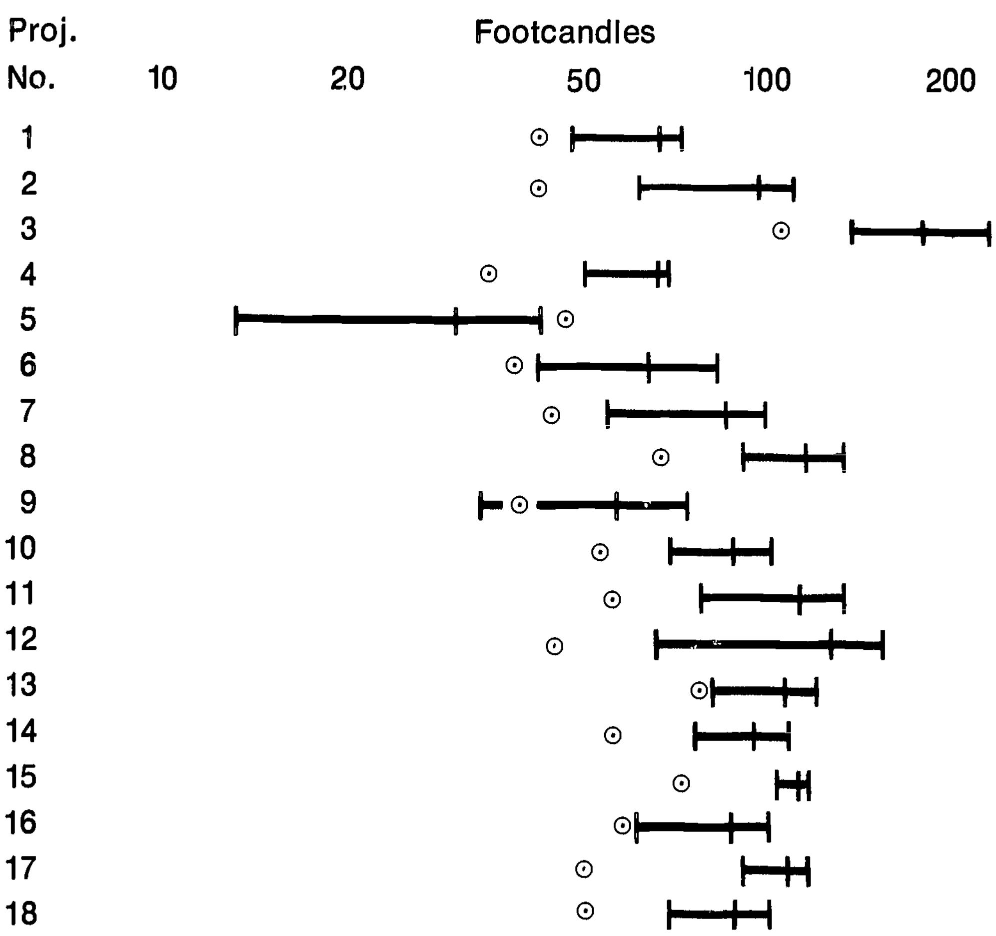


In order to draw direct comparisons of the levels of illumination found in the different projects, a composite bar graph is presented in Figure 3 to show the maximum, minimum, and average levels of illumination within the classroom seating area and on the major chalkboard. In all cases, these values are given for the electric system only and do not include any major daylight contribution. The project number is shown at the left edge, and the values for each location are plotted on a log scale in columns. Unusual conditions, if there are any, are covered in the individual project reports; however, there are several interesting general conclusions which can be made that apply to this group of rooms. There were no rooms with auxiliary provisions for chalkboard illumination, each depended upon spill light from the general lighting system, and there are 7 cases where the chalkboard lighting was 60 footcandles or higher. The average level of illumination on the desks is adequate by past recommendations, in almost all cases; however, the minimum levels were too low in 6 projects.

From a study of the ranges from minimum to maximum in each project, some very interesting conclusions may be drawn. Project 5 has only three coves where four were required, and the minimum level of 14 footcandles is only 31% of the maxi-

Levels of Illumination

The chalkboard column gives the level of illumination on the primary chalkboard. The highest and lowest columns refer to the levels in the seating area. The average column is the arithmetic average of locations 10-11-12 and 13, and experience has shown that as a short cut method this is very accurate.



Chalk-board	Lowest Level	Average Level	Highest Level	Proj.
45	51	71	78	1
45	66	105	120	2
115	154	200	258	3
37	54	71	74	4
50	14	33	45	5
41	45	69	90	6
47	59	92	108	7
72	99	127	147	8
42	36	61	80	9
57	75	95	111	10
60	84	125	147	11
48	71	140	171	12
84	87	118	132	13
60	83	104	119	14
78	114	125	128	15
63	66	95	111	16
54	99	119	129	17
54	75	97	111	18

Figure 3

mum. In Project 12, the four rows of luminaires were grouped to the center of the room which caused the low level to be only 41.5% of the high. In the best of the two luminous ceilings, Project 2, the low level was only 55% of the high. In Project 6, the large area coffers were grouped in the center of the room and, as a result, the minimum was only 50% of the maximum. Eight projects used conventional spacings on the luminaires, and the minimum ran from 55% to 70% of the maximum. Project 17 is unusual in that the minimum was 76.8% of the maximum even though a conventional layout of three continuous rows of surface luminaires was used. In this case, the side walls have a reflectance of 68% which is much higher than is usually found, and they utilized the side component of the surface-mounted units to excellent advantage. In Project 4, the minimum is 73% of the maximum as the result of the perimeter placement of the semi-indirect luminaires. The best system, Project 15, produced a minimum of 89% of the maximum. This was accomplished with the recessed troffers placed at the perimeter of the room.

The uniformity of lighting levels is less important than contrast rendition, in the broad sense, and the systems which produce the highest ESI, with reasonable efficiency, should be selected rather than those with uniform levels of illumination. In this study, the contrast rendition was evaluated in a very favorable location in all rooms. As soon as possible, a similar study should be conducted with the meter positions near the walls and facing in two or more directions to provide a more complete understanding of what happens to contrast rendition in these circumstances. It is very likely that veiling reflectance losses are higher in some corner and wall locations. These same locations usually have the lowest levels of illumination, so, on this basis, the corners and the peripheries of the rooms may be doubly poor and should be given much more light of good quality than would be necessary at the more favorable locations in order to provide equal visual efficiency.

The distribution and range of brightness within an environment are extremely important since they affect comfort, eye adaptation, and contrast rendition. It is agreed by experts in this field that the eye is most efficient for close visual work when the illumination level is adequate and the task is slightly brighter than its surround. There is general agreement that a uniformly bright environment would be psychologically depressing, and for the last 20 years or so it has been accepted that large dark areas in an environment should not be less than one-third the brightness of the task. Also, large bright areas should not exceed 10 times that of the task where the levels of illumination do not exceed 50 footcandles. Recent research shows that adaptation is equally affected by either dark or bright areas and that the past guidelines are not stringent enough for optimal comfort and accuracy, particularly in installations exceeding 50 footcandles.

Everyone agrees that glare is bad under any circumstances, but very few agree on how to design or evaluate lighting systems by a set of specific brightness limits which will assure comfort. There are so many variables which interact within a lighting environment that it is extremely difficult to establish definite values to cover size, location, or brightness limitations. It is not possibie to judge the effectiveness of a system by one simple glance; even a person who is thoroughly aware of the pitfalls of brightness control should work in an environment for an hour or more before attempting to make a qualified judgment. Volumes have been, and more will be, written on this particular subject, and until the independent researchers in the field of visual science can agree on a means of evaluation, the basic concepts must be our guide.

There is general agreement that where no close visual work is to be done, the environment brightnesses are relatively unimportant; however, where visual accuracy is required, the brightness of the surround becomes more critical as the need for accuracy becomes more important. In a hospital surgery, for example, every effort is made to provide the best possible visual environment with little or no concern for aesthetics. In a school classroom, on the other hand, although visual accuracy is important, there are human factors which architects and engineers must consider in developing a design which is pleasing, comfortable, and efficient.

The basic concept of a comfortable visual environment is that sources of high brightness be unobtrusive, and that there should be no large areas of low brightness. This is based upon the principle that areas of either high or low brightness cause fatigue and loss of visual accuracy due to the required changes in the adaptation level of the eye as it shifts between areas of high brightness difference. In general, no large area should be less than one-third task brightness, regardless of its position within the room. This means that desk tops and floors particularly should be as high in reflectance as is reasonable. The available tile materials of at least 30% RF or higher are normally very good.

Side wall reflectances, including large cabinets and tackboards, should be from 40% to 60% reflectance, and 80% if possible at locations above the top line of the chalkboard. The ceiling should be as nearly white as possible because this surface is most important in reflecting light back to the desk top, and to avoid large brightness differences between the ceiling and light sources, in or on the ceiling. Every effort should be made to make the ceiling at least as bright as the side walls, and it would be very desirable to have the lighter portions of the walls equal to, or more than, one-half task brightness.

The only two sources of high brightness are daylight sources such as windows or skylights and the electric luminaires. It is generally agreed that direct sunlight should rarely be allowed to come into the room, and windows in the side walls should be properly glazed or shielded in order to control the brightness to a maximum of 250 to 300 footlamberts. Under high illumination levels, say in excess of 150 footcandles, the windows might safely be as much as three times task brightness. The typical position of windows, directly at and above eye level, makes them particularly bothersome at brightnesses above those suggested.

The electric light sources should be as unobtrusive as possible and this can be accomplished in two ways: by keeping the ceiling as light as possible, to minimize the brightness difference between ceilings and luminaires, and by reducing the brightness of the luminaire to approach ceiling brightness. This should not be considered as a requirement which will allow only luminous ceilings or indirect lighting, but it is a caution against the situation observed in several of the projects surveyed. In project 6, for example, the only light on the ceiling was reflected from the floors, furniture, and side walls, and, because of the unfortunately dark colors, the ceiling was very dark. The strong brightness difference is annoying even though the luminaire brightness is quite low. In Project 16, this extreme brightness difference is even more bothersome because of the unusually high luminaire brightness. In this last case, the ceiling brightness was only 10 or 11 footlamberts, and the lens unit was from 350 to 1300, depending upon the angle of viewing. These values develop a brightness difference of from 35 to 1 to 130 to 1. On the other hand, in Project 12 the floor reflectance is 37%, and even though all desks were in place the reflected light produced a ceiling brightness of 27 to 35 footlamberts and the well-designed luminaires did not exceed 370 footlamberts, providing a maximum brightness difference less than 14 to 1. It is not at all unreasonable to set an upper limit on this particular ratio of ceiling luminaire brightness at 20 to 1, with lower ratios definitely desirable.

Particularly in those cases where recessed lighting is used, including luminous ceilings, the lighting units should be located reasonably near the side wall. This placement can provide excellent coverage for the chalkboards and tackboards, and when properly installed, the annoying dark corner where the ceiling meets the side wall is made less conspicuous. Project 15 is a good example of this design concept, and even this has been improved upon in a very recent installation. In the latter instance, the individual recessed luminaires are slightly regressed into the ceiling, allowing spill light to illuminate the adjacent ceiling coffer. This increases the apparent area of each fixture, reduces brightness difference between ceiling and fixture, and develops a degree of shielding so that fixtures more than 20 to 30 feet away are completely shielded from view.

The prime design goal for the development of a comfortable, yet efficient, visual environment is to provide adequate illumination of good quality with a minimum of brightness differences. To achieve these qualities and yet avoid a sense of sterility requires talent on the part of the architect, interior designer, and lighting engineer.

Unfortunately, photographs cannot give an accurate evaluation of the range of brightnesses found in these interiors; however, they do give a general idea, particularly when evaluated in conjunction with the Brightness Distribution tables. In all cases, the photographs were made with the ambient light, and the prints were not touched-up during processing.

In order to provide an evaluation of the projects as a group, Table I shows the TI, CRF, ESI, and LEF for each project, using the 25° viewing angle, the M1 meter position, and with electric lighting only. Each of these factors is basically comparable for each project. The added factor of LEF is the Lighting Effectiveness Factor which is obtained by dividing the ESI by TI, and this value shows the percentage of actual illumination which is effective as sphere illuminance. Adjacent to each of the columns showing the four factors, the rank is shown with the highest favorable factor shown as rating first.

Two of the projects, numbers 4 and 5, have CRF values in excess of 1.00 which means that the contrast in the task was actually greater than it would have been in a uniformly illuminated sphere. This is accomplished in these two projects by lighting systems which located the light sources at the periphery of the room. The ceiling in the center of the room was relatively dark so that the offending zone over the task provided only a small portion of the total task illumination.

Only three projects, 4, 10, and 15, provided 63 footcandles or more of sphere quality illumination, and the other 15 projects provided less than the recommended effective level for pencil handwriting.

Although Project 5 had a CRF of 1.12 the illumination provided in this installation was only 16 footcandles, which was

Proj.	TI	Rank	CRF	Rank	ESI	Rank	LEF	Rank
1	62	16	.882	11	27.6	13	.445	8
2	100	10	.900	6	46.1	5	.461	6
3	108	8	.749	17	17.8	17	.165	17
4	59	17	1.02	2	68.5	2	1.16	2
5	16	18	1.12	1	29.9	11	1.87	1
6	83	14	.886	9.5	35.6	9	.429	9
7	90	12.5	.915	5	46.7	4	.519	5
8	135	2	.742	18	18.3	16	.136	18
9	65	15	.886	9.5	29.3	12	.451	7
10	110	7	.956	3	79.4	1	.722	3
11	111	6	.845	12	33.8	10	.305	12
12	137	1	.832	13	36.1	8	.264	13
13	114	4	.798	14.5	24.9	14	.218	14
14	106	9	.887	8	44.2	6	.417	11
15	120	3	.919	4	63.6	3	.530	4
16	90	12.5	.766	16	16.4	18	.182	16
17	112	5	.798	14.5	24.2	15	.216	15
18	95	11	.889	7	40.4	7	.425	10

Table 1

in this case equal to 29.9 footcandles of sphere quality illumination.

Projects 16, 3, and 8, rated 18th, 17th, and 16th in terms of ESI, were all below 20 footcandles. The same three were the three lowest in terms of LEF, and Project 8 rates 18th with the lowest factor of only .135. All three of these projects are lens bottom systems with relatively small lens area per lamp. The resulting high brightness toward the task is the major factor for the low performance of all three installations.

Ten of the 18 projects provided 100 footcandles or more on the task, but of these only 2 provided the equivalent of 63 footcandles or more of sphere quality. Of the 5 projects with the lowest ESI, 4 had TI of 100 footcandles or more. It should be clear that high levels alone do not guarantee conditions for accurate seeing.

Although Project 5 had the highest CRF, 1.12, it had an ESI of only 29.9 which rated eleventh. From this it is clear that the CRF rating alone cannot be the whole basis of comparison. To be efficient, a satisfactory system must meet the requirement for an adequate ESI level, have a high LEF, and to rate well in these two respects, a high CRF is essential.

Of the 10 systems with the highest LEF rating, only one had a brightness, from the electric lighting, in excess of 390 footlamberts. Project 15 rated fourth and had a maximum of 900 directly toward the lamp image, and from a location almost directly under the luminaire. This is a very important point because it shows so well that the systems that are the most effective in providing high contrast in the task are the ones which are also rated best from the brightness balance standpoint. This is a most fortunate situation because the benefits of good brightness now can be shown to pay a bonus in good contrast rendition and vice versa.

The 5 projects with the lowest LEF all had luminaire brightness in excess of 680 footlamberts and the poorest of all shows 1700 directly overhead. The poorest system produced one of the highest levels of illumination, 135 footcandles, the effective level was only 18.3 for an effectiveness factor of only .135.

With the data provided in the report there is material for numerous other comparisons between installations. It might be very interesting for example to compute the watts per square foot in each project and divide that into the related ESI to give the ESI per watt per square foot. The differences would be extreme and the effective systems would prove to be far ahead of the poor ones; however, this value would be a good basis for comparison between two systems which might be comparable in other respects.

The conclusion most quickly apparent

regarding CRF and efficient ESI is that light sources of large area and low brightness are far more effective than small sources of high brightness. The luminous ceiling and conventional indirect systems covered nearly 100% of the ceiling and they had effectiveness factors of from 40-45% while the lens systems which covered about 15% of the ceiling had effectiveness factors of about 15-25%. Although insufficient tests were made in the course of this survey, it is reasonable from other testing that efficient polarizing panels will provide a CRF of about 10% more than diffusing panels, and in any geometry of lighting luminaires this 10% improvement could be expected. Lenses are of many different types and distribute light in different ways. Those that concentrate the light downward will provide low CRF values, far lower than diffusers; and lenses that have a broader pattern of distribution will approach but not surpass diffusers, when placed in comparable arrangements of luminaires. Work is being done at this time to develop a lens which will have wide distribution and which will produce a minimum of light in the zone which is most critical to veiling reflectances.

The only two systems with CRF values in excess of 1.00 placed the light at the periphery of the room and it would appear that this is the best procedure to achieve more than 50% effectiveness. Fortunately the effect of placing the light to the sides of the room has several other good effects. It should provide a more uniform level of illumination in the room, more light on the chalk and tackboards, and a better brightness balance in the visual environment.

appendix

The basic element in the evaluation of contrast rendition for any lighting system is the CRF which is developed by direct measurements; however, there are two other values modifying the complete story which, when taken together, can produce the Equivalent Sphere Illuminance and the Lighting Effectiveness Factor (LEF). Since the steps are exactly the same for each meter position in each project, this information is presented in tabular form following this explanation. And, since the 25° viewing angles are the only ones which are directly comparable for all projects, only these 25° CRF values for each meter position are tabulated along with the development of the ESI and LEF. The CRF values for 40° viewing angles are given with each project evaluation; however, these values are not directly comparable because of the irregularity of some of the lighting patterns. The values are shown for the benefit of those who might wish to know what they were, but they will not be included in the following tables.

The most direct way to explain the reasoning and derivations of the various values is to describe each of the qualities, using the M1 position of Project 1 as the example.

Task Illuminance is the footcandle level developed by the system being evaluated, at the M1 meter position, in this case 62 footcandles.

Luminance Factor is the preferred nomenclature for reflection factor, and in the case of this task, the factor is .72 and this means that 72% of the light falling on the task is reflected from it.

Task Luminance is the preferred nomenclature for task brightness, and the unit of measure is the footlambert. In this report, the Task Luminance is computed in each case; however, for greater accuracy, a measured value would be preferred. The major part of this survey had been completed prior to the time at which this system of evaluation was developed, and before the need for the Task Luminance was recognized. Fortunately, a record was kept of lighting levels at each meter position even though they did not coincide with the standard locations at which levels of illumination were recorded. In this example, Task Luminance is 44.6 footlamberts.

Relative Contrast Sensitivity (RCS) is a value taken from a table based upon Blackwell's research in vision. The two related values in this table are task brightness in footlamberts and the RCS. It is recognized that as brightness increases, the efficiency of the eye increases in its ability to see contrast. The RCS values are expressed as a percentage and as a function of luminance. RCS is considered to be 100% at 2920 footlamberts and 36.2 at 2.92 footlamberts. In that the relationships of RCS and footlamberts do not fall on a straight line, the use of the table is much more accurate than values taken from curves or individual calculations. The inclusion of the RCS factor adds to the accuracy of the total consideration because it produces a credit for the systems which produce higher illumination levels and discounts the systems with low levels. In the example, this value is 66.2.

Contrast Rendition Factor has already been defined and is the value resulting from the contrast measurements and their relationship to the task contrast when measured in glare-free illumination. In the example this value is .882.

Effective RCS is the product of RCS and CRF. The effectiveness of a system of relatively high RCS may be good or not depending upon the CRF, so the product of the two expresses this quality. In the example, the Effective RCS is 58.4.

Effective Sphere Luminance is determined by working back in the basic RCS table from the Effective RCS of 58.4 to find the Effective Luminance, which in this case is 19.85.

Effective Sphere Illuminance is determined by dividing the Effective Sphere Luminance by the Luminance Factor, and this value in our example is 27.6 footcandles. On this basis, because of the small loss due to low luminance and the somewhat larger loss due to veiling reflectances, it is established that the 62 footcandles produced by the system is only as effective as 27.6 footcandles of glare-free illumination.

Lighting Effectiveness Factor (LEF) is determined by dividing the Equivalent Sphere Illuminance, 27.6, by Task Illuminance, 62, to establish the value of .445 which means that the effective illumination is 44.5% of the level actually produced by the system.

The following tables are complete for each project and are given for the benefit of those who wish to follow the derivations in detail. The most important value is the ESI. This shows whether or not the combination of all factors produces an adequate level of sphere quality illumination. LEF is also important because this value shows whether or not the lighting system is effectively designed to use the light properly. A satisfactory ESI can be attained by brute force of pouring on light, but if this is the case the LEF shows it up.

project 1

Quality	Meter Locations		
	M1	M2	M3
CRF at 25° (electric)	.882	.925	.892
CRF at 40° (electric)	.948	.985	.942
CRF at 25° (electric & daylight)	1.03	1.05	1.00
CRF at 40° (electric & daylight)	1.09	1.11	1.05
(electric)			
Task Illuminance (TI)	62	61	69
Luminance Factor (LF)	.72	.72	.72
Task Luminance (TL)	44.6	43.9	49.7
Relative Contrast Sensitivity (RCS)	66.2	66.0	67.1
Contrast Rendition Factor (CRF)	.882	.925	.892
Effective RCS (ERCS)	58.4	61.1	59.9
Equivalent Sphere Luminance (ESL)	19.85	25.80	23.08
Equivalent Sphere Illuminance (ESI)	27.6	35.8	32.1
Lighting Effectiveness Factor (LEF)	.445	.587	.465
(electric & daylight)			
TI	172	188	106
LF	.72	.72	.72
TL	124	135.4	76.4
RCS	75.4	76.2	71.1
CRF	1.03	1.05	1.00
ERCS	77.7	80.0	71.1
ESL	159.00	201.00	76.40
ESI	220.8	279.2	106.1
LEF	1.28	1.48	1.00

project 2

Quality	Meter Locations		
	M1	M2	M3
CRF at 25°	.900	.939	.932
CRF at 40°	.972	.998	.991
TI	100	115	118
LF	.72	.72	.72
TL	72	82.8	84.9
RCS	70.5	71.9	72.1
CRF	.900	.939	.932
ERCS	63.5	67.5	67.2
ESL	33.20	52.30	50.40
ESI	46.1	72.6	70.0
LEF	.461	.631	.593

project 3

Quality	Meter Locations			
	M1	M2	M3	M4
CRF at 25° (inside pairs)	.749	1.00	.822	1.01
CRF at 40° (inside pairs)	.797	1.06	.913	1.06
CRF at 25° (both pairs)	.758	1.00	.831	1.03
CRF at 40° (both pairs)	.814	1.06	.925	1.07
CRF at 25° (outside pairs)	.764	—	.830	—
(inside pairs)				
TI	108	92	125	118
LF	.72	.72	.72	.72
TL	77.8	66.2	90.0	85.0
RCS	71.3	69.7	72.6	72.1
CRF	.749	1.00	.822	1.01
ERCS	53.4	69.7	59.7	72.8
ESL	12.80	66.20	22.70	92.00
ESI	17.8	91.9	31.5	127.8
LEF	.165	.999	.252	1.08
(all four lamps)				
TI	215	185	250	235
LF	.72	.72	.72	.72
TL	154.8	133.2	180	169.2
RCS	77.5	76.1	78.9	78.4
CRF	.758	1.00	.831	1.03
ERCS	58.7	76.1	65.6	80.8
ESL	20.45	133.40	41.80	222.00
ESI	28.4	185.3	58.1	308.3
LEF	.132	1.00	.232	1.311
(outside pairs)				
TI	107	—	125	—
LF	.72	—	.72	—
TL	.770	—	.90	—
RCS	71.2	—	72.6	—
CRF	.764	—	.830	—
ERCS	54.4	—	60.3	—
ESL	13.32	—	24.04	—
ESI	18.5	—	33.4	—
LEF	.173	—	.267	—

ERIC

project 4

Quality	M1 Meter Location		
	Elect.	Day	Combined
CRF at 25°	1.02	1.18	1.12
CRF at 40°	1.06	1.20	1.14
TI	59	36	95
LF	.72	.72	.72
TL	42.5	25.9	68.4
RCS	65.7	61.1	70.0
CRF	1.02	1.18	1.12
ERCS	67.0	72.1	78.4
ESL	49.30	84.80	169.80
ESI	68.5	117.8	235.8
LEF	1.16	3.27	2.48

project 5

Quality	Meter Locations		
	M1	M2	M3
CRF at 25°	1.12	.915	1.07
CRF at 40°	1.14	.908	1.12
TI	16	42	42
LF	.72	.72	.72
TL	11.5	30.2	30.2
RCS	52.9	62.6	62.6
CRF	1.12	.915	1.07
ERCS	59.2	57.3	67.0
ESL	21.54	17.80	49.30
ESI	29.9	24.7	68.5
LEF	1.87	.588	1.63

project 6

Quality	Meter Locations	
	M1	M2
CRF at 25°	.886	.911
CRF at 40°	.940	.964
TI	83	80
LF	.72	.72
TL	59.8	57.6
RCS	68.7	68.4
CRF	.886	.911
ERCS	60.87	62.31
ESL	25.60	29.40
ESI	35.6	40.8
LEF	.429	.510

project 7

Quality	Meter Locations M1	M2
CRF at 25°	.915	.942
CRF at 40°	.980	1.11
TI	90	90
LF	.72	.72
TL	64.8	64.8
RCS	69.5	69.5
CRF	.915	.942
ERCS	63.59	65.47
ESL	33.60	41.30
ESI	46.7	57.4
LEF	.519	.638

project 8

Quality	Meter Locations M1	M2	M3
CRF at 25°	.742	.908	.987
CRF at 40°	.794	.905	1.02
TI	135	135	120
LF	.72	.72	.72
TL	97.2	97.2	86.4
RCS	73.2	73.2	72.3
CRF	.742	.908	.987
ERCS	54.31	66.47	71.37
ESL	13.19	46.40	78.70
ESI	18.3	64.4	109.3
LEF	.136	.477	.911

project 9

Quality	Meter Locations M1
CRF at 25°	.886
CRF at 40°	.941
TI	65
LF	.72
TL	46.8
RCS	66.6
CRF	.886
ERCS	59.0
ESL	21.10
ESI	29.3
LEF	.451

project 10

Quality	Meter Locations M1	M2
CRF at 25°	.956	.972
CRF at 40°	.987	1.02
TI	110	97
LF	.72	.72
TL	79.2	69.8
RCS	71.5	70.2
CRF	.956	.972
ERCS	68.35	68.23
ESL	57.20	56.60
ESI	79.4	78.6
LEF	.722	.810

project 11

Quality	Meter Locations M1	M2
CRF at 25° (electric)	.845	.943
CRF at 40° (electric)	.916	1.01
CRF at 25° (electric & daylight)	.905	1.01
CRF at 40° (electric & daylight)	—	—
(electric)		
TI	111	110
LF	.72	.72
TL	80	79
RCS	71.5	71.4
CRF	.845	.943
ERCS	60.42	67.33
ESL	24.32	51.00
ESI	33.8	70.8
LEF	.305	.644
(electric & daylight)		
TI	147	146
LF	.72	.72
TL	106	105
RCS	74	73.9
CRF	.905	1.01
ERCS	66.97	74.64
ESL	49.30	113.50
ESI	68.5	157.6
LEF	.466	1.08

project 12

Quality	Meter Locations M1	M2
CRF at 25°	.832	.910
CRF at 40°	.902	.995
TI	137	140
LF	.72	.72
TL	98.6	100.9
RCS	73.4	73.6
CRF	.832	.910
ERCS	61.07	66.98
ESL	26.00	49.30
ESI	36.1	68.5
LEF	.264	.489

project 13

Quality	M1	Meter Locations M2	M3
CRF at 25°	.798	.973	.785
CRF at 40°	.879	1.03	.873
TI	114	108	87
LF	.72	.72	.72
TL	82.0	77.9	62.6
RCS	71.8	71.3	69.1
CRF	.798	.973	.785
ERCS	57.30	69.37	54.24
ESL	17.80	64.30	13.08
ESI	24.9	89.3	18.2
LEF	.218	.827	.209

project 14

Quality	Meter Locations M1	M2
CRF at 25°	.887	.962
CRF at 40°	.947	.947
TI	106	100
LF	.72	.72
TL	76.3	72.0
RCS	71.1	70.5
CRF	.877	.962
ERCS	63.06	67.82
ESL	31.80	54.10
ESI	44.2	75.1
LEF	.417	.751

project 15

Quality	Meter Locations		
	M1	M2	M3
CRF at 25°	.919	.985	.789
CRF at 40°	.933	1.06	.860
TI	120	126	120
LF	.72	.72	.72
TL	86.4	90.6	86.4
RCS	72.3	72.7	72.3
CRF	.919	.985	.789
ERCS	66.44	71.61	57.04
ESL	45.80	80.50	17.30
ESI	63.6	111.8	24.0
LEF	.530	.887	.200

project 16

Quality	Meter Locations		
	M1	M2	M3
CRF at 25°	.766	.977	.690
CRF at 40°	.836	1.05	.734
TI	90	84	70
LF	.72	.72	.72
TL	64.8	60.5	50.4
RCS	69.5	68.8	67.2
CRF	.766	.977	.690
ERCS	53.24	71.55	46.37
ESL	11.82	80.50	6.65
ESI	16.4	111.8	9.2
LEF	.182	1.33	.131

project 17

Quality	Meter Locations	
	M1	M2
CRF at 25°	.798	.996
CRF at 40°	.865	1.06
TI	112	115
LF	.72	.72
TL	80.6	82.8
RCS	71.6	71.9
CRF	.798	.996
ERCS	57.14	71.61
ESL	17.45	80.50
ESI	24.2	111.8
LEF	.216	.972

project 18

Quality	Meter Locations M1	M2
CRF at 25°	.889	1.00
CRF at 40°	.943	1.05
TI	95	90
LF	.72	.72
TL	68.4	64.8
RCS	70.0	69.5
CRF	.889	1.00
ERCS	62.23	69.50
ESL	29.10	64.80
ESI	40.4	90.0
LEF	.425	1.00

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