

**A STUDY OF ILLUMINATION  
AND LIGHT DISTRIBUTION WITHIN  
THE ART ROOM**

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**W. D. RICHARDS  
ELEMENTARY SCHOOL  
COLUMBUS, INDIANA**

**VITAL SIGNS VIII**  
CENTER FOR ENERGY RESEARCH/EDUCATION/SERVICE

**BALL STATE UNIVERSITY**  
COLLEGE OF ARCHITECTURE & PLANNING  
FALL 2003

**JOHN BALS  
CAZEMBE DAY**



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## ACKNOWLEDGMENTS

### **W. D. RICHARDS ELEMENTARY SCHOOL**

We would like to give a special thanks to the faculty, staff, and students of W. D. Richards Elementary School for their help and patience throughout the duration of this investigation.

Principal: Mrs. O. Excell Cody

### **BALL STATE UNIVERSITY**

#### **CENTER FOR ENERGY RESEARCH/EDUCATION/SERVICE (CERES)**

Thanks to the CERES faculty for their assistance throughout this investigation.

Robert Koester Professor of Architecture, CERES Director

Jeff Culp CERES Operations Manager

Robert Fisher Professor of Architecture, CERES Resident Fellow



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Fig 1.1 - W. D. Richards Elementary School main entrance

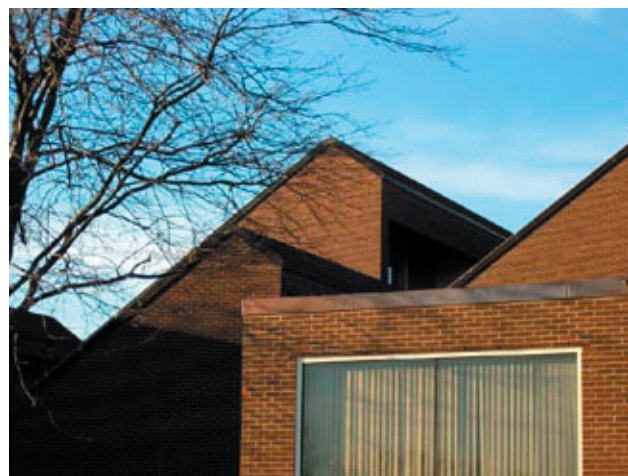


Fig 1.2, 1.3 - View of roof monitors with clerestory windows. Note: images show the roof structure over the art room.



## ABSTRACT

This report describes a semester long study conducted in the fall of 2003 of the natural and artificial lighting within the art room of the W. D. Richards Elementary School in Columbus, Indiana.

The study began with an initial visit to the school to become familiar with the history and design of the school. After the visit, we developed a hypothesis specifically focused on a single aspect of the lighting conditions within the school. In this case, the focus was on the investigation and measurement of the illuminance levels within the art room of the school. We hypothesized that the natural lighting and lighting fixtures were designed to provide the required illumination in foot-candles for the functions that took place within the art room of the school.

We undertook the investigation of the art room and the lighting conditions, using three main research phases: indicative, investigative, and diagnostic.

The indicative phase of the research within the room revealed an uneven distribution of natural illumination throughout the room. Furthermore, lighting fixtures appeared to be required to be on within the room for students to complete their art projects, even during clear sunny days. The research team recorded room dimensions, clerestory window locations and dimensions, fixture count, fixture location, and the lamp types of the light fixtures within the room.

The investigative phase involved using various instruments to record the lighting conditions within the room. This included the use of digital light meters to record instantaneous illuminance, hobo data loggers to record the illuminance within the room as it changed over a period of several days, and a digital camera to record images of the room.

During the diagnostic phase, a hypothesis was formed and the team took a closer look at the research data gathered to prepare a comprehensive analysis by which to prove or disprove the hypothesis. This analysis included the creation of several graphs and charts based on the illumination data gathered earlier. We also used digital photographs and a Minolta luminance meter to create a visual field evaluation of the brightness levels experienced by students within the room.

After gathering, recording, and analyzing the data, we arrived at several conclusions about the lighting conditions within the art room. We discovered that the daylight illumination alone does not meet the required foot-candles for an art room and we determined that the lighting fixtures within the room were sufficient to provide the required illuminance within the space.

After demonstrating our conclusions, this report includes proposed improvements for the design of the room based on the investigation. Finally, this report includes all the data collected during the three phases of the research.



## VITAL SIGNS VIII

### INTERIOR ILLUMINATION, DAYLIGHT CONTROL, AND OCCUPANT RESPONSE

The Vital Signs VIII course offered during the fall semester of 2003 at Ball State University is a comprehensive class that focuses on interior illumination, daylight control, and occupant response. The national vital signs program was developed by Cris Benton of the University of California, Berkeley to provide field investigations and evaluations of recognizable architecture to aid in future building design. The course at Ball State University was led by Professor Robert Koester, director of the Center for Energy Research/Education/Service (CERES). He chose the W. D. Richards Elementary School, a day lighting designed building, to help the participants develop a more complete understanding of the ideas presented during the course.

Through team-based field research, the participants were expected to use a specific methodology to form a hypothesis and then carry out several phases of research to come to informed conclusions about the design of the building, and then to provide educated recommendations for possible improvements of the design.

The research involved three main phases: indicative, investigative, and diagnostic. The indicative phase involved an initial visit to the school to become familiar with the existing lighting conditions and then to develop a hypothesis about a specific aspect of the conditions based upon our first visit.

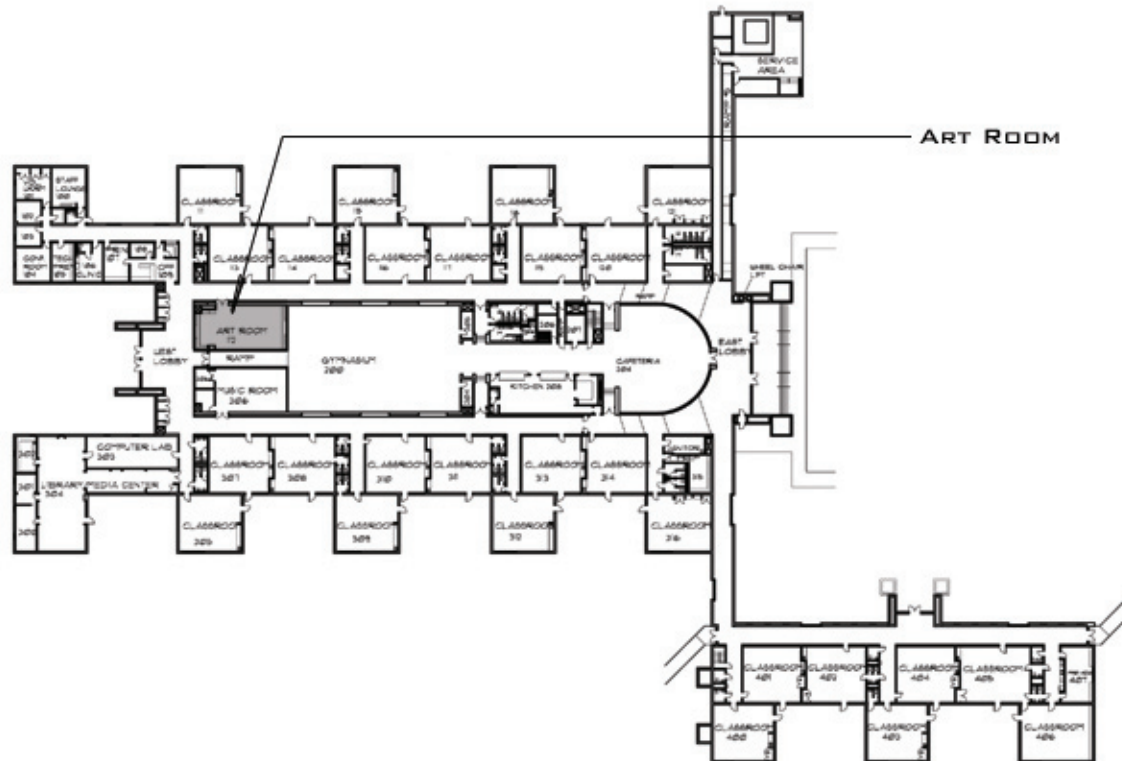
The investigative phase of the research focused on field-based data gathering over a short period of time. This information allowed us to identify existing lighting conditions at a specific moment in time.

The diagnostic phase of research involved longer-term data gathering methods, and the collection of user input. The information provided from the diagnostic phase allowed the participants to develop a comprehensive analysis of the conditions that lead to the evaluation of the hypothesis.

The ultimate goal of the course was to broaden technical and experiential credentials and to increase the marketable knowledge of the participants.

The research hypothesis and conclusion phase of the project revolves around 3 main factors: interior illumination, daylight control, and occupant response.

Interior illumination involves the processes necessary to light the interior spaces of the building by direct or indirect light sources. The two sources in this project include natural light (direct beam sun-light and inter-reflected sky-vault brightness) and artificial light (fluorescent lamps). The goal of daylighted buildings are to maximize natural light to reduce energy cost and provide a useful light source on vertical and horizontal worksurfaces. Daylight control is the ability to reduce the glare and or illuminance level of natural light with window coverings or by redirecting the light off interior walls designed for this purpose. The occupant response to the light levels are a very important criteria of the research. Light levels must allow for adequate illuminance levels at different points within the space for occupants to function efficiently at varied tasks.



## RICHARDS ELEMENTARY SCHOOL

SCALE: 1" = 100'

## W. D. RICHARDS ELEMENTARY SCHOOL

The W.D. Richards Elementary School has a vision of “providing a safe and positive learning environment where students will have the opportunity to gain basic knowledge through the use of appropriate curriculum and to achieve their potential.” The school spans grades from preschool to sixth, is located within a town with over 25,000 people in the Bartholomew County School Corporation, and has a five year accreditation. The school believes in four main principles: professional growth, continuous improvement, education excellence for all learners and accountability. The school is ranked as a four star elementary school, meaning it is within the top twenty five percent of all schools within Indiana in four categories (ISTEP\* total battery NCE, ISTEP Math Proficiency, ISTEP Language Proficiency, and Attendance Rate). The ethnic breakdown of the institution consist of 87.3% white, 1.9% black, 3.4% Hispanic, and 4% multiracial. Total enrollment at the school in the year 2001 was 555. The school maintains one of the highest retention rates in the state at 99.8%. There are 25 full time teachers with an average salary of \$50,446 and average age of 48. A large majority of the teachers have 18-20 years of experience and the student to teacher ratio remains around 22.3. The school also employs special needs programs for students with communication disorders and learning disabilities. Programs are also offered for exploring music, physical education, and visual arts.

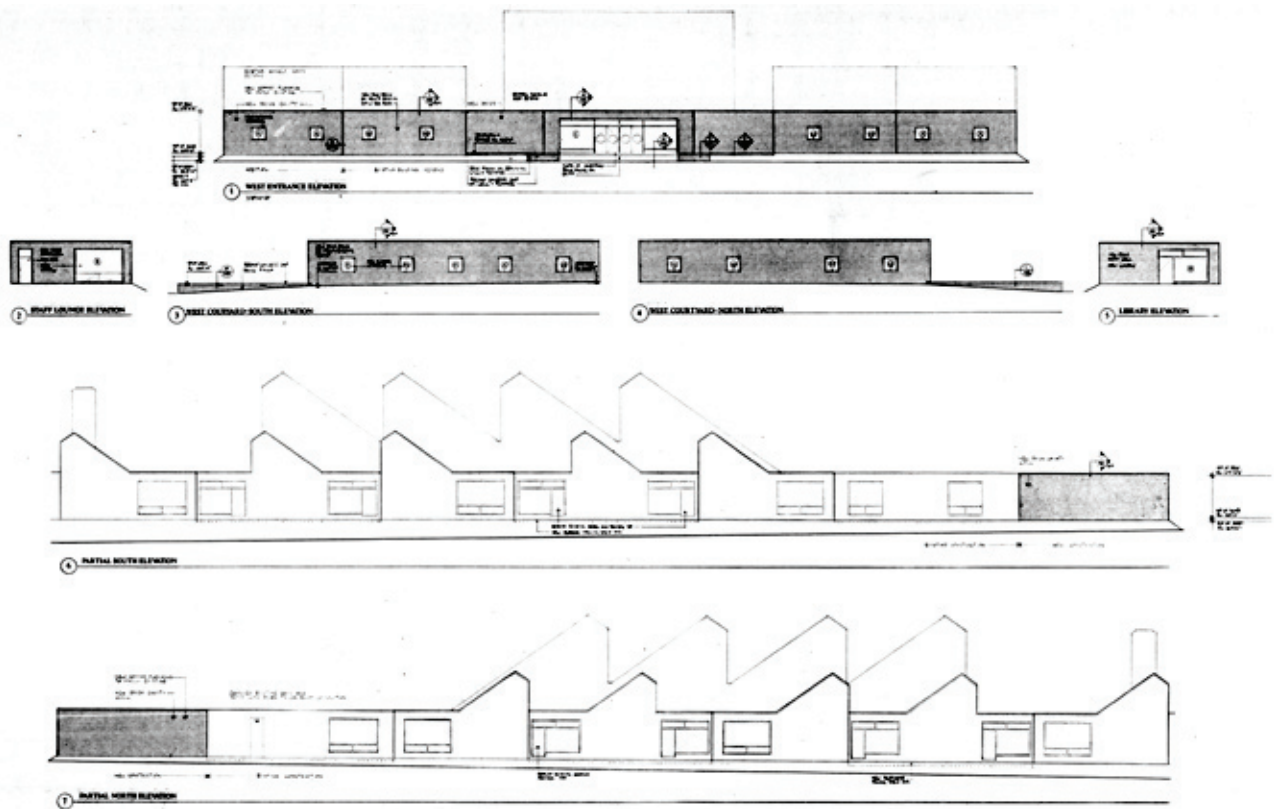
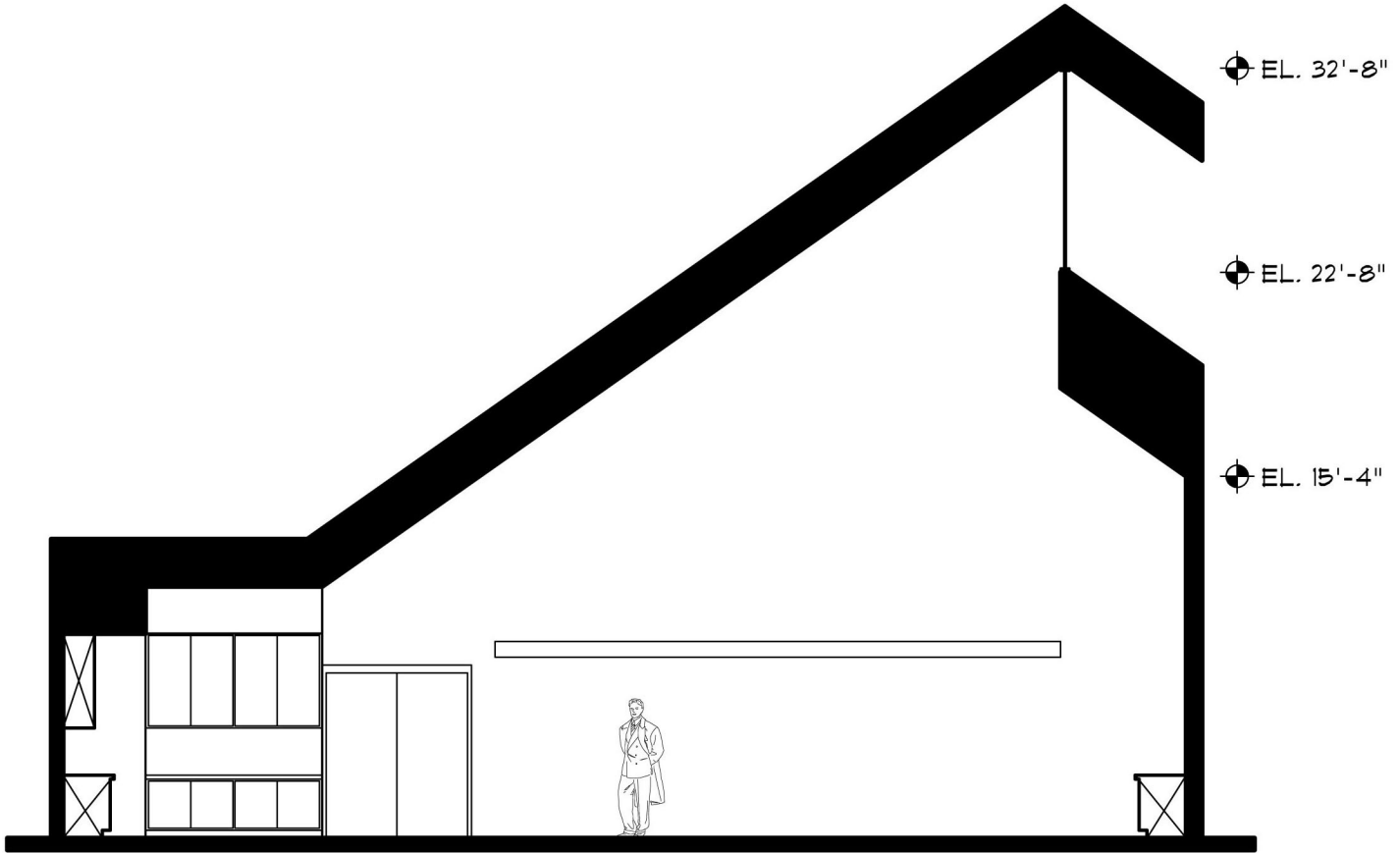


Fig. 2.2 - W. D. Richards Elementary School building elevations

The principal architect on the W. D. Richards Elementary School project was Mr. Edward Larrabee Barnes. Born in Chicago, Illinois Mr. Barnes acquired his BS from Harvard and his MA from the Harvard Graduate School of Design. He has taught at the Pratt Institute in New York and Yale University in Connecticut. His design experience extends through a broad range of projects including civic, educational and commercial buildings.

Construction was completed on the school in 1965. The school design incorporates the use of east facing clerestory windows placed within a double height space to provide natural light to each of the classrooms and gymnasium spaces. In 1997 the school added classrooms and support rooms. Lee & Timchula Architects, the architecture firm for the addition, used the original design concept in the new sections of the school, incorporating the same clerestory windows placed in a double height space to bring natural light into the rooms. The 20,000 square foot renovation included a school-wide network of computer and media wiring; new lighting and ceilings throughout the existing school corridors, a renovation of the existing food service preparation area, sound-proofing of the existing music room, and a renovation of the reception and administration area.

\* ISTEP: Indiana Statewide Testing for Educational Progress



**SECTION THROUGH ART ROOM**  
SCALE: 1/8" = 1'-0"  
0' 1' 2' 4' 8'

Fig. 3.1 - East-West section through the art room



Fig. 3.2, 3.3 - Interior photographs of the art room

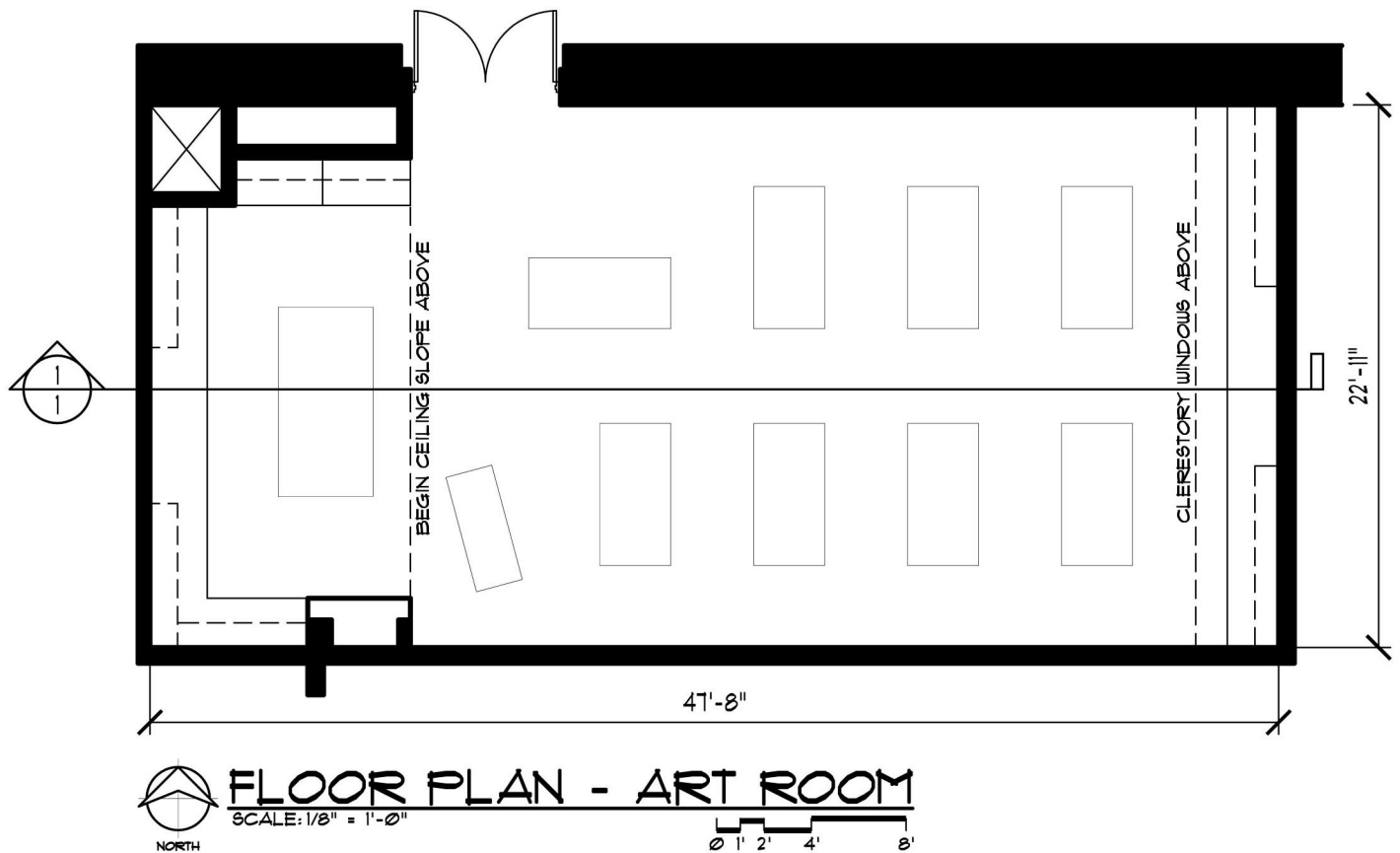
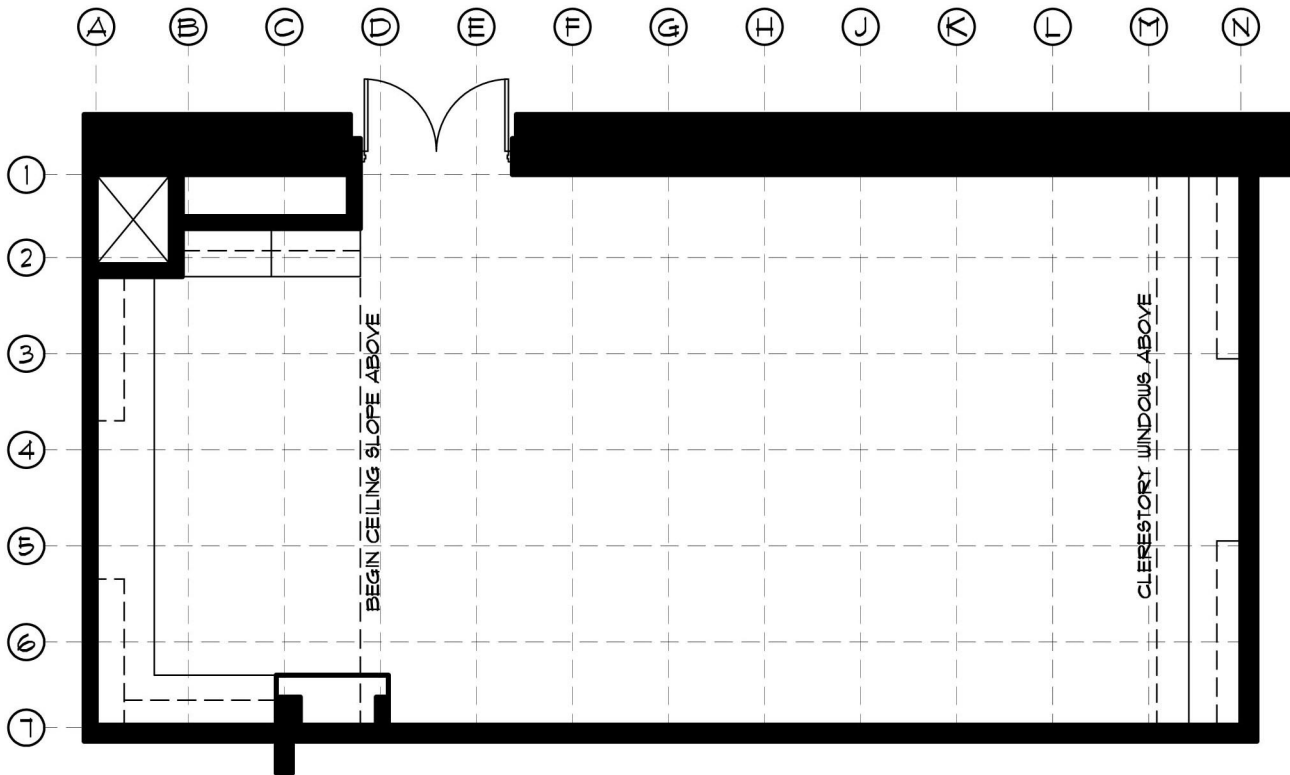


Fig. 3.4 - Floor plan of the art room showing section cut, casework locations, and furniture layout.

## HYPOTHESIS

The school's design incorporates clerestory windows placed along the entire east wall of double height spaces to allow natural illumination to enter the spaces. An indicative investigation of the school and the classrooms yielded several questions about the design. These included questions about uniformity of illumination, levels of satisfaction from the teachers, arrangement of school furniture to avoid direct glare from the clerestory windows above, and arrangement of illumination from the natural light to comfortably read or write. We selected the art room for our study of these questions. The intent of the space design is to provide required illumination for the functions within the room. Our initial analysis of the space suggested that the natural light within the art room did not provide the suggested illuminance levels for an art environment. It appeared the light fixtures were located independently of the natural lighting conditions. This is an inefficient method of lighting for this specific building. By not utilizing the natural light effectively, the need to use artificial light can result in an unnecessary use of energy. Based on this initial analysis, we developed a testable hypothesis; the natural light and lighting fixtures were designed to provide the required illumination in foot-candles for the functions that take place within the art room of the school.



**48" GRID - ART ROOM**  
 SCALE: 1/8" = 1'-0"  
 NORTH

Above: Fig. 4.1 - Working 48" grid layout within the art room.

Next page: Fig 4.2 - Working Hobo Data Logger placement within the art room. Note: Data loggers placed on the 48" grid.



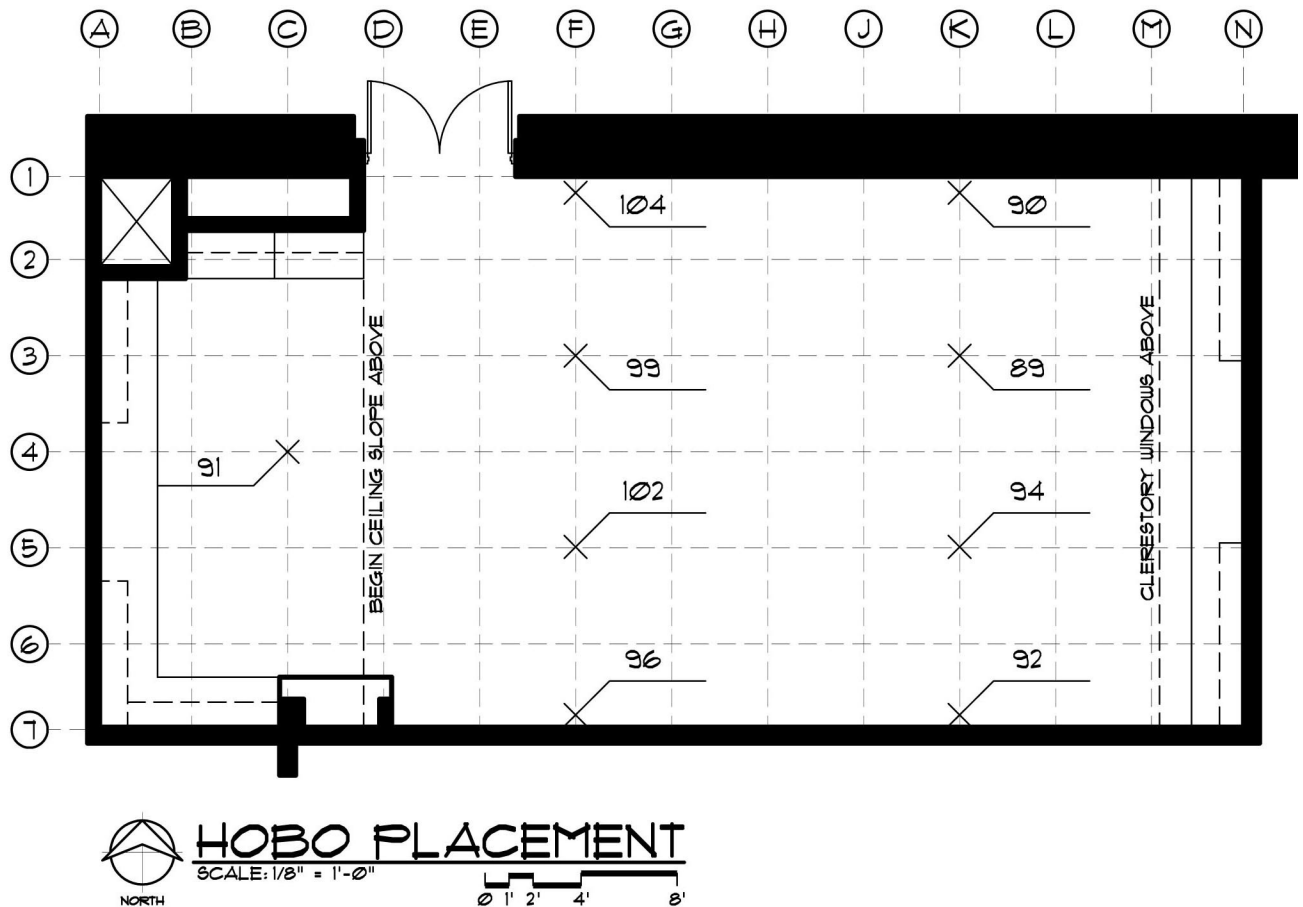


Fig. 4.2 - Hobo data logger placement

## METHODOLOGY

The investigation of the art room in the W. D. Richards Elementary School began with an initial school visit and the first phase of research: the indicative phase. This included general condition observations, quick illuminance measures, and a quantitative analysis of the art room. The investigative and diagnostic phases of the research focused on taking measurements of the amount of light in foot-candles within the room, identifying the sources of natural light, and locating the light fixtures within the room, their lamp types, number of lamps, lighting control, and light circuitry.

The research team divided the room into 48 inch sections (see above) and took measurements at the intersection points on the grid. The measurements were taken three different times. The first set of data was taken using only the natural light entering the room. The second set was taken using only the artificial light within the room. The final set was taken using a combination of both natural and artificial light. The next step involved the placing of data loggers\* on the grid to obtain the illumination within the room at specific points throughout the different times of day. Also, luminance measurements were taken on the work surfaces to identify contrast. Finally, all the data were analyzed to develop a conclusion and to suggest several possible improvements to the design of the room to enhance the design concept.

\* See appendix A for a description of the instruments



Fig. 5.1



Fig. 5.2



Fig. 5.3



Fig. 5.4

Above: Photographs displaying light sources within the art room.

Fig. 5.1 - Track lighting layout

Fig. 5.2 - Recessed can lights in soffit

Fig. 5.3 - Fluorescent bulbs along north and south walls

Fig. 5.4 - Clerestory window above east wall

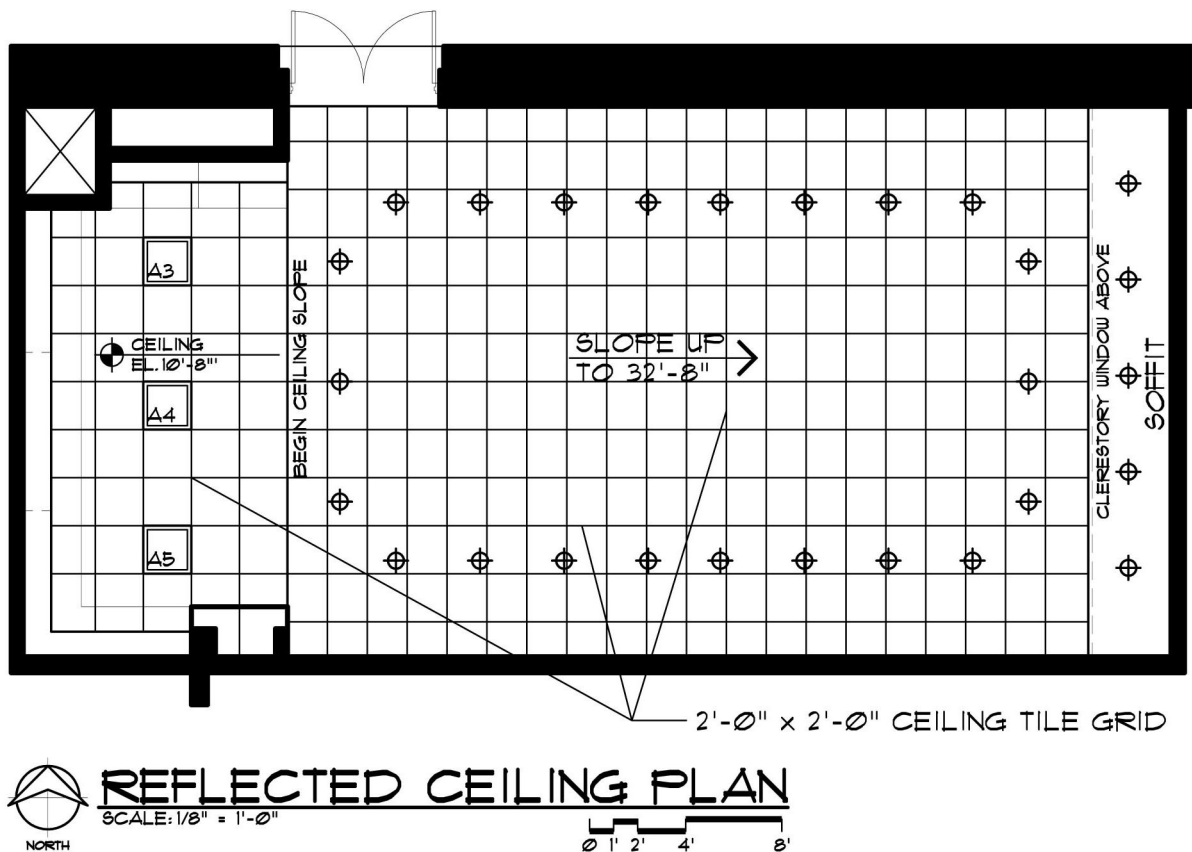


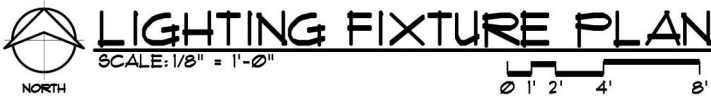
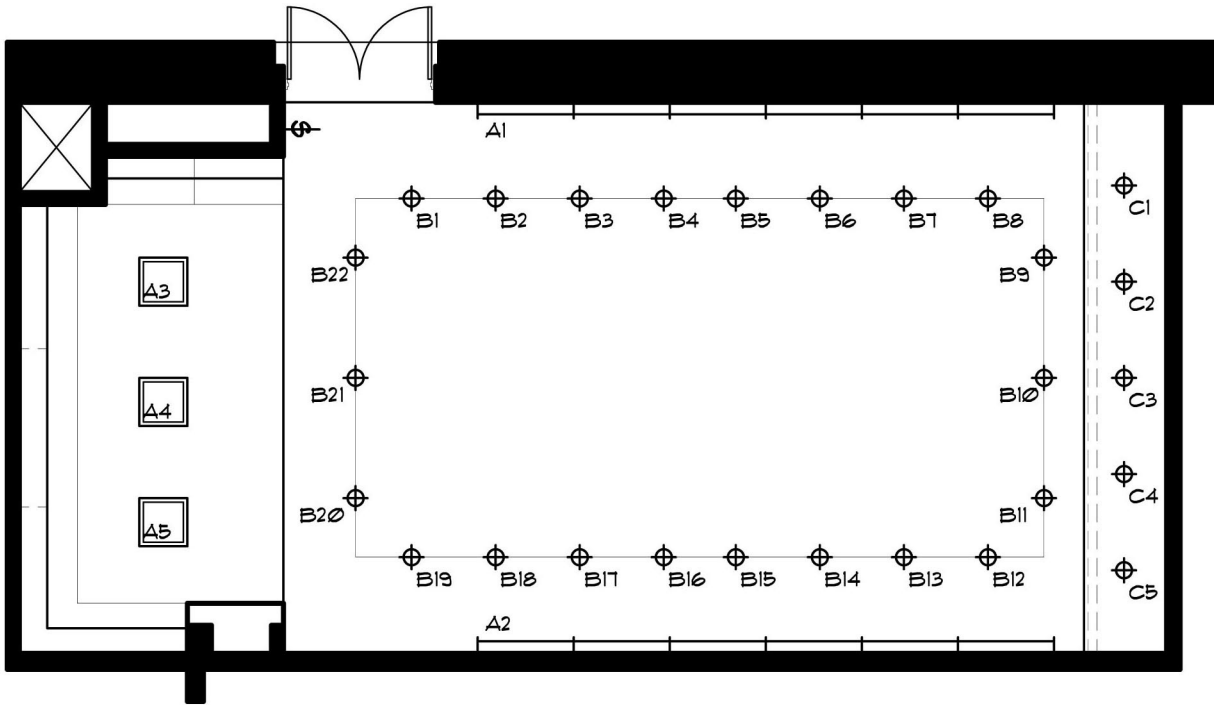
Fig. 5.5 - Reflected ceiling plan showing ceiling tile grid, ceiling heights, and lamp fixture locations

## INDICATIVE RESEARCH

The indicative phase of the research began with an initial visit to the W. D. Richards Elementary School on September 9, 2003. This research team focused our investigation within the school's art room. The art room is located in the center core of the school, adjacent to the gymnasium. Unlike most of the other classrooms, it does not have an exterior wall. The only source of natural light for the art room is the eastern clerestory window.

The room's ceiling slopes to a height of 32'-8". At the top of the slope is a 10'-0" deep clerestory window that runs uninterrupted the length of the eastern wall. The sloped ceiling is finished with a white 24 inch acoustical lay-in ceiling tile grid. The design concept of the room uses the clerestory window to bring exterior light into the room and uses the ceiling to reflect the natural light into the space and spread that light evenly within the room.

In addition to the natural light brought into the space by the clerestory window, the illumination of the room is supplemented by several sets of light fixtures. The first is a set of six 2-bulb, 4'-0" fluorescent light fixtures along the north and south walls of the room. Under the clerestory window, located in the soffit, are five recessed incandescent can lights. In the west end of the room there are three 24 inch square parabolic fixtures with two U-shaped fluorescent lamps. Finally, arranged in a rectangle around the work space are twenty-two incandescent can lights placed on a suspended track to provide task lighting over the student work area.

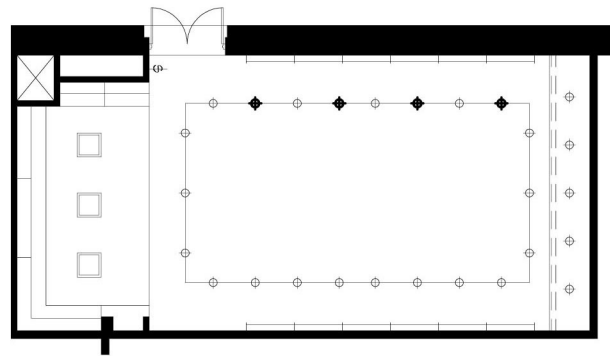


### SWITCH LEGEND

- S1 B2, B4, B6, B8
- S2 B1, B3, B5, B7
- S3 B20, B21, B22
- S4 B9, B10, B11, C1, C2, C3, C4, C5
- S5 B13, B15, B17, B19
- S6 B12, B14, B16, B18
- S7 A1, A2, A3, A4, A5

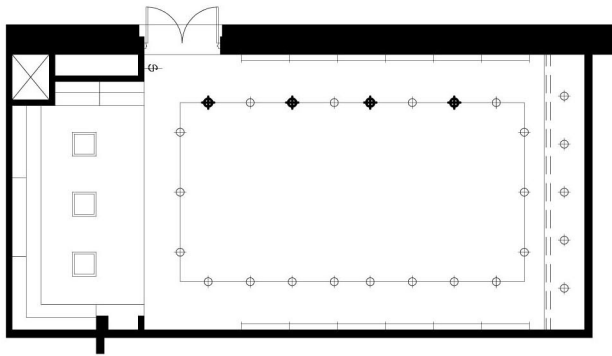
Above: Fig. 5.6 - Lighting plan and switch legend diagramming the art room artificial light sources

Right and Next Page: Figs. 5.7 - 5.13 - Switch keyplans displaying the lights on each switch as listed in the switch legend above. Note: Lights on each switch are displayed as dark symbols on each drawing.



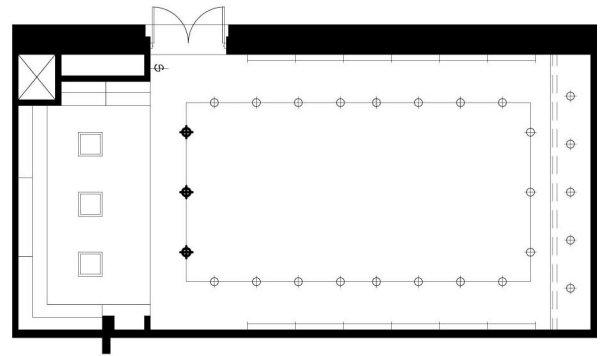
### SWITCH 1

Fig. 5.7



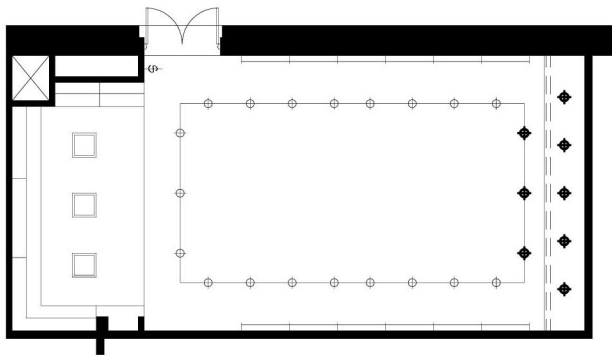
SWITCH 2

Fig. 5.8



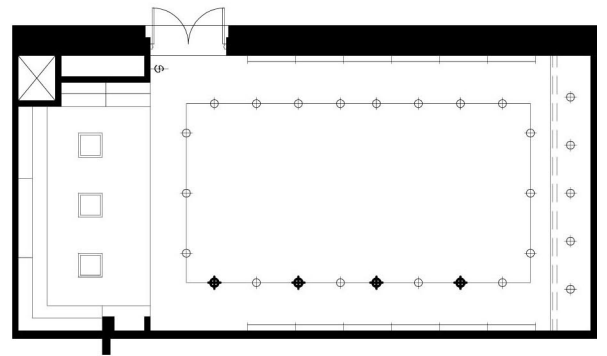
SWITCH 3

Fig. 5.9



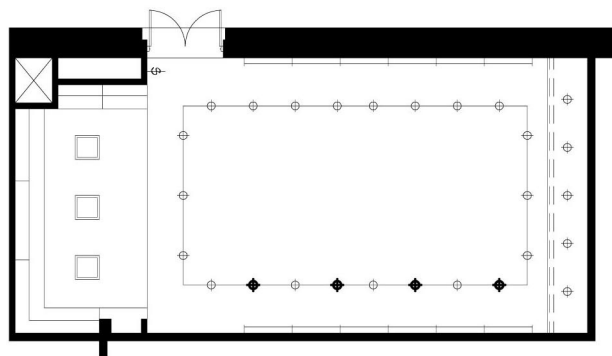
SWITCH 4

Fig. 5.10



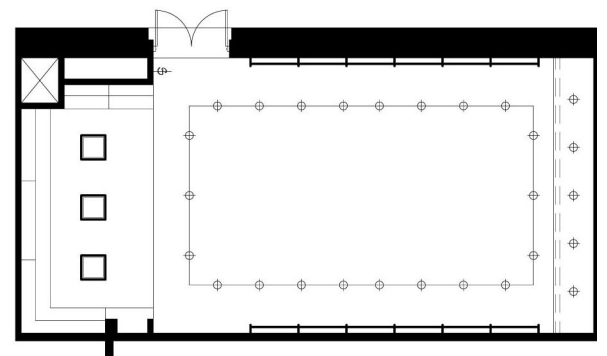
SWITCH 5

Fig. 5.11



SWITCH 6

Fig. 5.12



SWITCH 7

Fig. 5.13

## INVESTIGATIVE RESEARCH

The investigative phase of the research focused on the gathering of data within the art room. First, the research team recorded the lighting fixture layout. Each luminaire was located in plan and then associated with one of seven switches in the room. This enabled the team to identify the way in which artificial light within the art room could be manipulated for various tasks.

The next task was to record illuminance within the room. Using a Sylvania digital illuminance meter, the research team recorded the illuminance in foot-candles of various points within the room. These measurements were taken on the 48 inch grid seen in fig 4.2 and fig 6.1 below. The team took three sets of measurements. The first set of data measured only the natural light entering the space. The second set of data was taken with all the light fixtures turned on and the clerestory windows fully exposed to provide natural light. For the final set of data, the team covered the window and measured only the illuminance levels from the light fixtures.

The daylight-only data set shows that the highest value recorded for the room was 9 foot-candles. This is too low a value for a room used as an art room. It seemed that daylight alone was not enough to provide the recommended amount of light. Because the clerestory window faces the east, the team believed that the amount of daylight in the room during the morning hours would be greater than in the afternoon. To determine whether this was the case, the team placed 9 data loggers throughout the room to record daylight illumination changes within the room over a weekend, beginning at 4:00 P.M. November 21 until 9:00 A.M. November 24. See fig 4.2 for data logger placement.

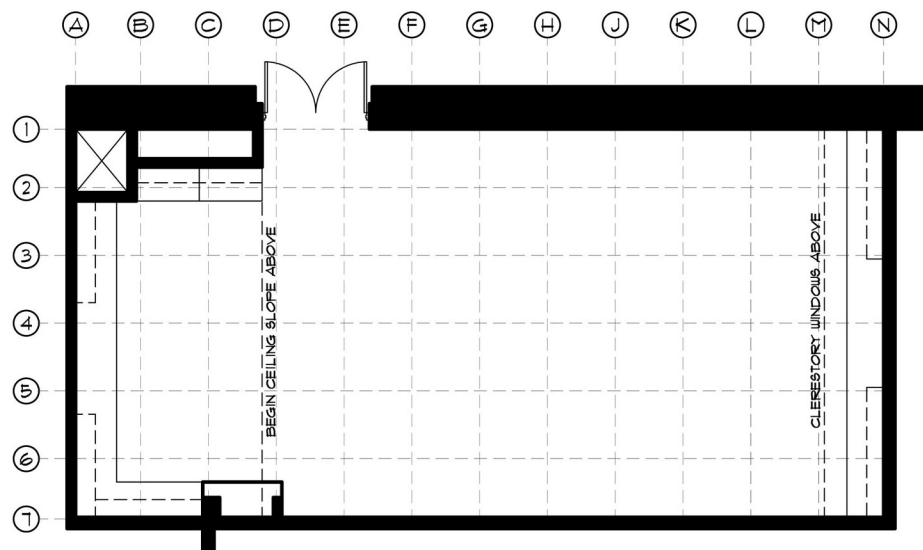


Fig. 6.1 - Keyplan displaying 48" grid

Natural Light - foot-candles													
	A	B	C	D	E	F	G	H	J	K	L	M	N
1	0	0	0	6	4	6	7	5	6	6	5	4	1
2	2	3	1	6	8	8	8	7	7	7	6	5	1
3	2	3	4	6	8	8	8	8	9	8	7	6	4
4	2	3	4	6	8	9	9	9	9	8	7	7	4
5	2	3	4	6	8	9	9	8	8	8	7	7	4
6	2	3	4	6	7	8	7	7	7	7	6	5	1
7	0	0	0	0	5	5	6	5	4	5	5	5	2

Fig. 6.2 - Natural light illumination, values in foot-candles.

Natural and Artificial Light - foot-candles													
	A	B	C	D	E	F	G	H	J	K	L	M	N
1	0	0	0	21	22	75	74	77	77	71	53	22	6
2	5	5	3	30	38	61	63	97	54	60	68	38	5
3	26	51	50	98	34	47	54	79	48	46	36	43	25
4	28	51	61	39	34	36	40	37	34	34	39	43	31
5	27	54	72	38	81	99	57	63	42	99	71	46	21
6	22	50	42	29	43	71	74	74	69	67	51	38	4
7	4	3	0	0	35	76	70	67	47	51	52	25	10

Fig. 6.3 - Natural and artificial light illumination, values in foot-candles.

Artificial Light - foot-candles													
	A	B	C	D	E	F	G	H	J	K	L	M	N
1	0	0	0	10	18	61	61	67	69	67	59	22	6
2	1	24	16	14	30	50	57	99	49	54	55	55	4
3	3	42	37	98	29	36	40	61	32	38	58	36	22
4	14	55	58	43	24	27	29	28	26	27	26	32	24
5	10	49	79	30	68	40	49	34	37	99	34	52	21
6	3	41	49	22	37	57	82	65	57	65	54	34	5
7	0	0	0	0	26	59	68	52	45	57	58	22	5

Fig. 6.4 - Artificial light illumination, values in foot-candles.

## DIAGNOSTIC RESEARCH

The diagnostic phase of the research focused on a detailed examination of the data gathered. The first set of data investigated was the illumination measurements gathered using the digital illuminance meter. The three sets of data were placed in a spreadsheet for evaluation. The team created a 3-dimensional graph showing the distribution of light within the art room (see figs 7.1 - 7.3). The data sets demonstrate that the natural light illumination is concentrated in the center of the room, although fairly evenly distributed over the children's work area. The graphs that display lighting fixture illumination and lighting fixture illumination with natural lighting show spikes of illumination within the room. These are caused by the hotspots of the incandescent can fixtures that provide task lighting in the children's work area. The illumination measurements were in some places recorded directly below one of the task lighting fixtures.

The team also imported the data logger values into spreadsheets. These data sets were used to create line graphs showing the change in the amount of natural light within the space over the weekend. The graphs all demonstrate that the amount of light in the art room is greatest in the morning. The light levels begin to drop in late morning and on through the afternoon. This corresponds with the location of the sun in relation to the clerestory window: the window faces east and therefore the amount of light in the room is greatest when the sun is in the eastern sky.

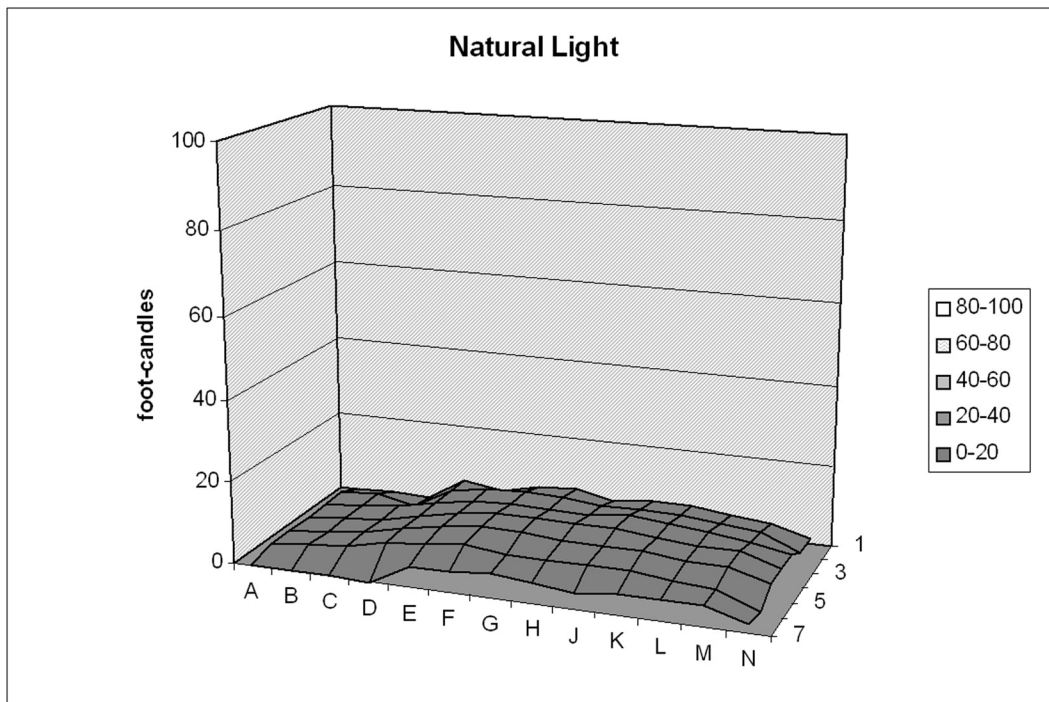


Fig. 7.1 - Chart diagramming the 3-dimensional distribution of natural light within the art room.



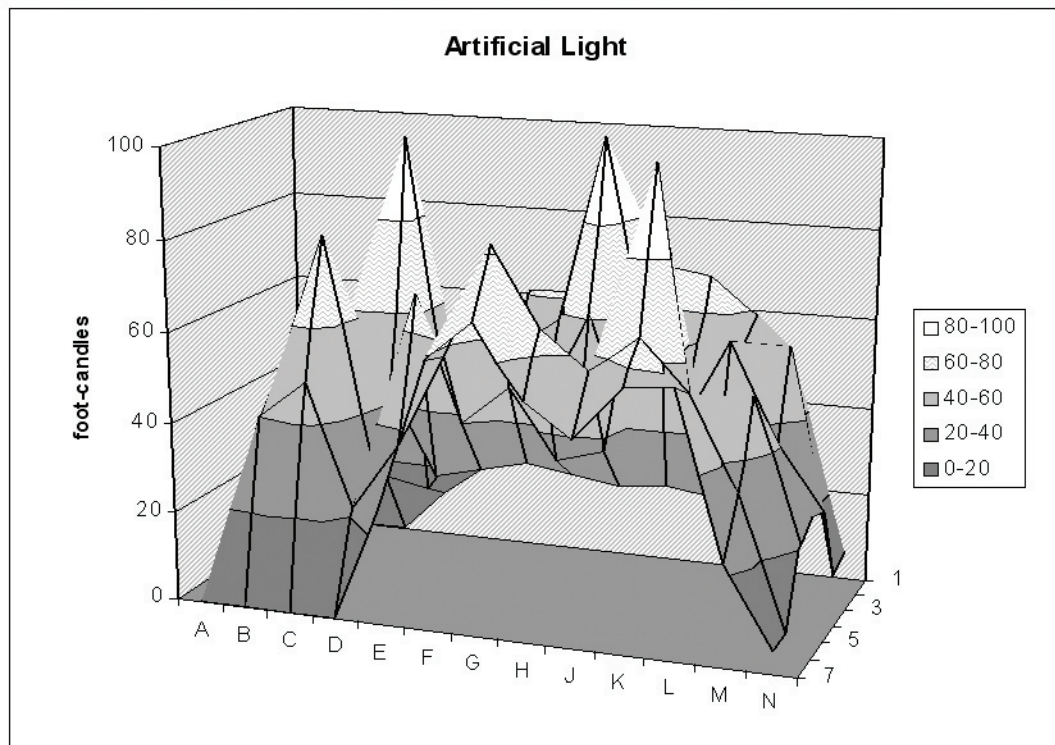


Fig. 7.2 - Chart diagramming the 3-dimensional distribution of artificial light within the art room.

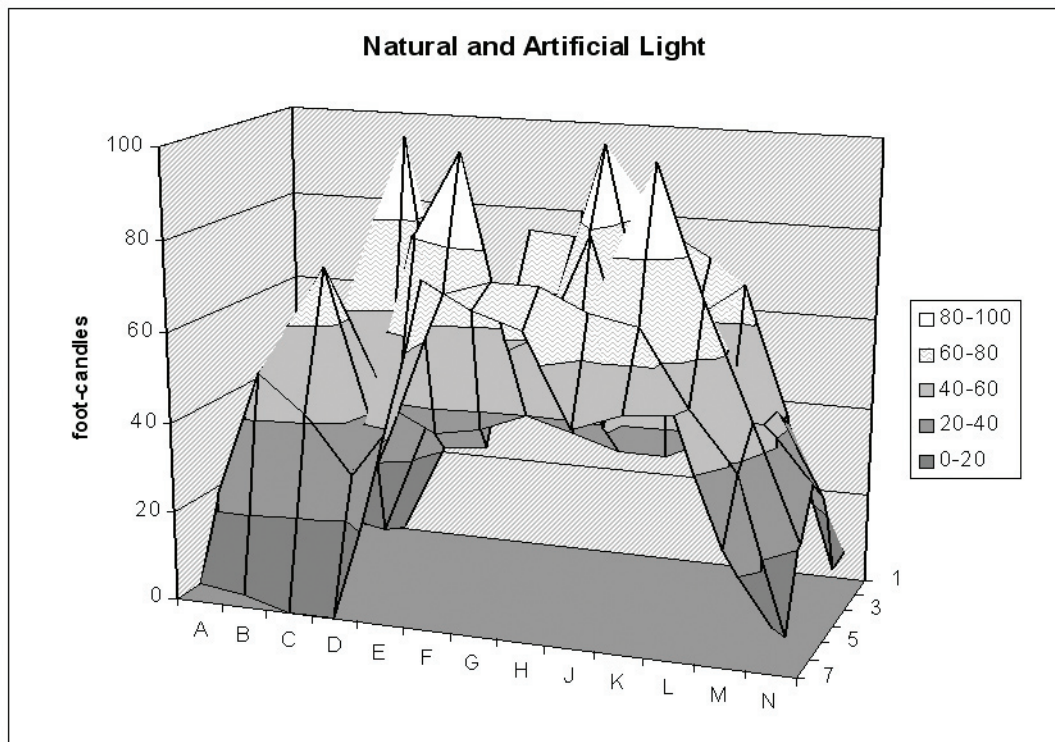


Fig. 7.3 - Chart diagramming the 3-dimensional distribution of natural and artificial light within the art room.

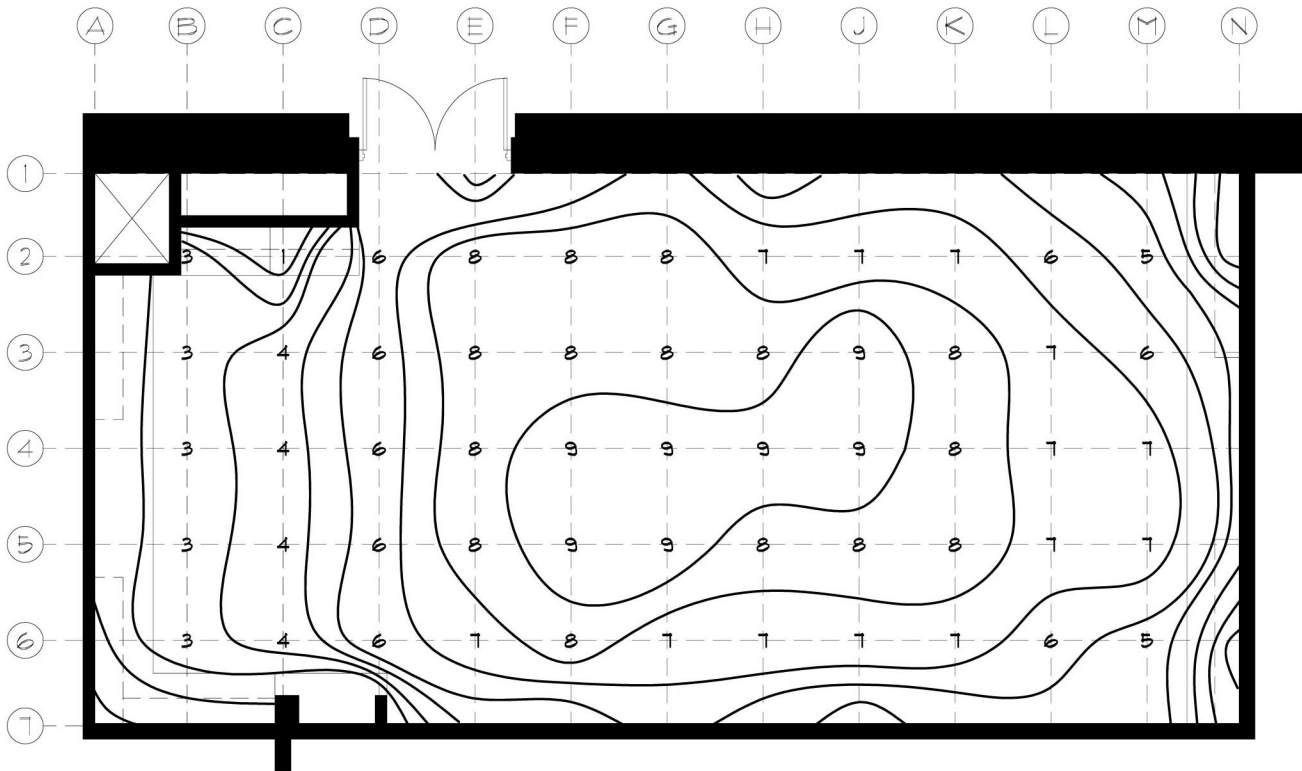


Fig. 8.1 - Isolux Plot - Natural Light

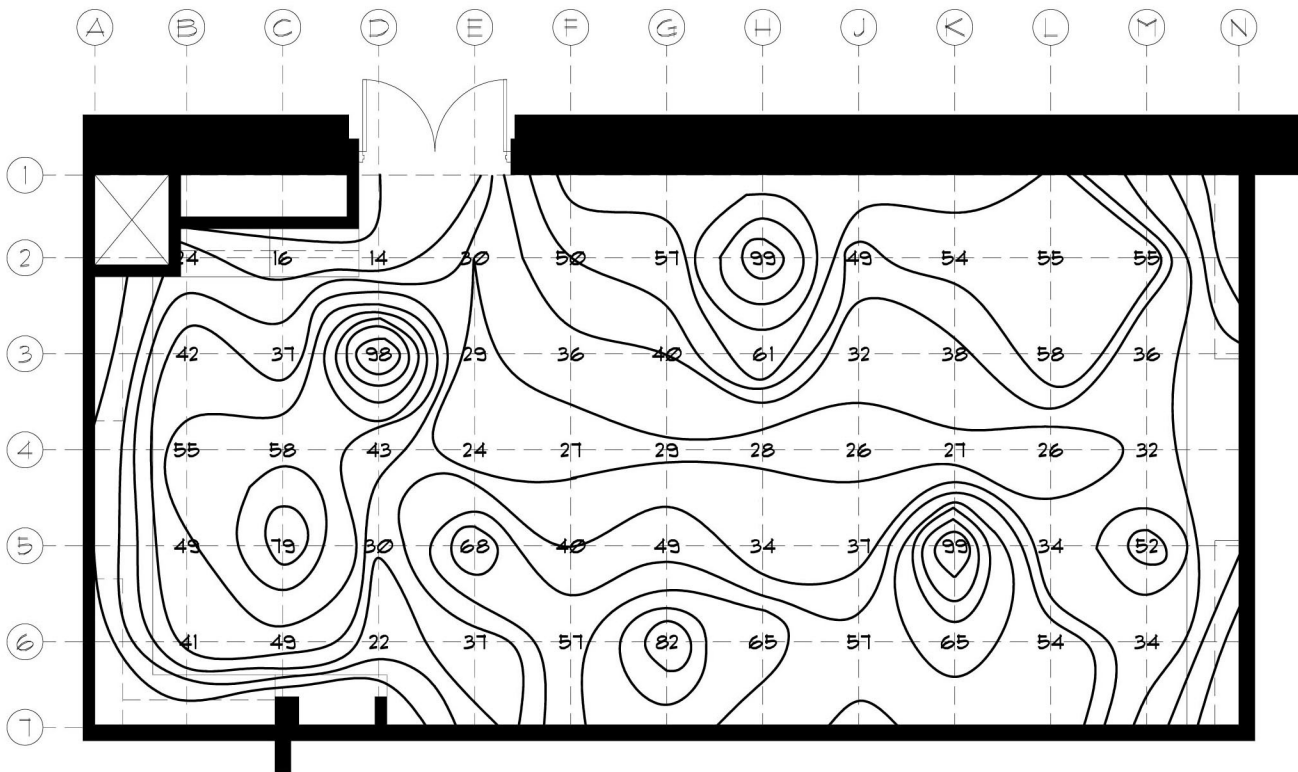


Fig. 8.2 - Isolux Plot - Artificial Light

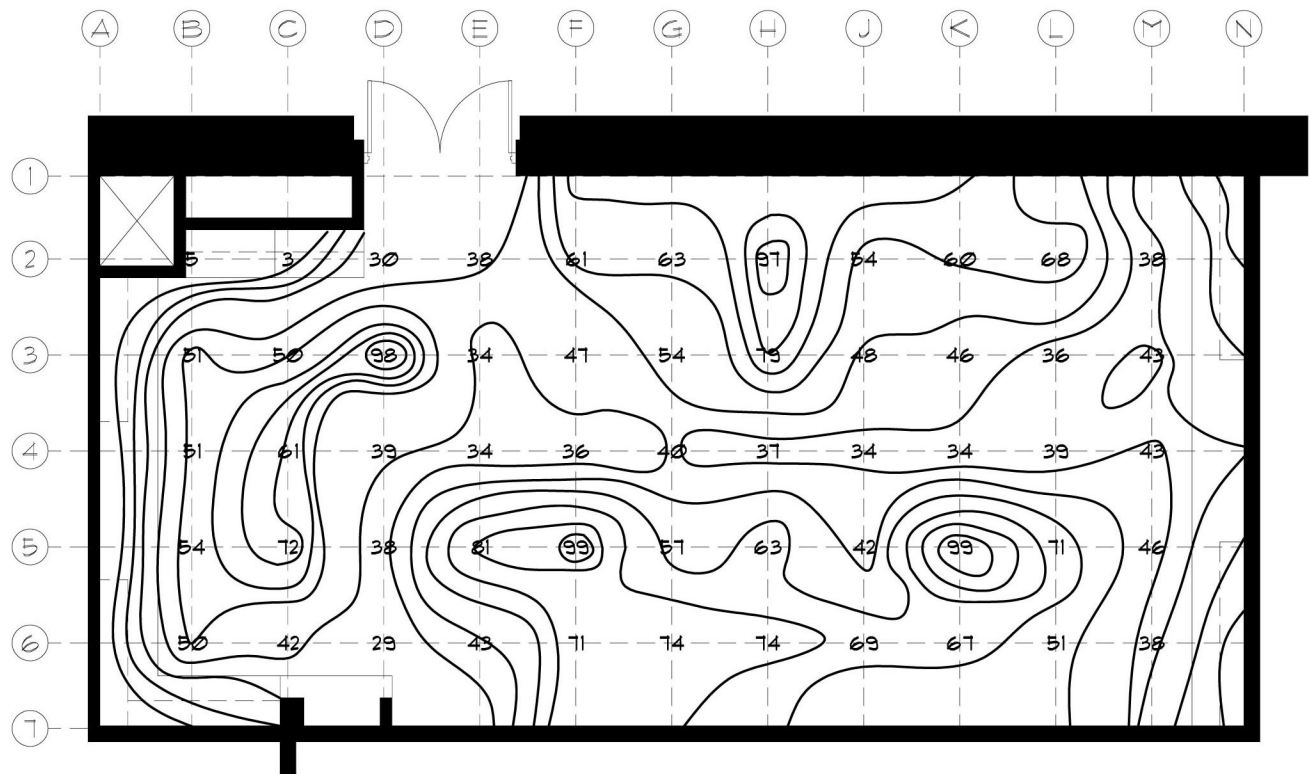


Fig. 8.3 - Isolux Plot - Natural and Artificial Light

## ISOLUX PLOTS

The team used data collected by the data illuminance meter recorded in figs 6.1 - 6.3 to create three isolux plots. These graphics (figs. 8.1 - 8.3) represent the distribution of light within the art room during the three defined conditions. Each isolux plot is formed by placing a contour line to represent an illumination value change. For the natural light plot, a change of 1 foot-candle is displayed. For the artificial light and the natural and artificial light plots, a value change of 10 foot-candles is displayed.

The natural light isolux plot demonstrates the relatively even distribution of natural light during the afternoon, although the values recorded are below the recommended values (see appendix B). In contrast, the other artificial light isolux plot displays a very uneven distribution of light ranging in values between 24 foot-candles to 100 foot-candles in the main student work area. The wide range of values is a result of the task lighting located on tracks around the room. These lamps provide very focused light aimed at student desks, creating hot spots on desks rather than evenly distributed light. The combination natural and artificial isolux demonstrates a similar situation as the natural light illumination only serves to raise the illumination values in the center of the room where there is no task lighting.

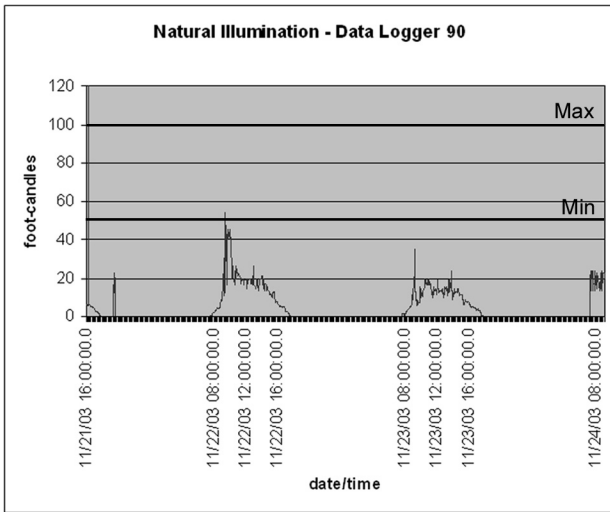


Fig. 9.1 - Foot-candle values at location 90 over the weekend

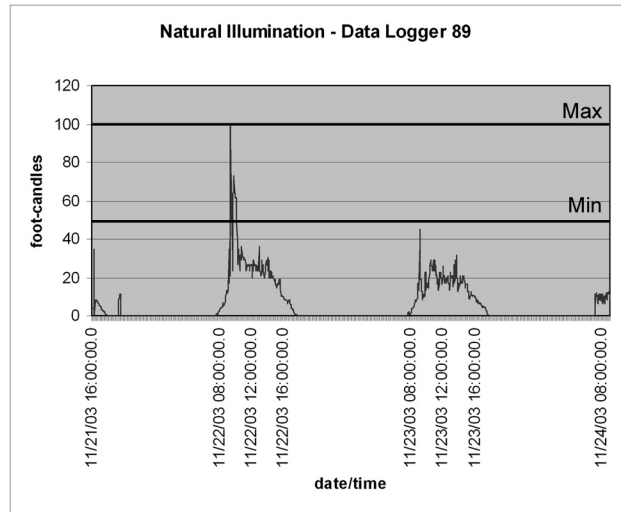


Fig. 9.2 - Foot-candle values at location 89 over the weekend

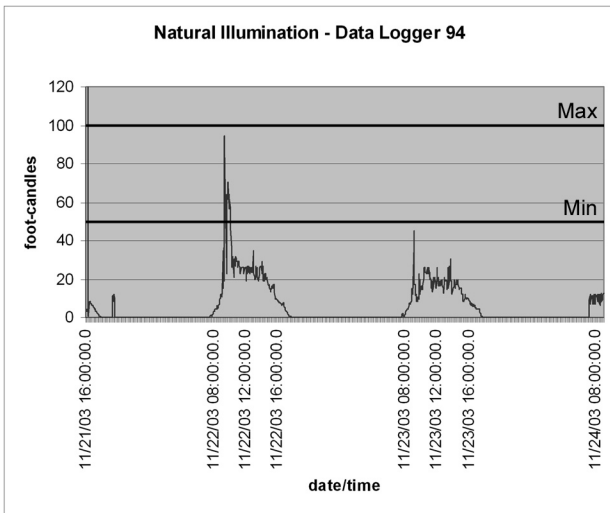


Fig. 9.3 - Foot-candle values at location 94 over the weekend

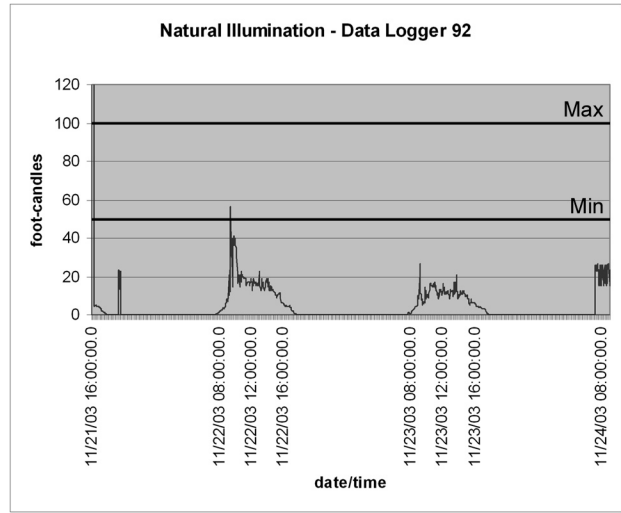


Fig. 9.4 - Foot-candle values at location 92 over the weekend

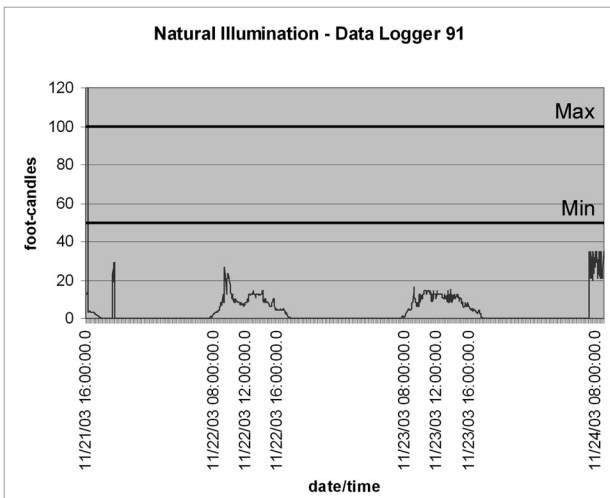


Fig. 9.5 - Foot-candle values at location 91 over the weekend

Above and Next Page: Figs 9.1 - 9.9 - Line graph charts displaying the adjusted data (see note below) collected by the nine hobo data loggers. Refer to fig. 9.10 keyplan for location within the art room.

Note: Values have been adjusted for natural light. Hobo data loggers are calibrated for incandescent lighting. Each value collected by the data loggers was multiplied by 6 to display the correct daylighting value.

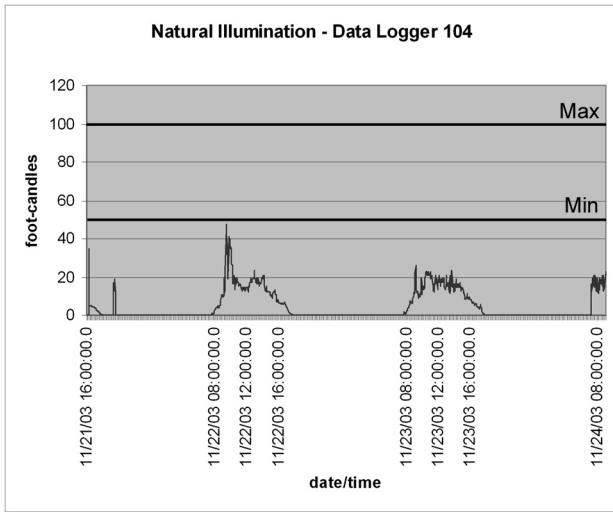


Fig. 9.6 - Foot-candle values at location 104 over the weekend

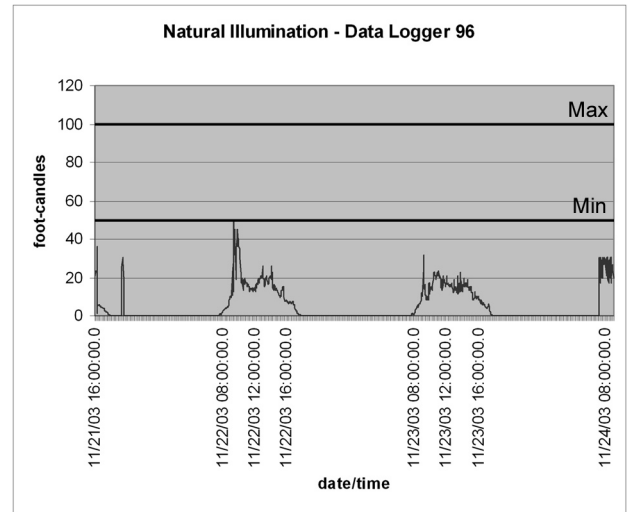


Fig. 9.7 - Foot-candle values at location 96 over the weekend

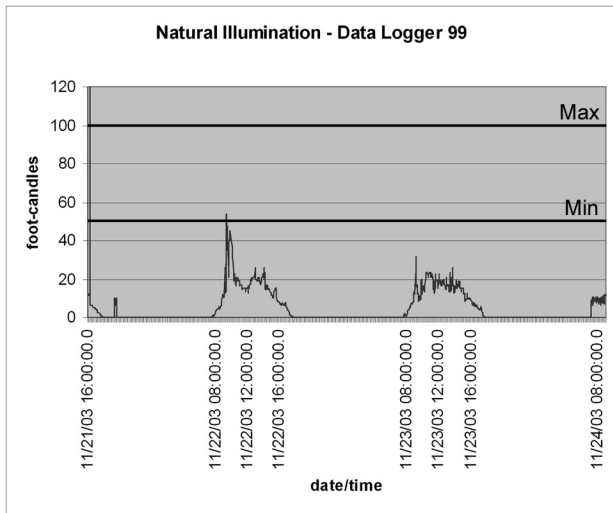


Fig. 9.8 - Foot-candle values at location 99 over the weekend

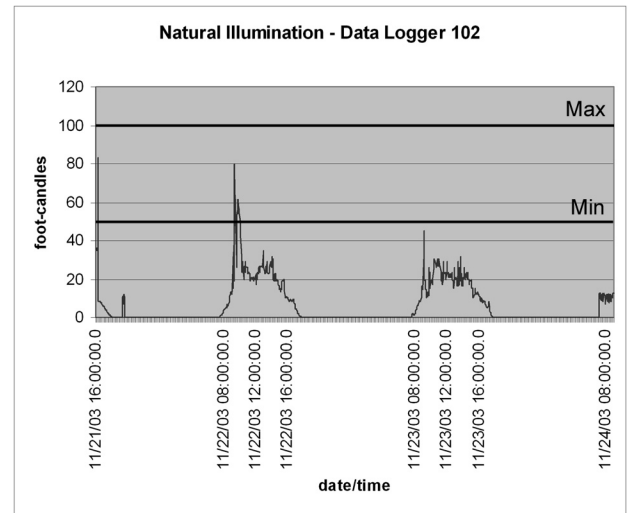


Fig. 9.9 - Foot-candle values at location 102 over the weekend

The line graph charts represent the illumination values within the art room between 4:00 pm Friday and 8:00 am Monday. They display the change in lighting levels within the art room throughout the day. On each graph, the max and min lines (shown as the dark horizontal lines) represent the suggested values in foot-candles for the performance of visual tasks of medium contrast: values between 50 and 100 foot-candles (see appendix B). These graphs demonstrate that during the autumn months, there is only a limited time in the morning during which natural light provides required illumination levels for art tasks.

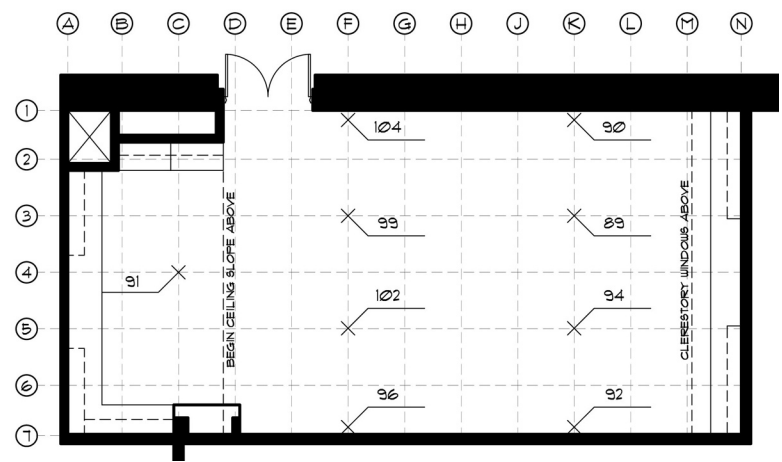
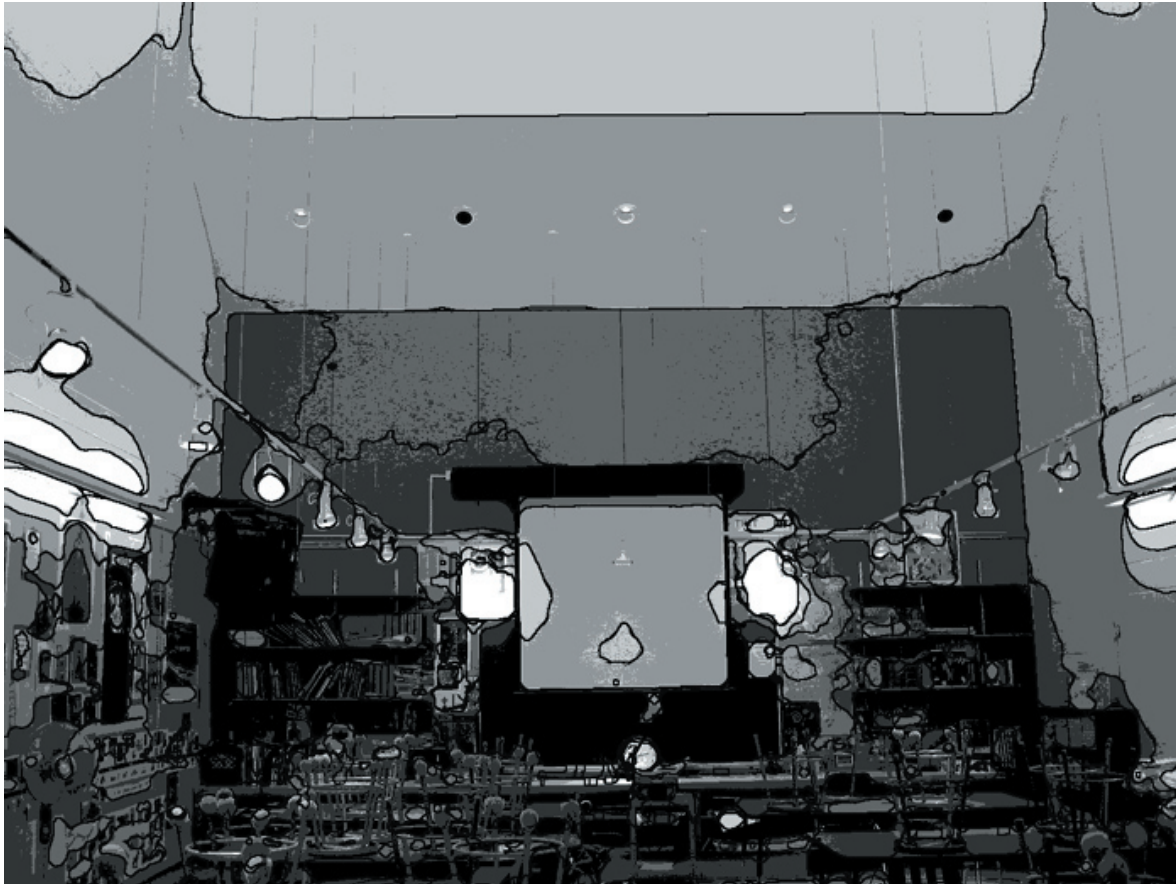


Fig. 9.10 - Keyplan displaying hobo datalogger placement



Above - Fig. 10.1 - Visual field map displaying lumination of surfaces within the art room. Note: Contour edges of fig. 10.2 added for clarity.



Fig. 10.2 - Photograph of eastern wall of the art room

Next page - Fig. 10.3 - Visual field map displaying values in foot-lamberts or lumens per foot of the art room.

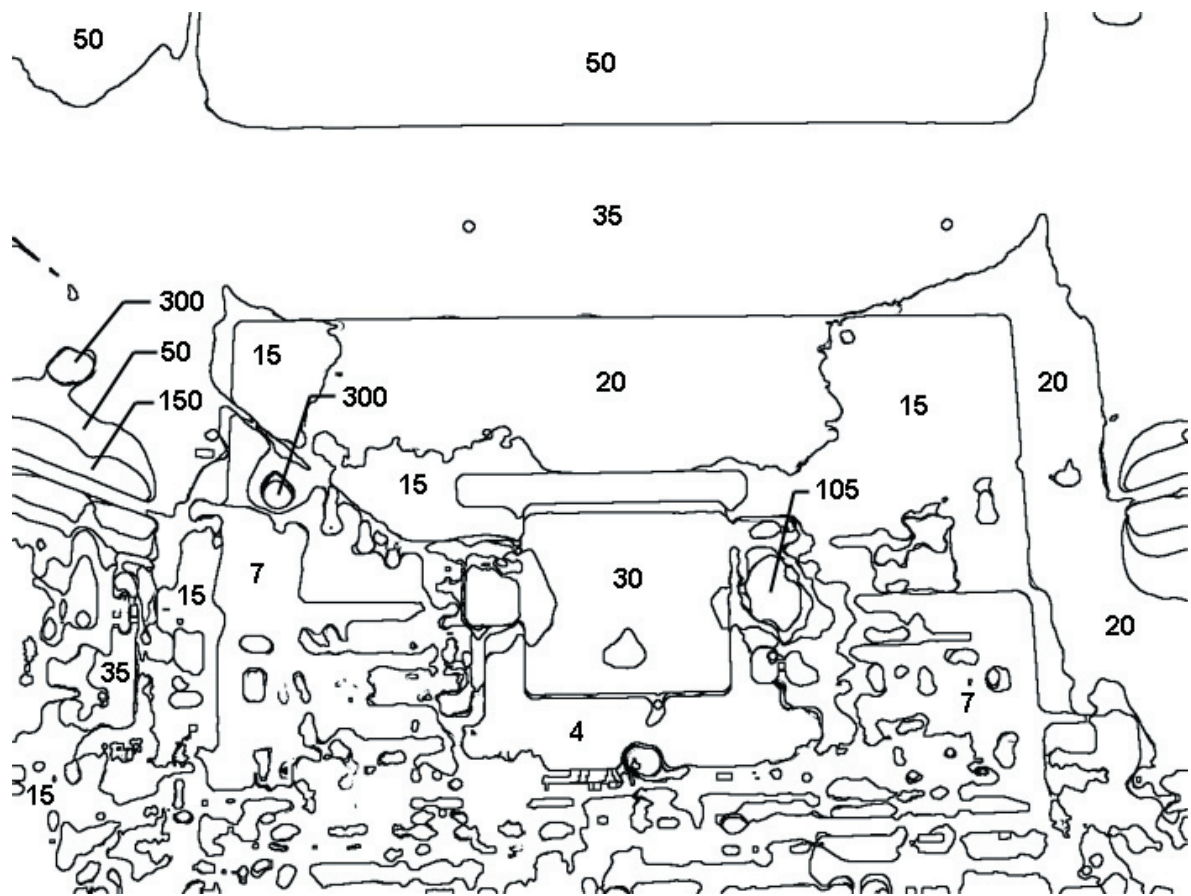


Fig. 10.3

## VISUAL FIELD MAPS

The research team also prepared a visual field map analysis based on Foot-Lambert measurements taken with the Minolta Luminance Spot Meter. The data were collected based on full lighting within the space from the natural and artificial light sources. Each area was targeted for measurement based on the visual field map created from photographs of the room. The values were then placed within the map. This map, shown above as fig. 10.3 diagrams the brightness of the surfaces on the east wall within the room. From the diagram above and fig. 10.1 on the facing page, the team noticed that several of the incandescent lights located on the track suspended from the ceiling create visually impairing glare for a student looking forward.

In addition to the graphic above, the team took several measurements of the ceiling to evaluate the luminosity of the largest surface within the space. The ceiling is white and reflects the light from the clerestory window and distributes it within the space. The values range from 23 fL at the top of the sloped ceiling to 50 fL at the approximate midpoint of the ceiling, down to 17 fL along the lowest edge at the south end of the room. (Note: Ceiling luminosity not represented in visual field maps.)





## CONCLUSION

After completing the investigation of the W. D. Richards Elementary School's art room, the research team came to some conclusions about the lighting characteristics of the space. These conclusions are based entirely upon an analysis of the research completed during the three phases of the investigation.

The recommended illumination values for various tasks used by this team can be found in Appendix B. An art room may have a wide variety of tasks performed within the space. As a general rule, it would be appropriate to have illumination of 50-100 foot-candles for performing visual tasks of small size and medium contrast. In addition, it would be advisable for a classroom to have adjustable light for performance of tasks which may not require the same amount of light.

The art room does provide the needed illumination for the tasks that are to be performed. The illumination provided at the height of the student desks by the track lighting is 100 foot-candles. Based on the data collected within the room and the isolux plots in figs 8.2 and 8.3, it can be seen that the foot-candle values within the work area are generally between the recommended 50-100 foot-candles when artificial lighting is provided. The exception to this is the center of the room where values are between 30 and 50 foot-candles. The children's desks, however, are all located around the perimeter of the room, underneath the track lighting.

The research team also observed that the natural light entering the space is not enough to provide even a minimum value of 50 foot-candles. The data collected by the data loggers, as seen on the line graphs (fig. 9.1 - 9.9) demonstrate that on sunny days of the autumn months, during the morning hours, the illumination of the room can fall within the recommended range of 50-100 foot-candles, but only for a short period of time before dropping and leveling off below the recommended level.

We conclude that the natural lighting within the art room is sufficient to provide for personal orientation and light for occasional visual tasks (see Appendix B). Understanding the limitations in amount of light and the time of day that light is provided, designers chose to incorporate the use of supplemental lighting found in various forms (see figs 5.7 - 5.13). The various light fixtures can be turned on and off to adjust the required lighting for the various tasks. The light fixtures can be used in conjunction with the natural light entering the space to provide the most efficient use of energy for the space, customizing and adjusting the light in the space depending on the task being performed at any given time.



## RECOMMENDATIONS

The research team arrived at several conclusions based on the evaluation of the art room. Primarily, it was observed that artificial light must be provided within the space to provide the recommended illumination for the space and its functions. The brightness of the ceiling ranged from 17 fL to 50 fL. This provides evenly distributed daylight over the workspace of the room, but does not provide the recommended foot-candle values into Appendix B. The designer understood the necessity for more light within the space and supplied several sources of light and the ability for the users to modify the lighting levels within the room using the seven switches that operate the various light fixtures.

The primary source of light for the students working on their projects is the suspended track supporting twenty-two incandescent bulbs. These fixtures provide the necessary light to achieve 100 foot-candles on the working surfaces of the room. Although they provide the necessary illumination, there are several problems with the fixtures.

The first problem uncovered by the team was based entirely on the experience of being in the space. It was observed that while the lights were on, the temperature underneath the lights at the desks was noticeably higher than when the lights were turned off. Therefore, the first recommendation would be to switch from the low efficiency heat producing bulbs to a lower wattage more efficient bulb that does not waste energy through high heat production.

The second problem uncovered by the team was that the illumination at the center of the room was much less than that near the walls. The primary reason for this is that the track lighting is located several feet off the perimeter of the wall. The light fixtures act as spotlights that provide the 100 foot-candle value over only a small percentage of the work plane. To counter this, the team recommends that the dimensions of the track be changed to center the fixtures over the workdesks. In addition, it would be beneficial to provide a luminaire that distributes the light over a larger area, thus eliminating the hot spot on the work surfaces.

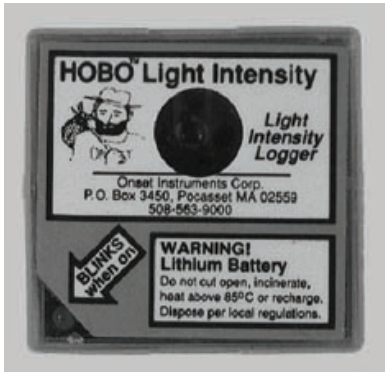
## APPENDIX A: EQUIPMENT

The HOBO (1.6" X 1.6") measures interior illuminance for a minimum of one minute or a maximum of 360 days. It has the capacity to store up to eighteen hundred measurements. A lithium battery provides power to the instrument for as long as two years. The unique computer interface of the device allows settings to be uploaded and measurements downloaded to DOS, Windows, and Macintosh programs. The BoxCar program which controls the measuring device allows remote launching and reading of illuminance levels. The time interval between each sample and the complete number of samples are options decided when uploading settings. Adjustments are made to the two options depending upon when light levels are deemed most critical for the experiment. Once measurements are acquired data is uploaded to the BoxCar program to compare exact light levels at varying times of day based on information gathered and placement of the device. Once data are downloaded, transferring the data to Microsoft-Excel or other spreadsheet programs allows straightforward comparison of illuminance levels in a chart or graph format. The recorder is also able to withstand extreme temperature conditions of negative forty degrees Celsius to seventy five degrees Celsius. The HOBO has a range of readings from .01-15,000 footcandles. The precision of the instrument is within .01 footcandles. The temperature dependency of the device is plus or minus 5%. The HOBO is partially cosine angle corrected, but it is not color corrected.

The G.E. illumination photometers are handheld manual illuminance meters. A partially cosine corrected meter allows more light to strike the reading surface to compensate for increased reflectance. This type of instrument commonly measures light on a horizontal plane. User error interference has to be taken into account requiring the user to be careful that light is not blocked by body parts that may interfere with the meter reading. The range of footcandles the device can measure extends from 0-10,000. Precision of the instrument varies from 20-200 footcandles. Accuracy of the piece of equipment extends from 10-15%. The G.E. light meter is cosine angle and color corrected. The handheld illumination photometers are the easiest way of making light measurements, but motionless devices are better for complete and dependable information.

The Sylvania Portable Digital Meter is a handheld meter with a liquid crystal display. It consists of a photovoltaic sensor with a photopia correction filter connected to an amplifier connected to an electronic display. This type of meter typically measures light anywhere within the 180 degree hemisphere, anything within the front of the meter characteristically covers 180 degrees of light. The Minolta meter measures a range between .01-100,000 footcandles. The precision of the gun is accurate to within .01 footcandles. The Sylvania Digital Meter is not cosine angle or color corrected.

Minolta's luminance meter measures the luminance (surface brightness) with a 1 degree acceptance angle, 9 degree field of view. The through-the-lens viewing system allows accurate data of the area to be measured. A microprocessor-based display offers a number of options for output (peak, max., response speed). The meter has a sighting feature, LCD display and a 0.001 to 299900 candela/sq meter range. A screw hole is located at the bottom of the handle for tripod mounting. The optical system reduces flare so measurements are unaffected by light sources outside the viewing area. The silicon photocell measure light received by the lens and is filtered to closely match the CIE Relative Photopic Luminosity Response. The signal from the sensor is processed by the built-in microprocessor, and measure values are displayed in four digits in both the external display and view-finder display. The peak measurement taken while the trigger is held in can be displayed, and a color correction factor can be used to automatically adjust the response of the meter when measuring colored subjects, or using close up lenses to measure small objects. In addition the meter has a digital data output terminal for sending data to the data computer or a separate computer.



Hobo Data Logger



Sylvania Light Meter



Minolta Luminance Meter

## APPENDIX B: DATA

Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors			
Type of Activity	Illuminance Category	Ranges of Illuminances	
		Lux	Footcandles
<i>General lighting throughout spaces</i>			
Public spaces with dark surroundings	A	20-30-50	2-3-5
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20
<i>Illuminance on task</i>			
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200
<i>Illuminance on task, obtained by a combination of general and local (supplementary) lighting</i>			
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000

Courtesy of Illuminating Engineering Society of North America.

Fig. B1 - Recommended illumination values for activities within interior spaces.



