W.D. RICHARDS ELEMENTARY SCHOOL: COMPUTER LAB LIGHTING STUDY COLUMBUS, IN

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05/05/04

VITAL SIGNS VIII
CENTER FOR ENERGY RESEARCH, EDUCATION, SERVICE

BALL STATE UNIVERSITY
COLLEGE OF ARCHITECTURE AND PLANNING
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Cover Image: Richards Elementary School: Computer Lab

CASE STUDY PARTICIPANTS:

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Jeff Culp…………..…Operations Manager, Adjunct Professor
Robert Fisher………..Resident Fellow, Professor of Architecture

Melisa Callahan…….CERES Secretary

A special thanks to Mrs. Ercell Cody, Principal of Richards Elementary School and the entire faculty of the school for their cooperation and assistance during this case study.

FIG. 0.1 Center for Energy Research/Education/Service
Ball State University

CONTENTS

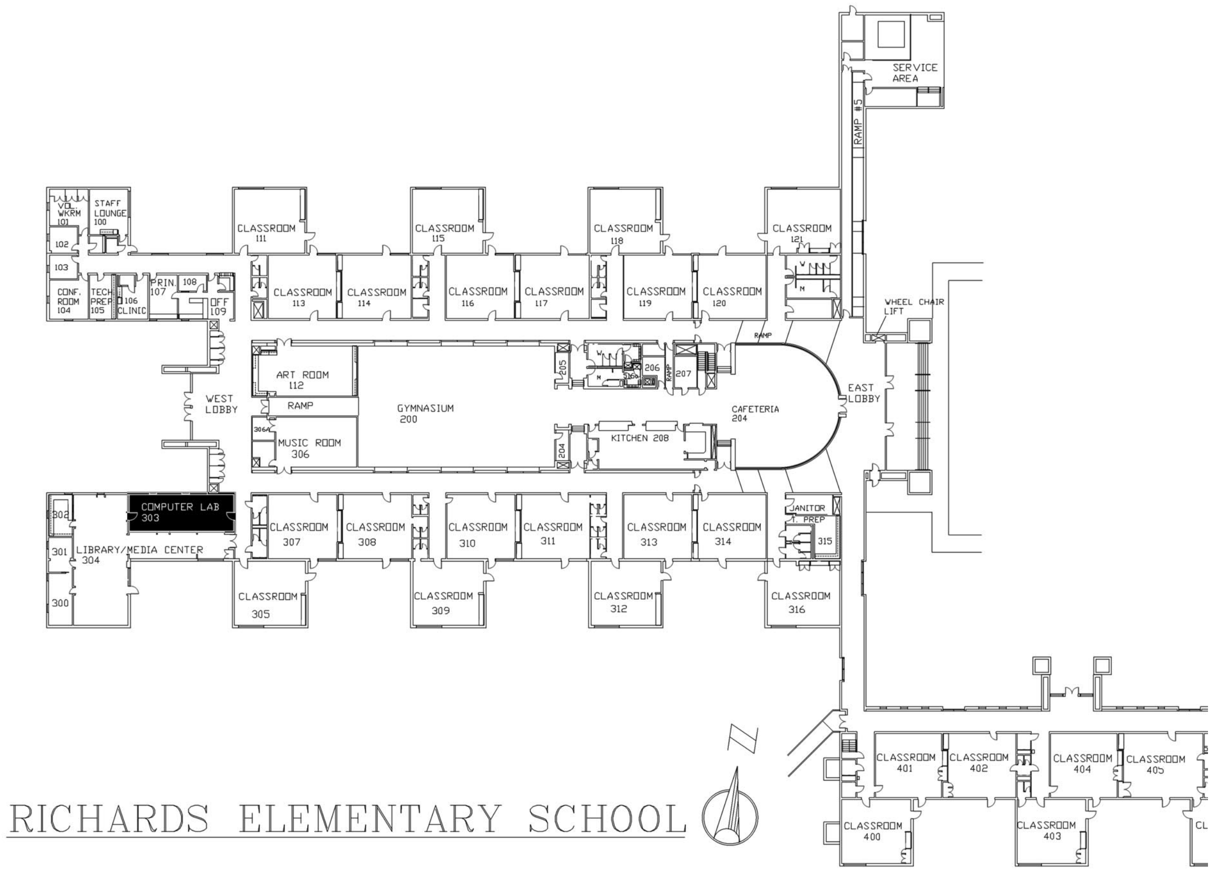


FIG. 0.2

Richards Elementary School: Ground Floor Plan

ABSTRACT

The following report describes a semester long study of the lighting characteristics of the computer lab at the W.D. Richards Elementary School in Columbus IN, the study was conducted by Michael Pardek and David T. Osterday in conjunction with the faculty of CERES at Ball State University. This was a study of the success of the existing lighting system within that computer lab. During the course of this study we used several diagnostic instruments to gather and analyze data pertaining to the lighting system. Both real time and time elapsed measurements were made. The measurements helped us in determining the visual effectiveness and comfort of the space

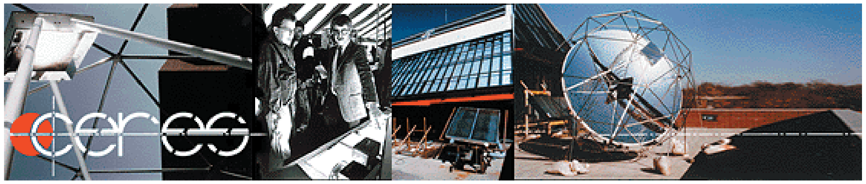


FIG. 0.3 Image source: http://www.bsu.edu/provost/ceres/ceres

VITAL SIGNS BACKGROUND

[Excerpt from *http://www.bsu.edu/provost/ceres/vitsi/index.html* *http://arch.ced.berkeley.edu/vitalsigns/Default.html*]

This university-wide program is designed for students with outstanding academic records, capable of bridging disciplinary interests and with a commitment to learning about the emerging field of environmental assessment. Using the nationally-developed Vital Signs curriculum materials, CERES Student Scholars develop environmental assessments of internationally recognized architecture, drawing on works in Columbus, Indianapolis, Muncie and the surrounding region. These case studies serve as prototypes for faculty and students employing the Vital Signs techniques throughout North American schools of architecture.

The interdisciplinary teams of students participating in this program work under the direction of faculty staffed through CERES. In addition, nationally recognized experts from around the country provide lectures and consultation to the student teams. The program adds to the technical and experiential credentials of participating students. As environmental issues continue to be of concern and as technical means for environmental assessment increase, substantial experience in this area can augment mainstream degree pursuits. An important lesson in this program is learning to work collaboratively across disciplinary lines. Whether students are pursuing a degree in life sciences, physical science, humanities, the arts, applied technology, business or the design professions, each has a role to play in the field of environmental assessment.

FIG. 0.4 Image source: http://arch.ccd.berkeley.edu/vitalsigns/

PROJECT BACKGROUND

This case study took place in the eighth installment of the Vital Signs program at Ball State University. It marked the return to Columbus, Indiana after 5 years of study in the cities of Indianapolis and Muncie. The city of Columbus is nationally recognized for its impressive collection of modern architecture and for its collaborations with A-list architects such as: Eliel and Eero Saarinen, Richard Meier, Harry Weese, and I.M. Pei.

Richards Elementary School, designed by Edward Larrabee Barnes, was constructed in 1965 following the traditions of innovative design and modernity established in this progressive city. The school is designed to allow for classroom spaces, corridors, and the gymnasium, to be illuminated predominantly by the light of the sun. Light clerestories (fig 0.5) are used to capture and direct light into the building.

However, not all spaces at Richards elementary use the benefit of the clerestory technique. The computer lab carries a different set of considerations for lighting requirements that does not necessarily lend itself to the daylighting principles used throughout the rest of the school.

FIG. 0.5 Richards Elementary School: Exterior View

RESEARCH METHODOLOGY

The focus of our study at Richards Elementary School, located in Columbus Indiana, was the Computer Lab. The first goal of the study is to determine whether the existing light levels reach approximately thirty foot-candles at a given surface for particular tasks, such as: viewing the computer monitor, viewing the projection screen, reading hardcopies, and writing. The second goal was to determine if glare from the two north facing windows or three banks of overhead luminaries caused visual discomfort for the users of the computer lab. The investigation, dictated by the nature of the subject in question, takes into account the variability of existing lighting conditions based on the hours that the computer lab is used during a typical school day and is based on the variable lighting conditions that occur throughout the school year. After determining that existing conditions met the established light level standards, we decided that additional architectural intervention was not needed.

We first visited Richards Elementary on September 9, 2003 to perform indicative research. We made general surface level observations, involving no instrumentation but including general photography of the school. Upon returning we then chose a specific space inside of the school to investigate further, the computer lab. We then formulated a hypothesis and proposal for investigative research. Returning to Richards Elementary School in mid October we used instrumentation to gather diagnostic information about the existing daylight and electric lighting conditions in the space, along with specific photos of the space, individual computer stations and their grouping. We then analyzed the information and contrasted it against our hypothesis.

FIG. 1.10 W. D. Richards Elementary School Computer Lab inventory

INDICATIVE RESEARCH

The first visit to W. D. Richards Elementary school included a tour of the general facilities so that we could understand the school and decide what space(s) to study further. We were also introduced to Mrs. O. Ercell Cody, Principal of W. D. Richards Elementary School; our main contact during the research process. While on the tour we took daylight factor readings, explored combinations of closed and open shading devices, took note of where skylights and windows were located, and photographed different areas of the building.

While on the tour we came across the computer lab, a small space connected to the library that is lined by computers on the north and south walls as well as one row of computer workstations in the middle. The lab is long and thin possessing only two (2) small windows located in the north wall. The computer lab, or media center as the Richards staff refers to it, is a place that is used on a daily basis by teachers and students in the educational setting. The computer is an important tool for teachers.

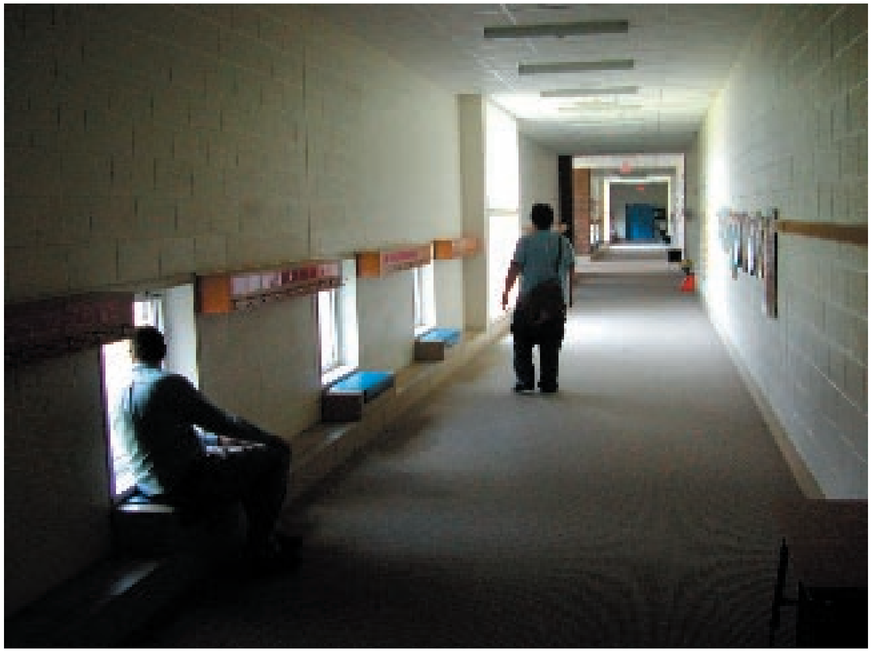


FIG. 1.11 View down corridor, looking South towards the newest classroom wing

Unlike typical classrooms found in W. D. Richards Elementary, the computer lab carries a different set of considerations for lighting requirements that does not necessarily lend itself to the daylighting principles used throughout the rest of the school. In our indicative phase of observation, we noted that the existing daylight levels in the space may not reach acceptable levels established by the Illuminating Engineering society of North America (IES) (fig 1.13). Investigating further, we hypothesized that the exclusive use of electric lighting would cause uncomfortable glare conditions in the work space. By gathering and analyzing information about the space we could determine if there is a need for architectural interventions in the space to meet the IES standard for daylight or electric light at a given surface, without any discomfort caused by glare.

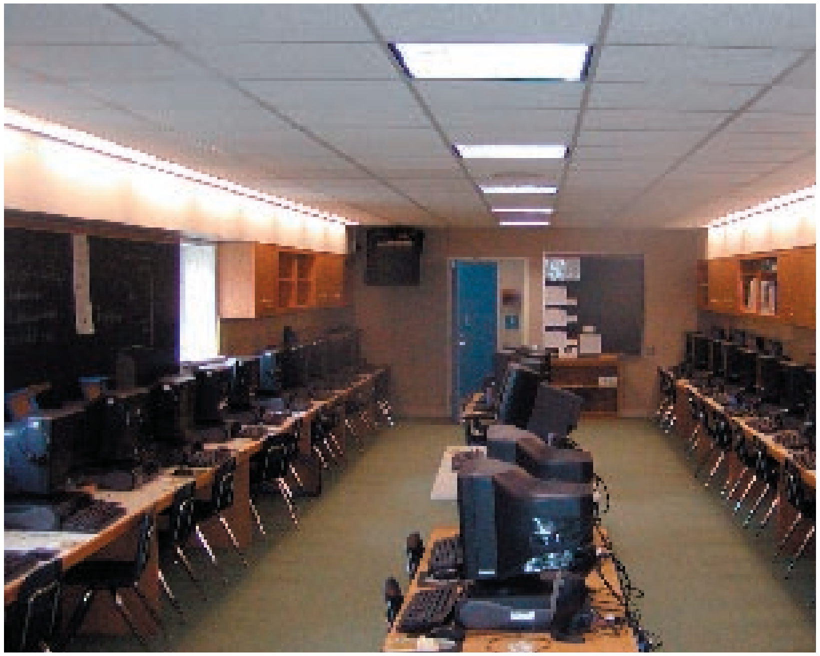


FIG. 1.12 W. D. Richards Elementary School Computer Lab looking East

HYPOTHESIS

The existing windows and luminaries, as sources of light, do not provide 30 foot-candles at 30 inches above the floor consistently throughout the space.

IES STANDARDS

IES standards are recommendations published by the Illuminating Energy Society outlining suggested ranges of illumination in foot-candles for specific tasks (Fig. 1.13). These are the guidelines for determining the validity of the hypothesis. The illuminance category for the computer lab according to the IES table is "D"; "performance of visual tasks of high contrast or large size". This means that the lab illumination should be in the range of 20-30-50 ft.candles at a given surface 30 inches above the floor throughout the lab. There is a complexity to the computer lab since there are both vertical and horizontal work surfaces. Adding to this dilemma is that the vertical work space is a light surface. At that vertical surface there needs to be a level of contrast without glare.

Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors

Type of Activity	Illuminance Category	Ranges of Illuminances: Lux	Ranges of Illuminances: Footcandles
General lighting throughout spaces			
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
Illuminance on task			
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
Illuminance on task, obtained by a combination of general and local (supplementary) lighting			
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. 1.13

INVESTIGATIVE RESEARCH

First, we established contact with the principal of Richards Elementary School to discuss possible dates and times when the computer lab would be accessible for our data collection. Through e-mail correspondence we came to an agreement on when to first arrive to place our instruments in the computer lab, take a sampling of photographs, take a few daylight readings, sketch, and gather physical measurements of the space. We wanted to arrive on a Friday at the end of the school day in order to create minimal inconvenience while we placed our measuring devices. Over the weekend we compiled the data we had recorded that Friday. We then prepared an itinerary for our next visit. Returning on the following Monday, we took further daylight readings, measured the reflectance values of the surfaces in the space within specified fields of view (computer stations), and gathered more photographic documentation.

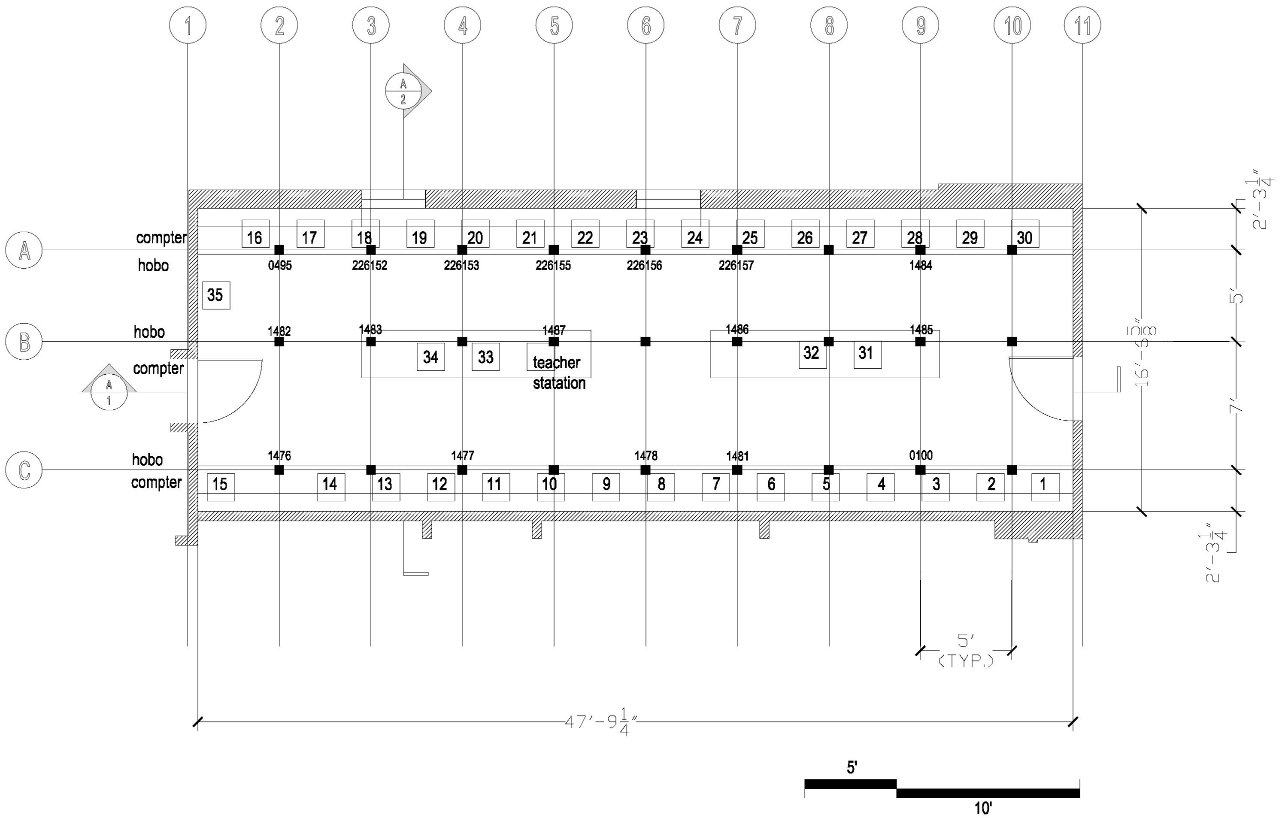


FIG. 1.14 Computer Layout and Corresponding Data Collector

SEQUENCING OF DATA COLLECTION PROCEDURES:

1. Existing day lighting conditions of the Computer Lab were measured at 30" above the floor.
   - A grid set at 5 foot intervals is established in the computer lab (see figure 1.14)
   - Hobos are placed on this grid, to collect data from 3:00 pm Friday the 14th until Monday the 17th at 9:00 am.
   - Collection for a total duration of 66 hours at 30-minute intervals.
   - All artificial luminaries are turned off for this portion of data collection.
2. Reflectance values of surfaces were measured
   - On Friday the 14th, Photographs are taken of the Computer Lab surfaces (see appendix B)
   - Photoshop is used to manipulate these images producing tonal images of the computer lab.
   - On Monday the 17th at Richard's Elementary the Minolta Luminance meter was used to measure the reflectance values present in the lab, based on the tonal areas revealed by the Photoshop image.
3. Detailed as-built drawings were aquired
   - On Friday the 14th we took a detailed inventory of all aspects of the Computer Lab was taken
   - We took into account all materials, dimensions, and relationships of objects within the Lab, paying special attention to relationships of objects, such as the computer monitors, to the existing luminaries and windows.

Computer Lab Section A2

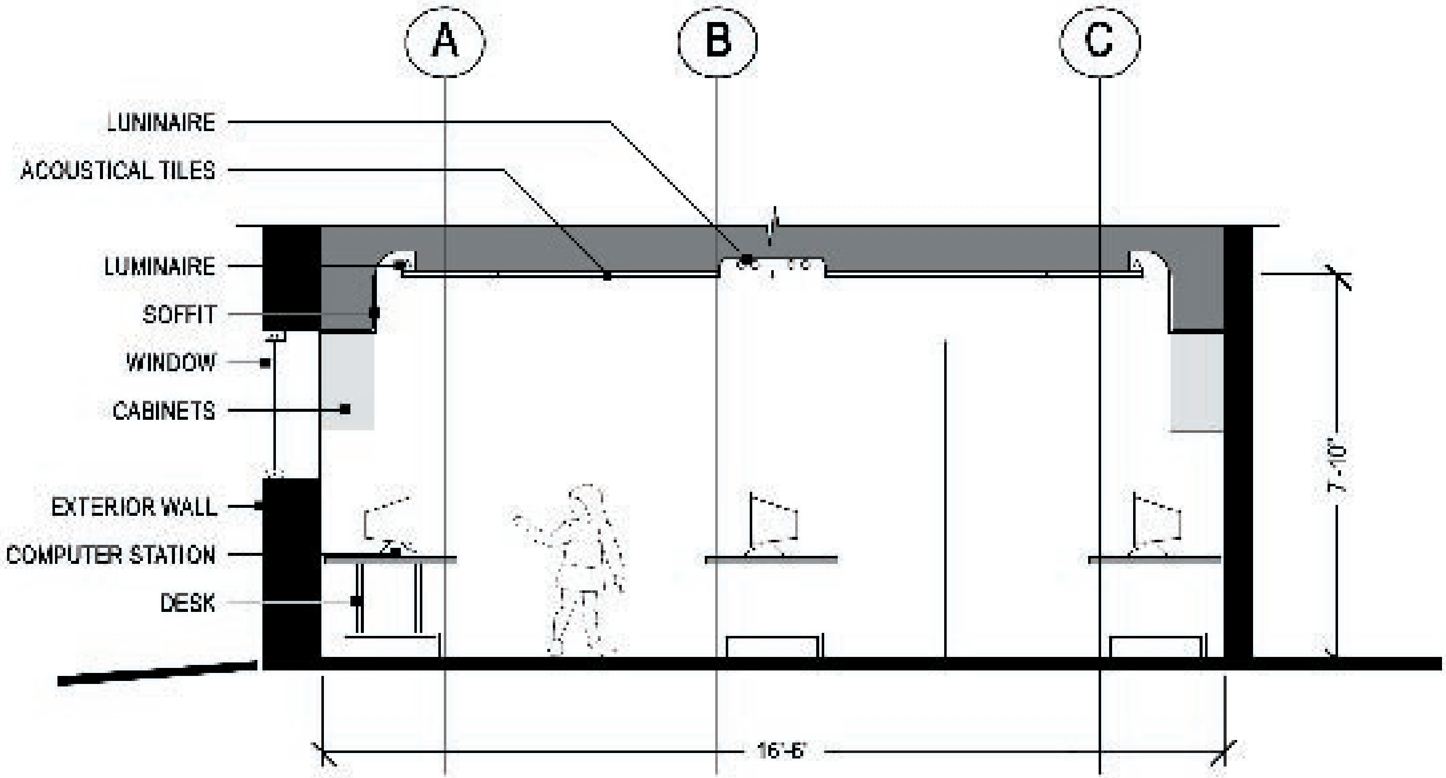


FIG. 1.15 Computer Lab Section A2 [looking east]

GLARE CONDITIONS

For purposes of data management we formulated an artificial grouping and referencing system.

(fig. 1.16)
This is the established numbering system at Richards Elementary School for purposes of identifying individual machines in the computer lab.

(fig. 1.17)
The first division we made in the system formulates "groups" for the workstations numbered one through ten. We select four "groups" (2, 4, 7, & 9) in order to study the variations of glare found throughout the lab.

Group 2 was selected to represent typical conditions found on the wall opposite the windows.

Group 4 was selected because it contained the swath with the worst glare conditions in the entire lab.

Group 7 was selected to represent typical conditions found on the exterior wall of the lab.

Group 9 was selected to represent typical conditions found for the workstations located in the center of the lab.

(fig. 1.18)
The "groups" are documented in elevation with a photograph. Each workstation now lies witin a vertical swath that takes on the established number system (see fig 1.16).

(fig. 1.19)
We documented all the materials in the lab and assigned them each a character (A through M).

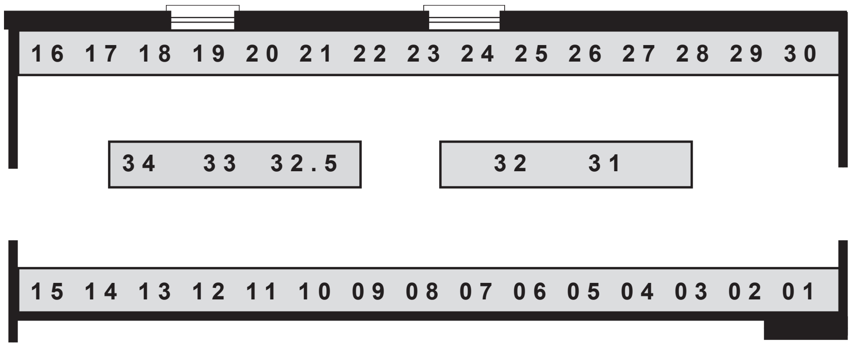


fig. 1.16

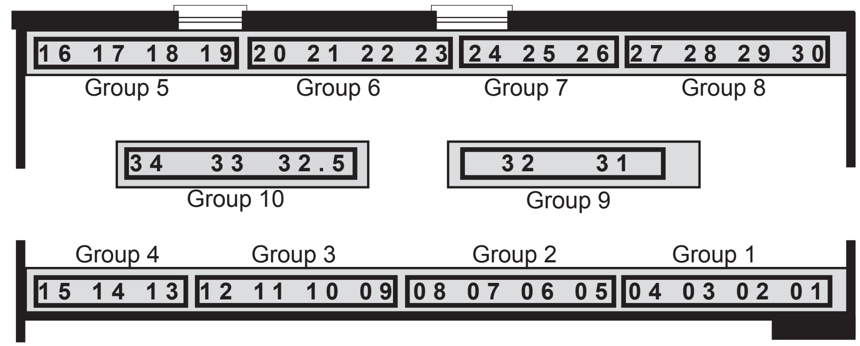


fig. 1.17

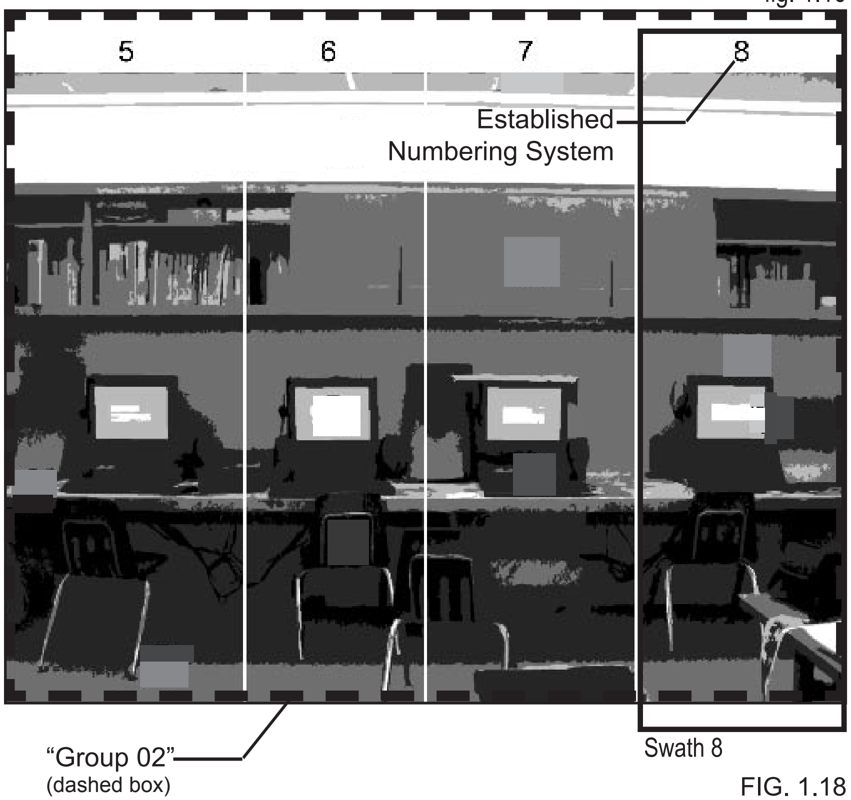


FIG. 1.18

Surface character	Description	Material
A	Header	Drywall, flat white paint
B	Cabinet	Lt.brown maple vaneer
C	Dry erase Board	White plastic
D	Desktop	Flat white veneer
E	Computer Monitor	Glass
F	Drop ceiling	White acoustical tile
G	Monitor Casing	Black plastic
H	Floor	Green burbler carpet
I	Chair	Blue plastic
J	Blackboard	
K	Window shades	White vinyl
L	Window	Double pain glass
M	Keyboard cover	Blue print on brown cardboard

FIG. 1.19 Materials Chart

(fig. 1.20)

For the sake of reducing the number of measurements, we measured the reflectivity of each material only once per “group”.

(fig. 1.21)

In order to achieve a random sampling of reflectivity values throughout the entire room we created a system in which the measurement point for any one material would shift one “swath” to the right.

(fig. 1.22)

Within the four “groups” that we studied, one monitor was selected for an in-depth study.

For three of the groups (2, 4, & 7) we choose a monitor that contained glare typically found within its “group”.

The remaining “group” was choosen because it contained the computer monitor with the worst glare in the entire lab. This was monitor 15.

(fig. 1.23)

After selection of a specific monitor (fig. 1.22) from a swath in a “group”, we investigaged the glare conditions within the field of vision.

(fig. 1.24)

We then isolated on the monitor screen to investigate veiling reflection; both with the power on and off. The glare conditions on each monitor were labeled using roman numerals.

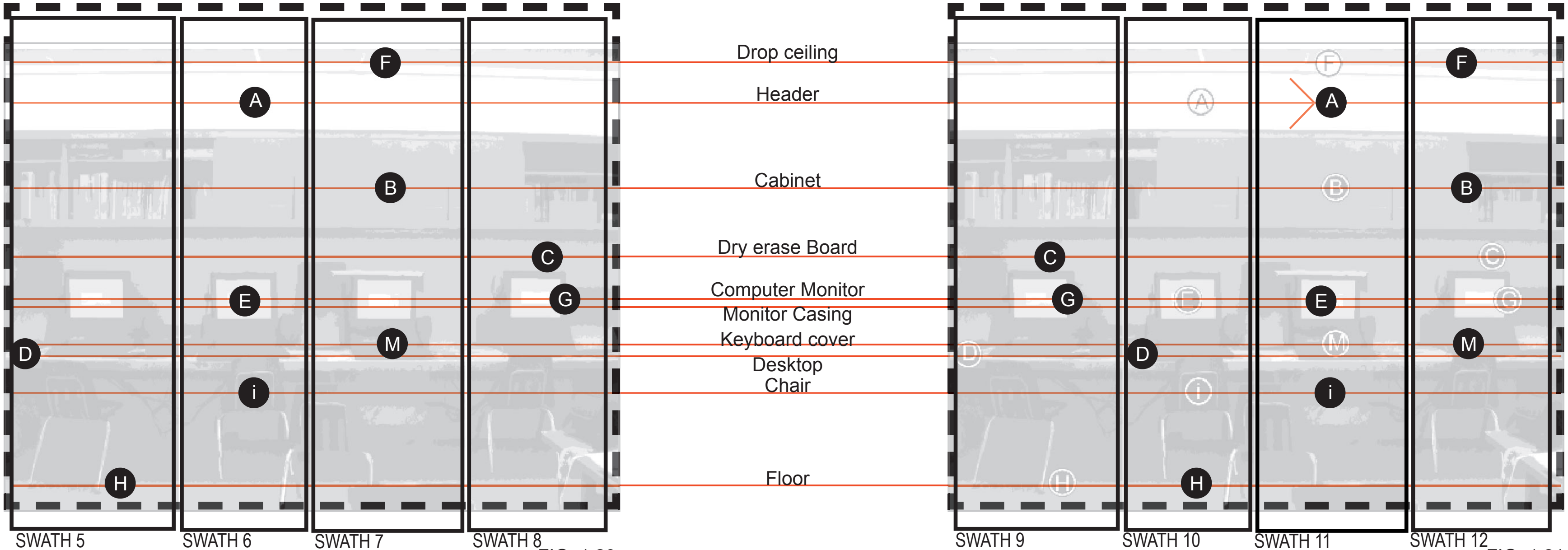


FIG. 1.20

FIG. 1.21

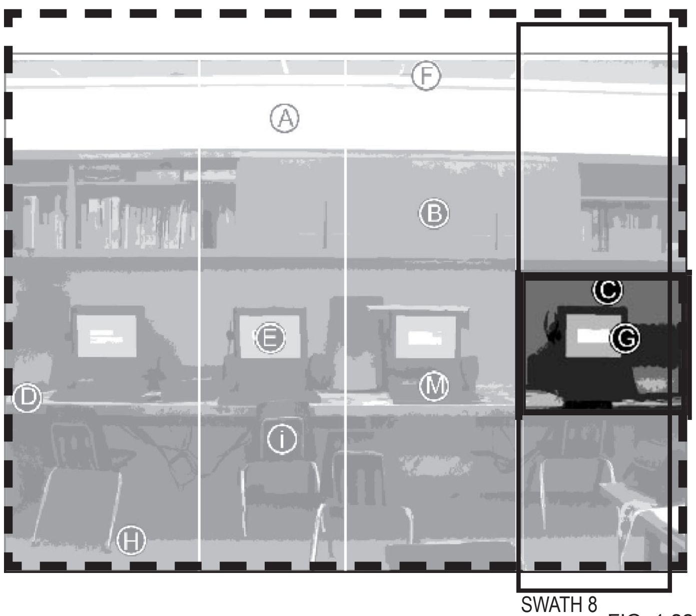


FIG. 1.22

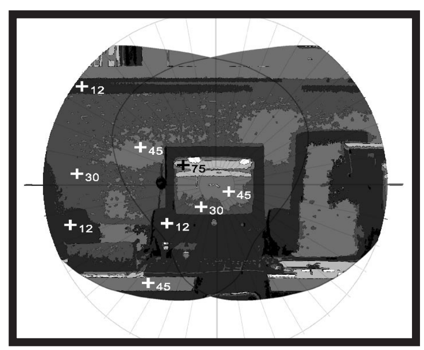


FIG. 1.23

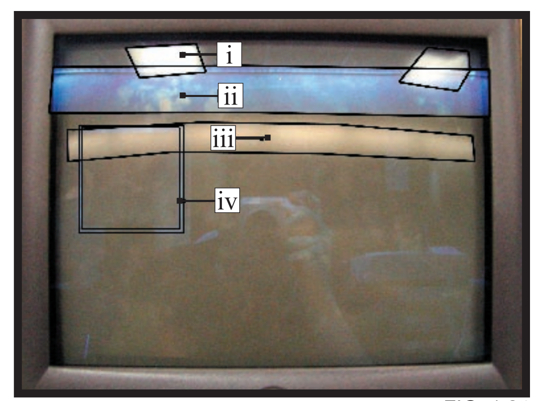


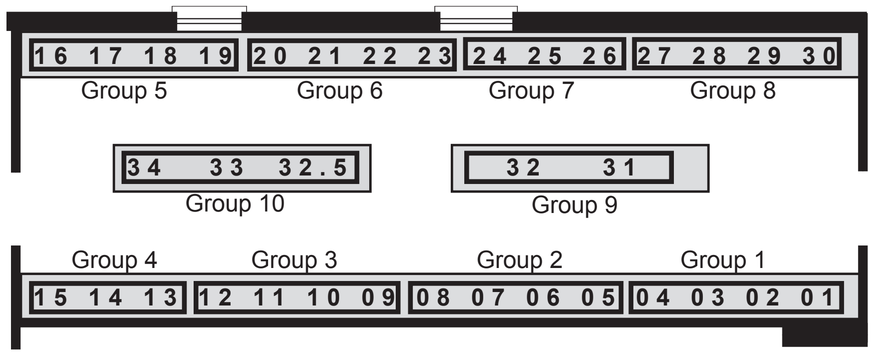
FIG. 1.24

OVERVIEW OF DOCUMENTATION

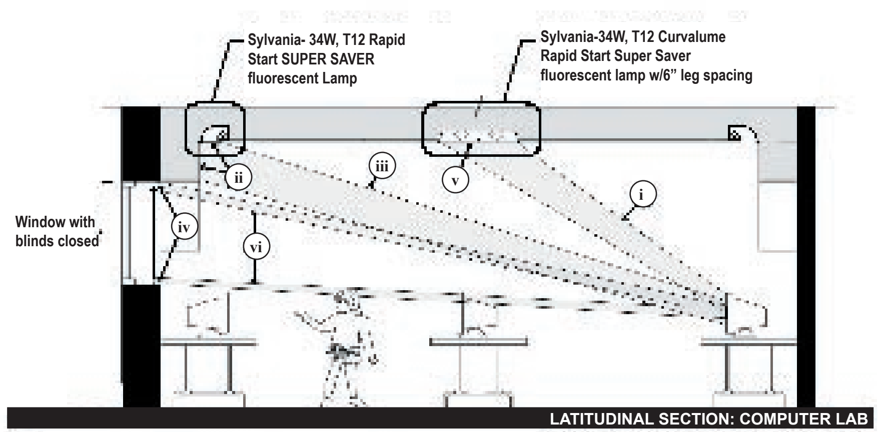
The following series of photographs document these measurement points of reflectivity, tonal values, and glare. All pictures were done with all luminaries in the computer lab turned on, and all window shades pulled down. This arrangement recognizes that this is the most extreme artificial lighting possibility, based on the idea that it is not feasible nor desirable to illuminate the computer lab using daylight methods. We determined that if the blinds were open, letting in daylight, that there would be an overwhelming amount of glare in the computer lab.

The tonal diagrams developed from the photographs show whether or not extreme differing quantitative values of light occur within a given students field of vision, creating undesirable glare conditions.

GLARE AND GROUPING LEGEND



Key Plan
FIG. 1.25



SOURCES OF GLARE
i- Light from luminaires reflects off computer monitor
ii- Luminaire and reflection off wall are mirrored off monitor
iii- Light from luminaires reflects of computer monitor
iv- Bright gaps between window frame and closed blinds are mirrored of monitor
v- Luminaires in ceiling is mirrored of monitor
vi- Light from window reflects of computer monitor

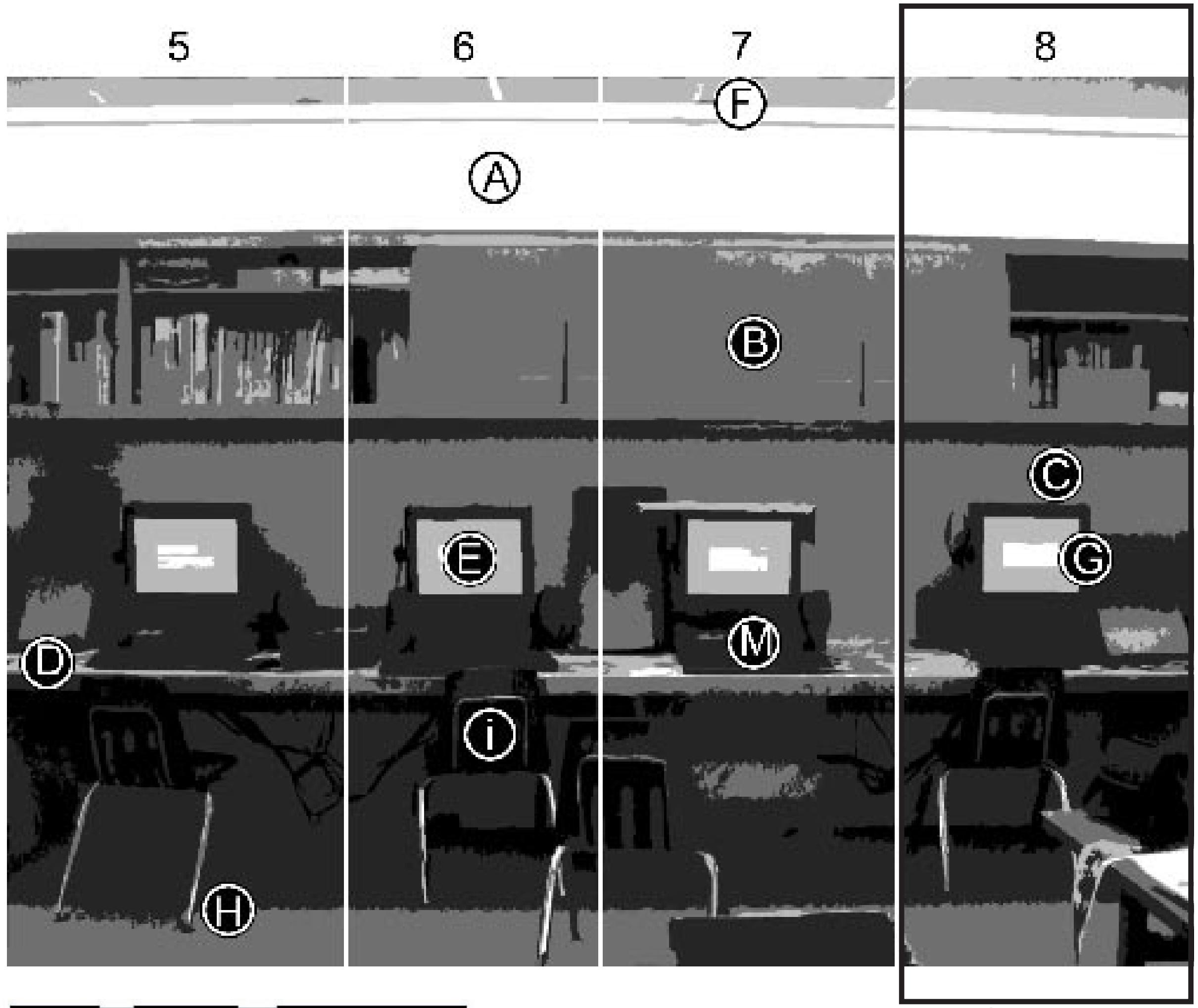
FIG. 1.26

	Group 2 [computer 5 - 8]		
	Computer	Surface	Luminance Value [ft.candle]
	6	A	84.8
	7	B	6.1
	8	**C**	**4.9**
	5	D	23.7
	6	E	35.0
	7	F	10.2
	8	**G**	**0.9**
	5	H	5.7
	6	I	0.7
	N/A	J	N/A
	N/A	K	N/A
	N/A	L	N/A
	7	M	4.0

TABLE 1

SURFACE MATERIAL REFLECTANCE VALUES:
COMPUTERS 5-8, GROUP 2.

This group contains the subject computer number 08. The specific surface materials measured for computer 08 are C, the dry erase board, and G, the monitor casing. Both of which have a low reflectance value, and not creating any glare.



SWATH 8

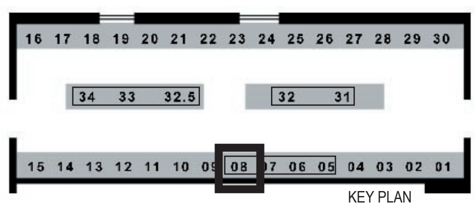


FIG. 1.27

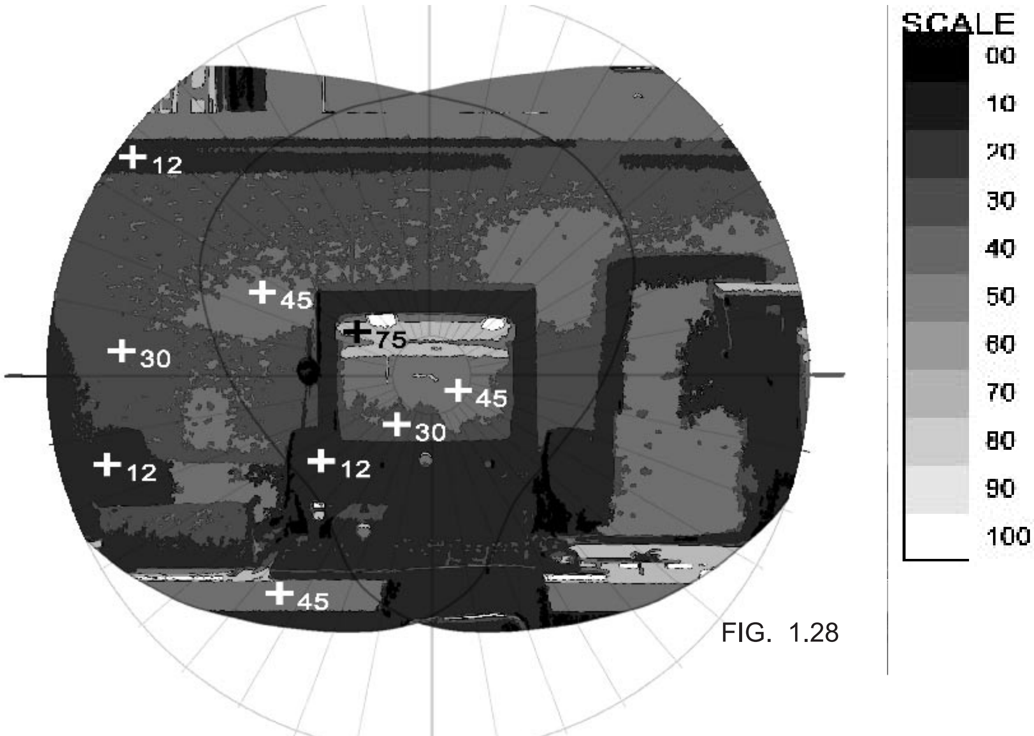
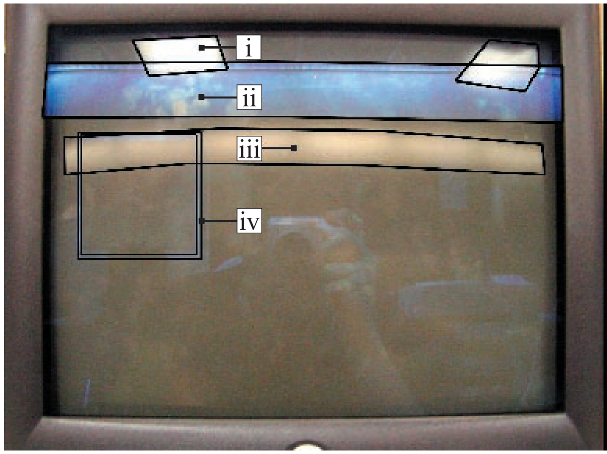


FIG. 1.28

GLARE WITHIN THE FIELD OF VISION

COMPUTER 08: IN-DEPTH INVESTIGATION OF GLARE



POWER OFF
FIG. 1.29

POWER ON
FIG. 1.30

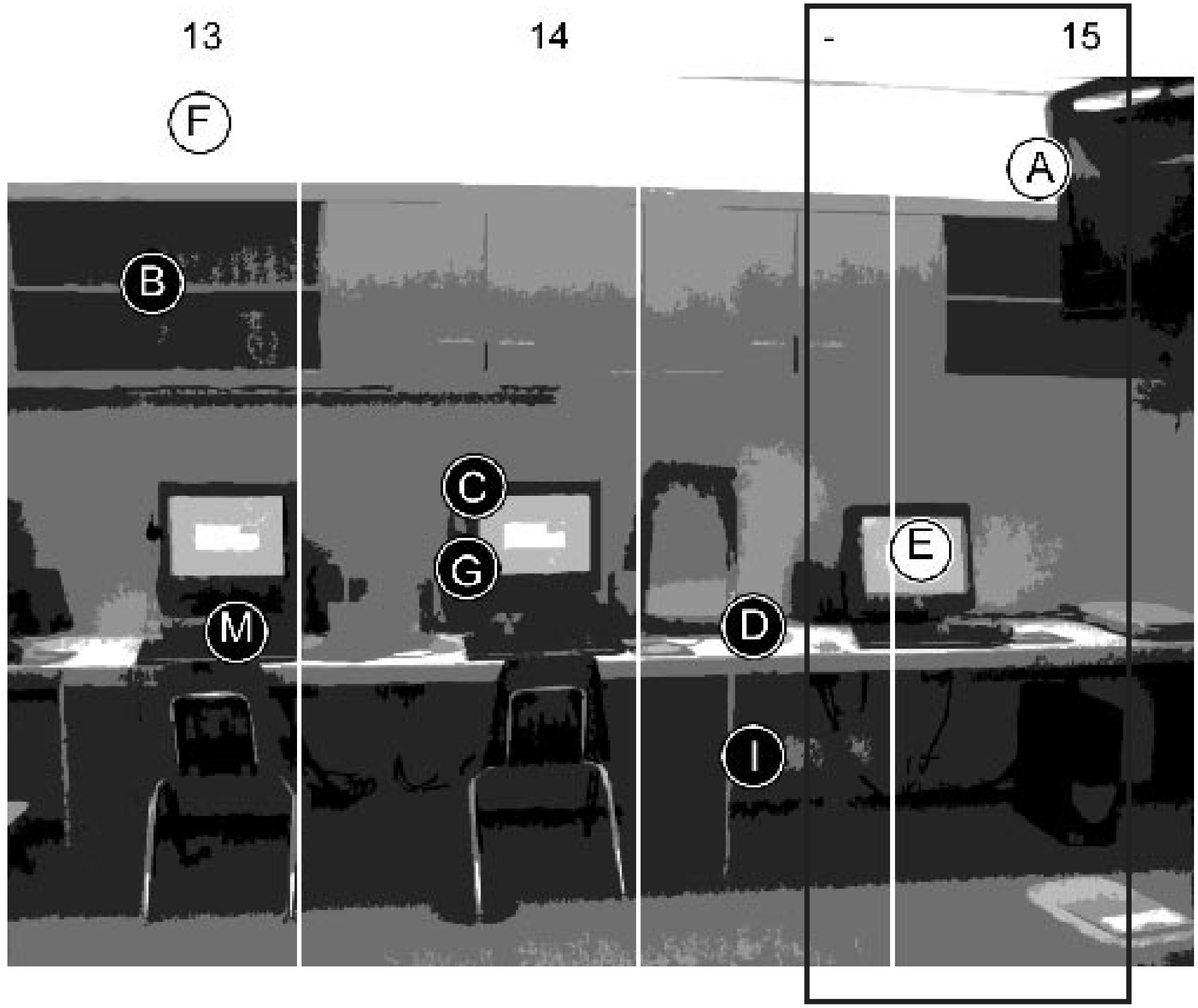
VEILING GLARE:

TYPICAL CONDITION FOR COMPUTERS 1-15

Computer 08 was chosen because of the presence of glare produced by three different sources. This was the one of the worst cases of glare we observed. The photo on the far left shows glare conditions i, ii, iii, and iv (fig. 1.26) occurring while the computer monitor's power is off. However, when the power is turned on, the glare is almost always eliminated, except for condition A.

Group 4 [computer 13 - 15]		
Computer	Surface	Luminance Value [ft.candle]
15	**A**	**79.1**
13	B	5.8
14	C	4.9
-	D	32.0
15	**E**	**34.2**
13	F	12.5
14	G	0.8
15	**H**	**4.7**
-	I	0.5
N/A	J	N/A
N/A	K	N/A
N/A	L	N/A
13	M	3.9

TABLE 2



SWATH 15

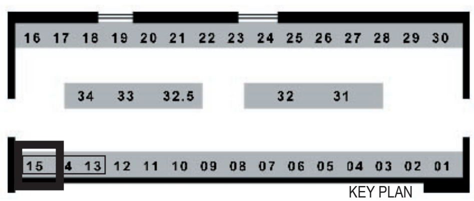


FIG. 1.31

SURFACE MATERIAL REFLECTANCE VALUES:
COMPUTERS 13-15, GROUP 4.

The specific surface materials measured for computer 15 are A, the header above the workstation, H, the floor, and E, the monitor screen. The header is the only material with a high reflectance value, which is inconsequential since the header is not in the field of vision while sitting at the workstation.

GLARE WITHIN THE FIELD OF VISION

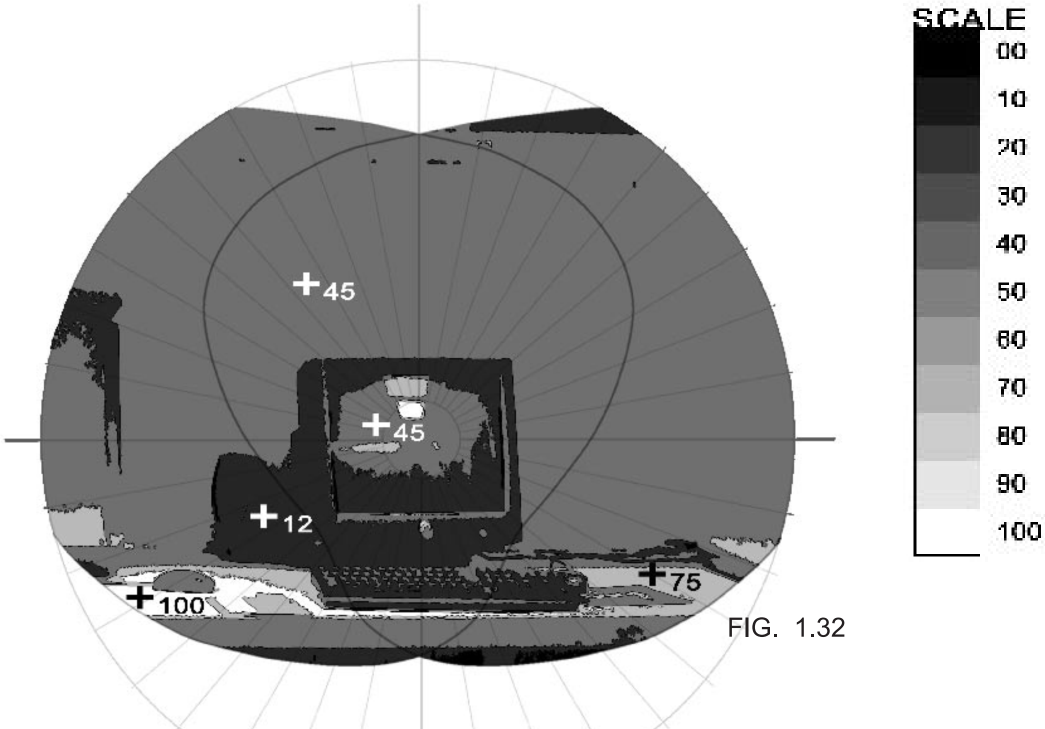
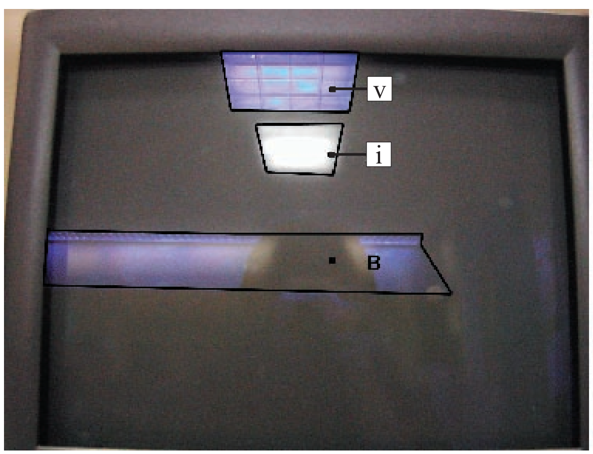


FIG. 1.32

COMPUTER 15: IN-DEPTH INVESTIGATION OF GLARE



POWER OFF
FIG. 1.33

POWER ON
FIG. 1.34

VEILING GLARE:
WORST-CASE-SCENARIO

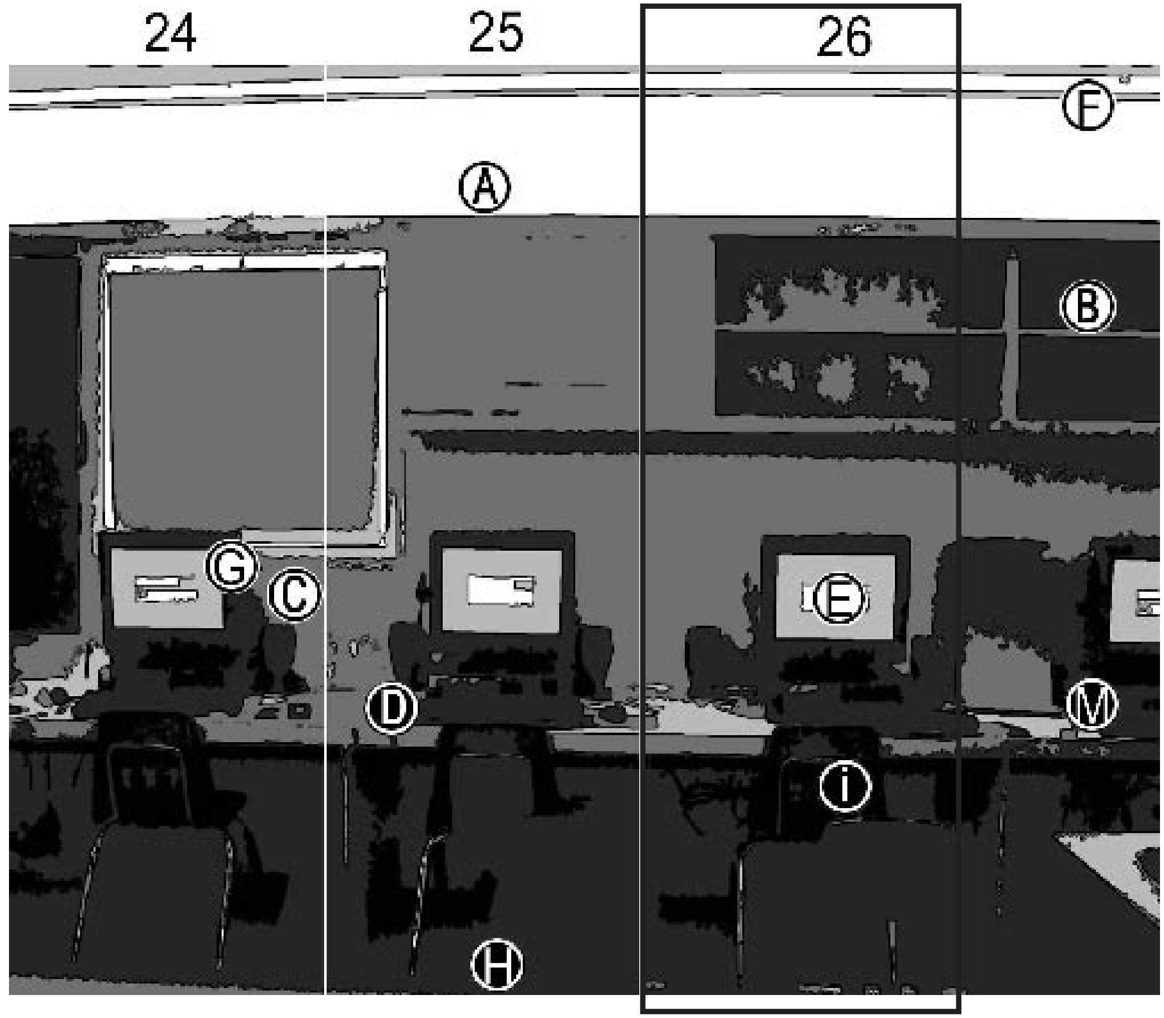
Computer 15 represents the worst glare conditions found in the computer lab. With the monitor turned off there were 3 conditions of glare, the most severe being caused by the luminaire located in the middle of ceiling. Even with the monitor's power on, the glare is still very uncomfortable (see areas v & i; fig. 1.26). In comparison to the rest of the computers, this monitor was not set on a computer, rather it sat directly on the desk surface. In order to see the monitor properly the monitor was tilted back accordingly. This positioning causes the glare to occur.

Group 7 [computer 24 - 26]		
Computer	Surface	Luminance Value [ft.candle]
26	**A**	**91.5**
-	B	2.2
24	C	8.1
25	D	21.4
26	**E**	**38.1**
-	F	12.6
24	G	0.8
25	H	4.5
26	**I**	**0.6**
N/A	J	N/A
N/A	K	N/A
N/A	L	N/A
-	M	5.2

TABLE 3

SURFACE MATERIAL REFLECTANCE VALUES:
COMPUTERS 24-26, GROUP 7.

The case study computer here is number 26. Within the group division that 26 falls, materials A- the header, E- computer monitor screen, and I- the workstation chair are measured. Once again the only material with a high reflectance value is A, however A is not within the field of view while at the workstation.



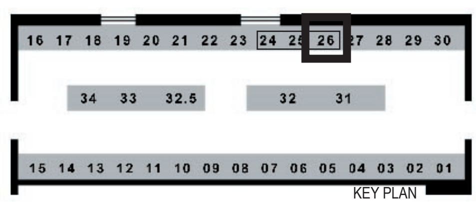


FIG. 1.35

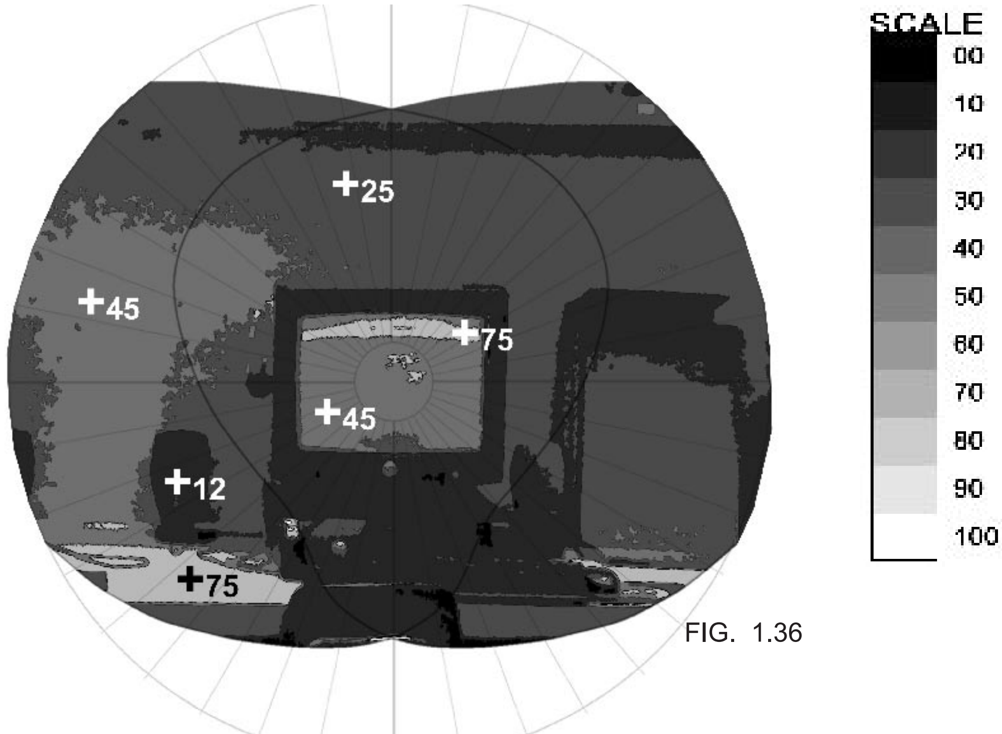
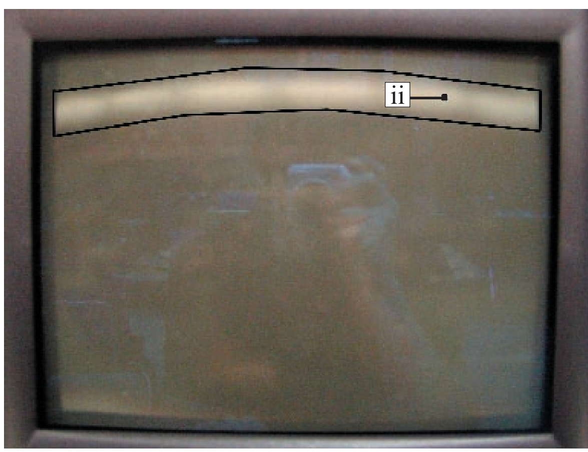


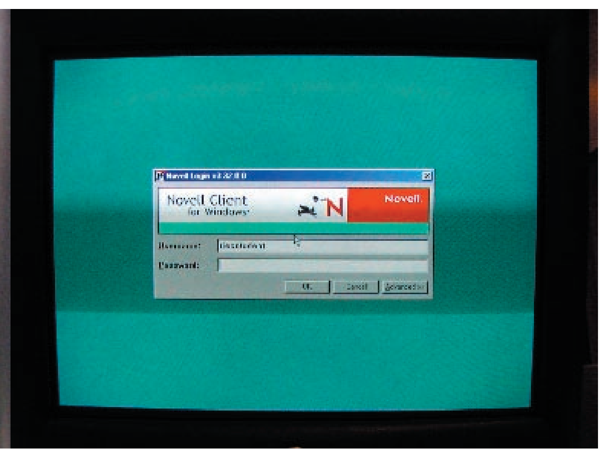
FIG. 1.36

GLARE WITHIN THE FIELD OF VISION

COMPUTER 26: IN-DEPTH INVESTIGATION OF GLARE



POWER OFF
FIG. 1.37



POWER ON
FIG. 1.38

VEILING GLARE:

TYPICAL CONDITION FOR COMPUTERS 16-30

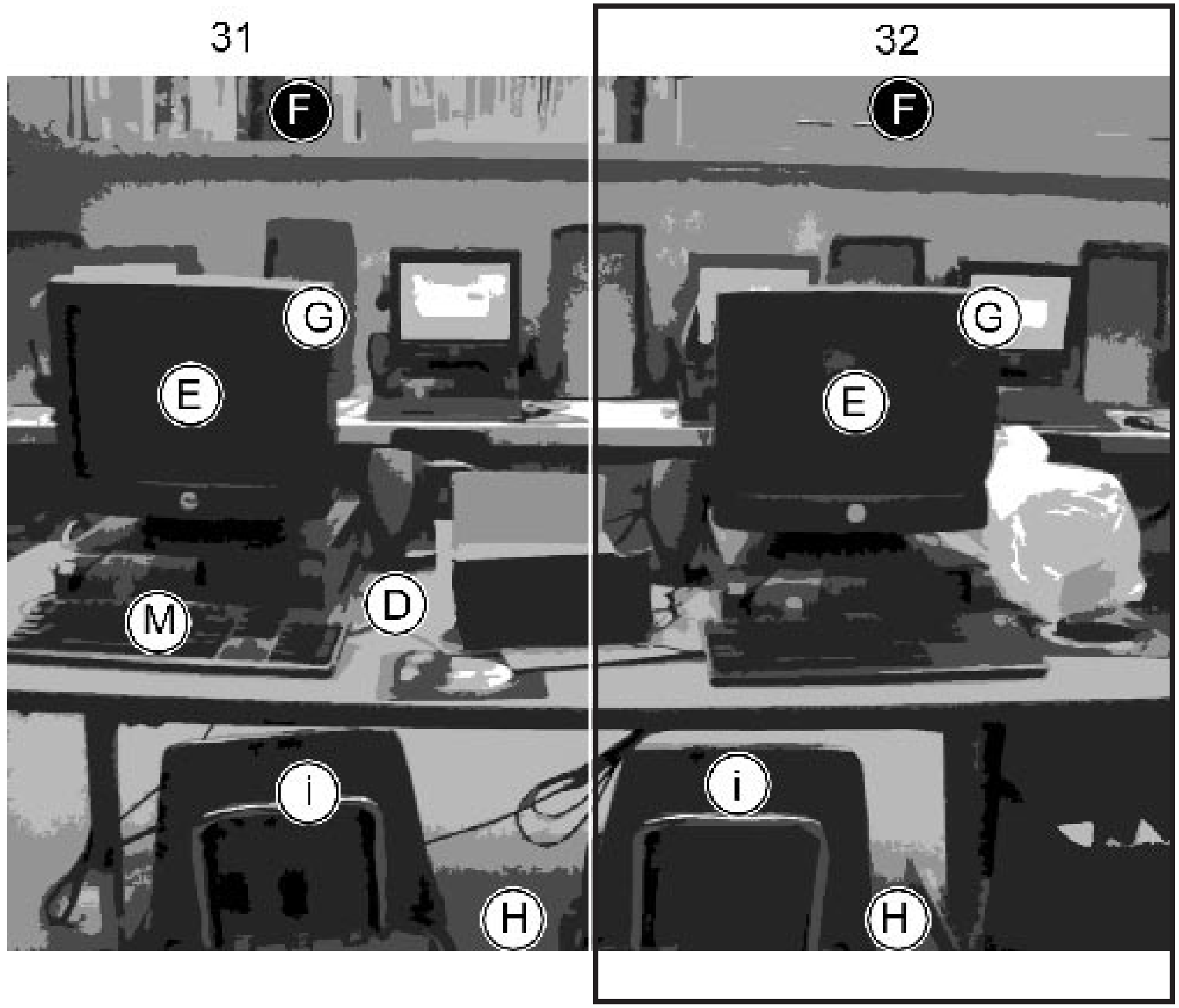
Computer 26 illustrates the typical conditions for computers that are located on the exterior wall of the computer lab. There is only one condition of glare which is caused by the side luminaire on the opposite side of the room (fig 1.26). However when the monitor power is on, this condition is not a factor.

	Group 9 [computer 31 - 32]		
	Surface	Luminance Value [ft.candle]	Average
		31,32	
	A	N/A	N/A
	B	N/A	N/A
	C	N/A	N/A
	D	**17.24, 12.58**	**14.91**
	E	**32.34, 36.16**	**34.25**
	F	**5.36, 5.43**	**5.43**
	G	**0.52, 0.73**	**0.63**
	H	**2.70, 2.50**	**2.60**
	I	**0.51, 0.54**	**0.53**
	J	N/A	N/A
	K	N/A	N/A
	L	N/A	N/A
	M	10.81	10.81

TABLE 4

SURFACE MATERIAL REFLECTANCE VALUES: COMPUTERS 31-32, GROUP 9.

Measurements for all materials were taken for both divisions in group 9 due to the smaller nature of the group. This gave us two Luminance values which were averaged for the overall grouping. None of the materials within the field of view in this group posseses a high value of reflectance when the monitors are turned on, allowing for no or very little glare.



SWATH 32

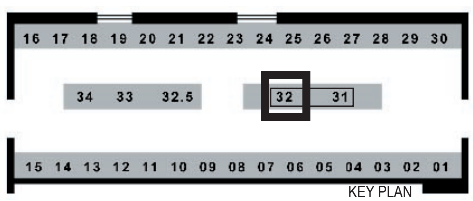


FIG. 1.39

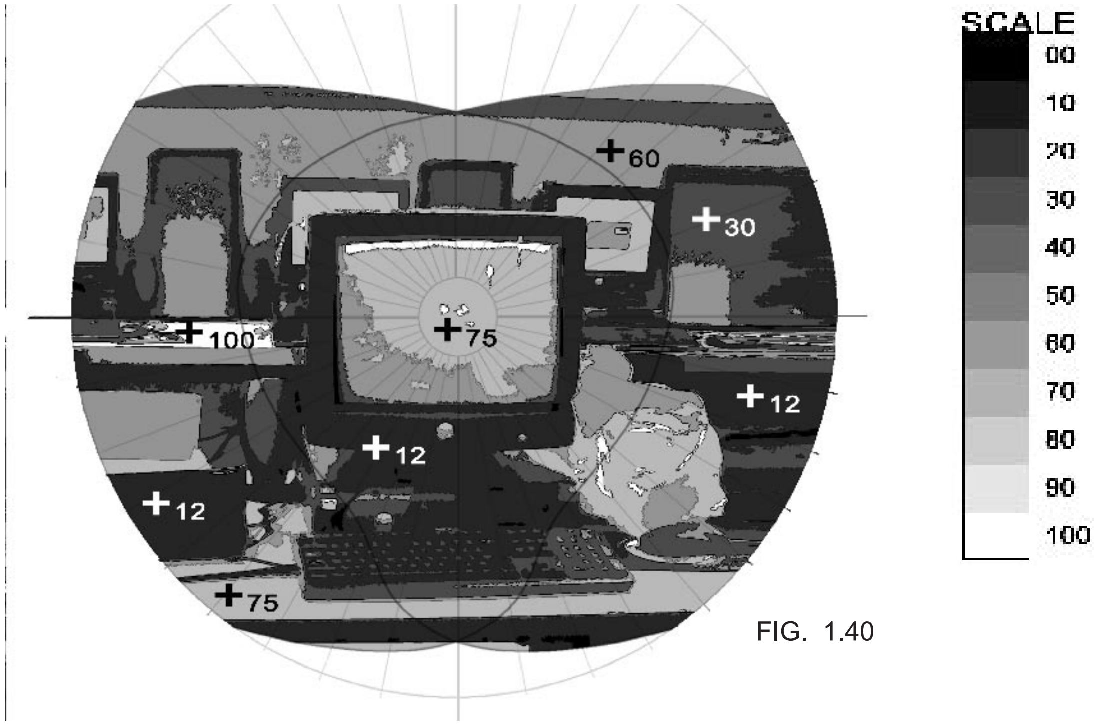
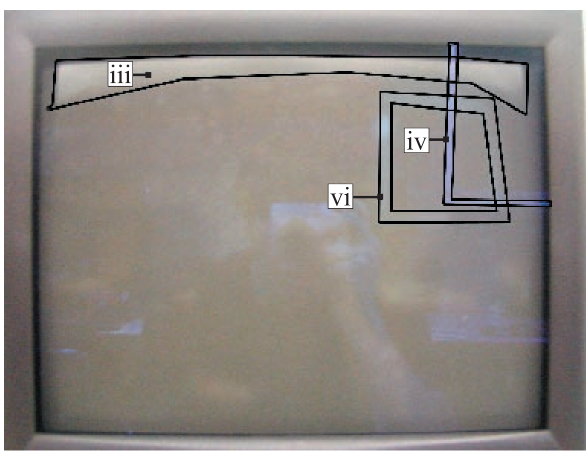


FIG. 1.40

GLARE WITHIN THE FIELD OF VISION

COMPUTER 32: IN-DEPTH INVESTIGATION OF GLARE



POWER OFF
FIG. 1.41

POWER ON
FIG. 1.42

VEILING GLARE:

TYPICAL CONDITION FOR CENTER ROW OF COMPUTERS

Computer 32 illustrates the typical conditions that the center row of computers is subjected to during use of the computer lab. There are three conditions of glare when the monitor's power is off (fig. 1.26). When the power is turned on these conditions are not evident.

INVESTIGATIVE: EXISTING ARTIFICIAL LIGHTING LEVELS

There two types of electric luminaries in the computer lab at Richards elementary school. One is the Sylvania T12 Curvalume rapid start super saver fluorescent lamp. This 34 Watt bulb has a 6" leg spacing, cool white phosphor color, and a 4200 K color temperature. These luminaries run along the center of the computer lab at 8' increments. The second type of light in the lab is the standard Sylvania T12 rapid start fluorescent bulb. It has the same wattage and 4200K color temperature. This luminaire is also Safeline coated. The pair run along the sides of the computer lab continuously. They are tucked in a cove above the dropped ceiling with a quarter-sphere directing the light downward and through vertically orientated diffusers.

FIG. 3.1 34 W, T12 Curvalume rapid start SUPER SAVER fluorescent lamp, 6" leg spacing, Cool White phosphor, 4200K color temperature, 62 CRI ECO-LOGIC

FIG.3.2 34 W, T12 Rapid Start SUPER SAVER fluorescent lamp, Cool White phosphor, 4200K color temperature, 62 CRI, SAFE-LINE coated

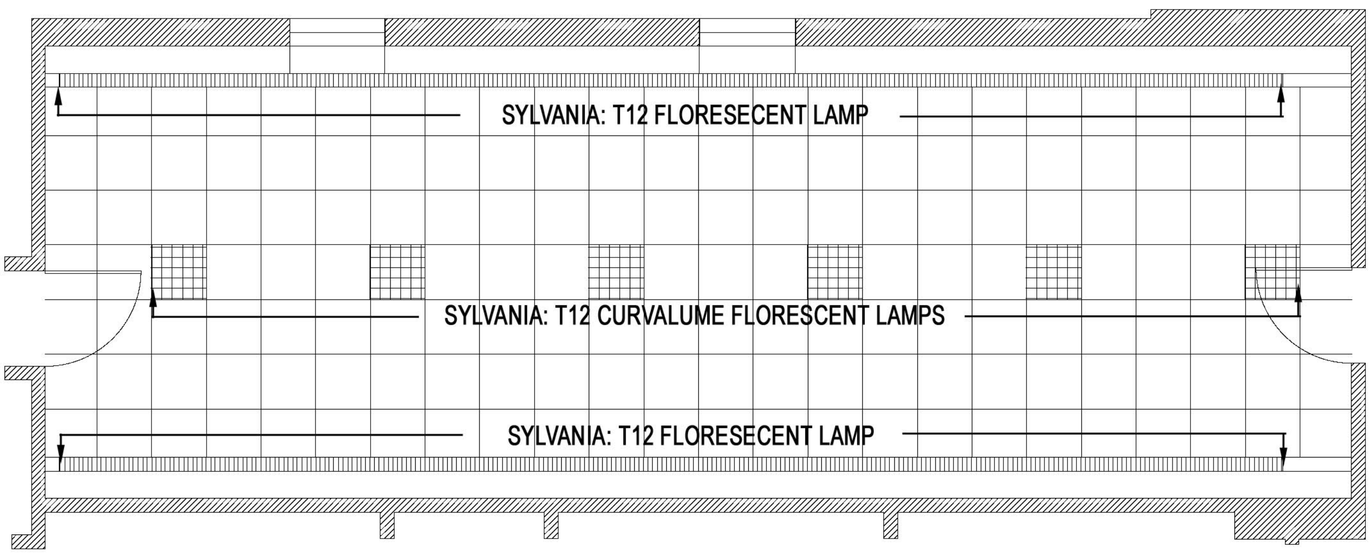


FIG. 3.3

GLARE CONCLUSION

We found that when all the artificial luminaries were turned on the typical glare did not cause an uncomfortable condition within computer workstation field of view. Extreme quantitative differences of light value do not exist within the field of view (see page 22 through 29). Veiling reflections from the computer monitors caused by light sources outside of the field of view also where determined not to be a factor.

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APPENDIX A:

[Instrumentation]

Listed here is a catalogue of all the instrumentation that were utilized in the investigation and diagnostic portion of the case study:

HOBO Light Intensity Logger by Onset Instruments: Used to measure the amount of light over a period of time. After data has been collected, the information can be downloaded using the accompanying software.

- Data recorded as lumens/ft^2
- Records between .01 and 15,000 foot-candles
- Partially cosine corrected
- Not color corrected

GE Light Meter: A handheld device used to measure foot-candles.

- Records between 0 and 10,000 foot-candles
- Cosine corrected
- Color corrected

Minolta Spot Luminance Meter: This handheld device utilizes a one-degree spot to measure the luminance on surfaces.

- Records between .001 and 87,530 footlamberts
- Cosine corrected
- Color corrected

Olympus Camedia C-700 Digital Camera

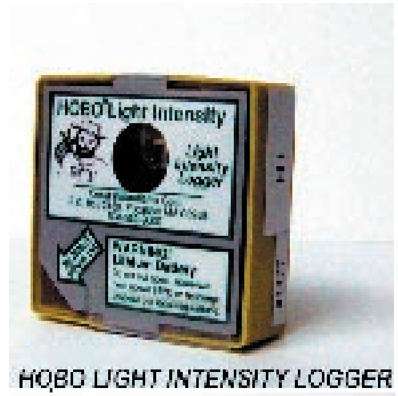


FIG. 4.1

FIG. 4.2


FIG. 4.3

APPENDIX B:

Appendix B contains a series of photos that divide the computers into groups of four (typical). These four groups where created as a way to get a cross section of material reflectance values within a possible given field of view. The various surfaces within the group were labeled alphabetically "A" trough "M". The following chart (fig. 5.01) illustrates the surface name, material, and its corresponding character (fig. 5.02 - 5.13). To gain a better cross section for average reflectance values of the entire space the measurement point for each material is shifted within each group based on its location in a prior grouping (see fig. 1.16).

Surface character	Description	Material
A	Header	Drywall, flat white paint
B	Cabinet	Lt.brown maple vaneer
C	Dry erase Board	White plastic
D	Desktop	Flat white vaneer
E	Computer Monitor	Glass
F	Drop ceiling	White accoustical tile
G	Monitor Casing	Black plastic
H	Floor	Green burbler carpet
I	Chair	Blue plastic
J	Blackboard	
K	Window shades	White vinyl
L	Window	Double pain glass
M	Keyboard cover	Blue print on brown cardboard

FIG. 5.01 Materials Chart

group 11 [teacher station]	
surface #	luminance value [ft candle]
A	n/a
B	n/a
C	n/a
D	27.44
E	36.63
F	5.63
G	5.78
H	2.62
I	0.44
H	n/a
K	n/a
L	n/a
M	n/a

TEACHER STATION

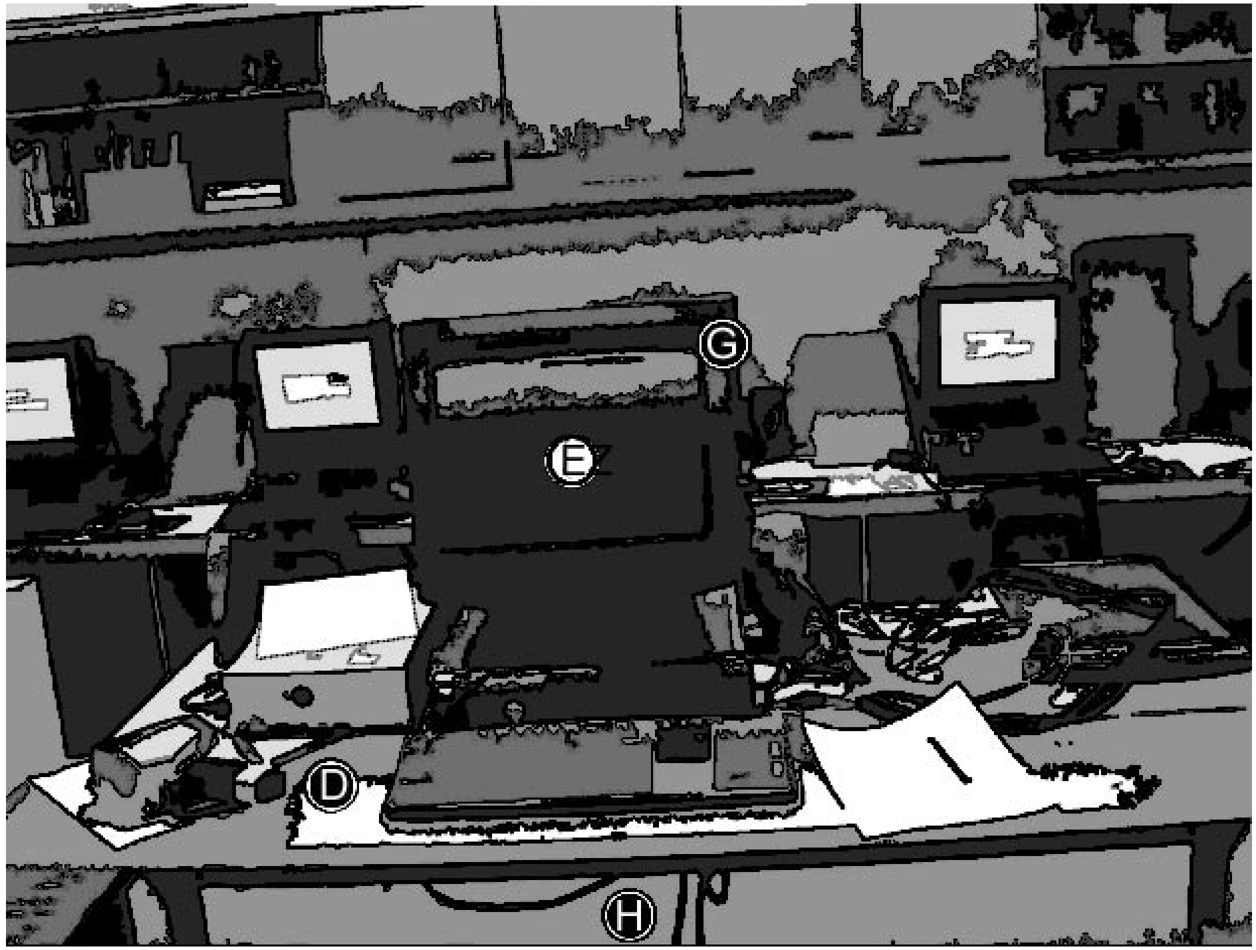


FIG. 5.02 GROUP 11

group 12 [computer 35]	
surface #	luminance value [ft.candle]
A	n/a
B	n/a
C	n/a
D	15.55
E	34.51
F	6.56
G	9.13
H	4.03
I	0.69
H	0.97
K	n/a
L	n/a
M	6.79

35

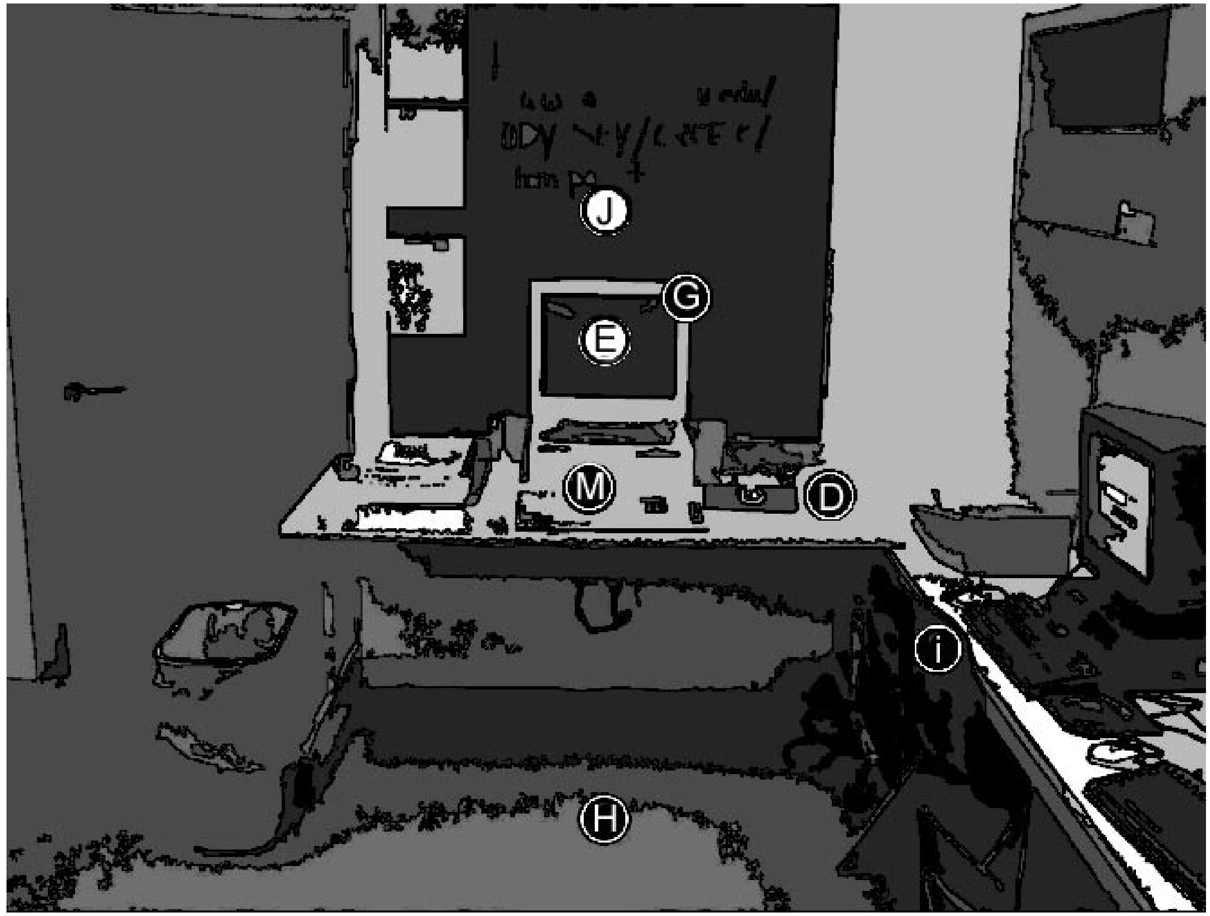


FIG. 5.03 GROUP 12

group 9 [computers 31,32]		
surface #	luminance value [ft.candle]	average
	31,32	
A	n/a	n/a
B	n/a	n/a
C	n/a	n/a
D	17.24, 12.58	14.91
E	32.34, 36.16	34.25
F	5.36, 5.49	5.43
G	0.52, 0.73	0.63
H	2.70, 2.50	2.6
I	0.51, 0.54	0.53
J	n/a	n/a
K	n/a	n/a
L	n/a	n/a
M	10.81	10.81

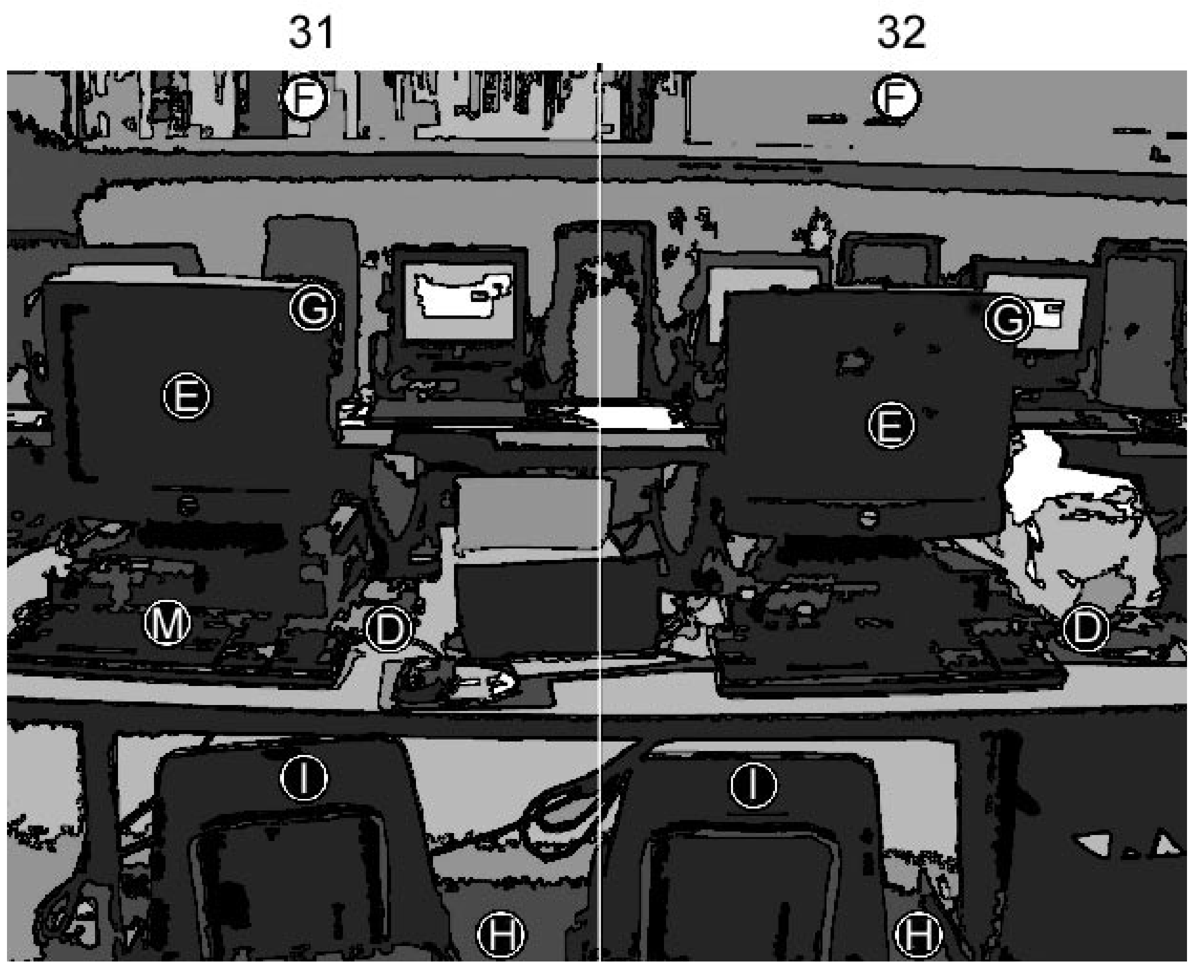


FIG. 5.04 GROUP 9

group 10 [computers 33,34]		
surface #	luminance value [ft.candle]	average
	33,34	
A	n/a	n/a
B	n/a	n/a
C	n/a	n/a
D	15.40, 16.94	16.17
E	33.91, 35.58	34.25
F	5.72, 5.75	5.43
G	0.65, 0.61	0.63
H	3.42, 3.40	2.6
I	0.60, 0.61	0.53
J	n/a	n/a
K	n/a	n/a
L	n/a	n/a
M	6.15	10.81

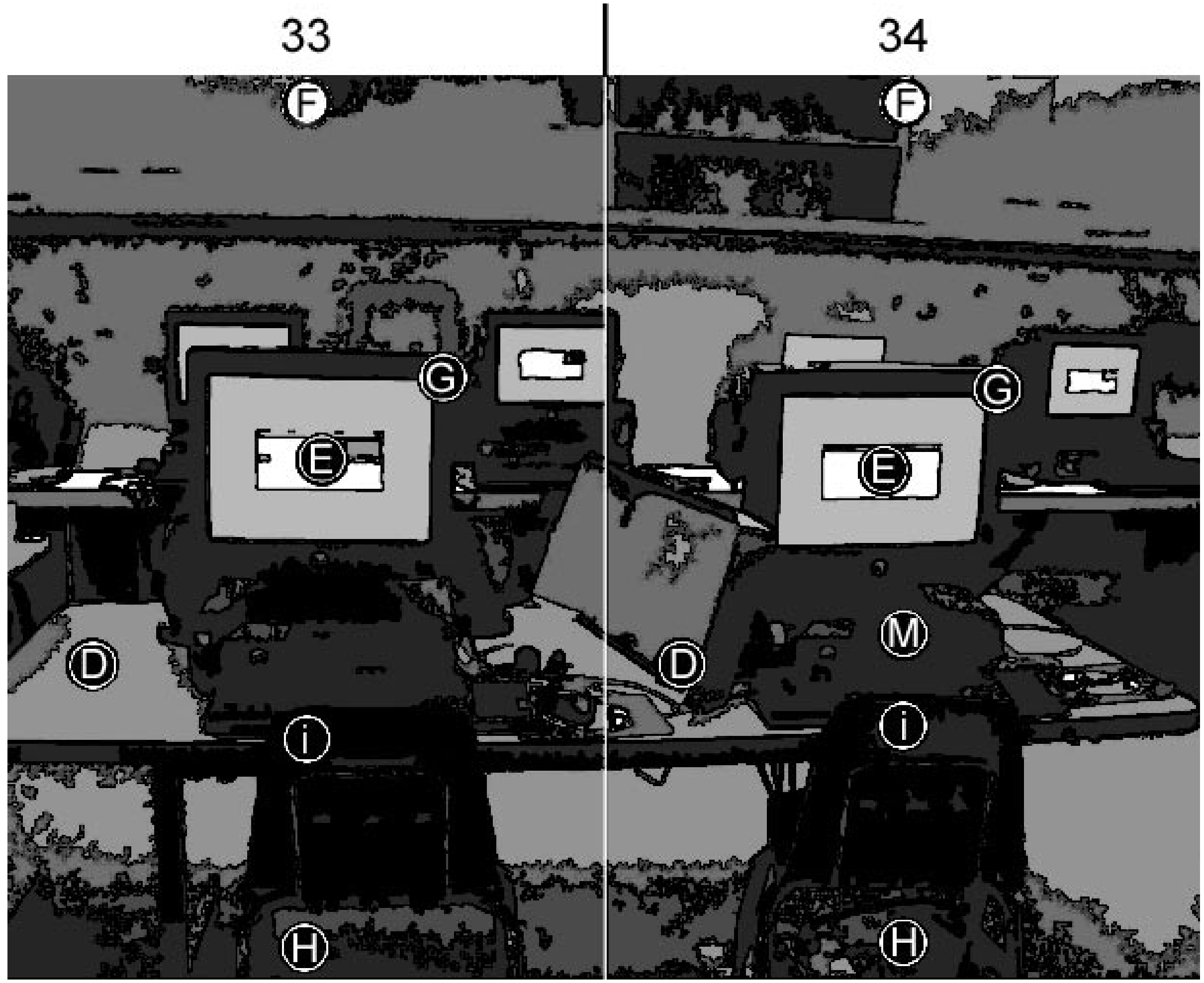


FIG. 5.05 GROUP 10

group 7 [computers 24- 26]		
Computer/ Area	Surface	Luminance Value [ft.candle]
26	A	91.47
-	B	2.16
24	C	8.14
25	D	21.44
26	E	38.09
-	F	12.58
24	G	0.82
25	H	4.49
26	I	0.64
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
-	M	5.23

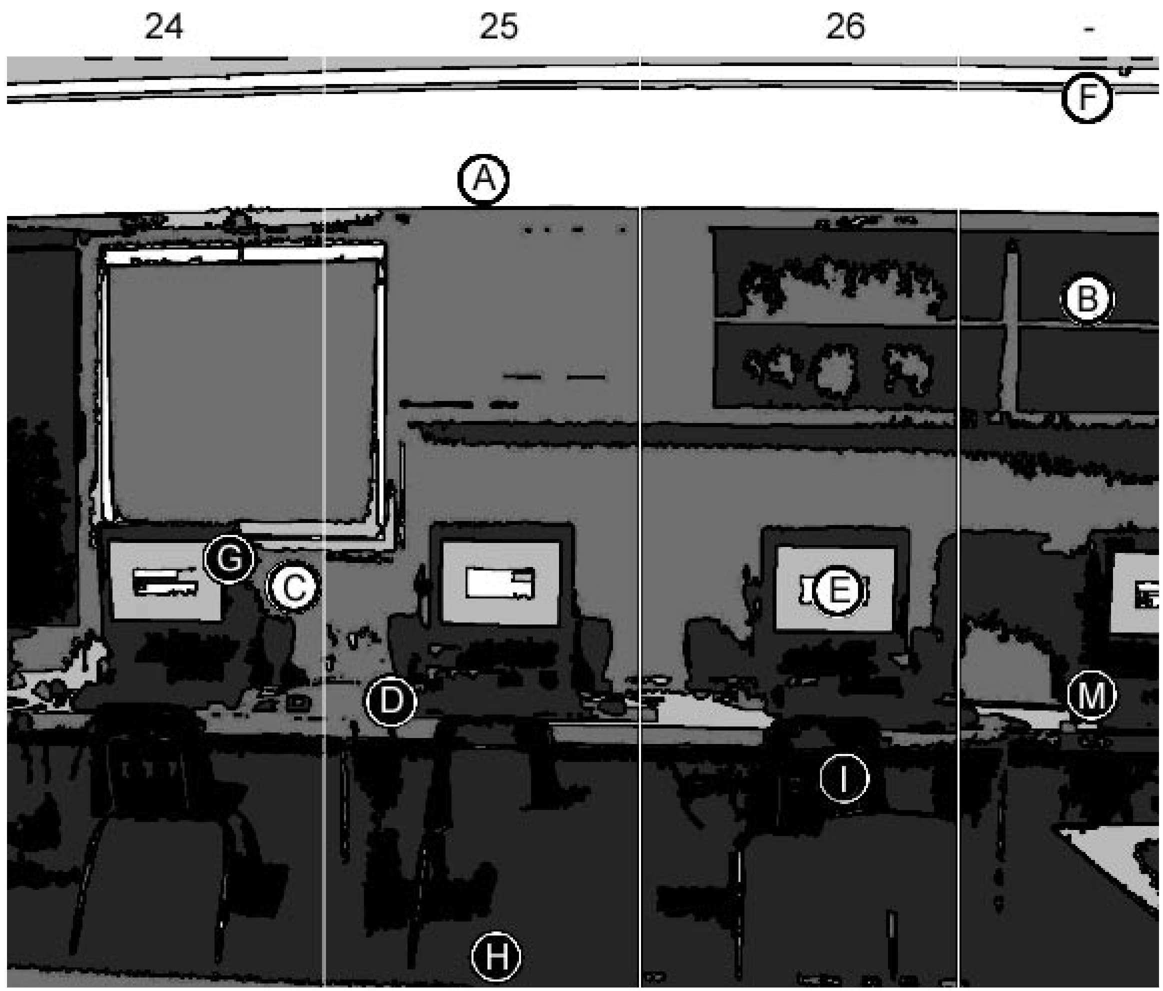


FIG. 5.06 GROUP 7

group 8 [computers 27 – 30]		
Computer/ Area	Surface	Luminance Value [ft.candle]
30	A	1.52
27	B	2.21
28	C	4.39
29	D	21.95
30	E	34.15
27	F	10.74
28	G	0.63
29	H	2.04
30	I	0.55
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
27	M	4.97

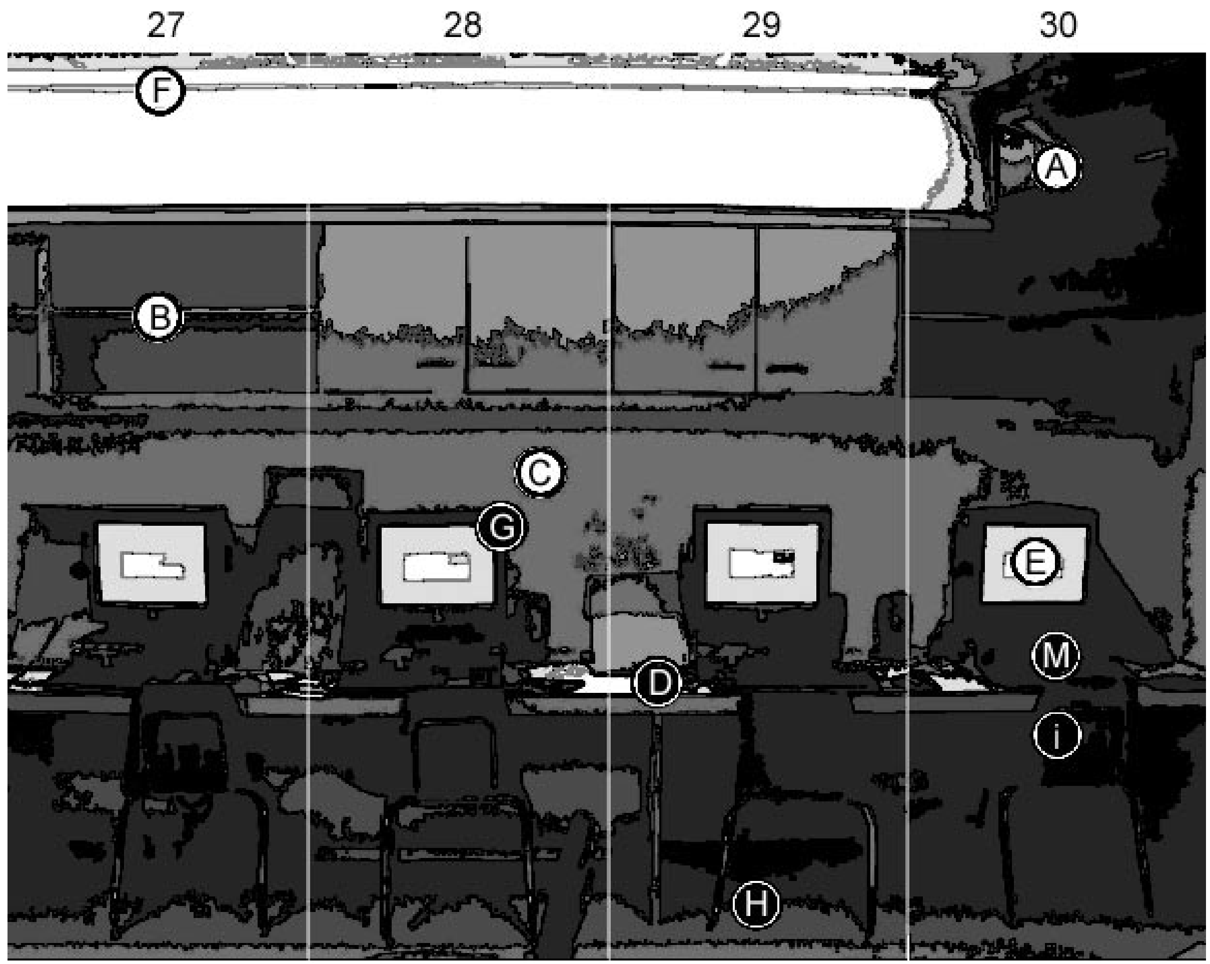


FIG. 5.07 GROUP 8

group 5 [computers 16 – 19]		
Computer/ Area	Surface	Luminance Value [ft.candle]
16	A	59.66
17	B	5.06
18	C	5.17
19	D	24.91
16	E	38.09
17	F	11.17
18	G	0.64
19	H	4.98
16	I	0.70
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
17	M	14.58

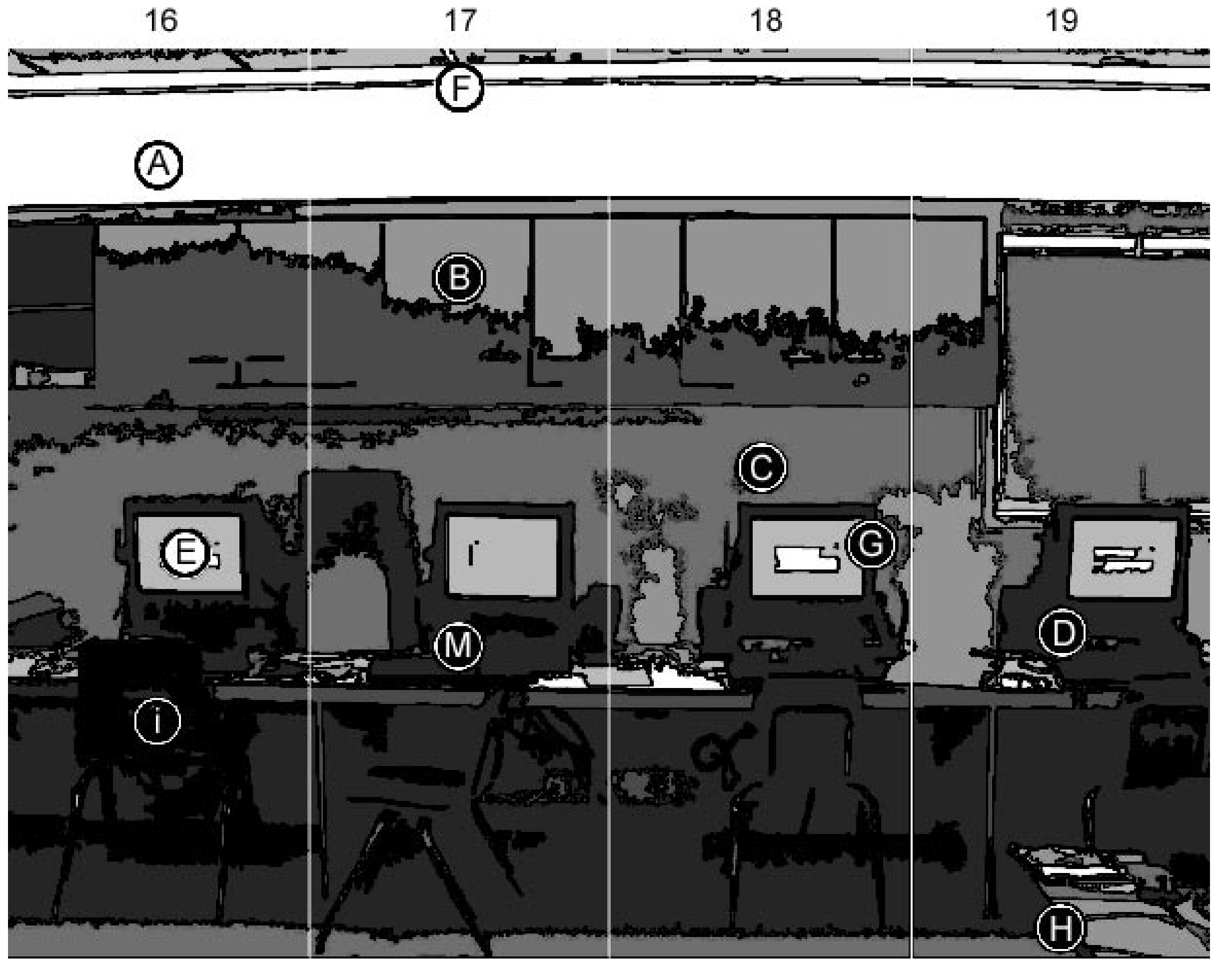


FIG. 5.08 GROUP 5

group 6[computers 20 - 23]		
Computer/ Area	Surface	Luminance Value [ft.candle]
21	A	67.77
22	B	n/a
23	C	n/a
20	D	24.80
21	E	36.34
22	F	11.67
23	G	0.86
24	H	5.29
20	I	0.70
20	J	0.88
21	J	0.86
22	J	0.78
23	J	0.75
20	K	6.09
23	K	5.90
20	L	46.90
23	L	49.76
22	M	6.31

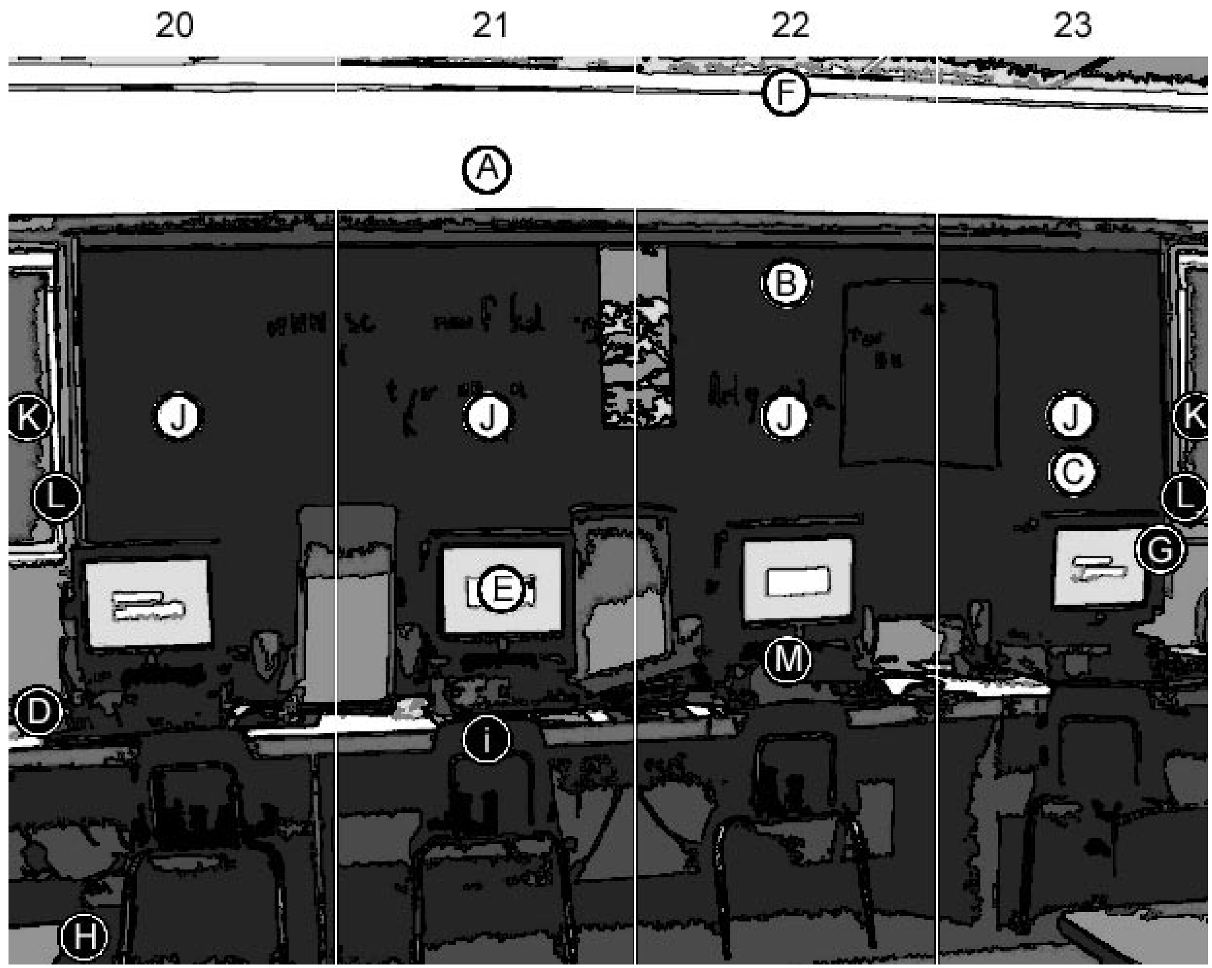


FIG. 5.09 GROUP 6

group 3 [computers 9 – 12]		
Computer/ Area	Surface	Luminance Value [ft.candle]
11	A	99.44
12	B	3.15
9	C	5.25
10	D	26.85
11	E	36.51
12	F	11.38
9	G	1.09
10	H	5.16
11	I	0.65
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
12	M	9.89

FIG. 5.10 GROUP 3

group 4 [computers 13 - 15]		
Computer/ Area	Surface	Luminance Value [ft.candle]
15	A	79.1
13	B	5.76
14	C	4.97
-	D	32.02
15	E	34.24
13	F	12.51
14	G	0.75
-	H	4.68
15	I	0.48
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
13	M	3.86

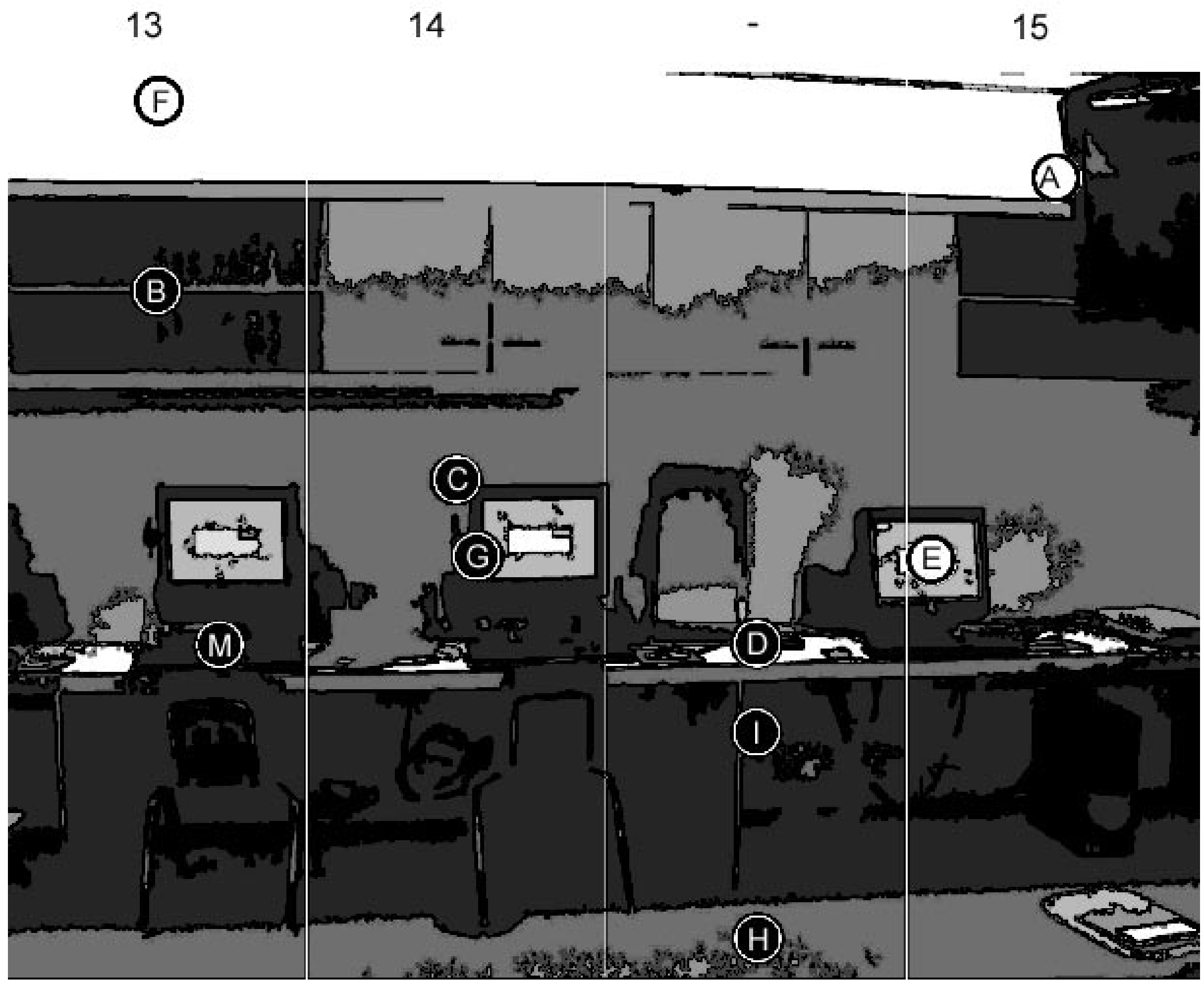


FIG. 5.11 GROUP 4

group 1 [computers 1- 4]		
Computer/ Area	Surface	Luminance Value [ft.candle]
1	A	4.45
2	B	5.72
3	C	4.56
4	D	17.00
1	E	30.62
2	F	8.92
3	G	0.74
4	H	3.74
1	I	0.79
n/A	J	n/a
n/a	K	n/a
n/a	L	n/a
2	M	3.56

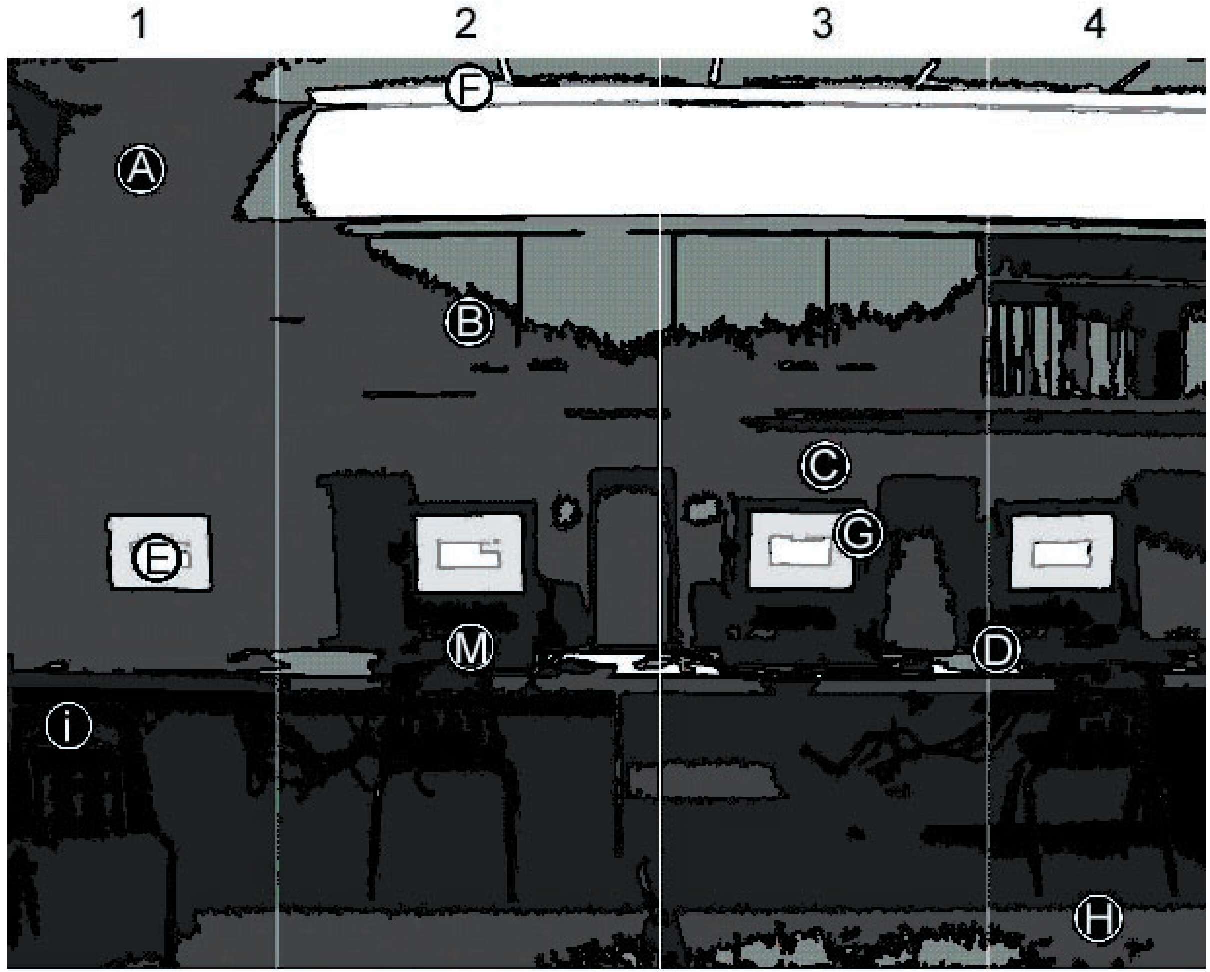


FIG. 5.12 GROUP 1

t

group 2 [computers 5 - 8]		
Computer/ Area	Surface	Luminance Value [ft.candle]
6	A	84.84
7	B	6.12
8	C	4.96
5	D	23.76
6	E	35.81
7	F	10.21
8	G	0.89
5	H	5.74
6	I	0.68
n/a	J	n/a
n/a	K	n/a
n/a	L	n/a
7	M	4

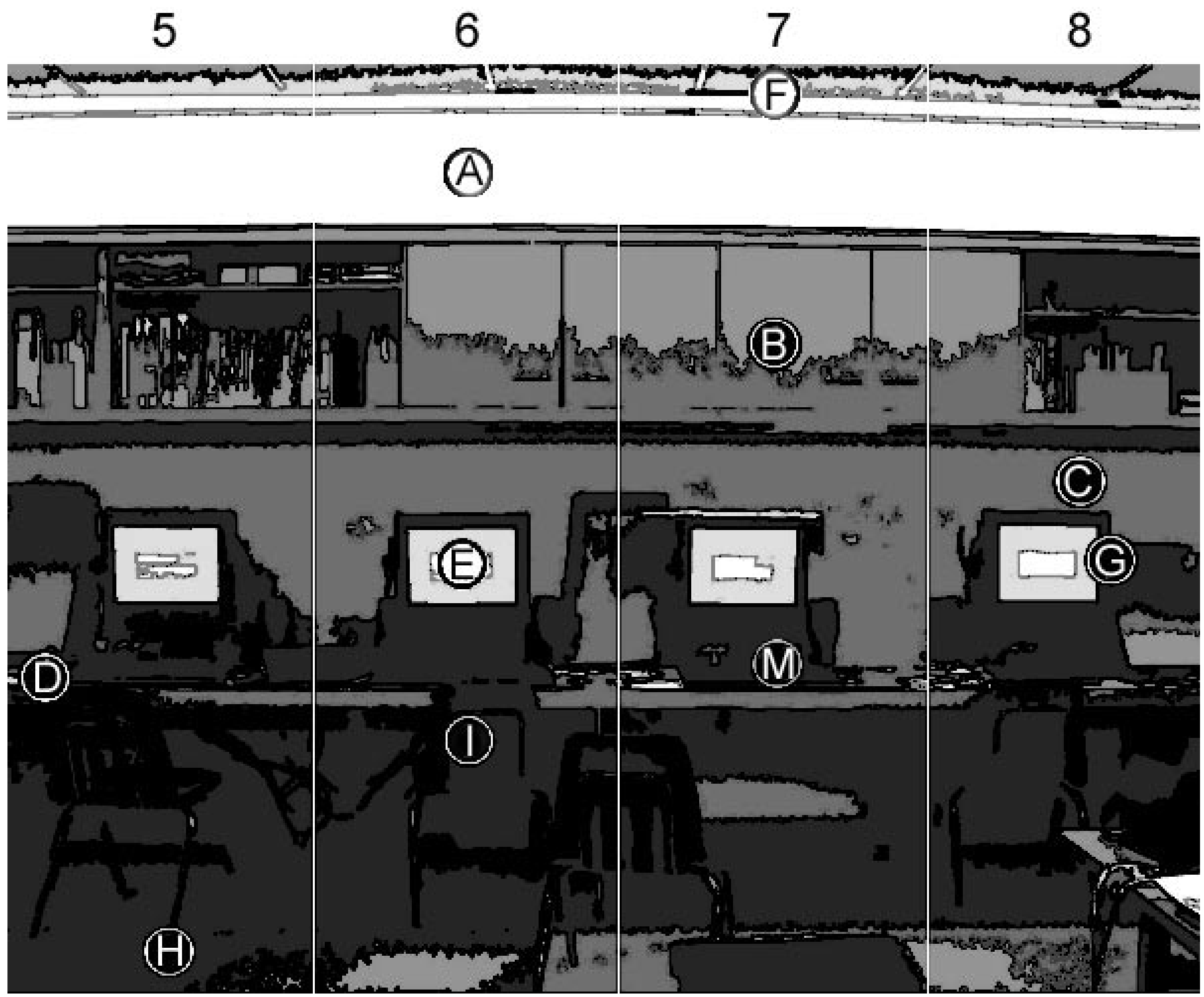


FIG. 5.13 GROUP 2

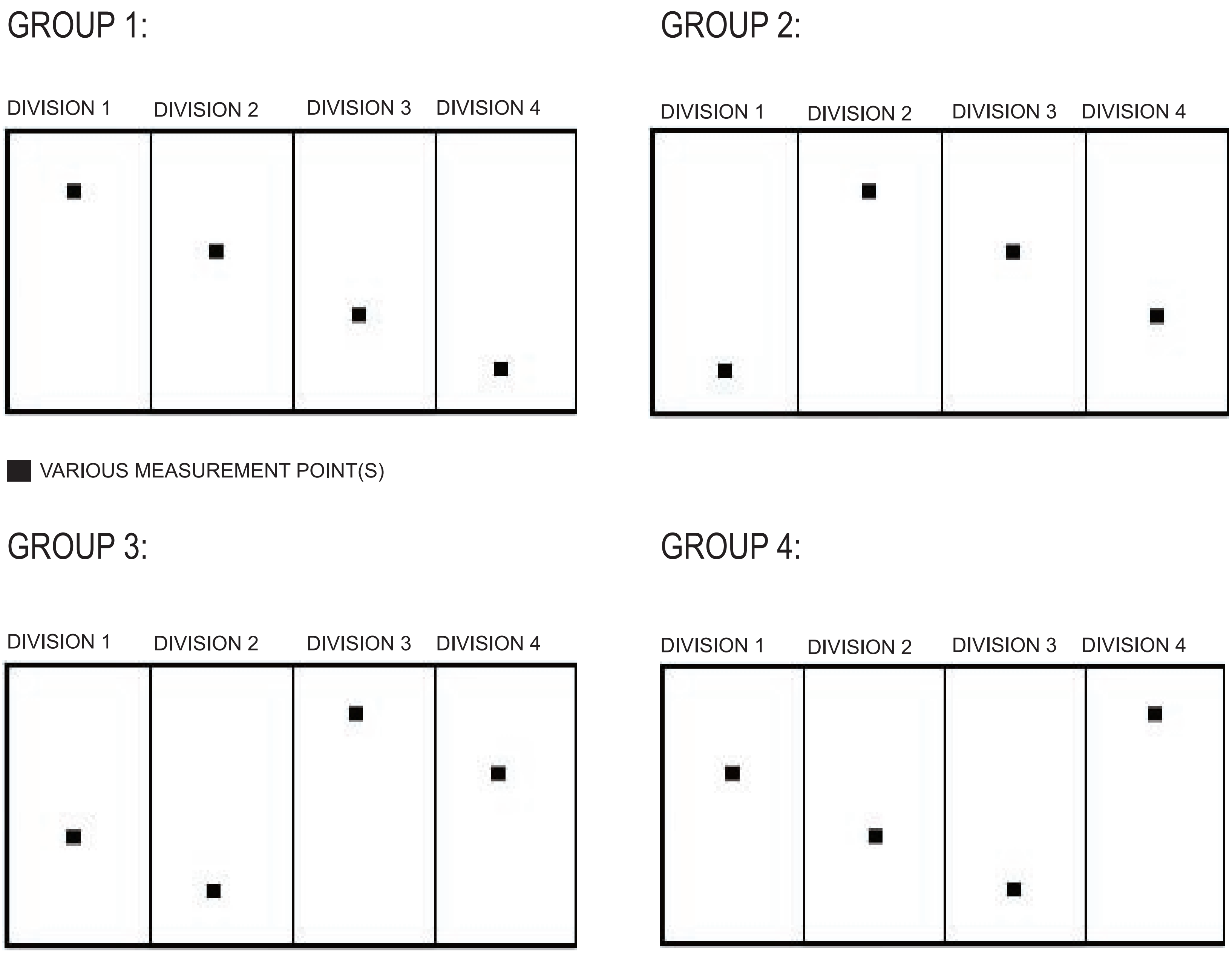
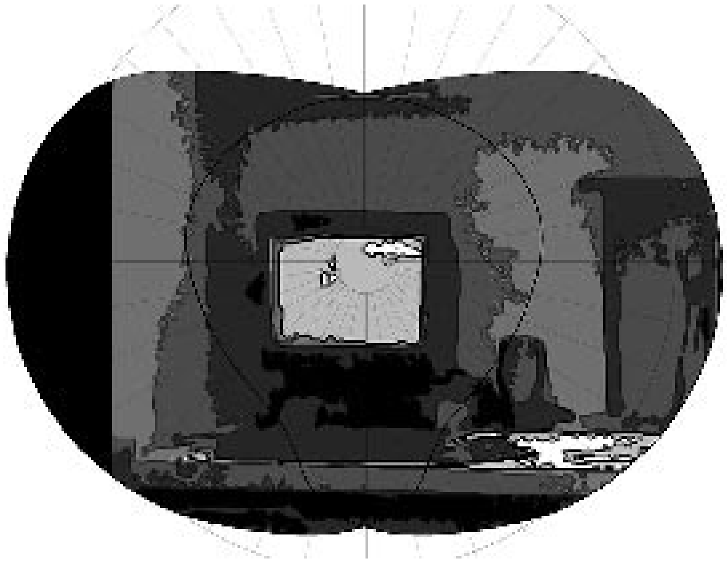

GROUP 1:
DIVISION 1
DIVISION 2
DIVISION 3
DIVISION 4
GROUP 2:
DIVISION 1
DIVISION 2
DIVISION 3
DIVISION 4
VARIOUS MEASUREMENT POINT(S)
GROUP 3:
DIVISION 1
DIVISION 2
DIVISION 3
DIVISION 4
GROUP 4:
DIVISION 1
DIVISION 2
DIVISION 3
DIVISION 4

FIG. 5.14

APPENDIX C:

Appendix C contains the complete series of tonal images that describes the quantitative differences of light value that exists within the field of vision of each individual work station. More in-depth investigations can be found, starting on page 18.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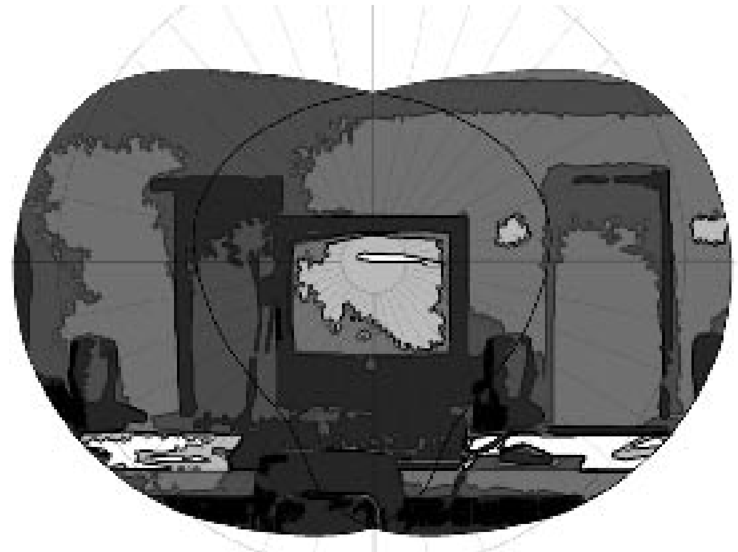
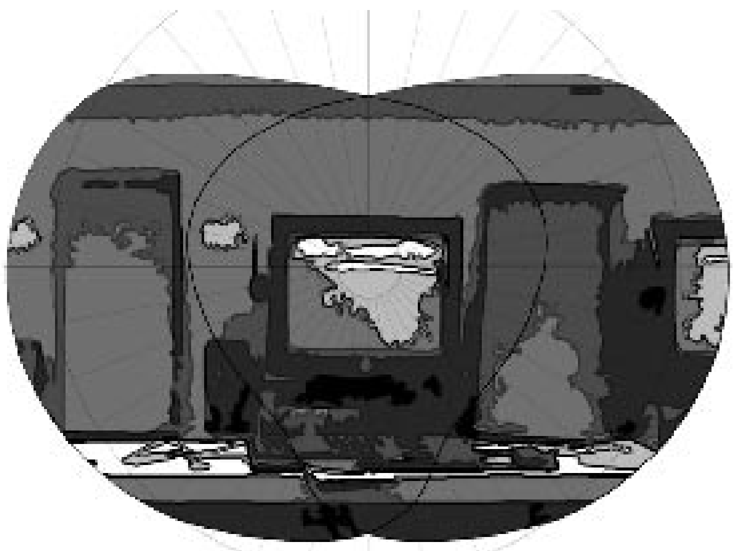

COMPUTER 02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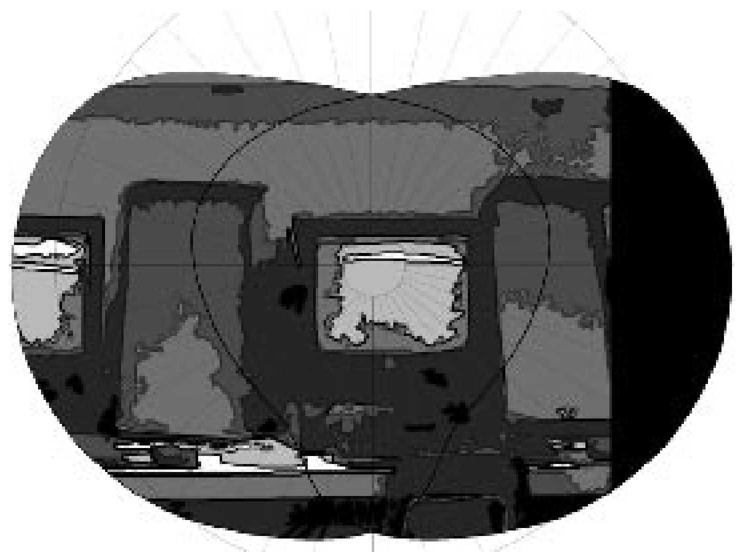
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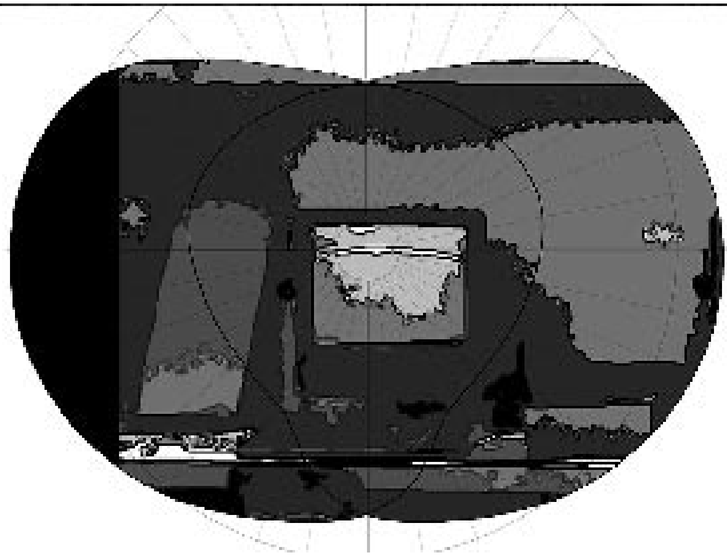
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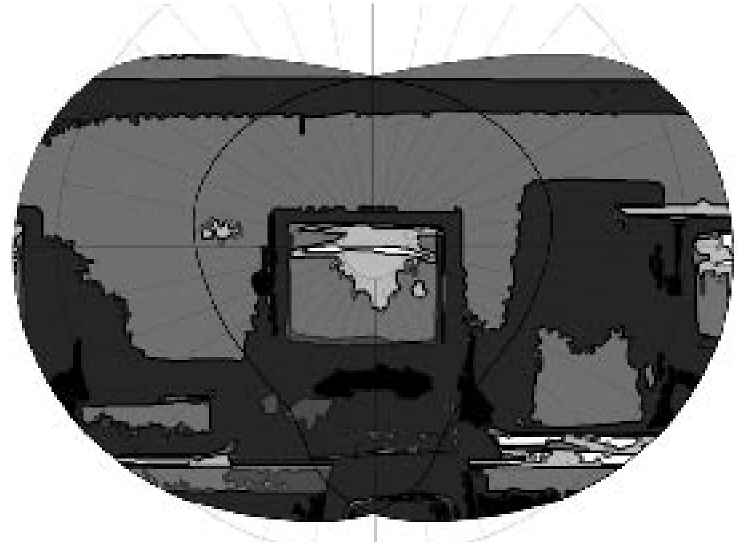
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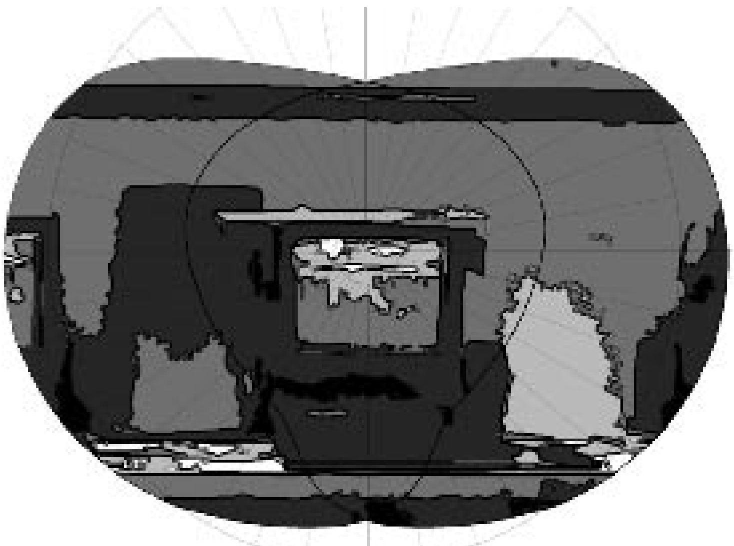
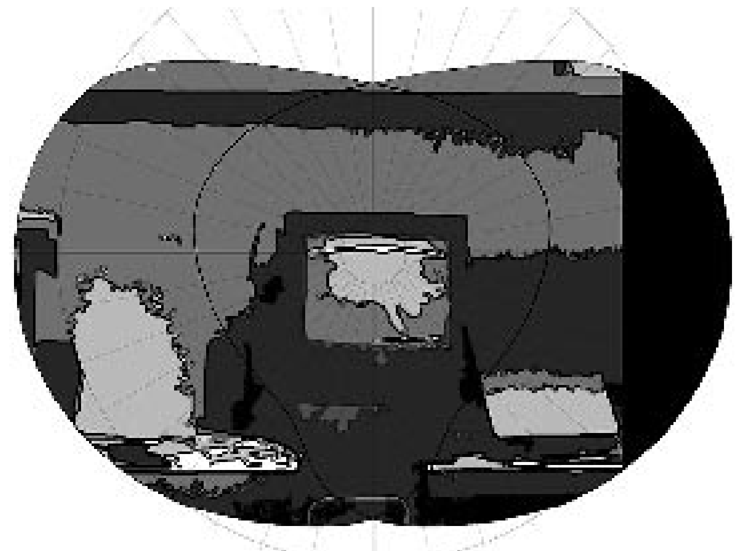
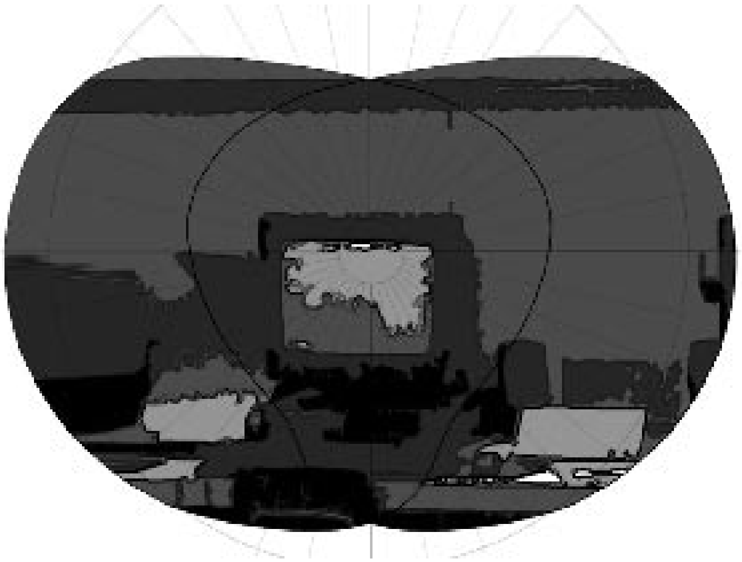
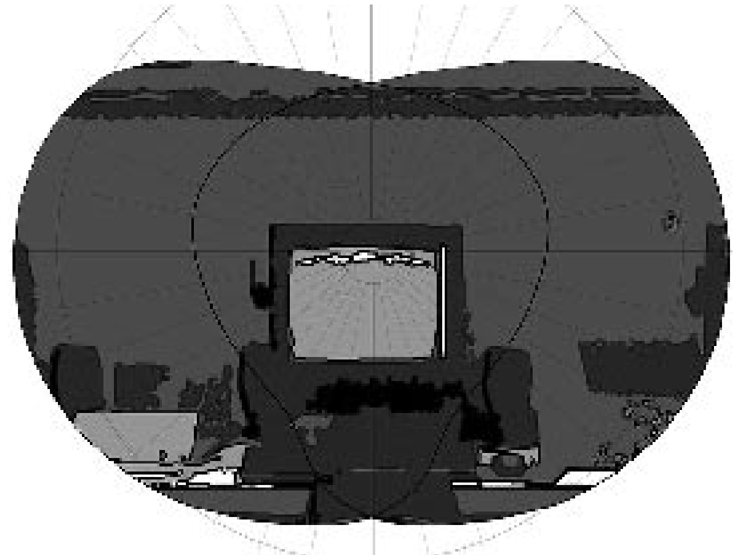

COMPUTER 07

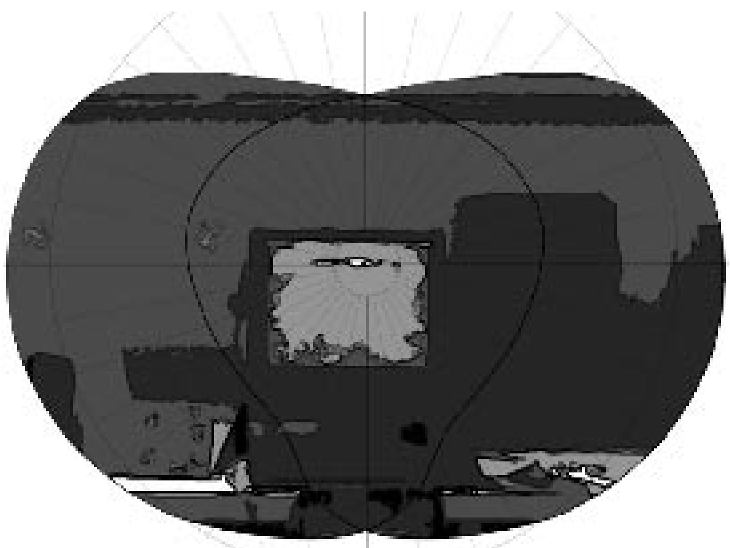

COMPUTER 08



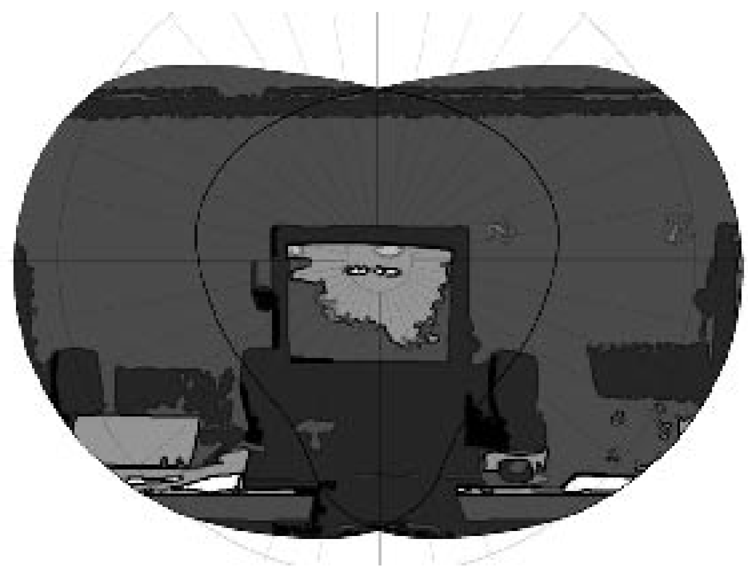
COMPUTER 09



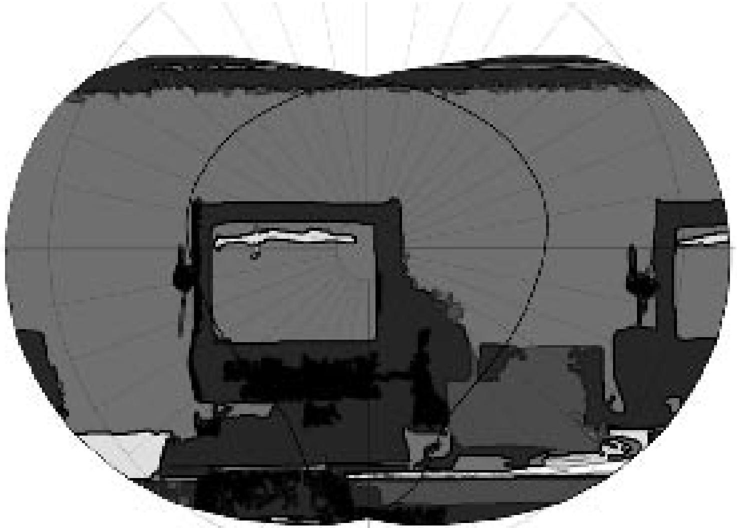
COMPUTER 10



COMPUTER 11



COMPUTER 12



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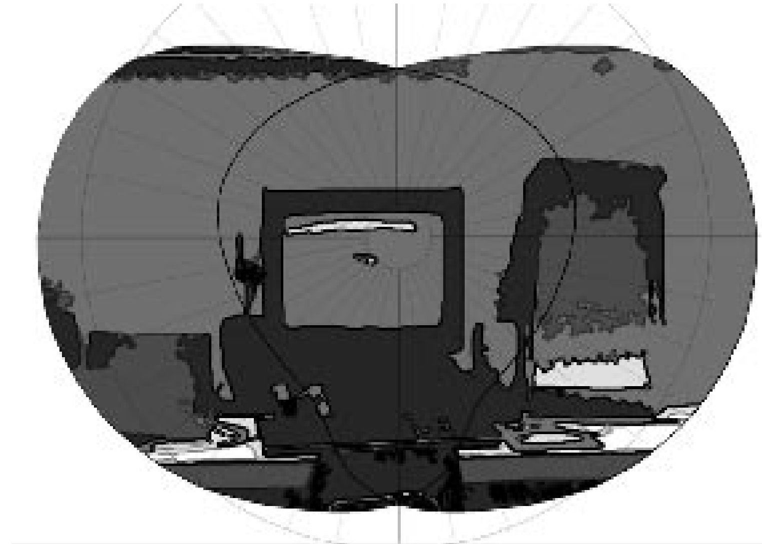
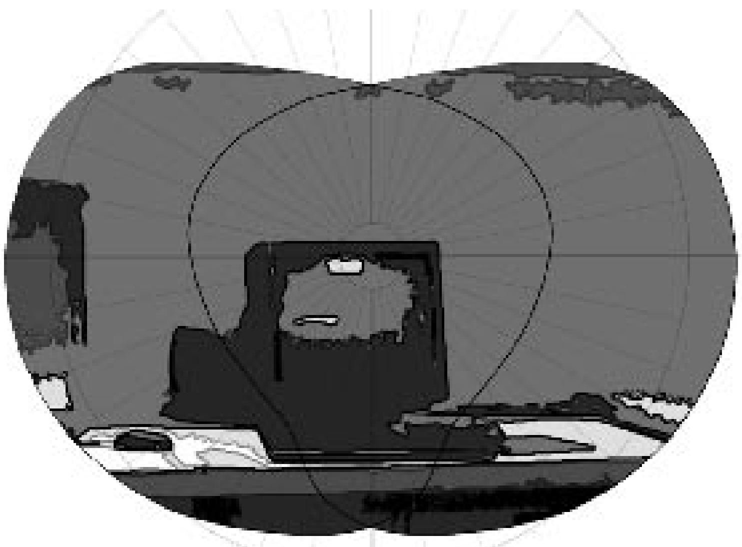
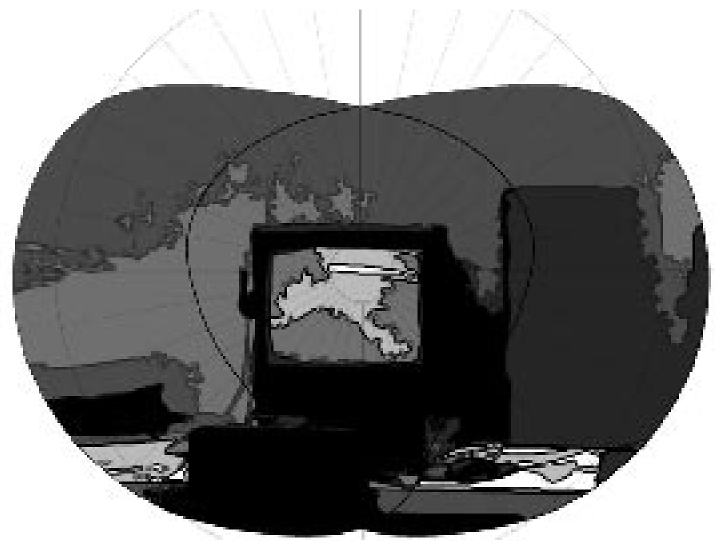


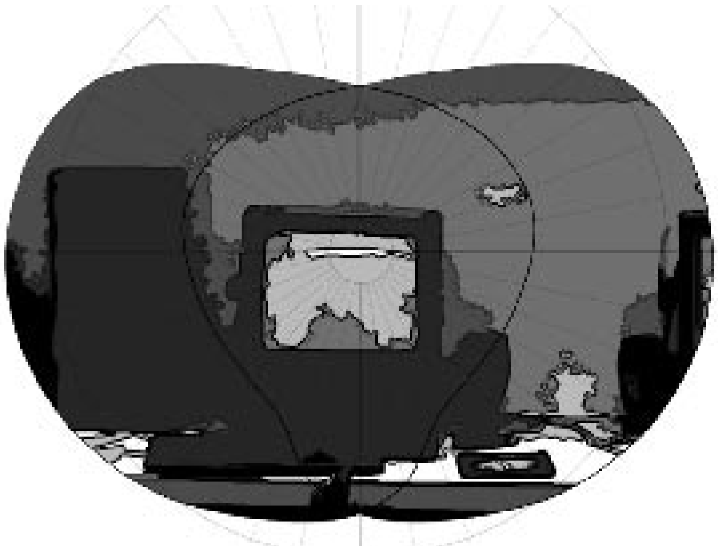
COMPUTER 14



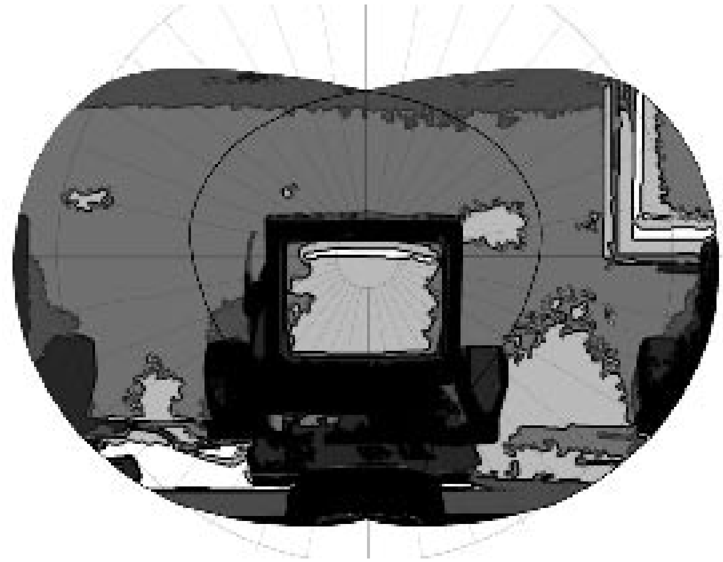
COMPUTER 15



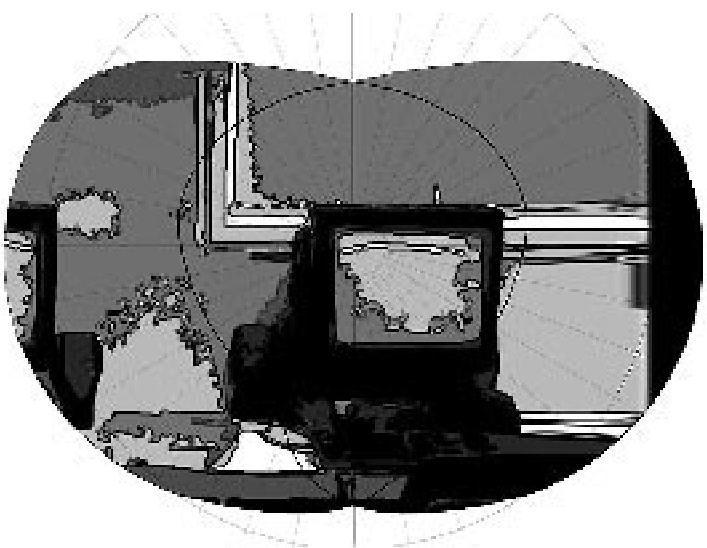
COMPUTER 16



COMPUTER 17

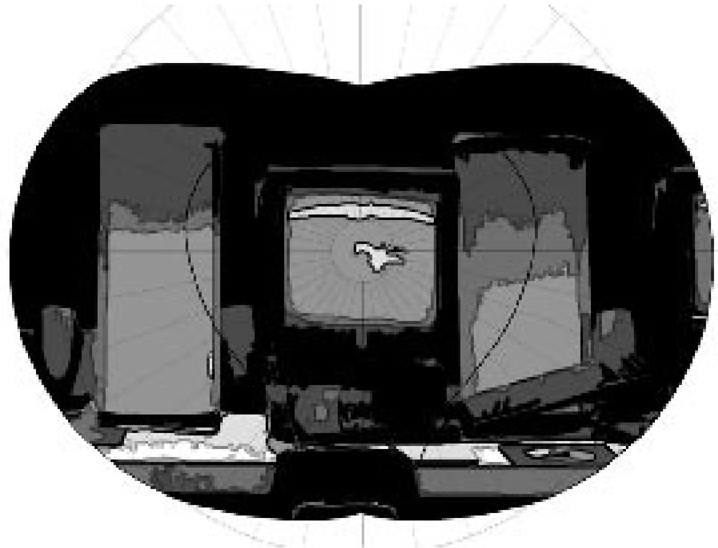


COMPUTER 18



COMPUTER 19

COMPUTER 20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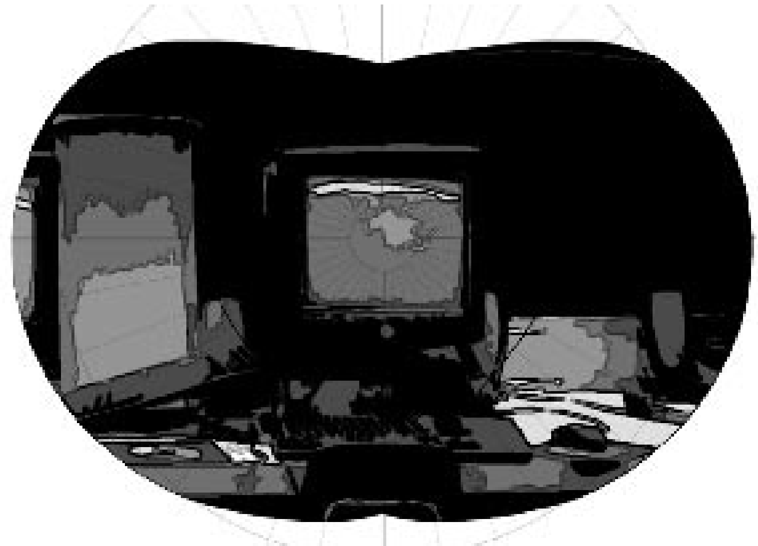
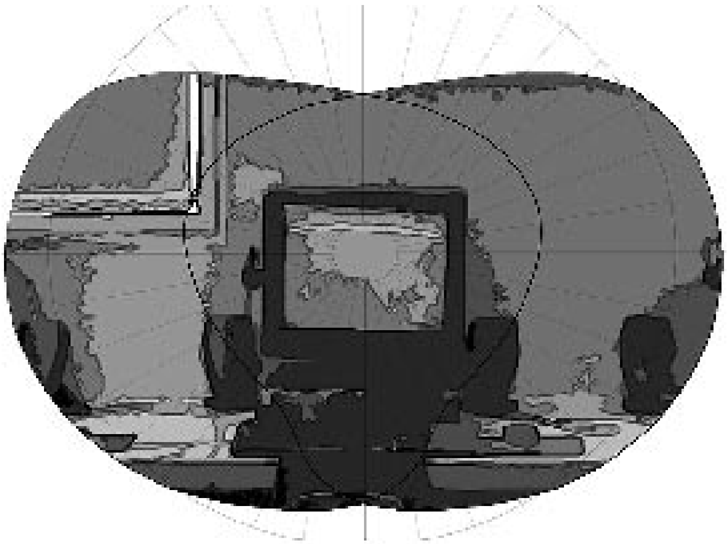
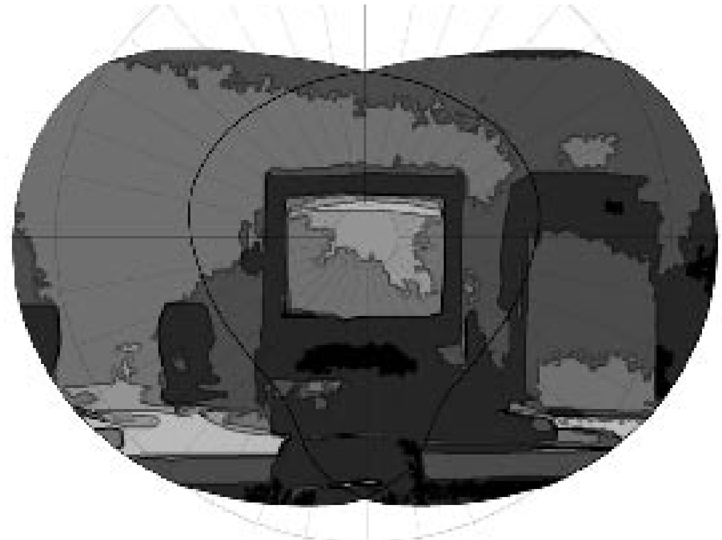

COMPUTER 22


COMPUTER 23


COMPUTER 24



COMPUTER 25



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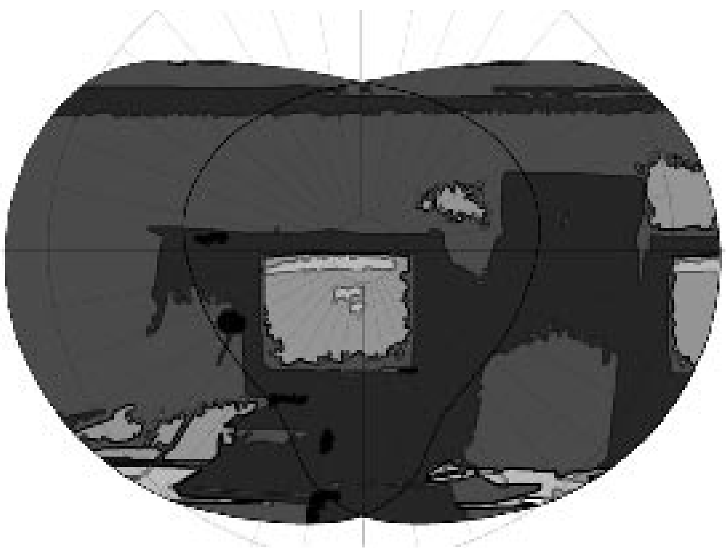

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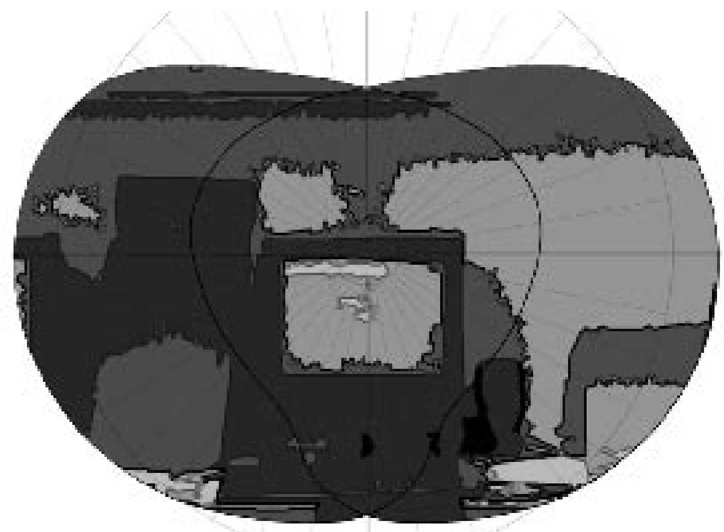

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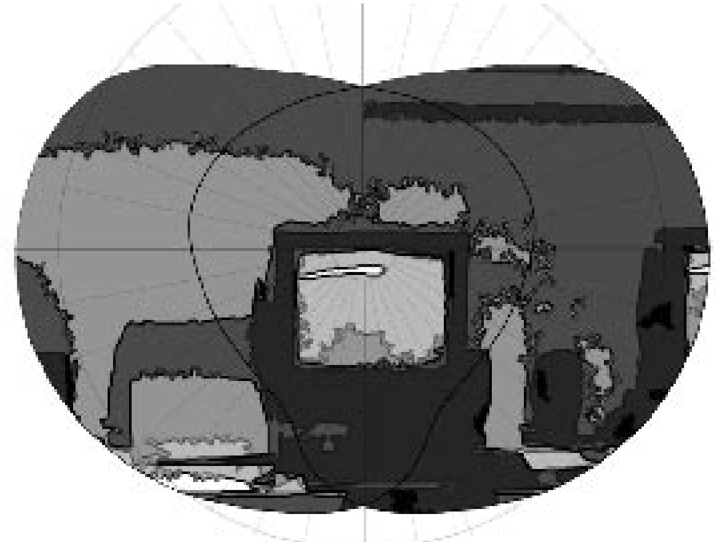

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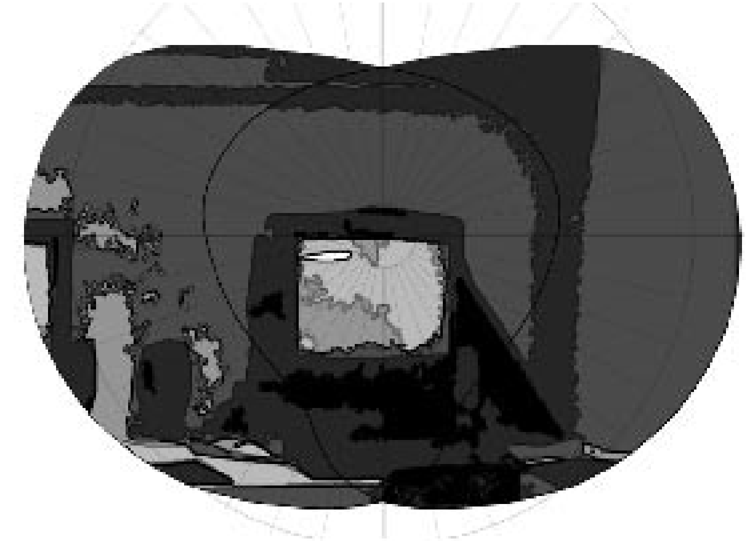

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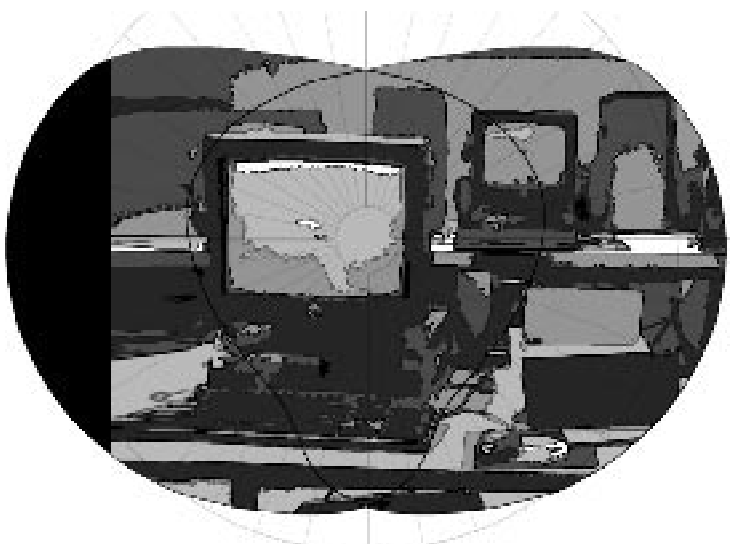

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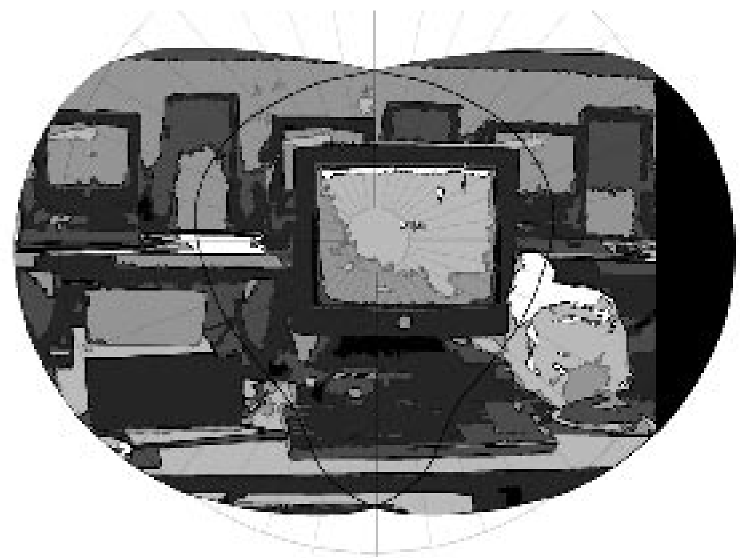

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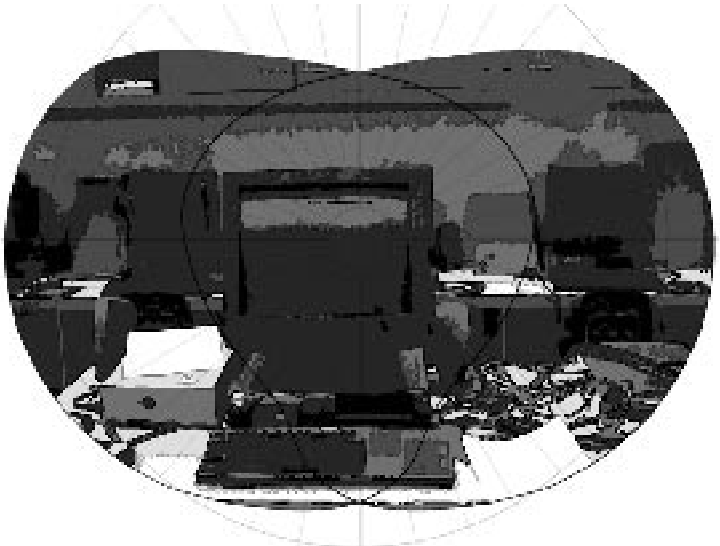

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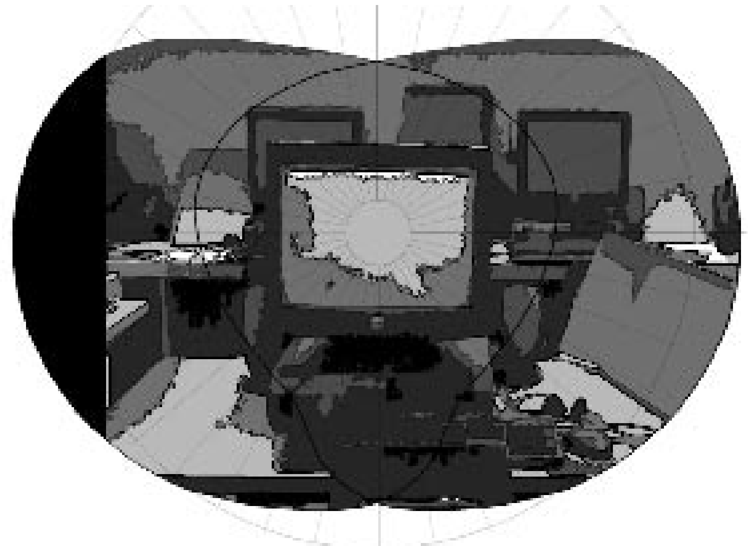

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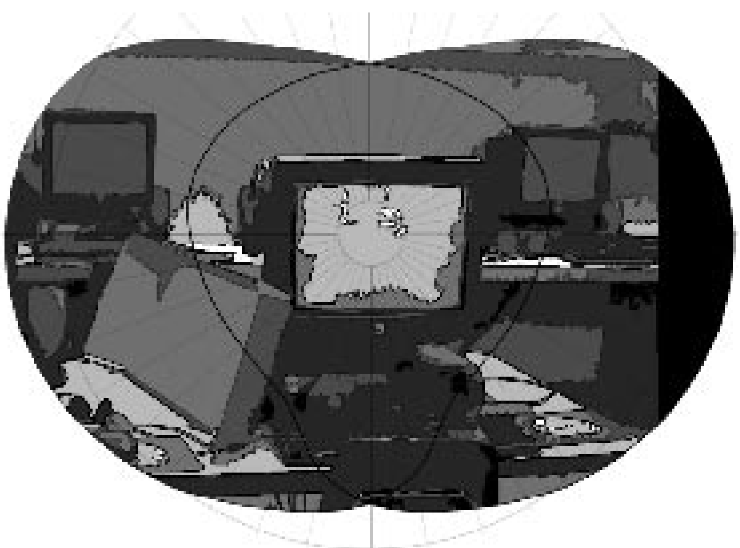

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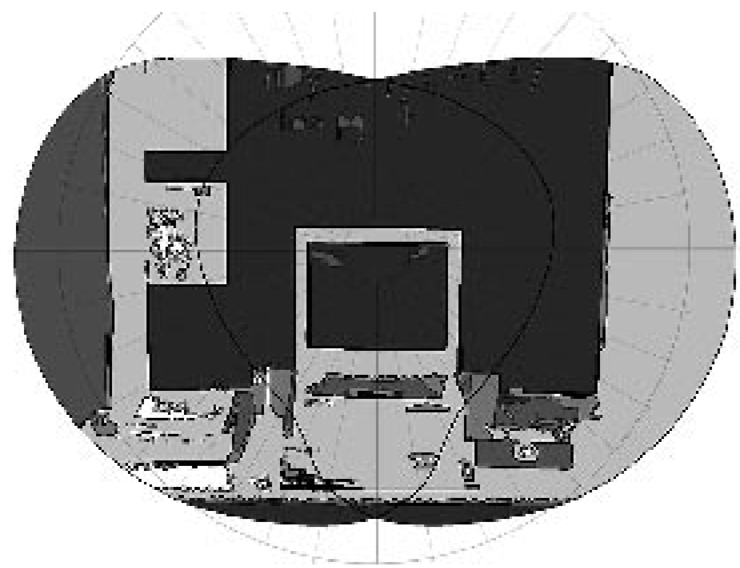

COMPUTER 35