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Thesis submitted in partial requirement for a Master's in Architecture,
University of California, Berkeley.

DEVELOPMENT AND USE OF A HEMISPHERICAL SKY SIMULATOR

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M.A. Thesis

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"The first illuminating engineer to get into the hair of his local architect was undoubtedly a fellow named ALADDIN, who performed all sorts of odd feats by rubbing a lamp of magical power. Presumably, when this hero of SHAHRZAD'S tales instructed his GENI to erect a castle, the architect's society of old Arabia assembled in solemn session and members warned one another....."Watch out for those lighting fellows..... they are beginning to invade our field and ALLAH knows where they will stop.....!" (John C. Kromhout, 1947¹.)

ACKNOWLEDGEMENTS

In submitting this thesis, I wish to thank a number of individuals: for theory of design S. Selkowitz, J. W. Griffith, Oyvind Aschehoug, and B. MacSwain; for architectural applications J. Esheric; for theory of accuracy D. MacGowan, J. P. Protzen, and R. Clear; for electrical specification and testing of lighting control system, F. Rubinstein, and D. DiBartolomeo; for construction N. Tenner; and for ventilation W. Inng.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Buildings Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

SUMMARY

The following thesis, submitted in partial satisfaction of the requirements for the degree of master of architecture, describes the design and construction of a sky simulator at the University of California, Berkeley, Department of Architecture. In 1979 a decision was made to explore the possibility of building a sky simulator as part of a DOE-supported program to advance the use of daylighting techniques in energy-conserving buildings. Although sky simulators were used extensively for important studies in the 1940s and 50s, by the mid-1970s no facilities appeared to be in routine use in the United States. Given the value of these facilities for design studies, computer model validation, and lighting quality studies, the University and Lawrence Berkeley Laboratory decided to build a sky simulator that could serve the functions of research, architectural design, and teaching. This thesis reports the design, construction, and calibration of the sky simulator. The study involved reviewing the modeling capabilities of sky simulators that have been built and used in North America and overseas.

TABLE OF CONTENTS	PAGE
INTRODUCTION	1
I. HISTORICAL REVIEW	7
II. DESIGN AND CONSTRUCTION OF A SKY SIMULATOR	21
A. Conceptual Method	21
B. Hemispherical Sky vs. Mirror Box vs. Translucent Sky	32
C. Construction of Opaque Reflecting Dome Structure	36
III. LIGHTING SYSTEM DESIGN AND LUMINANCE SIMULATION	42
A. Lighting System Concept	42
B. Lighting Power and Capability Estimation	44
C. Lighting System and Controls	52
D. Sun Simulator	64
E. Ground Reflectance Simulator	66
F. Ventilation	70
G. Model Platform	71
H. Models	72
I. Instrumentation	88
J. References	92
IV. C.I.E. OVERCAST, UNIFORM, AND CLEAR-SKY CONDITIONS	93
A. Capabilities of the System	95
B. Accuracy of the System	98
C. References	150
V. INSTRUCTION AND RESEARCH USES	152
A. Operation of Sky Simulator	152
B. Sky Luminance Measurements	154
C. Use of Photography in Visual Evaluation	156
D. Computer Programs	159
VI. BIBLIOGRAPHY	170

VII. APPENDIXES

173

A.	Model Furniture Supply	173a
B.	Installation Instructions for Sky Simulator	179
C.	Study Cases	182
D.	References	214
E.	Computer Program Listing and Outputs	215

LIST OF	FIGURES	PAGE
Fig. 1	(A through J) Historical Review	11-20
Fig. 2	Matrix of Conceptual Design	23
Fig. 3	Dome Sky	32
Fig. 4	Mirror Sky	34
Fig. 5	Translucent Sky	35
Fig. 6	Construction Pictures	38-40
Fig. 7	Solid-Angle	44
Fig. 8	Development Schedule	53
Fig. 9	Reflectors	55
Fig. 10	Reflectors	54
Fig. 11	Lamp and Dimmer Testing	56
Fig. 12	Lamp and Dimmer Testing	57-58
Fig. 13	Control and Switch Panel	63
Fig. 14	Effective Volume of Dome	46
Fig. 15	Sun Simulator Design Options	65
Fig. 16	Sun Simulator Design Options	66
Fig. 17	Ground Reflectance Simulator	68-69
Fig. 18	Fan Picture and Temperature Test	70
Fig. 19	Result on Temperature of Sky Simulator	70
Fig. 20	Platform and Photographs	71
Fig. 21	Platform for Simple Model Construction	81
Fig. 22	Effect of Glazing and Details on Fenestration System	83
Fig. 23	Ground Reflectance Results	84
Fig. 24	Photograph of Models	85
Fig. 24	(A and B) Photograph of All Instruments	91
Fig. 25	(A through G) Accuracy Figures and Graphs	100
Fig. 26	Accuracy Figures and Graphs	101
Fig. 27	(A through H) CIE Clear Sky Distribution (Horizontal Section)	103
Fig. 28	(A through H) CIE Clear Sky Distribution (Vertical Section)	111
Fig. 29	Model Measurements	123
Fig. 30	Sky Measurements plot	124
Fig. 31	(A, B and C) Effect of High Ground Reflectance	125-127
Fig. 32	Measurement Forms	129-130
Fig. 33	Horizon Scale Error	133
Fig. 34	Waldram and LIAM use for Horizon Scale Error	134
Fig. 35	Horizon Scale Error Reduction within Dome Sizes	135
Fig. 36	Use of LIAM Diagram	141
Fig. 37	Use of LIAM Diagram	143
Fig. 38	Use of LIAM Diagram (A,B,C)	145
Fig. 39	Sky Measurement for Accuracy within Dome Volume (A,B,C)	147
Fig. 40	Appendix C	183
Fig. 41	Study Case (2)	205-215
Fig. 42	Appendix D Sky Simulation Plots	253

INTRODUCTION

Daylight, as a source of illuminance in building interiors, provides the architect with one of his or her most effective means of esthetic expression. Consideration of site, orientation, proportion, and fenestration are all influenced by the degree of importance attached to utilitarian and aesthetic aspects of daylighting in structures. Optimal use of daylight requires considering the following in design:

1. The dynamic quality and direction of daylight and sunlight illuminance.
2. The luminance (photometric brightness) and luminance distribution of different sky conditions.
3. The effect of local terrain, landscaping, nearby buildings, and planning regulations on daylight availability (actual or theoretical).
4. The effect of window configuration and size and the color and distribution of reflectances, nature of internal surface materials, and orientation of internal surfaces.
5. The provision for human visual comfort, alleviating or avoiding disability glare.

The luminance ratio within space is of greater importance than the physical luminance of any surfaces. Garnett states, "The healthy functioning mind needs to secure a frequent change in the content of experience, which is usually achieved by a change in the focus of attention."¹ For

¹Garnet Campbell A., "The Mind in Action"

this reason, an evenly lighted room or space is characteristically undesirable. If one recalls the richness of experiences such as a stroll on a bright, sunny afternoon or the ease and relaxation which one experiences before a fireplace, it becomes obvious we can influence our psychological state with the correct use of light. The vast significance of this is clear. Functionally, as well as aesthetically, spaces often require specialized lighting to fulfill operational needs. Although these needs appear obvious in retrospect, most buildings are designed on three different stages: one for plane, one for the walls and elevations, and a third for equipment or furnishings.

To account for all three planes, the architect will have to enforce his prerogative; he or she must see each form evolve as it will actually be shaped by the light around it, adjacent to it, in front, and above it. Aesthetic considerations are preserved when a space or building is harmonious with its environment, its purpose, its background. To be architecturally sound, scale, proportion, and structure must be properly related among all elements.

Thermal and spacial requirement raise concerns about effective use of dwindling natural resources and has renewed interest in building design strategies that function harmoniously with the natural environment. People have always welcomed daylight in buildings, and much of the history of architecture can be seen as a conflict between the desire to admit daylight, sunlight, and view and the need to control extremes of local weather and other undesired intruders. Because light defines architectural space, the most successful building designers have been those who have successfully manipulated daylight and electric lighting

to provide for both function and aesthetics in the built environment.

A new concern for minimizing unnecessary energy use in buildings has prompted a re-evaluation of the role that daylight might play.⁽²⁾ In addition to a concern for the quality of light in an architectural space, the energy use and load management implications of daylighting are now of interest and concern to building designers. In order to successfully integrate daylighting as an energy-conserving strategy into the building design process, the designer must have available an array of appropriate design tools.

The use of physical models for analysis and prediction of daylighting distribution in a space is well established in the literature and in practice. Since the interreflectances of light in a geometrical volume is independent of size, a carefully constructed scale model can provide a highly accurate simulation of illuminance levels or ratios that would occur in the full-size space. Interior daylight levels can also be determined by designers using mathematical models. Although it is possible to model complex geometrical detail, in practice most mathematical models cannot fully account for geometrical complexities and details of surface texture and reflectance. When mathematical models are validated, it is almost always by comparison to measurements made in a real room or a scale model. It should be emphasized that most daylighting design decisions are made on a comparative basis between alternative fenestration and room designs. In this circumstance, many of the small systematic errors one might find in either a mathematical model or a scale-model study will disappear when competing designs are compared. The models can be used not only for evaluating and predicting lighting

quantity, but also for assessing some aspects of lighting quality and other more subjective factors in the building design.

Model tests conducted out of doors require only the availability of adequate photometric instrumentation and the scale model. Outdoor testing allows natural lighting to be evaluated under a wide range of standard and nonstandard sky conditions, including direct sun. It also permits evaluation of the effects of unique environmental factors at the building site--landscaping, adjacent buildings, and other microclimatic effects. The chief drawback to outdoor testing is that the sky is a constantly changing light source--no two clear or cloudy days will ever be quite alike. Attempts to develop a design concept by continuously modifying a design and then testing it on successive days requires that great attention be paid to normalizing the sky conditions under which all tests are made. It may also be desirable to test a model under clear skies with a varying solar altitude, and it may not be convenient to wait six months until those sun conditions are available. These problems can be solved--a model may be tilted to simulate a different solar altitude, but the apparent sky vault will then include a large portion of ground-reflected light. In the past, manual collection of photometric data at multiple points in a model was a tedious process that often resulted in errors because sky conditions could change significantly during a measurement sequence. This was further complicated by problems with sensitivity and the dynamic range of many of the sensors that were being used. Most of those problems have been alleviated by new silicon photodiodes and data acquisition systems that can record data from a large number of sensors in a matter of seconds.

A solution to many of the difficulties that arise from outdoor model testing is to reproduce the sky indoors in a controlled sky simulator. The absolute illuminance in a simulator will be less than the real sky, but if the luminance distribution is properly reproduced, model measurements need be adjusted only by a single scale factor. Depending upon the type of testing to be done and the available resources, a variety of sky simulators can be constructed.

In the past fifty years much work has been achieved in developing methods for estimating daylight in buildings. However, further information is required on interreflections of daylight in interior for CIE clear-sky distributions. There is also a pressing need for practicing architects, engineers, and researchers to have at their disposal simple, non-mathematical methods to determine the daylight performance of proposed building in compliance with CIE design skies.

Scale models can provide architects with the capability for predicting daylight performance under clear and overcast sky conditions in a simple and accurate way, and the use of scale models in architectural design process has a long history. The usefulness of conventional architectural model in luminance design can be improved by the use of a sky simulator while not negating the need to further develop empirical numerical and graphical designs aids for CIE sky conditions.

Specific performance capabilities envisioned for the sky simulator included:

1. uniform, CIE overcast, and CIE clear-sky luminance distributions;

2. variable ground reflectance;
3. a sun simulator;
4. a lighting control system that allows easy conversion from one type of sky to another; and
5. photometric instrumentation and data recording capabilities.

In addition, an important goal was to develop a facility that could be reproduced elsewhere at low to moderate cost. This report describes the design and construction of the facility, development of the required sky luminance distributions, test results from case studies, capabilities, calibration, accuracy of system, and future plans.

I. HISTORICAL REVIEW

Natural light within the building is one factor that controls the visual comfort and physiological well-being of the occupants. There is a need to predetermine values of natural light for architecture if one seeks to incorporate natural light. Long ago, architects used to compare an old building against a new one in order to determine the effectiveness of the new design. Nowadays, with the help of graphical techniques and drawings, a three-dimensional scale model can be constructed in order to evaluate different possible designs for fenestration systems. These techniques are very time-consuming. Engineers used physics to develop mathematical models for predicting illuminance levels within simple structures having no interreflectance. It was necessary, however, to check the prediction against actual measured values; therefore, physical models were first used simply by placing them under natural sky. It was found that sky conditions do not stay the same. As a result, researchers began experimental and theoretical daylight studies under sky simulators that could provide constant conditions.

In addition to the experimental advantages of taking daylight measurements in sky simulators, there are certain advantages from a purely scientific point of view:

1. The simulation of daylight condition remains stable but variable. The brightness pattern of the sky can be contrived to suit the specific model experiments.
2. The effect of the size and position of windows on the daylight received on the working plane can be determined simply, and dif-

ferent complex fenestration system can be evaluated.

3. The effect that direct skylight has on changes in reflection characteristics of exterior and interior surfaces can be studied.

Historically, the first artificial skies were light boxes () that used a uniform-area light source in a white painted box. These were used to study the daylight performance of skylights, lightwells, and vertical windows. When the light boxes were used to simulate sky conditions where fresh snow was on the ground (rooms having 30% to 90% reflectances), there was good correlation with actual conditions. However, these light boxes produced poor correlation with other sky and ground conditions. In 1950, this discrepancy was explained: illumination from below the horizon being reflected off the ceiling and upper walls produced less illumination on the workplane than did direct illumination from above the horizon (see discussion of horizon scale error in Section IV B, Accuracy of the System).

To overcome this problem of separating illumination from below-the-horizon illumination from above-the-horizon illumination, artificial skies had to be developed to simulate sky and ground conditions. It was also found that differences in luminance distribution between real clear and overcast skies and a uniform sky resulted in significant variation of daylight distribution in the room. Therefore, there was a need for developing a sky simulator which could take into account the variation of the real sky from a uniform sky pattern. The luminance distribution in light boxes was simulated for the overcast sky variation which is in its zenith and horizon with a ratio of 1 to 3. The CIE developed a standard overcast sky $[B_a] = (B_z/3) \times (1 + 2 \sin a)$ where $[B_a]$ is luminance

at altitude angle α and B_z is the luminance at zenith] for use in setting daylight codes.

Various types of three-dimensional skies have been built. They range from back-lit area sources some distance from the fenestration wall to spherical and elliptical sky vaults illuminated from below the horizon or from above the model being studied. In these skies the sky vault was painted white and luminance was varied by light sources that were not visible to fenestration.

The hemispherical sky simulator(3,4,5,6,7,8) has the advantage of allowing one to study the effect of various daylight distributions on multilateral fenestrations facing different orientations. However, they are illuminated from the inside, which can produce an excessive amount of heat depending on the type of lighting system. The hemispherical sky simulator can be made of translucent material and can rely on exterior illumination, which would eliminate the heat problem.

Another type of three-dimensional sky is the cylindrical sky or semielliptical sky vault. In these skies, the sky luminance is achieved on a reflecting surface illuminated by light sources shielded from the fenestration of the model and located below the horizon or above the model. But in these sky vaults one can only study the daylight distribution from a single orientation at a time.

Another variation of the three-dimensional sky vault is a mirror-type sky, in which the light flux from an overhead luminous source is redistributed by mirrored walls and produces an overcast sky distribution at the model location. This type of sky simulator is good for an overcast

sky, but the azimuth luminance cannot be varied.

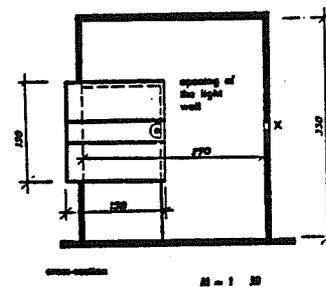
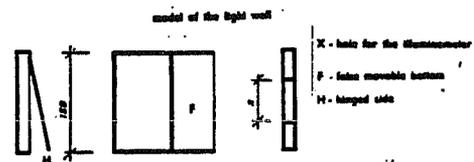
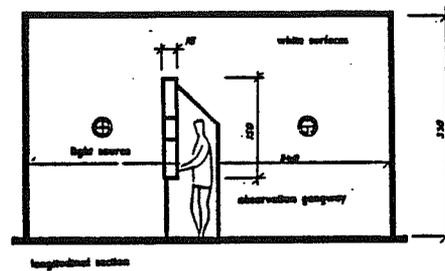
This historical review covers several significant daylighting multipurpose artificial skies. The methods of measurements are briefly described as follows:

1. type and dimensions of artificial skies;
2. the source of light and sky effectiveness;
3. measuring equipment;
4. the scale of the model;
5. names of authors, sponsoring institutions, and countries.

A

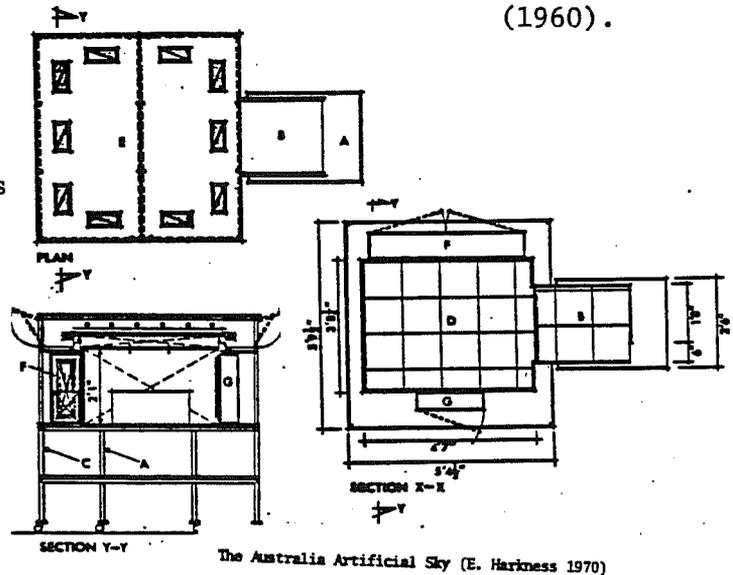
Equipment for Model Measurements
by H. F. Meacock and G. E. V. Lambert (Meacock, 1930).

1. Whitened room
540/270/330cm
2. Two gas filled lamps
uniform \pm 15%
3. Macbeth illumino-meter
4. 1:20
5. H. F. Meacock
G. E. V. Lambert
Dept. of Scientific and
Industrial Research
London, 1930



Source:
CIE Pub. No. 5
(1960).

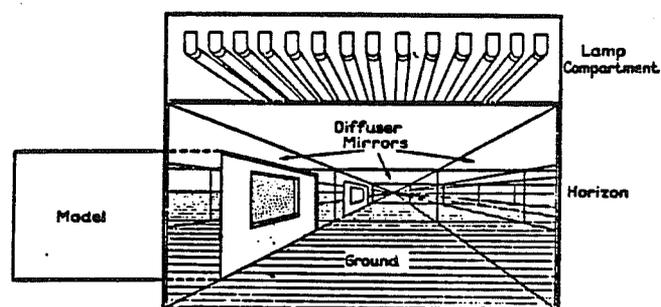
1. Mirror chamber
artificial sky
2. 20x4'6" cold cathode tubes
6x5' fluorescent tubes
3. EEL B.R.S. photocells
4. 1 inch
5. Harkness, E.L.
Building Science Lab
University of Newcastle
N.S.W., Australia 1970



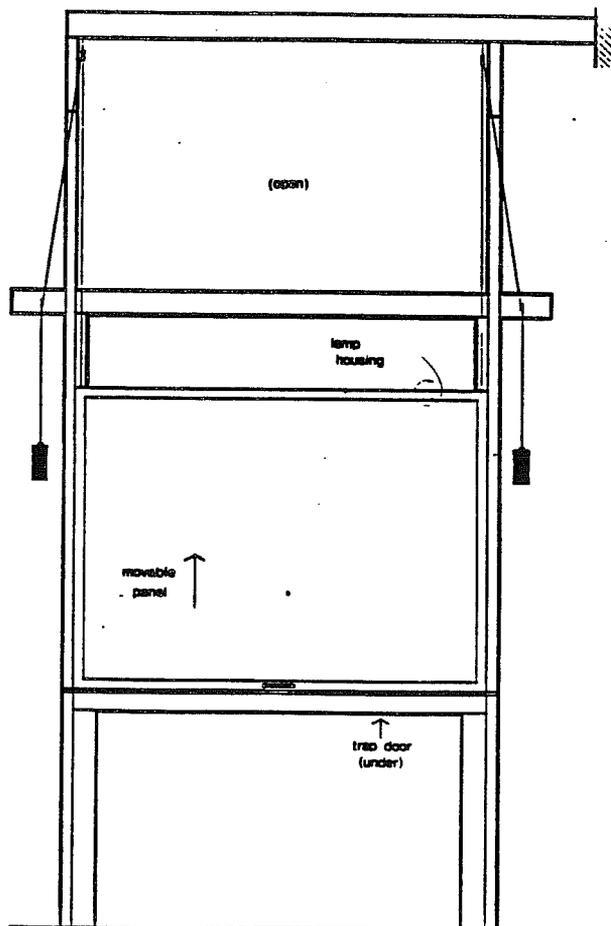
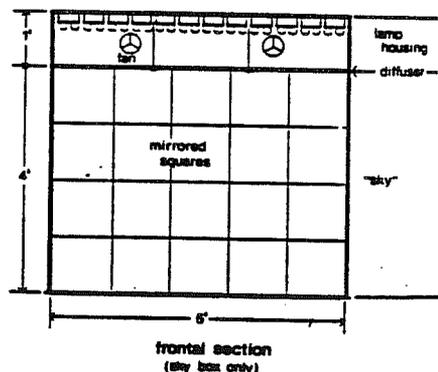
Source: CIE Pub. No. 5 (1960).

B

1. Reflectarized Box Rectilinear
5 x 4 x 3.6 ft.
2. M.B.Tu lamps
reflected and sidelight
C.I.E. sky
3. Silicon cells - the first to
use the Silicon cell (1964)
1:12, 1:96 cm. scale
4. University of Strathclyde 1963
5. David MacGowan (same
researcher using mirror
and M.B.Tu lamp in rectilinear
sky, used the same concept of
moveable luminance panel and
designed them in the University
of British Columbia in 1970
and Adelaide in 1971, and again
in the University of Washington
in 1974.)

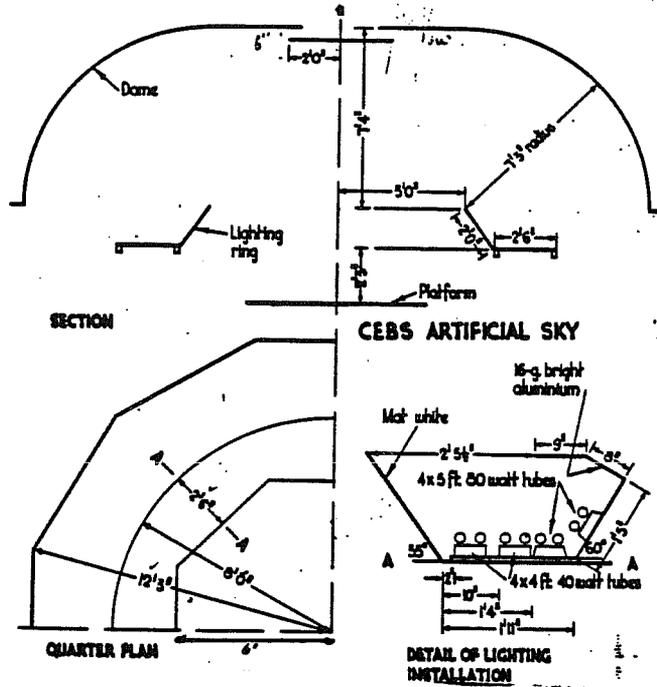


The Artificial Sky in University of Washington



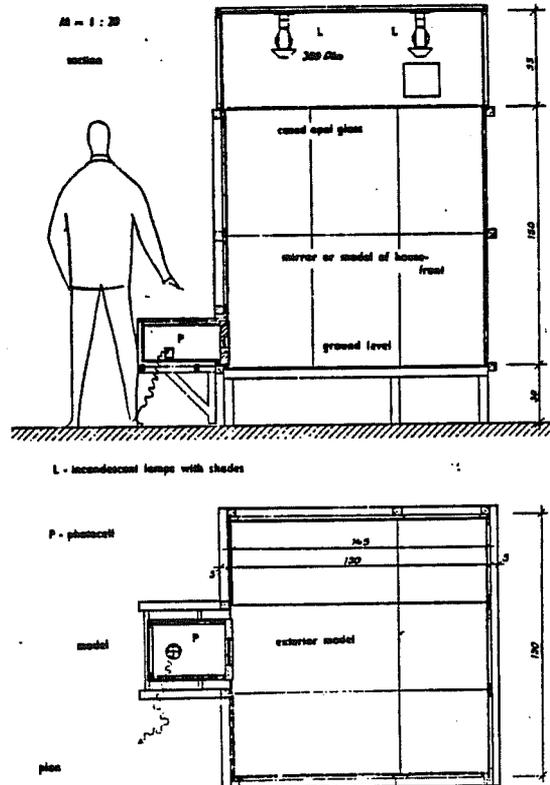
1. Flattened Dome
24 ft. diameter \emptyset
2. 4 x 5 ft. fluor 80 w.
4 x 5 ft. fluor 40 w.
3. 25mm. Selenium photocells
4. 1/8 through 1 1/2"
5. Commonwealth Experimental Building Station (C.E.B.S.) Australia 1962

Commonwealth experimental building station (1962)



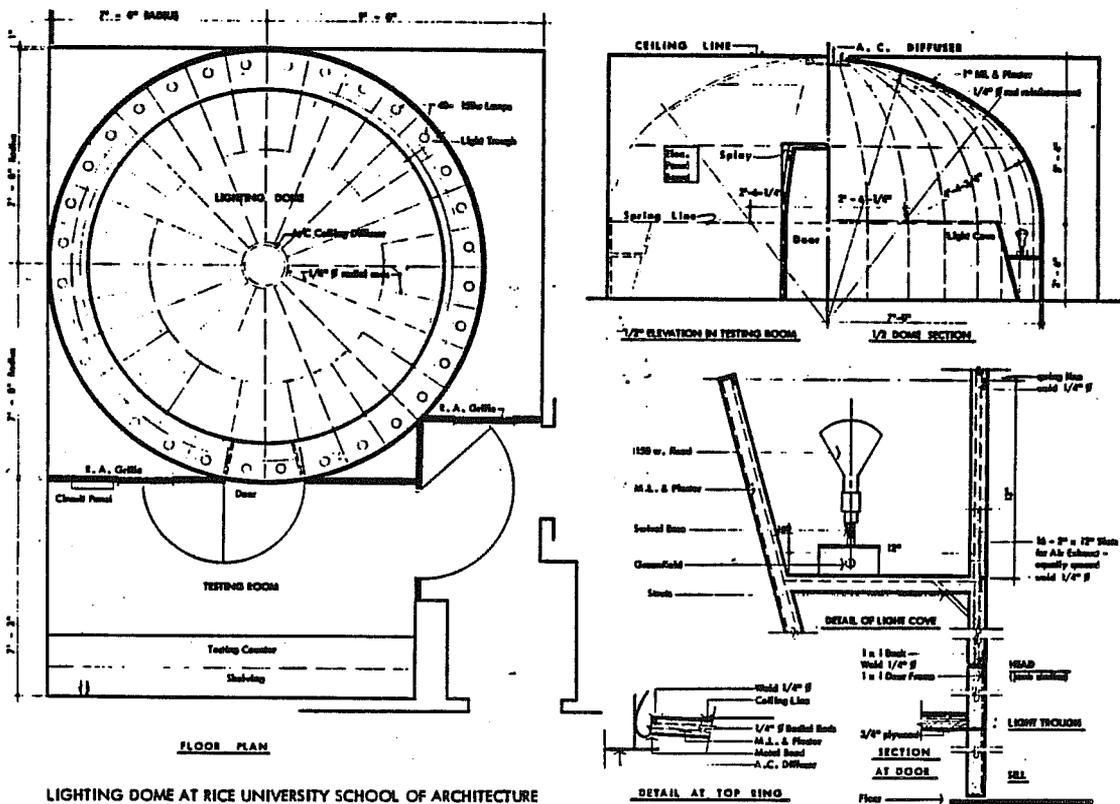
1. Rectilinear box
1.50 x 1.50M and 2.3M high
2. 16 x 200 w. incandescent on moveable arms uniform luminance $\pm 2\%$
3. 25mm. Selenium photocells
4. Approx. 1:10
5. Royal Institute of Technology Stockholm, Sweden G. Pleijel, 1949

The Pleijel Rectilinear Sky (Pleijel, 1949).



D

1. Hemispherical
14 ft. \emptyset
2. 40 x 150 w. flood lamp
overcast and graduated
luminance
3. Honeywell pentax light meter $3^{\circ}/12^{\circ}$
4. 1" inch
5. A. A. Leifeste, Jr.
Rice University,
Houston, Texas, U.S.A.
1966



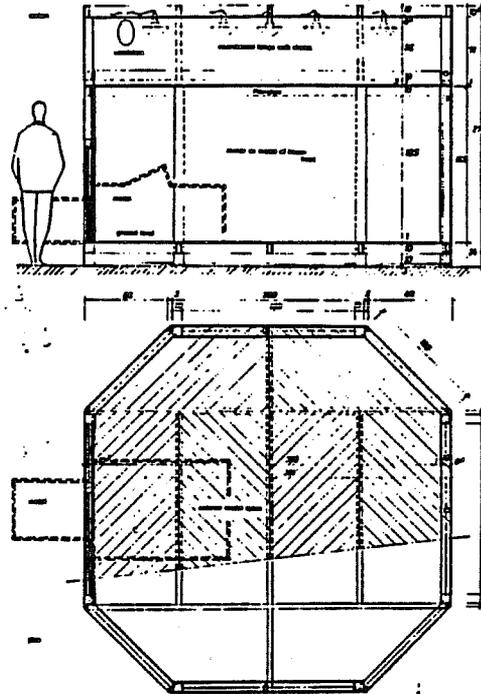
LIGHTING DOME AT RICE UNIVERSITY SCHOOL OF ARCHITECTURE

E

1. Octagonal plan
360/360 cm, 165 cm high
opal plexiglass
2. 12 fluorescent
13 incandescent
uniform and graduated
luminance
3. Selenium photocells
4. 1:10
5. R. Kittler
Institute of Build. and Arch.
Slovak, Academy of Science
Czechoslovakia. 1958

Source: CIE Pub. No. 5 (1960).

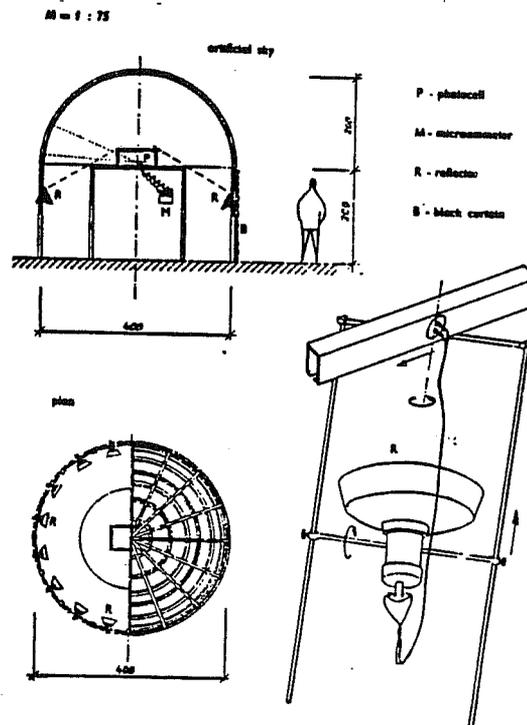
The Kittler Artificial Sky (Kittler, 1958).



A. A. Gershun's Model Sky (Zelenkov, 1933).

1. Hemisphere
4M Ø
2. 16 x 500 w.
lamps on moveable arms
3. Selenium photocells
4. Approx. 1:20 - 1:30
5. State Optical Institute
Leningrad
U.S.S.R.
A. A. Gershun,
V. A. Koy
and Associates,
1933

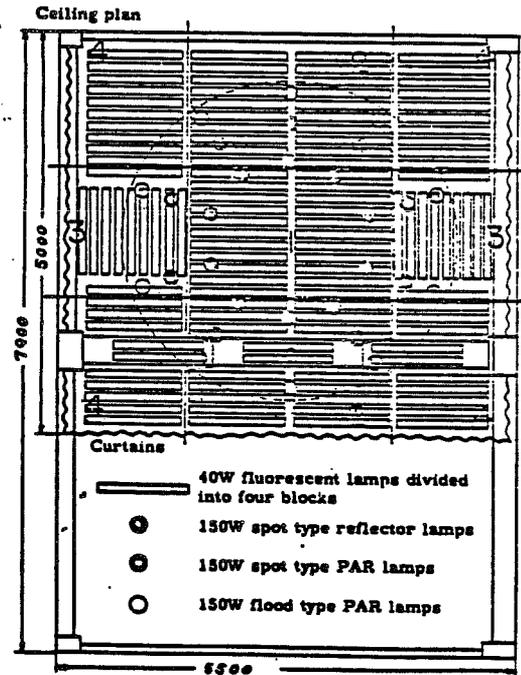
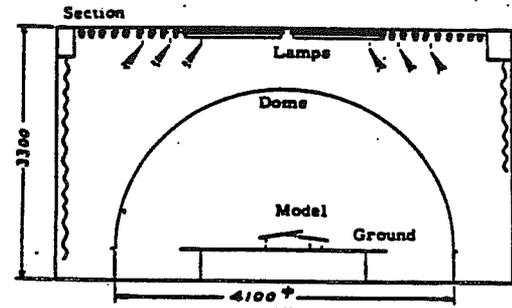
Source: CIE Pub. No. 5 (1960).



F

1. Room plus translucent hemisphere (dome)
Room 7 x 5.5 M.
Dome 4.1 M. Ø
2. 40 w. floor lamp
150 w. spot refl.
150 w. spot type P.A.R. lamps
150 w. floor P.A.R. lamps
650 CD/M² or 3000 lux for
C.I.E. overcast sky
3. Selenium photocells
4. Approx. 1 inch
5. M. Vitute, Inui, S. Matsuda,
Build. Research Inst.
Osaka, Japan 1967

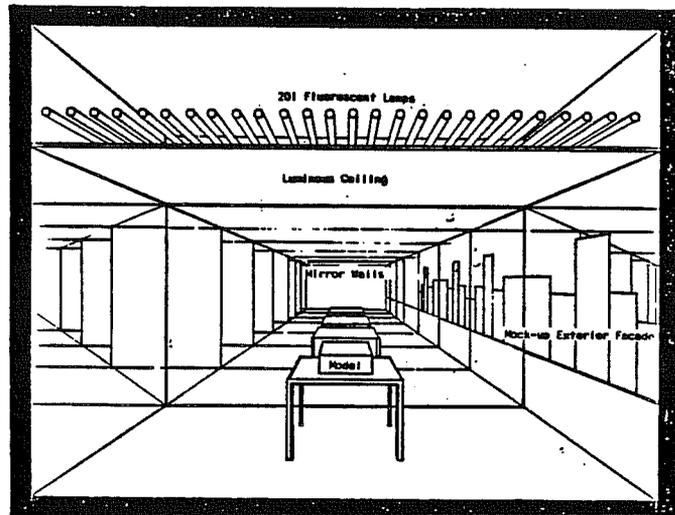
Section and ceiling plan of the B. R. I. sky Japan



(1:50)

(Longmore, 1962)

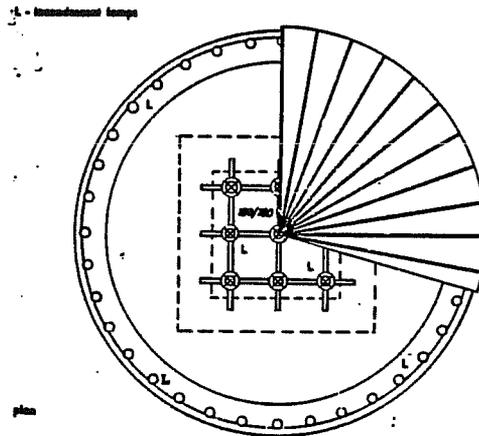
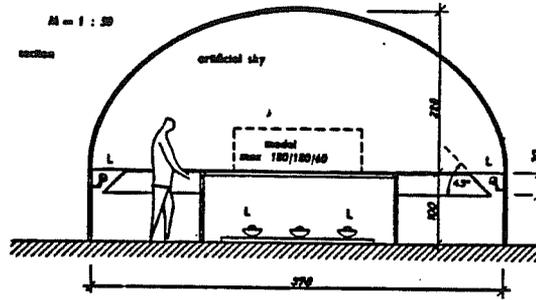
1. Rectilinear Box
2. 16 x 16 x 8 Mirrored Room
5' x 4' x 2.5 box
3. Selicon and E.E.L. BRS
photocells
4. Approx 1:20
5. Research Building Station
J. Longmore, 1962



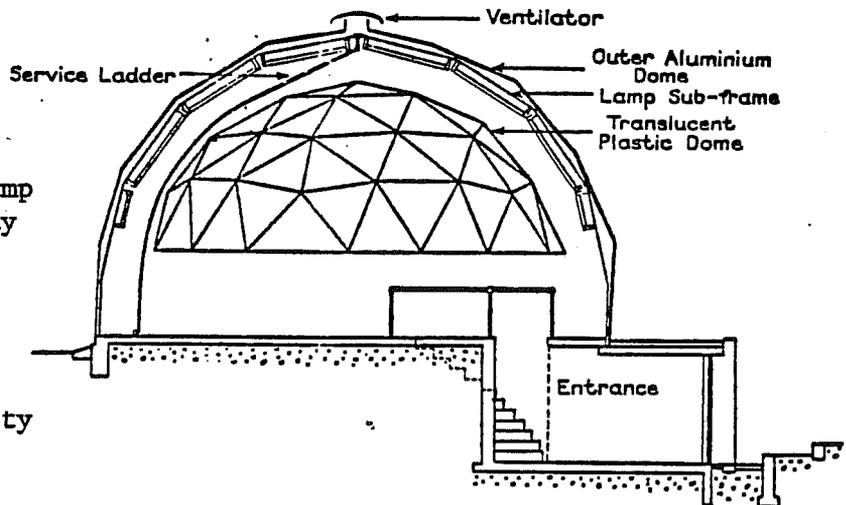
B.R.S. RECTILINEAR MIRRORED SKY

1. Semi-Ellipsoidal Dome
5.8M \emptyset
2.3M high
2. 36 incandescent plus extras on stands
Uniform and arbitrary luminance
1:2.5 to 2.1,
Horizon 343 cd/m²
Zenith 686 cd/m²
3. Selenium photocells
4. 1:12 - 1:24
5. Texas Engineering Experiment Station
Texas, U.S.A.
E. E. Vezey and Associates, 1955

The Sky at The Texas A&M Engineering Exp. Station (Vezey, 1955).



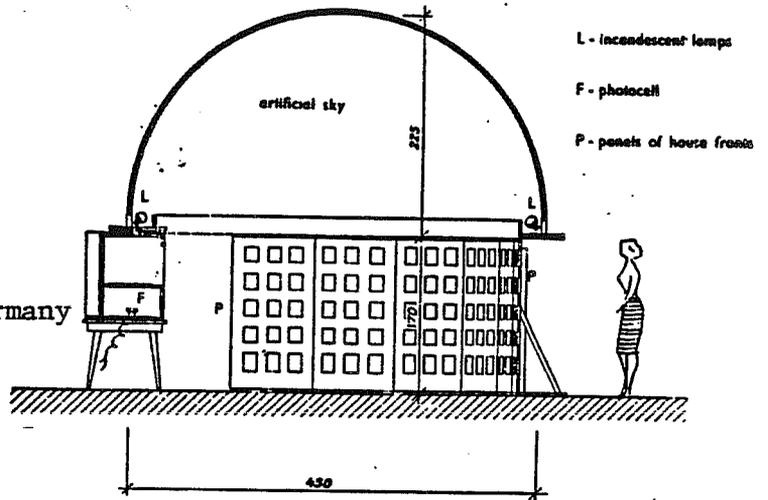
1. Hemisphere Translucent
24 ft. \emptyset
2. HPMV
Color corrected lamp
C.I.E. overcast sky
3. Silicon cells
4. 1" through 1½"
5. Cambridge University
D. Croghan, 1964



The transilluminated hemispherical artificial sky at the Cambridge School of Architecture.

1. Hemispherical
4.5M Ø
2. Row of incandescent graduated luminance
3. Selenium photocells
4. Approx 1:10
5. W. Buning
Inst. for Daylight
Technique 1 Berlin, Germany
1953

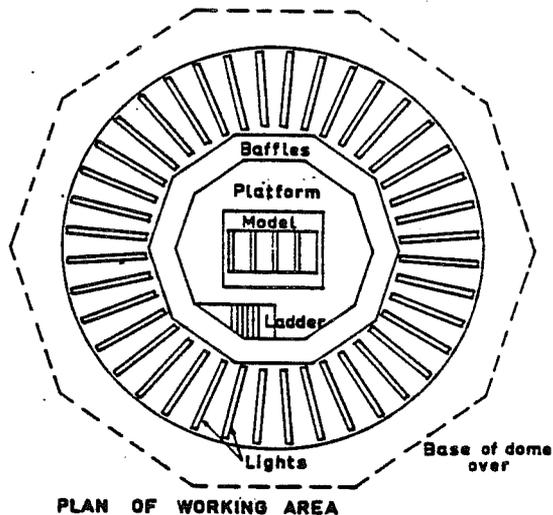
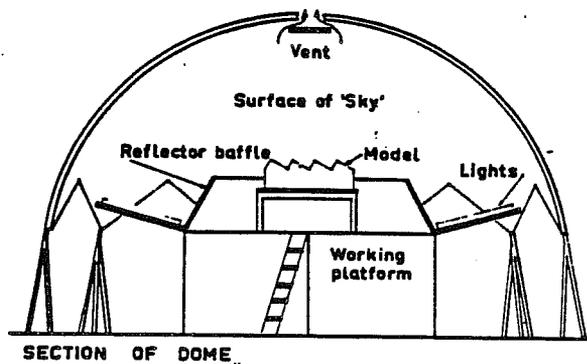
The German Artificial Sky in Stuttgart (Buning, 1953).



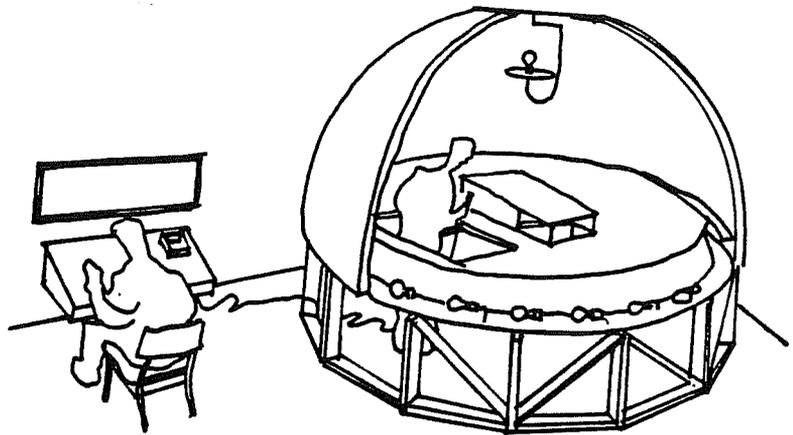
Source: CIE Pub. No. 5 (1960)

1. Flattened Dome
7.3 M Ø
2.9 M high
2. 48 x 40 w. fluorescent tube on suspending ring half way between the center uniform luminance $\pm 2\%$
3. Selenium photocells
4. Approx. 1:10 - 1:20
5. Commonwealth
Experimental
Building Station
(C.E.B.S.)
Australia
R. O. Phillips
and Associates,
1950

The artificial sky in Australia R-O Phillips

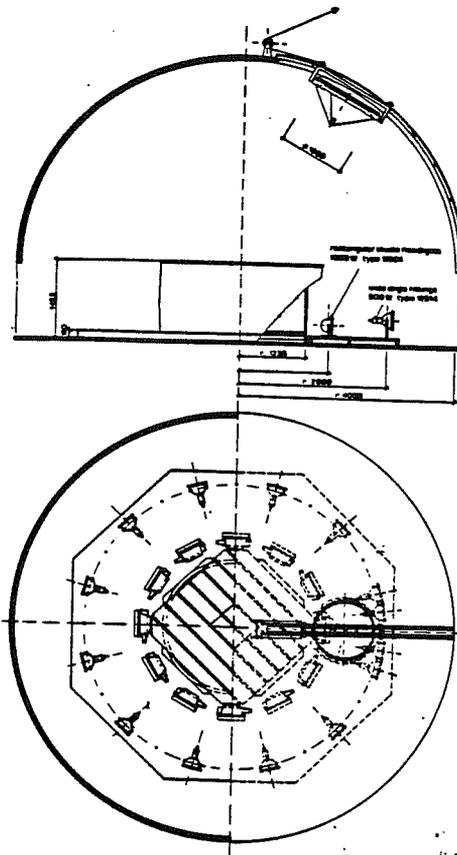


1. Hemisphere
3.05M \emptyset
2. Incandescent lamp
3. Selenium photocells
4. Approx.
1:20 - 1:30
5. Texas Engineering
Experiment Station
Texas, U.S.A.
E. E. Vezey,
1951



1. *Hemisphere
8M w/artificial
sun perbolic mirror
800 w. Tungsten -
Halogen lamp
2. 2000 w. x 12 spot light
clear & cloudy C.I.E. skies
3. EEL-BRS daylight
photometer
4. 1:5 - 1:30
5. Slovak Academy of Science
Czechoslovakia
R. Kittler,
1973

* Kittler, R., Ondrejick, S., and Hlt, S., Private
research report P 12-121-001-02-03/3, Institute
of Construction and Architecture, Bratislava
(1973).

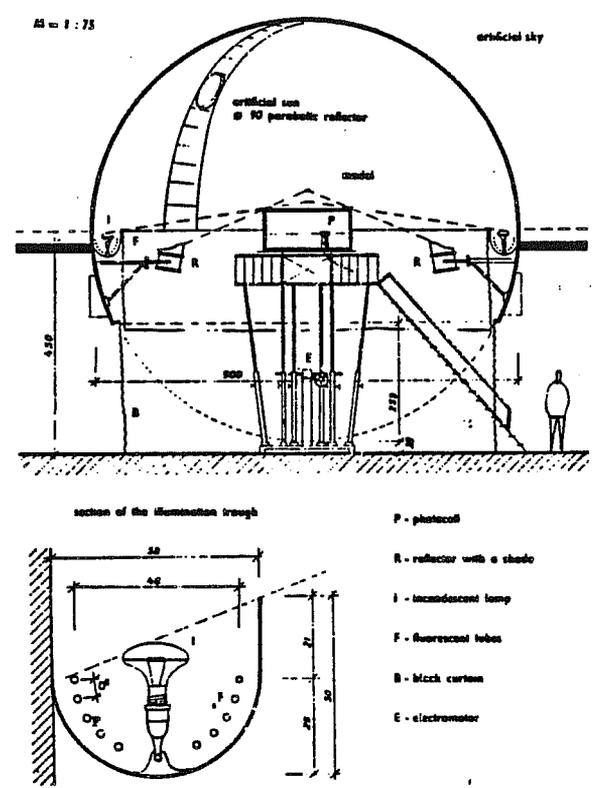


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Lighting Research and Technol-
ogy, London, England, © 1974.

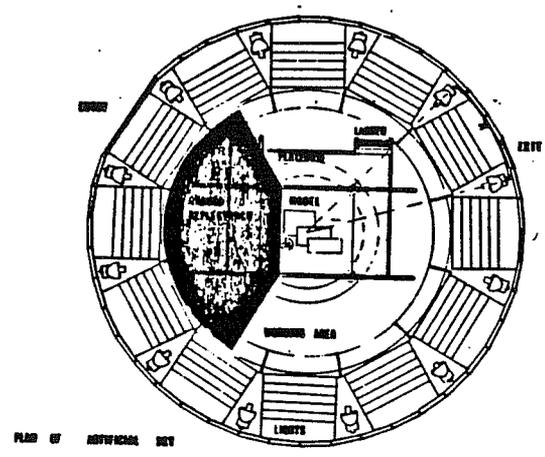
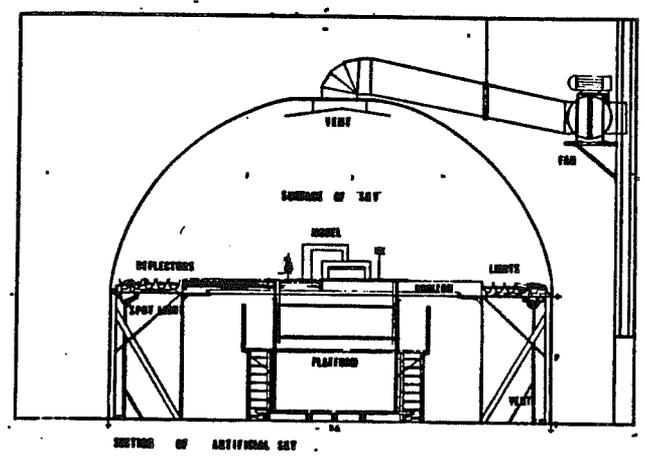
J The U.S.S.R. Skydome (Gusev, 1950).

From : CIE Pub. No. 5 (1960)

1. *Hemisphere
9M Ø w/artificial sun (2000 w. bulb with parabolic reflector 90mm.) moveable along a meridian
2. 72 x 300 w. incandescent
240 x 30 w. fluorescent
24 x 500 w. floor uniform luminance arbitrary graduated luminance, in range -5 cd/m^2 10-2000
3. Selenium photocells
4. 1:5 - 1:30
5. Academy of Building and Architecture Perovo-Moskva U.S.S.R.
N. M. Gusev and Associates, 1952



1. *Hemisphere
24 ft. Ø
w/ artificial sun
2. 100 flur. 4 ft. 1½" Ø
36 flur. 2 ft. 1½" Ø
spot 750 w. x 12
clear-cloudy automatic control
3. Megatron photocells
Silicon cells
4. 1/8" through 2"
5. Architecture Dept.
University of California
Lawrence Berkeley Lab
Berkeley
U.S.A.
S. Selkowitz
B. McSwain
M. Navvab, and
D. MacGowan
1980



II. DESIGN AND CONSTRUCTION OF A SKY SIMULATOR

A wide variety of design approaches and numerous specific construction details were developed and reviewed in the course of this project. A large, dome-type sky was selected as providing the greatest possible flexibility for future model measurements. The critical design and operating constraints were, first, the desire to provide a number of standardized sky distributions, a variable ground luminance, and a sun simulator; and second, the necessity for simple conversions between differing sky, sun, and ground conditions without the need for research personnel.

A. Conceptual Method

In order to review the advantages and disadvantages of each design, an evaluation matrix was developed to compare different approaches to the design of sky simulators, for example an opaque sky vault lit from the inside versus a translucent sky vault lit from the outside.

1. Introduction: Principle of the Evaluation, Methodology

Rather than starting from a specific design solution, present or past, it was decided to establish a conceptual framework that could accommodate any method. All that was required was apparatus that could artificially simulate the luminance distribution (overcast, uniform, clear) of the sky for buildings (parts of buildings, groups of buildings).

The evaluation method suggested here distinguishes two primary dimensions that help to analyze the problem:

- (a) The simulation criteria are shown as rows on the following evaluation matrix. They include criteria relative to the design, construction, and use of the simulator. They constitute a generalization of a simple cost/benefit analysis that requires a single decision-maker who has an open mind.

- (b) The elements of a design solution are shown as columns on the matrix. Any particular sky concept can be described in terms of these elements, so that several columns can be grouped to represent a design solution that can then be compared to other alternatives. This method allows comparison of radically different approaches as well as evaluation of the effect of relatively small modifications to a design solution.

The format used is schematized on the following matrix.

x format of the matrix

use pages 25 through 28

E	D	C	B	A	
					A
					B
					C
					D
					E
					F
					G
					H
					I
					J

use pages
28 through 32

With this matrix, a designer can identify those criteria that meet the design requirements for a particular sky simulator. Without prejudice one can look for similar or optimal design solutions. Depending on the criteria (such as space or budget), some of these solutions would be preferred. At this stage the decision-makers know that with the use of this evaluation matrix and the existing limitations, it can be decided which design proposal has the greatest advantage. In order to use this matrix one does the following:

1. identifies simulation criteria (heads and details of rows).
2. describes elements of solutions (columns).
3. ranks each element of a solution with regard to simulation attributes, on a scale such as --, 0 +, ++.

the + would indicate an advantage;

the - would indicate a disadvantage;

the 0 would indicate the absence of imaginable correlation:
irrelevance.

4. Ranks and gives weight to each attribute according to how critical it is to the particular design environment.
5. Combines weighted attributes to obtain a profile for each solution element, or for the entire solution.

At this stage, elements of the solution can be combined to generate numbers of alternative solutions. Steps 1,2, and 3 are general and tend

to be exhaustive, analytic. Steps 4 and 5 apply to the specific case: they tend toward selection, synthesis, design.

Step 1, Identifying simulation attributes. (The ordering used here implies no ranking.)

A. Simulation capabilities, types, ranges;

elements simulated; sky luminance distribution

1. overcast
2. uniform
3. clear
4. "arbitrary"
5. sun simulation
6. ground luminance

B. Accuracy

1. range of latitude, solar altitude
2. range of conditions covered
3. accuracy of simulation of standard conditions
4. replicability
5. possible orientations of building relative to sky
6. thorough rotation of model

7. thorough sky rotation

8. horizon error

C. Constraints on environment

1. physical dimensions of the enclosure (how large a scale model it can hold)

2. structural properties of enclosure (how many different luminance distribution can be simulated)

3. thermal environment: heat load

4. ventilating load

5. power load

6. outdoor or indoor location of enclosure

7. maintenance of the enclosure (how clean it can be kept)

8. functional purposes of the enclosure, time of operation devoted to sky

9. safety from theft, damage, wear and tear; ease of replacement, change

10. sensitivity of environment to failures (redundancy, emergency procedures); to fluctuations in the above physical variables

D. Financial constraints

1. construction budget
2. maintenance budget
3. equipment budget

E.

1. Operator, user access; possibility of direct observation from side, underneath
2. time and skills to complete construction
3. to explain operation
4. to set up simulation session
5. to vary simulation conditions
6. to calibrate equipment
7. to monitor simulation, collect outputs
8. to maintain equipment

Step 2, Describing Elements of Solutions

Elements include physical parts as well as characteristics of the equipment and of the simulation procedure.

A. Optical principle used for enclosure

1. direct

2. diffuse
3. refracted
4. reflected

(combination of above indicated by combining matrix columns);
total absorption of sky simulator (luminous, thermal) is a consequence

B. Physical properties of sky simulator

1. structural: outer dimensions of proposed design
2. available structural forms
3. mirror box, geodesic, elliptical, hemispherical, rigid, collapsible, translucent, opaque

C. Material

1. transmissivity, reflectivity of materials
2. air flow for thermal effect
3. durability of material
4. precision and variability associated with material and structural elements

D. Accommodation and access of models

1. range of model scales for buildings; space, orientation, available foreground and ground luminance

2. uncertainty and errors due to model's luminous interaction
 3. errors in luminous distribution and measurement due to size
- E. Accommodation and access of operator
1. access: space available; movements allowed, required
 2. errors in luminous distribution and measurements due to presence or movements of operator
 3. schedule of simulation procedure
- F. Characteristics of light sources
1. emission type: incandescent
fluorescent
high-intensity discharge, etc.
 2. dimmability/dimming effects
 3. geometric control: point, line, area source
 4. color rendition; spectral distribution
 5. effects over life of light sources
 6. location
 7. time-lag to full operation
- G. Controls associated with sky simulator: moving parts automatic, motorized, or manual.

- H. Controls associated with sky simulator's environmental parameters:
(thermal) ventilation, passive or active systems, power load access.

- I. Lighting controls associated with enclosure: mechanical; moving, changing parts.
 - 1. manual or automatic variability of reflectivity, transmission, absorption associated with light sources; dimmers/reflectors with lenses focusing - diffusers - diffractors; moving direction of flux

 - 2. control location centralized, dispersed;
calibration manual, automatic

- J. Sensors: type and measurement procedure
 - 1. size

 - 2. location

 - 3. sensitivity

 - 4. calibration

 - 5. reading: visual - automatic

digital - scalar

 - 6. recording method: manual, automatic

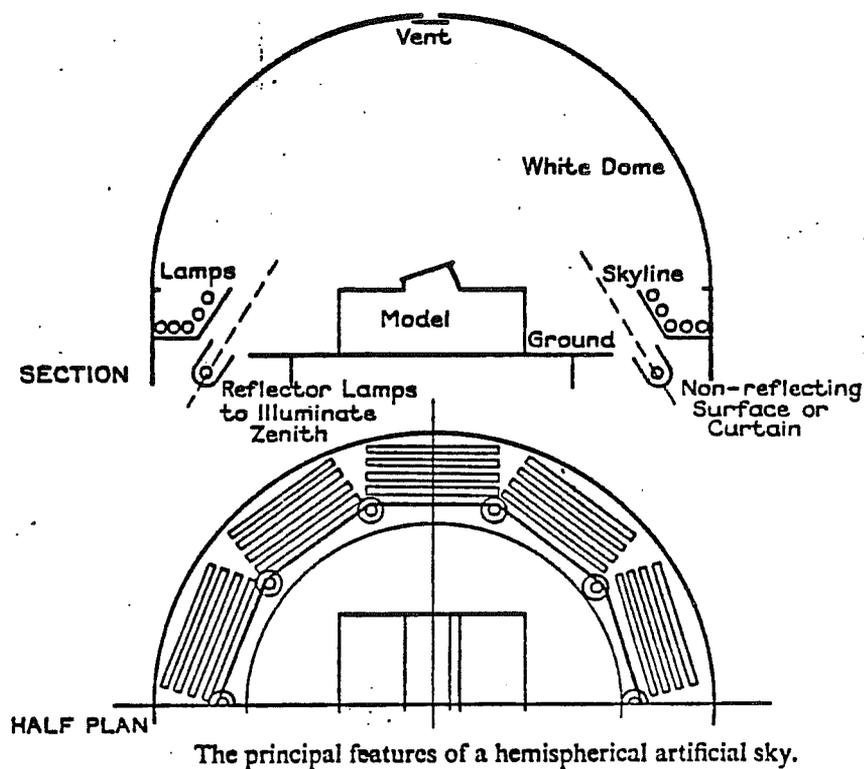
Once this method was developed it was decided to seek out a series of options that would include all possible capabilities within our space

and budget limitation. The following is a discussion of the possible options.

B. Hemispherical Sky vs. Mirrored Box vs. Translucent Sky

The luminance distribution provided by a sky simulator should be very close to real sky luminance patterns while at the same time providing enough light for taking measurements. It is possible to achieve the overcast or clear sky condition, or both, with a sky simulator and to have a minimum number of errors. A review of the advantages and disadvantages of various designs led us to three options:

1. the hemispherical, or "dome" sky;
2. the rectilinear or "mirror-box" sky;
3. the translucent "dome" sky;



Source:
Daylighting
 by R.G. Hop-
 kinson, P.
 Petherbridge,
 and J. Long-
 more.

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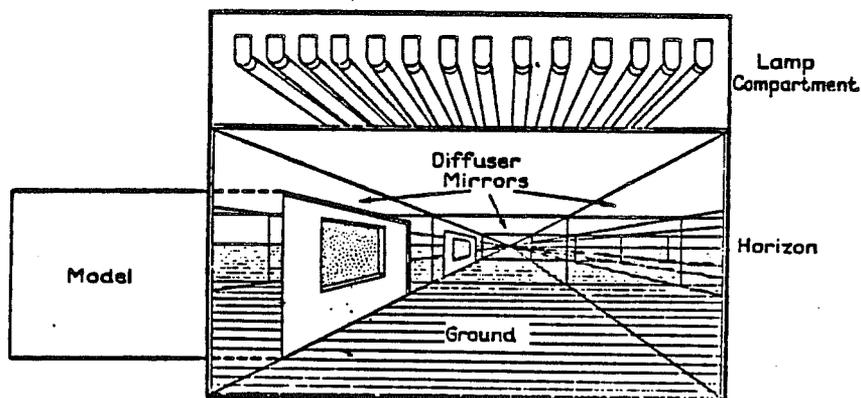
FIG. 3

1. Dome Sky

The dome-type artificial sky consists of one of a number of sizes of hemispherical vaults having a lighting system at its base which illuminates the interior of the sky, usually made of reflecting material. The lights can take many shapes and designs. The distribution is either close to CIE standard or some type of uniform brightness. Some artificial skies have an artificial sun either at a fixed point or on a track to produce a clear-sky distribution. They perform a simple and straight-forward function in respect to models and architectural use. A disadvantage of these types of skies is horizon error. This effect occurs because the dome's horizon edge is a finite distance away, but in real situations the horizon is infinitely distant. In hemispherical skies light from below the horizon reaches the ceiling of the model (which is placed at the center of the dome) and back room wall. But light from the actual sky never reaches a horizontal ceiling directly, but only by reflection from surrounding environment, and light on the back wall is often obstructed by trees or other buildings. This error can be corrected by reducing the scale of the model or by increasing the size of the sky simulator (See discussion of horizon scale error in Section IV B, Accuracy of System). Achieving a luminance distribution a hemispherical sky close to that of the real sky is usually a difficult, trial-and-error process. This difficulty can be reduced to some extent in the "translucent" dome. However, exposure of the translucent material to high temperatures and ultra-violet levels is a major disadvantage, as a higher cost of construction.

2. Mirror Box Sky

A sky simulator that overcomes the errors that can result in hemispherical skies is the mirrored-box, or rectilinear, sky. Basically it is built like a box in different sizes. The vertical walls are mirrored, producing an infinite series of reflections from horizontal sheets of white diffusing luminance material illuminated by its lighting system from behind thus an overcast sky distribution is easily achieved. A model can be placed inside if the simulator is big enough or can be outside with the window wall exposed to the sky simulator. With the rectilinear sky simulator it is possible to achieve high levels of illumination, comparable to real skies. There is an unavoidable error which is produced by the reflection of the model itself.



The principal features of a small rectilinear mirrored artificial sky.

Source: Daylighting,
by R.G. Hopkinson,
P. Petherbridge, and
J. Longmore.

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England, © 1966.

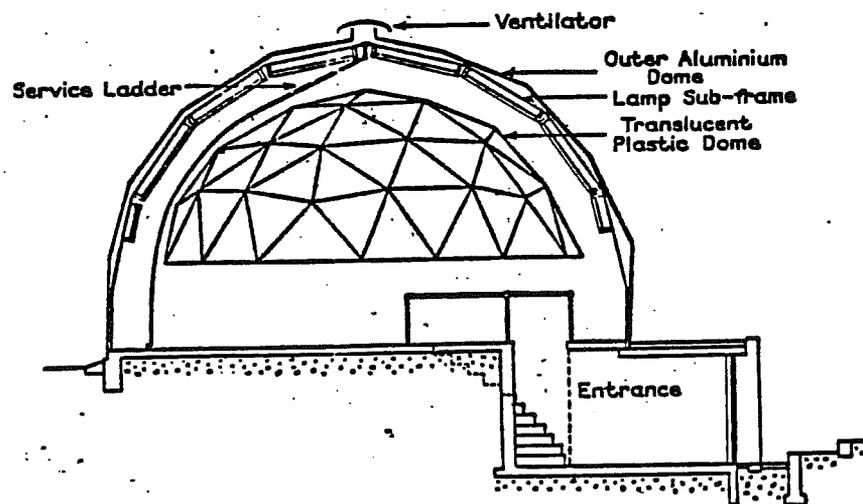
FIG. 4

3. Translucent Sky

A concept that involved a modified "translucent" dome was considered. This design consisted of a dome having a series of small standardized surface modules, each of which acts as a light-emitting element with an output intensity that is computer-controlled. This effect could be

achieved in several ways. Each surface module could hold a cluster of fiberoptic sources, each driven by a controlled-output lamp. The angular output of the fiberoptic cable is intrinsically limited and can be altered, if desired, with a lens assembly. Another approach considered was to use a surface composed of discrete light-emitting sources, such as is now used in large arrays for scoreboards at athletic events. These are already computer-driven to produce messages and visual displays. The use of other discrete light-emitting sources is possible too.

FIG.5



Source: Daylighting by R.G. Hopkinson, P. Petherbridge, and J. Longmore. Reproduced with permission of William Heinemann Ltd., London, England, ©1966.

A review of these three options led us to believe that with the space available to us it was possible to design and build a sky simulator which could have many more capabilities than a "mirror-box sky." At the same time the "translucent sky" could not be constructed within budgetary constraints. Thus an opaque reflecting shell 24 feet in diameter (maximum size within available space) was selected in order to minimize the horizon scale error.

C. Construction of Opaque Reflecting Dome Structure

We were fortunate in being able to use a large interior space within the College of Environmental Design at the University of California, Berkeley. Being inside simplified the problem of weatherproofing the dome structure. In order to provide adequate space to work within the structure, to allow access to relatively large models, to minimize horizon errors, and to accommodate a ground reflectance capability, we decided upon a relatively large structure, approximately 24 feet in diameter. After investigating a variety of sources for ready-made domes of this size, we selected a pre-manufactured 24-foot-diameter metal dome used as the top of a silo. These are cheap, provide a rigid fireproof structure, are easily assembled with unskilled labor, and with minor modifications provide an adequate interior reflecting surface.

To provide better working conditions within the simulator, the metal dome was placed atop a seven-foot high plywood cylindrical wall having double doors to allow scale models to be moved in and out. (Fig. 6)

First, the sheet metal dome was assembled on the floor of the room housing the artificial sky. The dome consists of 44 sheet metal panels that

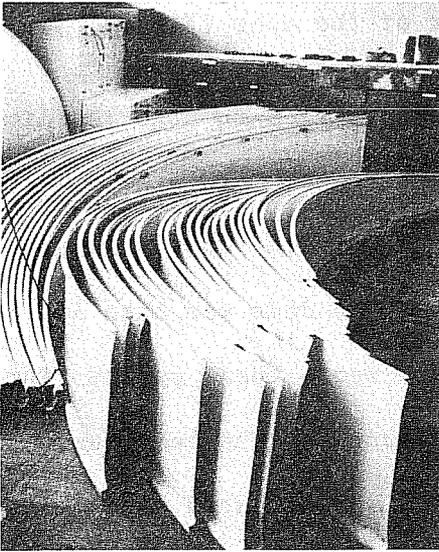
fasten to a support ring, interlocked and secured with clamps. (See Figure 6.) (These domes come in a range of sizes and are relatively easy to erect.) Care must be taken the the alignment of the panels and their attachment to the ring, so that the structure is symmetrical (Figure 6_f). Once the sheet metal dome was assembled, the support walls were fabricated from 1/2" plywood sheets and 2 x 4 supports (see detail in Figure 6), and propped in place around the perimeter of the dome (Figure 6).

At this point in the construction, a pulley was affixed to the ceiling of the room in which the dome was being constructed, and a hand winch was bolted to the wall. A cable was attached to the dome's support ring, run through the pulley and to the winch. The dome was then lifted off the floor and raised above the walls, which were then pushed into place underneath the dome, as shown in Figure 6. The dome was then lowered onto the walls and the entire structure was secured and reinforced.

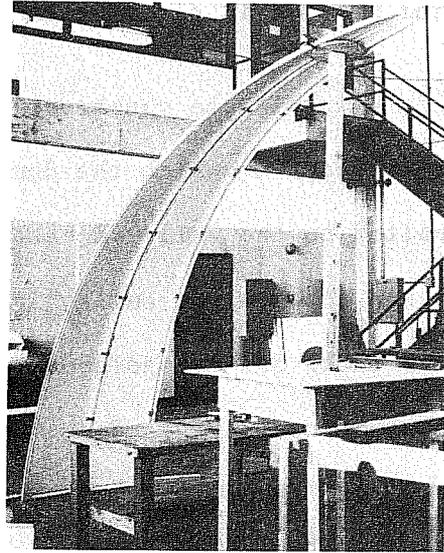
Once this structure was completed, the clamps holding the panels together were replaced with rivets, the seams between panels were covered with specially selected masking tape, and the interior was sprayed with a flat white paint which provided a diffuse surface having approximately 80% reflectance. A dexion support structure was constructed around the inside perimeter of the dome to support lighting fixtures and reflectors.

Initial experiments and measurement were conducted on a simple platform constructed in the center of the structure (Figure 6). Later, a more elaborate model table, with provision for rotation and lateral and vertical adjustments, was designed and constructed.

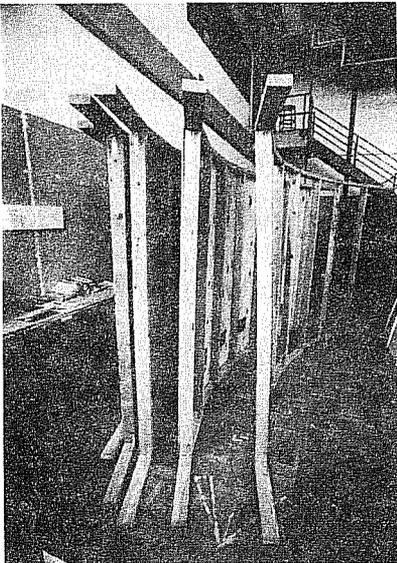
One end of a 24" diameter flexible aluminum duct was fastened to the support ring on the top of the dome, and covered from within by a cone-shaped battle. As shown in Figure (6) the other end of the duct was attached to a 2600 CFM fan that exhausts air to the outside of the building through a window.



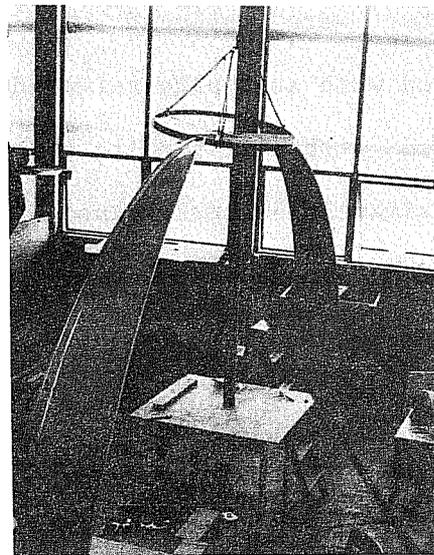
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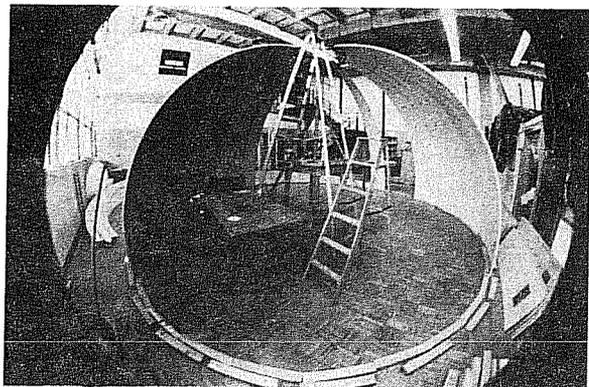


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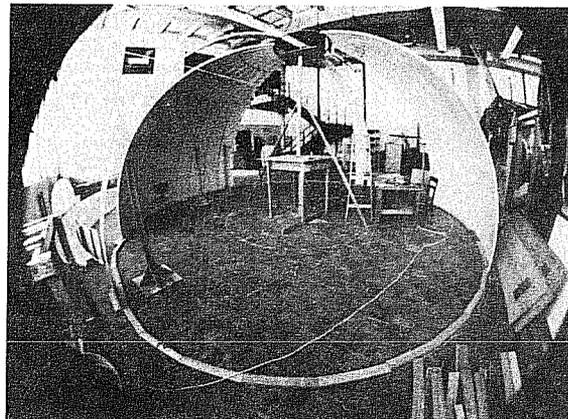


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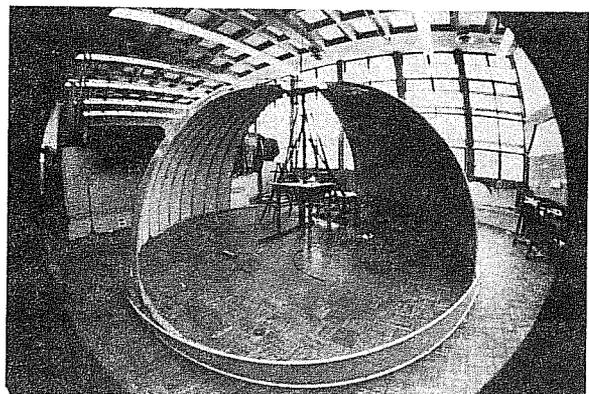
Figure 6



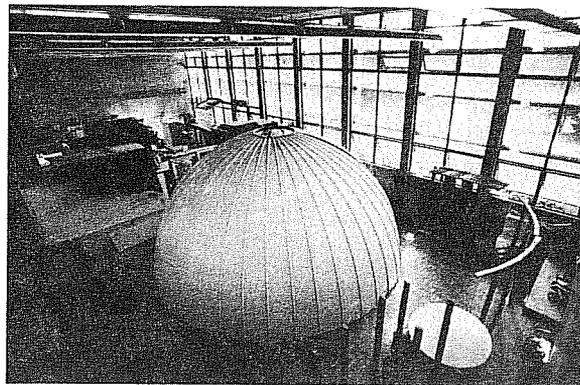
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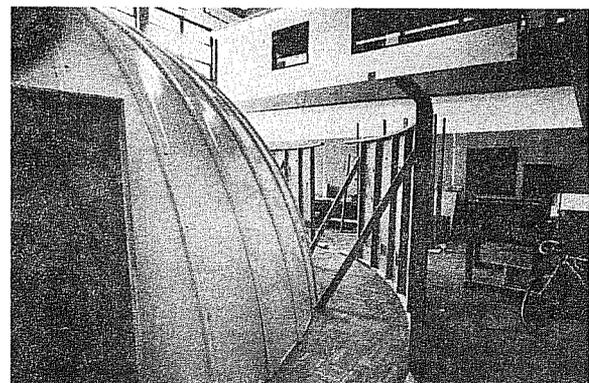
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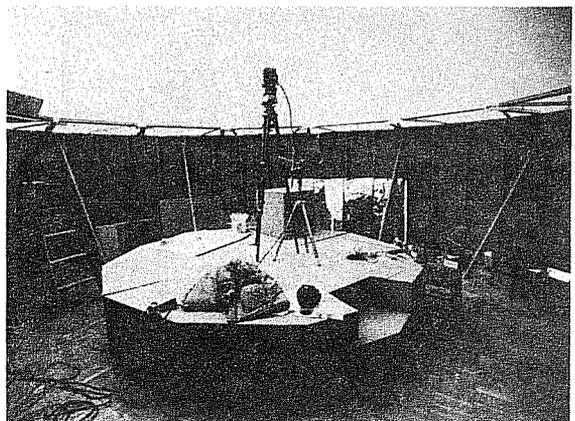
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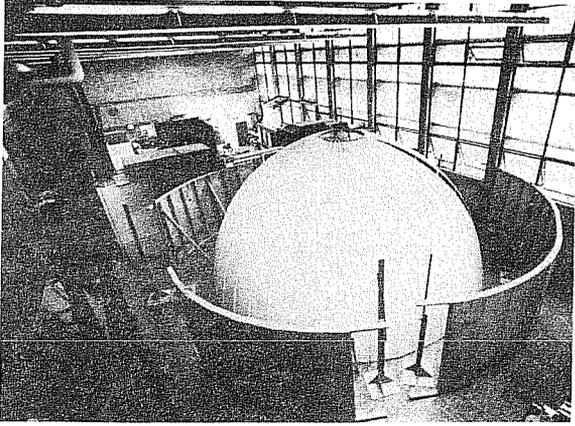


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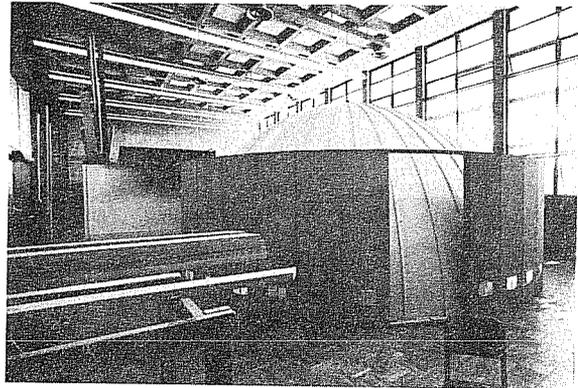


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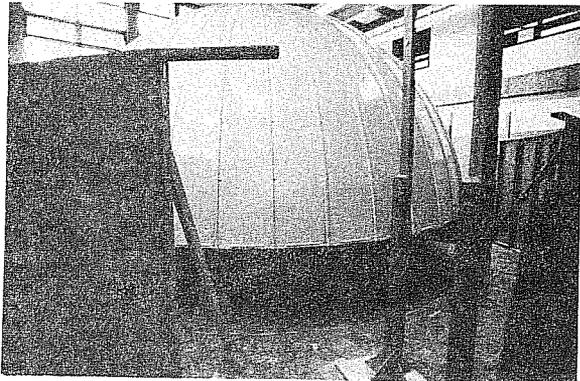
Figure 6



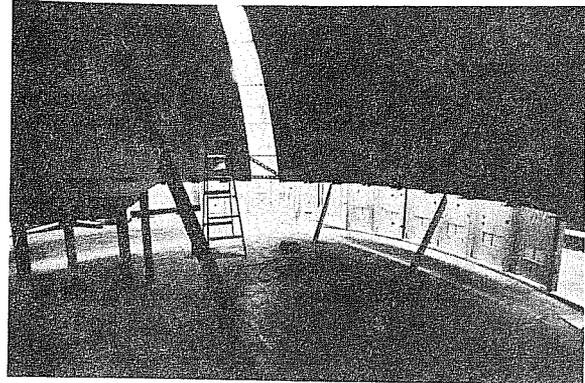
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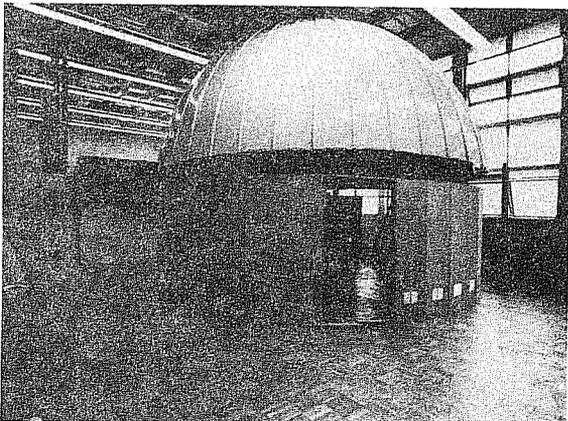
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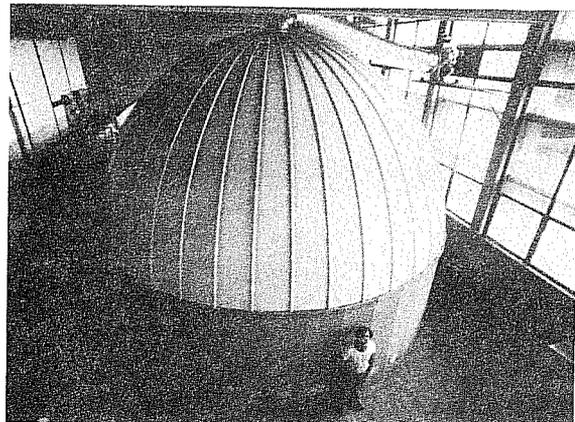
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XBB 804-5185



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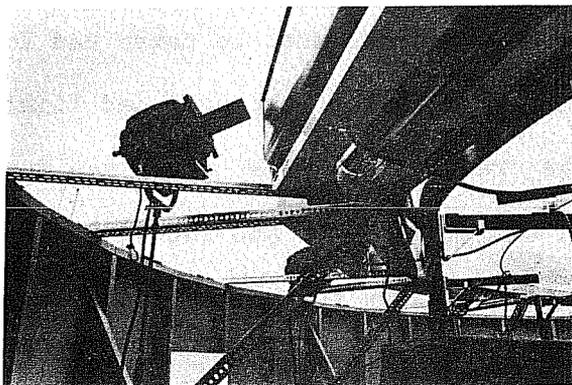
III. LIGHTING SYSTEM DESIGN AND LUMINANCE SIMULATION

A. Lighting System Concept

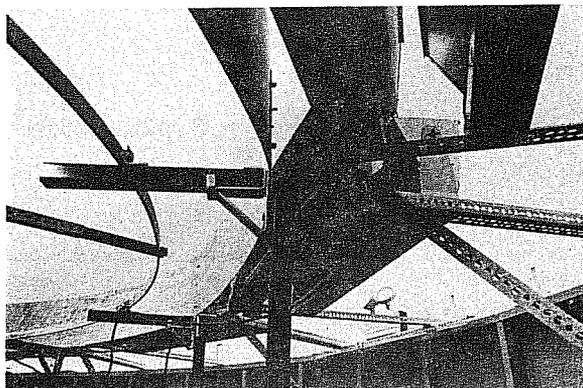
Developing an interior lighting system to provide the desired luminance distribution on the underside of the dome is generally a long and tedious trial-and-error process. We developed a procedure that has worked well to speed this process. Any single light source and/or fixture having an arbitrary spatial output distribution will provide a unique luminance distribution over the inner surface of the dome. The net luminance distribution over the entire surface from all light sources can be found by superimposing the contributions from each source. A computer program was developed(1,2,3) that stores a library of luminance distributions (relative to zenith luminance) from many source types. The program will add the contributions from any selection of sources to produce the net total distribution. Since there is rotational symmetry in the circular floor plan, both the position and the intensity of each source can be varied. This technique has proved to be a highly successful approach to arriving at desired luminance distributions with a minimum of hardware investment and time. Data files were initially created for approximately 60 light sources where a "source" represents a single combination of lamp, reflector, radial location in the dome, and tilt angle. As each source was positioned in the dome, a luminance probe (10 field of view) was used to scan the dome. Luminance measurements were recorded at 118 standard locations. The computer program then allows selection of any number of source files, which can be positioned in any of 12 sectors in the dome, the intensities of which can be individually adjusted to simulate dimming. The resultant luminance distribution can

be compared to the desired values and modified in the computer by adding or subtracting sources until an approximation of the desired distribution is obtained. The lighting fixtures can then be set up and fine-tuned as necessary to obtain the final luminance distribution.

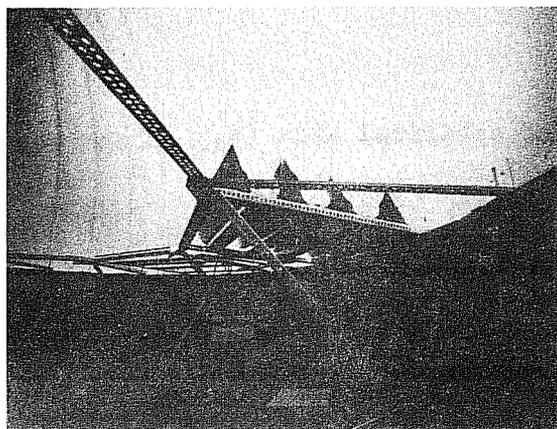
Typical lighting fixtures



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B. Lighting Power and Capability Estimation

Before designing the lighting system inside the sky simulator, the size and the reflectivity of the sky hemisphere was defined. Based on these assumptions the effective use of the sky simulator volume and the boundaries of which the measurements must be taken had to be defined. Also the effective photometric output of the proposed lighting system had to be calculated. The result of this study was determining the total installed lighting equipment power and the limits for the measuring equipment. The following shows the calculations based on these assumptions (2,3,9,10)

Basic Units

luminance: $1 \text{ footlambert} = 1/\pi \text{ cd/ft}^2 = 3.426 \text{ cd/m}^2$

m = meter
 cd = candle
 lm = lumen
 I = cd/in²

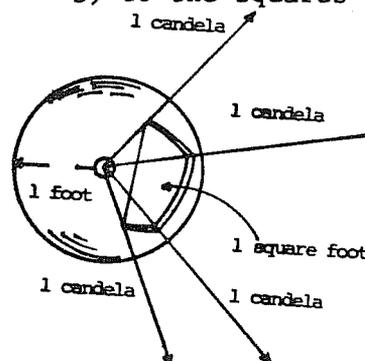
w = solid angle
 Φ = luminance flux
 I = luminous intensity
 cp = candle power

E = illumination
 Footcandle = Φ/ft^2
 lux = Φ/m^2
 Footlambert = Φ/A

Solid Angle = ratio of spherical area (A_s) to the squares of the radius (R). Its units \rightarrow steradian (Sr)

$$\omega = A_s/R^2$$

FIG. 7



Luminous flux Φ = time rate of flow of light.

Luminous intensity (I) = solid angular luminous flux density in a given direction:

$$I = \frac{\Phi}{\omega}$$

Candle power = luminous intensity: ability of a light source to produce illumination in a given direction.

Illumination (E) = incident luminous flux density.

When the unit of luminous flux is the lumen and the area is in square feet, its units = footcandle (fc).

When the unit of luminous flux is the lumen and the area is in square meters, its units = lux (lx).

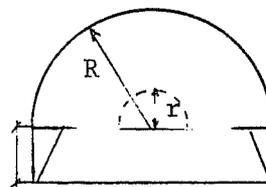
$$E = \frac{\Phi}{A}$$

Luminance (photometric brightness) (L) = the luminous flux per unit of projected area and unit solid angle either leaving a surface at a given point from a given direction or arriving at a given point from a given direction.

When the unit of luminous flux is the lumen and the area is in square feet its unit = footlamberts (FL). Luminance is luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction.

when (I) is in lcd/in² = 144π fl = 452fl

"The effective volume" within the boundaries of which the measurements must be taken, in order to achieve considerable accuracy. (The dotted line shows this "effective volume" within the artificial sky system).
See fig (14)



R = 12.25 ft
r = 3 ft
h = 7 ft

The radius of the sky hemisphere (already defined) r[m]

Luminance of a theoretical uniform sky. This sky is equivalent (judging by the horizontal light intensity it can create at the base of the hemisphere) to the nonuniform sky we would like to work with.*

$L_{eq} [cd/m^2]$

The horizontal light intensity created by the "equivalent uniform sky" at the hemisphere base. The uniform sky is defined by L_{eq} , and we can show that $E_H = \pi L_{eq}$ ** $E_H [lux]$.

The lowest measuring range in which the measuring equipment can still supply accurate and reliable results (in units of light intensity).
 $\geq [lux]$

The lowest D.L.F. (Day Light Factor) that we might be interested in detecting, in a reliable way. $D_k [%]$

The reflection coefficient of the internal coating of the sky dome.
 $R_s [%]$

The efficiency of the sky dome lighting system - the photometric flux reaching the surface of the sky dome compared to the photometric output

*If, for example, test work with a "clear sky" is going to be done. The luminance of the equivalent "uniform sky" can be calculated by integrating the contribution of a certain "clear sky" sky dome (through Kittler's formula) to horizontal light intensity.

of light sources of the systems.

η [%]

The photometric efficiency of the sky dome lighting system light source.

E [lm/watt]

The light intensity that can be measured on the internal sky dome surface, when lighted for the equivalent uniform sky conditions.

E_s [lux]

Solid angle = ratio of spherical area (A_s) to square of radius (R)

$$w = A_s/R^2$$

Horizontal light intensity at the center of sky simulator

E_H [lux]

integration all over the sky simulator hemisphere**

$$\begin{aligned} E &= \pi \cdot L_{eq} & E_H &= L \sin \alpha \, dr \\ &= L_{eq} \int_0^{\pi/2} \left[(r \cos 2\pi \, d\alpha r) / 2\pi r^2 \right] 2\pi \sin \alpha \\ &= 2\pi L_{eq} \int_0^{\pi/2} \cos \alpha \sin \alpha \, d\alpha = \\ &= 2\pi L_{eq} \left[\frac{1}{2} \sin^2 \alpha \right]_0^{\pi/2} = 2\pi L_{eq} \times \frac{1}{2} = E_H = \pi L_{eq} \end{aligned}$$

The multiplying factor that might be needed to define the maximal point luminance we would like to have at the sky simulator, when working with "nonuniform sky" luminance conditions (compared to L_{eq}).

K_1

The preferable diameter of the parallel light beam (column) representing the direct sun radiation

$2r'$ [m]

The cross-section area of the parallel light beam (when measured within the effective measuring volume). πr^2

$$A \text{ [m]}$$

The multiplying factor that might be need to define the maximal horizontal light intensity from the "direct sun radiation" (simulated by the parallel light beam), for a "sun" in the zenith, compared to the horizontal light intensity received due to the luminance of the sky dome.

$$k_2$$

The efficiency of the parallel light beam, lighting system.

$$N' \text{ [%]}$$

The photometric efficiency of the parallel light beam, light source.

$$E' \text{ [lm/watt]}$$

Assuming that the coating of the sky dome has a perfect diffusive qualities.

$$E_s \frac{R_s}{\pi} = L$$

To enable the measurement of the small (as needed) DLF, taking into account the sensivity of the equipment. In the minimal case we will require (remembering that $E = \pi L_{eq}$):

$$E_H = S \frac{100}{D_k}$$

$$E_s \frac{R_s}{\pi} = \frac{E_H}{\pi}$$

$$E_s \frac{R_s}{\pi} = S \frac{100}{D_k}$$

$$E_s = 10^4 \frac{S}{D_k R_s} = 10^4 \frac{.025}{.01 \times 80}$$

The dimensions of the sky dome hemisphere, as already defined

$$r = 12^{-3} = 3.75[m]$$

Assuming: that we would like to measure DLF as small as 0.01%. The lower reliable sensitivity of the measuring equipment is 0.025lux. The light source being used is Tungsten Halogen, having a photometric output of 25 [lm/watt], and with other assumptions, the variables will get the values of: $D_k = 0.01[\%]$

$$S = 0.025[\text{lux}], 0.050 [\text{lux}]$$

$$r = 3.75[m]$$

$$n = 40[\%]$$

$$R_s = 70[\%], 75 [\%], 70[\%]$$

$$k_1 = 5$$

$$E = 67 \text{ for PG17/cw fluor. lamps} = \text{lm/watt} = 7450/110 = 67$$

therefore:

For $S = .025$, $R_s = 70[\%]$.

$$E_H = S \frac{100}{D_k} = 250 [\text{lux}]$$

$$L_{eq} = \frac{E_k}{n} = 79.6 [\text{lux}]$$

$$E_s = \frac{10^4 S}{D_k R_s} = 357 [\text{lux}]$$

The effective photometric output of the sky dome lighting system, the

minimal case, and not including the "sun" system:

$$\pi_s = 2\pi \cdot 10^4 \frac{S \cdot r^2}{D_k \cdot R_s} = 31,556 \text{ [lm]}$$

and the electrical power needed in this case:

$$P_s = 2\pi \cdot 10^6 \frac{S r^2}{D_k R_s \cdot n \cdot e} = 783.3 \text{ [watt]}.$$

The effective photometric output of the sky dome lighting system, the maximal case, not including the "sun" system:

$$\Phi_s \cdot k_1 = 104,975 \text{ [lm]}$$

and the electrical power needed in this case:

$$P_s \cdot k_1 = 3916.9 \text{ [watt]}.$$

The power can be as high as ten times the diffused horizontal light intensity from the "sky": $k_2 = 10$ and that the diameter of the parallel light beam is $2r = 1 \text{ [m]}$ and assuming that the same light source will be used (Tungsten Halogen), and with other assumptions, the variables will get values of:

$$r' = 0.5 \text{ [m]} = A = \pi r'^2 = 0.785 \text{ [m}^2\text{]}$$

$$n' = 20\% F' = 25 \text{ [lm/watt]}$$

$$n' = 20\% E = \text{lm/watt} = 5700/2000 = 28.5$$

The effective photometric output of the "parallel light beam" system, the minimal case:

$$\Phi_D = 10^2 \frac{S \cdot A \cdot k_2}{D_k} = 1960. \text{ [lm]}$$

$$\Phi_D = 10^4 \frac{S \cdot A \cdot k_2}{D_k} \cdot n \cdot e = \ll 390. \text{ [watt]}$$

The above values, defining the proposed system, are the minimum possible to enable the reliable operation of this system. However, to allow for uninterrupted measurement work on whole sequences of natural lighting situations, such as the typical changes during a "clear sky" day - there will be a need for a much wider range of operation. A practical range of work is four times the minimal value. Therefore the work values should be higher than the above mentioned values, to ensure that in practical work the system would not operate in higher range than 2/3 of its highest working values. So that the effective range of operation of the system will be within the intervals of:

$$E_H = 250[\text{lux}] \div 1000[\text{lux}]$$

$$L_{eq} = 320 \div 80 \left[\frac{\text{cd}}{\text{m}^2} \right]$$

$$E_S = 1440 \div 360 [\text{lux}]$$

$$\Phi_S = 31,536 \div 126,200. [\text{lm}]$$

$$P_S = 783 \div 12,600 [\text{watt}]$$

$$\Phi_D = 1,960 \div 7,850 [\text{lux}]$$

For a cross section area of $.785\text{m}^2 = E_D = 2,500 \div 10,000 [\text{lux}]$

$$P_D = 1,570 [\text{watt}]$$

So the effective photometric output of the whole system will be within the range of: $32,560 \div 134,070 [\text{lm}]$ and the corresponding electrical power: $3,550 \div 14,200. [\text{watt}]$.

Therefore it was decided to design the heat-dissipating system for a

load of 14. kW.

It was important to find out that the total installed lighting equipment power in this case was

$$(783 \times 5 + 390.)6 \cong 26,000. [\text{watt}] = 26 [\text{kw}]!$$

However, in no practical situation would there be a need to use all this power, at the same time!

C. Lighting System and Controls

A four-stage development plan for the artificial sky lighting and detection system is shown in the following table.

DEVELOPMENT SCHEDULE

FIG.8

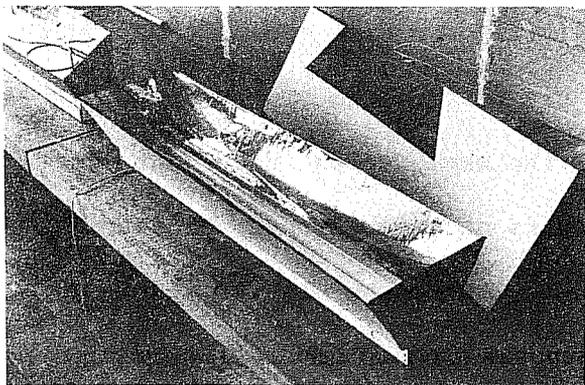
	SKY LIGHT	SUN	DETECTOR SYSTEM	CONTROLS	MODEL
STAGE 1	C.I.E. OVERCAST, TEST SET UP	-	-	INDIVIDUAL LIGHT SWITCH INSIDE	SINGLE TABLE ON PLATFORM
STAGE 2	C.I.E. OVERCAST AND CLEAR SKY TEST CONFIGURATION FOR ONE SUN POSITION	-	MEGATRON READING AT MODEL	EXTERNAL CONTROL PANEL INDIVIDUAL LIGHT SWITCH OUTSIDE	ROTATING PLATFORM WITH ADJUSTABLE HEIGHT
STAGE 3	C.I.E. OVERCAST AND CLEAR SKY PERMANENT CONFIGURATION FOR 3 SUN POSITIONS	SUN TEST SYSTEM	MEGATRON TEST SYSTEM READOUT AND CONTROL PANEL	CONTROL PANEL WITH DIMMING SWITCHES	HORIZON CURTAIN
STAGE 4	C.I.E. OVERCAST AND CLEAR SKY ALL SUN POSITION	SUN IN PLACE	LI-COR PHOTO CELLS CUSTOM RECORDING SYSTEM CUSTOM DETECTOR SYSTEM	CONTROL PANEL WITH CHARTS AND VOLTAGE MONITORS	GROUND REFLECTANCE SIMULATOR

The lighting system was designed to provide uniform, CIE overcast, and several CIE clear skies and consists of two major elements. A fluorescent lamp system arranged in 12 banks of fixtures on a steel frame just below the horizon line, evenly spaced around the edge of the dome, provides the basic background luminance of the sky, which does not vary with azimuth angle. Each sector consists of five fixtures holding two 4-foot fluorescent lamps mounted perpendicular to the dome radius. By using various reflecting and absorbing panels positioned at different angles between the lamps, uniform and CIE overcast skies have been duplicated and the horizon-to-zenith variation of clear skies can be achieved. An array of narrow and wide-angle spotlights has been

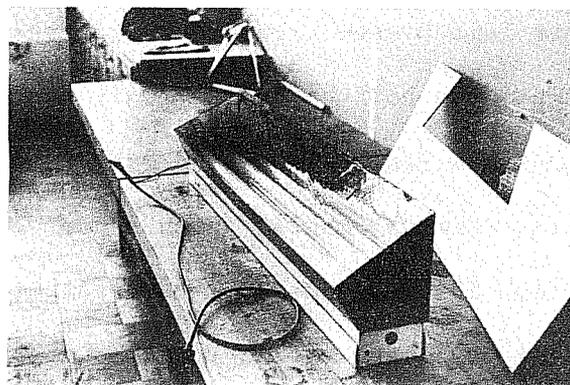
installed to provide the azimuthal variation in clear skies for sun altitudes of 90° , through 40° . Agreement between the uniform and CIE overcast sky distributions and those achieved in the sky simulator are excellent. A uniform, overcast, and clear-sky distribution as measured in the dome are compared to standard CIE distributions in Figure fig.42

The lighting fixture design began with a study of fluorescent fixture reflectors available on the market. New reflectors with their geometrical properties were constructed out of cardboard and Mylar and mounted on the 4-foot fluorescent fixtures. After extensive testing, four different design configuration were constructed, one for each ring. (See Figure 9.) Based on this design a series of tests was conducted to produce certain luminance distribution. New modifications were made to change the cardboard reflectors to aluminum reflectors having adjustable turn knobs to control the altitude angle. (See Figure 10.)

FIG.9

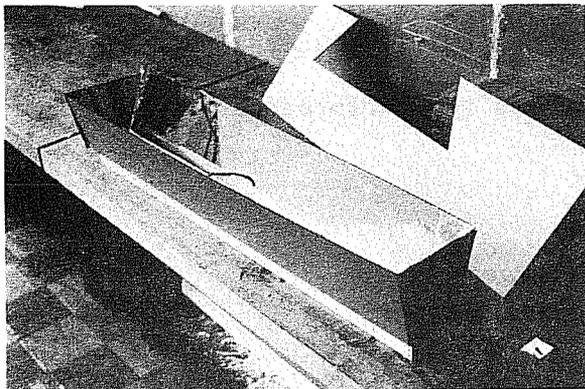


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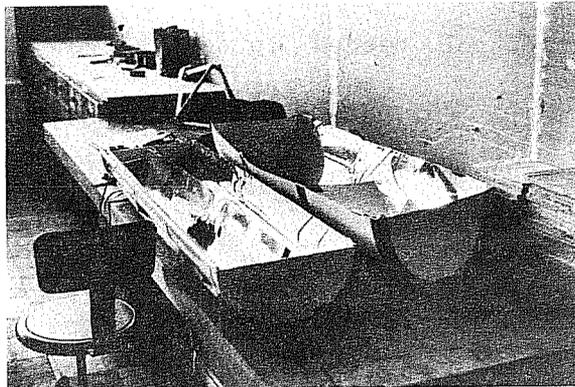


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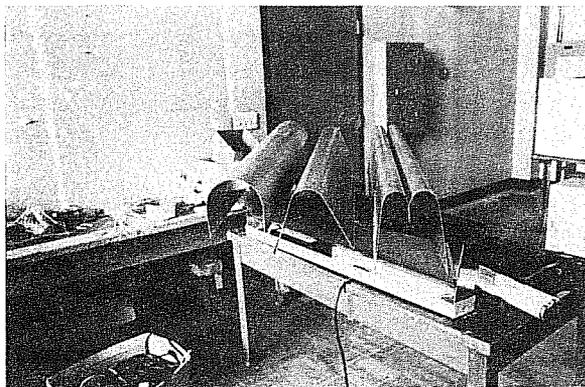
FIG.10



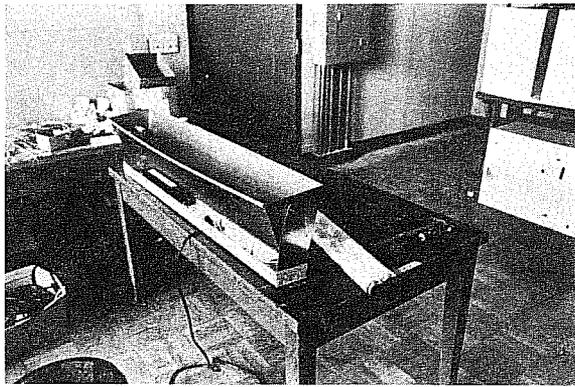
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XBB 816-5183



XBB 816-5145

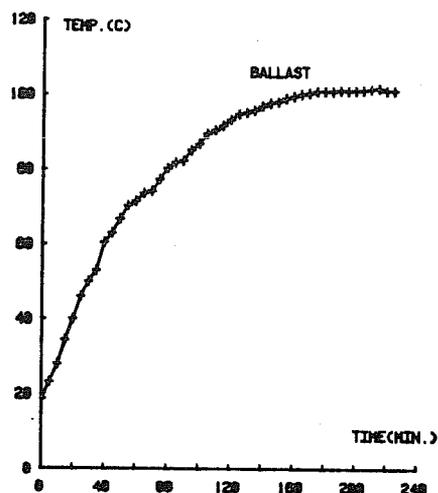


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The original lighting design concept included the use of individually dimmable fluorescent ballasts to control the light output of each fixture. In theory this would allow fine-tuning of the distribution and recalibration of light output, fixture by fixture, based upon lumen depreciation, temperature effects, and intrinsic lamp-to-lamp variations. Extensive testing in 1980 showed that as of that date, dimmable ballast technology was not sufficiently robust and cost-effective to warrant this approach. It was decided to change to on-off switching,

voltage control techniques, and group dimming hardware to provide the control needed to switch from a uniform sky to either an overcast or a clear-sky distribution. The test results for performance of group dimming are shown in Figures 11 and 12.

FIG.11



1. Test results on temperature of ballast, lamps, reflector without dimming system

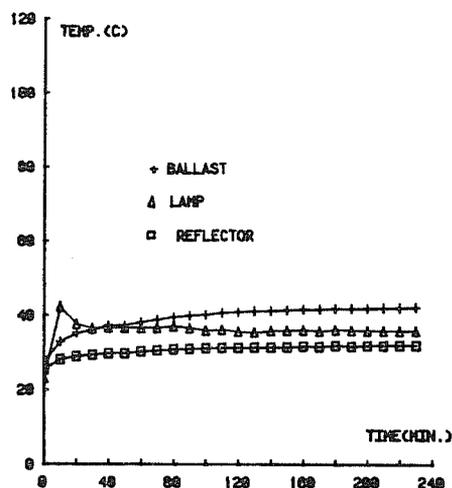
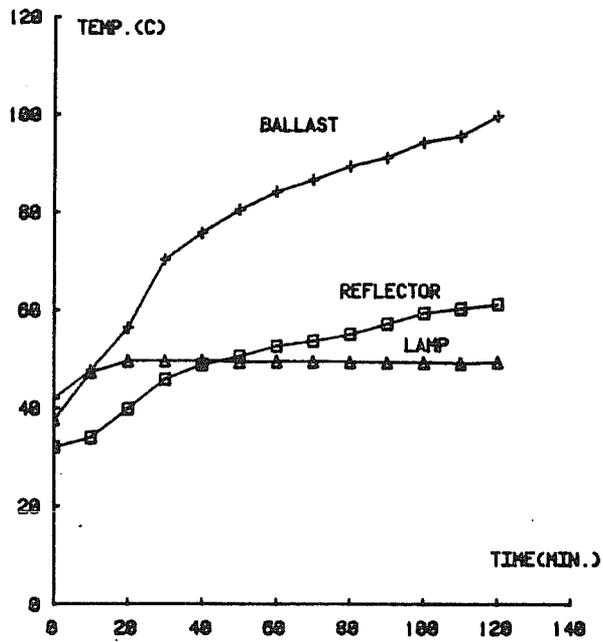


FIG.12



2. Test results on temperature of ballast, lamps, reflector with dimming system

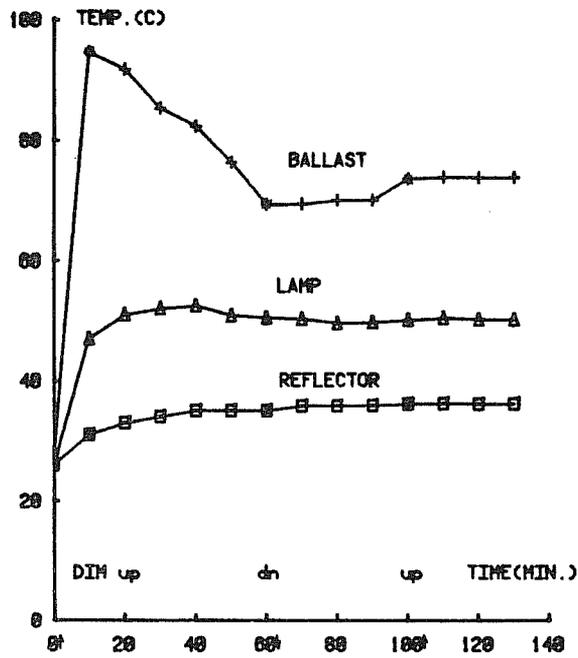
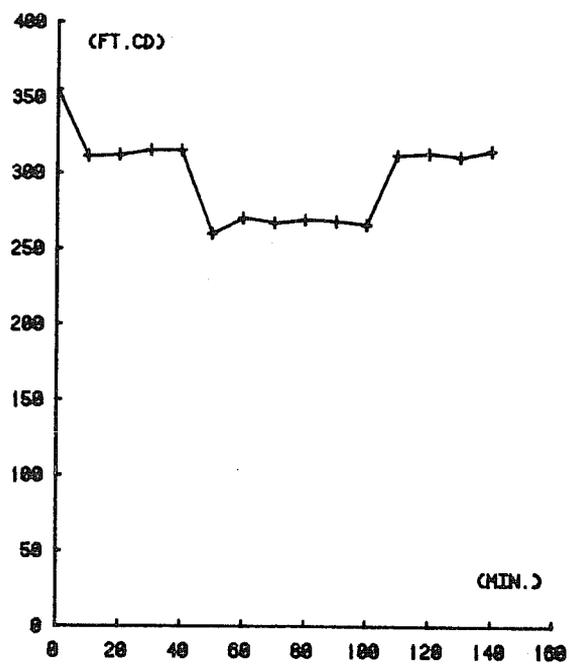
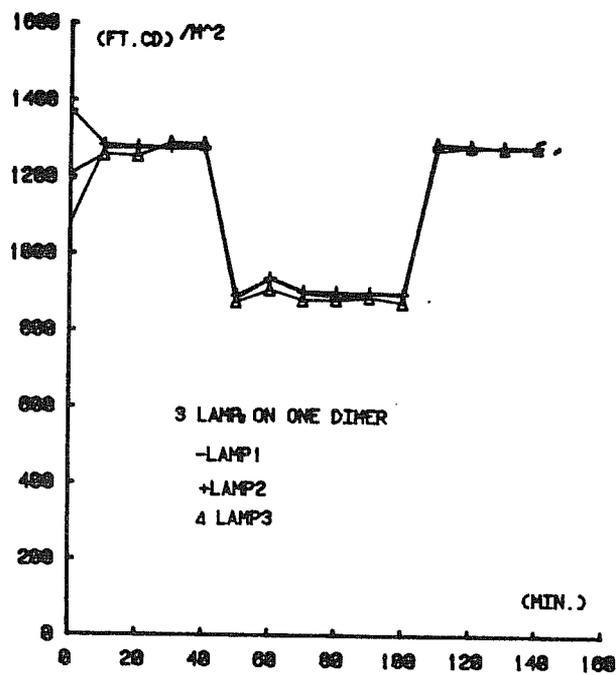


FIG.12



3. Test results on dimming system



4. Test results on uniformity of dimming system

An additional study of the advantages and disadvantages of reflectors, lamps, and ballasts was conducted. The study showed that the initial lighting system design provided approximately 150 footcandles on a horizontal surface at the model location for an overcast sky. This was done by cardboard Mylar reflectors and WATTMISERII 35 lamps. The study also showed in order to do a series of conversion for achieving different conditions electronically, the following were required:

CONDITION OF SKY

1. clear
2. uniform
3. overcast

CONVERSION OF CONDITION

1. cloudy---uniform---clear (A)
2. clear---uniform---cloudy (B)

There is a need for higher level of illumination than 150 footcandles. The 40-watt lamps were replaced by PG17 Power Grove and the reflectors were changed to aluminum Mylar reflectors.

REFLECTORS:

- | | | |
|--------------------|---------------------------|----------------|
| 1. Cardboard Mylar | 2\$ per ref. | Total= \$120 |
| 2. Aluminum Mylar | 5\$ per ref. | Total= \$300 |
| 3. ALZAK | 60\$ per ref. (materials) | Total = \$3600 |

This will raise illumination levels to 500 footcandles for uniform sky.

The following table shows the summary of all test results and availability of lamps on the market for the system and their cost.

2.Lamps:

	Intensity (LUX)*10		Cost Dollar=\$	Adv--Dis
	A	B		
Watt Miser II35				
Clear	77	151	.79 per lamp	--low
Uniform	115	126	Ballast \$10	
Cloudy	138	89	600+120=720\$	
<u>F 40 Daylight</u>				
Clear	90	172	1.12 per lamp	Dim--
Uniform	136	146	Ballast Dim \$40 Reg \$18	Mid-L-- --low
Cloudy	162	100	Total 2400+140=\$2540	--color
PG 17 Power Grove				
Clear	302	600	4.04 per Lamps	
Uniform	450	504	Ballast \$26 (\$63)	DIM---
Cloudy	540	336	Lumecon 280	
			Total=1560(280)+480=3780\$	

which can be converted by dimming and addition of spotlight to either clear sky or overcast sky. Now availability of 400ftcd., or 350ftcd. on horizontal surface at the model location for clear or overcast sky gives a benefit to the facility to become more useful for visual assessment of designs lighting disabilities.

3. Dimming:

The three options for dimming the lighting system and their cost

1. Lutron System

Continuous Dimming or 3 Position which gives limited options

Cost =

2540

2. Fixed Dimming

Using Different Capacitors for Different Level of Intensity

Cost=\$1200

3. Lumecon System

%50 Continuous Dimming With 1500 MA Ballast

Cost=3780

Life Time estimation for the lamp was based on these assumptions:

4HR/Day 5Day/Week 50 Week/Year

1000HR/Year

Approx. Lumen at 40% Average Life

1. Watt Miser II 35 losses 7% of its initial output
2. F40 Daylight losses 2% of its initial output
3. PG17 Power Groove loses 7% of its initial output

RECOMMENDATION:

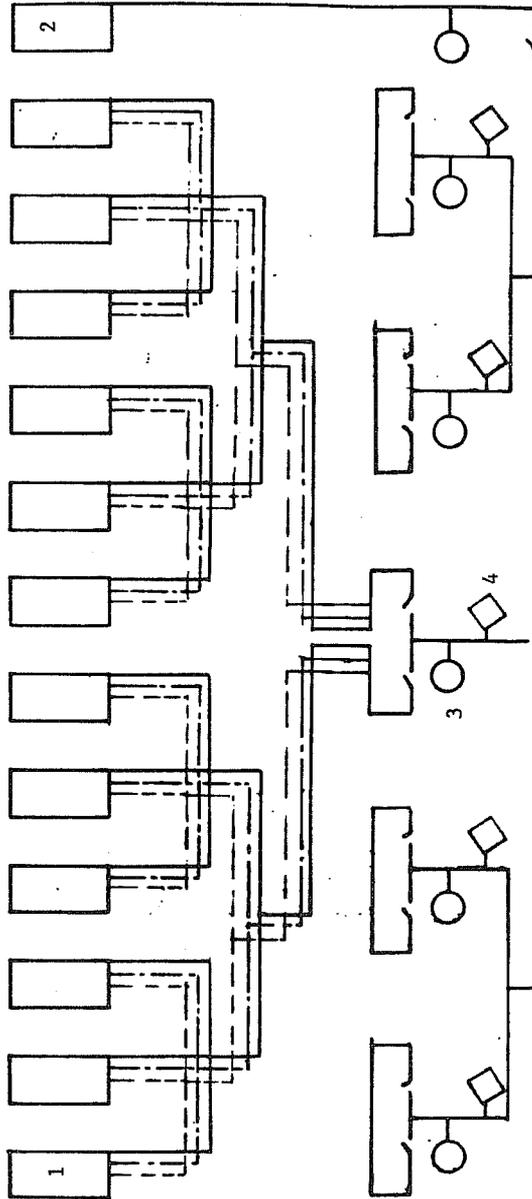
1. Aluminum Mylar Reflector
2. Within 5 Rings of Lamps:
Ring 1st thru 4 Use PG 17 Power Groove
3. Usage of Lumecon Dimming System
for Ring 1 thru 4 or Voltage Regulator.

Control

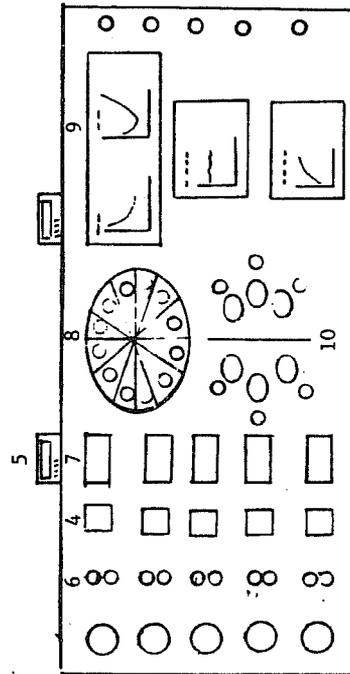
The lighting system was installed within 12 sectors inside the dome. The system consists of five rings (see Fig 13). There are twelve fixtures within each ring. Each ring has been divided into two half-rings for control. Each half a ring can be switched off or on or dimmed to desired intensity. Figure 13 shows a simple diagram of control system for fluorescents lamps and control panel.

FIG.13

Schematic Diagram of One Ring Wiring



- 6. on/off switch
- 7. volt meter
- 8. luminance meters
- 9. charts & references
- 10. projector switches



- 1. fluor. lamp
- 2. projection lamp
- 3. lumencon dimmer
- 4. dimming switch
- 5. Tektronix

D. Sun Simulator

We considered three approaches to adding a direct sun simulation capability.(7,8) The simplest approach is to separate sun simulation from sky simulation by constructing a stand-alone sun simulator. We designed such a facility, which has the advantage of providing a large-area collimated beam (approximately 5 feet in diameter) while introducing no disturbances in the sky simulator. It does, however, require taking two separate measurements and then adding both results.

A sun simulator can be added to the sky simulator in two ways (see Figs. 15,16). The artificial sun can be mounted on a track that traverses from near the horizon to the zenith. (See Fig. 15) The circumsolar sky component may be added to the movable sun source as described in Reference 8. Alternatively, the sun source itself may be mounted remotely from the dome structure, and a moving planar mirror can be used to introduce a collimated beam at the model position. The latter approach places fewer constraints on the size, weight, and power consumption of the sun source. It requires a porthole in the dome skin which can be moved from horizon to zenith in order to vary solar altitudes. (See Fig. 16.) In both designs the full range of incident angles at the glazing may be obtained by rotating the model platform.

The metal dome was built with a removable skin section that would allow either of the sun simulator designs to be incorporated into the sky facility. In the short term, a separate sun simulator will be constructed. After some experience is gained using the facility a decision about adding an artificial sun inside the sky dome itself will be made.

Figure 15

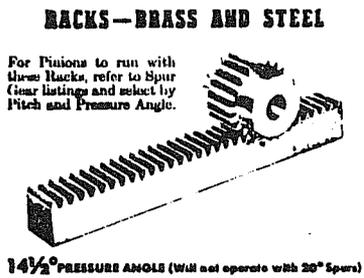
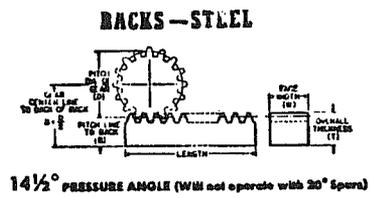
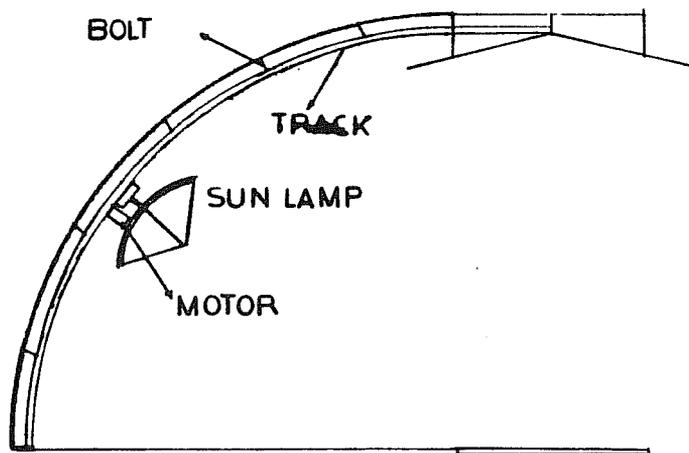
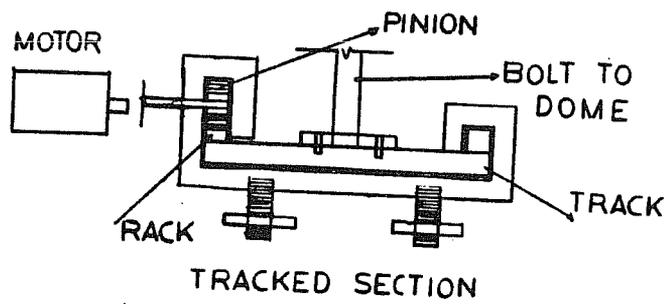
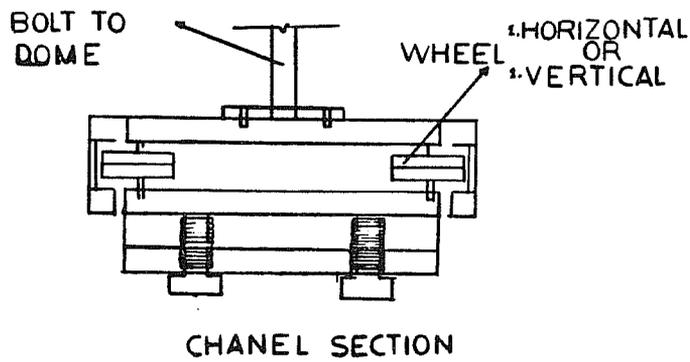
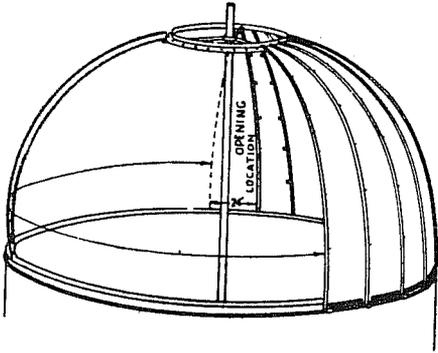
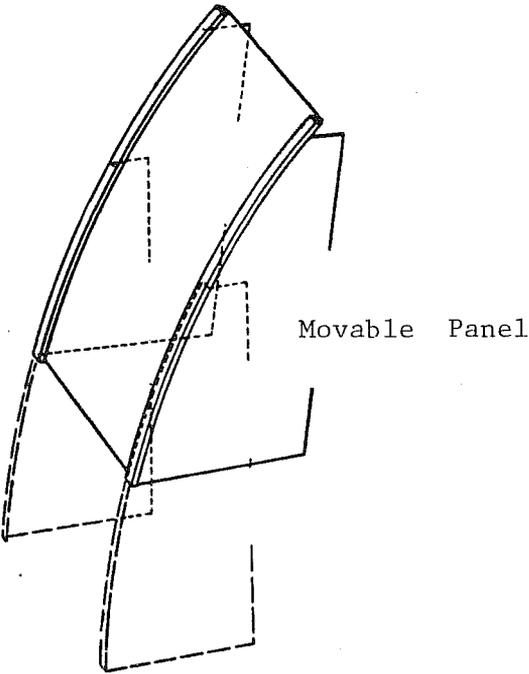
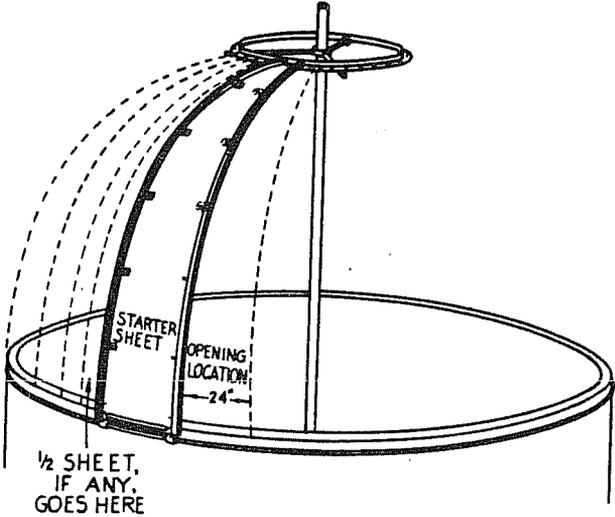


Figure 16

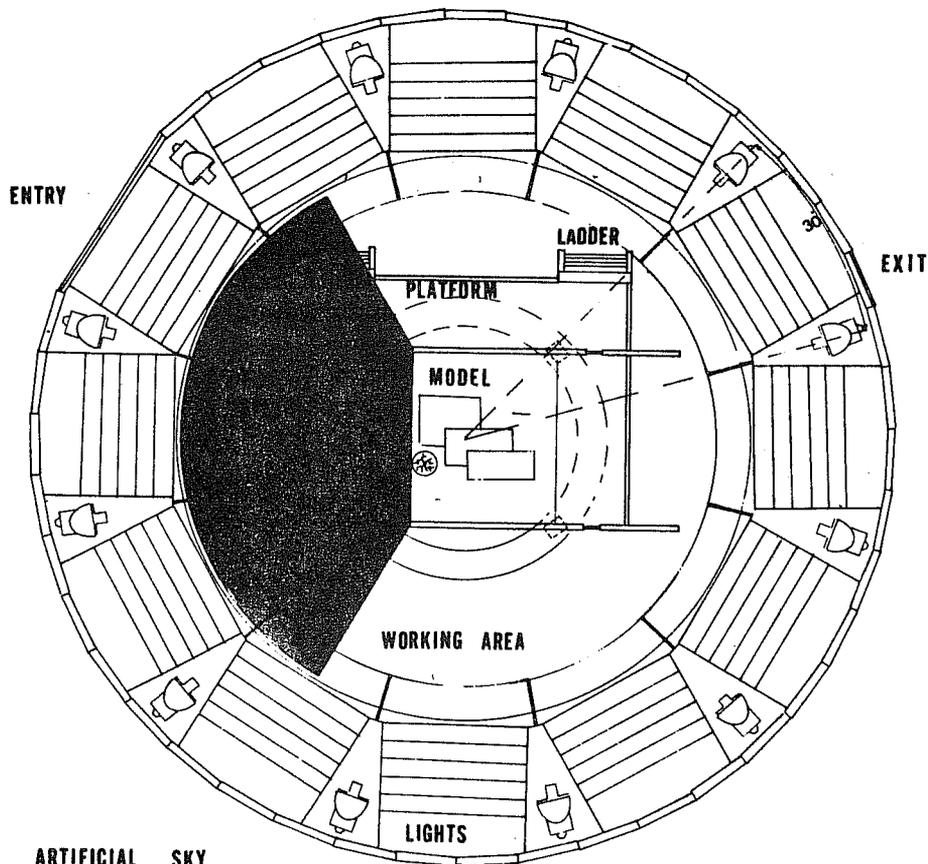


E. Ground Reflectance Simulator

Ground-reflected light must be considered in both indoor and outdoor model studies. The ground reflectance can be minimized by using a black foreground that extends to the horizon line. The ground-reflected contribution can then be added to the sky component by a separate measurement in which the model is inverted and the sky used as an effective ground plane. The desired ground-plane reflectance can also be simulated by providing an area with the appropriate reflectance in front of the model. This may introduce two difficulties. The diffuse ground-reflecting plane will bounce light back to the sky, altering the apparent sky luminance distribution. Second, it is possible to simulate ground-reflected light derived only from the sky. In actual design situations the sunlit ground can be the major contributor to light in a room. We have developed a design that provides a ground reflectance capability without these difficulties. The model foreground is constructed as a translucent surface, lit from below by a dimmable light source. For any given sun position, sun intensity, and ground reflectance being simulated, the ground luminance is easily determined. The light output of the sources below the translucent foreground is then adjusted to provide the proper luminance relative to the sky luminance. (See Fig. 17)

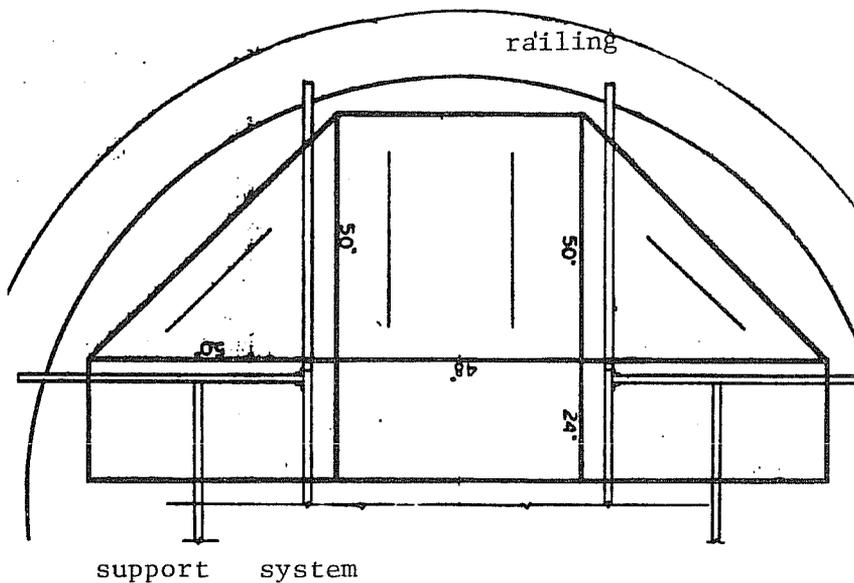
This method provides the proper ground brightness for the model, but would add an unacceptably large luminous flux to the sky vault, altering the sky luminance distribution. This problem is solved by placing a louvered screen over the translucent ground plane so that the emitted light flux is selectively directed toward the model aperture. This permits a high apparent ground luminance for the model with a minimal disturbance of the sky luminance distribution. In addition, variable foreground reflectance can be simulated by using neutral-density overlays properly positioned on the ground plane. Preliminary tests indicate that this approach will provide the desired control of ground-plane luminance.

FIG.17

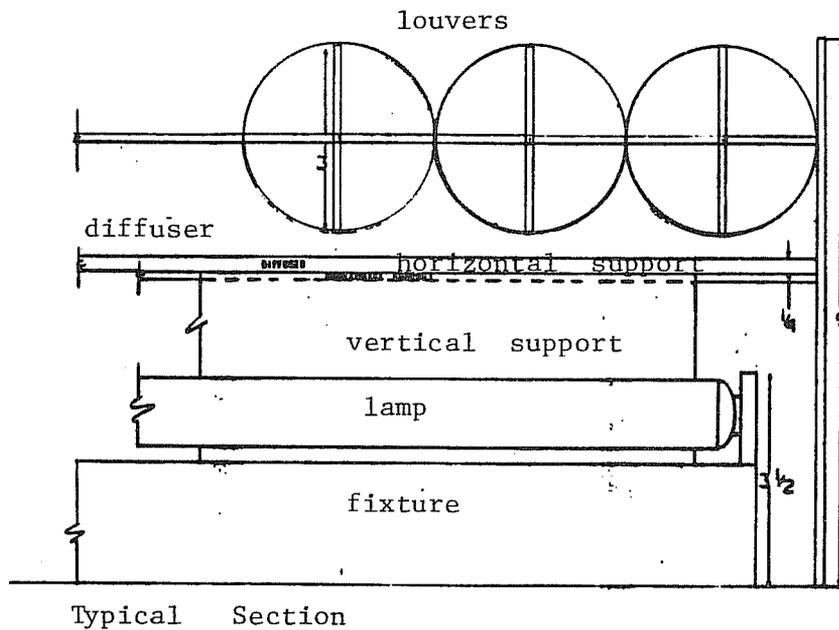


PLAN OF ARTIFICIAL SKY

FIG.17



GROUND SIMULATOR



F. Ventilation

A large heat load was generated by the lighting system inside the dome. A 2-speed, 2600 cfm fan was installed to remove air through a circular duct attached to the top of the dome. (Fig.19) The intake to the dome is through 40 filtered openings at the base of the dome. As it moves toward the outlet, incoming air flows over the light fixtures at the periphery. Without the fan, dome temperature rose 160 F with approximately 5 kW of installed lighting. With the fan on a low-speed setting, the temperature increase was limited to less than 20 F. With a full lighting load of 15-20 kW, the fan will limit the temperature increase to less than 50 F. See Fig . 18

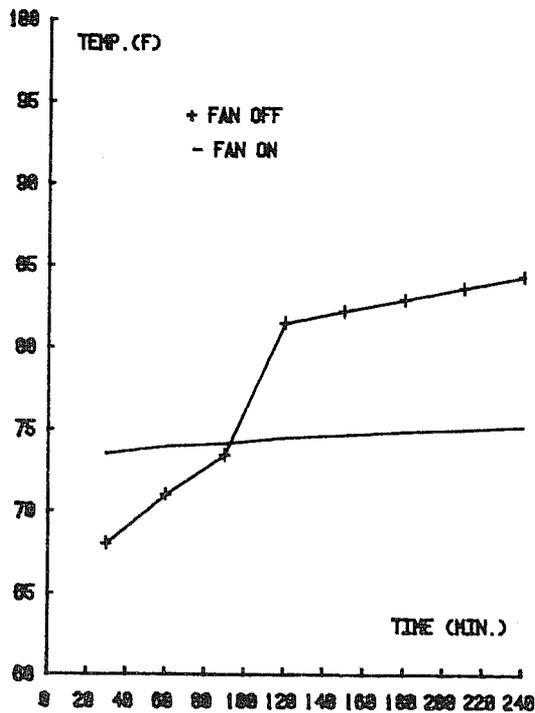
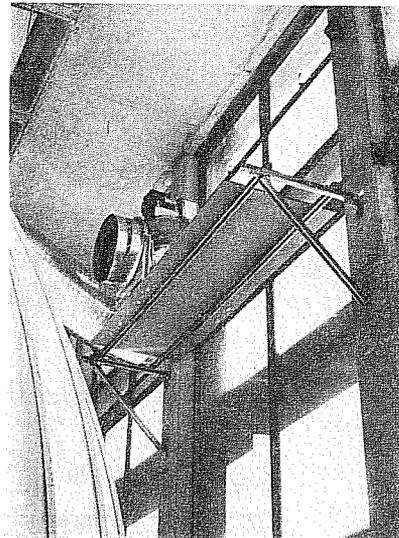
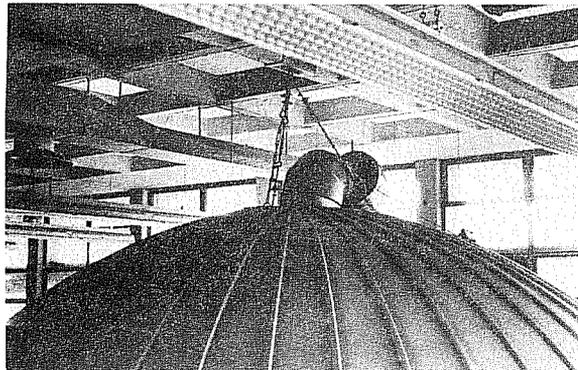


FIG.18

FIG.19



XBB 816-5172

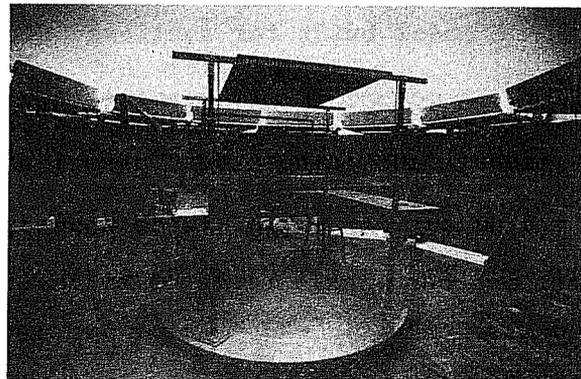
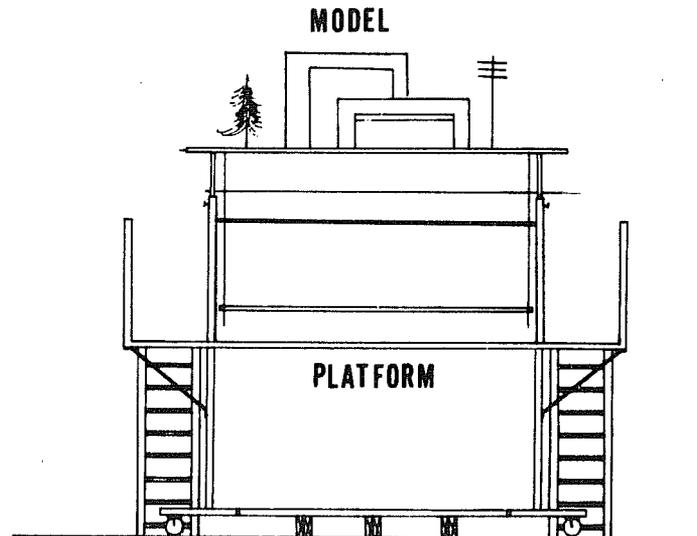


XBB 816-5173

G. Model Platform

A model platform was constructed that could hold large architectural models (up to 6 feet across), that would allow for required adjustments of model height relative to sky horizon, and and that would allow safe access to the elevated model. (Fig. 20) The height of this platform can be adjusted to replicate positioning of fenestration in multistory buildings relative to the horizon. The entire platform rotates, allowing the model to be positioned relative to a clear-sky distribution. This rotational capability is not required for uniform or overcast skies.

FIG.20



XEE 816-5179

H. Models

Current uses of scale models were examined to reveal how they might be used more effectively. The purposes of this section are as follows:

1. Classification of three-dimensional models according to their use, purpose, or scale.
2. Investigation of the use of three-dimensional models in architecture. Evaluation of the current uses of three-dimensional models.
3. Models for research in lighting.

1. Classification

The proposed system is comprehensive, permitting all the three-dimensional models to be assigned to categories and types. Some models may have more than one function and would qualify for more than one classification. In these cases, the model is classified as to its intended major purpose. A model built for small-scale study but later used for demonstrating a scheme or for testing and analysis would be such a multi-purpose model. Some models may change classification depending upon the intent of the user and the way they are used.

All three-dimensional models can be classified into two major categories. These are Demonstration and Investigation. Each group can be further divided into several types which are employed within or are

related to the architectural curriculum. See listing below.

The following is a description and critical discussion of the two groups and the types of models included in each.

Definitions

A number of terms relevant to the study are defined as follows:

1. MODEL (n.)-That which "exactly" resembles something: a copy. A miniature representation of a thing: sometimes, a facsimile of the same size. An archetype. Something intended to serve, or that may serve, as a pattern for something to be made: as a clay model.
2. THREE-DIMENSIONAL MODEL-A model which has length, breadth, and height. A representation of a system, object, structure, or any of their respective elements which have definable form or occupies a volumetric space.
3. DEMONSTRATION MODEL-A model used as a process or means of pointing out various facts, situations, or conditions: a portrayal or proof: an explanation or illustration.
4. INVESTIGATION MODEL- A model uses primarily to obtain information by a process of synthesis, inquiry, or research. The information sought may be of a visual, technical, or conceptual nature.
5. PROTOTYPE MODEL- An original or model after which anything is copied: pattern archetype: a primary form.
6. MOCK-UP MODEL- An imitation of a system, object, or structure, or any of their respective elements: normally at full or expanded scale: a demonstration device.
7. VISUAL STUDY MODEL- A model primarily intended only for information, instruction, or assistance of the maker: for the purpose of assisting visualization or expressing conditions otherwise not easily assimilated in other media.
8. TESTING AND ANALYSIS MODEL - A model primarily intended to obtain specific data normally of a technical nature, relating to physical performance. A device which is so related to a physical system that observations on the model may be used to predict accurately the performance of that aspect of the physical system.

9. EXPLORATION MODEL- A model used to systematically seek or search for information: a device which may be employed to inquire into areas of unknown, unpredictable, or conceptual nature related to architecture: a tool for research.
10. SMALL-SCALE MODEL- Miniature: reduced in size but generally retaining the same proportions as the prototype or intended system.
11. FULL-SCALE MODEL- Same size as the prototype or intended system.
12. DIMENSIONAL ANALYSIS- A mathematical method for determining specific variables of homogeneous functions. The method may be applied to models to determine certain data relating to performance.

2. use of the Model

The model has two primary purposes in architectural education and study. The first is for the three-dimensional model to serve as a tangible object that aids in communication. It may function in the following ways:

- (a) as an aid for the instructor to communicate information to the student. As an aid for the student to communicate to the instructor, staff members, or students.
- (b) as an aid for the users to communicate information to themselves.
- (c) as an aid for the users to communicate their ideas to other staff members.
- (d) as an aid for communicating information to the layman who would otherwise find it difficult to interpret that information.

The second purpose is for the three-dimensional model to serve as an aid for investigation, a way to obtain information of a visual, technical, or conceptual nature by, testing and analysis or by exploration. Every model must fulfill at least one of these two purposes or it is of no value as an educational device.

Several major problems concerning the use of three-dimensional models have been raised by this study. They will be discussed in the following

Models have their best applications in the creative phases of the curriculum. Models are the most vital to the basic design sequence. They are employed at the time when the student is least familiar with three-dimensional conception. Models help to stimulate thinking and visual association.

Models for architectural design and city planning have an equal position of importance. Although they have been extensively applied in these areas of study, they have many limitations and should be carefully evaluated before their use

Demonstration models for structural theory and design would make a valuable contribution to the curriculum. Special models or devices can be effectively applied to illustrate stress distribution and other structural conditions.

3. Models for Research in Lighting

Scale models are most useful for studying daylight conditions. The light property shows the validity of this method simply because the daylight factor is a dimensionless quantity that depends only on angles and lengths. (See Section IV B. This makes the daylight factor appear only as a ratio. It is valuable to have a method at the early stages of design to obtain a rough estimate of the effect of changes in design. The scale model is the most appropriate tool for this purpose, but the selection of the scale for the model is very critical. It cannot be too small, making it impossible to do measurements, or so big it becomes intractable. This applies especially to materials that have to do with the transmission, reflection, and scattering of light. The remaining

part of this section discusses the scale of models and its limitations of scale, construction of models from different materials, internal reflectance and reflectivity of materials, and glazing detail and material. The following charts summarize the study's results.

(a) General scales of models

Metric 1/100 1/200, 1/300 in site planning

= 1/8" volume shown

= 1/4" doors, windows shown

= 1/2" windows and doors, details shown

= 1" interior design, details shown

(b) Limitation in scale

Because of the size of the platform inside the dome there are limitations to making test models. The size of the platform is 4 x 4; if relate this size to the above scales we are dealing with areas such as:

= 1/8" = 384` x 384`

= 1/4" = 192` x 192`

= 1/2" = 96` x 96`

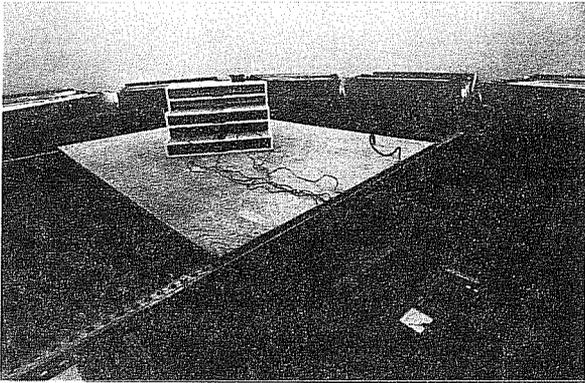
= 1" = 48` x 48`

see next page for figures

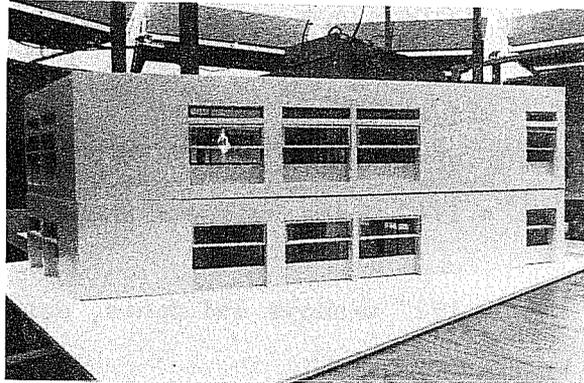
(c) Useable scales for light testing

In conclusion we can say the scales that are useable for all our purposes (light fixtures, furniture) are 1/2" = 1/` and 1" = 1`.

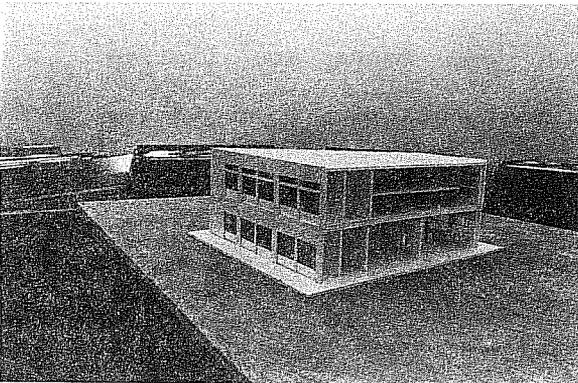
For information regarding model furniture for building architectural daylighting models, see Appendix A.



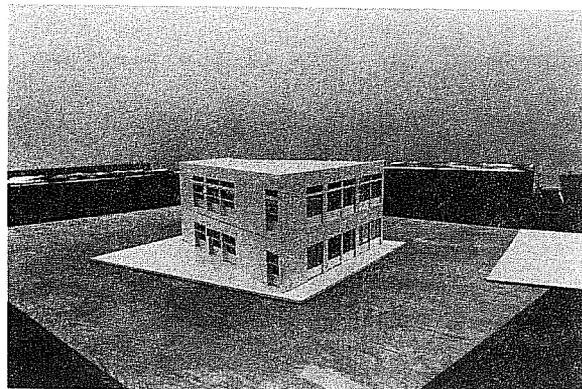
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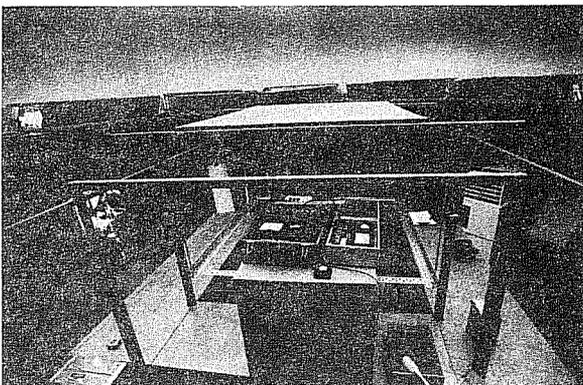
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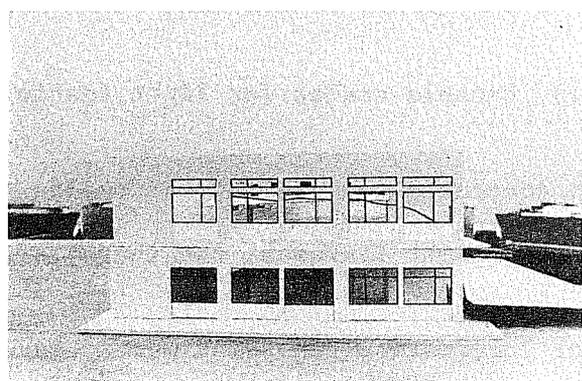
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XBB 817-6202



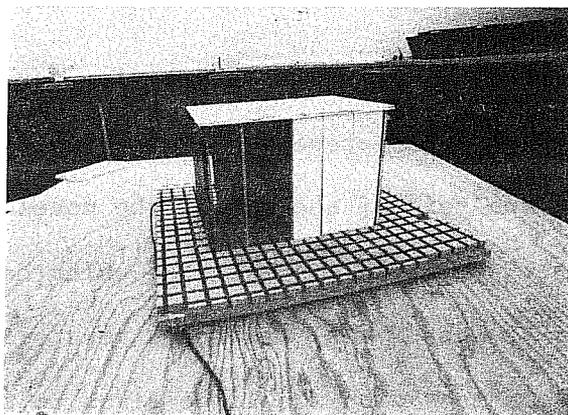
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Construction of accurate models requires special tools, skills and experience.^{3,4,5} The model should be built strong enough to tolerate a lot of moving, being mounted and dismounted for different studies. Corners should be square and light. Plywood, fiberboard, presswoods, foamboard, cardboard, and balsa wood are acceptable materials for models and are the ones most often used. Each material has advantages and disadvantages: for example, plywood is heavy and splinters. Presswood and balsa wood are brittle, and foamboard is reflective up to 80%. Sometimes it takes a great deal of skill and experience to construct a satisfactory model. In order to facilitate construction of simple geometric models, a platform was designed which has slots that can hold a series of small-scale wall panels. (See Figure 21)

Figure (21)



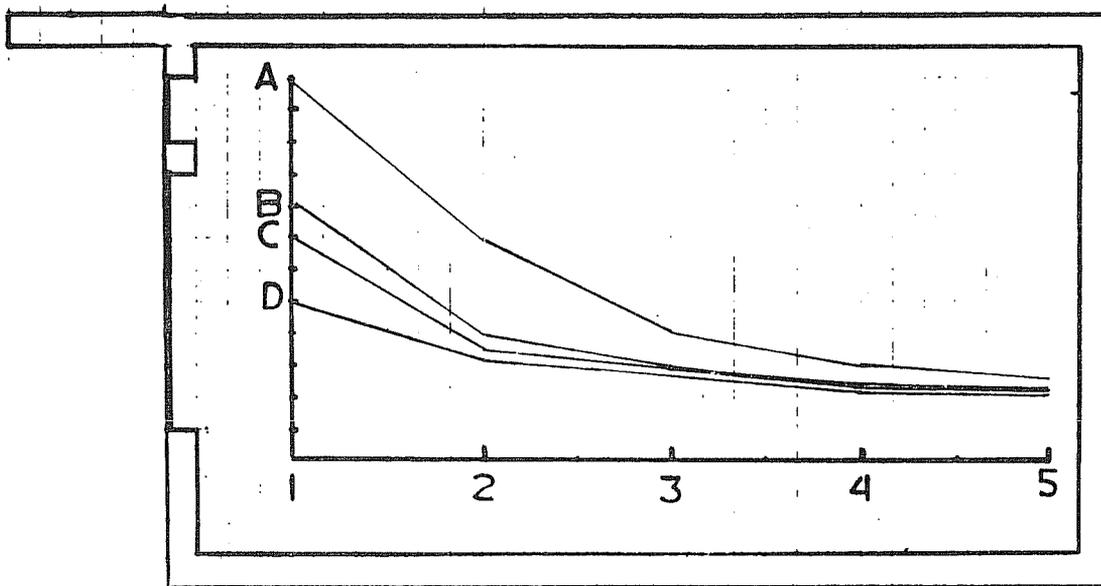
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With this platform small rooms having a simple geometry can be constructed quickly. For modeling reflectivity, the walls could be painted or a different cardboard having a known reflectivity could be pasted over an existing model.

The study shows (See Figure 23) that reflectivity of different materials and surfaces has a great effect on the light intensities in the space. It is important to model the effect very accurately. The major surfaces the reflectivity of which must be considered are first ceiling, then wall opposite fenestration, and last the floor, because the measurements are usually made at task level which is 3 feet or 30 inches above the floor. To prepare for modeling or duplicating different reflectivities or surfaces, a survey was made on the availability of different cardboards. Their reflectivities under the sky simulator were measured. Now for any desired reflectivity materials are available which can be used not only for accurate internal reflection measurements but also for representation of surfaces for visual evaluation and architectural presentation.

Another important issue in modeling is duplicating fenestration systems. The openings in models which represent the glazed windows are satisfactory but for accurate analysis of the system the model has to show the glass and, if possible, mullions. A material which has been used as an actual shading device (Dupont Mylar) was found very suitable for modeling glass. Special consideration should be given to the effects of all obstructions, the spacing of columns and mullions, horizontal and vertical louvers, or elements within a fenestration system (See Figure 22)

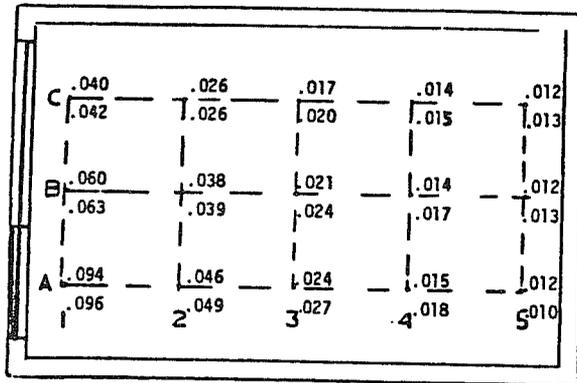
Figure(22)



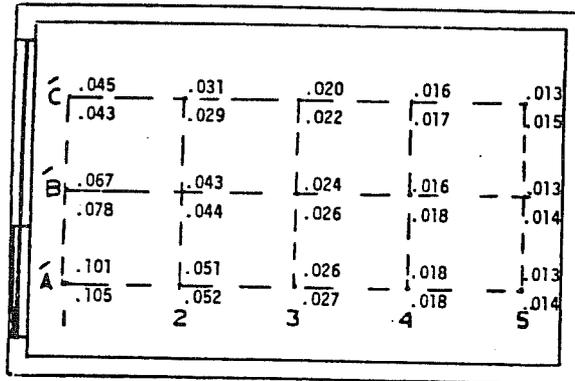
- A - Simple Opening
- B - Opening with Window Frame
- C - Opening with Window Frame and Glass
- D - Opening with Window Frame and Shading Device

Early experiments and studies showed that ground reflectance and the terrain are important factors to the illuminance distribution of the space adjacent (See Figure 23). The ratio of the light striking the fenestration system from the ground or terrain to the total illuminance reaching the fenestration should be the same for both the actual building and its model. With a curtain inside the sky simulator, there is no ground reflectance but with the use of a ground reflectance simulator different ground reflectivities could be produced. For testing methods and the use of model within sky simulator, see Section IV B Accuracy of the System.

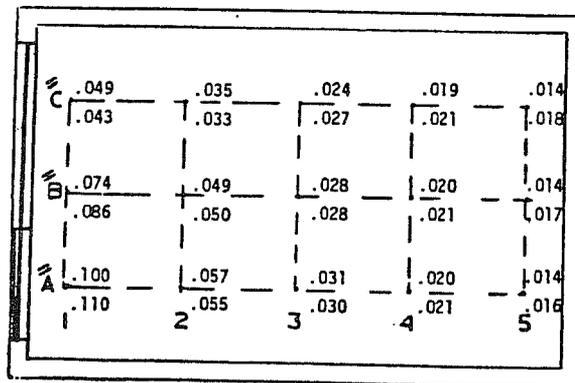
FIG. 23



a) Ground Reflectance = 0.01 Indoors
= 0.06 Outdoors



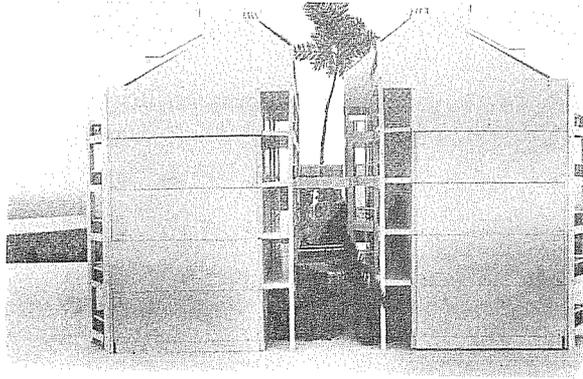
b) Ground Reflectance = 0.39 Indoors
= 0.41 Outdoors



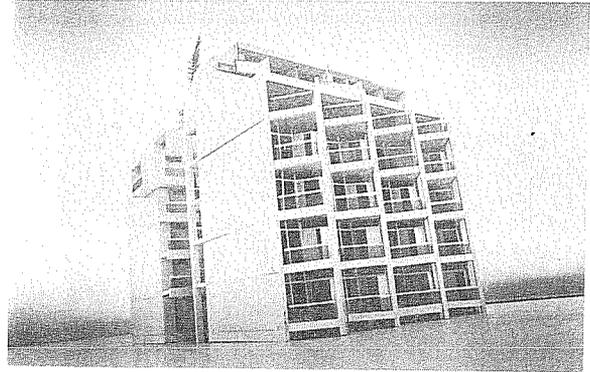
c) Ground Reflectance = 0.86 Indoors
= 0.89 Outdoors

a), b), and c). Values shown are dimensionless: Measured interior illumination divided by vertical surface illumination at the window. At each point, upper value is measured in the sky simulator; lower value is measured outdoors.

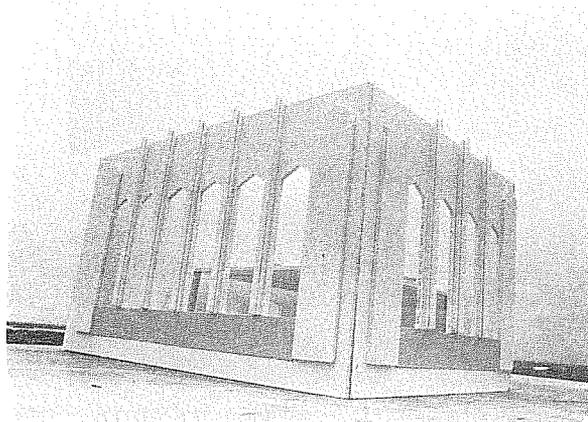
Figure
24



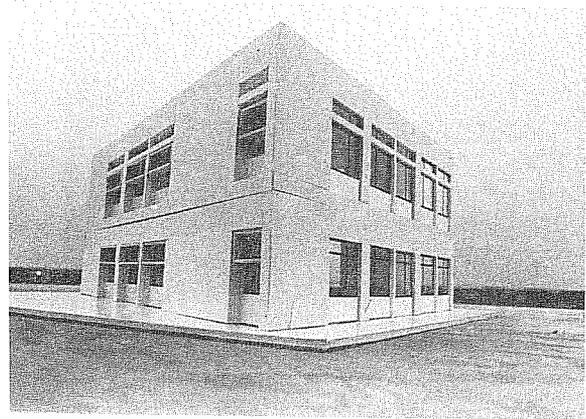
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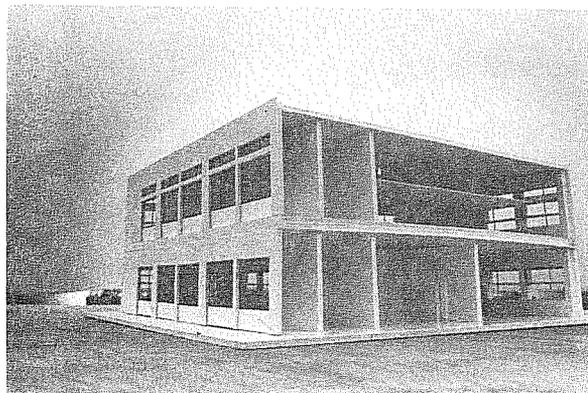
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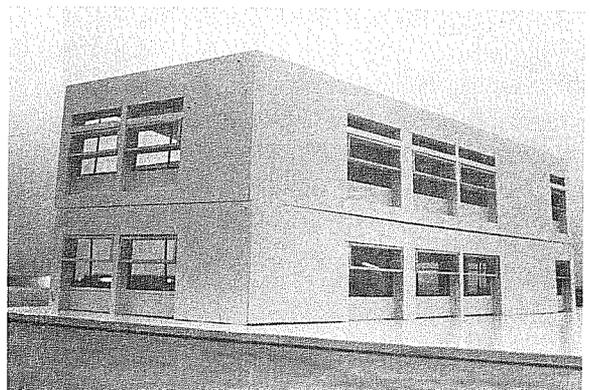
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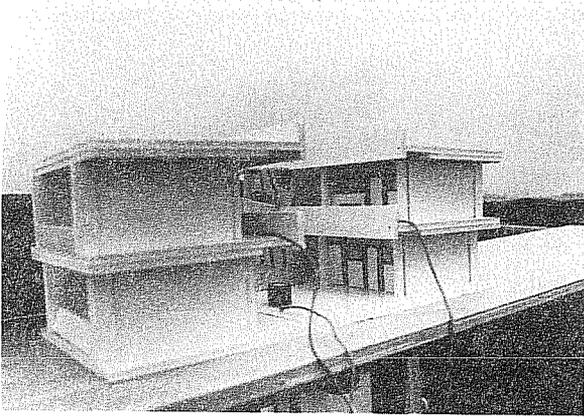


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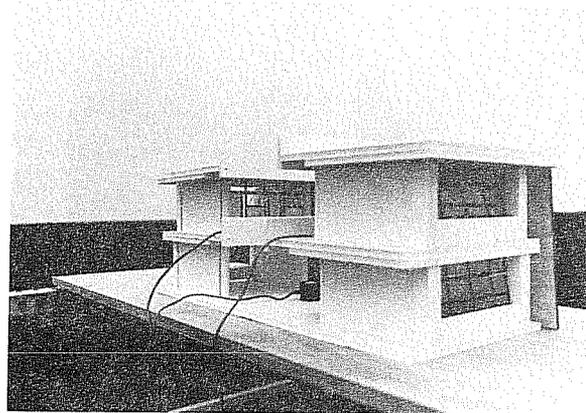


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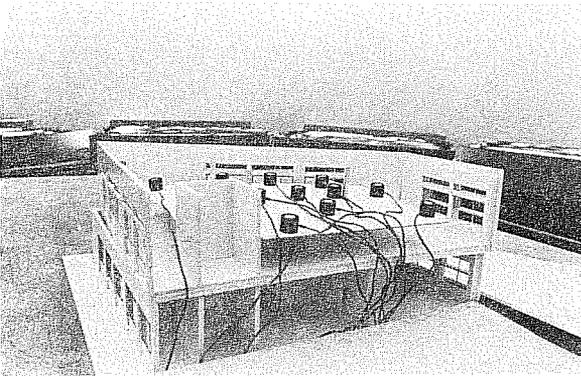
Figure
24



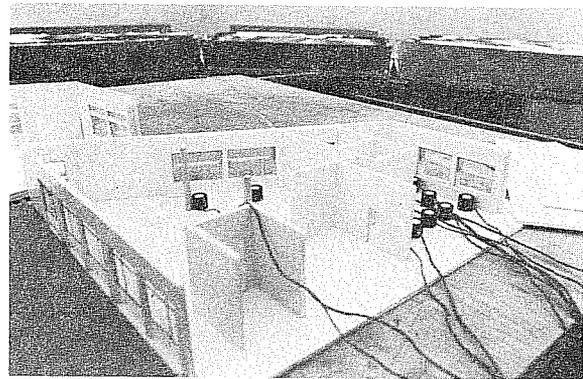
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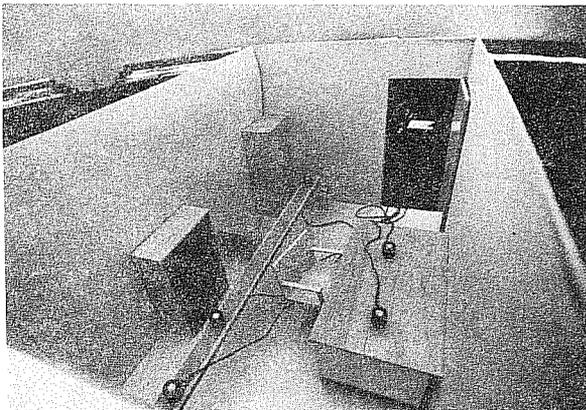
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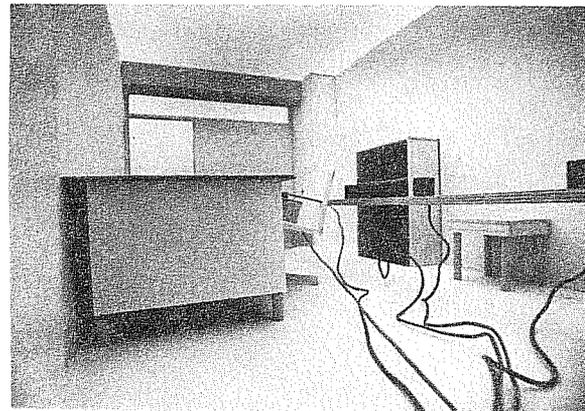
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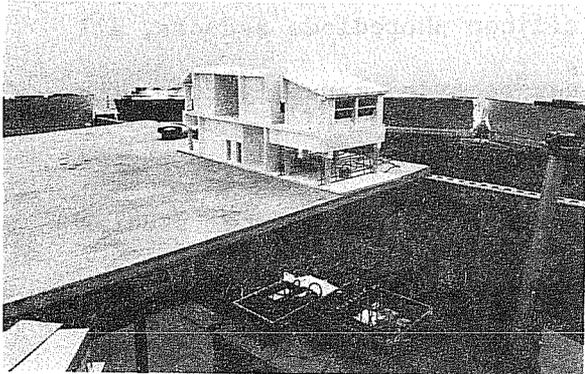


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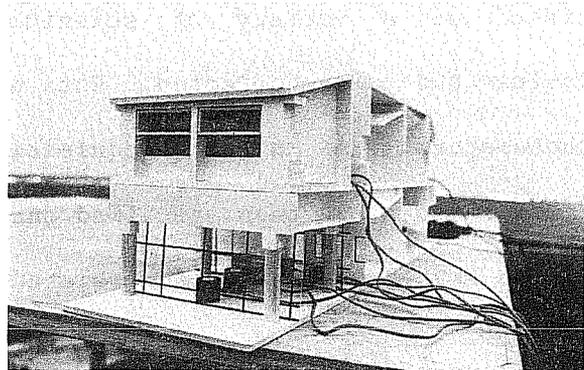


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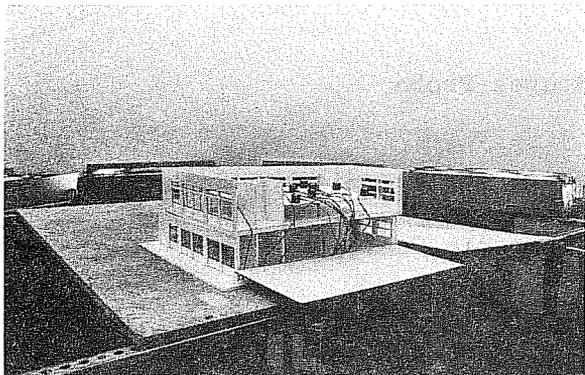
Figure
24



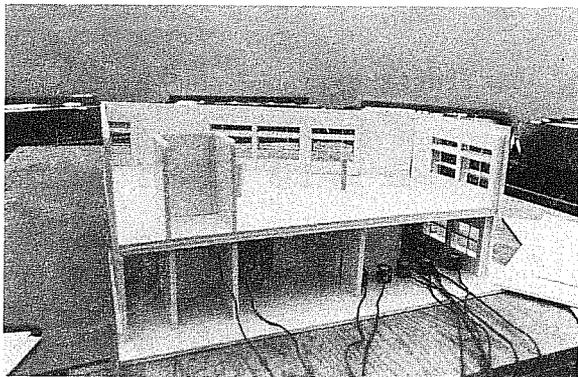
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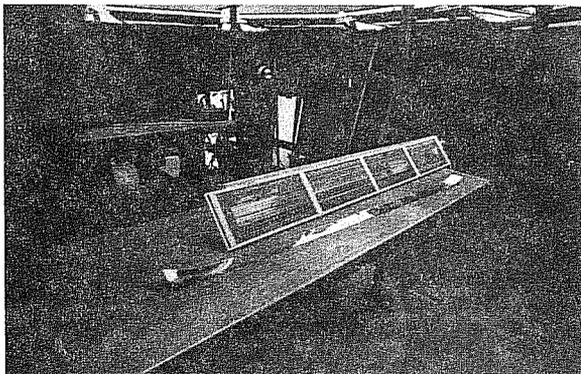
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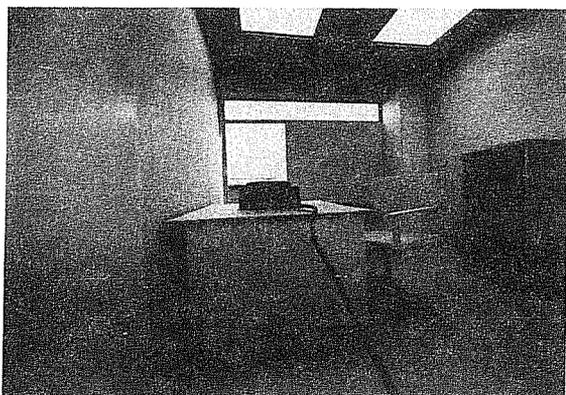
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XFB 817-6189



XBB 816-5165



XFB 804-5192

I. Instrumentation

The instrumentation that has been used in model studies to date has consisted of a variety of selenium and silicon photodiode sensors, all cosine- and color-corrected. Data have been recorded manually from the photometers. A new data acquisition system using small silicon photodiode sensors has been specified and will be used in all future studies in the sky simulator and for related outdoor model studies.

The instruments used for illumination studies in the artificial sky are as follows (See Fig. 24a):

1. Tektronix option 1 and 2 j16 Digital Photometer
2. Tektronix option 1 and 2 j6511 Illuminance Probe
3. Tektronix option 1 and 2 j6523 One Degree Angle Luminance Probe
(option 1 English Scale, option 2 Metric Scale)
4. Megatron Architectural Model Luxmeter
5. Spectra Model 1980A Photometer
6. Li-cor Illuminance Probes
7. Litemate/Spotmate System 500 Photometer
8. Photoelectric Cells

2. The Obliquity Correction of A Silicon Photovoltaic Cell for Specific Use

An investigation into the characteristics of the various types of light

sensing devices marketed in Great Britain, and U.S. led to the selection of the silicon photoelectric device. (5961-602-6510) P/N 1025-161 This unit, manufactured by Marvellum Company, has approximately 1/4" to 1/8" overall sensitive surface.

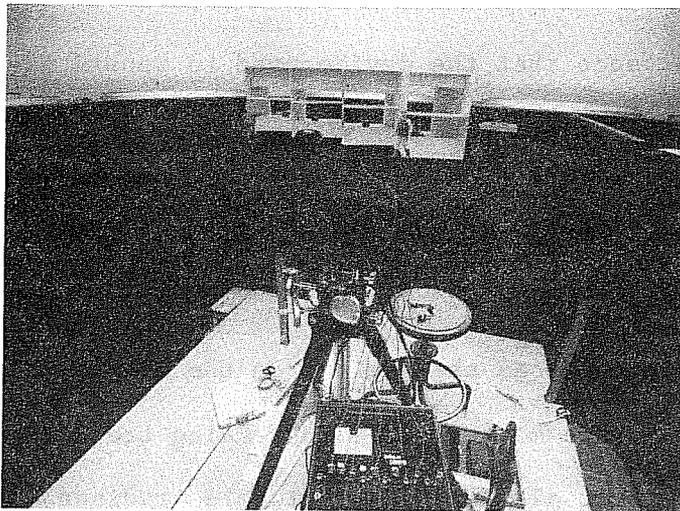
Due to reflection from the specular surface that forms a protective window over the photoelectric sensitive surface, and screening introduced by its protective casing, the response of this unit to obliquely incident light was not proportional to $I_{\Omega} = I \cos\Omega$. In other words, the unit did not obey the cosine law of illumination. Since illumination incident on a horizontal plane at the far point in a normal side-lit room is from angles of elevation in the vicinity of 30° or less, it is a fact of prime importance that the device used to record the magnitude of illumination must obey Lambert's Law. (6)

The same basic correction technique used by Pleijel and Longmore was used in the obliquity correction of the photoelectric device. Since the ratio $I \cos \Omega / I_{\Omega}$ increased as the angle from the normal increased, with the latter showing the most rapidly increasing trend towards zero, it was necessary to collect all incident visible radiant energy in an artificial intermediate device which would project the correct amount of flux onto the receptor surface.

Because of its nearly ideal diffusing and transmitting properties, No. 2447 Plexiglass white manufactured by Rohm and Hass was selected as the obvious light collector and diffuser. This material provided the additional advantage of being non-selective within the visible spectrum. After constructing of a housing from cylindrical Plexiglass tubing for the photoelectric device, a 1% precision resistor was placed across the

output of the silicon photoelectric cell in order to set the output voltage calibration to $1\text{mv} = 10\text{ lux}$. With a small cable the photovoltaic device can be connected to a voltmeter for reading out the measurements. Overall cost of this device compared to other cosin-corrected photocells is very low. This device can be used for model measurement inside the sky simulator since the overall illuminance output of different sky luminance distribution is defined. Also the device can be calibrated for any desired level of illumination for outside measurement.

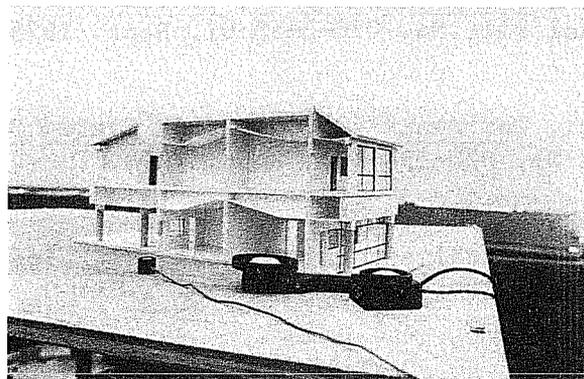
FIG.24A



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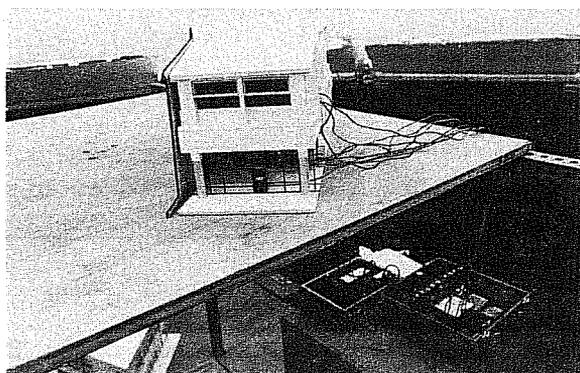
MEGATRON
LUXMETER

Figure
24B



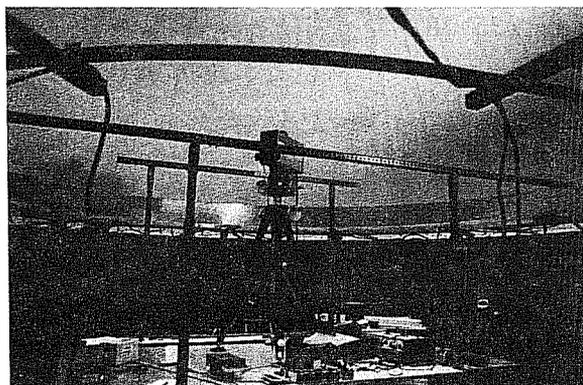
XFB 817-6188

(LI-cor probs) (Megatron luxmeter) (Tektronix probs)



XEB 817-6204

(Litmate photometer)



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(Spectra model 1980 A Photometer)

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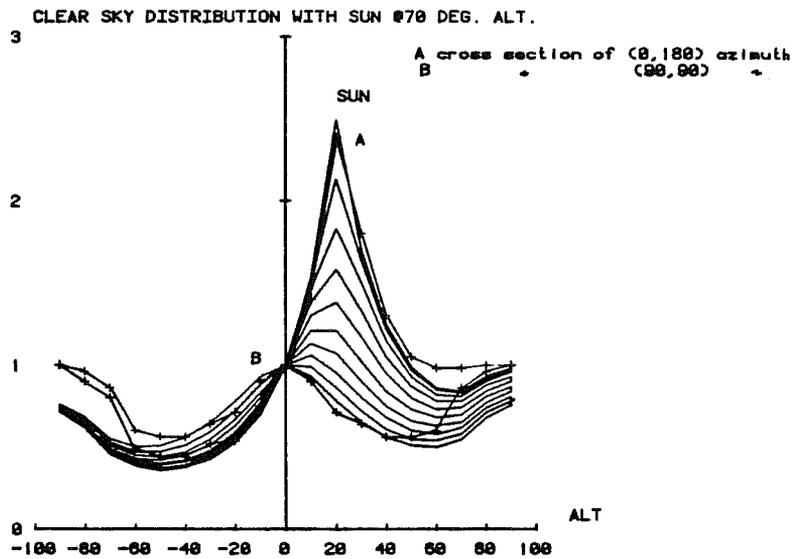
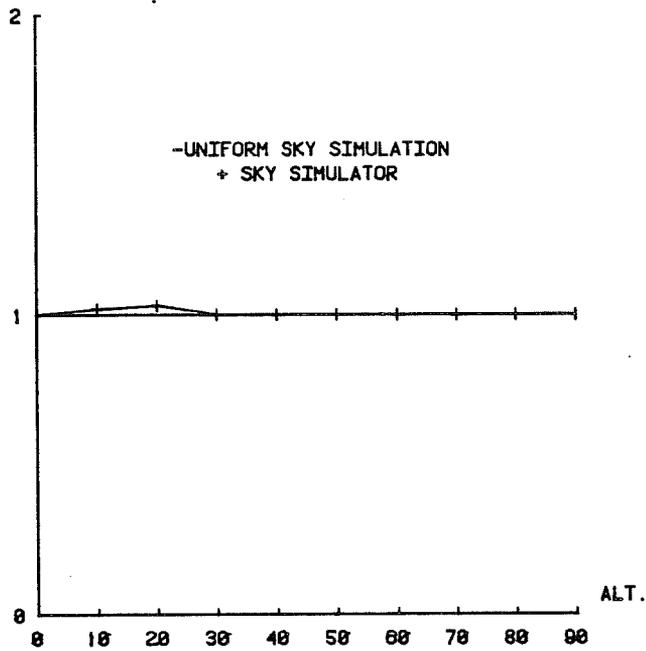
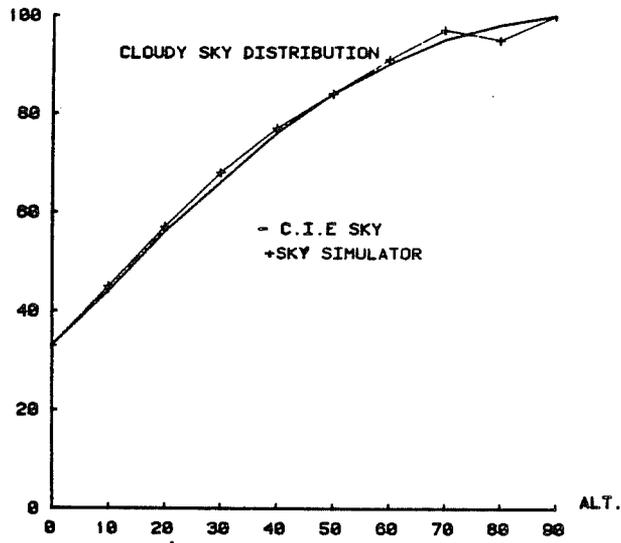
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IV. C.I.E. OVERCAST, UNIFORM, AND CLEAR SKY CONDITIONS

The working overcast sky distribution was attained in the summer of 1980. Since that time the facility has been used successfully by several architectural firms for designing office buildings. Comparative measurements were made for a small office model both in the sky simulator and out-of-doors. (Fig. 23) Results of indoor tests were compared to the C.I.E. standard. Agreement was excellent, as was shown in Figure 23. Studies are now in progress to compare the output of several computer programs with results from the sky simulator.

Reflectors were adjusted upward toward the center of the sky, aiming at zenith. The spotlights are adjustable and can be aimed at desired solar altitude for producing the luminance distribution around the sun. The fluorescent lamps are adjusted and dimmed to simulate uniform luminance distribution in the sky simulator. The illumination on a horizontal level is 400 ft.cd \approx 4000 lux over an area 10 feet in diameter at the center of the simulator plus or minus one per cent after 8ft. diameter. The overall brightness of the sky these conditions is about 1,280 foot-lamberts. Figure 24. shows preliminary results for sky simulation of an C.I.E. overcast sky and clear uniform sky.

FIG. 4.



Continuous refinement and testing of the lighting system in late 1980 to achieve the desired clear-sky distributions led to the major change in the basic fluorescent lighting system described earlier. The standard lamps and ballasts are being replaced with high-output units, and the reflectors have been modified from planar units to curved surfaces, which provide better directional control. With selective control of concentric groups of fixtures, this system provides a uniform sky, a C.I.E. overcast sky, and the horizon-to-zenith variation for clear skies. Arrays of spotlights are then used to fine-tune the clear-sky distribution for each solar altitude. The large size of the sky and the custommade platform within the center, along with the special curtain hung from the edge of the horizon line within a circle 16 feet in diameter at the center of the simulator, there is great flexibility for various model studies. The capabilities of the system, its accuracy and calibration, will be discussed next.

A. Capabilities of the System

The sky simulator can be used:

1. to analyze photometric configurations inside scale models under simulated daylight conditions; special attention will be given to the development of techniques for the study of glare
2. to observe (or take pictures) of the inside of modeled spaces, from the proper point of view, under proper illuminance distribution and with the correct architectural background scenario for visual evaluation.

3. to map natural light radiation availability inside a built environment, not only from the photometric aspect but also from the irradiance and illuminance aspect.

1. Analysis

One of the benefits of using a scale model for photometric measurements rather than a mathematical model, is that one has the advantage of the "perceptual" dimension. Not only is it possible to measure several photometric quantities inside a scale model (quantities that can also be calculated from a mathematical model if the proper physical equations are used), but one can to some extent experience the space, which the model represents, directly through the visual sense.(1,2,3,4)

Each of the above-named purposes will require specific instrumentation and some special modifications of the system.

The following guideline is for each of the possible uses of the system:

(a) Analyzing photometric configurations: This is the most popular use of such a system. It involves measurements of light intensity, but could also include spherical and luminance measurements. The most important factor needed to ensure successful measurements is the ability to take a great number of "point measurements" (using sensors as "miniaturized" as possible). The second factor is the flexibility of this system, enabling us to create different lighting scenarios in a fast and accurate way. One specific area of investigation is of instrumentation and techniques for the study of glare using models in an artificial sky simulator with the use of sun simulator and clear-sky luminance distribution along with usage of LIAM diagram computer program.

(b) Observation or picture-taking: This field has been neglected by many architects. In many cases the designer is unable to observe his model from the necessary points of view, especially from internal eye-level points. One cannot be inside the model, so must be satisfied with observing the model from above. A similar situation occurs when taking pictures of scale models. The pictures are frequently taken in a photographic lab, under random illuminance. The relative intensity of direct and diffused illumination is uncontrolled, as is the number and directionality of the light sources. But now with some additional equipment (camera) all these options are possible. (See instruction and research uses.)

(c) Mapping availability: The photometric aspect is an obvious energy study option. No artificial sky system has been used before for the quantitative study of overall solar energy availability. For example, it would be possible to make direct measurements of the quantity of radiated natural energy reaching a certain element of a building (in particular urban, geographical, climatical and environmental constellations). This can be done with the standard photometric equipment, with some modifications of the recording system (giving it some kind of integrating over time capacity), single multiplying factor and with proper calibration of the lighting systems. The successful result for such a project strongly depends upon the control flexibility and control of the lighting system. (See instruction and research uses.) The following tables and graphs shows the result of different sky luminance distribution against Kittler's sky luminance distribution as C.I.E. standard.

B Accuracy of the System

The great interest of architects and designers in using daylight in building design requires simple and accurate methods of predicting the natural illumination in designed buildings. Before the development of model-testing techniques, designers attempted to compare the effect of the architectural spaces and shapes under natural lighting by the use of full-size models. Then it was realized that in order to do the comparison accurately, they had to keep the landscaping and the sky condition the same. The landscape was fairly constant except for different seasons, but sun and sky conditions changed constantly. It was obvious that an accurate comparison was impossible; thus the need for a sky simulator. In a sky simulator the sky condition could be held constant and the model tested with a fixed landscape. The architectural effect now is isolated, and accurate comparisons could be made.

1. Definitions

Daylight Factor: The daylight factor is a measure of daylight illumination at a point on a given plane expressed as a ratio of illumination on the given plane at that point and the simultaneous exterior illumination on a horizontal plane from the whole of an unobstructed sky of assumed or known luminance distribution. Direct sunlight is excluded for both interior and exterior values of illumination. (10) p. 576

Daylight Factor: (Revised Definition, 1963) The ratio of the daylight illumination at a given point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution to the illumination on a horizontal plane due to an unobstructed

hemisphere of this sky. Direct sun is excluded for both values of illumination. (10) p. 576

In the use of this method, the sky simulator was set for an overcast sky condition which was calibrated against C.I.E. overcast sky standard. (5,6,7,8,9,10) The model were placed on the platform at horizon level, and a series of surveys were made for light intensities at various points on task level inside the model. These points are shown by EN in Figure 25a. Simultaneously with each measurement taken inside the model, a reference measurement was made outside of the model at the horizontal and vertical level of the fenestration system plate which are presented as EV and EH in Figure 25a. The daylight factor, which is dimensionless, could be calculated for each measured point inside the model by the use of following equations:

$$DE_V = EN/EV \text{ or } DE_H = EN/EH \quad (1)$$

DE_V is the daylight factor when a vertical reference reading was used and DE_H for a horizontal reading. Results in are shown a curve of DE_V , or DE_H , or E_N in Figures 25 and 26

Figure 25a

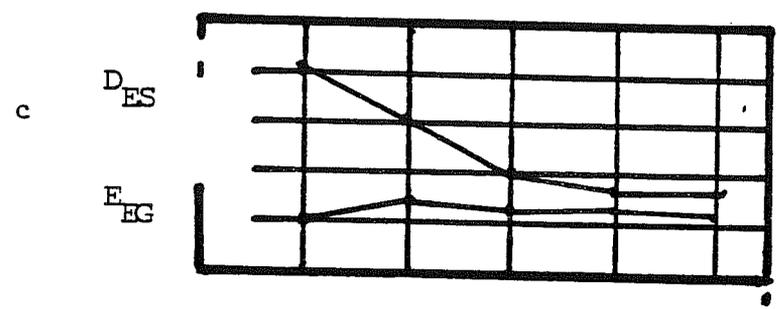
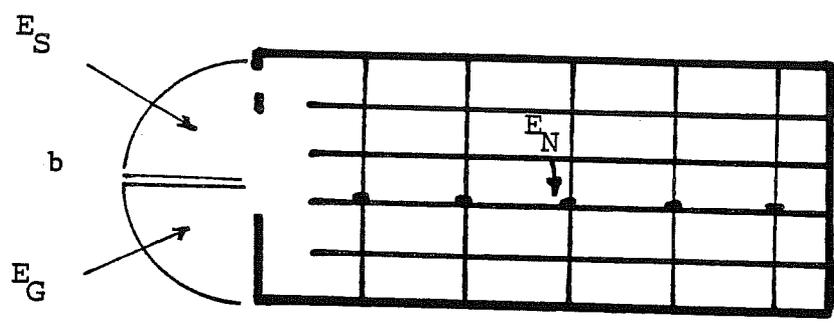
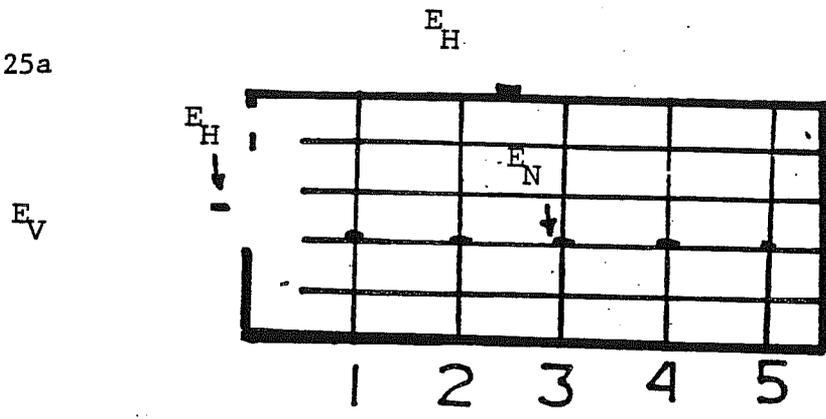
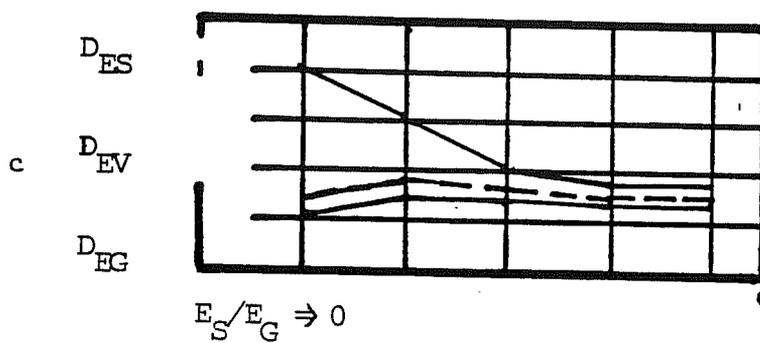
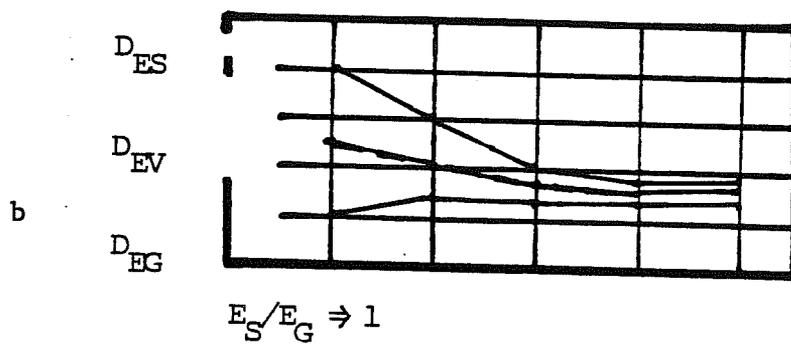
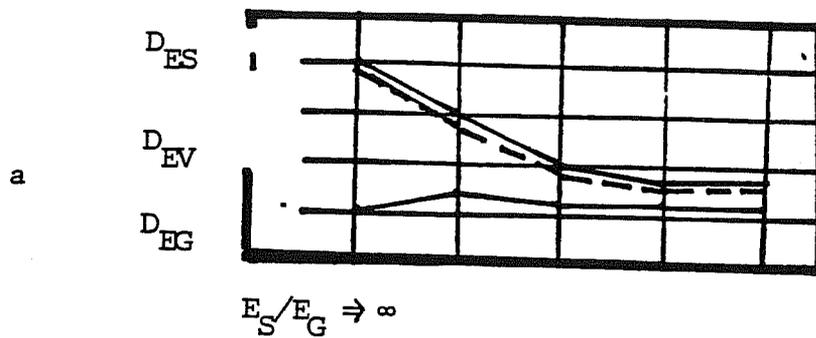


Figure 26a



Then, the values of luxes or footcandles for the inside measured points (EN) can be calculated for any time and sky intensity by multiplying DE_v or DE_N by the value of EN or EH appropriate to a given sky intensity.

Reliable comparisons can be made among different architectural shapes and spaces. The natural lighting of a proposed building could also be predicted. The accuracy of this method depends on the sky's ability to simulate luminance distribution.

Skies are never uniform, and clear skies have maximum brightness in the direction of the sun.⁽¹⁹⁾ Overcast skies have minimum brightness at the horizon and maximum at the zenith. Based on C.I.E. expressions for daylight illumination for overcast skies, the brightness ratio of zenith to horizon is 3 to 1. For clear skies brightness varies with sun position (altitude). See Figures 27 and 28. By accounting for this variation in helios in the sky simulator, these variations were reproduced close to the C.I.E. standard. (See Section 5, following, on LIAM diagrams.)

SKY LUMINANCE DISTRIBUTION

Clear skies

The CIE standard luminance distribution for clear skies is given by the following formula:

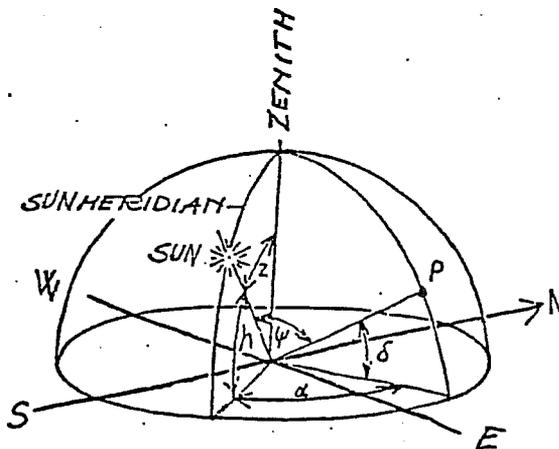
$$L_{\alpha, \delta} = L_z \cdot \frac{(1 - e^{-0,32/\cos \delta}) \cdot (0,91 + 10e^{-3\psi} + 0,45\cos^2 \psi)}{0,274 \cdot (0,91 + 10e^{-3z} + 0,45\cos^2 z)}$$

where $L_{\alpha, \delta}$ is the sky luminance for the point P positioned by
 δ angle of altitude and
 α angle of azimuth from the sun's meridian
 L_z sky luminance in zenith
 ψ angular distance from the sun to the point P
 z the sun's zenith angle (angular distance between sun and zenith)

The figure below shows the geometrical relationships involved. The luminance distributions for two sun altitudes is shown on next page on a sky vault projection.

An empirical formula for the zenith luminance is given below. With solar altitude h entered in degrees the formula gives luminance in metric units (cd/m^2). Division with 3.426 will give the luminance in foot-Lamberts.

$$L_z = 100 + 63h + h \cdot (h-30) \cdot e^{0,0346(h-68)}$$



A= horizontal plot of sky luminance distribution
 B= vertical
 C= liam diagram plot

guidelines for fig.27 & fig 28
 page 105 through 118A

Overcast skies

The CIE standard luminance distribution for overcast skies is given by this formula:

$$L_{\delta} = L_z \cdot \left(\frac{1+2 \sin \delta}{3} \right)$$

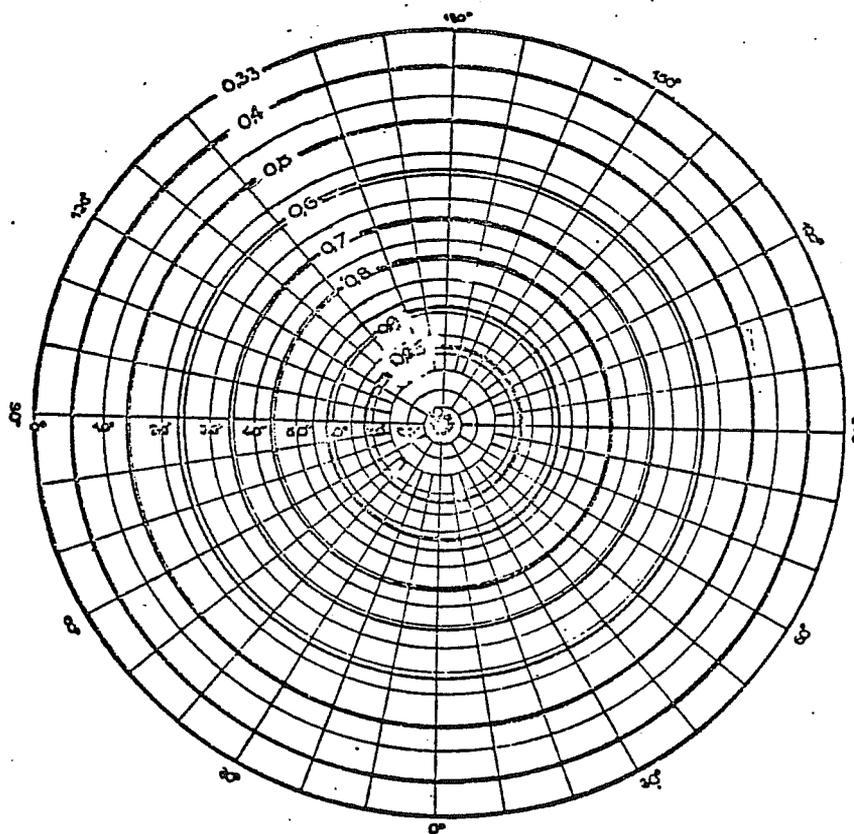
where L_{δ} is the sky luminance for points with an altitude of δ degrees above the horizon
 L_z sky luminance in zenith

Note that the distribution is independent of the sun's position. The relative distribution is shown on the sky vault projection below.

An empirical relation for the zenith luminance is:

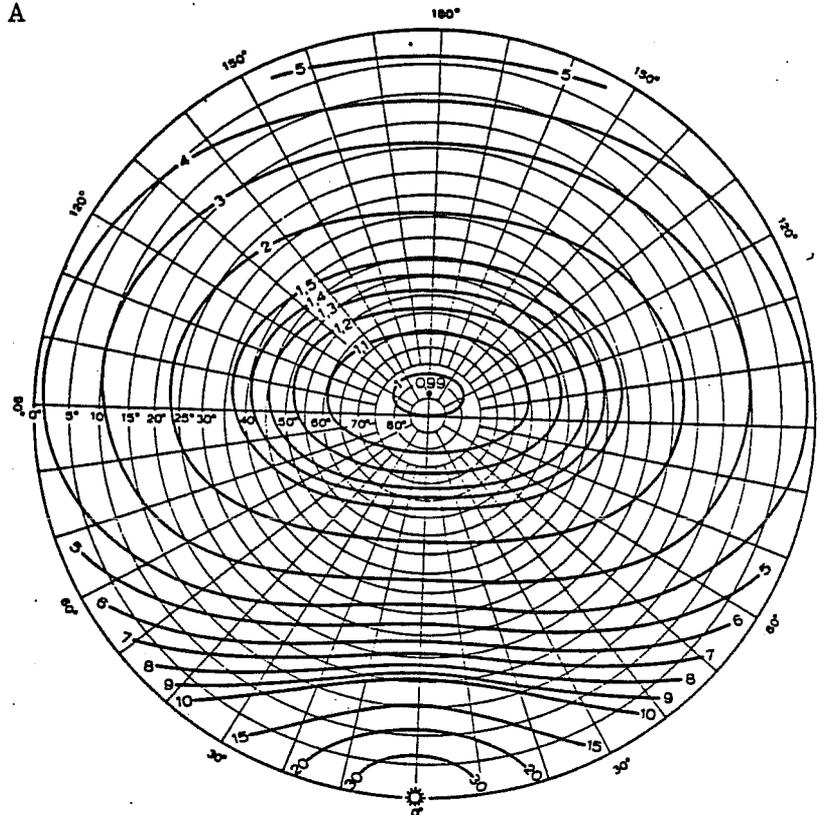
$$L_z = 123 + 8600 \sin h$$

where h is the sun's altitude above the horizon. The formula gives the luminance in cd/m^2 .

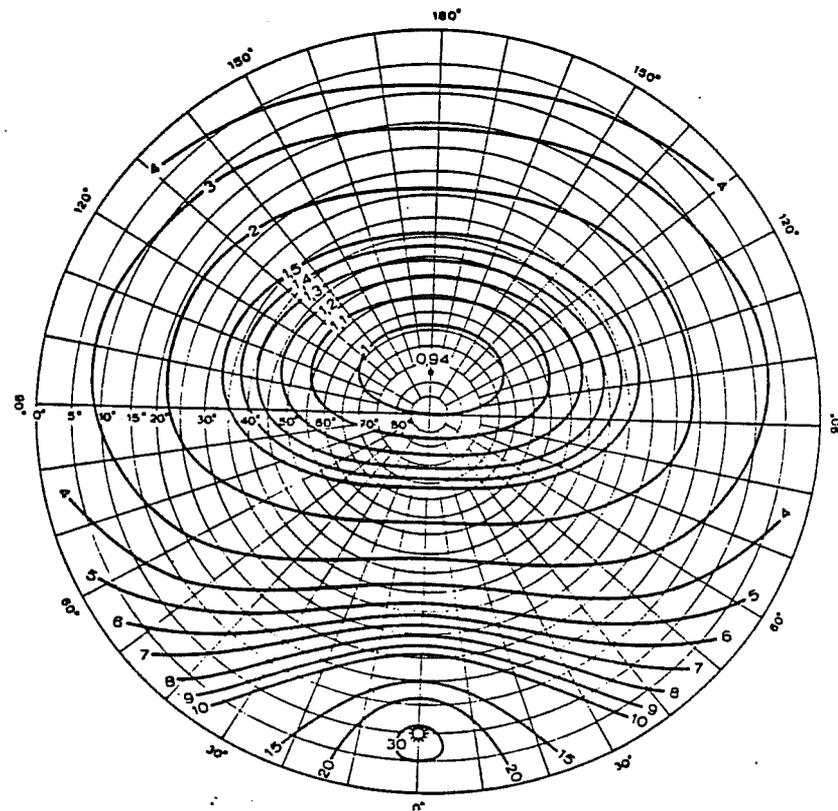


A

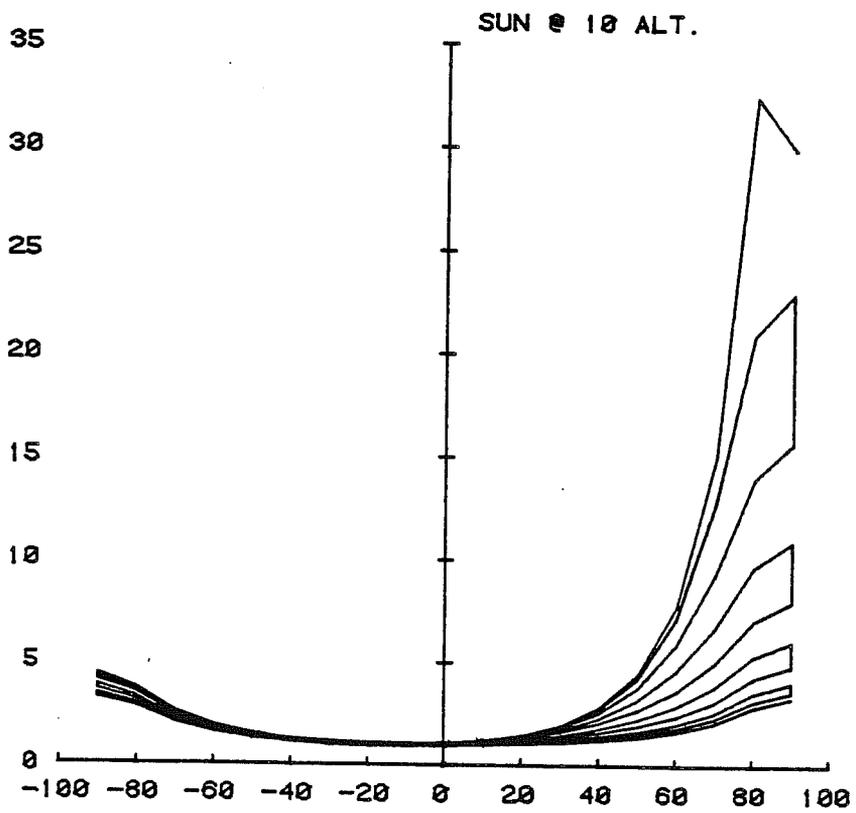
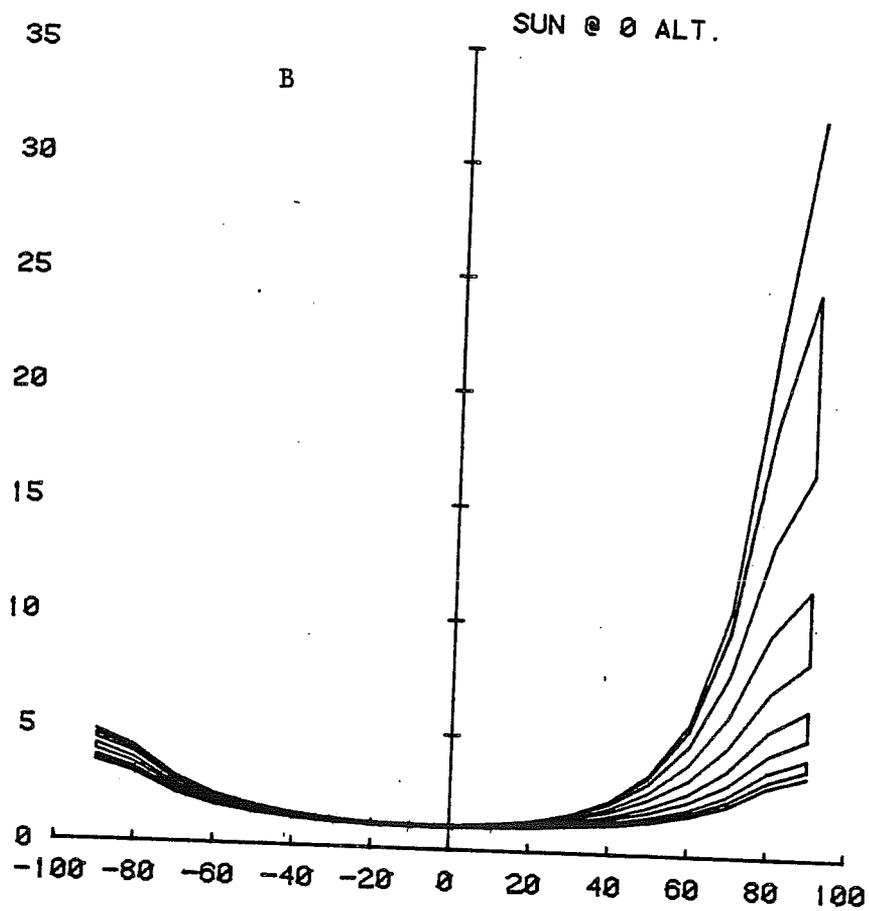
SUN HEIGHT: 0°
ZENITH SUN DISTANCE: 90°



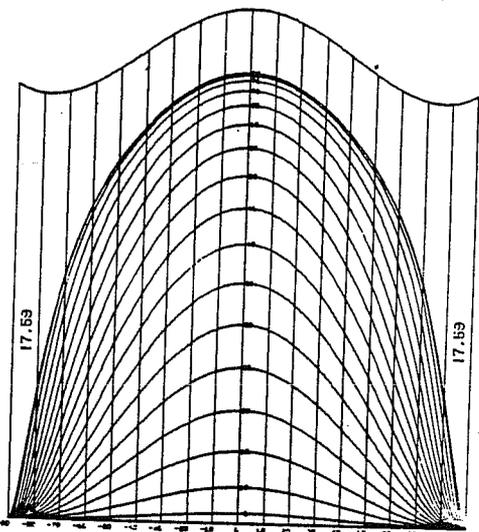
SUN HEIGHT: 10°
ZENITH SUN DISTANCE: 80°



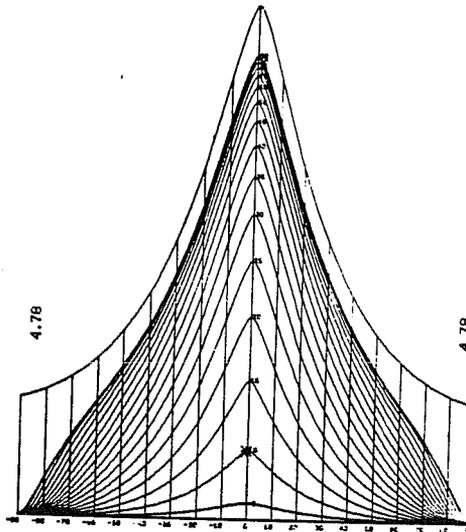
Source: CIE Pub. No. 22 (1973).



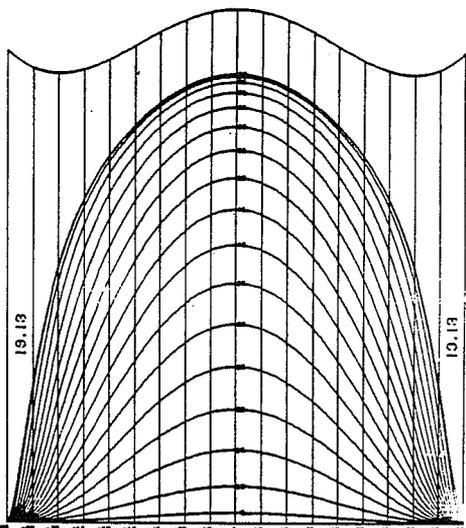
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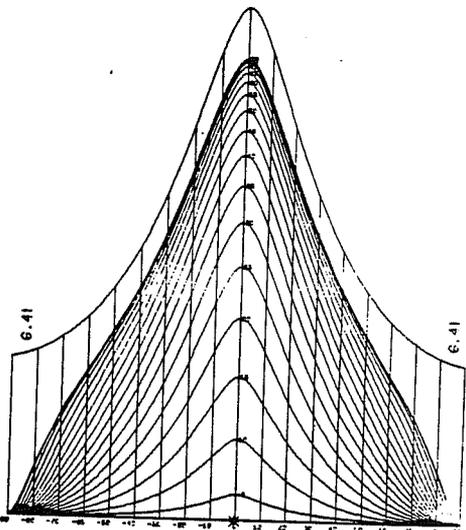
LIAM DIAGRAM WINDOW SOLAR AZIM = 182 DEG
 CIE KITTLER SKY SOLAR ALT = 0 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN, CLEAR;
 SKY AREA 339.28 SQ. CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 2 DEG
 CIE KITTLER SKY SOLAR ALT = 13 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN, CLEAR;
 SKY AREA 179.96 SQ. CM.



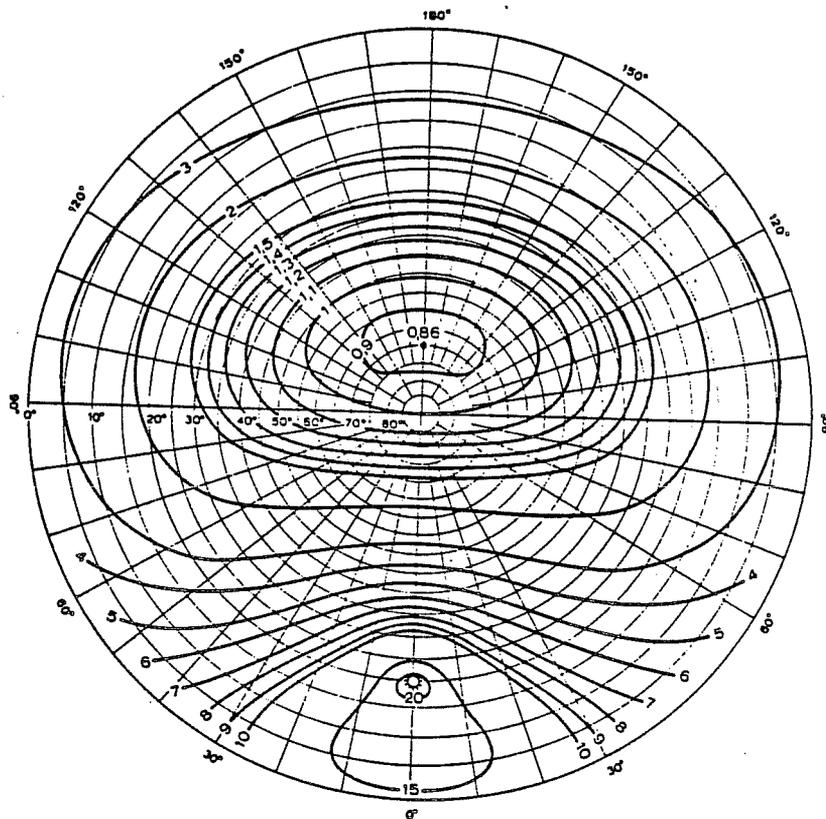
LIAM DIAGRAM WINDOW SOLAR AZIM = 182 DEG
 CIE KITTLER SKY SOLAR ALT = 10 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN, CLEAR;
 SKY AREA 347.84 SQ. CM.



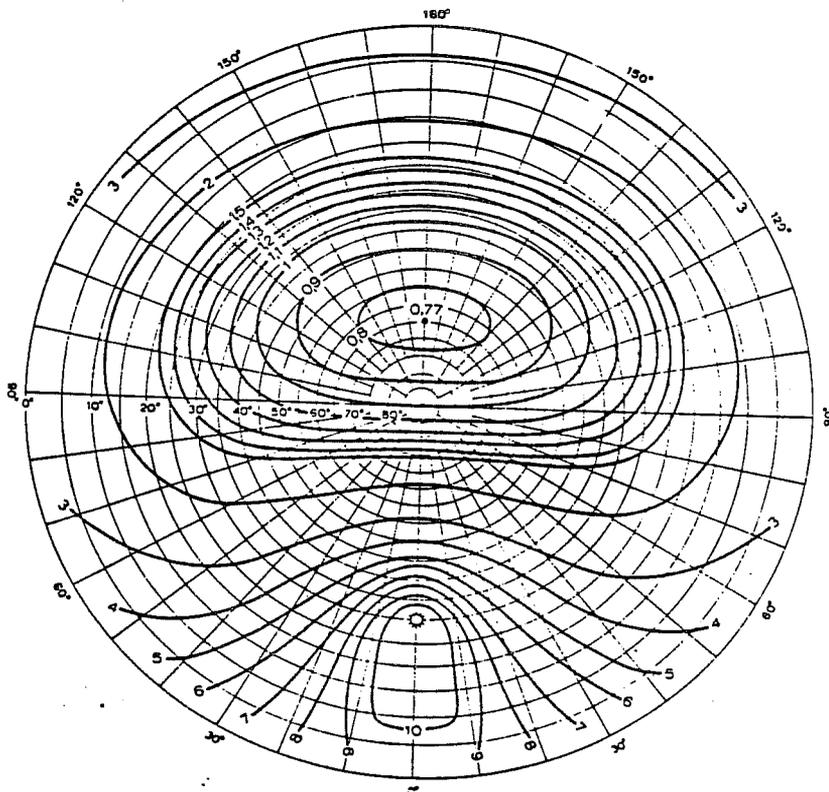
LIAM DIAGRAM WINDOW SOLAR AZIM = 2 DEG
 CIE KITTLER SKY SOLAR ALT = 0 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN, CLEAR;
 SKY AREA 228.67 SQ. CM.

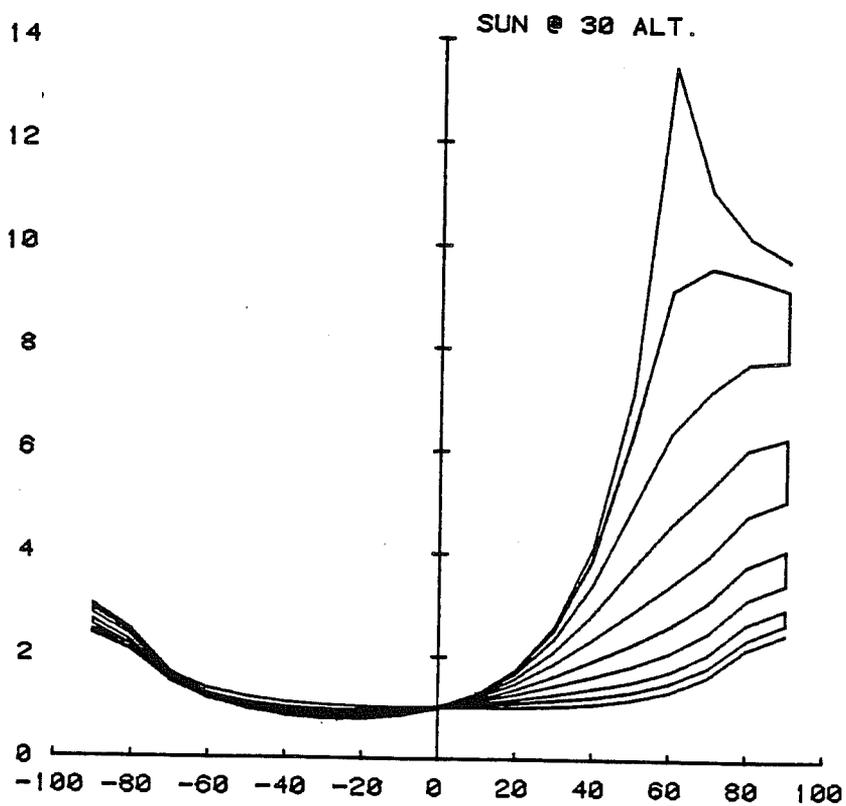
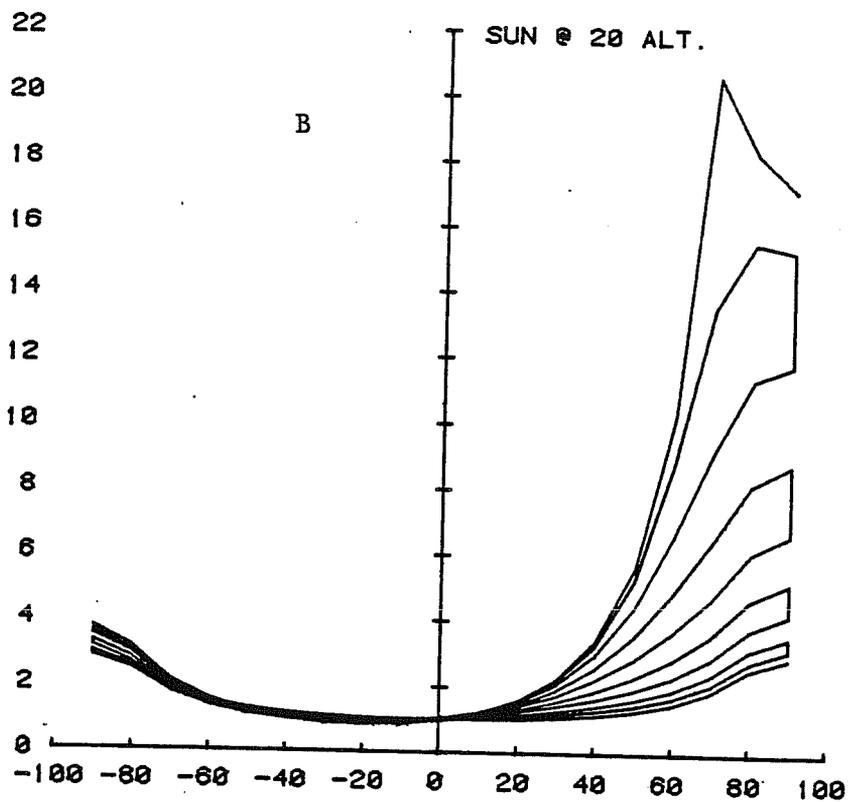
A

SUN HEIGHT: 20°
 ZENITH SUN DISTANCE: 70°

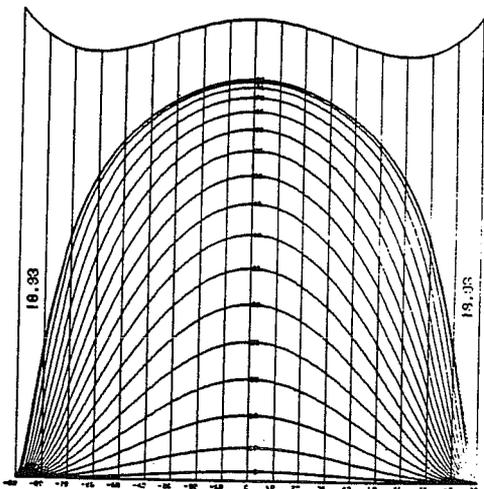


SUN HEIGHT: 30°
 ZENITH SUN DISTANCE: 60°

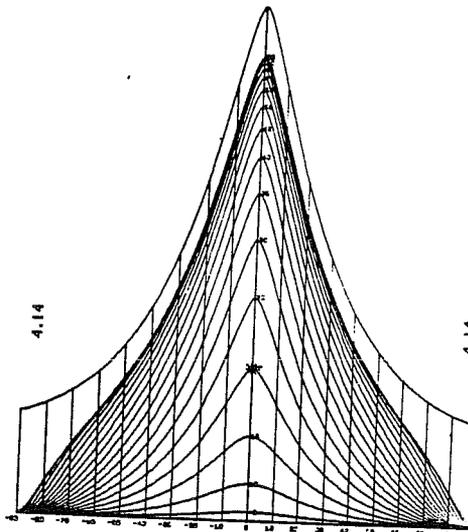




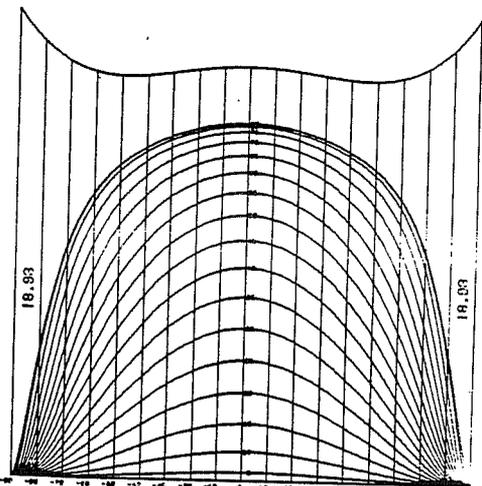
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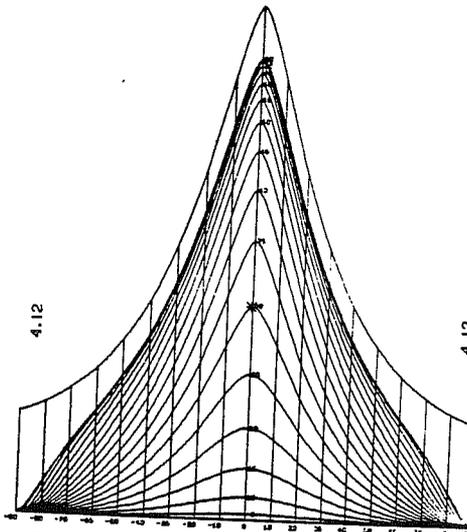
LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 CIE KITTLER SKY SOLAR ALT = 20 DEG
 HORIZONTAL PLANE GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 322.35 SQ. CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 CIE KITTLER SKY SOLAR ALT = 20 DEG
 HORIZONTAL PLANE GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 170.63 SQ. CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 CIE KITTLER SKY SOLAR ALT = 30 DEG
 HORIZONTAL PLANE GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 302.10 SQ. CM.

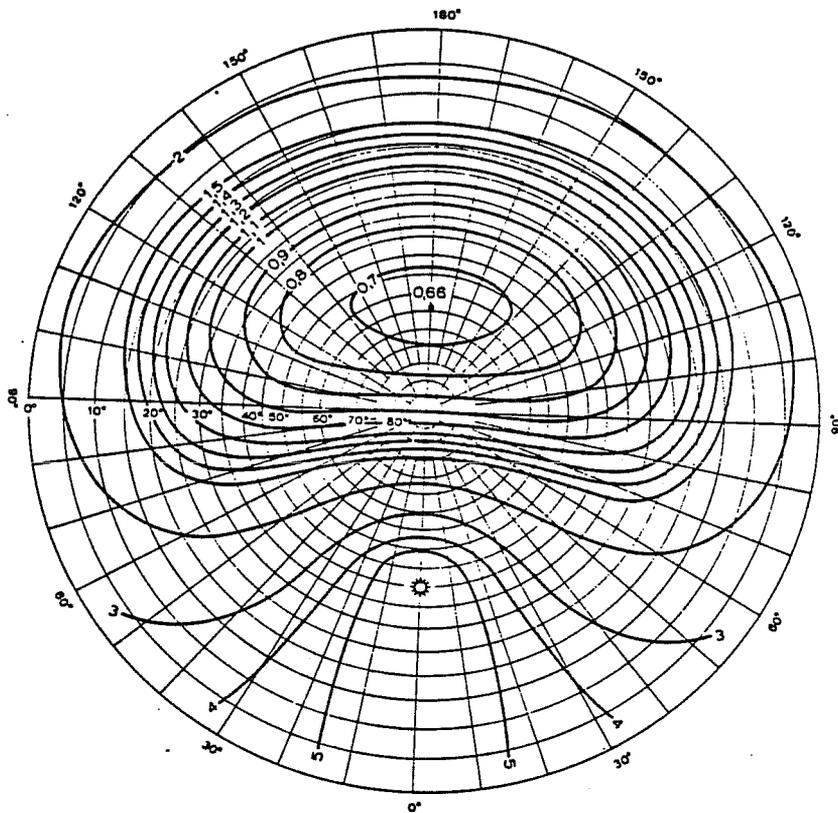


LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 CIE KITTLER SKY SOLAR ALT = 30 DEG
 HORIZONTAL PLANE GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 173.99 SQ. CM.

A

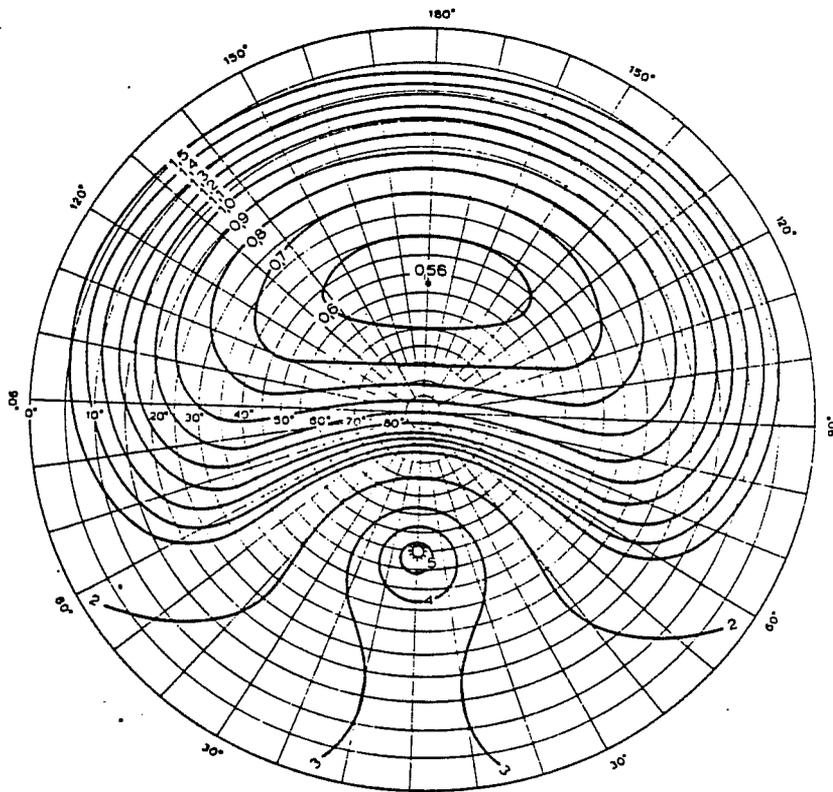
SUN HEIGHT: 40°

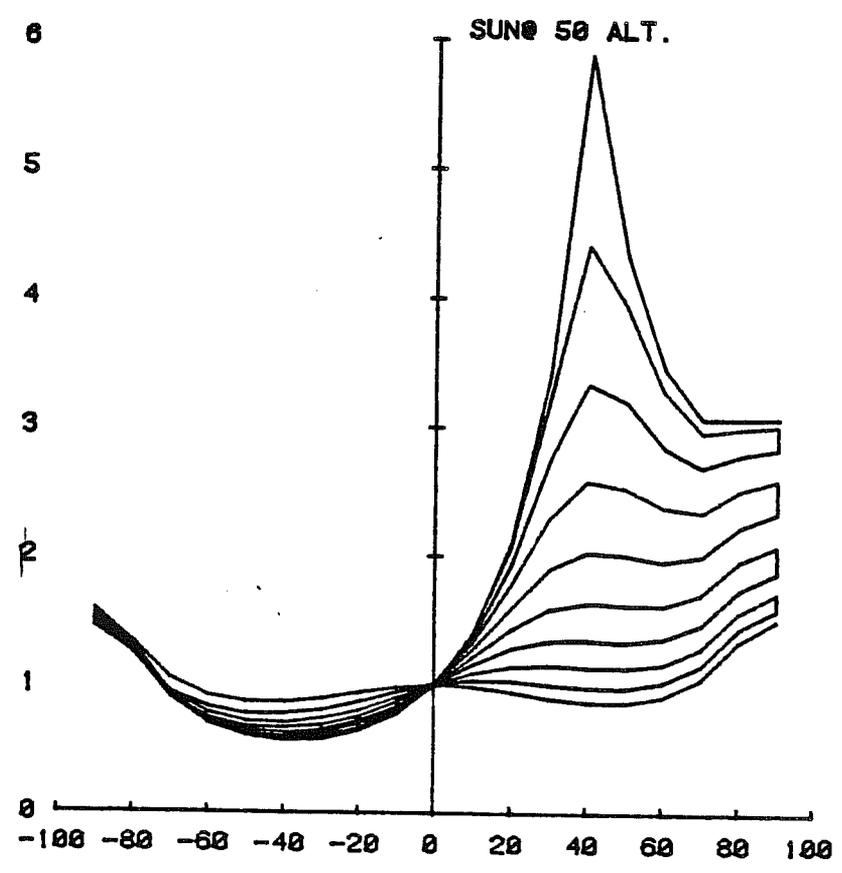
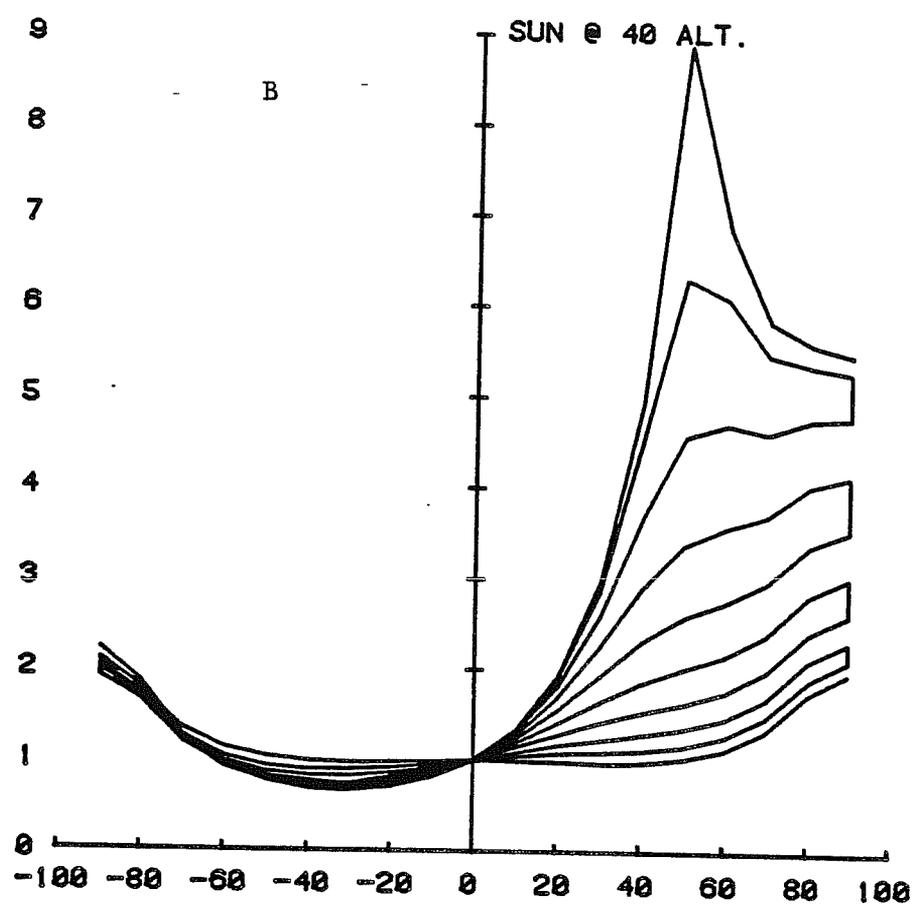
ZENITH SUN DISTANCE: 50°



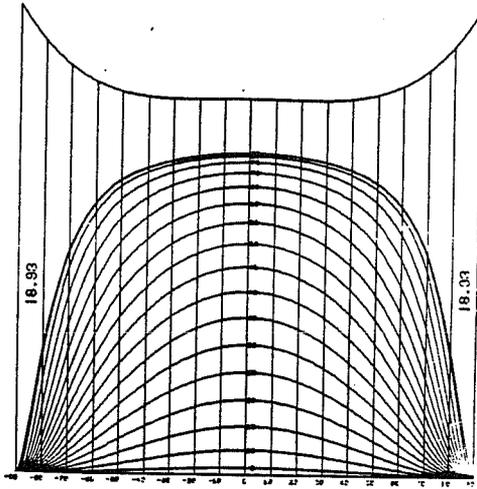
SUN HEIGHT: 50°

ZENITH SUN DISTANCE: 40°

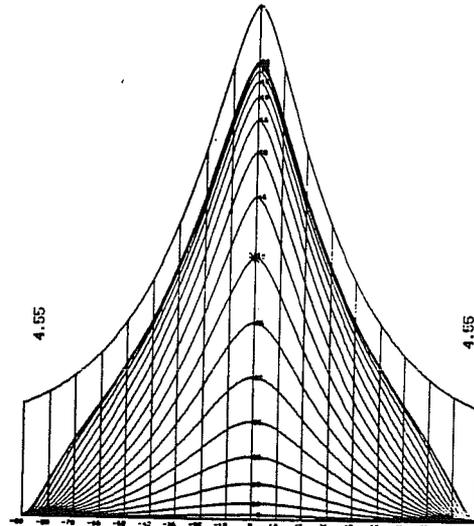




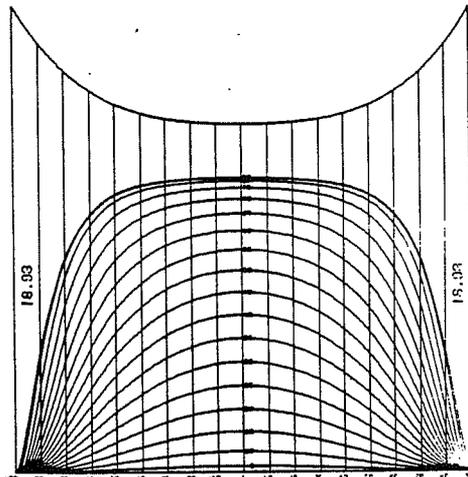
C



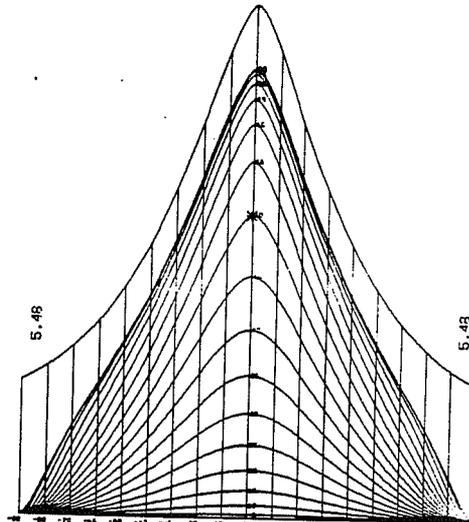
LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 CIE KITTLER SKY SOLAR ALT = 40 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUB;N,CLEAR; SKY AREA 285.81 SQ.CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 CIE KITTLER SKY SOLAR ALT = 40 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUB;N,CLEAR; SKY AREA 185.79 SQ.CM.



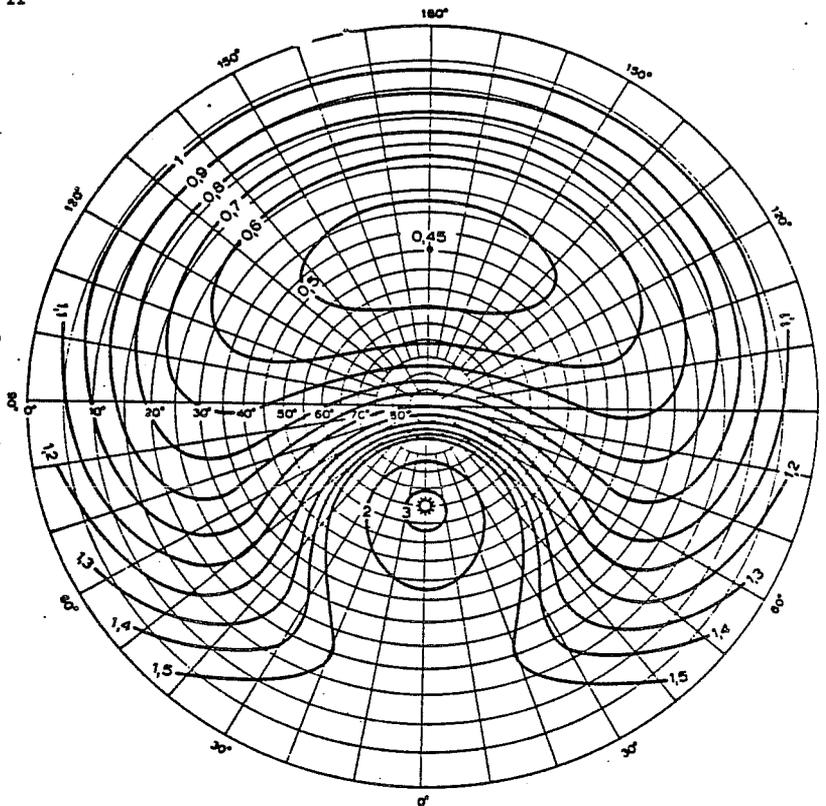
LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 CIE KITTLER SKY SOLAR ALT = 50 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUB;N,CLEAR; SKY AREA 275.18 SQ.CM.



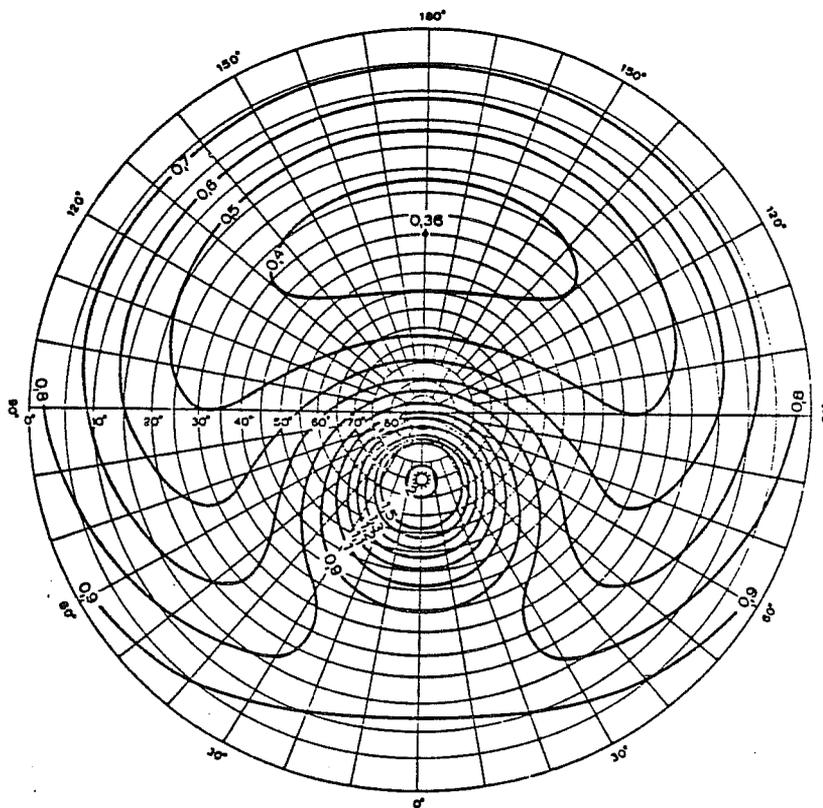
LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 CIE KITTLER SKY SOLAR ALT = 50 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUB;N,CLEAR; SKY AREA 295.34 SQ.CM.

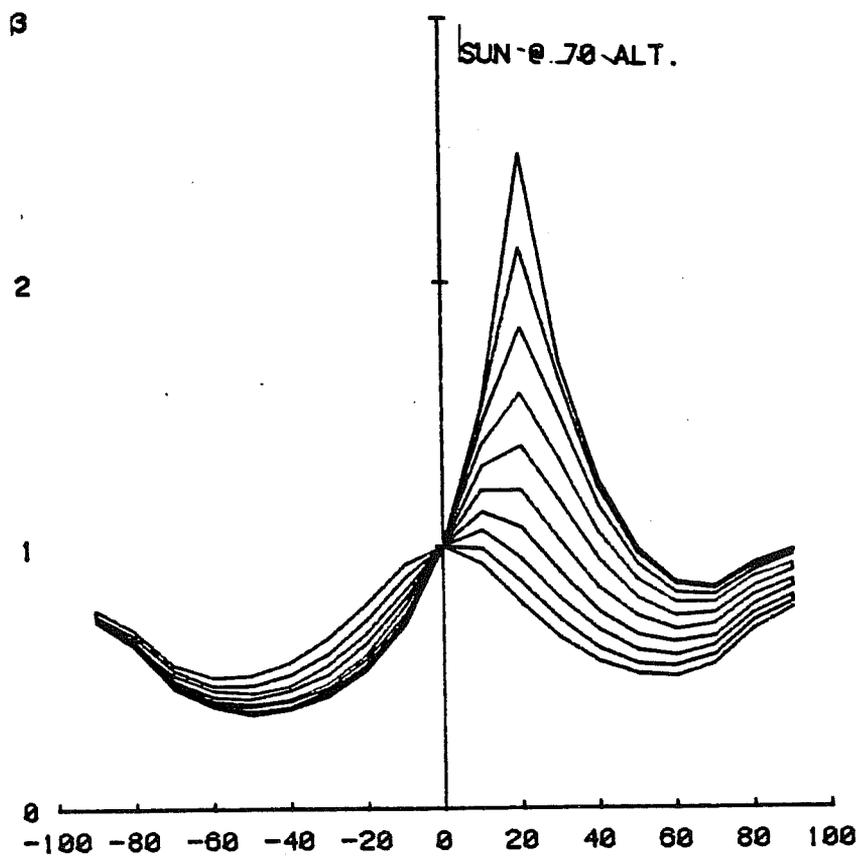
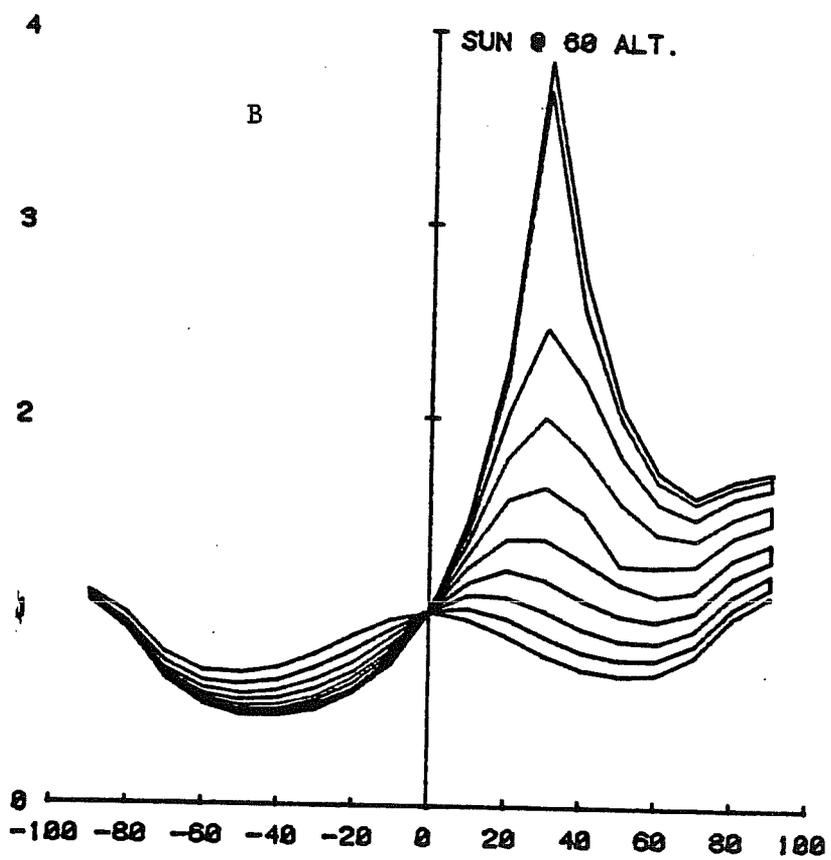
A

SUN HEIGHT: 60°
ZENITH SUN DISTANCE: 30°

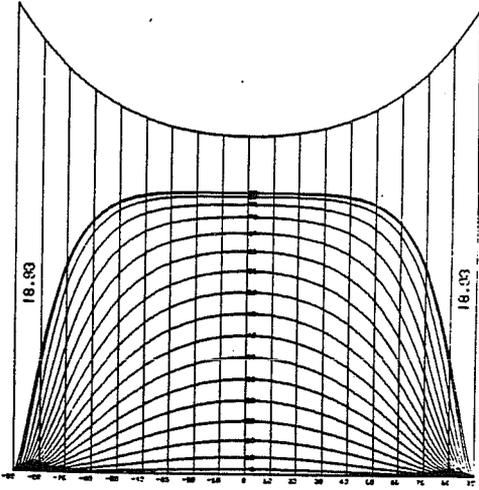


SUN HEIGHT: 70°
ZENITH SUN DISTANCE: 20°

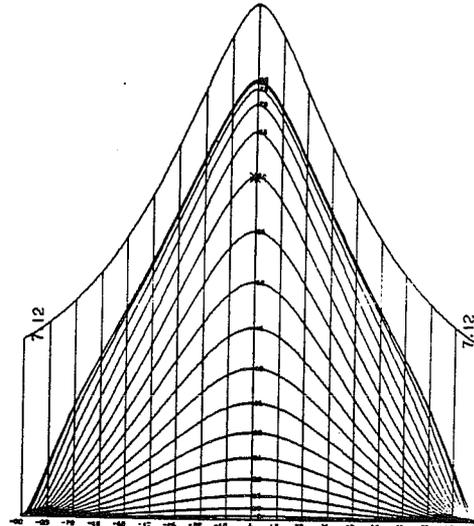




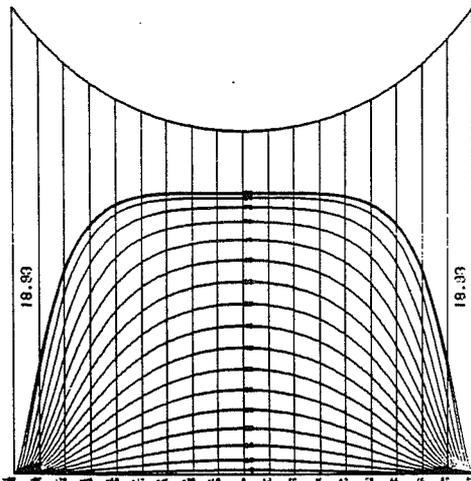
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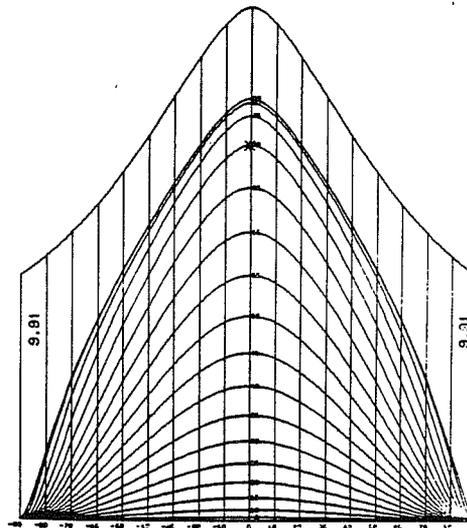
LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 SOLAR ALT = 60 DEG
 CIE KITTLER SKY GLASS TRANS= LBL/RUBIN,CLEAR
 HORIZONTAL PLANE SKY AREA 271.64 SQ.CM.



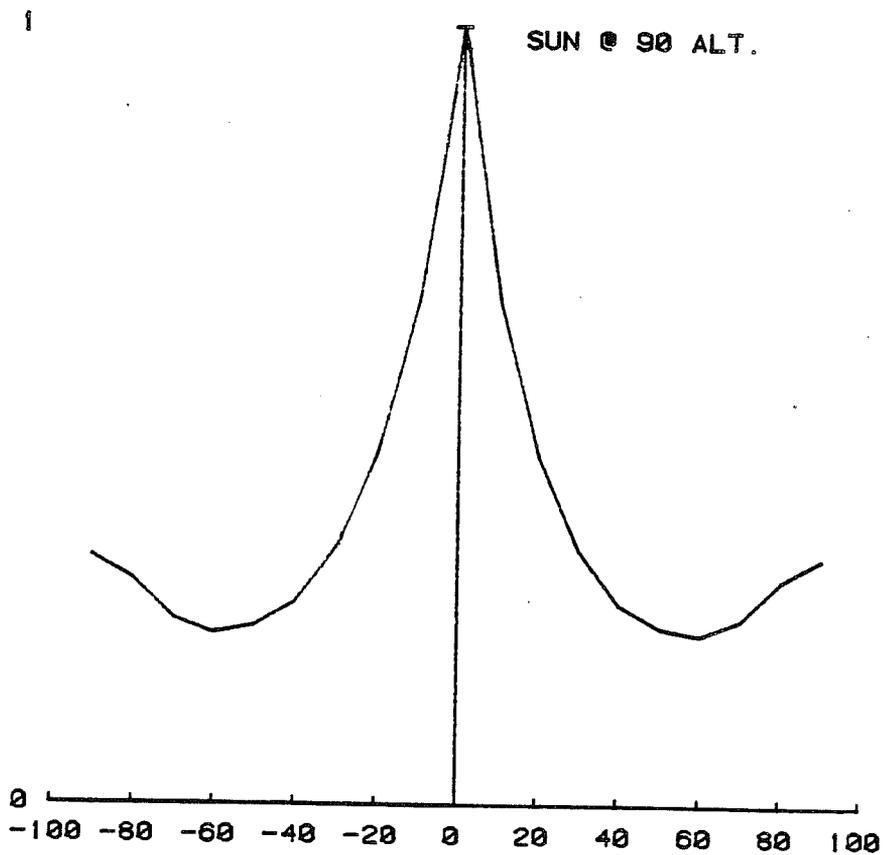
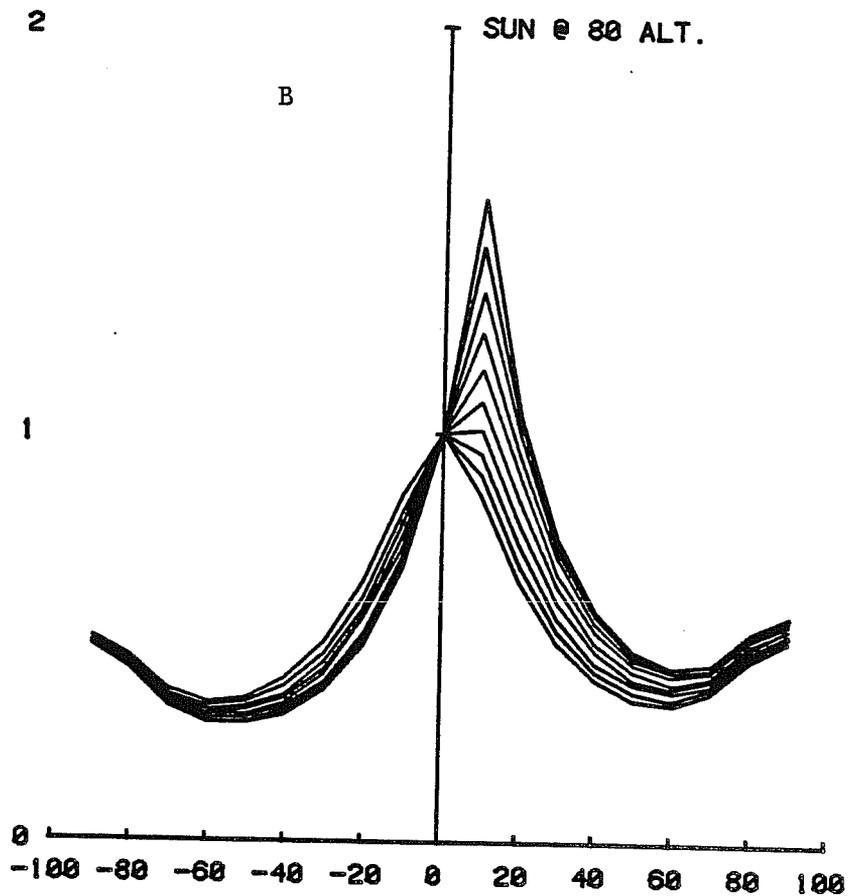
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 HORIZONTAL PLANE SKY AREA 233.75 SQ.CM.



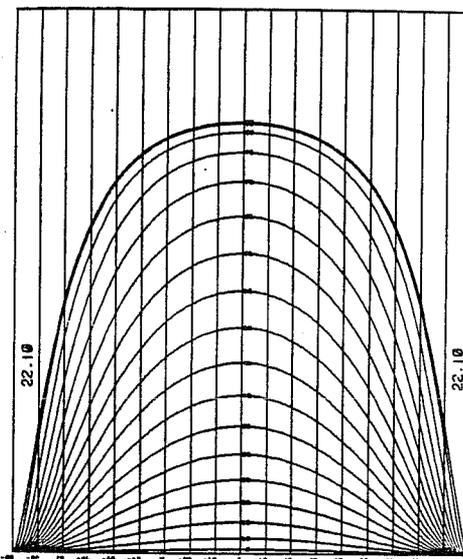
LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 SOLAR ALT = 70 DEG
 CIE KITTLER SKY GLASS TRANS= LBL/RUBIN,CLEAR
 HORIZONTAL PLANE SKY AREA 277.23 SQ.CM.



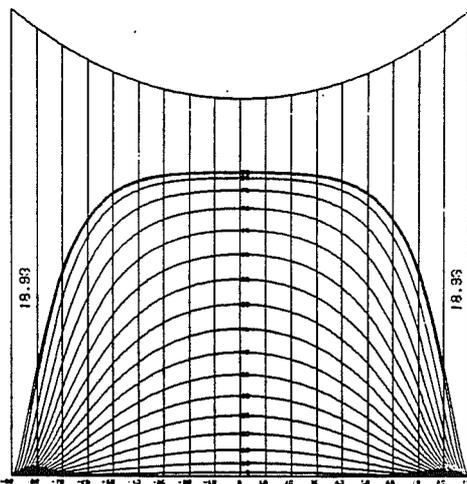
LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 70 DEG
 CIE KITTLER SKY GLASS TRANS= LBL/RUBIN,CLEAR
 HORIZONTAL PLANE SKY AREA 273.02 SQ.CM.



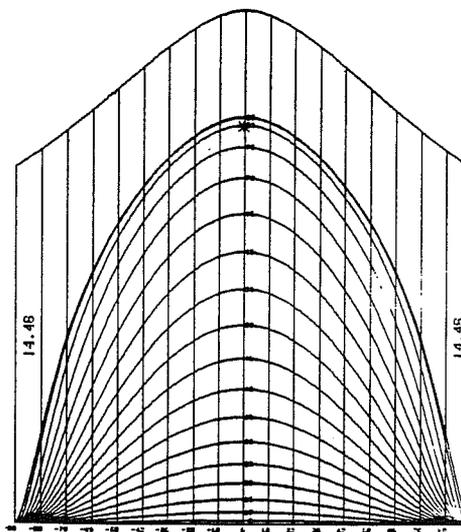
C



LIAM DIAGRAM WINDOW SOLAR AZIM = ∞ DEG
 CIE KITTLER SKY SOLAR ALT = 90 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN,CLEAR;
 SKY AREA 397.76 SQ.CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
 CIE KITTLER SKY SOLAR ALT = 90 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN,CLEAR;
 SKY AREA 296.3E SQ.CM.



LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 CIE KITTLER SKY SOLAR ALT = 90 DEG
 HORIZONTAL PLANE GLASS TRANS= LBL/RUBIN,CLEAR;
 SKY AREA 329.61 SQ.CM.

There are limitations on producing the actual or theoretical sky luminance distribution depending on the size, structural form, and lighting system of the sky simulator. (See historical review). The remainder of this section discusses horizon scale errors and the use of LIAM diagrams for defining the accuracy of a sky simulator. It also describes calibration for different luminance distributions and instruments.

2. Accuracy of the Method

The model was tested on three different days in the artificial sky under C.I.E. overcast sky conditions which were calibrated very carefully. Three tests were made because the power output of the sky simulator changes in response to different usage of the building, which might affect the intensity of the sky. Thus we obtained three readings for each point. Predictions were made at Rows A, B, C and Points 1 through 5 located 3 feet away from each other and at a height of 3 feet height under three different ground reflectances Fig.29,31 The model was then tested twice with the same method under real sky because it happened to present the desired conditions. Results were compared Fig31abc. Since real sky conditions changes continuously, the sky simulator should be used for accurate design comparisons. For predicting the natural light for a proposed building, the sky simulator could be calibrated the against the calculated sky luminance distribution according to C.I.E. standards. But, if a specific site exists for a proposed building, those conditions could be simulated and modeled with the sky simulator. The following analysis is based on the model-testing done to compare the accuracy of prediction under the sky simulator and real sky.

(a) Analysis of results

The model predictions were very close to results for real sky in the first test. (Fig. 31). But in the second test correlation was low because total illumination in the sky simulator was lower than from the actual sky. The study also showed that landscaping or the ground reflectance has a definite effect on illumination inside the model. Three different ground reflectances were chosen for the study. The study shows that to make accurate predictions of daylight illumination you have to separate the effects of ground light and sky light. In using this method, the illumination on a vertical plane is separated into ground light and sky light as shown by E_g and E_s , respectively, in Figs. 25a and 25b.

In applying this method it is assumed that:

$$E_N = DE_s E_s + DE_g E_g, \quad (2)$$

where E_N represents the illumination at any point on the working plane in the model, DE_s is a daylight factor for the sky light, and DE_g is a daylight factor for ground light. E_N , E_g , and E_s are measured simultaneously for each point being considered in the model by collecting two sets of readings under conditions that produce widely different values of E_s/E_g . Generally, DE_s is much higher than DE_g except in the case of diffusing type of fenestration. A typical curve of DE_g and DE_s is shown in Figure 25c.

$$\text{Now since } E_N = DE_V E_V \text{ (See Eq. 1)}$$

$$\text{and since } E_N = DE_s * E_s + DE_g E_g \text{ (Eq. 2),}$$

when separating sky light and ground light, then

$$DE_V \times E_V = DE_s \times E_s + DE_g \times E_g \quad (3)$$

$$DE_V = (DE_s E_s + DE_g \times E_g) / (E_s + E_g) \quad (4)$$

Obviously for any value of E_s/E_g , DE_V must lie between DE_s and DE_g

$$DE_g < DE_V < DE_s$$

if $E_s = E_g$ then $DE_V = (DE_s + DE_g) / 2$
 if E_g decreases or E_s increases or
 if E_s/E_g goes to infinity, overcast sky
 if E_s/E_g equals to 1, uniform sky
 if E_s/E_g goes to 0, clear sky (See Fig. 2 4, 31, a, b, c)

It follows then, that when trying to isolate and compare architectural spaces or shapes and when using the method that uses vertical illumination E_V for reference, the value of E_s/E_g should be the same for the different designs. Otherwise sky light and ground light measurements should be separated.

This analysis explains the agreement between the results under the artificial sky and real sky given different ground reflectances. The model was tested first with a ground that had 0.01% reflectance as a minimum and 0.86% reflectance as a maximum, which shows the contribution of high ground reflectance to overall illumination in the room (Figs. 31 a, b, and c). The study also shows the accuracy of predicting and duplicating illumination of terrain.

Two methods were used to compare the prediction of natural lighting. First, the original method that calculates illumination on a vertical surface, E_V , as daylight factor. This would be Equation (1) $DE_V = E_N / E_V$. Second, the method in which only the illumination from the sky, E_s , is used as the reference value and which calculates DE_s as daylight factor. This is the equation:

$$DE_S = E_N/E_S \text{ or } DE_H = E_N/E_H, \quad (5)$$

these values are very easy to find with an artificial sky with its corrected horizon, which has .01 reflectivity. In other words, you measure E_S at the horizontal level which is E_H in Eq. (5)

The graphs in Figure 31a (No. 1) show the level of illumination throughout the room, including the effect of ground reflectance. The results from the artificial sky and in Figure 31a (No. 2) are the same as under real sky but higher because of the high illumination level under real sky.

In order to see the effects of changes in the E_S/E_g ratio, the two definitions of the daylight factor used in the testing methods, look at those graphs in Figures 31b and 31c that show a higher E_g . The DE_v goes toward zero, which agrees with the definitions

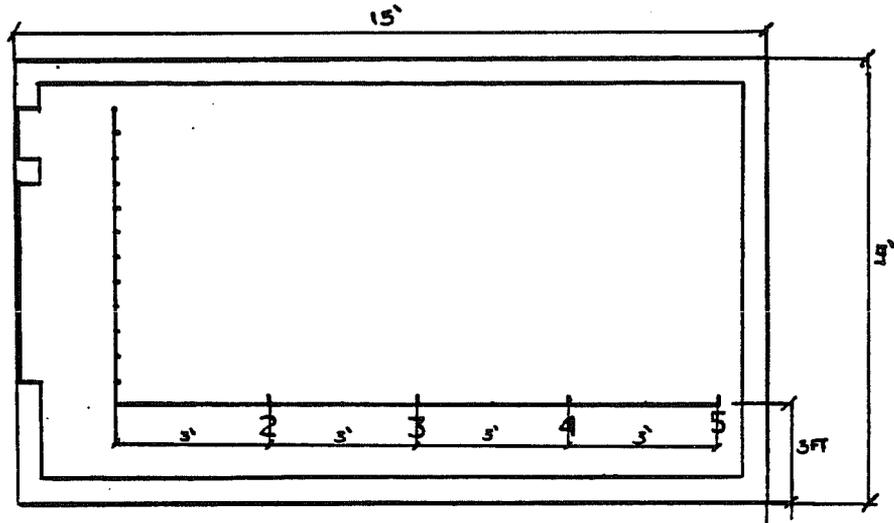
if E_S/E_g goes to infinity, overcast

if E_S/E_g goes to 1, uniform

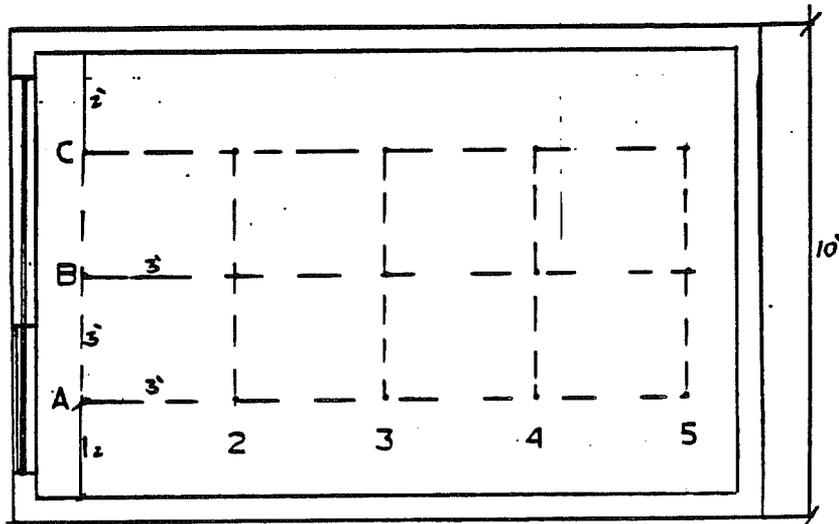
if E_S/E_g goes to 0, clear sky.

The prediction of E_S/E_g was very accurate except for minimum ground reflectance because the outside ground was different from the artificial sky (see Figs. 31a, b, and c).

Figure 29

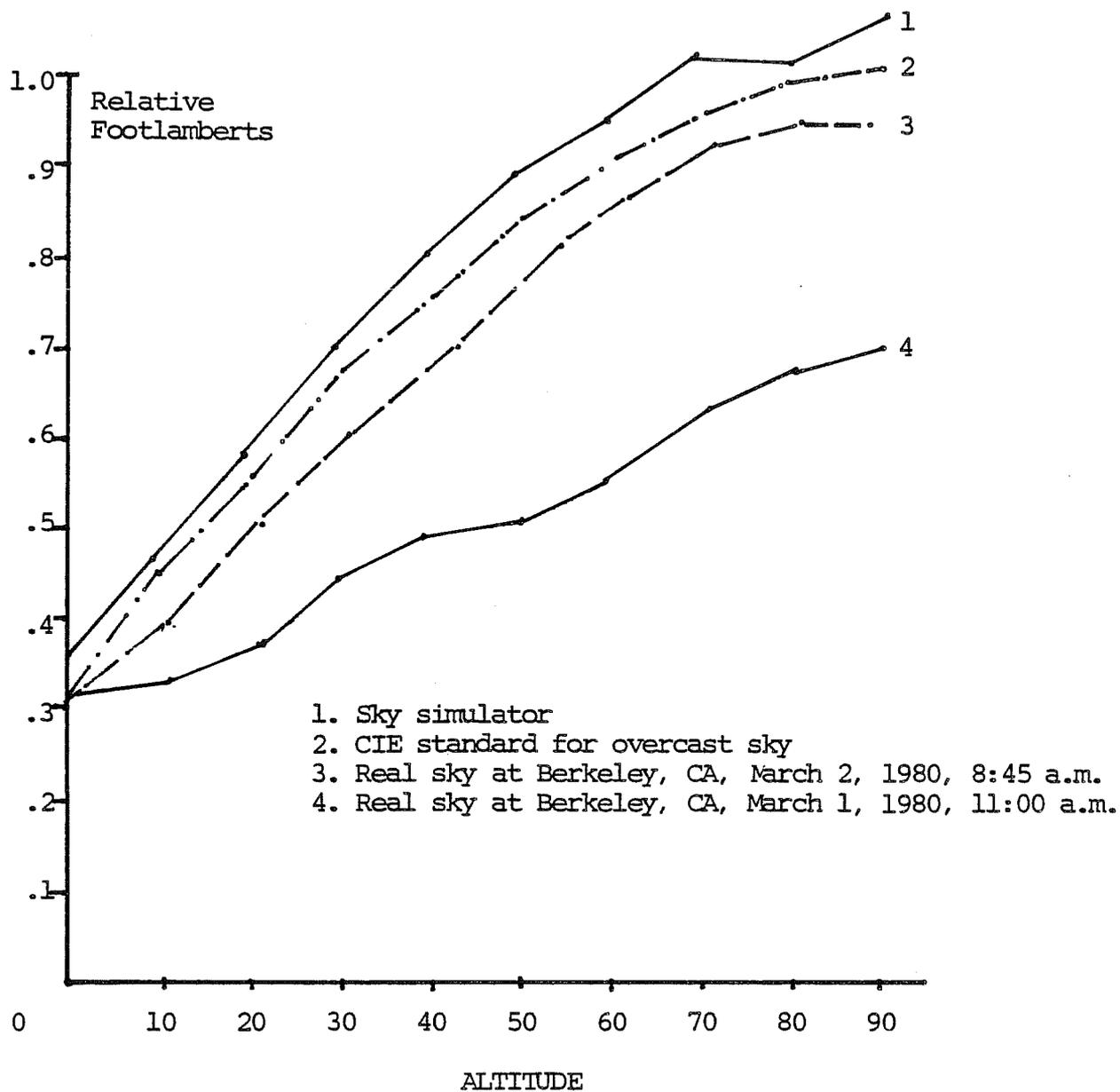


SEC. POSITION OF PHOTOCELLS



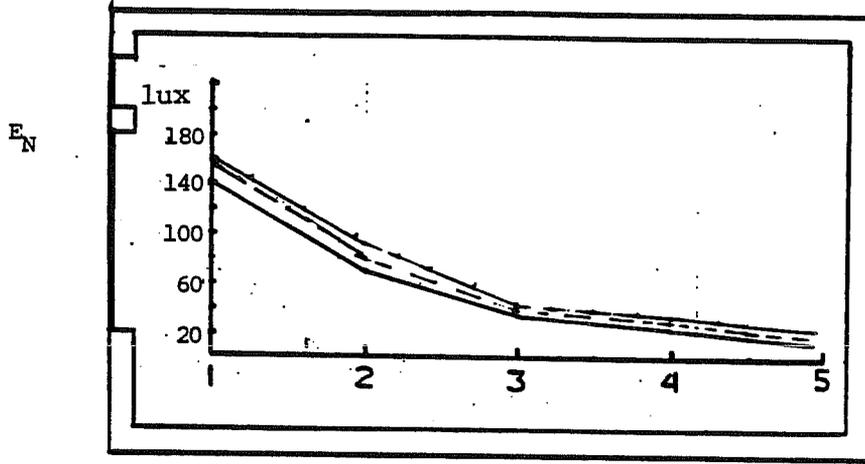
FL. POSITION OF PHOTOCELLS

Figure 30



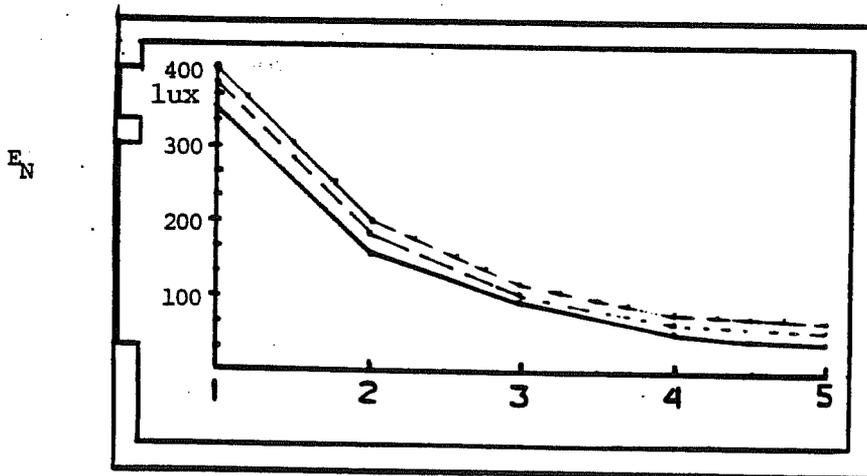
LUMINANCE DISTRIBUTION FOR OVERCAST SKY

Figure 31 a(1,2)



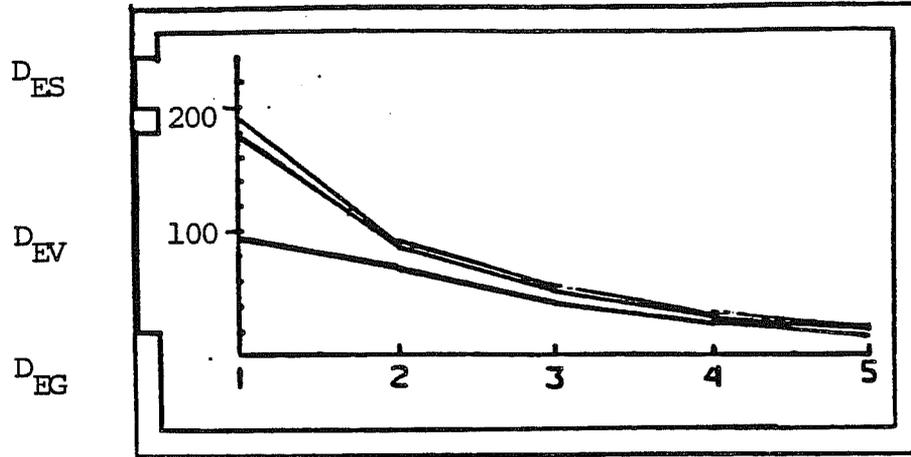
A = 0.01% ———
 A' = 0.39% - - - Ground Reflectance
 A'' = 0.86% - · -

SKY SIMULATOR

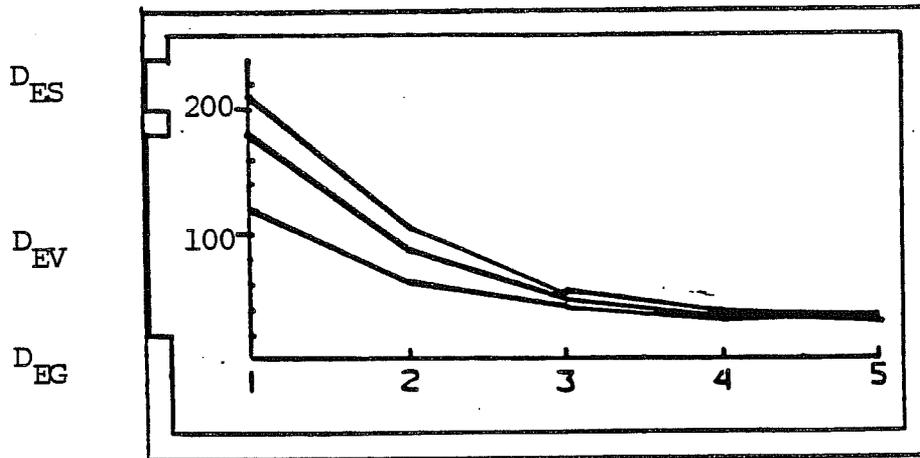


A = 0.06% ———
 A' = 0.41% - - - Ground reflectance
 A'' = 0.89% - · -
 REAL SKY

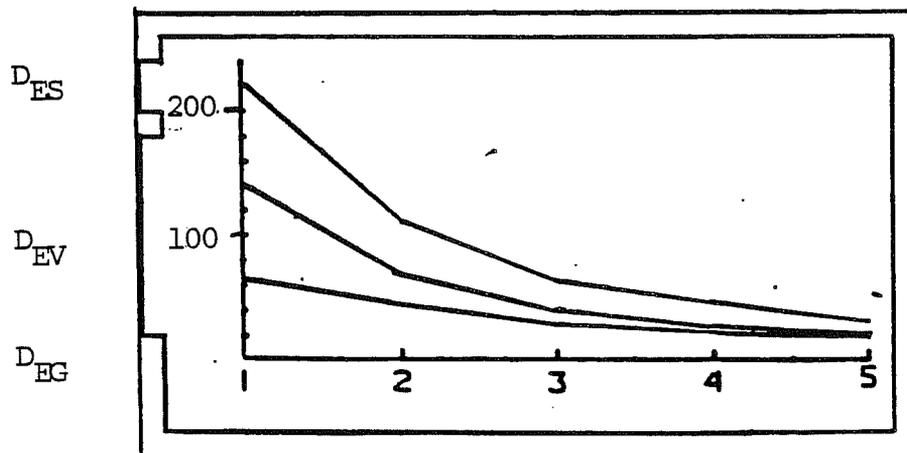
Figure #1b



A Real Sky Ground Refl. $.06\% \frac{EG}{EG} = 15.6$

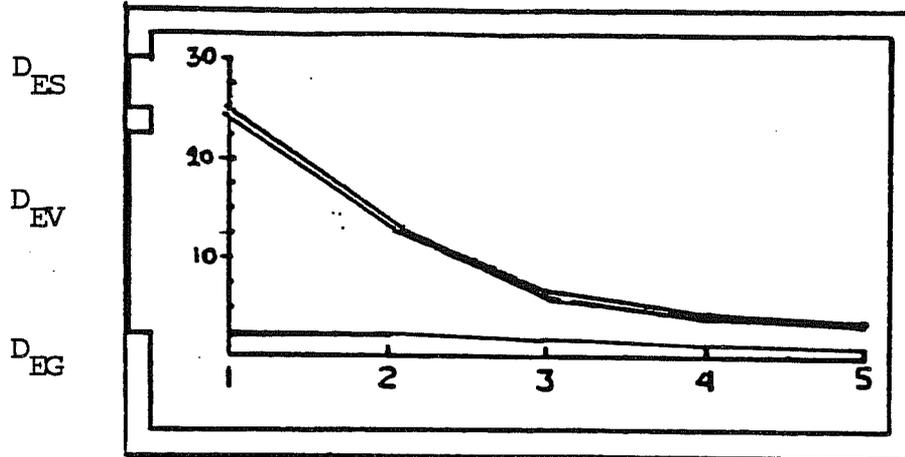


A' Real Sky Ground Refl. $.41\% \frac{ES}{EE} = 5.68$

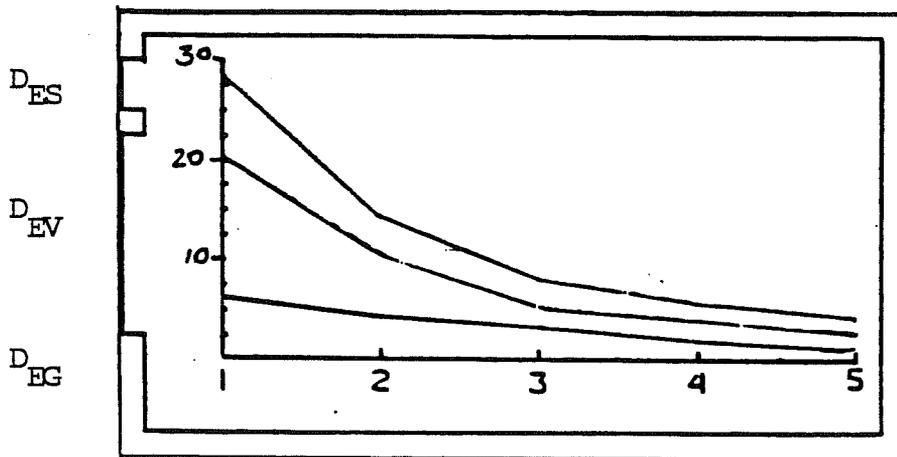


A'' Real Sky Ground Refl. $.89\% \frac{ES}{EE} = 1.95$

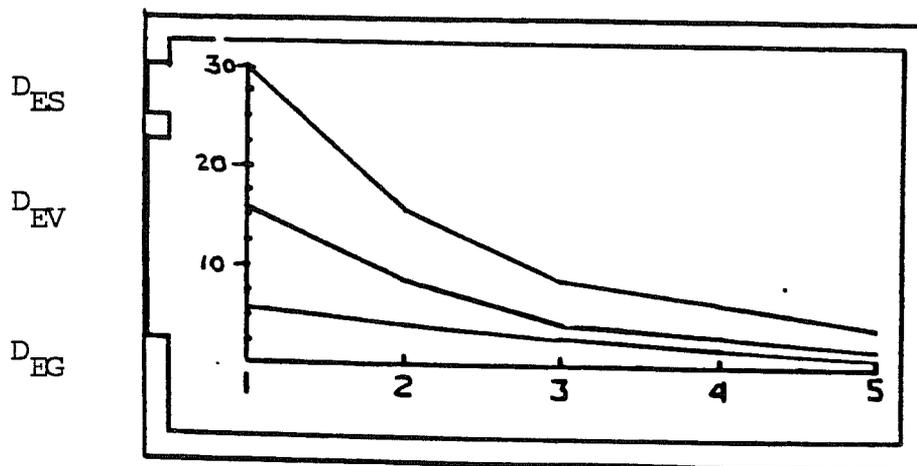
Figure 31c



A Sky Simulator Ground Refl. $.01\% \frac{ES}{EG} = 99.3$



A' Sky Simulator Ground Refl. $.39\% \frac{ES}{EG} = 2.50$



A'' Sky Simulator Ground Refl. $.86\% \frac{ES}{EG} = 1.12$

(b) Conclusions

1. Model testing can provide accurate comparison and prediction of natural lighting of designed buildings when sky luminance distributions are the same. This is true when there is no ground reflectance.
2. Changes in ground reflectance or the landscape around a building affect illumination levels in the spaces within the building. In order to do an accurate comparison or prediction, the E_s/E_g ratio (in other words the ground reflectance and sky conditions) should be simulated the same in both situations.
3. Limitations such as height of the model and problems such as horizon scale error must be given greater consideration for accurate predictions or comparisons.
4. Reflections from internal surfaces have great effects on the level of illumination in the space.
5. A full-scale model could be used for prediction of a specific site. Comparison of two full-scale models on one site can be done accurately by doing simultaneous measurements under the same sky condition.

2. Calibration of the System

In order to simulate different sky luminance distributions the sky simulator must be calibrated.

If using a sky simulator to simulate daylight conditions, it is necessary to calibrate the sky by measuring the various sky distribution luminance patterns. These patterns normally remain fairly constant even though electric energy input may vary with the time of day. Since there is considerable variation in sky luminance if the electric supply system is not closely regulated, it is necessary to measure the incident illuminance on the simulated fenestration area. If there is a large variation in the distribution of the incident illumination over the total area of the model's fenestration, a smaller model should be used.

Another way of calibrating the sky distribution is to use computer programs (No. 4 and 5) (see Section V D, Computer Programs). The computer plots the calculated sky distribution for a specific sun location against measured sky. See Figure 28 for an example of computer program No. 5 plots of calculated sky.

In order to use this program, record the data on the appropriate form. One can measure the sky simulator luminance by using a SPECTRA photometer or Tektronix luminance probe.⁽⁸⁾ Center the photometer on the marked spot on the platform. Turn it to adjust its azimuth to 0° ; by locking it you can change the altitude to the desired degree position, in this case every 10° . Record the data on a form. This data could be plotted by either computer program No. 10 (LIAM) or No. 5 (x vs. y plot).^(15,16). See Figure 32 for examples of the special forms; also see Section V B,

Also, if there is a past hysteresis effect on the receptors used for measuring the illumination (a variation in output when previously exposed to high luminance), the receptors should be used and calibrated at more or less constant levels of illumination. This is relatively easy to do if multiple receptor cells are used to measure the interior distributions. However, if one cell is used for different measurements, great care should be taken to reach stable adaptation before readings and calibration. If the same cell is used to measure the exterior and interior illumination, stabilization should be established before measurements at different levels are undertaken. Using the same cell to measure both exterior and interior model readings reduces the need for accurate calibration, if the receptor is used over its linear response range.

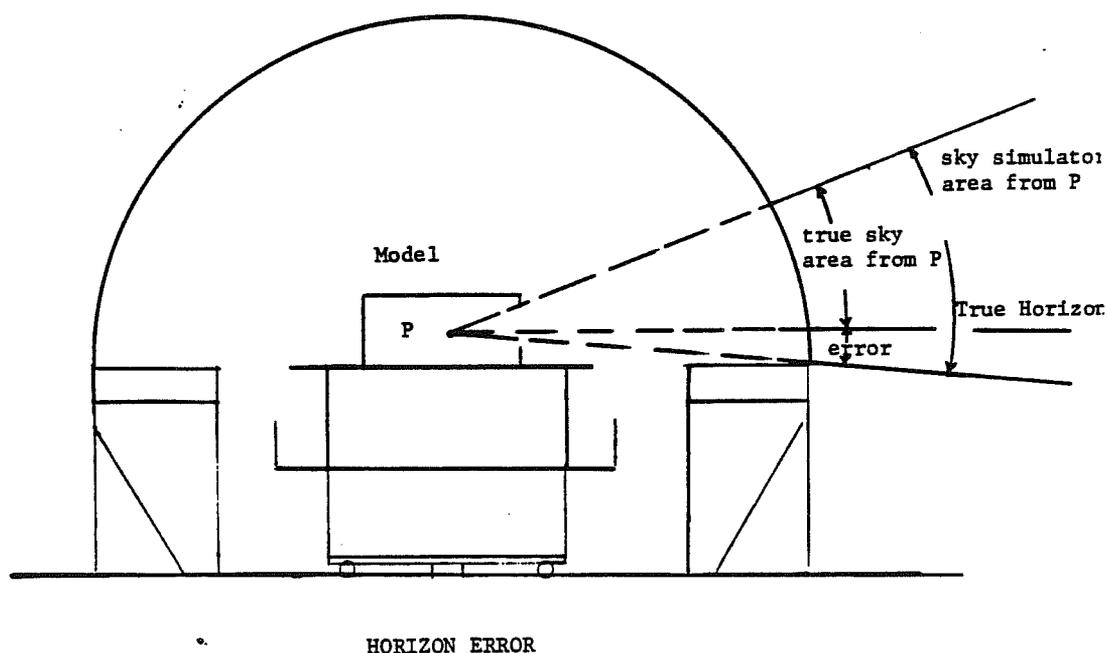
If multiple cells are used, it is desirable to calibrate each cell at its approximate level of illumination based on readings after each series of tests, which can be easily done with the SPECTRA Photometer.)

4. Horizon Scale Error

In artificial skies generally, there is a problem because of the location of the horizon with respect to the openings (windows) of the model. (2,9,10,) This means the ceiling of the model room or building receives direct light from the sky, which does not happen in real situations under the real sky. This error would differ for different model scales and different sky luminance distributions. For example, we might place a 1-inch scale model at the center of the artificial sky and select a position for the photocell at p point (see Figure 33). If we take the measurements we will see that at a distance of 12 feet and 3 inches from

the horizon and with the photocell at the position of a 3-foot-high task level, you can see how many degrees of sky fall into horizon error (see Computer Program 7 results in Appendix D). Also if you make an 8-inch-high opening for a model having a height of 9 inches, the angle of depression is 8 degrees, which means the ceiling is receiving direct sky luminance.

Figure 33



There are ways of reducing these horizon effects such as making the luminance below the horizon zero by hanging a black curtain or arranging to have a zero ground reflectance. Also, under certain conditions the horizon error does not occur or is very minor such as when taking measurements for top lighting (e.g., light wells, or for a roof-lighted building, or if the window is facing another building and the distance

of the building to the window is less than the scaled-down distance of the artificial sky to the window. One way of finding the size of a dome-type artificial sky that will have minimum error is to select a common scale model and place it on the same level as the sky horizon and then to measure the angle of error for some typical window sizes. This will show how large a dome-type artificial sky must be in order to bring the horizon scale error to within acceptable limits. (See Fig. 34). One can use the LIAM diagram computer program or Waldram diagram grid and draw an opening of the window and see what percentages of that opening fall into the degree of horizon error (see Fig. 35).

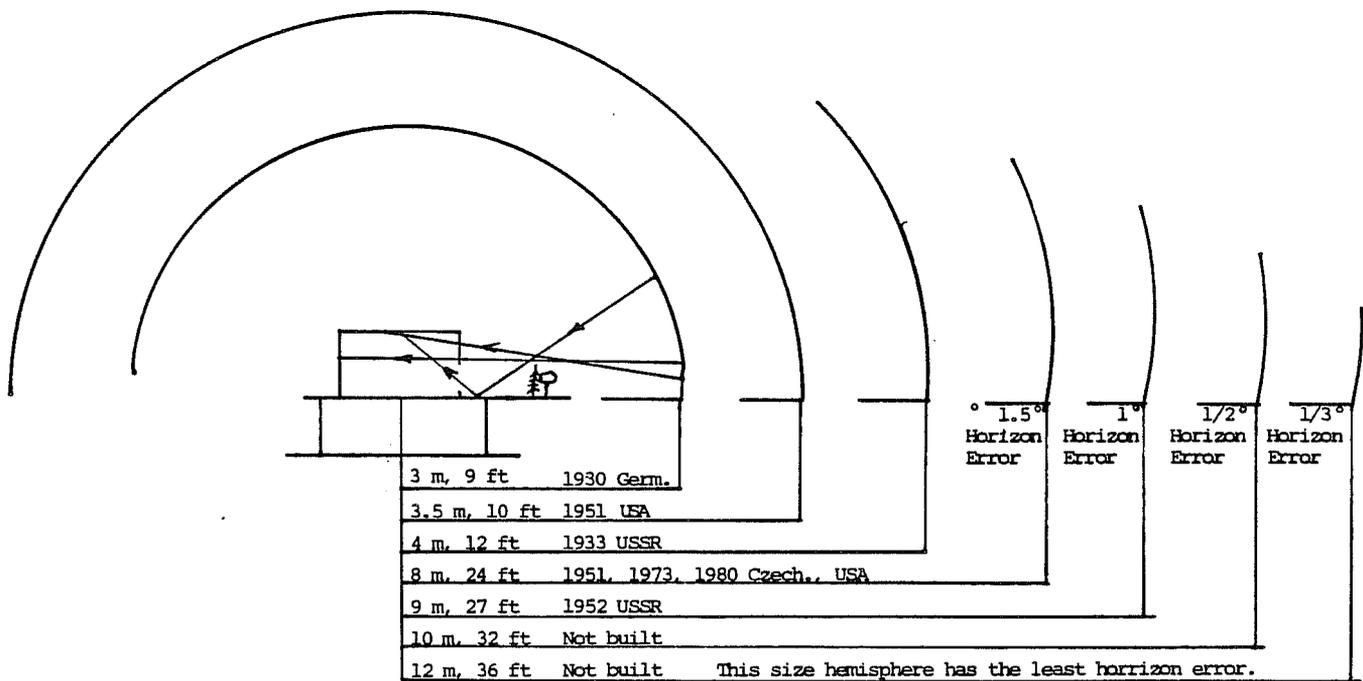
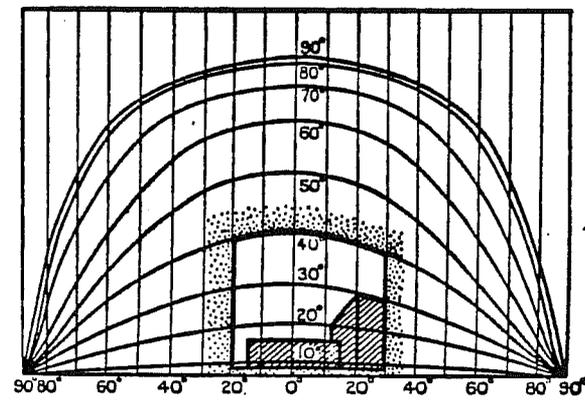
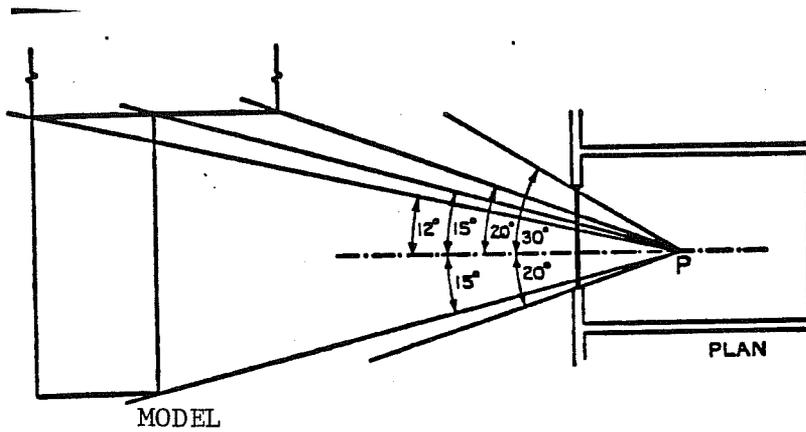
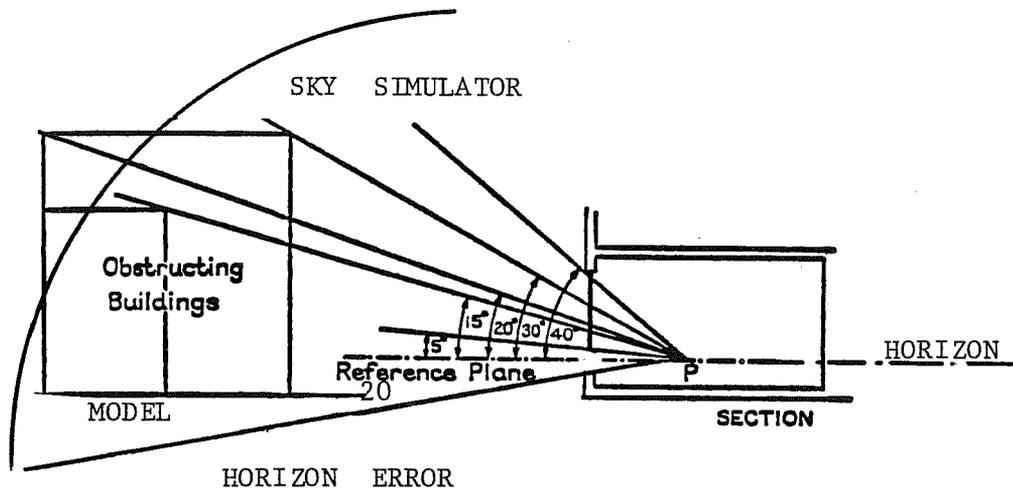


fig. 34

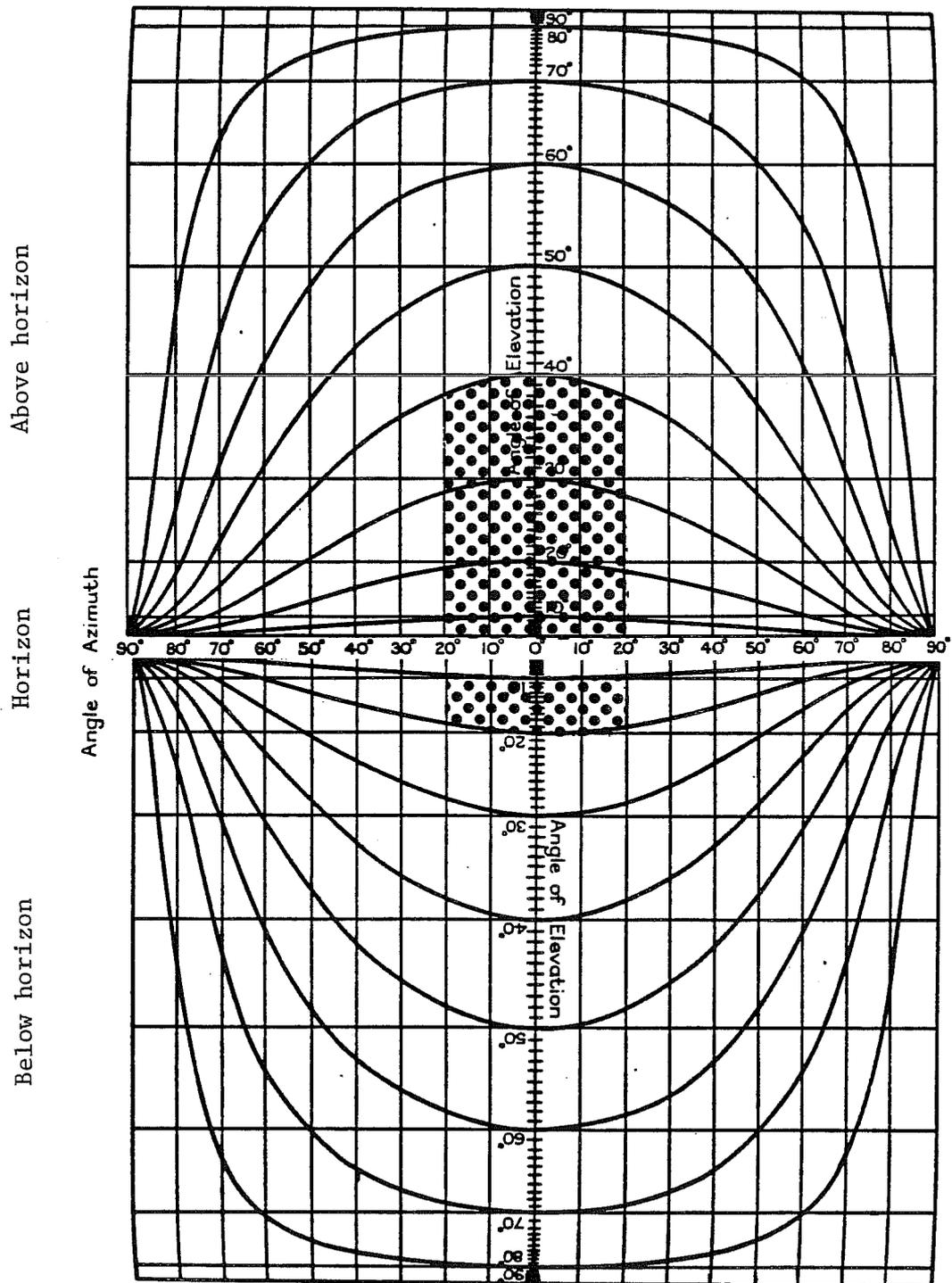


The use of the Waldram Diagram to plot the outlines of external obstructions.

Figure 35

Source: *Daylighting* by R.G. Hopkinson, P. Petherbridge, and J. Longmore. Reproduced by permission of William Heinemann Ltd., London, England, ©1966.

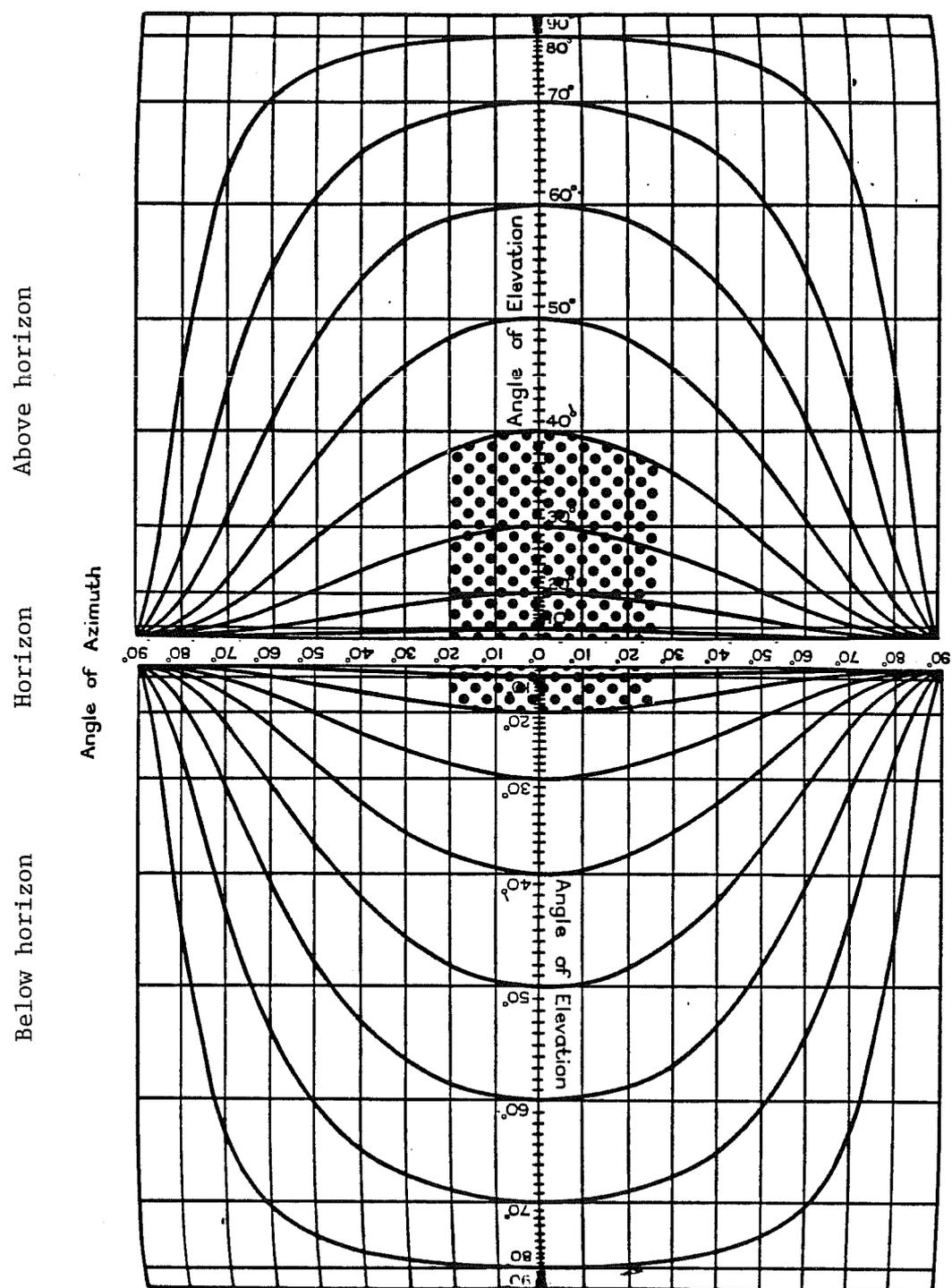
Figure 34a



Waldram Diagram for unglazed apertures and uniform sky (i.e. true sky factors).

Source: Daylighting by R.G. Hopkinson, P. Petherbridge, and J. Longmore. Reproduced by permission of William Heinemann Ltd., London, England, ©1966.

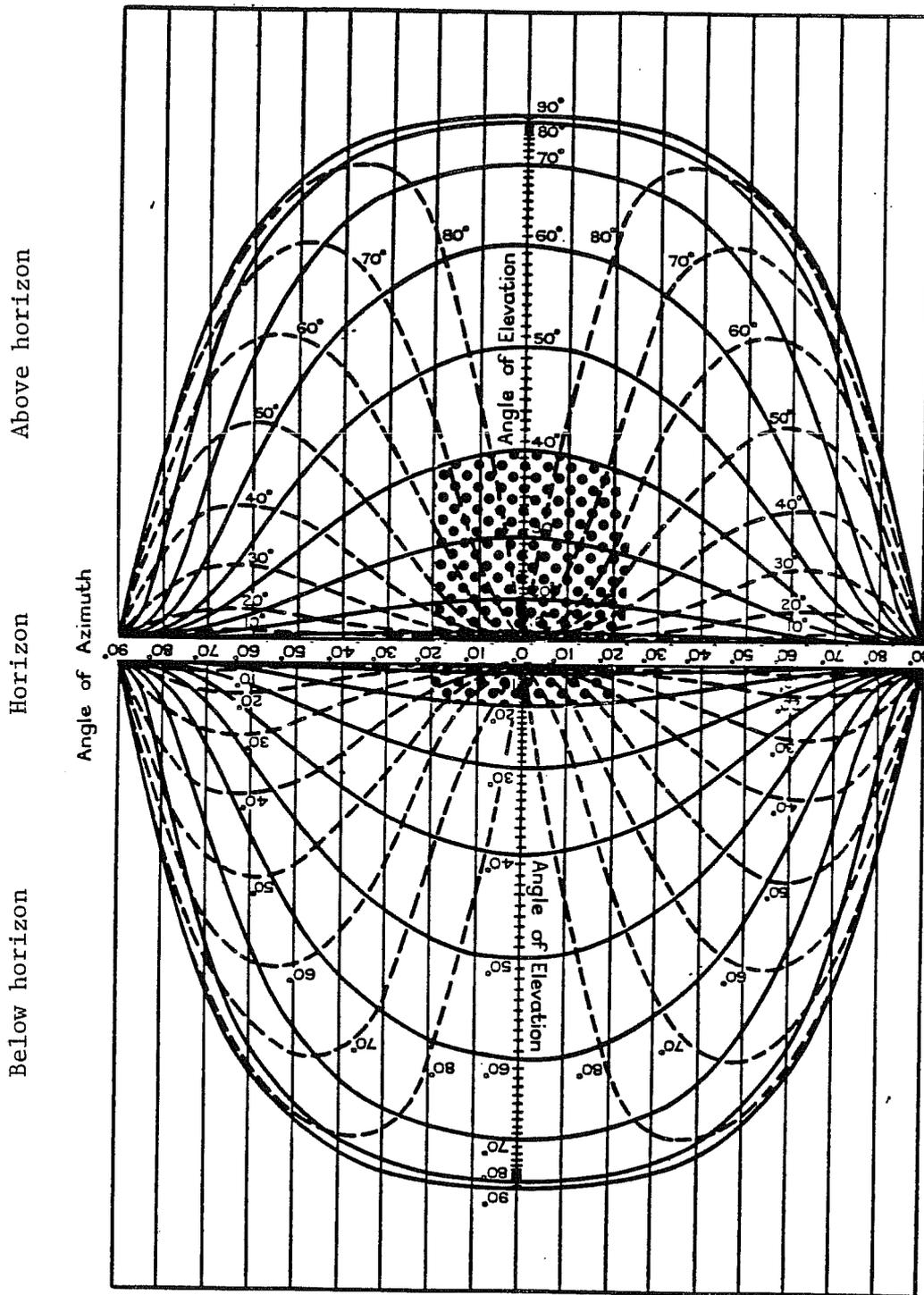
Figure 34b



Waldram Diagram for unglazed apertures and C.I.E. Overcast Sky luminance distribution (i.e. sky components on a horizontal reference plane).

Source: Daylighting by R.G. Hopkinson, P. Petherbridge, and J. Longmore. Reproduced by permission of William Heinemann Ltd., London, England, © 1966.

Figure 34c



Waldram Diagram droop-lines for glazed windows and C.I.E. Overcast Sky luminance distribution (i.e. sky components on a horizontal reference plane indoors).

Source: Daylighting by R.G. Hopkinson, P. Petherbridge, and J. Longmore. Reproduced by permission of William Heinemann Ltd., London, England, © 1966.

It is possible to say that measurement from a window with no degree of horizon error is 100% accurate compared to a window having a different placement or an obstruction which makes it fall into horizon error limits. One also has to keep in mind that a different sky luminance distribution changes the degree of accuracy of the measurement inside the room if the window placement is in horizon error limits. (See Computer Program No. 5 output in Appendix D.)

4. LIAM Diagram Computer Program

The construction of a Waldram diagram is explained by Walsh⁽²⁾. The LIAM diagram used by MacGowan⁽¹⁷⁾ is based on a graphical construction similar to the Waldram diagram but it also accommodates azimuthal changes in sky luminance. That is to say, the LIAM diagram for zero azimuthal luminance changes is the same as a Waldram diagram, but the LIAM diagram can accommodate variations of sky luminance in the azimuthal direction, thereby extending the concept developed by Waldram. The diagrams are dimensional in centimeters, and their areas have been computed. These values are clearly indicated on the plots. The program can execute diagrams using Kittler's nebulosity expressions (12,13,14) or can be used to check the accuracy of any sky component as a prediction device or as a distribution simulation device against any chosen sky distribution.

The use of the LIAM diagram is adequately described by MacGowan⁽¹⁷⁾ (See Figures 36, 37, and 38a,b,c.) To use a LIAM diagram to calculate the glass plane rotation or discomfort glare index needed to calculate the traditional sky component one has to determine the solar altitudes and then select the appropriate pair of diagrams for the window orientation

being evaluated. By measuring the window with respect to azimuth and altitude angles, it can be converted to an image on the LIAM diagram. Now this image can be measured by using graph paper marked in centimeters.

If window area = A cm and sky component, S.C., = (MECs) = modified external sky component, then $S.C. (MECs) = \frac{A}{cm} \times 100 \frac{\text{area of front of sky} + \text{scale} \times \text{area of rear of sky}}{\text{area of front of sky} + \text{area of rear of sky}}$.

Scale = height of front \div height of rear

Now one can calibrate the sky for a desired luminance distribution. Then after surveying the luminance distributions and recording them on one of the special forms, transfer them into the LIAM diagram computer program for plotting. At this point the program can take one quarter of the sky measurements in an array of 10x10, and by linear interpolation for one-degree interval it plots the sky luminance distribution at the horizontal plane. This plot of sky simulator luminance distribution can be checked against Kittler's sky or any other distribution if necessary. And the accuracy of each can be calculated using:

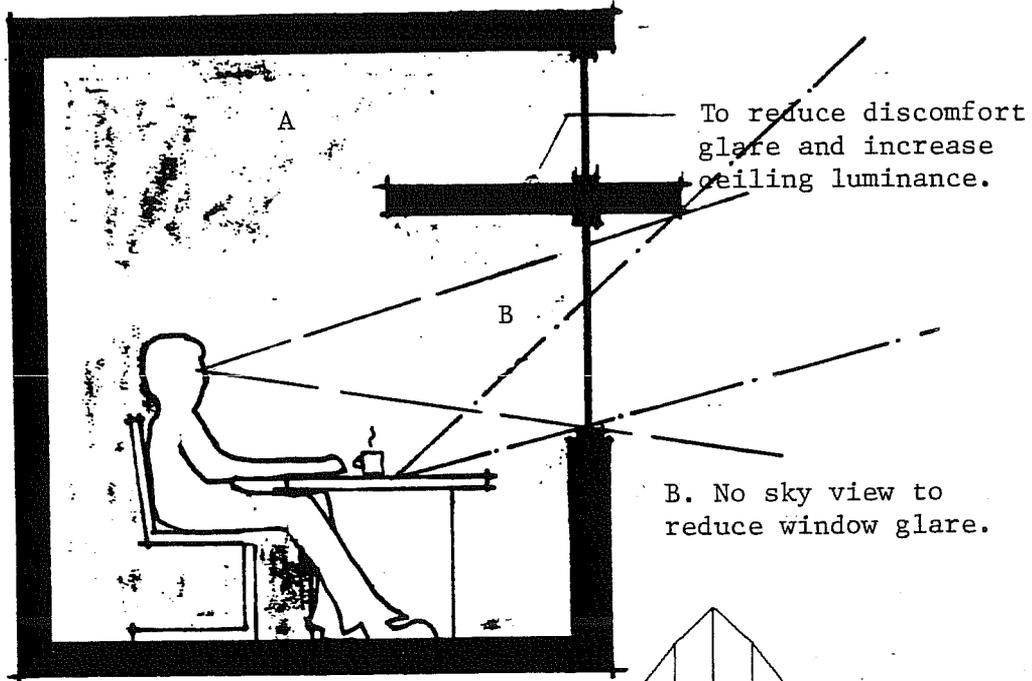
A = area of sky simulator diagram

A_h = height of sky simulator diagram

B = area of C.I.E. Kittler sky

B_h = height of C.I.E. Kittler sky

Scale = $\frac{A_h}{B_h} = \%$ then: $B \times \frac{A_h}{B_h}$ should be close A_h



A. Light-colored interior surfaces raise luminance level and visual adaptation level and hence reduce window glare.

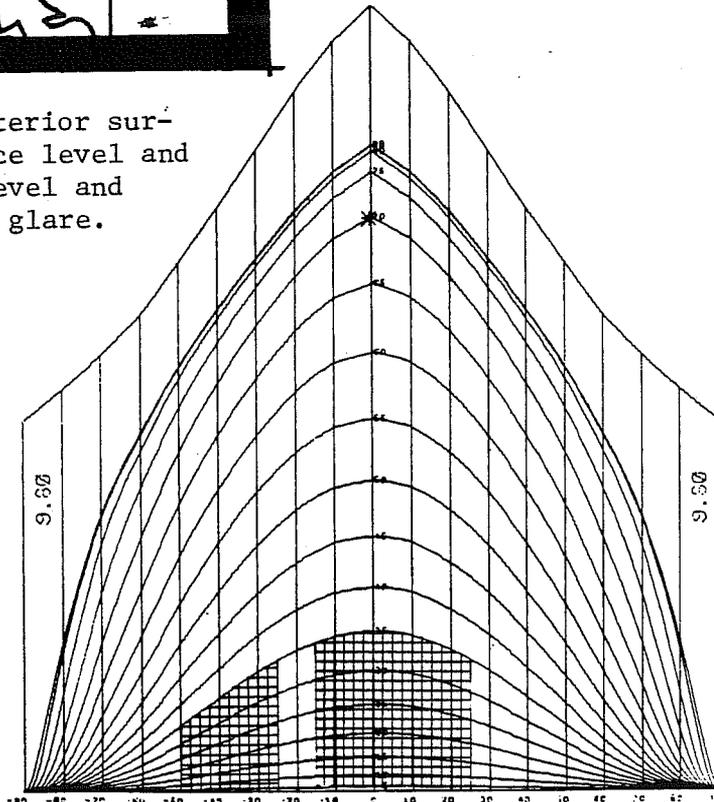
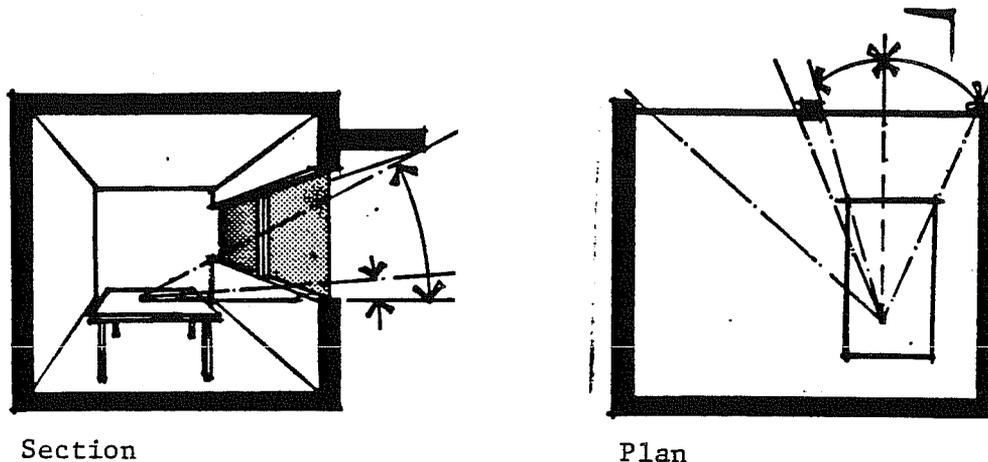


Figure 36

LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
 NAVVAB, M SKY SOLAR ALT = 70 DEG
 HORIZONTAL PLANE GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 269.49 SQ. CM.

USING THE LIAM DIAGRAM

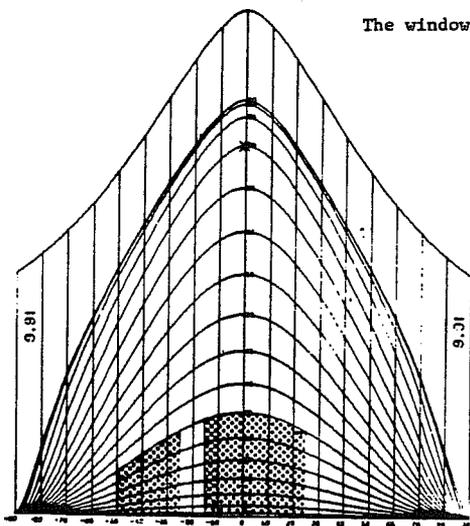
Daylight factor using the MEC computation should be called modified daylight factor (M.D.F.).



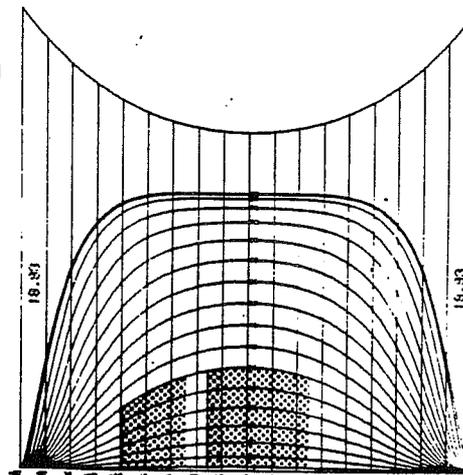
Section
Forward Half
of Sky Vault

Plan
Rear Half
of Sky Vault

The window was depicted on cm graph paper.



LIAM DIAGRAM WINDOW SOLAR AZIM = 0 DEG
SOLAR ALT = 70 DEG
CIE KITTLER SKY GLASS TRANS= LBL/RUBIN,CLEAR
HORIZONTAL PLANE SKY AREA 273.82 SQ. CM



LIAM DIAGRAM WINDOW SOLAR AZIM = 180 DEG
SOLAR ALT = 70 DEG
CIE KITTLER SKY GLASS TRANS= LBL/RUBIN,CLEAR
HORIZONTAL PLANE SKY AREA 277.23 SQ. CM

A. The forward half of sky vault:

$$S.C. = \frac{21.5 \times 100}{273.03 + 9.91/18.83 \times 277.23} = 5.13\%$$

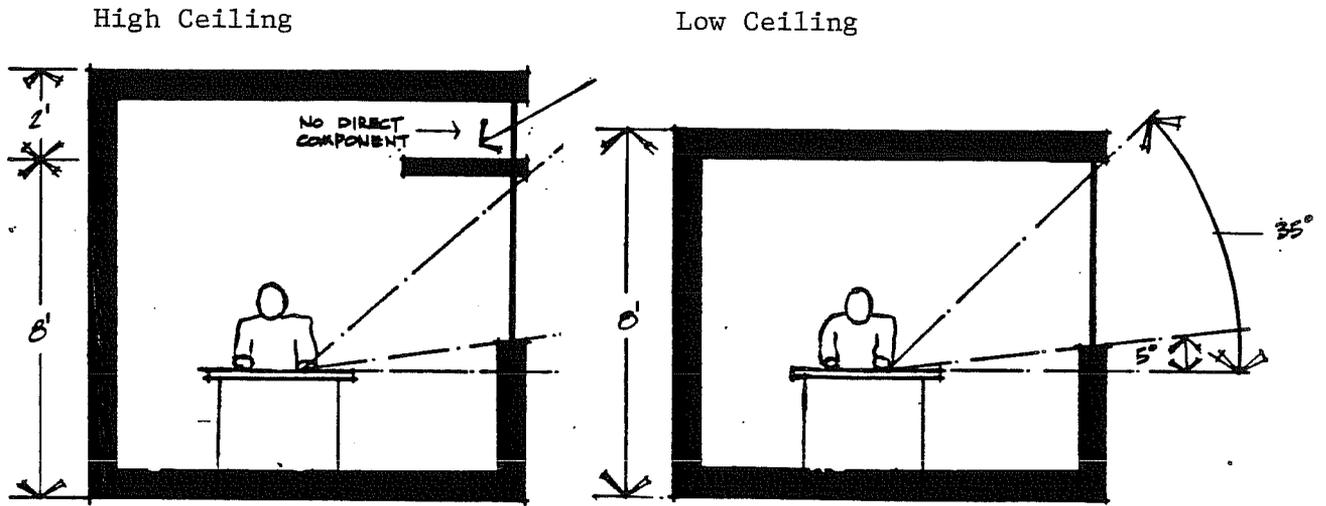
$$MeC_S = \frac{21.5 \times 100}{273.03 \times 2} = 3.93\%$$

B. The rear half of sky vault:

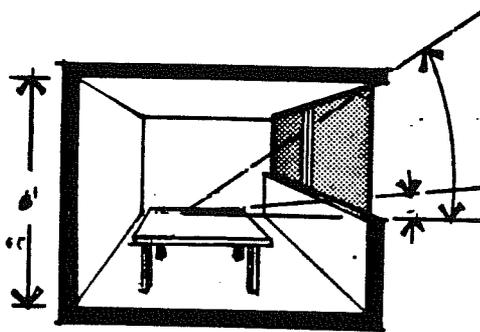
$$S.C. = \frac{23.35 \times 100}{277.23 + 18.83/9.91 \times 273.03} = 2.93\%$$

$$MeC_S = \frac{23.35 \times 100}{277.3 \times 2} = 4.21\%$$

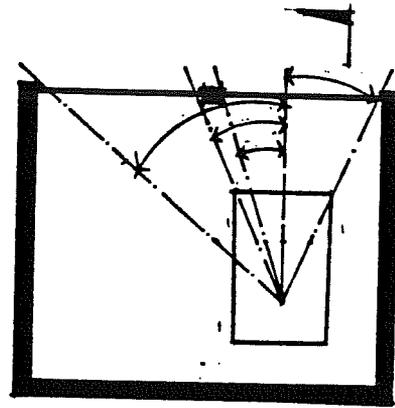
Figure 37



Low Ceiling

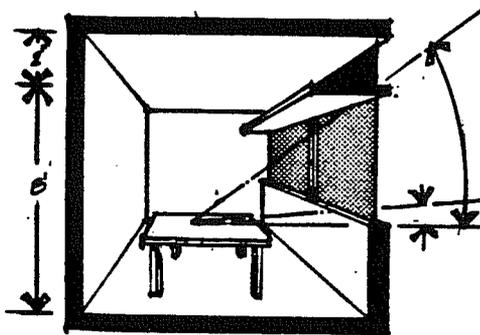


Section

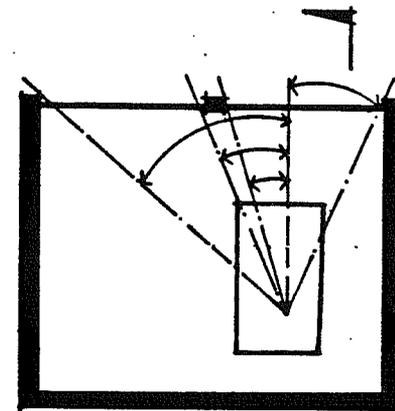


Plan

High Ceiling



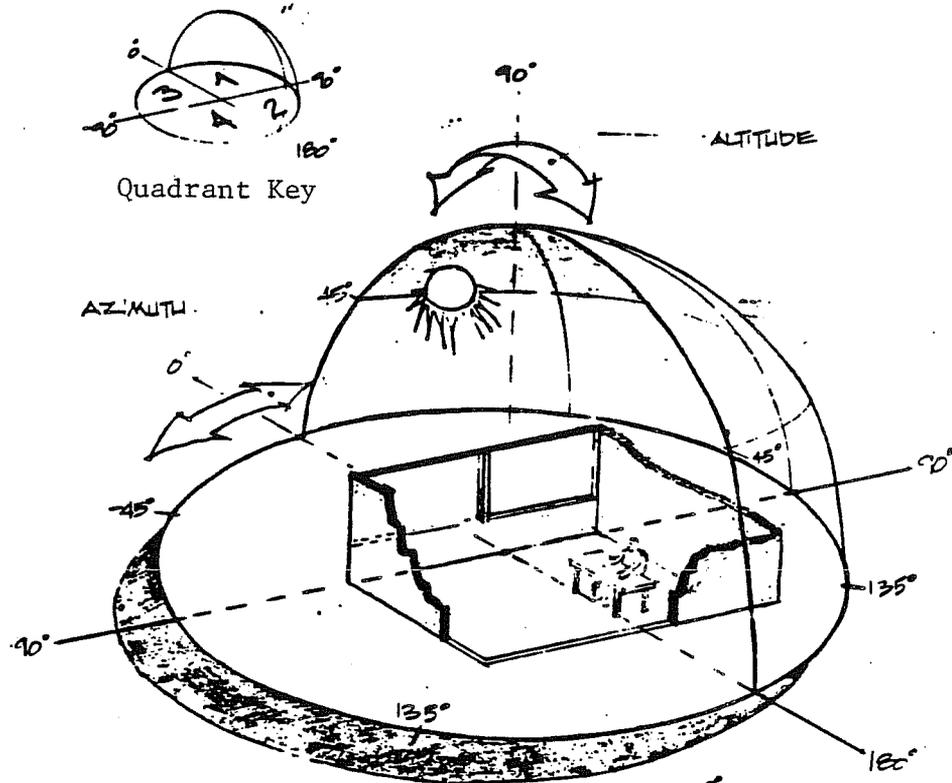
Section



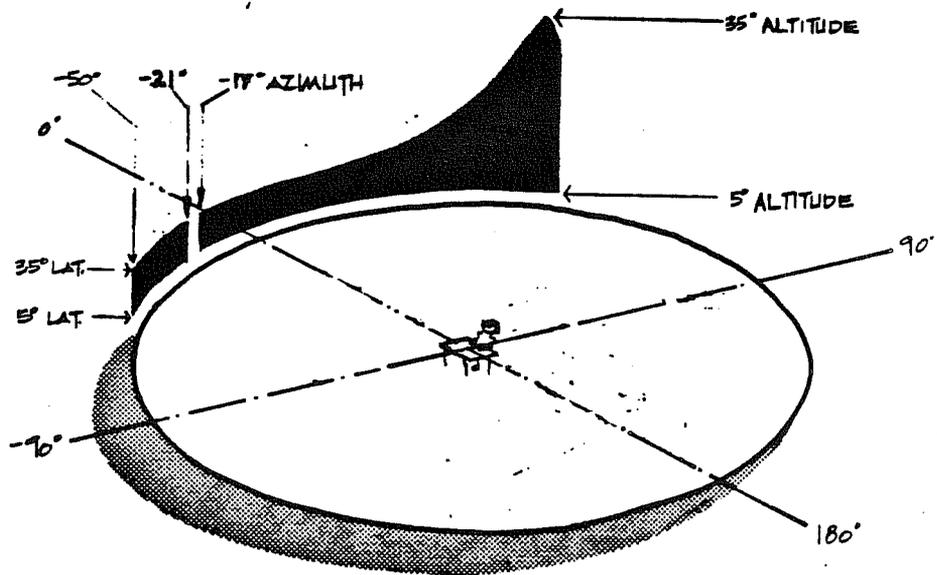
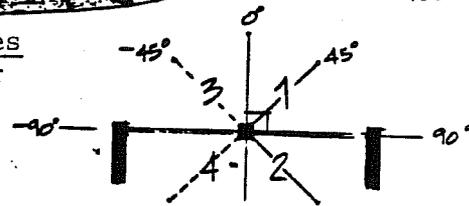
Plan

Figure 38a

THE SKY VAULT
 Measuring Solar Azimuth & Altitude



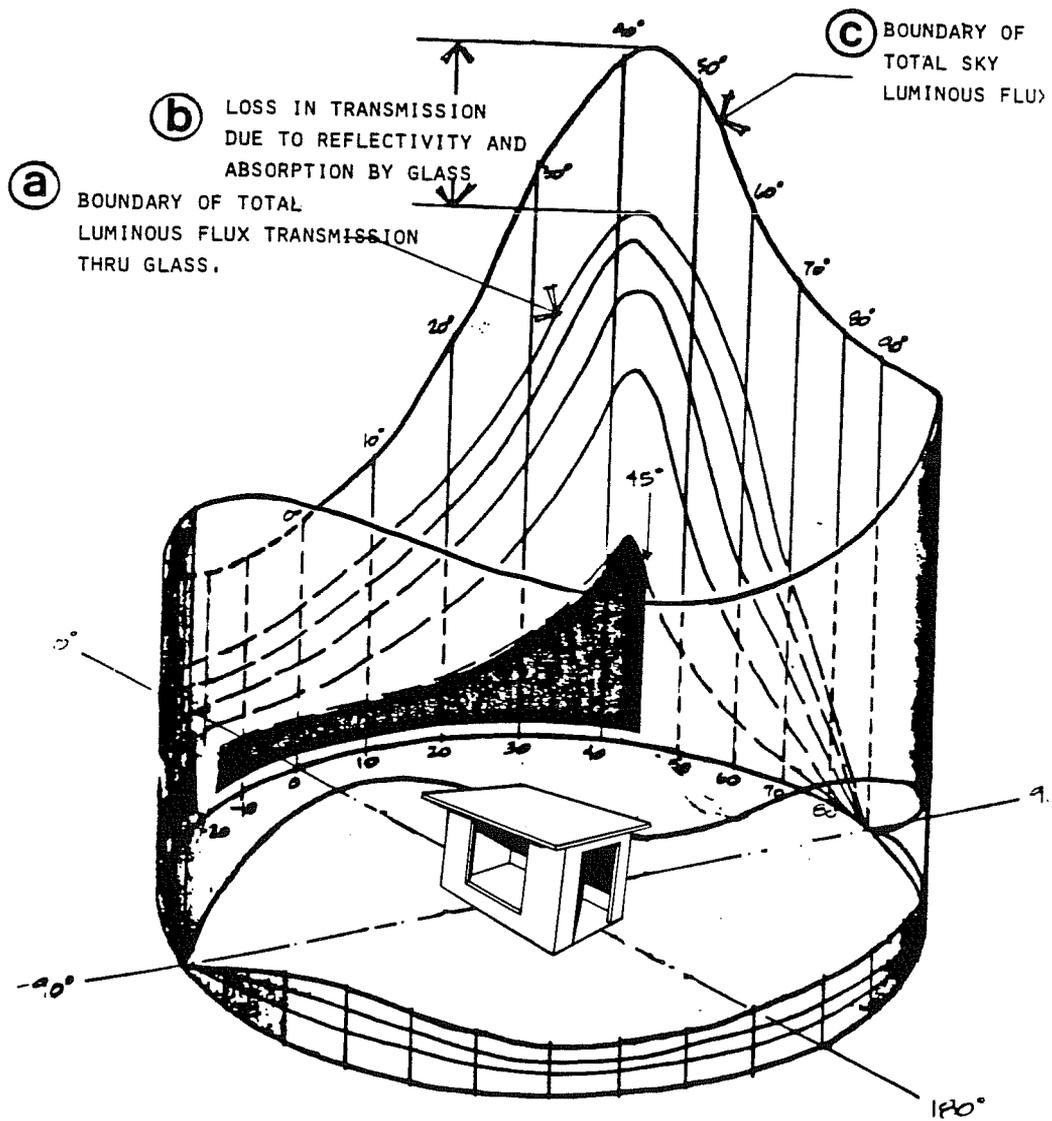
Measuring Window Solar Azimuth Angles
 Graphs are produced for window solar azimuths in quadrants 1 & 2. For quadrants 3 & 4 see diagrams in LBL publication by D. MacGowan, 1981.



Note: Use measured angles to convert between window in building & window image on LIAM diagram.

Figure 38b

FIGURE 38c

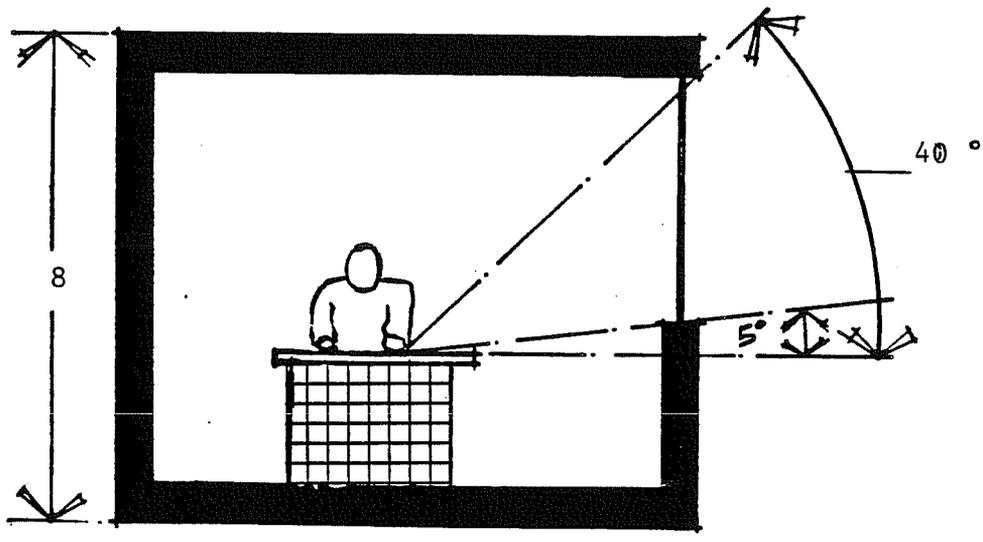


LIAM DIAGRAM

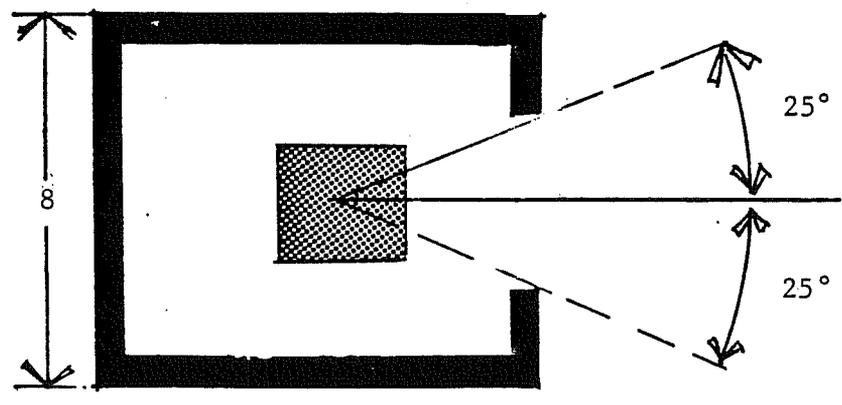
To obtain the desired accuracy, the sky was calibrated for the sun at 60°, 70°, 90° degree altitudes. These were plotted by LIAM diagram and their error came to less than 5% compared to C.I.E. Kittler's sky luminance distribution. Because of the control dimming system which is available in this facility other distributions can be achieved. Therefore, as a check on luminance measurement of the sky simulator, one can use either LIAM diagrams or for fast checking, the C.I.E. data.

One last, more elaborate way to check the accuracy of a specific sky distributions is model measurement. A model in one-inch scale was constructed, and a 1% reflective board was placed at ceiling, wall, and floor surfaces in order to measure only the direct sky component at a 4-foot distance from the window (4x4) on the task level height. The photocell reads the illuminance level as number x. Now if we plot the image of that window on appropriate LIAM diagram and calculate the MECs, it should be close to the number x which was measured inside the model. A series of measurements taken inside the above model at different horizontal and vertical positions showed that there is a high level of accuracy at the center of the sky simulator within a volume of 30x30x24 inches (Fig. 39).

Figure 39a

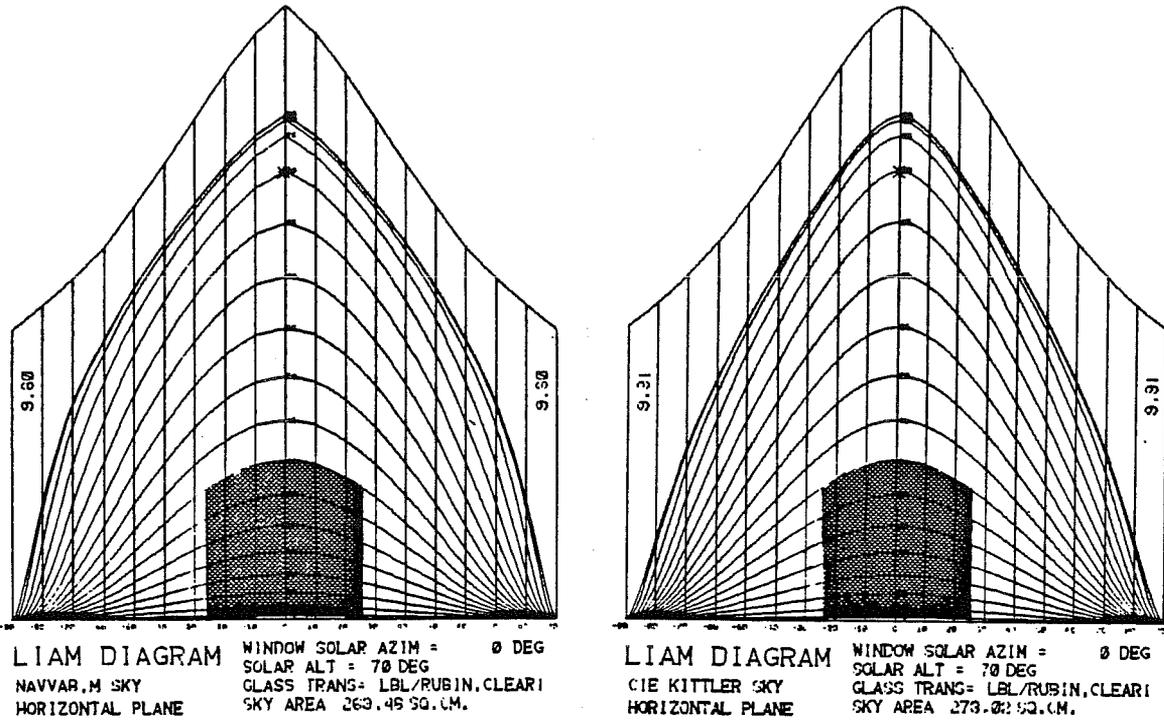


SECTION



PLAN

Figure 39b



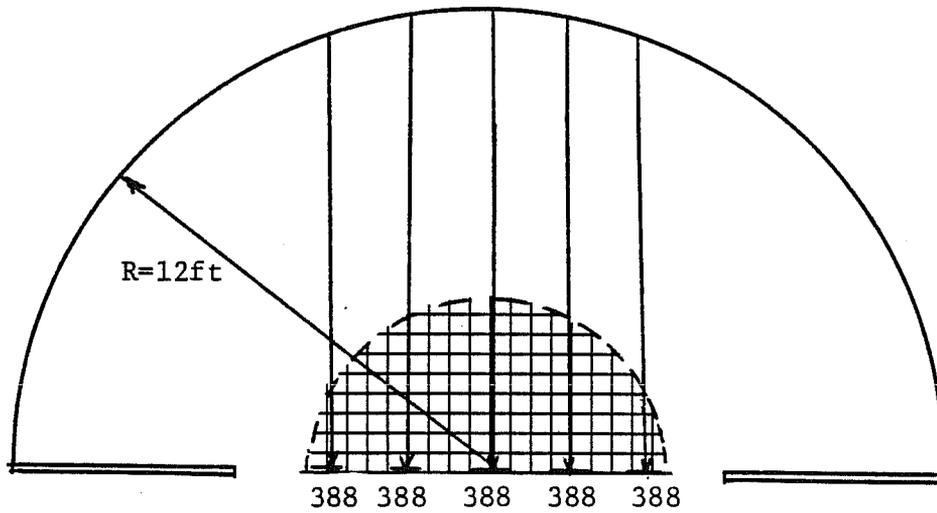
THE FRONT HALF OF SKY VAULT

$$S.C. = \frac{25.80 \times 100}{269.48 + 9.80 / 18.93 \times 269} = 6.31 \%$$

$$MeCs = \frac{25.80 \times 100}{269.48 \times 2} = 4.79 \%$$

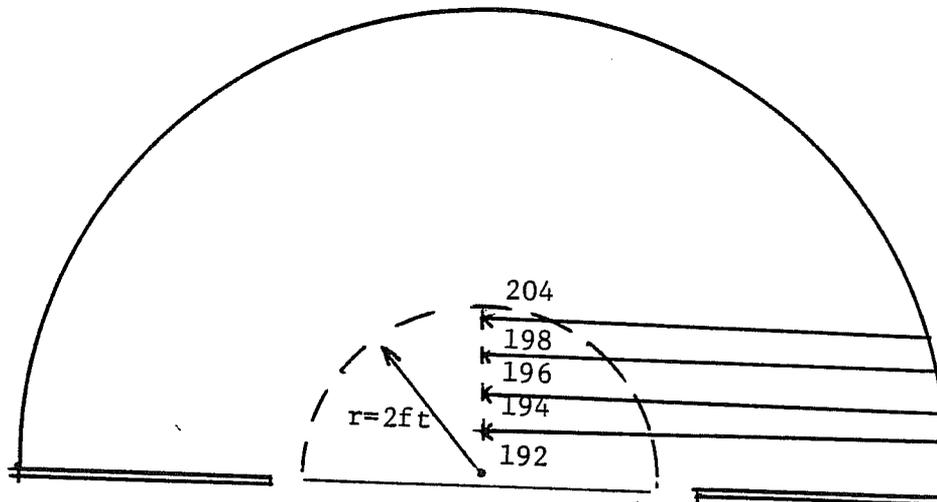
S.C. FROM SKY SIMULATOR 4.21 %

Figure 39c



HORIZONTAL

UNIFORM DISTRIBUTION



VERTICAL

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V. INSTRUCTION AND RESEARCH USES

A. Operation of Sky Simulator

The sky simulator was built to support activities such as research, architectural design, and teaching. The sky simulator has to be operated in such a way that the greatest benefit can be obtained. In order to achieve such a goal one has to be familiar with the operation and function of each part of the sky simulator. In case of power failure or problems with lamps one has to know how to replace them without disturbing any other system. Therefore throughout all the testing it was determined that in using the sky simulator one should follow certain guidelines:

1. After turning the main power switch on, one can turn on the lamp switches for each ring.
2. There is a waiting time of between 20 to 30 minutes during which the lamps warm up to reach the maximum level of output or dimming option.
3. Next turn on the fan.
4. Then by climbing up on the platform one can check to see if there are any flickering or non-functional lamps (control panel).

The lamps are numbered and dated according to their positions within the rings and sectors. Example: A 23,5,S1,R1

A = first lamp toward the center of the dome
 5,23 = date on which lamp was install
 S1 = sector one by the door, counting counter-clockwise
 as you are walking
 RI = ring one--first ring of lamps close
 to the center of dome

5. Now it is time to calibrate the sky for the desired luminance distribution. (See section on calibration of the system in IV B; also see SPECTRA Photometer Manual, pgs. 8,12,13, and 40.)²⁹
6. Set up the platform at the horizon level if the model is more than 24" high; make sure it is not blocking the projector lamps.
7. For more accurate measurement set the model at the center of the platform.
8. Decide whether to use ground reflectance simulator or sun simulator; if so set desired position.
9. Intensity of ground simulator changes by dimming. Its direction toward the wall or windows changes by louvers.
10. The platform can rotate for azimuthal changes. The accuracy of your changes within azimuth can be checked by using the LIAM diagram computer program, or use calibration model to calibrate orientation.
11. Set the photocells at desired working plane height.
12. Close all the model walls very tightly.
13. Follow the MEGATRON instructions for reading your measurements.

B. Sky Luminances Measurements

For calibration and determining the degree of accuracy of the sky simulator in order to do a comparison and prediction for a proposed building in a specific site, one must have the sky luminance distribution of that location. With the capabilities of the sky simulator it is possible to simulate the real sky (see Appendix D) rather than simulating the calculated sky based on the C.I.E. standard. In order to do the calibration for that purpose one has to measure the sky luminance. The following guidelines simplify the procedure for taking measurements:

1. Open and extend legs of tripod; mount it securely, locking with bottom and top screws.
2. Screw transit unit to top of tripod head.
3. Mount luminance probe to transit cradle; lock with small screw and Allen wrench inside transit case.
4. Adjust transit to horizontal position, using the four base screws and the level on the upright. Rotate so that the sight line coincides with the base screw diagonals and adjust with the two screws along the diagonal.
5. Connect luminance probe to J16 readout unit having extension cable. Readout unit can be hung by its handle on tripod screw.
6. Loosen both lock screws on vertical axis (azimuth adjustment) and adjust horizontal scale to 0-reading at A-index, then lock top screw. Rotate whole body to vertical plane through sun's position,

checking the image formed on a piece of paper held behind the luminance probe's eye piece. Avoid turning instrument power on when turned against the sun, and never look through the eye piece! Lock bottom screw.

7. The horizontal scale will now read azimuth=0 for sun's bearing. Scan through every 10 degrees in altitude from horizon to zenith, then change vertical plane (azimuth) at 15-degree increments from azimuth=0 (sun) to azimuth =180. Use top screw on base for azimuth adjustments.
8. Reading: Turn J16 power on and check battery condition (max=7.8). Push luminance probe "Readout hold" button in and depress "Momentary override" for reading when instrument is in correct position. Select range button that gives highest number of digits $\neq 0$ on display. Flashing display means overload-- select higher range. Multiply reading with a range factor (x.1 x1 x10 x100 x1000) and record.

Note: Luminance probe on US unit J16 gives reading in deka-candela/m². Multiply reading by 10 to obtain cd/m².

9. Record results on the special form. Record also: date, time when starting and ending measurements, site, sky conditions, observers, solar altitude, and compass bearing to sun's position.
10. See SPECTRA Photometer instruction and maintenance manual for model No. 1980A, pages 8,12,13, and 40.²⁹

C. Use of Photography in Visual Evaluations

Photography can be used for the following:

1. Evaluating a specific luminous environment or lighting effect quantitatively and qualitatively.
2. Recording different model configurations, positions, and orientations along with photocell positions in complex floor plans.
3. Comparing and evaluating light distribution patterns with direct sun and clear sky luminance distribution.

1. Evaluating a specific luminous environment:

With the increase of high-rise buildings within the downtown areas of major cities comes a growing need for light zoning and, as a result, height and setback regulation. However, limitations on height and setback do not guarantee adequate sunlight although they do provide a fair amount of open sky above. Also this amount of sky does not maximize the amount of sunlight. If one follows the sun's passage 180 degrees from east to west, it is possible to arrange the setback with a different slope or other design change. Now to do the study for generating different designs follow these instructions:

- (a) Set up the platform on the correct height position with respect to horizon.
- (b) Calibrate the sky for the desired luminance distribution.
- (c) Turn the sun simulator on with the desired altitude.

- (d) Set up the model of the building on a sheet of Plexiglass on the platform or the opening between them.
- (e) Use photocell to measure the amount of light falling on street level.
- (f) Use the camera to take a picture of all areas with or without shadow.
- (g) With a camera equipped with a fisheye lens, photograph the sky vault from street level (bottom of platform).
- (h) Using an L.O.F. graph over those above photos also determines the amount of open skylights.

2. Recording model configurations:

One should know that several photos will be needed to record all cases adequately. They include:

- Top view showing layout or plans
- Side view (section) by removing one wall
- Interior shot from critical point of view to show workplan.
- Interior shot to show photocells
- Interior shot to show human scaled figures
- Overall view to show platform, model orientation
- Shots from different perspectives for architectural use

All photographs should have a clear picture of wall, ceiling, and work plane surfaces.

Because of the fluorescent lamps, use standard Y2 filters if the photographs are in color.

3. Evaluating light patterns: The photographs will allow you to see the light distribution patterns on walls, ceiling, and workplane and to be able to identify normal and dark areas within the model. Unlike the configuration cases these settings have to stay constant. Now in order to do the visual evaluation one must follow these instructions:

- Keep aperture and speed of camera constant.
- Use one type of film and paper.
- Use the same developer and processing for all films.
- Maintain the same agitation time and developing time on all films and prints.

D. Computer Programs

The programs and the lighting data are stored on a magnetic tape cartridge (Scotch DC 300 A), and can be used on the Tektronix graphic computer system, at Wurster Hall (Department of Architecture, University of California, Berkeley).

Programs and data are stored as separate files, numbered from 1 to 60, but the cartridge is capable of taking more files. The current inventory of major program follows:

1. Program for calculation of lighting combinations
2. Program for storing lighting data on tape files
3. Program for printing out data files
4. Program for calculation of C.I.E. clear sky distribution tables
5. Program for storing data and graphing x vs. y plot
6. Program for calculating the accuracy of the uniform overcast sky distribution
7. Program for horizon scale error.
8. Program for graphing y plot
9. Program for graphing histogram plot
10. Program (subroutine) for graphing measured data from sky simulator in LIAM program (uses Fortran on CRT at LBL, 7600 series).

When a program is changed for different data or a special function, the new version is put on different cartridges. Also, all the measurements from the sky simulator have been stored on the same cartridge that contains programs related to that data. See the listings for further details.

How to run programs:

Put tape cartridge in the slot on right-hand side of the Tektronix unit. Power switch is placed on underside of keyboard to the right. Line-printer hook-up is on backside of unit: put line-printer plug into socket. For printouts, make sure line printer has power; set LINE mode, set PITCH to 10.

Wait until unit is warmed up, then clear screen by using HOME PAGE key. Remember that information shown on the screen will not enter the system until you hit the RETURN key. That is, every entry of data or command must be followed by RETURN key.

To run specific program (e.g., no. 1 in file no. 1)

```
Type command: FIND 1 (RETURN key)
Type command: OLD   (RETURN key)
Type command: RUN   (RETURN key)
```

Program no. 1 will now be in unit memory and running, and the first program message will appear on screen. The same procedure is used for all programs.

During tape operations the BUSY (and I/O) light will be on. Do not attempt to type anything on the keyboard until operations are finished. The system is very slow on many operations, so be patient.

To make new programs, or alter existing programs:

Ask for assistance from a computer consultant or read BASIC manual. When the screen is full, use the PAGE key. To take an inventory of a tape cartridge, use the command: TLIST (RETURN key). For printout version (check that line printer is hooked up) use: TLIST(a)40 (RETURN

key). To stop during run-time use BREAK key twice. Mistyping during program runs can be corrected before the RETURN key is used, by using the BACKSPACE and RUB-OUT keys. The flashing rectangle on the screen indicates where one is typing in the line. When a mistake is deleted with RUB-OUT, type the correct character in the same space. Refresh image on screen with SHIFT key.

When finished running the program, just turn off the power and release tape cartridge with PUSH button.

1. Program No. 1

This program calculates lighting system combinations. The program takes an indefinite number of data files and adds them up, then calculates luminance distributions relative to the zenith value. Each data file (which is a set of luminance measurements for one specific lamp) can be entered with its main azimuth (pointing to the lamp) in any relative position in 15-degree increments around the whole sky. The positions are numbered 1,2,3,...to 24, corresponding to azimuth 0° , 15° , 30° ...to 345° or 0, 10, 20,30. The program is most useful for testing the effect of a whole bank of lights, when only one lamp has been measured. Then the same data file is used several times, but in new positions. In general, the simplest way of calculating a full circle of lamps is to use the file for position 1,3,5,7 etc., i.e., every 30 degrees. Each calculation is entered with a scaling factor which can be used to simulate lamps having different wattages different from the one measured, or more than one lamp in the same position. The scaling factor can also be used to account for data taken with different types of instruments.

Input to program:

The program gives screen messages for all necessary input.

(a) "Enter calculation description."

Type in a description of the calculation to be performed, using at most 72 characters (one line). This will later appear as the heading on the output. (RETURN key).

(b) "Enter number of calculations to be performed."

This is the total number of files (or repeated files) to be added up. For the same file used every 30 degrees (position 1,3,5,etc.) the number is 12. Type in the number. The program will only accept this number of calculations (RETURN key).

(c) "Enter file number."

Type in correct file number for first calculation (RETURN key).

(d) "Enter position number."

Type in position number for this file (see above) (RETURN key).

5. "Enter scaling factor."

Type in scaling factor for this file in this position. Use 1 if simulating the kind of lamp that was measured (RETURN key). At this point the tape will run to the file called for in step 3, and the data will be copied into the computer memory. Steps 3,4, and 5 will be repeated the number of times stipulated in Step 2. Each calculation takes some time (15 sec.), so wait for BUSY lights to

go out before entering new data.

When the last data file has been processed, the screen gives the message: "Connect line printer."

"Printing will start when single digit is typed on keyboard." This is put into the program so that other terminals can use the line printer while calculations are being performed. Plug in the printer at this point, check power switches, and type in a single number (RETURN key). Printing will start immediately. Output consists of the heading, a list of all the positions and scaling factors that have been used, a table of relative luminances for the whole sky, and the zenith scaling factor which is the sum of all the zenith file values.

2. Program No. 2

This program is used when a new set of measurements is to be stored in a data file. New data can also be stored in files that contain obsolete data. The old data is of course destroyed in the process. The program is basically set up for storing a 13x10 array of numbers, with ample possibility for checking and correcting as you go.

Measurement data is taken for every 15 degrees in azimuth and every 10 degrees in altitudes for half of the sky, usually starting in such a way that the lamp position is indicated as azimuth=0 degrees. Towards zenith some points are skipped during measurements because they are so close. These points must be filled in by manual interpolation, as the program can only handle a complete 13x10 array. The numbers to be entered should be the actual values seen on the instrument display (but corrected for range) and not the values relative to the zenith

luminance.

Running program:

- (a) "Enter lighting system description, max 72 characters."

Type in one line (72 characters) that identifies the lighting system, both lamps used, reflector, position in sky, and angle of tilt (RETURN key).

- (b) "Enter lighting data, line by line, starting with 0° altitude."

"All data should be absolute measurement values." Type in data for one altitude (13 numbers), starting with 0 altitude and 0° azimuth. The program starts out with the message:

- (c) "Altitude degrees"

Type in value for azimuth 0 degrees (RETURN key), then 10 or 15 degrees (RETURN key), and so on to 180 degrees.

- (d) The program then repeats the whole set of values for this altitude, giving a position number in front of each value. The entered values can now be checked against the measurements.

- (e) "Enter number of wrong data."

Type in the number of values that have been entered incorrectly. If none, use 0 (RETURN key). If 0, the program returns to step c, this time for "altitude 10."*

*PS. When reaching 0 wrong data, the sequence:

0
HOME PAGE
RETURN will ensure that next set of data can start at
the top of the screen.

- (f) If numbered entered in step 5 is different from 0, the computer will respond with:

"Enter data (line) number that is incorrect"

Type in the line (or position number) where the incorrect value is (RETURN key)

- (g) "Enter correct data"

Type in the correct value for the line given in step 6. (RETURN key) Steps 6 and 7 are repeated the number of times given in step 5. The whole data-set is then printed on screen as in step 4, for rechecking. Step 5 is repeated until 0 is given when all the data is correct. When 0 is finally reached, the program returns to step 3, this time with value "Altitude 10 degrees". The steps 3 thru 7 are repeated till the whole array has been filled up.

- (h) "Enter file number for storing data."

Type in which file number should be used for this measurement. Make sure the line printer is hooked up before the RETURN key is used!!!

The program will print out lighting description and the whole array on the line printer. Final message is "Data stored and printed out".

3. Program No. 3

This programs reads a data file into memory and prints it out on the line printer. By doing alterations to the program resting in the com-

puter memory, it is also possible to do corrections to the file and store the corrected version afterwards in the same place on the tape.

Running the program:

The program gives initial messages, then:

- a. "Enter data file number"

Type in the file number wanted (RETURN key), if the file is empty, the screen will give an error message. Make sure the line printer is hooked up before using RETURN key!!!

To do corrections to data file, alter program between lines 170 and 180.

For example, multiplying all values by a factor of 5.22:

```
171 LET      A=A*5.22
172 FIND     X
173 WRITE(A) 33:A$,A
```

These program steps must be entered after the program has been copied into memory, but before giving the command RUN.

4. Program No. 4

This program calculates a table of CIE clear-sky luminance distributions for every 10 degrees of azimuth from 0° (towards the sun) to 180°, and every 10 degree of altitude (starting at a 5 ° because the CIE formula is not defined for 0-degree altitude). After initial messages, the program needs the solar altitude:

- a. "Enter solar altitude in degrees."

Type in altitude desired, but make sure the line printer is

hooked up before using the RETURN key!!!

5. Program No. 5

This program takes a data file into memory which can be stored in files like program (2) but this program is capable of an x-y data plot which graphs the correlation between two sets of data x and y. The data on either axis can be continuous or discrete. A continuous variable may take a value anywhere within the limits of data series which can be changed easily. A discrete variable takes values that have definite breaks or steps between them. For a program that plots x and y on the screen, the Textronic, Inc., instruction manuals for the Textronix Plot 50 and the 4051. (34,35) These programs can be modified to make the use of the plotter.

6. Program No. 6

This program calculates the accuracy of the uniform sky distribution. It takes the survey data of the inside the dome from memory files and, through standard deviation calculation, calculates the confident interval-degree of freedom at every 10 degree of altitude. You can easily check these figures against C.I.E. standard distribution.

7. Program No. 7

This program calculates the horizon error. It takes the position of photocell (height from horizon level and distance from center of sky simulator), then prints out all possible positions at which you can have the photocell inside the model the number of degrees that fall into horizon error. You can use these to check the accuracy of your measure-

ments within the limitations of the platform and the scale model.

8. Program No. 8

This program graphs y-plot. It takes a data file into memory which can be stored in files like Program No. 6 and graphs them in the order in which they have been stored. It is good for plotting maximum and minimum quantities of different light outputs and distributions.

9. Program No. 9

This program graphs a histogram, working the same way as Program No. 8.

10. Program No. 10

This program graphs LIAM diagrams. See Section IV, Accuracy of the System).

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VII. APPENDIXES

A.	Model Furniture Supply	173a
B.	Installation Instructions for Sky Simulator	179
C.	Study Cases	182
D.	References	214
E.	Computer Program Listing and Outputs	215

Appendix A: Model Furniture Supply

The following is the information necessary to obtain model furniture for building architectural lighting models. The information on companies and magazines states how each could be a useful source for model furniture, and gives a short synopsis on the scales of available furniture, their costs, quantity, and variety.

Model sizes that could prove most beneficial for successful results in lighting experiments appear to be of sizes from $1/4" = 1'$ to $1" = 1'$. Once this was decided, it was necessary to discover what model furniture is available in those sizes.

Furniture of the scale $1"=1'$ was the most available in variety and quantity. Any premanufactured furniture of smaller or larger sizes was virtually impossible to find. It would be possible to make furniture with preassembled parts. If one must resort to this type of furniture assemblage, it would be best to go about making smaller or larger scaled furniture, in the manner by which most architectural students make and supply their models. The other problem is that the cost of each assembled piece is much higher than the complete piece of premade furniture.

1. Furniture Sizes and Availability

- 2" = 1' None preassembled. One would have to make this size of furniture oneself.
- 1" = 1' This size is the easiest to obtain. It is the typical scale for doll houses, so there is a large quantity and variety of furniture. This size is satisfactory for carrying on lighting experiments.
- 1/2" = 1' It is not possible to find preassembled furniture this size. One would have to make this size oneself.
- 1/4" = 1' It is not possible to find preassembled furniture this size. One would have to make this size oneself.
- 1/8" = 1' furniture (preassembled) through model train and hobby shops.
- 1/6" = 1' It is possible to obtain this size of furniture (preassembled) through model train and hobby shops.

2. Cost

The cost of building and furnishing architectural lighting models will depend upon the scale chosen and the degree of accuracy and sophistication required. The companies and stores listed are all similar in cost since prices are based on the degree of intricacy of each piece of furniture.

The following list is of premade furniture beginning with the most expensive company, ending with the least expensive. The architectural model supply companies are fairly similar in their price listings.

(a) Gerald Shainin and Co.

- (b) Reevesline
- (c) Lundy
- (d) Amsi
- (e) H.O. Railroad and Craft Trains

3. Companies

Reevsline

1107 Broadway

New York, NY 10010

Reevsline carries high quality wood furniture in a large assortment, at a scale of 1" = 1'.

King Tenaka

800 W. Santa Inez

Hillsborough, CA 94010

If it is not possible to deal with the Reevesline company directly, then we could obtain the necessary quantity of furniture through a sales representative.

Lundy

1107 Broadway

New York, NY 10010

This company sells plastic furniture at a scale of 1" = 1'. The problem is that they sell completely furnished houses, offices, etc. It may be possible to buy individual furniture pieces.

Gerald Shainin and Co.

844 Mahler Rd.

Burlingame, CA 94010

This company provides the highest quality of doll house furniture. It is made of wood at a scale of 1" = 1`.

AMSI

P.O. Box 3497

San Rafael, CA 94902

An architectural model supply company. They sell models completely assembled and furnished, and individual pieces to build your own models.

H.O. Railroad and Craft Trains

5601 W. Florist Ave.

Milwaukee, WN 53218

Model train supply house which carries furniture at scales of 1/8" = 1`,
1/16" = 1`.

4. Magazines

Narrow Gage and Shortline Gazette

Lists itemized pieces to assemble models. This is used mostly for train models.

Chrysnbon

P.O. Box 13

Western springs, IL 60558

Model trains supply magazine which may be helpful in finding individual components for model building.

AMSI

P.O. Box 3497

San Rafael, CA 94902

- 1) Doll House Materials; AMSI Miniatures; Houseworks L.T.D., 1979
- 2) AMSI Model Builders Catalogue

These catalogues would be the most helpful since this company caters to those building architectural models.

H.O. Railroad and Craft Train Catalogue

5601 W. Florist Ave.

Milwaukee, WI 53218

Model train supply magazine which carries doll house furniture of various sizes.

H.O. Reflections Industry, Inc.

133/3031 Williams Rd.

Richmond, BC V7C 4G1

Canada

Train model supply magazine. It contains individual model building pieces which might be useful when building models.

APPENDIX B: Installation Instructions for Sky Simulator

These tools will speed installation:

"Spider" or temporary ring support
 2-speed wrenches w/deep 7/16" hex socket
 screw driver
 hammer
 sharp drift pin
 tin snips
 tape measure
 hacksaw
 visegrip
 crescent wrenches
 on 20' silo and larger, a catwalk
 on 24' silo and larger, a masonry drill

1. Steps of Dome Assembly

(a) Preliminary ground work

(i) Place metal sheets on sawbucks or other waist-high supports, and put clips and 1/4" X 1 7/32" carriage bolts within easy reach; attach roof clamps as shown in Fig. 1.

(ii) Tie straps should be attached to fiberglass cap as shown in Fig. 2.

(b) Assembling

(i) Level hoop 3-1/2" from top with a lug at center of proposed door opening. If dome is definitely out-of-round, rod spacing down from top of silo should be increased proportionately where wall is "flat." Hoop tension should be relaxed during dome installation. On silos 24' and larger, drill directly through wall and install hoop supporting "J" bolts at even intervals.

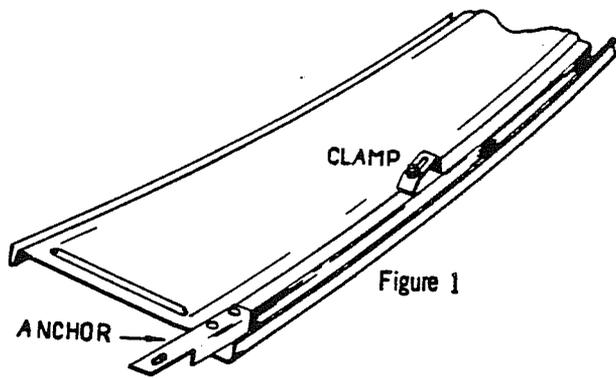


Figure 1

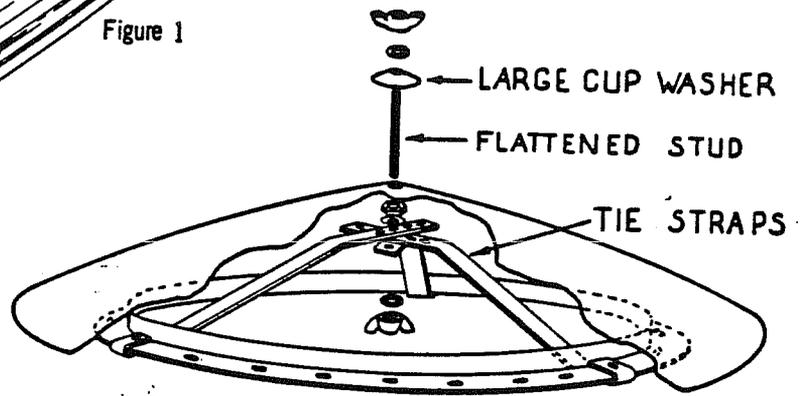


Figure 2

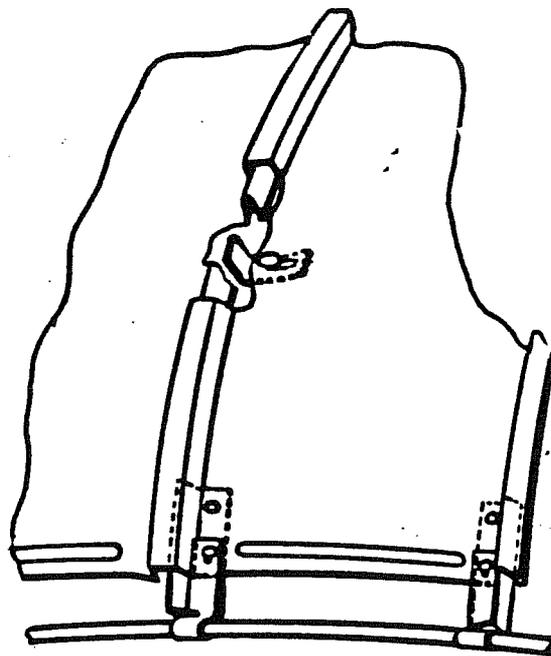


Fig. 4

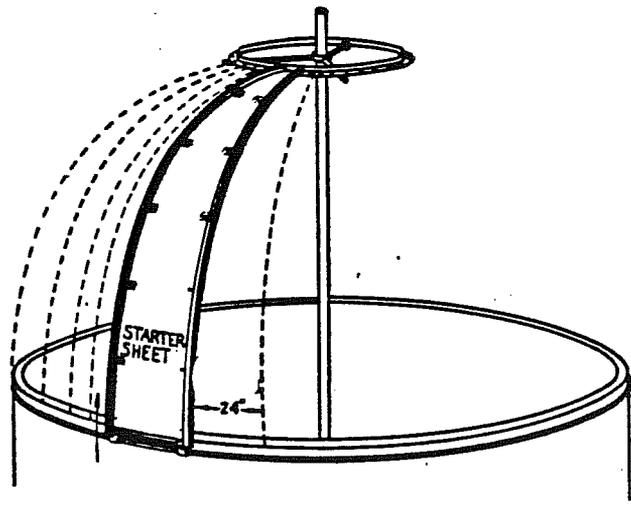


Fig. 3

Support dome ring at center of dome by means of "Spider."

- (ii) On smaller dome, ring may be positioned after the first few metal sheets are installed, (Steps iii and iv) supporting back of ring with a temporary support or pairs of metal sheets loosely attached.
- (iii) Starting to the right (Note: all references "right" or "left" are from inside of dome, facing out) of proposed roof door opening (Fig. 3), install the starter sheet, (the sheet with the wide rib along each edge). Fasten the two anchors to the hoop (Fig. 4) and bolt sheet to ring at the two closely spaced holes marked "ST."
- (iv) If dome has narrow 1/2 sheet groove, place it to right of starter sheet (Fig. 3). Then add regular metal sheets by slipping the narrow rib under the wide rib of the last sheet installed while sliding the dome anchor tab under the hoop. Fasten the anchor, as shown in Fig. 4, by bending up tab and fitting slotted tab over bottom anchor bolt, securing with a nut. Turn clamps into narrow rib of metal sheet, tightening clamping nut finger-tight. Bolt sheet to ring. After four sheets have been added to starter sheet, plumb sheets so joints are running straight and tighten clamps securely. Keep dome ring level at all times.

- (v) Install additional sheets, securing anchors but leaving clamps finger-tight. Re-tighten hoop at lugs before they are out of reach as dome assembly progresses.
- (vi) After securing all metal sheets and setting the dome on supporting walls, replace the clamps with rivets.
- (vii) Cover all the clamp holes with aluminum foil tape No. 425 and all the seams between metal sheets with masking tape such as 3M's No. 234 (Scotch Co.)
- (viii) Attach the fiberglass cap from inside to tie straps.
- (ix) Paint the inside with flat white paint having a high reflectivity (greater than 75%).

APPENDIX C: Study Cases**1 Case No. 1****Table of Contents**

- (a) Table of Illustrations
- (b) Introduction
- (c) Findings
- (d) Recommendations
- (e) General Conditions to the Analysis

1. List of Illustrations

- Figure 1: Distribution of natural light--south facing windows, worst conditions.
- Figure 2: Effectiveness of natural lighting-clear sky, minimal conditions.
- Figure 3: Effectiveness of natural lighting-overcast sky, minimal conditions.
- Figure 4: Daylighting zone on a typical office floor.
- Table 1: Annual demand for artificial lighting in the daylight zone during work hours.
- Figure 5: Distribution of natural light-north-facing windows.
- Figure 6: Distribution of natural light-north-facing windows.
- Figure 7: Distribution of natural light-north-facing windows.
- Figure 8: Distribution of natural light-south-facing windows.
- Figure 9: Distribution of natural light-south-facing windows.
- Figure 10: Daylight intensity with tinted glazing--north-facing windows.
- Figure 11: Daylight intensity with tinted glazing south-facing windows.
- Table 2: Daylight transmittance of glass.
- Table 3: Sun intensity chart for Hawaii.
- Figure 12: The orientation of scale model units used in daylighting analysis in the artificial sky.
- Figure 13: Typical section-south.
- Figure 14: Typical section-north.

(b) Introduction

This is a report on the preliminary daylighting analysis performed for the Hawaii Medical Services Association Office Building in Honolulu, Hawaii, in the summer of 1981. The analysis is a study of the daylighting performance of the fenestration facing the streets and the undeveloped part of the property slated for possible future expansion. No consideration is given to the courtyard location and form, since those had not been determined at the onset of this analysis. Fenestration into the courtyard will provide supplementary daylighting for the offices and will further increase the area of the building which can be daylit.

The daylighting performance of this building will probably change somewhat as the design is developed in more detail. The addition of furniture and partitions inside office spaces will inevitably reduce the availability of natural light in some areas of the building. The extent of this reduction will be determined after the interior design of floor space has been finalized.

(c) Findings

It is clear that the proposed design will result in a well daylit building (Figs. 1-3). The depth of the daylighting zone varies according to the orientation of each particular window. Measured perpendicular to the middle of each window, the daylighting zone behind the southwest windows is 24 feet deep, and behind the southeast-facing windows it is 22 feet deep. Northwest-facing windows create a 35-foot deep daylighting zone, while the northwest-facing daylighting zone is 33 feet deep

(Fig. 4). These results are based on the simulation of a clear sky, a task surface 36 inches above the floor, 9'-0" floor-to-ceiling height, single-pane clear glazing in all windows. The varying daylighting zone depths result in a floor area of 24,480 square feet which is well lit by daylighting under most conditions. This means that 73% of the usable floor area can be naturally lit by windows facing the surrounding streets.

Since the conditions of natural lighting depend on the conditions of the sky (that is, on the cloud coverage and the time of day), the daylighting availability has to be adjusted for sky conditions. Based on 180 work hours per month (workdays 8 am. to 5 pm. during the week), and distributed over one year, the intensity of natural light under the worse conditions at the back of the daylighting zone can be expected to be 40 footcandles 53% of the time if the sky is overcast, and 85% of the time if the sky is clear. Sixty footcandles can be expected 43% of the time with overcast sky, and 64% of the time with clear sky (Table 1).

Clear glazing provides too much light close to the windows (Figs. 5-9). This problem can be reduced through introducing tinted glazing that will reduce daylight transmittance in the windows below the daylighting shelves. If a blue-green glass (single pane with transmittance of 72%) is introduced, the lighting intensity drops by 28% twelve feet behind the windows. Grey or bronze glass 3/16 inch thick (with 51% transmittance) in the same place reduces daylight intensity by 49% ten feet behind the window. One-eighth inch grey or bronze glass (61% transmittance) reduces daylighting intensity by 39% twelve feet behind the window (Figs. 10-11).

All aforementioned results are based on a 9-foot floor-to-ceiling height. If this height is increased to 11 feet, daylighting intensity increases by as much as 27%.

(d) Recommendations

The amount of available light is so abundant that the 9-foot floor-to-ceiling height will provide adequate daylighting. A higher floor-to-ceiling height would only result in further excess of light in the area immediately behind the windows.

The glazing above daylighting shelves (2) should be clear for all orientations. The glazing below daylighting shelves should have reduced daylighting transmittance. One-eighth inch grey or bronze glass having 61% transmittance should be adequate (Table 2).

All windows should have a daylighting shelf. The top surface of the daylighting shelf should be horizontal for windows facing southeast and southwest and should have a 5-degree tilt inward for windows facing notheast and northwest. This top surface should have 80% reflectivity. The bottom surface of the daylighting shelf should be nonreflective. Inside office space the floor reflectivity should be 40%. Full walls inside should have a reflectivity of more than 60%, while low partitions should have only 50% reflectivity. The reflectivity of ceilings should be at least 75%.

(e) General Conditions to the Analysis

This daylighting analysis is based on experimentation with 1/2-inch scale models of typical window modules. These scale models represent

areas of a typical floor with the appropriate orientations (Fig. 12). Models include no partitions nor furniture, and all surfaces are white with 80% reflectivity. It is assumed that no obstructions (e.g., from surrounding buildings or trees) exist on the outside.

Window design and details are based on the requirements for effective external shading. Windows facing generally south are 8 feet wide; those facing north are 10 feet wide (Figs. 13 and 14). Southeast and southwest window orientations are 10 degrees off true south, while northeast and northwest orientations are 10 degrees off true north.

The sunlight in Honolulu is extremely intense.⁽¹⁾ Sun intensities for the different months of the year are shown in Table 3.

The net usable floor area per typical floor, used in calculating the percentage of the daylit portion of a typical floor, is assumed at 33,500 square feet.

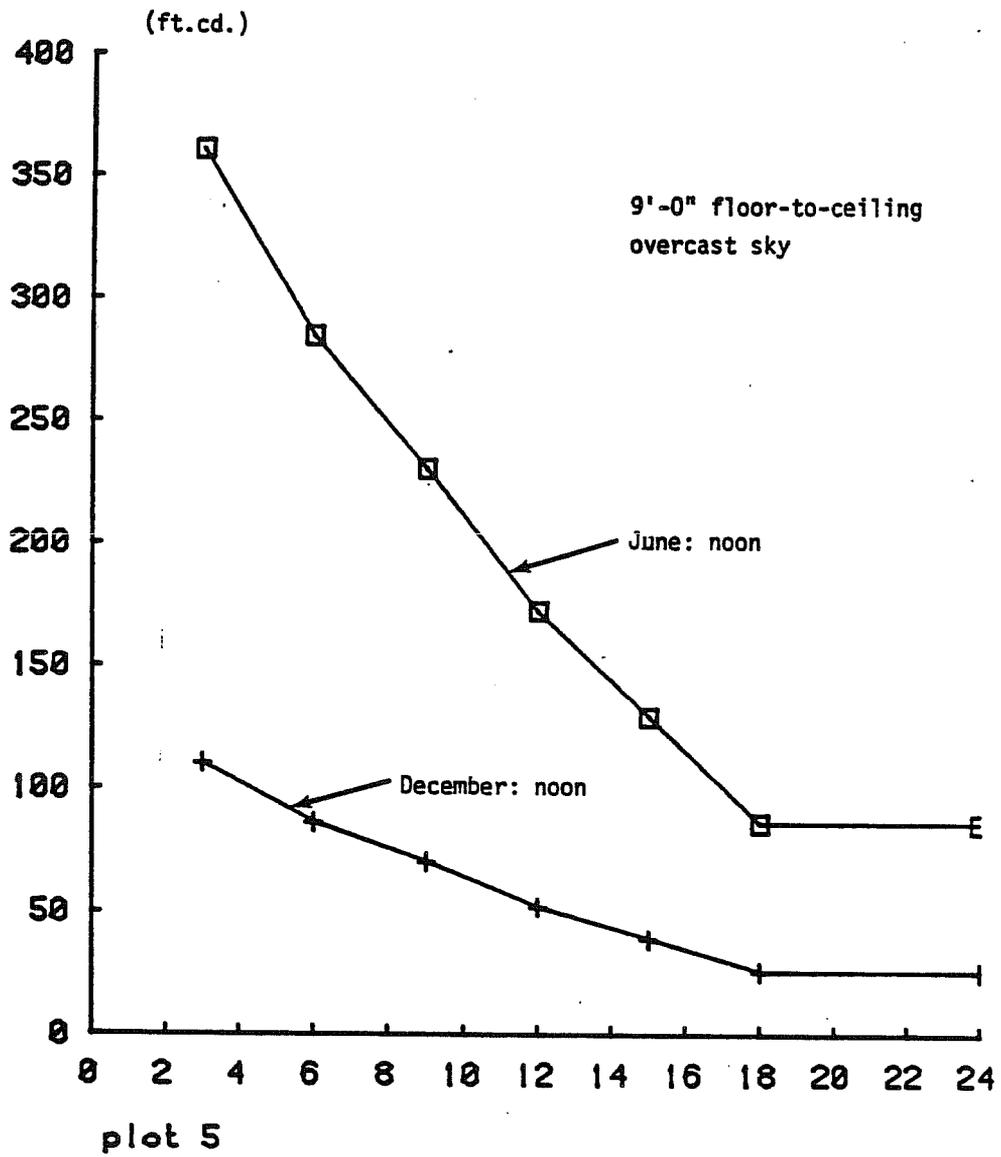


Figure 1 : Distribution of natural light - south-facing windows: worst conditions.

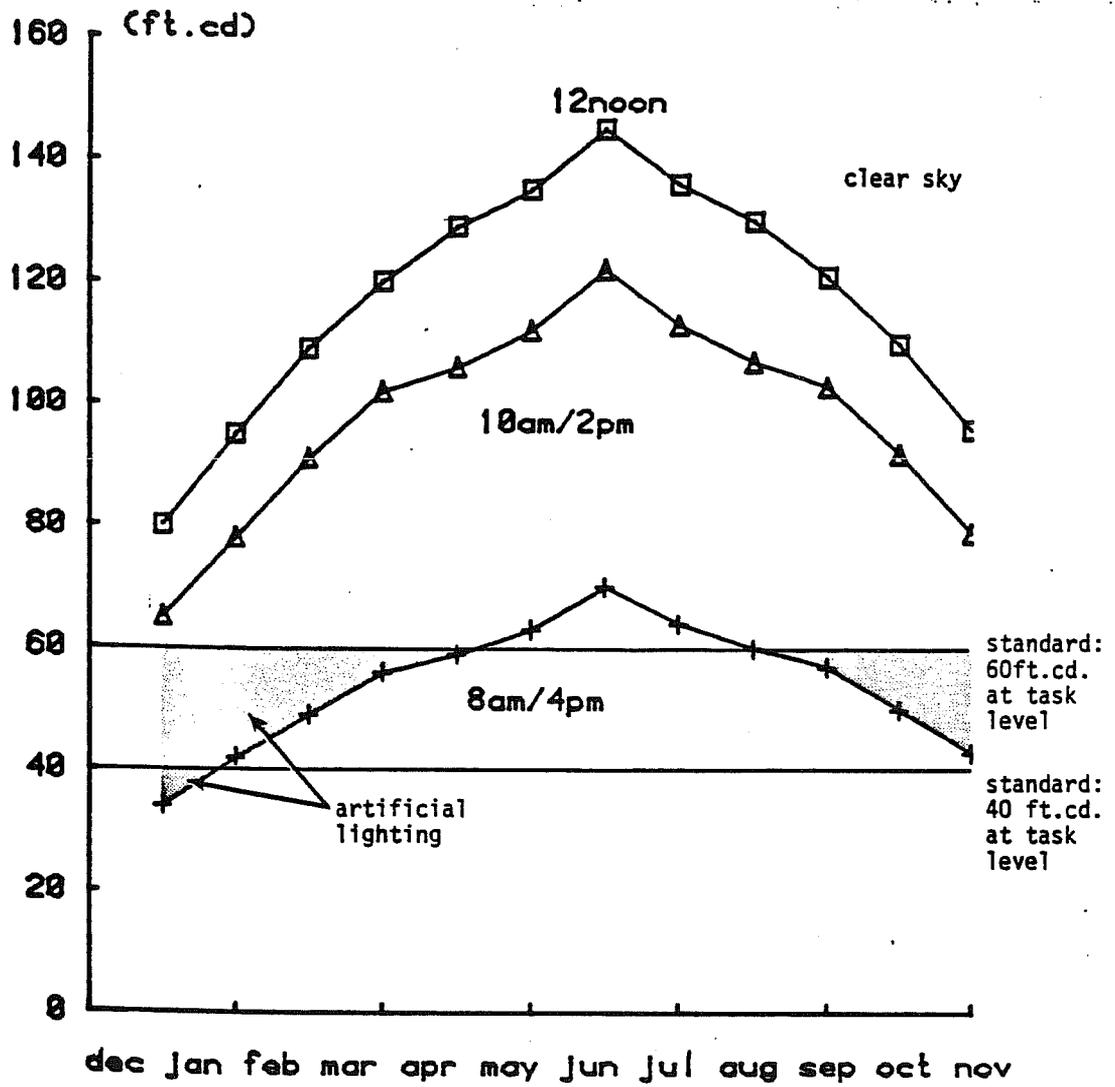


Figure 2 : Effectiveness of natural lighting - clear sky , minimal conditions.

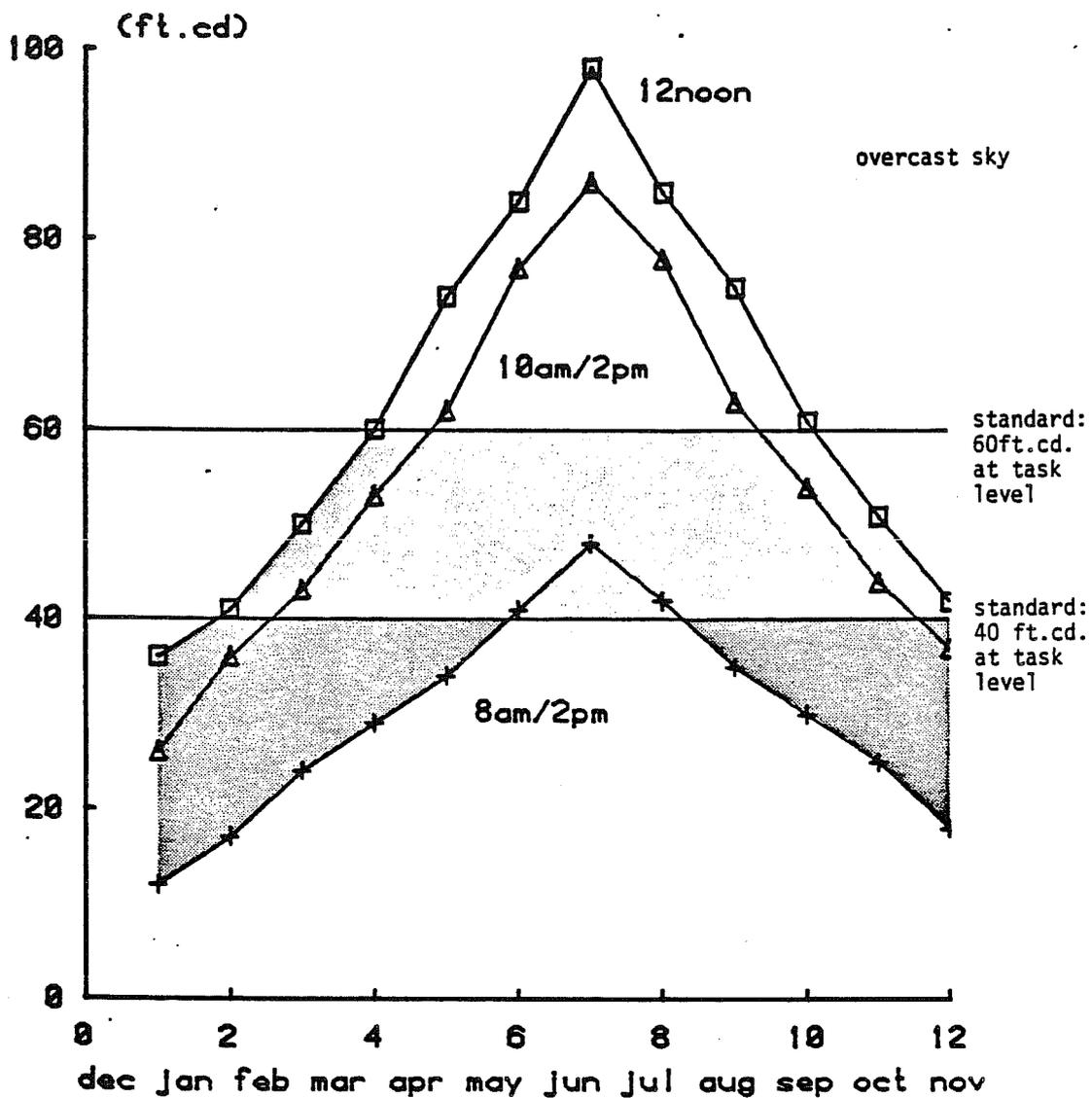


Figure 3 : Effectiveness of natural lighting - overcast sky, minimal conditions.

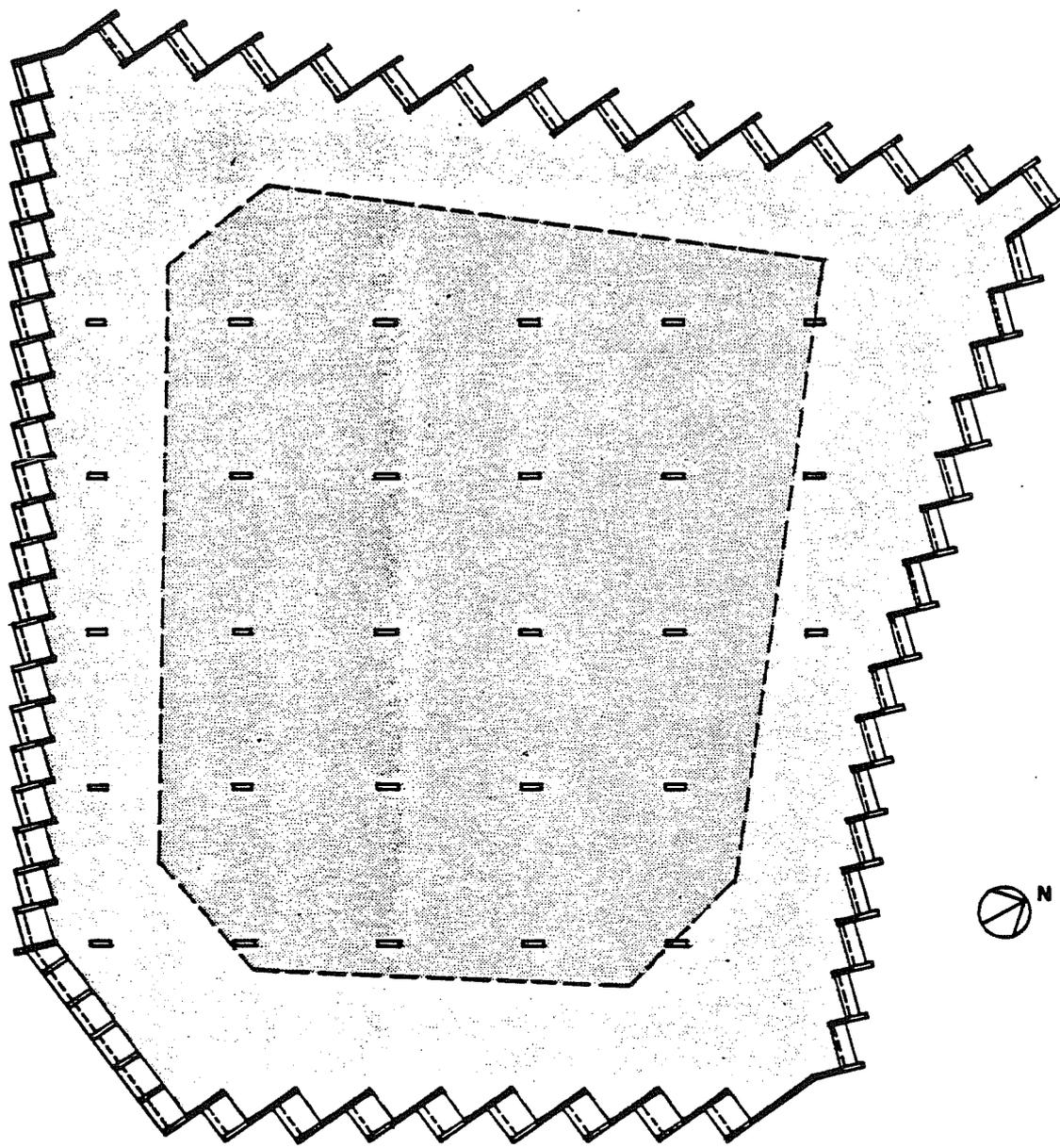


Figure 4 : Daylighting zone on a typical office floor .

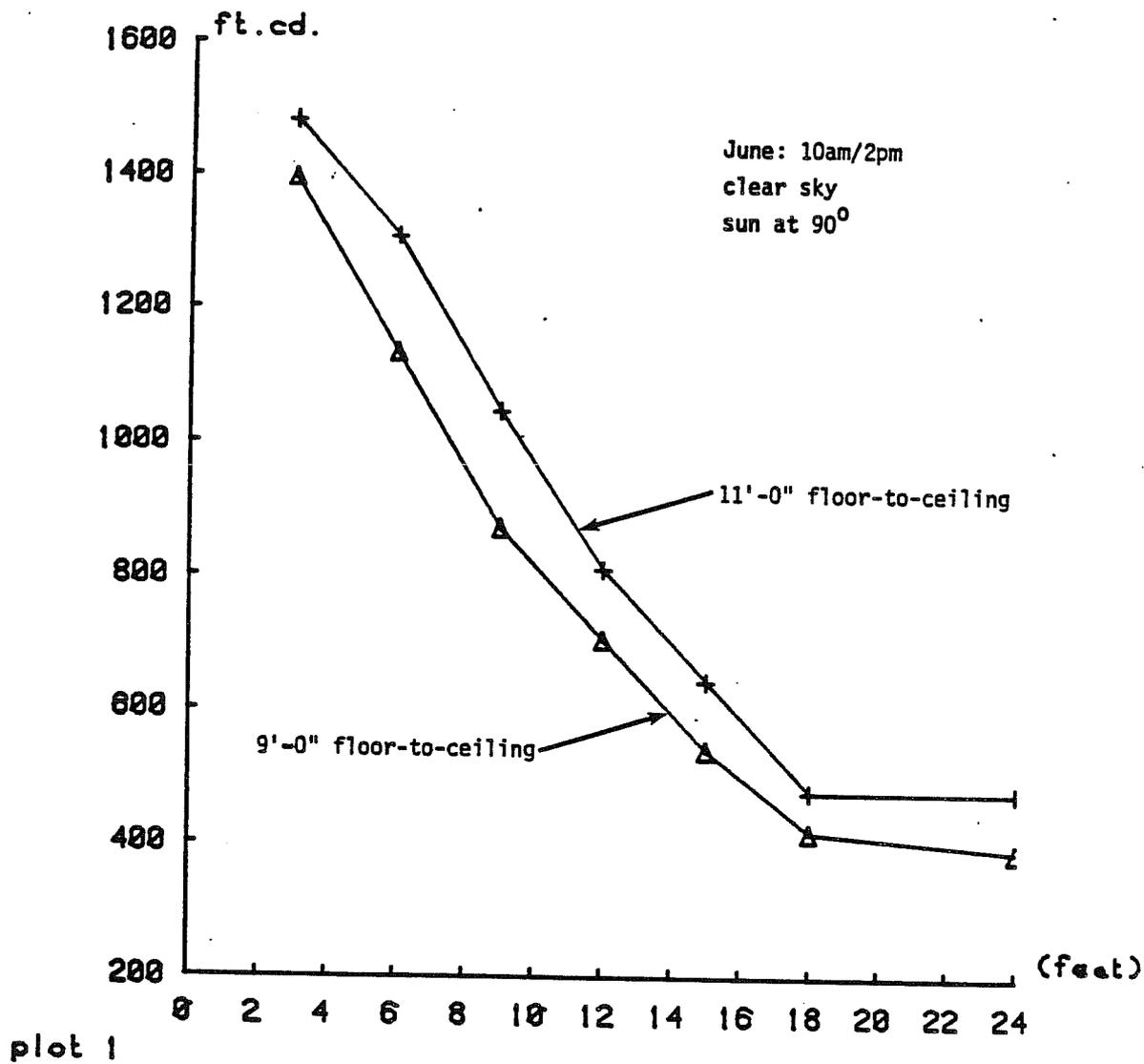


Figure 5 : Distribution of natural light - north-facing windows.

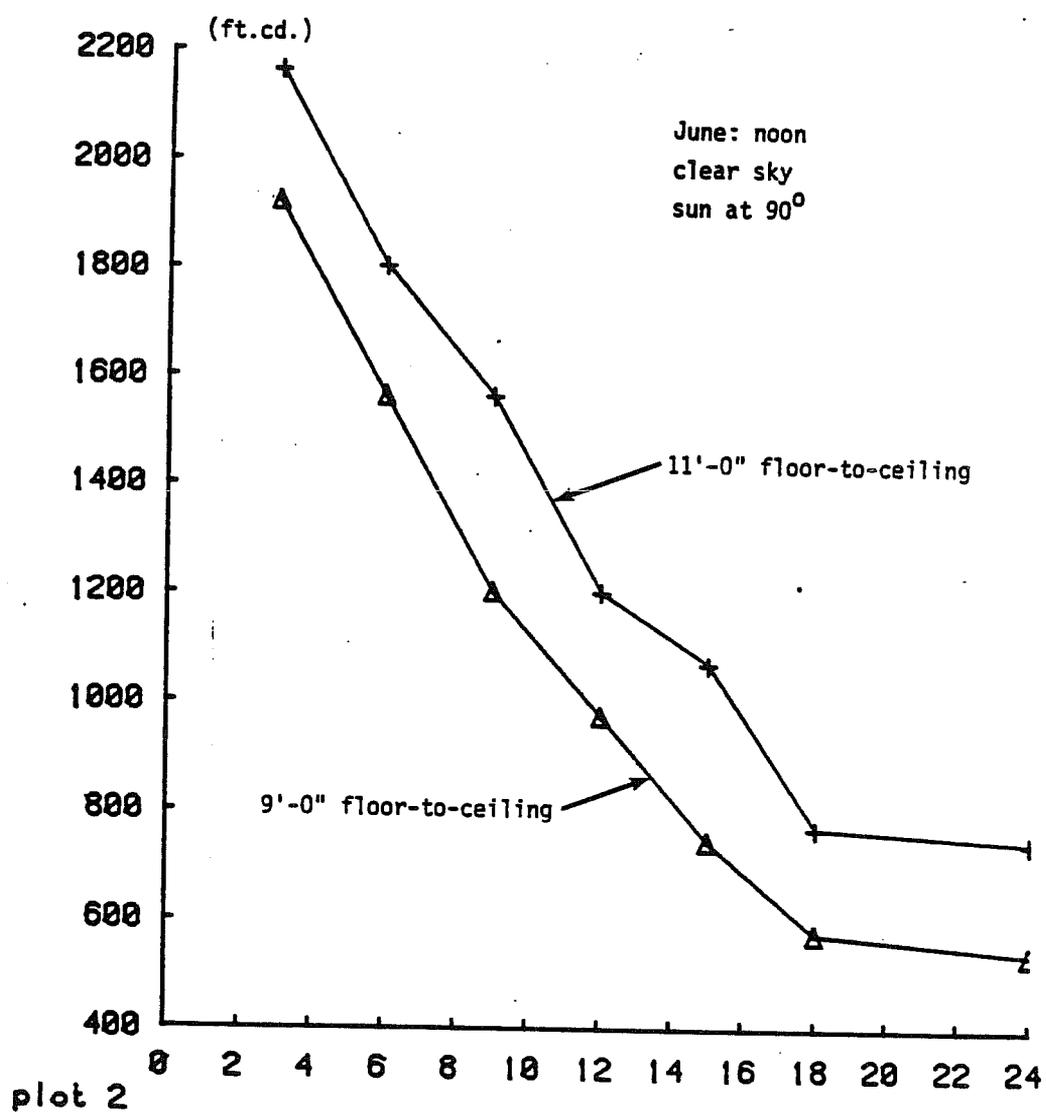


Figure 6 : Distribution of natural light - north-facing windows.

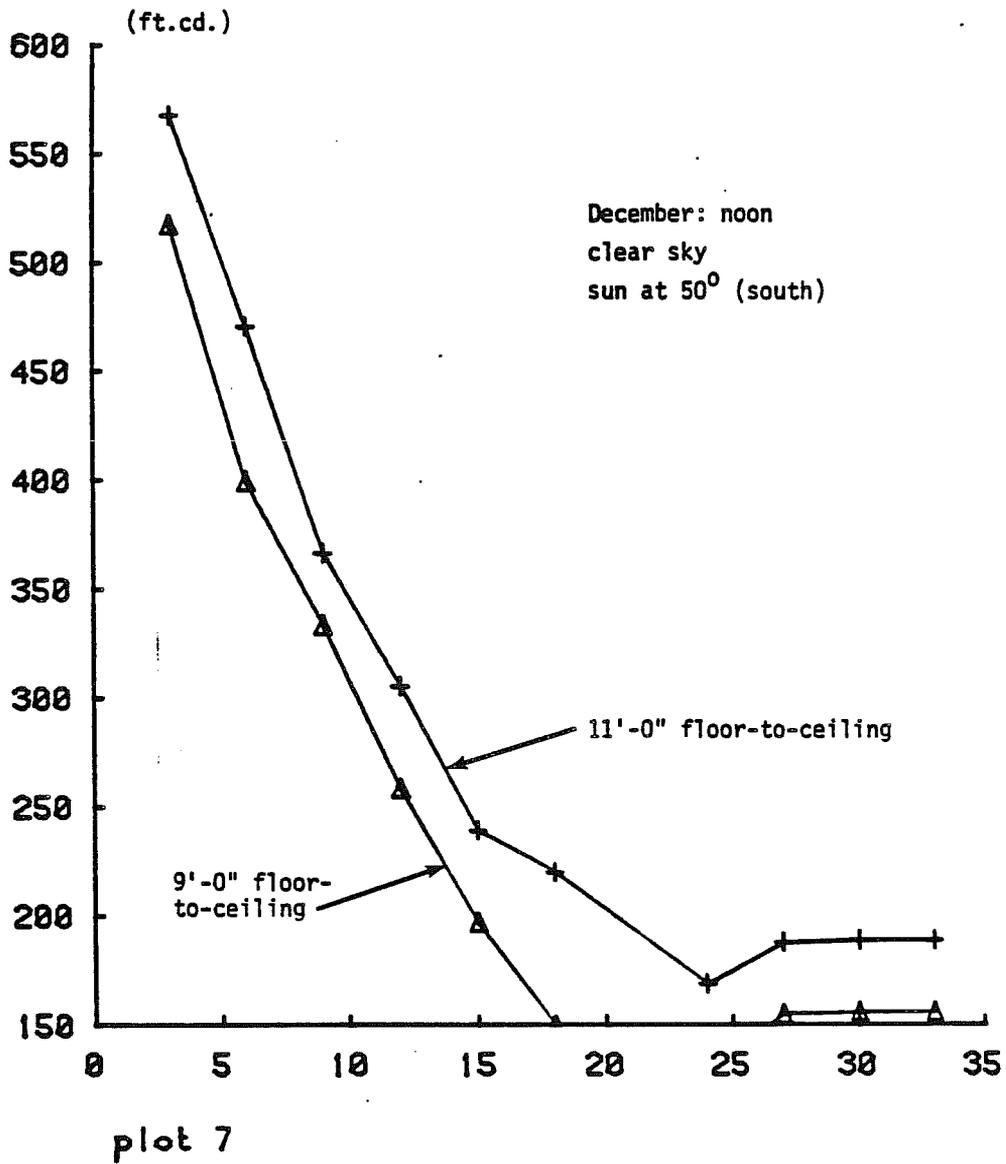
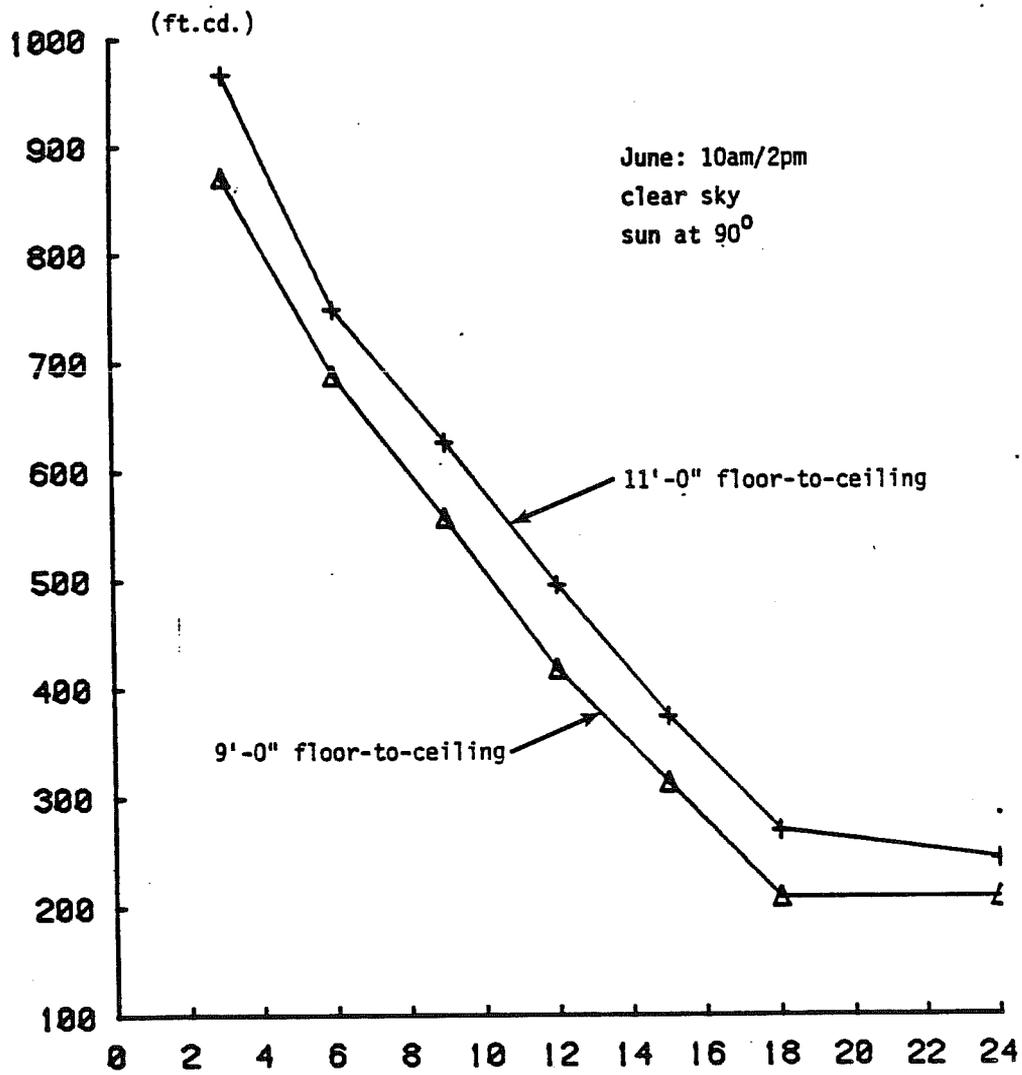


Figure 7 : Distribution of natural light - north-facing window.



plot 3

Figure 8: Distribution of natural light - south-facing windows.

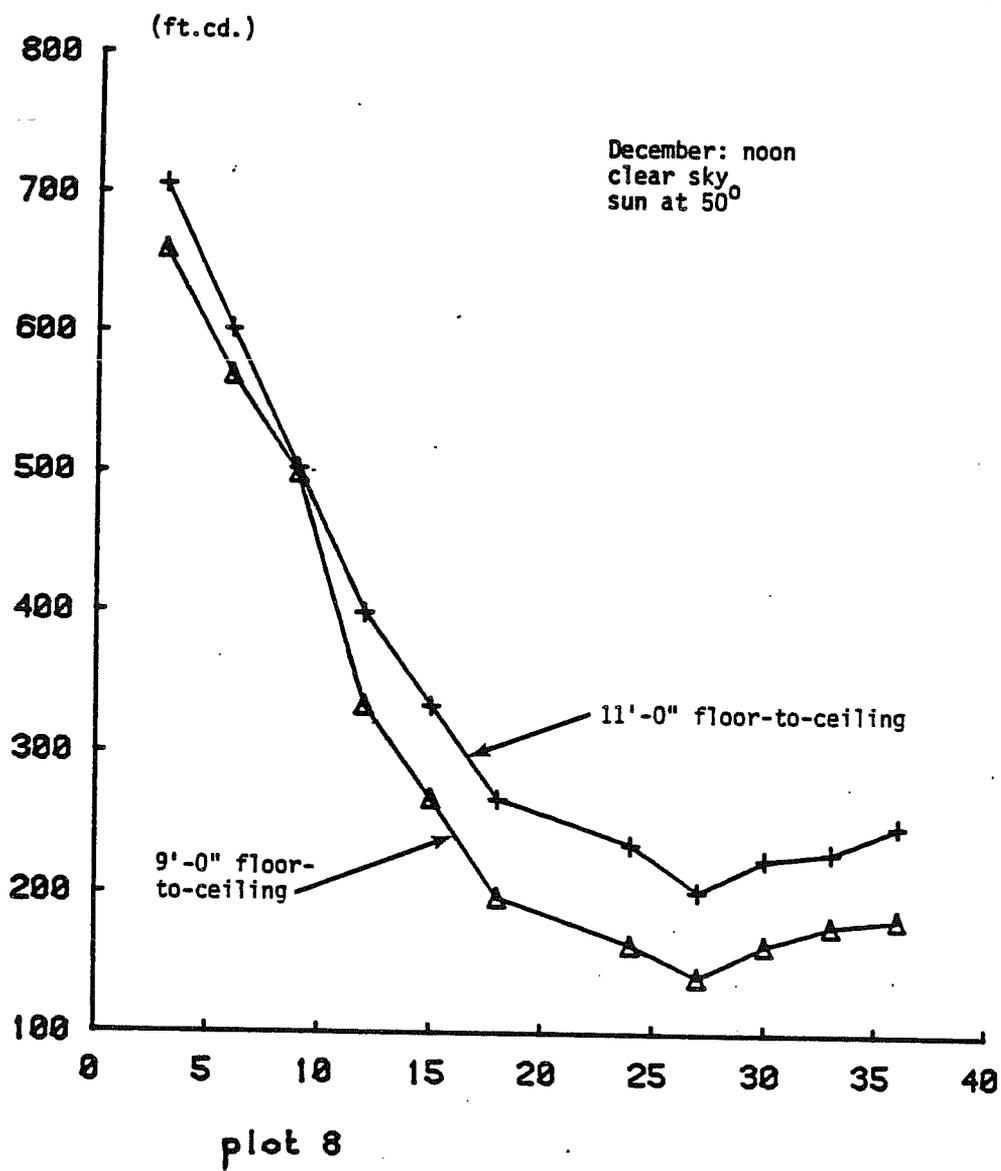


Figure 9 : Distribution of natural light.- south-facing window.

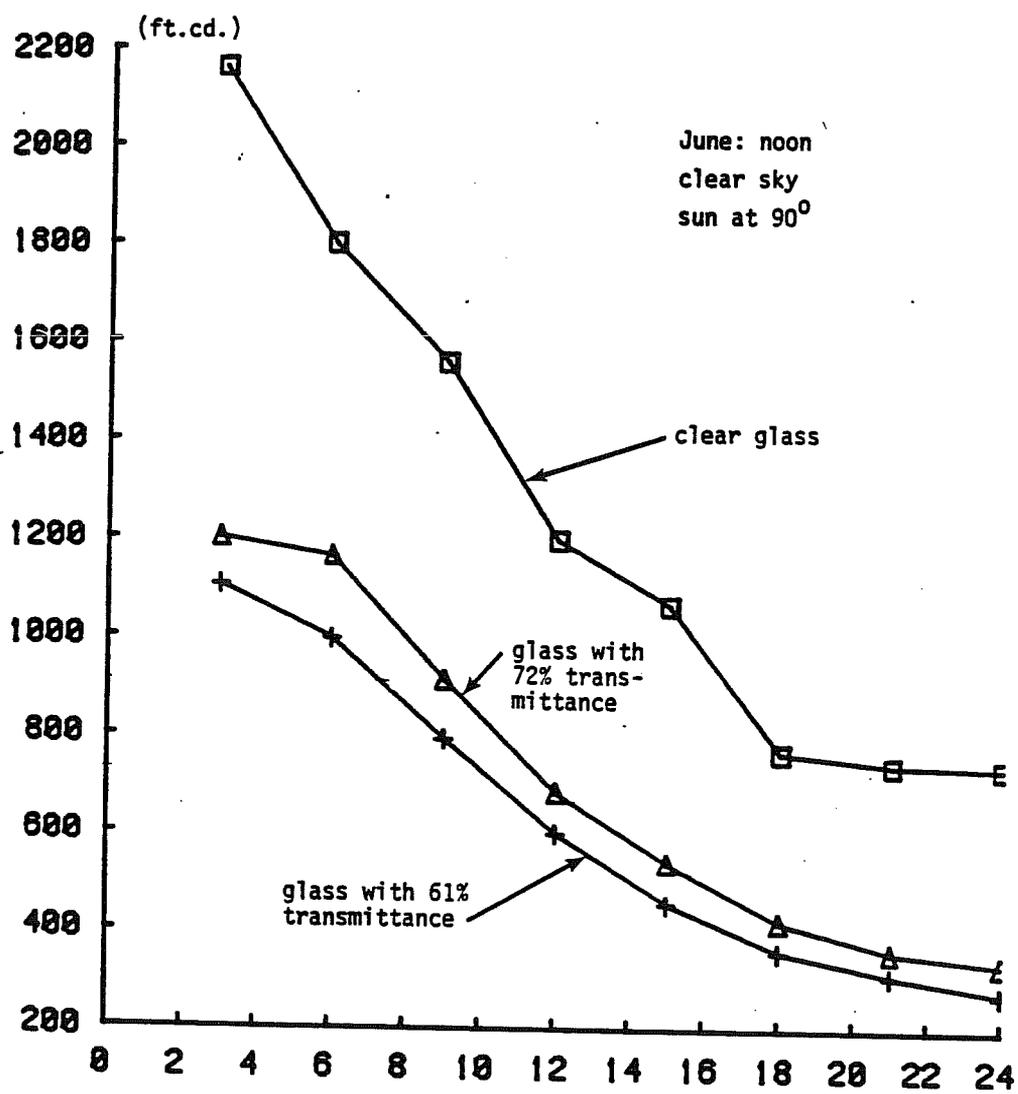


Figure 10: Daylight intensity with tinted glazing - north-facing windows.

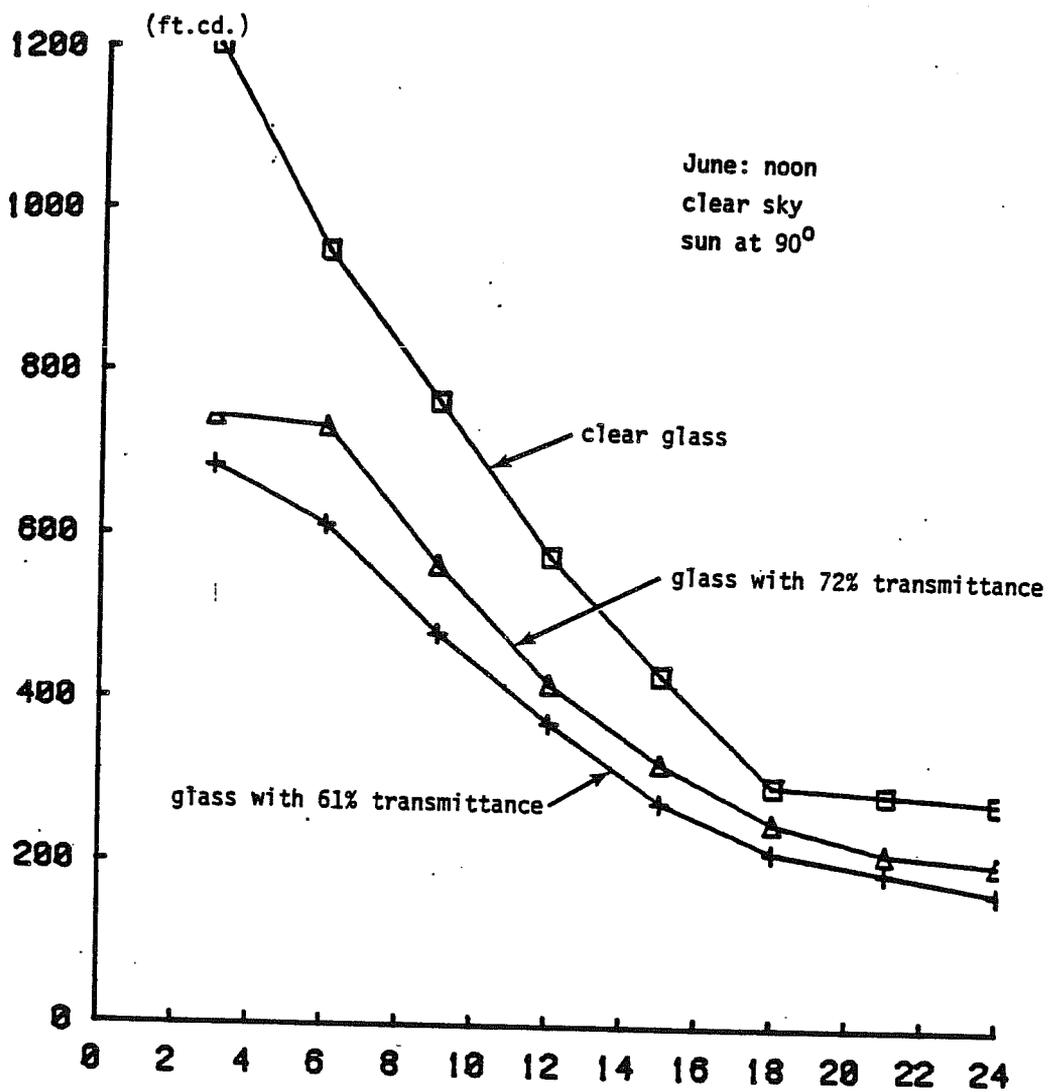


Figure 11: Daylight intensity with tinted glazing - south-facing windows.

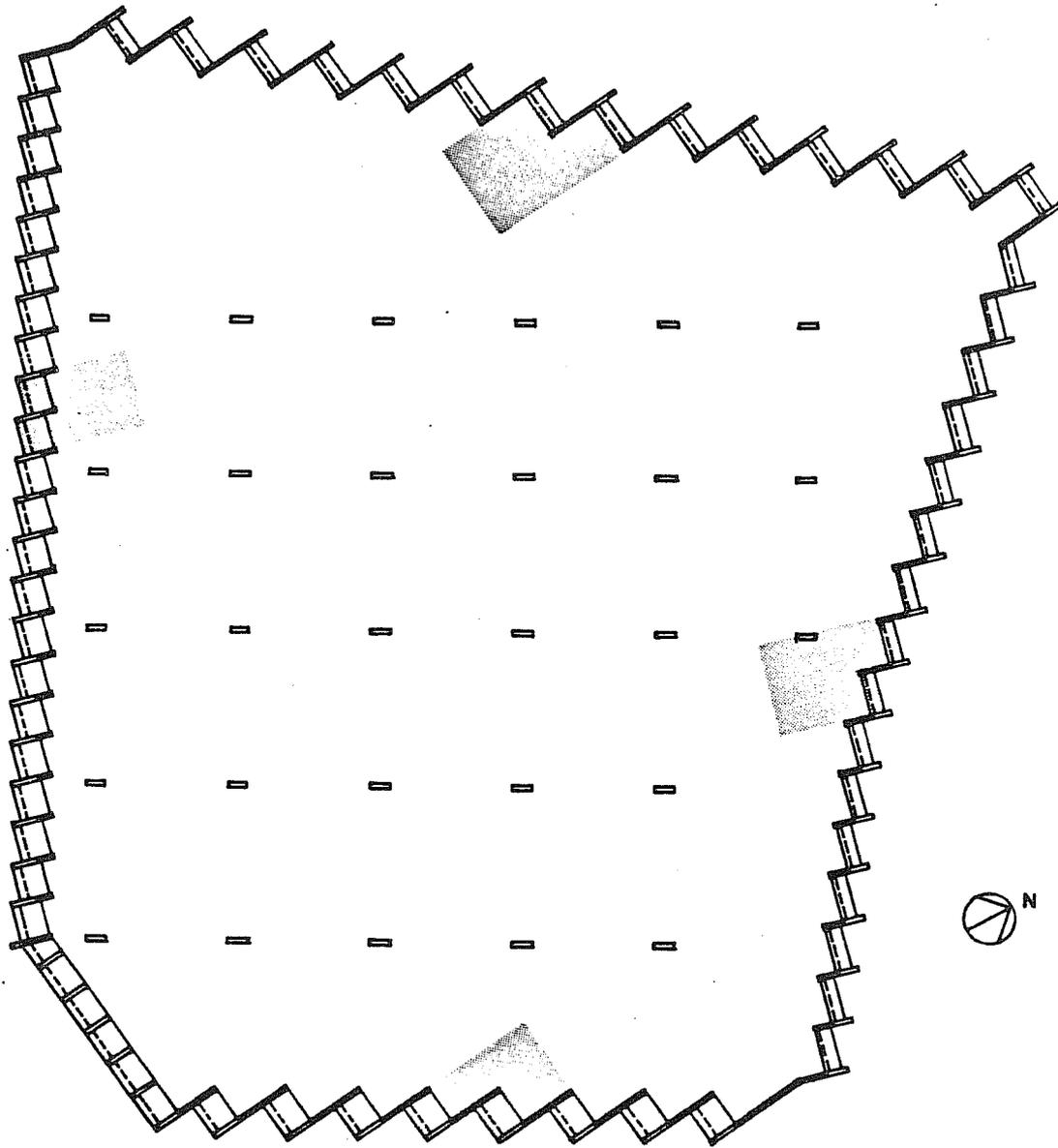
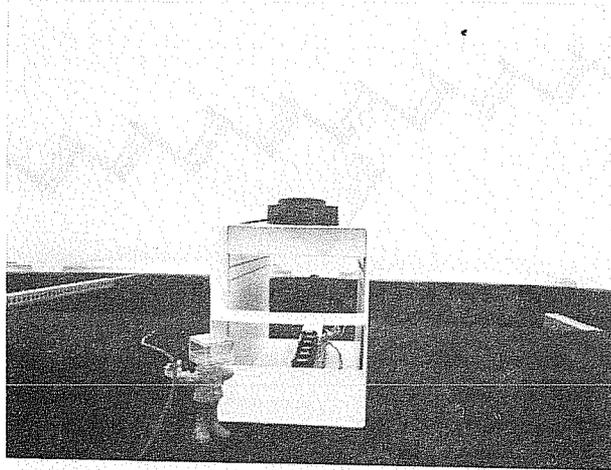
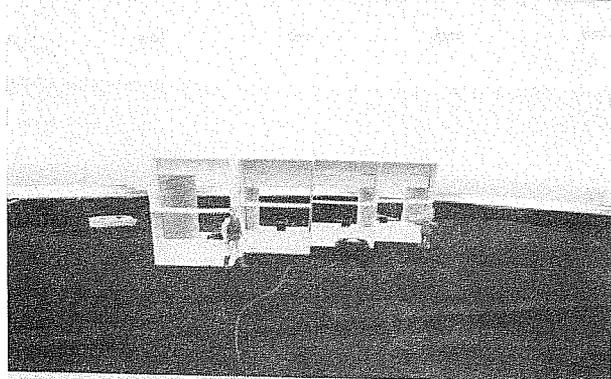


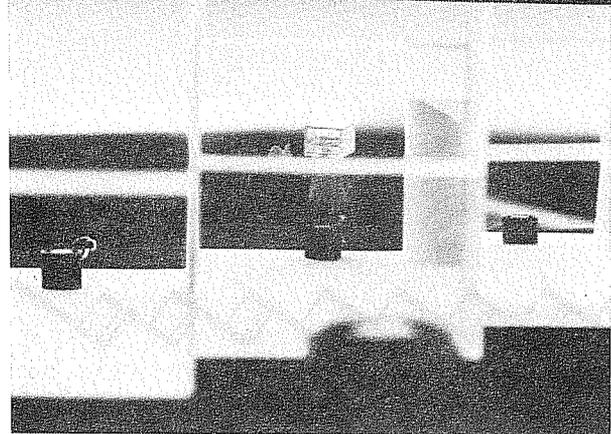
Figure 12 : The orientation of scale model units used in daylighting analysis in the Artificial Sky.



XBB 818-7752



XBB 818-7750



XBB 818-7749

	design standard: 40 ft.cd. hours*			design standard: 60 ft.cd. hours*		
	clear sky % of work hours*	overcast sky % of work hours*	total hours	clear sky % of work hours*	overcast sky % of work hours*	total hours
January	77	100	140	83	100	150
February		55	0	25	77	45
March		33	0	16	66	30
April		22	0	40	0	0
May			0	0	0	0
June			0	0	0	0
July			0	0	0	0
August		19	0	16	63	31
September		30	0	22	75	40
October		100	0	80	100	145
November		100	0	88	100	160
December	100	100	180	100	100	180
			total hours 320			781
			1,010			1,230

*expected demand 24 ft. from the window when sky conditions are as indicated

Table 1: Annual demand for artificial lighting in the daylight zone during work hours.

	8 AM & 4 PM		10 AM & 2 PM		noon	
	clear	overcast	clear	overcast	clear	overcast
June	5,000 ft.cd.	2,000	8,700	3,600	12,000	4,100
May & July	4,500	1,700	8,000	3,200	9,700	3,500
April & August	4,200	1,400	7,600	2,600	9,200	3,100
March & September	4,000	1,200	7,300	2,200	8,600	2,500
February & October	3,500	1,000	6,500	1,800	7,800	2,100
January & November	3,000	700	5,600	1,500	6,800	1,700
December	2,400	500	4,700	1,100	5,700	1,500 ft.cd.

Table 3: Sun Intensity Chart for Hawaii

transmittance	MONOLITHIC	THERMOPANE	triple THERMOPANE
97%	1/8" clear		
72%	1/4" blue green	3/16" blue green	3/16" clear
51%	1/16" grey	3/16" bronze	1/8" grey
61%	1/8" grey	1/8" bronze	3/16" blue green

Table 2: Daylight Transmittance of Glass

2. Case No. 2

The study and comparison of the daylighting in eight state office buildings was done to show that good lighting design is potentially an excellent energy saver. The model studies were made to compare available daylight that reaches into the various building sections.³

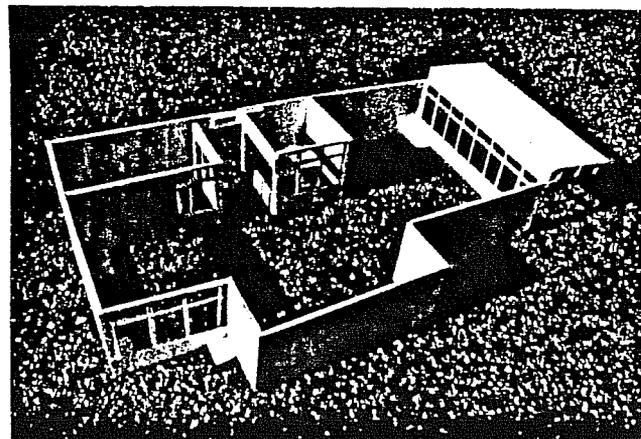
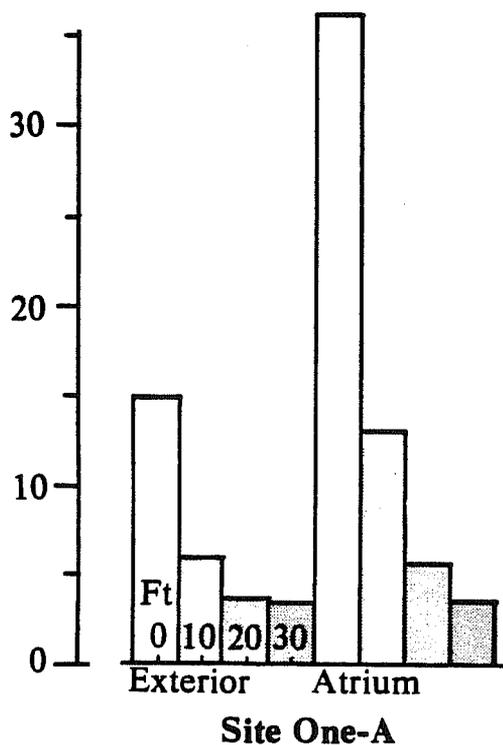
The models were 1/2 " scale models of office modules. They were tested under the sky simulator under C.I.E. overcast condition. The models were made of identical materials with identical reflectance and at the same scale. The measurements taken were of light quantity (footcandles) available from the sky through the facade, at horizontal level, to obtain the daylight factor. The same measurement was taken outside the model. The results are in footcandles.

These measurements were taken for a few sections, depending on the actual building design. Due to time and money constraints, only "typical" modules were built and tested. The actual office section, its depth, and the two exterior surfaces affected the daylighting measurements. These were chosen to be as "typical" as possible, given the variety of architectural treatments on any one building.

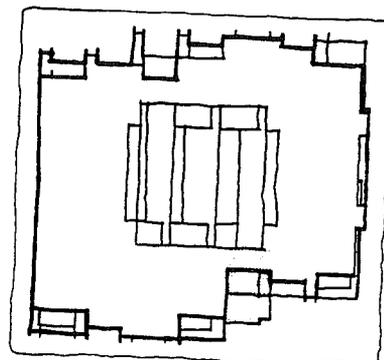
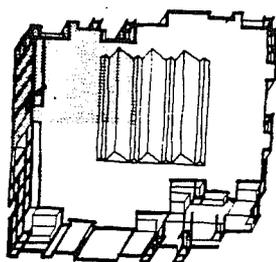
Each building and the results for that building will be described as follows:

(a) Site 1A

The percentage of possible sunshine at 15 feet within the building was low, due to the large overhangs on the south side. This value was greater for the atrium side's full glass section. This section is not typical. At the same time, the large shading device over the atrium will be closed almost all summer. As with all buildings, the winter daylight is better than summer due to the shading devices. The two sections in the graph are for the exterior and the atrium. Overall, the low perimeter-to-floor area ratio affects the lighting for the entire building.



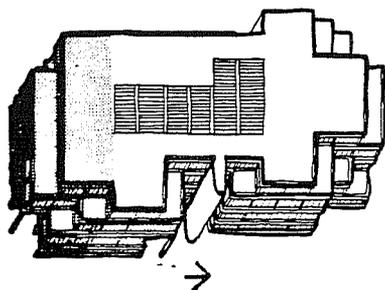
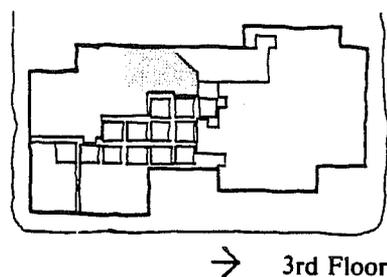
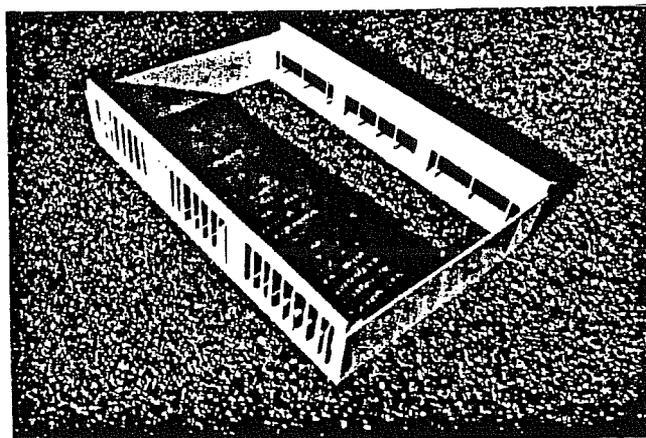
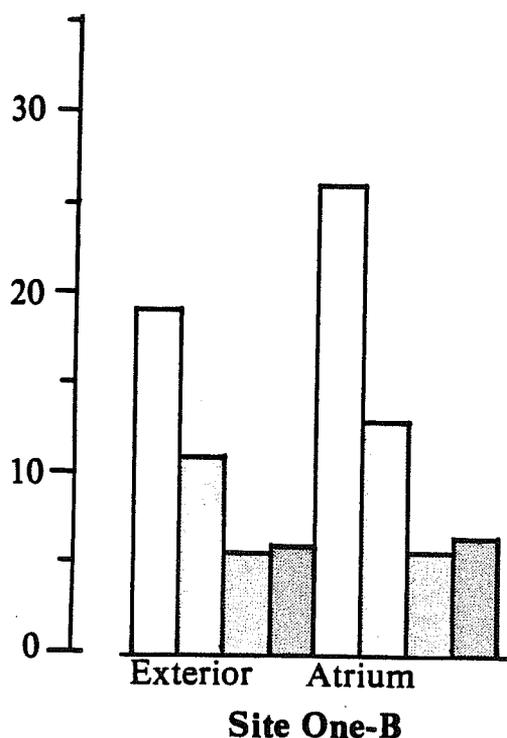
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→ 1st Floor

(b) Site 1B

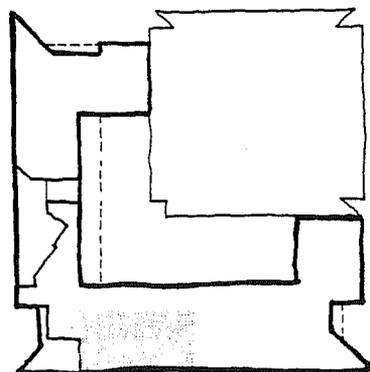
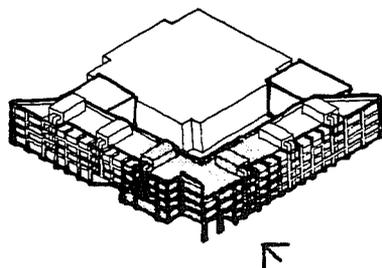
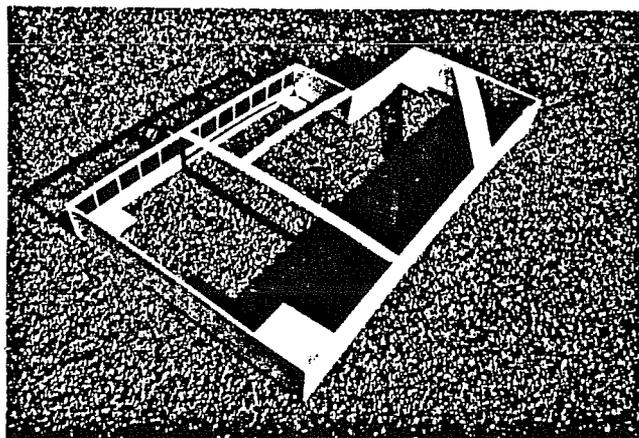
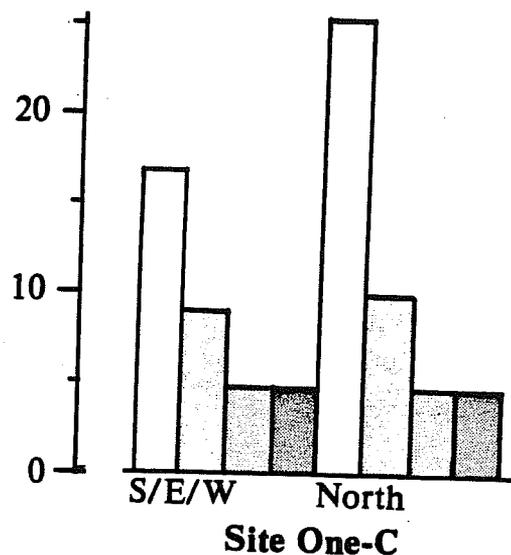
This building has a fairly thin section, typically. The atrium section is better because there are no vertical overhangs; just the one large shading device on top, which is open in winter. It was assumed that the vertical shading devices were open on a cloudy day, not blocking much of the window's view of the sky. The model tests show that the facade for 1B is favorable in daylighting aspects.



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(c) Site 1C

Site 1C has no atrium; it is a high-perimeter building. The horizontal overhangs on the south, east, and west affect the window's view of the sky. The north side has better daylighting because the window sees more than the sky. All windows were modelled as 7.5 feet tall, typically larger than most of the other buildings.

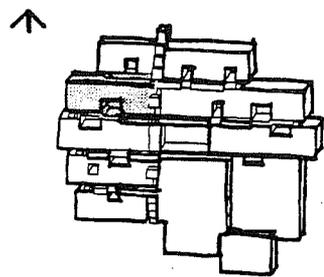
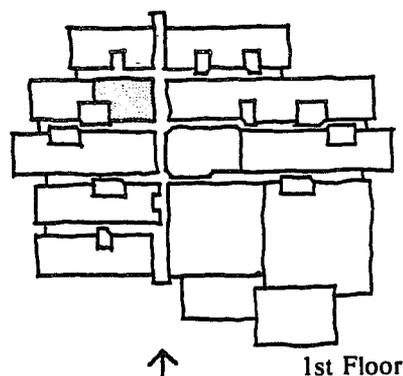
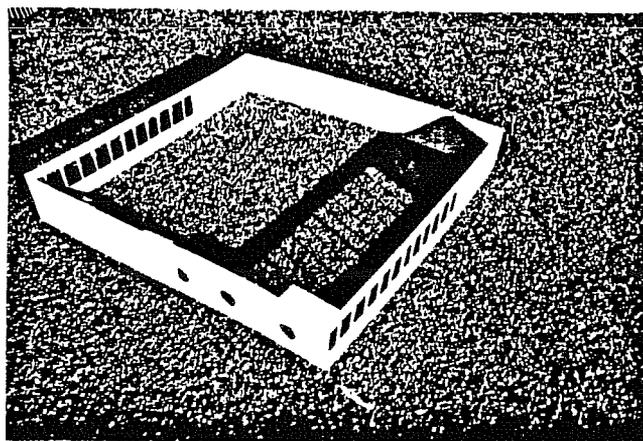
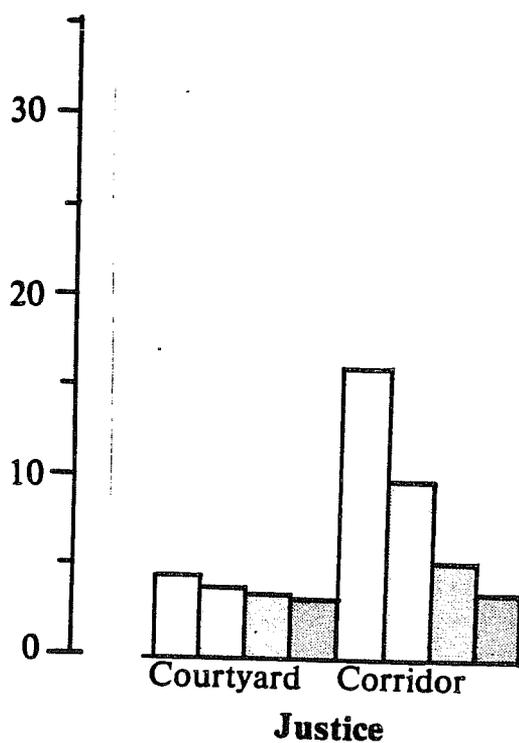


↑ 2nd Floor

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(d) Justice

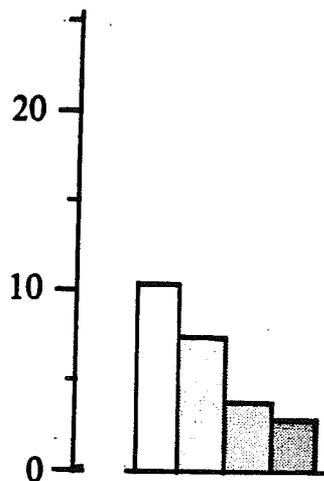
The corridor lighting appears better than the courtyard lighting. Most of the courtyard walls have comparatively small amounts of glazing. The corridor lighting may be somewhat overated because the amount of lighting reaching the interior is reduced due to the fact that it must pass through two sets of glazing and has more surfaces to reflect off of or be absorbed in.



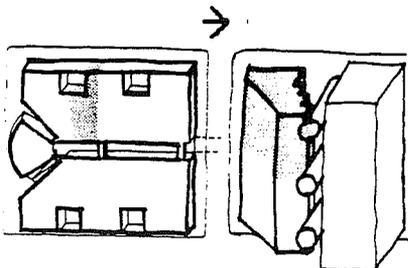
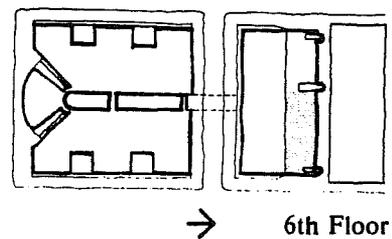
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(e) Site 3

The lighting in Site 3 drops to a low level very quickly, and the building section is wide. The north glazing is shaded by another building close by; it does not see much of the sky. The south glazing is shaded by the collectors. It too does not see much of the sky. The glazing sections are not large: 4.5 feet for the north side and 3.4 feet for the south side.



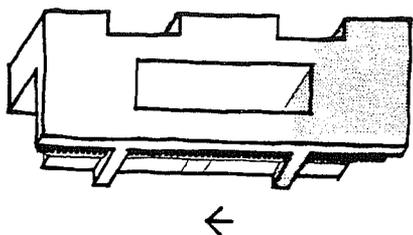
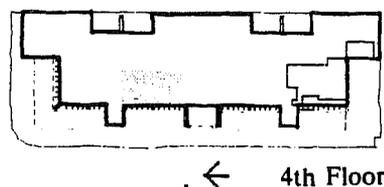
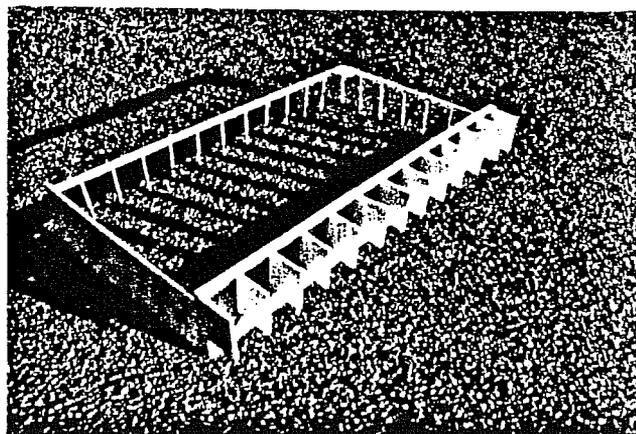
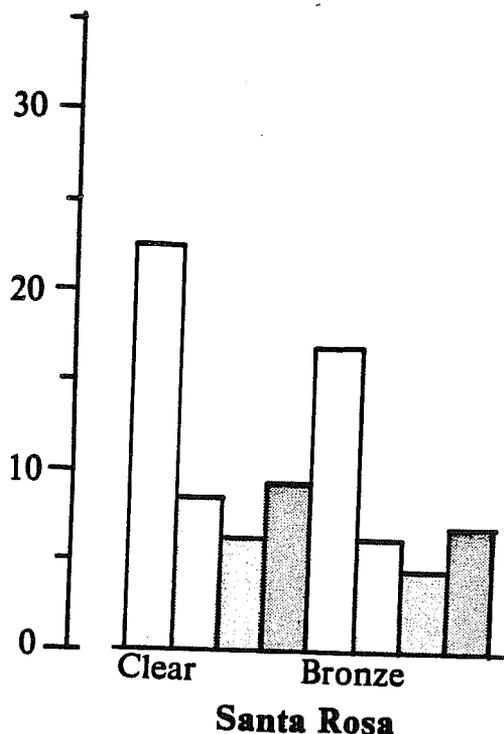
Site Three



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(f) Santa Rosa

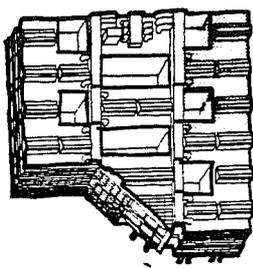
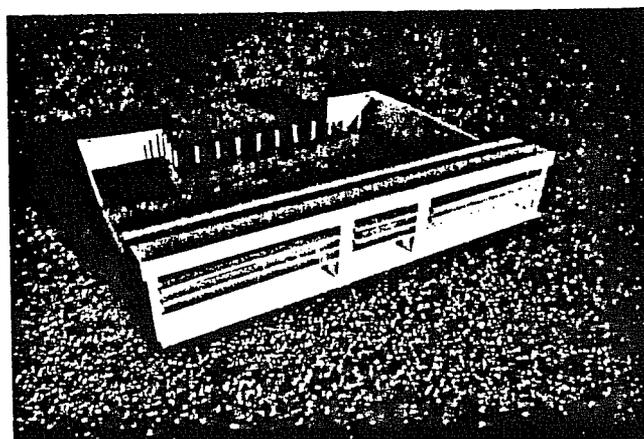
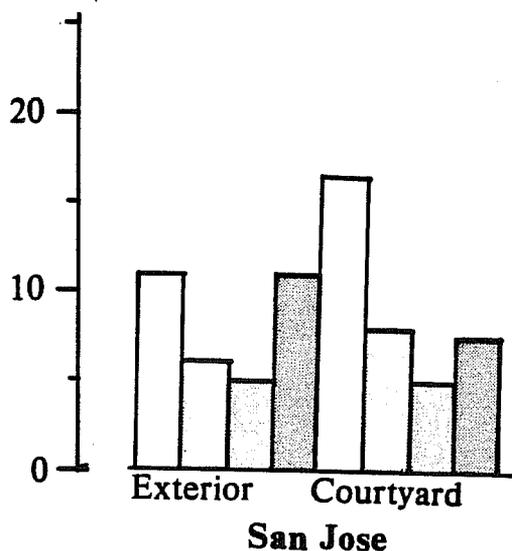
The Santa Rosa building had very good daylighting on the 4th floor. The other office floors (2 and 3) were not modeled as their conditions were more specific. The greatest amount of office floor space is on the fourth floor. The shading devices were fixed vertical panels having a slight horizontal overhang. Again, the windows could see much of the sky. Bronze glass is planned for those 4th floor windows, so the lighting levels were reduced 25% due to the reduced transmission, to make the lighting assumptions more accurate.



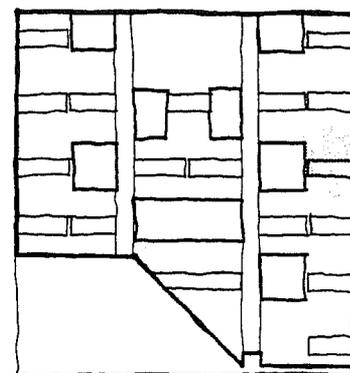
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(g) San Jose

The lighting in the San Jose building is good, mainly because the building section is so thin that the lighting levels begin to increase again beyond 20 feet within the building. The many courtyards make the building section thin. The San Jose lighting would be better if the glass were higher. The courtyard section appears better because no overhang was modeled. The overhangs are moveable; presumably they would be drawn back on a cloudy day. The south, east and west side overhangs are slightly horizontal ones, compared with the moveable canvas shades in the courtyards. The third floor, not modeled, would have increased lighting levels due to the skylight monitors.



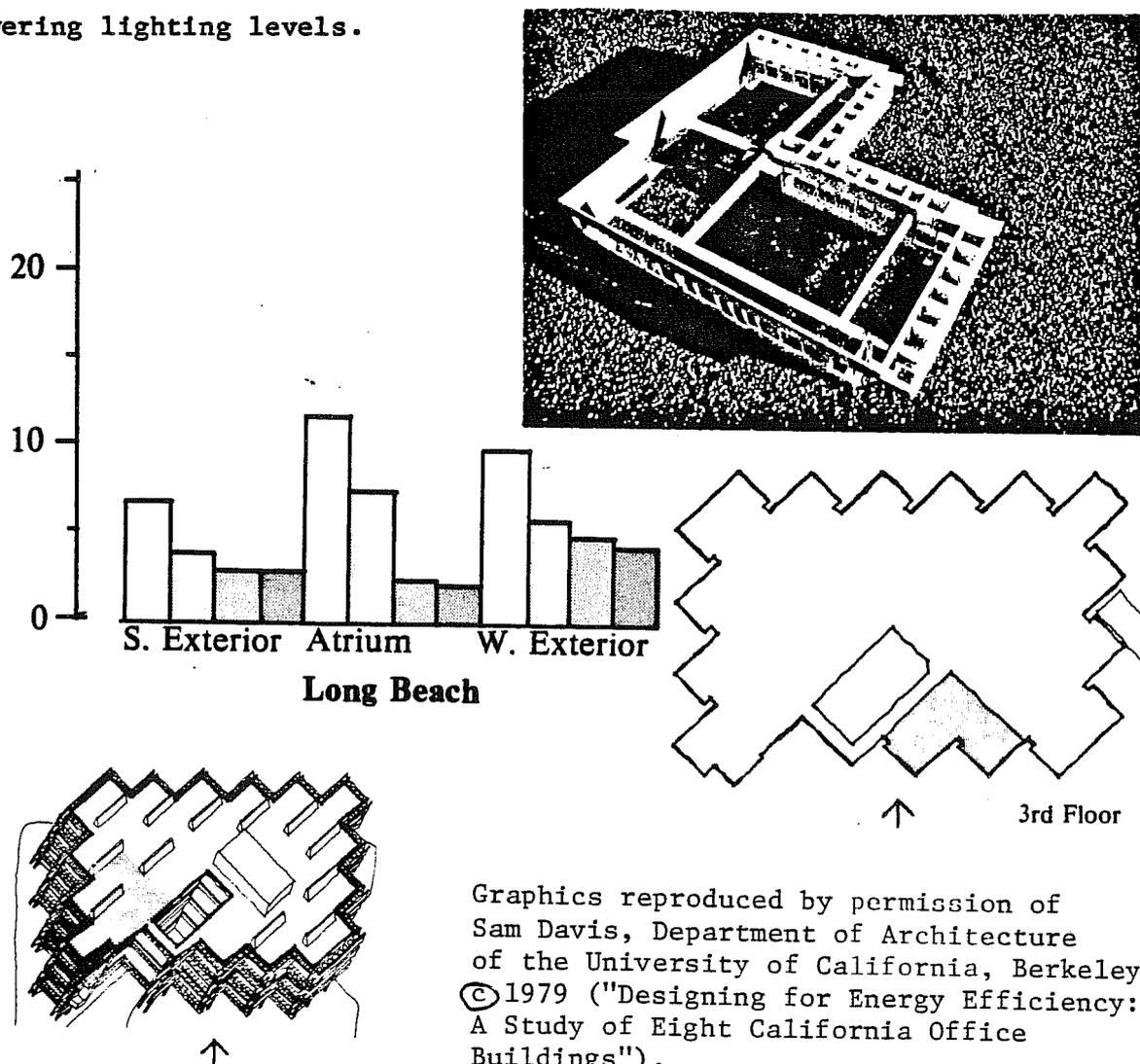
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2nd Floor

(h) Long Beach

The atrium section and the exterior section were similar in light levels. The exterior section is a much more "typical" building section. The lighting levels are not as high as in some of the other buildings due to the elaborate shading devices for all sides. The lighting levels do not decrease too rapidly due to the amount of glazing and the large perimeter areas as the building steps back. The atrium section was modeled, and the lighting levels decrease further into the interior. Some of the Long Beach building will have bronzed glass (parts of the western facade). Of course, this would reduce transmission thereby lowering lighting levels.



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Fig. 1

Light Levels in the daylit zones in footcandles.

Figures are for a cloudy sky on December 21 (worst condition) for most times of the day. The ratings high (H), medium (M), and low (L) are used to compare these buildings.

<u>Place</u>	<u>Measured Footcandles</u>			<u>Rating</u>	
	8am/4pm	Noon	10AM/2PM		
Site 1A		12	43	32	L
Site 1B		17	60	45	H
Justice		16	56	43	M
Long Beach		12	42	32	L
Santa Rosa		17	59	45	H
Site 3		15	52	39	L
San Jose		16	55	42	M
Site 1C		20	69	52	H

Daylighting characteristics	% Possible Daylight 15 Ft.	Perimeter Zone Ft.
Site One-A	4.0	12
Site One-B	5.6	15
Justice	5.3	15
Long Beach	4.0	14
Santa Rosa	5.6	15
Site Three	4.9	10
San Jose	5.2	13
Site One-C	6.5	15

Percentage of possible daylight 15 feet within the building: the lighting in the building as measured in the model under the dome.

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REFERENCES

1. Lord, D., Design for Daylighting, Hawaii Architect, pp. 30-34. Mar. 1981.
2. Libbey-Owens-Ford Company, Glass for Construction, Jan. 1980.
3. Davis, S., Designing for Energy Efficiency: A Study of Eight California State Office Buildings, University of California, Architecture Dept., June 1981.

APPENDIX D: Computer Program Listing and Outputs

Page

1. Program No. 1	216, 229
2. Program Nos. 2 and 3	230, 231
3. Program No. 4	234
4. Program No. 5, 8, and 9 -- See Bibliography, Nos. 34 & 35	
5. Program No. 6	230
6. Program No. 7	240
7. Program No. 10	252

```

100 PRINT "Artificial sky"
110 PRINT "This program calculates lighting system combinations"
120 INIT
130 DIM A(10,13)
140 DIM B(10,24)
150 DIM AS(72)
160 DIM BS(72)
170 PRINT "Enter calculation description"
180 INPUT BS
190 LET B=0
200 PRINT "Enter number of calculations to be performed"
210 INPUT N
220 DIM C(N)
230 DIM D(N)
240 DIM E(N)
250 FOR M=1 TO N
260 PRINT "Enter file number"
270 INPUT X
280 PRINT "Enter position number"
290 INPUT P
300 PRINT "Enter scaling factor"
310 INPUT S
320 FIND X
330 READ #33:AS,A
340 LET C(M)=X
350 LET D(M)=P
360 LET E(M)=S
370 LET A=A*S
380 FOR J=1 TO 10
390 FOR I=P TO P+12
400 LET K=I-P+1
410 IF I>24 THEN 440
420 LET B(J,I)=B(J,I)+A(J,K)
430 GO TO 460
440 LET L=I-24
450 LET B(J,L)=B(J,L)+A(J,K)
460 NEXT I
470 NEXT J
480 FOR J=1 TO 10
490 FOR I=P+13 TO P+23
500 LET K=P+25-I
510 IF I>24 THEN 540
520 LET B(J,I)=B(J,I)+A(J,K)
530 GO TO 560
540 LET L=I-24
550 LET B(J,L)=B(J,L)+A(J,K)
560 NEXT I
570 NEXT J
580 NEXT M
590 PRINT "Connect line printer"
600 PRINT "DO YOU WANT TO USE PRINTER (40)OR SCREEN(32)";
610 INPUT Q
620 IMAGE 9A,2D,4X,10A,2D,S
630 IMAGE 4X,16A,4D
640 PRINT @Q:"ARTIFICIAL SKY LIGHTING CALCULATION"
650 PRINT @Q:BS
660 PRINT @Q:
670 FOR M=1 TO N
680 PRINT @Q: USING 620:"Pos.no.: ",D(M),"File no.: ",C(M)
690 PRINT @Q: USING 630:"Scaling factor: ",E(M)
700 NEXT M
710 PRINT @Q:
720 PRINT @Q:
730 LET Z=0
740 FOR I=1 TO 24
750 LET Z=Z+B(10,I)
760 NEXT I
770 LET Z=Z/24
780 LET B=B/Z
790 IMAGE 12A,5(6A),S
810 IMAGE 5(6A)
820 IMAGE 12A,5(6A),S
830 IMAGE 5(6A)
840 IMAGE 4D,5X,5(3D.2D),S
850 IMAGE 5(3D.2D)
860 PRINT @Q: USING 790:"ALTITUDE" "0" "10" "20" "30" "40"
870 PRINT @Q: USING 810:"50" "60" "70" "80" "90"
880 PRINT @Q:"AZIMUTH"
890 PRINT @Q:
900 PRINT @Q:
910 PRINT @Q: USING 820:"C.I.E.SKY" "0.33" "0.44" "0.56" "0.66" "0.76"
920 PRINT @Q: USING 830:"0.84" "0.90" "0.95" "0.98" "1.00"
921 PRINT @Q:
922 PRINT @Q:
923 END

```

ARTIFICIAL SKY LIGHTING CALCULATION
CLOUDY SKY STUDIES:WATT MISER II (FILE 36,37,38,39,40)

Pos.no.:	2	File no.:	36	Scaling factor:	1
Pos.no.:	2	File no.:	37	Scaling factor:	1
Pos.no.:	2	File no.:	38	Scaling factor:	1
Pos.no.:	2	File no.:	40	Scaling factor:	1
Pos.no.:	4	File no.:	36	Scaling factor:	1
Pos.no.:	4	File no.:	37	Scaling factor:	1
Pos.no.:	4	File no.:	38	Scaling factor:	1
Pos.no.:	4	File no.:	40	Scaling factor:	1
Pos.no.:	6	File no.:	36	Scaling factor:	1
Pos.no.:	6	File no.:	37	Scaling factor:	1
Pos.no.:	6	File no.:	38	Scaling factor:	1
Pos.no.:	6	File no.:	40	Scaling factor:	1
Pos.no.:	8	File no.:	36	Scaling factor:	1
Pos.no.:	8	File no.:	37	Scaling factor:	1
Pos.no.:	8	File no.:	38	Scaling factor:	1
Pos.no.:	8	File no.:	40	Scaling factor:	1
Pos.no.:	10	File no.:	36	Scaling factor:	1
Pos.no.:	10	File no.:	37	Scaling factor:	1
Pos.no.:	10	File no.:	38	Scaling factor:	1
Pos.no.:	10	File no.:	40	Scaling factor:	1
Pos.no.:	12	File no.:	36	Scaling factor:	1
Pos.no.:	12	File no.:	37	Scaling factor:	1
Pos.no.:	12	File no.:	38	Scaling factor:	1
Pos.no.:	12	File no.:	40	Scaling factor:	1
Pos.no.:	14	File no.:	36	Scaling factor:	1
Pos.no.:	14	File no.:	37	Scaling factor:	1
Pos.no.:	14	File no.:	38	Scaling factor:	1
Pos.no.:	14	File no.:	40	Scaling factor:	1
Pos.no.:	16	File no.:	36	Scaling factor:	1
Pos.no.:	16	File no.:	37	Scaling factor:	1
Pos.no.:	16	File no.:	38	Scaling factor:	1
Pos.no.:	16	File no.:	40	Scaling factor:	1
Pos.no.:	18	File no.:	36	Scaling factor:	1
Pos.no.:	18	File no.:	37	Scaling factor:	1
Pos.no.:	18	File no.:	38	Scaling factor:	1
Pos.no.:	18	File no.:	40	Scaling factor:	1
Pos.no.:	20	File no.:	36	Scaling factor:	1
Pos.no.:	20	File no.:	37	Scaling factor:	1
Pos.no.:	20	File no.:	38	Scaling factor:	1
Pos.no.:	20	File no.:	40	Scaling factor:	1
Pos.no.:	24	File no.:	36	Scaling factor:	1
Pos.no.:	24	File no.:	37	Scaling factor:	1
Pos.no.:	24	File no.:	38	Scaling factor:	1
Pos.no.:	24	File no.:	40	Scaling factor:	1

ALTITUDE	0	10	20	30	40	50	60	70	80	90
AZIMUTH	1	1	1	1	1	1	1	1	1	1
ZENITH SCALING FACTOR:	0.41	0.69	0.85	0.95	1.00	1.00	1.00	1.00	1.00	1.00


```

950 PRINT @0: USING 850:B(6,I),B(7,I),B(8,I),B(9,I),B(10,I),B(11,I),B(12,I),B(13,I),B(14,I),B(15,I)
960 NEXT I
970 PRINT @0:"ZENITH SCALING FACTOR: ";Z
980 PRINT "Calculations completed, results printed out"
990 GO TO 600
1000 END

100 PRINT "Artificial sky"
110 PRINT "This program loads lighting data on magnetic tape files"
120 DIM AS(72)
130 PRINT "Enter lighting system description, max. 72 characters"
140 INPUT AS
150 DIM A(10,13)
160 PRINT "Enter lighting data, line by line, starting with 0 altitude"
165 PRINT "All data should be absolute measurement values"
170 FOR I=1 TO 10
180 PRINT "Altitude ";(I-1)*10;" degrees"
190 FOR J=1 TO 13
200 INPUT A(I,J)
210 NEXT J
220 FOR J=1 TO 13
230 PRINT J;" : ";A(I,J)
240 NEXT J
250 PRINT "Enter number of wrong data"
260 INPUT K
270 IF K=0 THEN 315
280 FOR I=1 TO K
290 PRINT "Enter data (line) number that is incorrect"
300 INPUT M
310 PRINT "Enter correct data"
320 INPUT A(I,M)
330 NEXT I
340 GO TO 220
350 NEXT I
360 PRINT "Enter file number for storing data"
370 INPUT X
380 FIND X
390 WRITE @33:AS,A
400 PRINT @40:"FILE NUMBER: ";X
410 PRINT @40:AS
420 PRINT @40:
430 IMAGE 1A,5(6A),S
440 IMAGE 5(6A)
450 IMAGE 2D,5X,5(5D),S
460 IMAGE 5(5D)
470 PRINT @40: USING 400:"ALTITUDE" "0" "10" "20" "30" "40"
480 PRINT @40: USING 410:"50", "60", "70", "80", "90"
490 PRINT @40:"AZIMUTH"
500 FOR J=1 TO 13
510 PRINT @40: USING 420:(J-1)*15,A(1,J),A(2,J),A(3,J),A(4,J),A(5,J)
520 PRINT @40: USING 425:A(6,J),A(7,J),A(8,J),A(9,J),A(10,J)
530 NEXT J
540 PRINT "Data stored and printed out"
550 END

100 PRINT "Artificial sky"
110 PRINT "This program prints data files"
120 DIM AS(72)
130 DIM A(10,13)
140 PRINT "Enter data file number"
150 INPUT X
160 PRINT "ENTER DATA FILE SCALING FACTOR"
170 INPUT B
180 FIND X
190 READ @33:AS,A
200 LET A=A*B
210 FIND X
220 WRITE @33:AS,A
230 PRINT "DO YOU WANT TO USE PRINTER (40)OR SCREEN(32)"
240 INPUT M
250 PRINT @M:"FILE NUMBER: ";X
260 PRINT @M:AS
270 PRINT @M:"SCALING FACTOR: ";B
280 PRINT @M:"ALTITUDE"
290 IMAGE 5X,5(7A),S
300 IMAGE 5(7A)
310 IMAGE 2D,5(1X,3D,2D),S
320 IMAGE 5(1X,3D,2D)
330 PRINT @M: USING 220:"0" "10" "20" "30" "40"
340 PRINT @M: USING 230:"50", "60", "70", "80", "90"
350 PRINT @M:"POS.:"
360 FOR J=1 TO 13
370 PRINT @M: USING 240:J,A(1,J),A(2,J),A(3,J),A(4,J),A(5,J)
380 PRINT @M: USING 250:A(6,J),A(7,J),A(8,J),A(9,J),A(10,J)
390 NEXT J
400 END

```

-FILE NUMBER: 19
CLEAR SKY STUDIES (45).

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	177.0	642.0	402.0	254.0	184.0	140.0	105.0	85.0	58.0	62.0
15	1159.0	1064.0	539.0	311.0	206.0	145.0	105.0	85.0	56.0	62.0
30	266.0	536.0	360.0	249.0	177.0	134.0	106.0	80.0	54.0	62.0
45	68.0	151.0	170.0	158.0	135.0	107.0	97.0	77.0	53.0	62.0
60	48.0	62.0	85.0	93.0	96.0	89.0	93.0	76.0	53.0	62.0
75	44.0	46.0	53.0	61.0	68.0	65.0	75.0	71.0	55.0	62.0
90	44.0	45.0	46.0	50.0	54.0	59.0	60.0	63.0	58.0	62.0
105	43.0	43.0	44.0	45.0	47.0	50.0	53.0	55.0	62.0	62.0
120	41.0	43.0	45.0	45.0	45.0	46.0	50.0	46.0	63.0	62.0
135	42.0	42.0	42.0	45.0	45.0	44.0	45.0	36.0	64.0	62.0
150	41.0	41.0	42.0	45.0	45.0	45.0	45.0	35.0	63.0	62.0
165	45.0	42.0	42.0	43.0	44.0	46.0	45.0	41.0	63.0	62.0
180	42.0	42.0	42.0	43.0	43.0	44.0	45.0	42.0	61.0	62.0

ARTIFICIAL SKY LIGHTING CALCULATION
CLEAR SKY STUDIES.

Pos.no.:	2	File no.:	19	Scaling factor:	1
Pos.no.:	4	File no.:	19	Scaling factor:	1
Pos.no.:	6	File no.:	19	Scaling factor:	1
Pos.no.:	8	File no.:	19	Scaling factor:	1
Pos.no.:	10	File no.:	19	Scaling factor:	1
Pos.no.:	12	File no.:	19	Scaling factor:	1
Pos.no.:	14	File no.:	19	Scaling factor:	1
Pos.no.:	16	File no.:	19	Scaling factor:	1
Pos.no.:	18	File no.:	19	Scaling factor:	1
Pos.no.:	20	File no.:	19	Scaling factor:	1
Pos.no.:	22	File no.:	19	Scaling factor:	1
Pos.no.:	24	File no.:	19	Scaling factor:	1

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
15	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
30	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
45	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
60	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
75	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
90	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
105	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
120	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
135	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
150	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
165	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
180	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
195	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
210	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
225	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
240	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
255	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
270	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
285	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
300	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
315	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00
330	3.77	3.73	2.39	1.78	1.47	1.23	1.13	0.98	0.95	1.00
345	1.48	2.87	2.15	1.69	1.43	1.25	1.15	0.97	0.94	1.00

ZENITH SCALING FACTOR: 744

FILE NUMBER: 28
 CLOUDY SKY STUDIES :NO. 5 OFF 1,4 DIMMED

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	28.0	57.0	75.0	87.0	83.0	86.0	82.0	79.0	65.0	70.0
15	37.0	69.0	72.0	88.0	83.0	85.0	84.0	80.0	69.0	70.0
30	26.0	45.0	65.0	82.0	83.0	86.0	80.0	76.0	62.0	63.0
45	25.0	27.0	51.0	74.0	90.0	85.0	80.0	75.0	65.0	69.0
60	18.0	25.0	47.0	63.0	72.0	78.0	82.0	76.0	64.0	68.0
75	18.0	23.0	39.0	52.0	60.0	65.0	66.0	70.0	66.0	68.0
90	18.0	22.0	33.0	44.0	55.0	61.0	65.0	64.0	67.0	63.0
105	18.0	20.0	28.0	39.0	49.0	55.0	63.0	68.0	69.0	63.0
120	17.0	18.0	23.0	30.0	39.0	48.0	54.0	60.0	69.0	62.0
135	18.0	19.0	22.0	29.0	36.0	43.0	49.0	54.0	70.0	68.0
150	18.0	19.0	22.0	28.0	34.0	41.0	43.0	54.0	70.0	67.0
165	19.0	19.0	22.0	27.0	35.0	40.0	47.0	51.0	70.0	67.0
180	18.0	19.0	22.0	28.0	32.0	38.0	45.0	50.0	70.0	67.0

ARTIFICIAL SKY LIGHTING CALCULATION
 CLOUDY SKY STUDIES:NO. 5 OFF,&NO.1,4 DIMMED.

Pos.no.: 2	File no.: 28	Scaling factor:	1
Pos.no.: 4	File no.: 28	Scaling factor:	1
Pos.no.: 6	File no.: 28	Scaling factor:	1
Pos.no.: 8	File no.: 28	Scaling factor:	1
Pos.no.: 10	File no.: 28	Scaling factor:	1
Pos.no.: 12	File no.: 28	Scaling factor:	1
Pos.no.: 14	File no.: 23	Scaling factor:	1
Pos.no.: 16	File no.: 28	Scaling factor:	1
Pos.no.: 18	File no.: 28	Scaling factor:	1
Pos.no.: 20	File no.: 28	Scaling factor:	1
Pos.no.: 22	File no.: 28	Scaling factor:	1
Pos.no.: 24	File no.: 28	Scaling factor:	1

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	0.33	0.45	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
15	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
30	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
45	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
60	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
75	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.98	1.00
90	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
105	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
120	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
135	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.98	1.00
150	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
165	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
180	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
195	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
210	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
225	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
240	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
255	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
270	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
285	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.98	1.00
300	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
315	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00
330	0.33	0.43	0.57	0.76	0.86	0.91	0.95	0.97	0.98	1.00
345	0.29	0.41	0.58	0.74	0.83	0.92	0.96	0.97	0.97	1.00

ZENITH SCALING FACTOR: 817.5

-FILE NUMBER: 29
 CLEAR SKY STUDIES :NO.1 OFF NO. 2 THRU 5 ON (NO DIMMING)

ALTITUDE	0	10	20	30	40	50	60	70	80	90
0	292.0	345.0	215.0	128.0	100.0	93.0	85.0	71.0	48.0	47.0
15	555.0	508.0	266.0	145.0	103.0	91.0	81.0	72.0	47.0	47.0
30	164.0	255.0	198.0	129.0	106.0	95.0	85.0	72.0	47.0	47.0
45	41.0	58.0	77.0	86.0	88.0	84.0	75.0	69.0	47.0	47.0
60	29.0	35.0	53.0	66.0	70.0	70.0	66.0	65.0	47.0	47.0
75	26.0	28.0	34.0	44.0	52.0	56.0	55.0	55.0	49.0	47.0
90	26.0	28.0	31.0	36.0	43.0	47.0	55.0	55.0	49.0	47.0
105	26.0	28.0	31.0	34.0	40.0	43.0	39.0	51.0	51.0	47.0
120	25.0	28.0	28.0	30.0	33.0	35.0	38.0	41.0	51.0	47.0
135	25.0	25.0	28.0	29.0	31.0	33.0	38.0	40.0	52.0	47.0
150	25.0	25.0	28.0	29.0	31.0	33.0	36.0	37.0	53.0	47.0
165	25.0	26.0	28.0	29.0	31.0	33.0	37.0	37.0	55.0	47.0
180	25.0	26.0	28.0	29.0	31.0	33.0	37.0	39.0	55.0	47.0

ARTIFICIAL SKY LIGHTING CALCULATION
 CLEAR SKY STUDIES: NO.1 OFF, NO.2 THRU 5 ON. (NO DIMMING)

Pos.no.:	2	File no.:	29	Scaling factor:	1
Pos.no.:	4	File no.:	29	Scaling factor:	1
Pos.no.:	6	File no.:	29	Scaling factor:	1
Pos.no.:	8	File no.:	29	Scaling factor:	1
Pos.no.:	10	File no.:	29	Scaling factor:	1
Pos.no.:	12	File no.:	29	Scaling factor:	1
Pos.no.:	14	File no.:	29	Scaling factor:	1
Pos.no.:	16	File no.:	29	Scaling factor:	1
Pos.no.:	18	File no.:	29	Scaling factor:	1
Pos.no.:	20	File no.:	29	Scaling factor:	1
Pos.no.:	22	File no.:	29	Scaling factor:	1
Pos.no.:	24	File no.:	29	Scaling factor:	1

ALTITUDE	0	10	20	30	40	50	60	70	80	90
0	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
15	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
30	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
45	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
60	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
75	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
90	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
105	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
120	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
135	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
150	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
165	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
180	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
195	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
210	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
225	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
240	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
255	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
270	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
285	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
300	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
315	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00
330	2.40	2.39	1.65	1.30	1.22	1.21	1.15	1.15	1.06	1.00
345	1.52	1.97	1.63	1.31	1.24	1.20	1.21	1.15	1.05	1.00

ZENITH SCALING FACTOR: 564

FILE NUMBER: 08
 PEGU.2*10W 4FIXTURE (4,3,2,1)POS. ALU/CARDBOARD REF.ON ONE SECTOR.

ALTITUDE		0	10	20	30	40	50	60	70	80	90
POS.:											
1	38.00	38.00	42.00	54.00	61.00	75.00	80.00	81.00	66.00	78.00	
2	27.00	36.00	38.00	51.00	55.00	71.00	78.00	81.00	66.00	77.00	
3	31.00	33.00	35.00	52.00	59.00	73.00	77.00	79.00	67.00	78.00	
4	30.00	38.00	46.00	51.00	63.00	79.00	84.00	80.00	69.00	78.00	
5	26.00	45.00	56.00	68.00	73.00	76.00	78.00	84.00	72.00	77.00	
6	32.00	44.00	54.00	67.00	72.00	74.00	73.00	72.00	76.00	77.00	
7	26.00	33.00	44.00	54.00	66.00	76.00	80.00	76.00	77.00	77.00	
8	24.00	27.00	39.00	45.00	53.00	60.00	65.00	67.00	74.00	77.00	
9	23.00	26.00	30.00	38.00	47.00	56.00	62.00	68.00	75.00	77.00	
10	22.00	24.00	28.00	35.00	43.00	52.00	58.00	63.00	66.00	77.00	
11	21.00	23.00	25.00	32.00	37.00	44.00	52.00	57.00	66.00	77.00	
12	21.00	23.00	24.00	28.00	34.00	43.00	53.00	57.00	66.00	77.00	
13	21.00	22.00	24.00	28.00	34.00	43.00	50.00	57.00	66.00	77.00	

ARTIFICIAL SKY LIGHTING CALCULATION
 SIMULATION FOR CLOUDY SKY. CALCULATION OF 12 POSITION @30 DEG. SECTOR.

Pos.no.:	1	File no.:	38	Scaling factor:	1
Pos.no.:	3	File no.:	38	Scaling factor:	1
Pos.no.:	5	File no.:	38	Scaling factor:	1
Pos.no.:	7	File no.:	38	Scaling factor:	1
Pos.no.:	9	File no.:	38	Scaling factor:	1
Pos.no.:	11	File no.:	38	Scaling factor:	1
Pos.no.:	13	File no.:	38	Scaling factor:	1
Pos.no.:	15	File no.:	38	Scaling factor:	1
Pos.no.:	17	File no.:	38	Scaling factor:	1
Pos.no.:	19	File no.:	38	Scaling factor:	1
Pos.no.:	21	File no.:	38	Scaling factor:	1
Pos.no.:	23	File no.:	38	Scaling factor:	1

ALTITUDE	0	10	20	30	40	50	60	70	80	90
AZIMUTH										
0	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
15	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
30	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
45	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
60	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
75	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
90	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
105	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
120	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
135	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
150	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
165	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
180	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
195	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
210	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
225	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
240	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
255	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
270	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
285	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
300	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
315	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
330	0.34	0.41	0.48	0.62	0.71	0.83	0.89	0.93	0.93	1.00
345	0.34	0.41	0.49	0.60	0.69	0.82	0.89	0.91	0.90	1.00
ZENITH SCALING FACTOR:	926.5									

FILE NUMBER: 46
GROUND REF. DISTRIBUTION.

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	16.0	16.0	15.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
15	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
30	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
45	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
60	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
75	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
90	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
105	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
120	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
135	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
150	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
165	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
180	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

ARTIFICIAL SKY LIGHTING CALCULATION
GROUND REFLECTION DISTRIBUTION

Pos.no.: 2	File no.: 46	Scaling factor:	1
Pos.no.: 3	File no.: 46	Scaling factor:	1
Pos.no.: 4	File no.: 46	Scaling factor:	1
Pos.no.: 6	File no.: 46	Scaling factor:	1
Pos.no.: 10	File no.: 46	Scaling factor:	1
Pos.no.: 12	File no.: 46	Scaling factor:	1
Pos.no.: 13	File no.: 46	Scaling factor:	1
Pos.no.: 14	File no.: 46	Scaling factor:	1
Pos.no.: 15	File no.: 46	Scaling factor:	1
Pos.no.: 20	File no.: 46	Scaling factor:	1
Pos.no.: 22	File no.: 46	Scaling factor:	1
Pos.no.: 24	File no.: 46	Scaling factor:	1

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
45	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
75	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
90	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
105	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
120	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
135	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
150	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
165	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
180	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ZENITH SCALING FACTOR: 1.00

```

100 PRINT "Artificial sky"
110 PRINT "This program calculates lighting system combinations"
120 INTT
130 DIM A(10,37)
140 DIM B(10,36)
150 DIM AS(72)
160 DIM BS(72)
170 DIM Z(10)
180 PRINT "Enter calculation description"
190 INPUT BS
200 LET B=0
210 PRINT "Enter number of calculations to be performed"
220 INPUT N
230 DIM C(N)
240 DIM D(N)
250 DIM E(N)
260 FOR M=1 TO N
270 PRINT "Enter file number"
280 INPUT X
290 PRINT "Enter position number"
300 INPUT P
310 PRINT "Enter scaling factor"
320 INPUT S
330 FIND X
340 READ #33:AS,A
350 LET C(M)=X
360 LET D(M)=P
370 LET E(M)=S
380 LET A=A*S
390 FOR J=1 TO 10
400 FOR I=P TO P+36
410 LET K=I-P+1
420 IF I>36 THEN 450
430 LET B(J,I)=B(J,I)+A(J,K)
440 GO TO 470
450 LET I=I-36
460 LET B(J,L)=B(J,L)+A(J,K)
470 NEXT I
480 NEXT J
490 FOR J=1 TO 10
500 FOR I=P+19 TO P+35
510 LET K=P+37-I
520 IF I>36 THEN 550
530 LET B(J,I)=B(J,I)+A(J,K)
540 GO TO 570
550 LET I=I-36
560 LET B(J,L)=B(J,L)+A(J,K)
570 NEXT I
580 NEXT J
590 NEXT M
600 PRINT "Connect line printer"
610 PRINT "DO YOU WANT TO USE PRINTER (40)OR SCREEN(32)";
620 INPUT Q
630 IMAGE 9A,2D,4X,10A,2D,S
640 IMAGE 4X,16A,4D
650 PRINT @Q:"ARTIFICIAL SKY LIGHTING CALCULATION"
660 PRINT @Q:BS
670 PRINT @Q:
680 FOR M=1 TO N
690 PRINT @Q: USING 630:"Pos.no.: ",D(M),"File no.: ",C(M)
700 PRINT @Q: USING 640:"Scaling factor: ",E(M)
710 NEXT M
720 PRINT @Q:
730 PRINT @Q:
740 LET Z=0
750 FOR J=1 TO 10
760 FOR I=1 TO 36
770 LET Z(J)=Z(J)+B(J,I)
780 NEXT I
790 Z(J)=Z(J)/36
800 NEXT J
810 LET B=B/Z(10)
820 IMAGE 12A,5(6A),S
830 IMAGE 5(1X,6D),S
840 IMAGE 5(6A)
850 IMAGE 5(1X,6D)
860 IMAGE 4D,5X,5(3D,2D),S
870 IMAGE 5(3D,2D)
880 PRINT @Q: USING 820:"ALTITUDE" "0","10","20","30","40"
890 PRINT @Q: USING 840:"50","60","70","80","90"
900 PRINT @Q:"AZIMUTH"
910 FOR I=1 TO 36
920 PRINT @Q: USING 860:(I-1)*10,B(1,I),B(2,I),B(3,I),B(4,I),B(5,I)
930 PRINT @Q: USING 870:B(6,I),B(7,I),B(8,I),B(9,I),B(10,I)
940 NEXT I
950 PRINT @Q: USING 830:Z(1) Z(2) Z(3) Z(4) Z(5)

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960 PRINT @: USING 850:Z(6);Z(7);Z(8);Z(9);Z(10)
970 PRINT @:"ZENITH SCALING FACTOR: ";
980 PRINT "FINISHED"
990 GO TO 610
1000 END

```

```

100 PRINT "Artificial sky"
110 PRINT "This program prints data files and result of deg.of accuracy"
120 INIT
130 DIM AS(72)
140 DIM A(10,37)
150 DIM Z(10)
160 DIM K(10,37)
170 DIM F(10,37)
180 DIM E(10,37)
190 DIM C(10)
200 DIM S(10)
210 DIM P(10)
220 DIM Q(10)
230 PRINT "Enter data file number"
240 INPUT X
250 PRINT "ENTER DATA FILE SCALING FACTOR"
260 INPUT B
270 FIND X
280 READ @53:AS,A
290 LET A=A*B
300 FIND X
310 WRITE @53:AS,A
320 PRINT "DO YOU WANT TO USE PRINTER (40)OR SCREEN(32)"
330 INPUT M
340 PRINT @M:"FILE NUMBER: ";X
350 PRINT @M:AS
360 PRINT @M:"SCALING FACTOR: ";B
370 PRINT @M:"ALTITUDE"
380 IMAGE 5X,5(7A),S
390 IMAGE 5(7A)
400 IMAGE 2D,5(1X,3D,2D),S
410 IMAGE 5(1X,3D,2D)
420 PRINT @M: USING 380:"0" "10" "20" "30" "40"
430 PRINT @M: USING 390:"50" "60" "70" "80" "90"
440 PRINT @M:"POS.:"
450 FOR J=1 TO 37
460 PRINT @M: USING 400:J,A(1,J),A(2,J),A(3,J),A(4,J),A(5,J)
470 PRINT @M: USING 410:A(6,J),A(7,J),A(8,J),A(9,J),A(10,J)
480 NEXT J
490 IMAGE 5(1X,3D,2D),S
500 IMAGE 5(1X,3D,2D)
510 IMAGE 2D,5(1X,2D,3D),S
520 IMAGE 5(1X,2D,3D)
521 IMAGE 5(1X,2D,3D),S
522 IMAGE 5(1X,2D,3D)
530 LET Z=0
540 FOR I=1 TO 10
550 FOR J=1 TO 37
560 LET Z(I)=Z(I)+A(I,J)
570 NEXT J
580 Z(I)=Z(I)/37
590 NEXT I
600 PRINT @M:"AVRAGE LUMINANCES ";
610 PRINT @M:Z
620 PRINT @M: USING 490:Z(1);Z(2);Z(3);Z(4);Z(5)
630 PRINT @M: USING 500:Z(6);Z(7);Z(8);Z(9);Z(10)
640 LET K=0
650 C=0
660 FOR I=1 TO 10
670 FOR J=1 TO 37
680 LET K(I,J)=A(I,J)-Z(I)
690 LET E(I,J)=K(I,J)^2
700 LET C(I)=C(I)+E(I,J)
710 NEXT J
720 C(I)=SOR(C(I)/37)
730 S(I)=SOR(27/36)*C(I)
740 P(I)=S(I)*SOR(37)
750 Q(I)=P(I)/37
760 NEXT I
770 PRINT @M:"DEVIATION OF AVERAGES";
780 PRINT @M:
790 PRINT @M:
800 PRINT @M:
810 FOR J=1 TO 37
820 PRINT @M: USING 510:J,K(1,J),K(2,J),K(3,J),K(4,J),K(5,J)
830 PRINT @M: USING 520:K(6,J),K(7,J),K(8,J),K(9,J),K(10,J)
840 NEXT J
850 PRINT @M:"(DEVIATION OF AVERAGES)^2";
860 PRINT @M:
870 PRINT @M:
880 PRINT @M:
890 PRINT @M:

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910 PRINT GM: USING 520:E(6,J),E(7,J),E(8,J),E(9,J),E(10,J)'
920 NEXT J
930 PRINT GM: "STANDARD DIVIATION = ";
940 PRINT GM:
950 PRINT GM:
960 PRINT GM: USING 521:C(1),C(2),C(3),C(4),C(5)
970 PRINT GM: USING 522:C(6),C(7),C(8),C(9),C(10)
980 PRINT GM: "SD+=SD OF MEASUREMENT*SCR(37/37-1)=";
990 PRINT GM:
1000 PRINT GM:
1010 PRINT GM: USING 521:S(1),S(2),S(3),S(4),S(5)
1020 PRINT GM: USING 522:S(6),S(7),S(8),S(9),S(10)
1030 PRINT GM: "SE FOR THE SUM OF DEVIATIONS=";
1040 PRINT GM:
1050 PRINT GM:
1060 PRINT GM: USING 521:P(1),P(2),P(3),P(4),P(5)
1070 PRINT GM: USING 522:P(6),P(7),P(8),P(9),P(10)
1080 PRINT GM: "STANDARD DIVIATION(SE FOR AVERAGES=";
1090 PRINT GM:
1100 PRINT GM:
1110 PRINT GM: USING 521:Q(1),Q(2),Q(3),Q(4),Q(5)
1120 PRINT GM: USING 522:Q(6),Q(7),Q(8),Q(9),Q(10)
1130 GO TO 320
1140 END

```

```

100 PRINT "Artificial sky"
110 PRINT "This program loads lighting data on magnetic tape files"
111 INPUT
120 DIM AS$(72)
130 PRINT "Enter lighting system description, max. 72 characters"
140 INPUT AS$
150 DIM A(10,37)
160 PRINT "Enter lighting data, line by line, starting with 0 altitude"
165 PRINT "All data should be absolute measurement values"
170 FOR I=1 TO 10
180 PRINT "Altitude ";(I-1)*10;" degrees"
190 FOR J=1 TO 37
200 INPUT A(I,J)
210 NEXT J
220 FOR J=1 TO 37
230 PRINT J;" ";A(I,J)
235 NEXT J
240 PRINT "Enter number of wrong data"
245 INPUT K
240 IF K=0 THEN 315
250 FOR I=1 TO K
260 PRINT "Enter data (line) number that is incorrect"
270 INPUT M
280 PRINT "Enter correct data"
290 INPUT A(I,M)
300 NEXT I
310 GO TO 220
315 NEXT I
320 PRINT "Enter file number for storing data"
330 INPUT X
340 FIND X
370 WRITE #3:AS$,A
371 PRINT "DO YOU WANT TO SEE (32)OR PRINT(40)";
372 INPUT Q
375 PRINT #Q:"FILE NUMBER: ";X
380 PRINT #Q:A$
390 PRINT #Q:
400 IMAGE 11A,5(6A),S
410 IMAGE 5(6A)
420 IMAGE 4D,5X,5(5D),S
425 IMAGE 5(5D)
430 PRINT #Q: USING 400:"ALTITUDE" "0","10","20","30","40"
440 PRINT #Q: USING 410:"50","60","70","80","90"
450 PRINT #Q:"AZIMUTH"
455 FOR J=1 TO 37
460 PRINT #Q: USING 420:(J-1)*15,A(1,J),A(2,J),A(3,J),A(4,J),A(5,J)
470 PRINT #Q: USING 425:A(6,J),A(7,J),A(8,J),A(9,J),A(10,J)
480 NEXT J
490 PRINT "Data stored and printed out"
491 GO TO 371
500 END

```



```

100 PRINT "Artificial sky"
110 PRINT "This program calculate C.I.E. clear sky distribution "
130 PRINT "Enter solar Altitude in degrees"
140 INPUT H
150 DIM B(10,19)
160 LET Z=(90-H)*PI/180
170 LET F2=0.91+10*EXP(-3*Z)+0.45*COS(Z)^2
180 FOR J=1 TO 19
190 LET A=(J-1)*10*PI/180
200 FOR I=2 TO 10
210 LET E=(10-I)*10*PI/180
220 GOSUB 500
230 NEXT I
240 LET I=1
250 LET E=85*PI/180
260 GOSUB 500
270 REM
280 NEXT J
281 PRINT "DO YOU WANT TO SEE(32)OR PRINT (40)"
282 INPUT Q
290 PRINT @Q:"RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY"
300 PRINT @Q:"SOLAR ALTITUDE";H
301 PRINT @Q:""
302 PRINT @Q:""
303 PRINT @Q:"H";"DEGREES"
310 PRINT @Q:""
320 IMAGE 12A,5(6A),S
330 IMAGE 5(6A)
340 IMAGE 4D,5X,5(3D,2D),S
350 IMAGE 5(3D,2D)
360 PRINT @Q: USING 320:"ALTITUDE" "0", "10", "20", "30", "40"
370 PRINT @Q: USING 330:"50", "60", "70", "80", "90"
380 PRINT @Q:"AZIMUTH"
390 FOR J=1 TO 19
400 PRINT @Q: USING 340:(J-1)*10, B(1,J), B(2,J), B(3,J), B(4,J), B(5,J)
410 PRINT @Q: USING 350:B(6,J), B(7,J), B(8,J), B(9,J), B(10,J)
420 NEXT J
421 GO TO 281
430 END
460 GO TO 281
500 REM
510 G=ACS(COS(Z)*COS(E)+SIN(Z)*SIN(E)*COS(A))
520 F1=0.91+10*EXP(-3*G)+0.45*COS(G)^2
530 P1=1-EXP(-0.32/COS(E))
540 LET B(I,J)=F1*P1/(0.27385*F2)
550 RETURN

```

RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY
SOLAR ALTITUDE90DEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
10	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
20	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
30	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
40	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
50	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
60	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
70	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
80	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
90	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
100	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
110	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
120	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
130	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
140	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
150	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
160	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
170	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
180	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00

-RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY
SOLAR ALTITUDE0

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	32.22	22.35	10.69	5.74	3.45	2.28	1.64	1.28	1.09	1.00
10	24.61	18.78	9.79	5.46	3.34	2.24	1.62	1.28	1.09	1.00
20	16.75	13.56	7.92	4.77	3.07	2.12	1.58	1.26	1.08	1.00
30	11.69	9.72	6.15	3.98	2.72	1.97	1.51	1.23	1.08	1.00
40	8.50	7.17	4.76	3.28	2.37	1.80	1.43	1.20	1.07	1.00
50	6.47	5.51	3.78	2.72	2.06	1.65	1.35	1.17	1.06	1.00
60	5.16	4.43	3.10	2.31	1.82	1.49	1.27	1.13	1.04	1.00
70	4.33	3.73	2.65	2.02	1.63	1.38	1.21	1.10	1.03	1.00
80	3.83	3.30	2.37	1.83	1.51	1.30	1.16	1.07	1.02	1.00
90	3.56	3.07	2.22	1.73	1.45	1.25	1.13	1.05	1.01	1.00
100	3.48	3.00	2.17	1.69	1.40	1.22	1.11	1.04	1.01	1.00
110	3.54	3.05	2.20	1.70	1.41	1.22	1.10	1.03	1.00	1.00
120	3.70	3.19	2.29	1.76	1.44	1.23	1.11	1.03	1.00	1.00
130	3.94	3.39	2.41	1.84	1.49	1.26	1.12	1.05	0.99	1.00
140	4.20	3.61	2.55	1.93	1.54	1.29	1.13	1.03	0.99	1.00
150	4.45	3.82	2.69	2.02	1.60	1.33	1.15	1.04	0.99	1.00
160	4.65	3.99	2.81	2.09	1.65	1.36	1.16	1.04	0.99	1.00
170	4.79	4.10	2.88	2.14	1.68	1.37	1.17	1.05	0.99	1.00
180	4.83	4.14	2.91	2.16	1.69	1.38	1.17	1.05	0.99	1.00

RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY
SOLAR ALTITUDE10

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	29.96	32.47	15.00	7.73	4.43	2.79	1.92	1.43	1.15	1.00
10	22.95	20.92	12.72	7.14	4.24	2.72	1.89	1.42	1.15	1.00
20	15.67	13.93	9.50	5.87	3.76	2.53	1.81	1.39	1.14	1.00
30	10.95	9.66	6.73	4.61	3.19	2.28	1.71	1.35	1.12	1.00
40	7.98	7.01	4.99	3.61	2.67	2.02	1.59	1.29	1.11	1.00
50	6.08	5.33	3.85	2.89	2.24	1.78	1.46	1.24	1.09	1.00
60	4.85	4.24	3.09	2.38	1.91	1.58	1.35	1.18	1.07	1.00
70	4.07	3.55	2.60	2.03	1.67	1.42	1.25	1.13	1.05	1.00
80	3.58	3.12	2.28	1.79	1.50	1.30	1.17	1.09	1.03	1.00
90	3.32	2.88	2.10	1.65	1.39	1.22	1.11	1.05	1.01	1.00
100	3.23	2.80	2.02	1.58	1.33	1.17	1.07	1.02	1.00	1.00
110	3.28	2.82	2.02	1.57	1.30	1.14	1.04	0.99	0.98	1.00
120	3.42	2.93	2.08	1.60	1.31	1.13	1.03	0.98	0.97	1.00
130	3.62	3.09	2.18	1.65	1.33	1.14	1.02	0.97	0.96	1.00
140	3.84	3.28	2.29	1.72	1.37	1.16	1.03	0.96	0.95	1.00
150	4.06	3.46	2.40	1.78	1.41	1.17	1.03	0.96	0.95	1.00
160	4.25	3.61	2.50	1.84	1.44	1.19	1.04	0.96	0.94	1.00
170	4.37	3.71	2.56	1.88	1.47	1.20	1.04	0.96	0.94	1.00
180	4.41	3.74	2.58	1.90	1.47	1.21	1.04	0.96	0.94	1.00

RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
 SOLAR ALTITUDE 20

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	17.20	18.34	20.68	10.30	5.66	3.40	2.23	1.58	1.21	1.00
10	15.30	15.55	13.59	8.88	5.29	3.28	2.19	1.56	1.21	1.00
20	11.81	11.36	9.20	6.65	4.45	2.98	2.07	1.52	1.19	1.00
30	8.83	8.22	6.46	4.90	3.59	2.59	1.91	1.46	1.18	1.00
40	6.68	6.10	4.73	3.69	2.87	2.22	1.73	1.39	1.15	1.00
50	5.22	4.71	3.61	2.87	2.32	1.89	1.56	1.31	1.12	1.00
60	4.24	3.78	2.88	2.31	1.92	1.63	1.41	1.23	1.09	1.00
70	3.59	3.18	2.40	1.95	1.64	1.43	1.27	1.16	1.06	1.00
80	3.17	2.79	2.09	1.68	1.44	1.28	1.17	1.09	1.04	1.00
90	2.95	2.57	1.90	1.52	1.30	1.17	1.08	1.03	1.01	1.00
100	2.86	2.47	1.80	1.43	1.21	1.09	1.02	0.99	0.98	1.00
110	2.88	2.47	1.78	1.39	1.17	1.04	0.98	0.95	0.96	1.00
120	2.98	2.54	1.80	1.39	1.15	1.01	0.94	0.92	0.94	1.00
130	3.13	2.66	1.86	1.41	1.15	1.00	0.92	0.90	0.93	1.00
140	3.31	2.80	1.94	1.45	1.17	1.00	0.91	0.89	0.91	1.00
150	3.48	2.94	2.02	1.49	1.19	1.00	0.91	0.88	0.91	1.00
160	3.62	3.05	2.09	1.53	1.21	1.01	0.90	0.87	0.90	1.00
170	3.71	3.13	2.13	1.56	1.22	1.02	0.90	0.87	0.90	1.00
180	3.75	3.16	2.15	1.57	1.22	1.02	0.90	0.86	0.89	1.00

 RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
 SOLAR ALTITUDE 30

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	9.74	10.18	11.09	13.48	7.16	4.13	2.58	1.74	1.27	1.00
10	9.14	9.39	9.57	9.14	6.32	3.91	2.51	1.72	1.27	1.00
20	7.78	7.72	7.16	6.36	4.91	3.41	2.34	1.66	1.25	1.00
30	6.30	6.06	5.28	4.57	3.73	2.84	2.11	1.58	1.23	1.00
40	5.07	4.76	3.97	3.40	2.87	2.34	1.86	1.47	1.19	1.00
50	4.12	3.80	3.09	2.62	2.26	1.93	1.63	1.37	1.16	1.00
60	3.44	3.13	2.49	2.10	1.83	1.62	1.42	1.26	1.12	1.00
70	2.97	2.67	2.08	1.74	1.53	1.39	1.27	1.17	1.06	1.00
80	2.66	2.36	1.81	1.50	1.32	1.21	1.14	1.09	1.04	1.00
90	2.48	2.18	1.64	1.34	1.18	1.09	1.04	1.01	1.00	1.00
100	2.40	2.08	1.54	1.24	1.08	1.00	0.96	0.95	0.97	1.00
110	2.40	2.06	1.50	1.18	1.02	0.93	0.90	0.91	0.94	1.00
120	2.46	2.10	1.49	1.16	0.98	0.89	0.86	0.87	0.92	1.00
130	2.56	2.17	1.52	1.16	0.97	0.86	0.83	0.84	0.89	1.00
140	2.68	2.26	1.56	1.18	0.96	0.85	0.80	0.81	0.83	1.00
150	2.79	2.35	1.61	1.20	0.97	0.84	0.79	0.80	0.87	1.00
160	2.89	2.43	1.65	1.22	0.97	0.84	0.78	0.79	0.86	1.00
170	2.95	2.48	1.68	1.23	0.98	0.84	0.78	0.78	0.85	1.00
180	2.98	2.49	1.69	1.24	0.98	0.84	0.78	0.78	0.85	1.00

RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
SOLAR ALTITUDE 40

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	5.48	5.60	5.85	6.87	8.91	4.97	2.98	1.92	1.34	1.00
10	5.28	5.36	5.47	6.08	6.31	4.52	2.87	1.89	1.33	1.00
20	4.78	4.76	4.61	4.71	4.57	3.67	2.60	1.81	1.31	1.00
30	4.15	4.04	3.71	3.58	3.38	2.90	2.26	1.69	1.27	1.00
40	3.54	3.37	2.97	2.75	2.58	2.31	1.93	1.55	1.25	1.00
50	3.03	2.83	2.40	2.17	2.02	1.86	1.65	1.41	1.19	1.00
60	2.62	2.41	1.99	1.76	1.63	1.53	1.42	1.28	1.14	1.00
70	2.32	2.11	1.69	1.47	1.36	1.29	1.23	1.17	1.09	1.00
80	2.11	1.89	1.49	1.27	1.16	1.11	1.09	1.07	1.04	1.00
90	1.98	1.75	1.34	1.13	1.03	0.98	0.97	0.98	0.99	1.00
100	1.92	1.68	1.26	1.04	0.93	0.89	0.89	0.91	0.95	1.00
110	1.91	1.65	1.21	0.98	0.86	0.82	0.82	0.86	0.92	1.00
120	1.93	1.65	1.19	0.94	0.82	0.77	0.77	0.81	0.89	1.00
130	1.99	1.69	1.19	0.93	0.79	0.74	0.73	0.78	0.86	1.00
140	2.05	1.73	1.21	0.92	0.78	0.71	0.71	0.75	0.84	1.00
150	2.12	1.78	1.23	0.93	0.77	0.70	0.69	0.73	0.83	1.00
160	2.18	1.82	1.25	0.93	0.77	0.69	0.67	0.71	0.82	1.00
170	2.22	1.85	1.26	0.94	0.77	0.68	0.67	0.71	0.81	1.00
180	2.23	1.86	1.27	0.94	0.77	0.68	0.66	0.70	0.81	1.00

RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
SOLAR ALTITUDE 50

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	3.08	3.07	3.07	3.46	4.35	5.89	3.41	2.11	1.40	1.00
10	3.02	3.00	2.96	3.28	3.94	4.41	3.20	2.07	1.39	1.00
20	2.84	2.79	2.69	2.85	3.20	3.34	2.75	1.94	1.36	1.00
30	2.60	2.52	2.34	2.38	2.53	2.58	2.29	1.78	1.32	1.00
40	2.34	2.23	2.00	1.96	2.01	2.03	1.90	1.60	1.27	1.00
50	2.09	1.97	1.71	1.62	1.62	1.64	1.59	1.43	1.21	1.00
60	1.88	1.74	1.47	1.36	1.33	1.35	1.34	1.28	1.15	1.00
70	1.72	1.57	1.29	1.16	1.13	1.13	1.15	1.14	1.09	1.00
80	1.59	1.44	1.15	1.02	0.97	0.98	1.00	1.03	1.03	1.00
90	1.51	1.34	1.05	0.91	0.86	0.86	0.89	0.94	0.98	1.00
100	1.46	1.29	0.98	0.83	0.77	0.77	0.80	0.86	0.94	1.00
110	1.45	1.26	0.94	0.78	0.71	0.70	0.74	0.80	0.90	1.00
120	1.45	1.25	0.91	0.74	0.67	0.66	0.68	0.75	0.86	1.00
130	1.47	1.26	0.90	0.72	0.64	0.62	0.65	0.72	0.83	1.00
140	1.50	1.27	0.90	0.71	0.62	0.59	0.62	0.69	0.81	1.00
150	1.53	1.29	0.91	0.70	0.61	0.58	0.60	0.66	0.79	1.00
160	1.56	1.31	0.91	0.70	0.60	0.57	0.58	0.65	0.78	1.00
170	1.58	1.33	0.92	0.70	0.60	0.56	0.57	0.64	0.77	1.00
180	1.59	1.33	0.92	0.70	0.60	0.56	0.57	0.64	0.77	1.00

RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
SOLAR ALTITUDE 60

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	1.73	1.69	1.60	1.73	2.07	2.73	3.85	2.30	1.47	1.00
10	1.71	1.66	1.57	1.68	2.00	2.56	3.07	2.22	1.45	1.00
20	1.65	1.60	1.49	1.57	1.81	2.20	2.47	2.03	1.42	1.00
30	1.57	1.50	1.38	1.41	1.57	1.83	2.01	1.80	1.36	1.00
40	1.47	1.40	1.25	1.24	1.35	1.52	1.65	1.58	1.30	1.00
50	1.37	1.29	1.12	1.09	1.15	1.27	1.38	1.38	1.23	1.00
60	1.28	1.19	1.01	0.96	0.99	1.07	1.17	1.22	1.15	1.00
70	1.21	1.10	0.92	0.85	0.86	0.92	1.01	1.08	1.09	1.00
80	1.14	1.03	0.84	0.76	0.76	0.80	0.88	0.97	1.02	1.00
90	1.10	0.98	0.78	0.69	0.68	0.71	0.78	0.86	0.96	1.00
100	1.07	0.94	0.74	0.64	0.62	0.64	0.71	0.80	0.91	1.00
110	1.05	0.92	0.70	0.60	0.57	0.59	0.65	0.74	0.87	1.00
120	1.05	0.91	0.68	0.57	0.54	0.55	0.60	0.69	0.83	1.00
130	1.05	0.90	0.67	0.55	0.51	0.52	0.56	0.66	0.80	1.00
140	1.06	0.90	0.66	0.54	0.49	0.49	0.54	0.63	0.78	1.00
150	1.07	0.91	0.65	0.53	0.48	0.48	0.52	0.60	0.76	1.00
160	1.08	0.91	0.65	0.52	0.47	0.47	0.50	0.59	0.74	1.00
170	1.08	0.92	0.65	0.52	0.46	0.46	0.50	0.58	0.74	1.00
180	1.09	0.92	0.65	0.52	0.46	0.46	0.49	0.58	0.73	1.00

RELATIVE LUMINANCE DISTRIBUTION, CIE CLEAR SKY
SOLAR ALTITUDE 70

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	0.98	0.93	0.84	0.86	0.99	1.25	1.70	2.49	1.53	1.00
10	0.97	0.92	0.83	0.85	0.97	1.22	1.64	2.13	1.51	1.00
20	0.96	0.90	0.81	0.82	0.93	1.15	1.50	1.83	1.46	1.00
30	0.93	0.83	0.76	0.78	0.87	1.05	1.33	1.59	1.39	1.00
40	0.90	0.84	0.74	0.73	0.80	0.95	1.17	1.52	1.30	1.00
50	0.87	0.81	0.70	0.68	0.73	0.84	1.02	1.21	1.21	1.00
60	0.84	0.77	0.65	0.63	0.66	0.75	0.90	1.07	1.13	1.00
70	0.81	0.74	0.62	0.58	0.60	0.68	0.80	0.95	1.06	1.00
80	0.78	0.71	0.58	0.54	0.55	0.61	0.72	0.86	0.99	1.00
90	0.76	0.69	0.55	0.50	0.51	0.56	0.65	0.78	0.95	1.00
100	0.74	0.66	0.53	0.47	0.47	0.51	0.59	0.72	0.88	1.00
110	0.73	0.65	0.51	0.45	0.44	0.47	0.55	0.67	0.83	1.00
120	0.73	0.64	0.49	0.43	0.42	0.45	0.51	0.63	0.80	1.00
130	0.72	0.63	0.48	0.41	0.40	0.42	0.48	0.59	0.77	1.00
140	0.72	0.63	0.47	0.40	0.39	0.41	0.46	0.57	0.74	1.00
150	0.72	0.62	0.47	0.39	0.37	0.39	0.45	0.55	0.72	1.00
160	0.72	0.62	0.46	0.39	0.37	0.38	0.44	0.54	0.71	1.00
170	0.72	0.62	0.46	0.39	0.36	0.38	0.43	0.53	0.70	1.00
180	0.72	0.62	0.46	0.39	0.36	0.36	0.43	0.53	0.70	1.00

RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY
 SOLAR ALTITUDE&O

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	0.56	0.52	0.44	0.43	0.47	0.57	0.75	1.05	1.58	1.00
10	0.56	0.51	0.44	0.43	0.47	0.57	0.74	1.04	1.46	1.00
20	0.55	0.51	0.44	0.43	0.46	0.56	0.72	1.00	1.35	1.00
30	0.55	0.50	0.43	0.42	0.45	0.54	0.70	0.95	1.25	1.00
40	0.54	0.50	0.42	0.41	0.44	0.52	0.66	0.90	1.16	1.00
50	0.53	0.49	0.41	0.39	0.42	0.49	0.63	0.84	1.08	1.00
60	0.53	0.48	0.40	0.38	0.40	0.47	0.59	0.78	1.01	1.00
70	0.52	0.47	0.39	0.37	0.39	0.44	0.55	0.73	0.95	1.00
80	0.51	0.46	0.38	0.35	0.37	0.42	0.52	0.68	0.90	1.00
90	0.50	0.45	0.37	0.34	0.35	0.40	0.49	0.64	0.85	1.00
100	0.50	0.45	0.36	0.33	0.34	0.38	0.46	0.60	0.81	1.00
110	0.49	0.44	0.35	0.32	0.33	0.36	0.44	0.57	0.78	1.00
120	0.49	0.44	0.35	0.31	0.32	0.35	0.42	0.55	0.75	1.00
130	0.49	0.43	0.34	0.31	0.31	0.34	0.41	0.53	0.72	1.00
140	0.48	0.43	0.34	0.30	0.30	0.33	0.39	0.51	0.70	1.00
150	0.48	0.43	0.33	0.29	0.29	0.32	0.39	0.50	0.69	1.00
160	0.48	0.42	0.33	0.29	0.29	0.32	0.38	0.49	0.68	1.00
170	0.48	0.42	0.33	0.29	0.29	0.31	0.37	0.48	0.67	1.00
180	0.48	0.42	0.33	0.29	0.29	0.31	0.37	0.48	0.67	1.00

 RELATIVE LUMINANCE DISTRIBUTION,CIE CLEAR SKY
 SOLAR ALTITUDE90

HDEGREES

ALTITUDE AZIMUTH	0	10	20	30	40	50	60	70	80	90
0	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
10	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
20	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
30	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
40	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
50	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
60	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
70	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
80	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
90	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
100	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
110	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
120	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
130	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
140	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
150	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
160	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
170	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00
180	0.32	0.29	0.24	0.22	0.23	0.26	0.33	0.45	0.65	1.00

```
100 INIT
110 PAGE
120 PRINT "WHAT IS THE HIGHT OF PROBL POSITION";
130 INPUT A
140 PRINT "WHAT IS LENTH OF MODEL";
150 INPUT C
160 PRINT "DO YOU WANT TO SEE (32) OR PRINT(40)";
170 INPUT M
180 PRINT @4:"THIS PROGRAM CALCULATES HORIZON ERROR FOR ARTIFICIAL SKY";
190 PRINT @4:
200 PRINT @4:"A-HIGHT OF PROBE POSITION"
210 PRINT @4:"E-DISTANCE OF PROBE FROM CENTER"
220 PRINT @4:"X-NUMBER OF DEGREE 1.00 IN HORIZON ERROR"
230 FOR I=0 TO A
240 FOR J=0 TO C
250 A=I
260 B=105+J*1
270 FOR K=1 TO 5
280 B=B+1
290 Y=A/E
300 NEXT K
310 SET DEGREES
320 X=ATN(Y)
330 PRINT @4:"A=";A,"E=";E,"X=";X
340 NEXT J
350 NEXT I
360 GO TO 120
370 END
```

THIS PROGRAM CALCULATES HORIZON ERROR FOR ARTIFICIAL SKY

A=HEIGHT OF PROBE POSITION

B=DISTANCE OF PROBE FROM CENTER

X=NUMBER OF DEGREE 1.00 IN HORIZON ERROR

A=0	B=1	X=0	.47745377731
A=0	B=1	X=0	.473508058735
A=0	B=1	X=0	.46962701966
A=0	B=1	X=0	.465809082765
A=0	B=1	X=0	.462052721451
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A=0	B=1	X=0	.451138546767
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A=0	B=1	X=0	.434065721156
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A=0	B=1	X=0	.421458002169
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A=0	B=1	X=0	2.414326532000
A=0	B=1	X=0	2.436186280000
A=0	B=1	X=0	2.458166028000


```

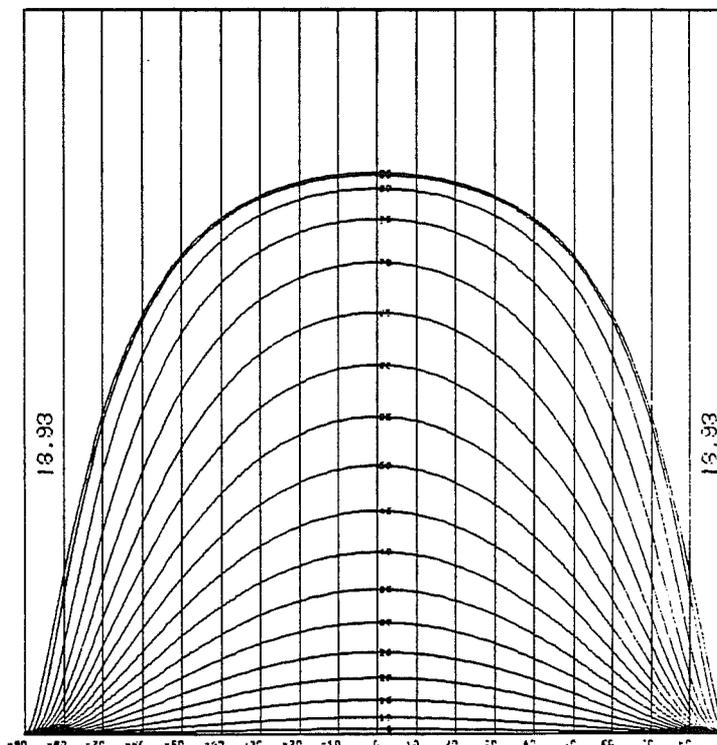
868 15 CONTINUE
869 CALL LINESG(ZMODE,91,X,Y)
870 IF(MYSIDE.EQ.2) YNB = Y(91)
871 IF(MYSIDE.EQ.1) YNB = Y(1)
872 IF(MYSIDE.EQ.1) CALL NUMBRG(ZMODE,DD,YNB,2,IDEGR)
873 IDEGR = IDEGR - 5
874 10 CONTINUE
875 RETURN
876 C===== RESET ORIGIN FOR NEXT FRAME =====
877 ENTRY ORIG
878 CALL FRAME
879 RETURN
880 END
881 C
882 C===== SUB FOR NAWAB,M SKY=====
883 SUBROUTINE AFILL(II,J,GET,IJ,MYSIDE)
884 C SUBROUTINE TO READ IN 10*10 MEASURED SKY AND STORE
885 C VALUES ARE INTERPOLATED BY A FIND TO NEAREST DEGREE.
886 C DATA CARD FOLLOW THE CONTROLLING DATA CARDS AS SHOWN
887 C 789 CARD
888 C PLOT*****
889 C AZINUTH*** 0.0
890 C PLOT HORIZONTAL000000 0707 7 7 MINI MEASURED
891 C 0000. .1111 2.222 33.33 444.4 5555. .6666 7.777 88.88 999.9
892 C (ETC FOR 10 (ALT.) (10 AZ PER LINE)
893 C END*****
894 C 6789 CARD
895 C
896 C
897 DIMENSION A(10,10)
898 C-
899 C-
900 IF(IJ.EQ.1) GO TO 50
901 READ(5,1) ((A(I,J),J=1,10),I=1,10)
902 1 FORMAT(10F6.2)
903 RETURN
904 C
905 C
906 C ARRAY FILLED , INTERPOLATE WHEN NEEDED
907 50 CONTINUE
908 C II IS ALT-COUNTING FROM 91 DOWN
909 C J IS AZI-COUNTING FROM 1 UP
910 C K IS ALT IN OUR A ARRAY
911 C L IS AZI IN OUR A ARRAY
912
913 IF(MYSIDE.EQ.1) GO TO 60
914 J=92-J
915 60 CONTINUE
916 K=(II-1)/10+1
917 L=(J-1) /10+1
918 IF(K.EQ.10) GO TO 100
919 IF(L.EQ.10) GO TO 200
920 C
921 C CHECK WE'RE NOT ON EXTREME EDGE OF ARRAY
922 C
923 C
924 SLOPER=(A(K+1,L+1)-A(K,L+1))/10.
925 SLOPEL=(A(K+1,L)-A(K,L))/10.
926 SLOPED=(A(K,L+1)-A(K,L))/10.
927 C
928 C TAKE WEIGHTED AVERAGE OF VERTICAL
929 C SLOPES (L&R)

```

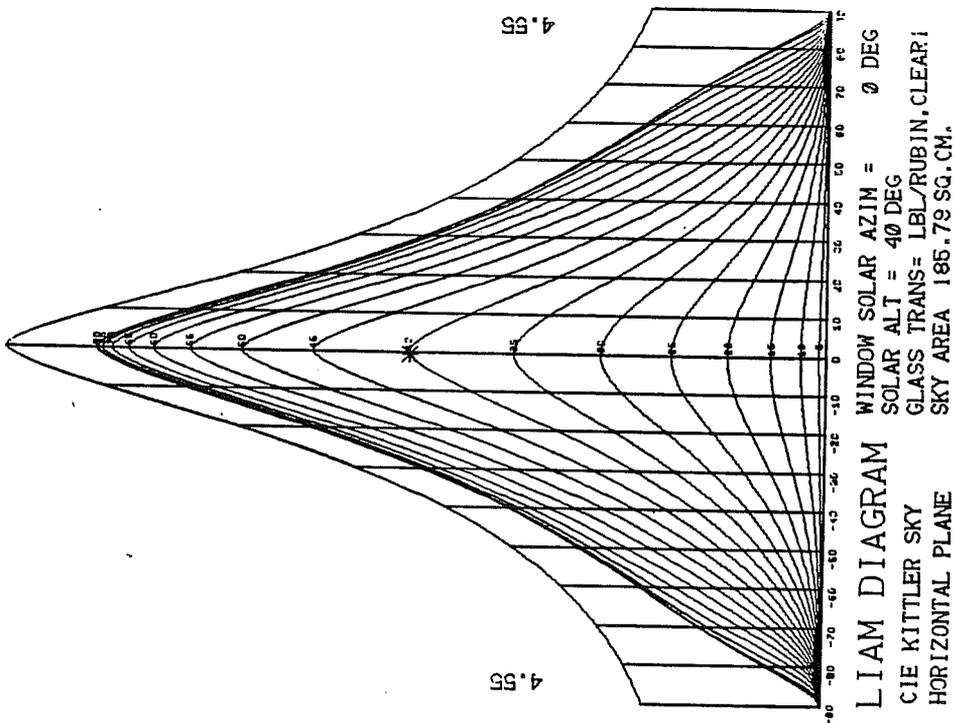
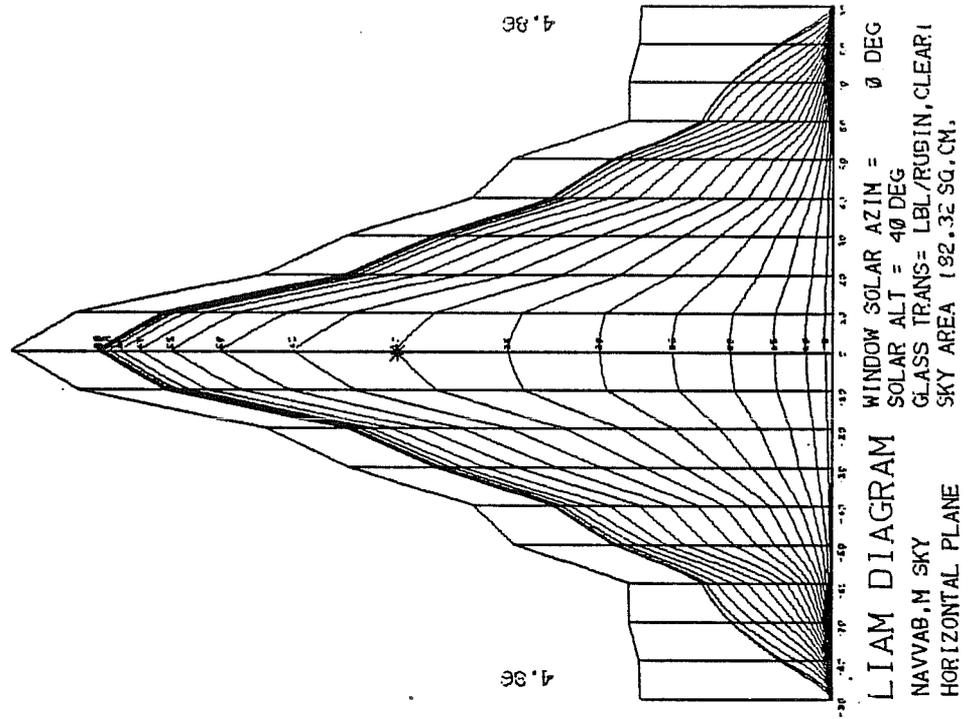
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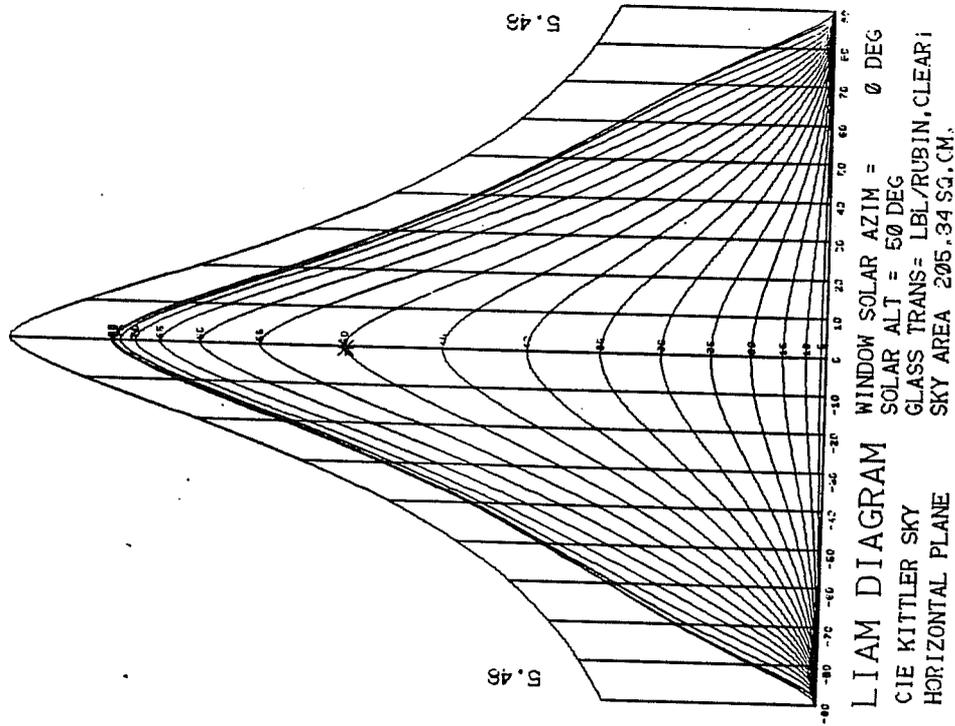
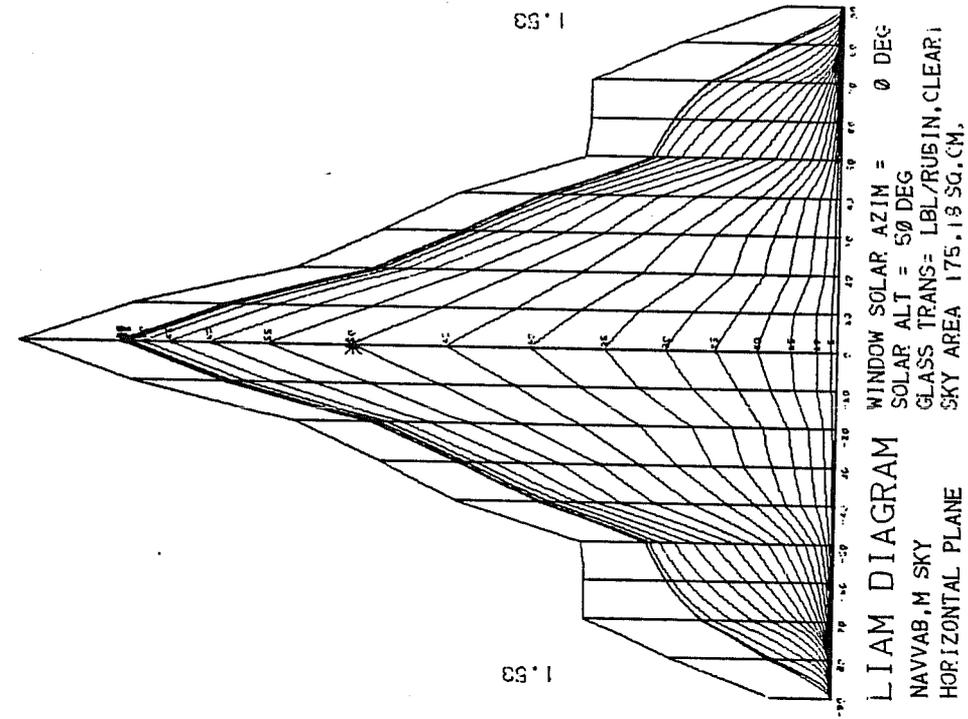
931 C ALPHA IS FRACTION FOR ALTITUDE 0=<ALPHA=<1
932 C BETA ..... AZIMUTH .. BETA..
933
934 ALPHA=((II-1)-10.*(K-1))/10.
935 BETA =((J -1)-10.*(L-1))/10.
936 SLOPE=SLOPEL*(1-BETA)+SLOPER*(BETA)
937 C
938 C GET THE INTERPOLATED POINT
939 C
940 GET=A(K,L)+10*BETA*SLOPEB+10*ALPHA*SLOPE
941 C
942 C DONE FOR GENERAL CASE NOW RETURN
943 C
944 RETURN
945 C
946 C EDGE CONDITION ,TOP
947 C
948 100 IF (L.EQ.10) GO TO 300
949 SLOPEB=(A(K,L+1)-A(K,L))/10.
950 BETA=((J-1)-10*(L-1))/10.
951 GET=A(K,L)+10*BETA*SLOPEB
952 RETURN
953 C
954 C RIGHT EDGE CONDITION
955 C
956 C
957 200 SLOPER=(A(K+1,L)-A(K,L))/10.
958 ALPHA=((II-1)-10.*(K-1))/10.
959 GET=A(K,L)+10*ALPHA*SLOPER
960 RETURN
961 C
962 C IN UPPER RIGHT CORNER
963 C
964 300 GET=A(K,L)
965 RETURN
966 END
---
```

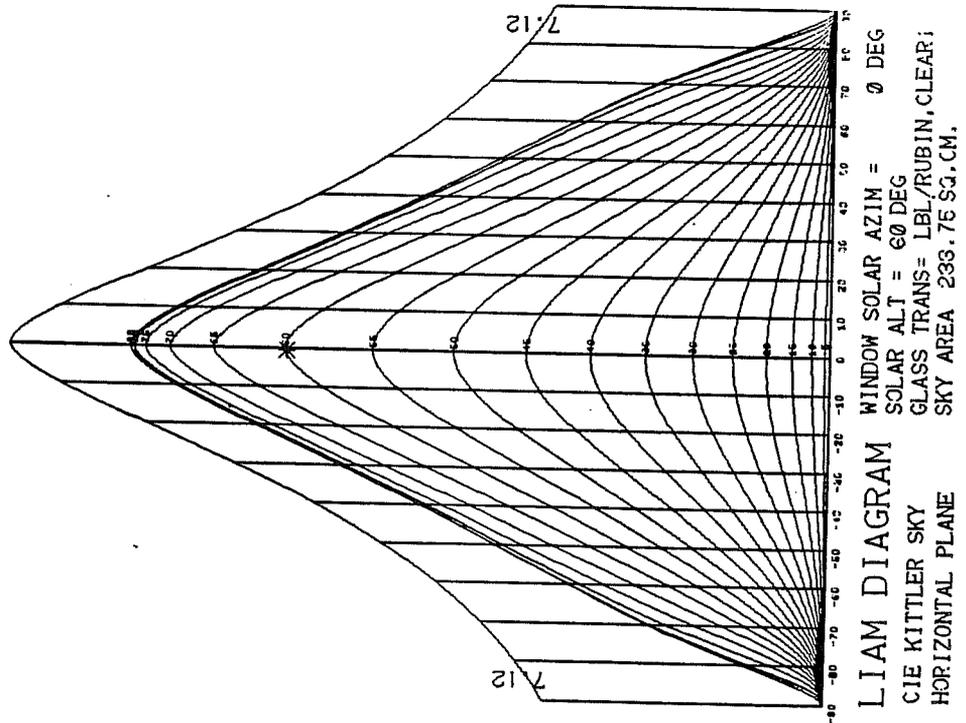
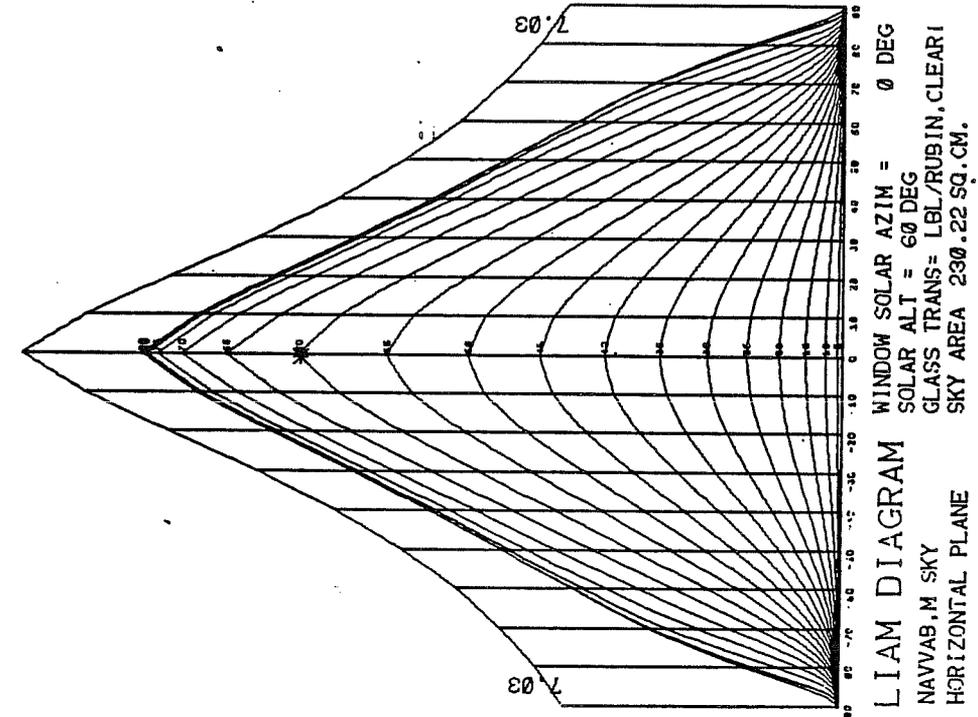
The following figures are the clear sky luminance distribution within sky simulator page (254-260)

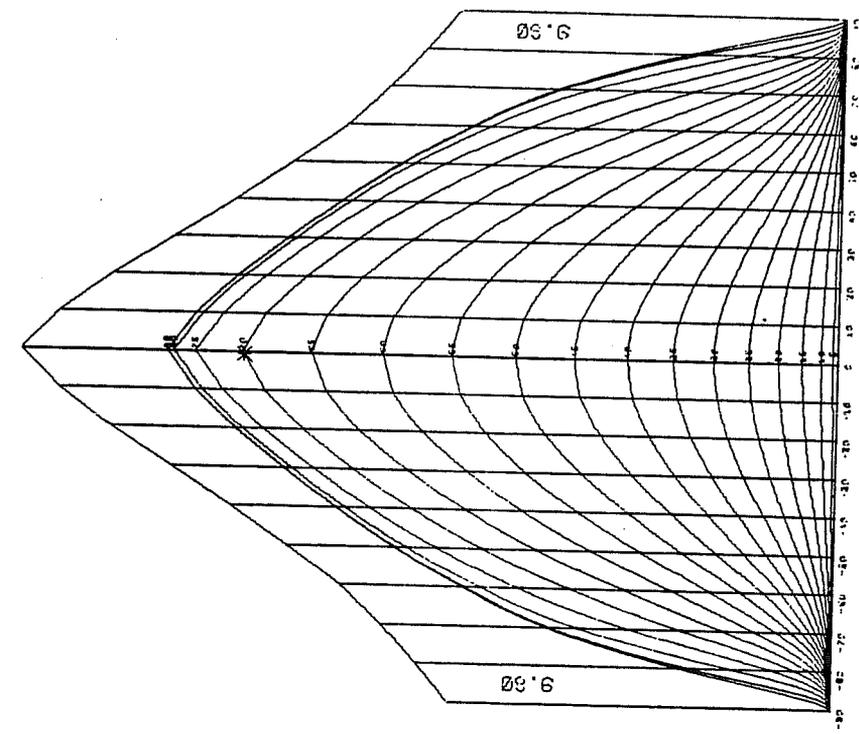


LIAM DIAGRAM. WINDOW SOLAR AZIM = 187 DEG
 SOLAR ALT = 90 DEG
 HAWAB, M OVERCAST SKY GLASS TRANS= LBL/RUBIN,CLEAR;
 HORIZONTAL PLANE SKY AREA 340.52 SQ.CM.

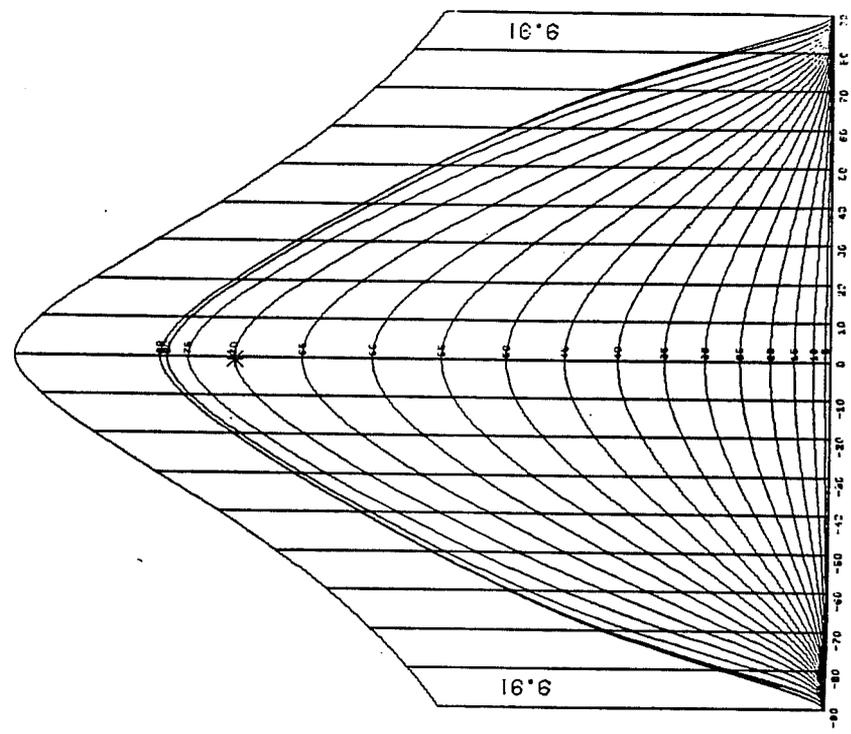




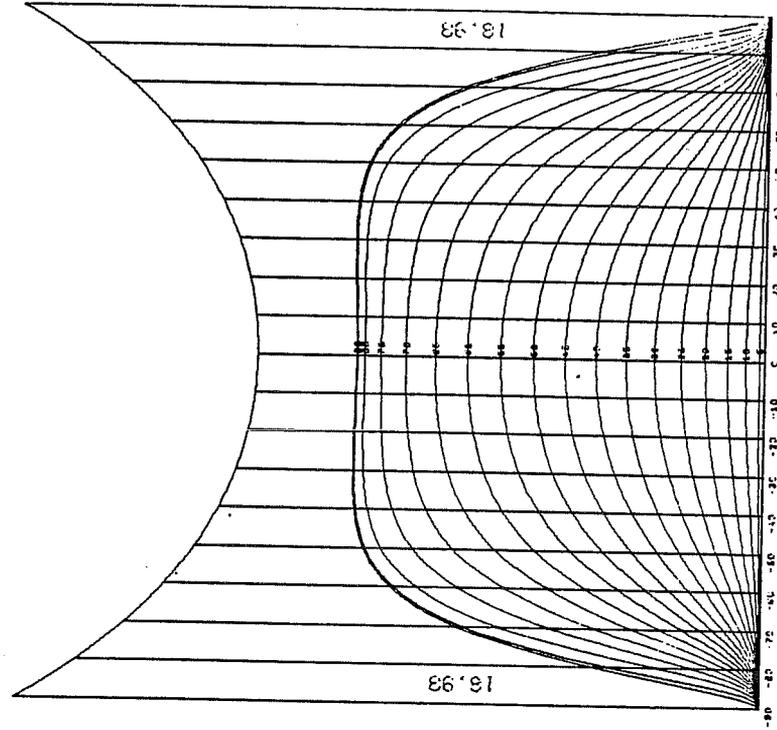




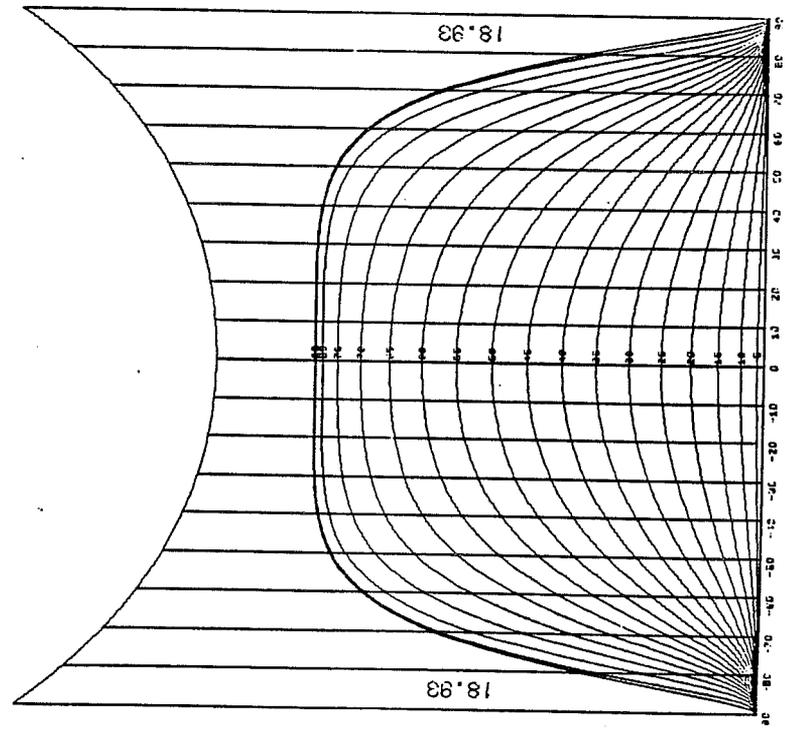
LIAM DIAGRAM
 NAVVAB, M SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 70 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 263.45 SQ. CM.



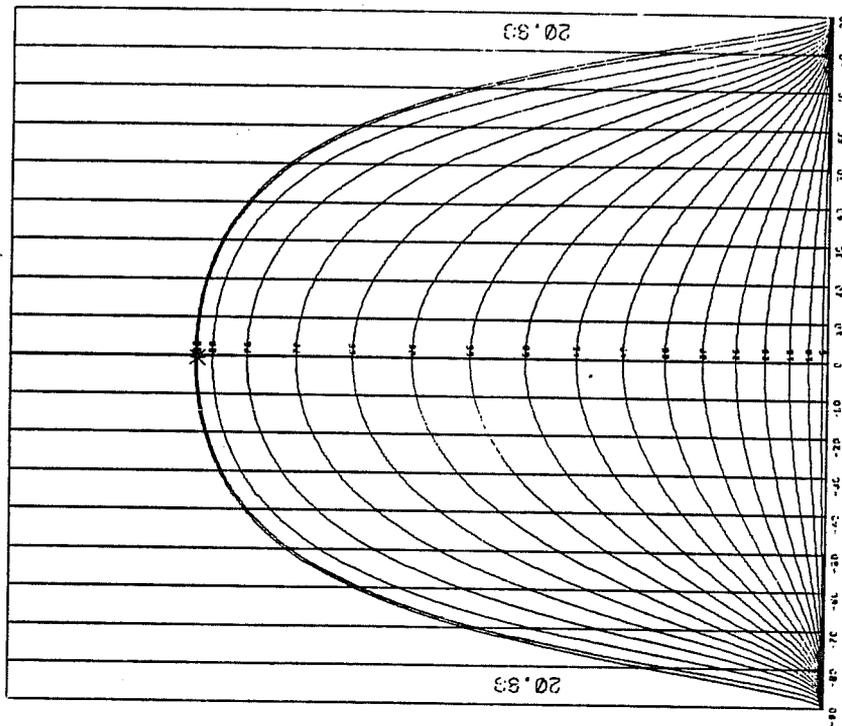
LIAM DIAGRAM
 CIE KITTLER SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 70 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR;
 SKY AREA 273.02 SQ. CM.



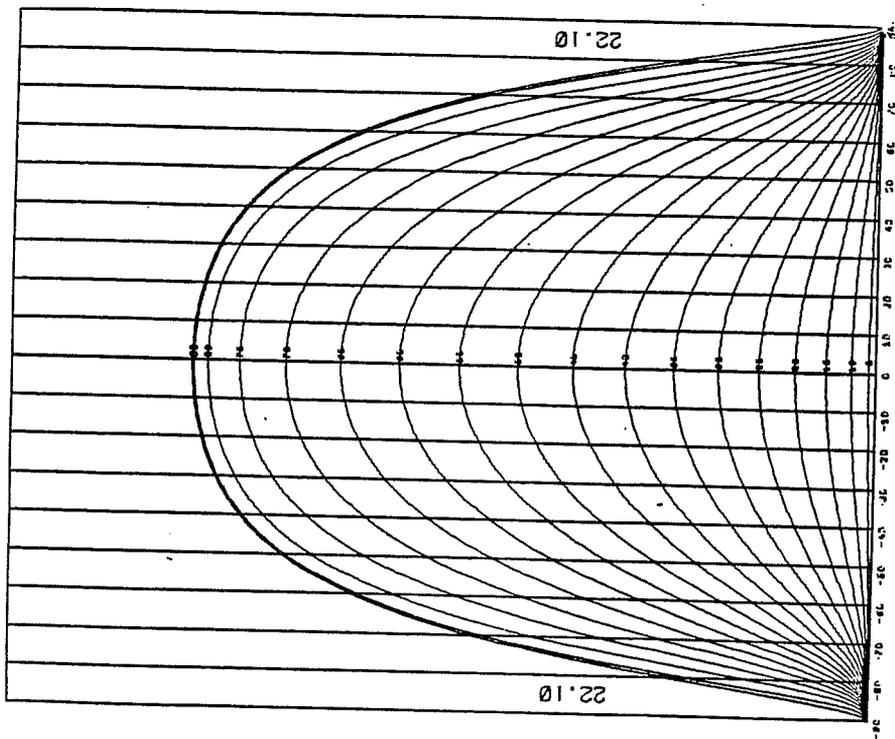
LIAM DIAGRAM
 N.W.B. H. SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 180 DEG
 SOLAR ALT = 70 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR
 SKY AREA 264.22 SQ. CM.



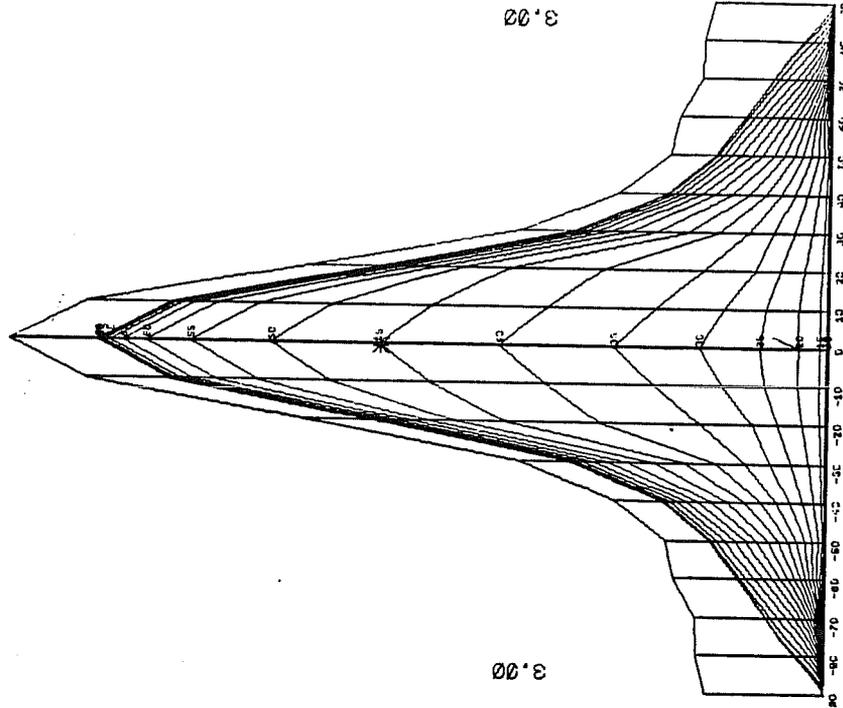
LIAM DIAGRAM
 CIE KITTLER SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 180 DEG
 SOLAR ALT = 70 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR
 SKY AREA 277.23 SQ. CM.



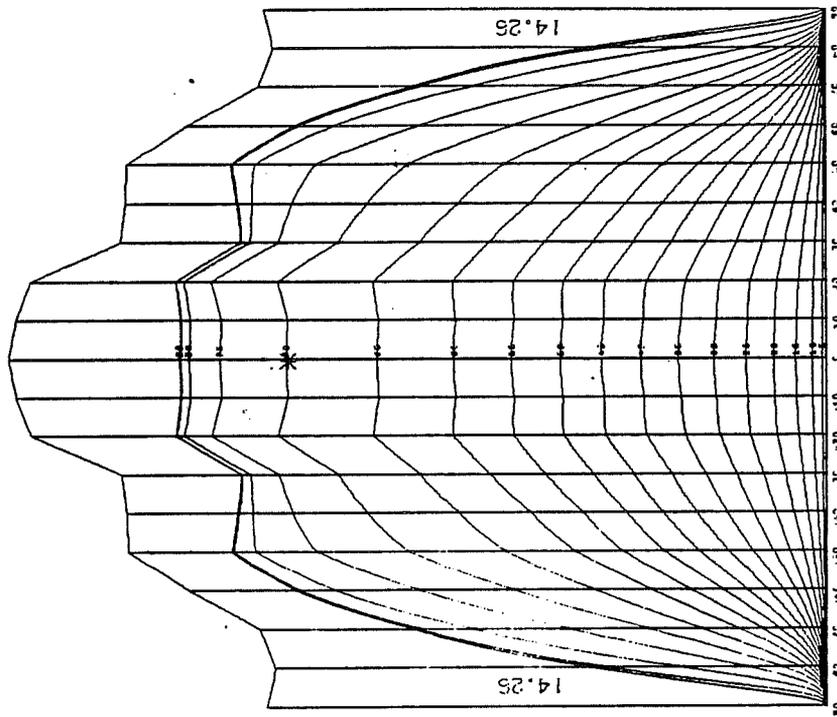
LIAM DIAGRAM
 WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 90 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR
 SKY AREA 374.90 SQ. CM.
 HWYB. H SKY
 HORIZONTAL PLANE



LIAM DIAGRAM
 WINDOW SOLAR AZIM = +/- ∞ DEG
 SOLAR ALT = 90 DEG
 GLASS TRANS = LBL/RUBIN, CLEAR
 SKY AREA 397.76 SQ. CM.
 CIE KITTLER SKY
 HORIZONTAL PLANE



LIAM DIAGRAM
 BERKELEY SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 45 DEG
 GLASS TRANS= LBL/RUBIN, CLEAR
 SKY AREA 143.42 SQ. CM.



LIAM DIAGRAM
 BERKELEY SKY
 HORIZONTAL PLANE
 WINDOW SOLAR AZIM = 0 DEG
 SOLAR ALT = 70 DEG
 GLASS TRANS= LBL/RUBIN, CLEAR
 SKY AREA 313.45 SQ. CM.