ILLUMINANCE LEVELS AND LUMINANCE DISTRIBUTIONS IN SUNLIT ATRIA WITH DIFFERENT CANOPY SYSTEMS AND WELL CONFIGURATIONS

A Dissertation

by

KYOO DONG SONG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 1993

Major Subject: Architecture

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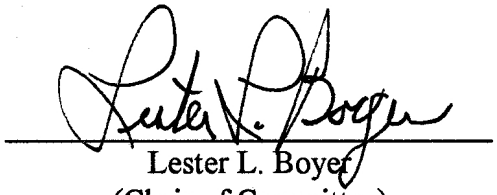

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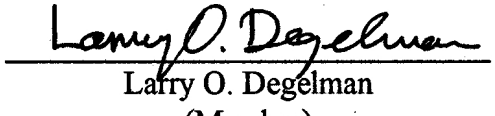

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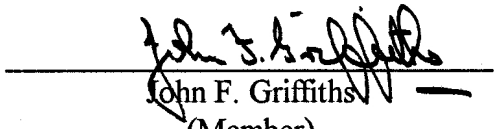

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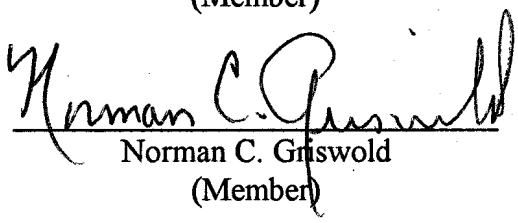

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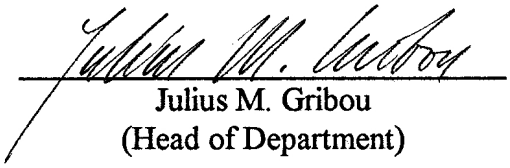

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ABSTRACT

Illuminance Levels and Luminance Distributions in Sunlit Atria with Different Canopy Systems and Well Configurations. (December 1993)

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Chair of Advisory Committee: Dr. Lester L. Boyer

The goal of this study is to provide building designers with daylighting and sunlighting performance data and design guidelines for sunlit atria with different well and canopy configurations which can be referenced during the early stages of an atrium design.

Several instrumentation systems were developed to overcome the limitations of conventional photometric instruments. The instrumentation systems include a video-based luminance mapping system to determine geometric and photometric daylighting parameters and an integrating box to measure hemispherical transmittance of canopy systems. Then, a total of seven different atrium well configurations and a total of thirty-six atrium canopy configurations were parametrically evaluated with physical scale models in terms of their impacts on the illuminance levels on the atrium floor and luminance distributions on the walls under different sky and sunlight conditions.

To obtain daylighting performance data, lighting measurements were conducted in a large-scale sky simulator which can create clear and overcast skies. To obtain net sunlighting performance data, lighting measurements were conducted with an artificial sun at an outdoor location at night.

Initial data analysis for diffuse skies was performed with Base Case Daylight Factors obtained without canopy. Then, Effective Transmittances of each canopy system at different atrium well configurations were determined as the ratio of canopy-covered Daylight Factors (DF) to the Base Case Daylight Factors. In addition, daylight luminance distributions and Luminance Ratios on the atrium walls were determined from luminance distribution maps captured by the video-based luminance mapping system.

Data analysis for sunlit atria was performed with Sunlight Illuminance Ratios (SIR) obtained with and without canopies. Furthermore, a new method was developed to quantitatively evaluate sunlight patches on atrium walls using the video-based luminance mapping system and physical scale models. With this method, it is possible to account for the locations and sizes of sunlight patches.

An example is presented to show how to determine the combined effect of diffuse daylight and sunlight contributions on the atrium floor using DF and SIR together with actual outdoor illuminance data.

Finally, an existing atrium building was selected to demonstrate the application of the findings of this study in the field.

ACKNOWLEDGMENTS

As with this dissertation, I would like to extend my gratefulness to many people for invaluable encouragement and support. I would like to express greatest appreciation to Dr. Lester L. Boyer, chairman of the advisory committee, for his encouragement, advice, and insight throughout my Ph.D. program at Texas A&M University. I also would like to thank Professor Larry O. Degelman, member of the advisory committee, for his encouragement and helpful advice throughout this study. Particular thanks are due to Dr. John F. Griffiths at the Department of Meteorology and Dr. Norman C. Griswold at the Department of Electrical Engineering, members of the advisory committee, for their helpful suggestions throughout this study.

I would like to extend my gratefulness to Dr. Jang-Yeul Sohn at the Department of Architectural Engineering, Hanyang University, Seoul, Korea, who encouraged me to consider a futuristic view of life ten years ago when I was in my first master program.

I would like to remember Dr. Eren Erdener, Professor Joel K. Dietrich, and Professor M. Iver Wahl at the College of Architecture, University of Oklahoma, Norman, Oklahoma, thesis advisors of my second master program, for their encouragement and support during the early days of my life in the United States.

I also very much appreciate Mr. Gon Kim's assistance during the lighting measurements. He spared me substantial amount of his precious time. Furthermore, I would like to extend gratefulness to all Korean fellow students at the Department of Architecture for their encouragement.

This study could not have been completed without the support from the Center for Energy and Mineral Resources of Texas A&M University. Major financial support was provided by the institute for two contiguous years from September 1991 to August 1993. I also would like to thank CRSS Architects, Inc., Houston, Texas, for awarding me the William Wayne Caudill Research Fellowship during the early stage of this study.

Last but not least, I am deeply in gratitude to my wife, Kang-Yi, daughters, Jeeyoung and Minyoung, and son, Doheon for their endless love.

For my father and mother

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NOMENCLATURE

BCDF	Base Case Daylight Factor measured without canopy [%]
BCSIR	Base Case Sunlight Illuminance Ratio [%]
CDF	Corrected Daylight Factor considering light reduction factors [%]
CF	Configuration Factor
CSIR	Corrected Sunlight Illuminance Ratio [%]
CU	Coefficient of Utilization
DDF	Design Daylight Factor [%]
DF	Daylight Factor [%]
DSC	Direct Sun Component [lux]
DSIR	Design Sunlight Illuminance Ratio [%]
EP	Equidistant Projection
ERC	Externally Reflected Component [%]
ET	Effective Transmittance [%]
FF	Framing Factor [%]
HT	Hemispherical Transmittance [%]
IRC	Internally Reflected Component [%]
LI	Luminance Index
LLF	Light Loss Factor
LR	Luminance Ratio
OP	Orthographic Projection
PAR	Plan Aspect Ratio
SAR	Section Aspect Ratio
SC	Sky Component [%]
SIR	Sunlight Illuminance Ratio [%]
SPL	Sunlight Patch Location [elevation angle, ° or deg.]
SPS	Sunlight Patch Size [Configuration Factor, no unit]
WI	Well Index
WWI	Waffle Well Index
$\overline{L}$	average field luminance [cd/m²]
θ	incident angle of light or elevation angle of a wall element [° or deg.]
ρ	reflectance [%]
ϖ	solid angle of a surface source [sr]
δ	thickness of each linear member for FF calculation [in.]

NOMENCLATURE (CONTINUED)

τ_θ	transmittance of sunlight at incident angle θ
τ_h	transmittance of flat horizontal skylight
A	bottom area of skylights for FF calculation [m², in², or ft²]
d	distance [m, in., or ft]
D	distance from surface source to a receiving point [m]
$d\omega$	solid angle of infinitesimal area [sr]
dE	illuminance of infinitesimal area [lux]
d_{ep}	distance from the center in equidistant projection image
dL	luminance on infinitesimal point source [cd/m²]
d_{op}	distance from the center in orthographic projection image
dS	area of infinitesimal element on surface source [m²]
dS'	area of infinitesimal element on the surface of a unit hemisphere [m²]
dSo	orthographic projection area of an infinitesimal surface element [m²]
E	illuminance [lux]
E_c	average of light intensity measured with canopy (for HT calculation) [lux]
E_{crit}	illuminance criterion [lux] (1000 lux in this study)
E_{di}	indoor horizontal illuminance measured under diffuse sky [lux]
E_{dic}	indoor horizontal illuminance calculated for clear sky [lux]
E_{do}	outdoor horizontal illuminance available from unobstructed diffuse sky [lux]
E_i	illuminance of a pixel [lux]
E_o	average of light intensity measured without canopy (for HT calculation) [lux]
E_p	indoor illuminance at point P [lux]
E_{si}	indoor horizontal illuminance measured under direct sunlight only [lux]
E_{so}	outdoor horizontal illuminance from direct sunlight only [lux]
h	height [m, in., or ft]
l	length [m, in, or ft]
L	luminance [cd/m²]
L_i	pixel luminance in video image [cd/m²]
L_s	average luminance of remainder of the field of vision (surrounding) [cd/m²]
L_v	average luminance of visual task area [cd/m²]
M	luminance emittance [rlx or lm/m²]
n	number of pixels in orthographic projection image of surface source
N	total number of pixels in orthographically projected circle

NOMENCLATURE (CONTINUED)

r	radius of orthographic projection circle [m]
S	total area of surface source [m²]
S'	area of surface source on the surface of a unit hemisphere [m²]
S_o	orthographic projection area of a surface source on unit circle [m²]
sr	steradian (unit of solid angle)
w	width [m, in., or ft]