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Abstracts of Daylighting Research

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Prepared for:
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The bibliography is organized under the following major headings:

1. Daylighting - Books
2. General
3. Energy Saving Design
4. Tools - Design and Research
5. Control Systems
6. Models
7. Skylight Research and Applications
8. Atria
9. Daylight/Sunlight Measurements
10. Fenestration Systems - Design & Construction
11. Shading Devices
12. Delivery Systems - Sunlight/Daylight
13. Responses to Light
14. Case Studies

Within each category, the entries are organized by date, with the most recent publication appearing first. This procedure was followed to facilitate the identification of most recent work.

Finally, some entries thought to be worthy of inclusion in the report do not contain abstracts, because they were not readily available.

Table of Contents

1. Daylighting - Books

Robbins, C.L., "Daylighting Design and Analysis", Van Nostrand Reinhold Co. Inc., New York, NY, 1986.

All aspects of daylighting in commercial, institutional, industrial and residential buildings are discussed. All types of buildings in all geographic areas are examined with extensive case studies, models, analytical tools and data for calculation of annual cost and energy savings also are included. This book features newly developed computer, factorial, graphic and modeling analysis formulas, nomograms, material reflectances, illuminance categories, and cooling load factors.

"Illumination Engineering" Murdoch, J.B. Macmillan Publishing Co., New York, NY, 1985.

This book covers the state-of-the-art in illumination knowledge. It provides a broad, practical foundation in the science and mathematics of light, sight, and seeing; teaches the analytical tools and skills required for lighting calculations, and describes lighting measurement techniques in detail. Chapter 9 is devoted to daylighting principles and applications.

"Designing for Daylighting, A Key to Energy Performance", Silver Spring, MD: McGraw-Hill Information System, March 1984.*

The following aspects of daylighting are discussed: benefits and applicability, sources and fundamentals, siting and building form, space and fenestration layout, integrated lighting design, performance estimation, solar and lighting controls, and additional resources.

Evans, B.H., "Daylighting in Architecture", New York: Architectural Record Books, 1981.*

This is an excellent, non-mathematical text for daylighting design. Its section on evaluating energy and economic performance, however, is limited.

Lam, W.M.C., "Perception and Lighting as Formgivers for Architects". New York: McGraw-Hill, 1977.*

The psychology of visual perception is a primary thesis in this text. Professional experience is the source for much the information provided. Many case studies are presented with photographs.

Turner, D.P., "Windows and Environment", London: Architectural Press, 1971.*

There is an excellent qualitative treatment of daylighting in first section, and a fine technical treatment in second section.

Emery, A.F., "Daylight in Architecture", New York: McGraw-Hill, 1971.*

This design-oriented book is intended as a primer. It is strong on basic concepts and model testing, weak on calculation methods. It is a good place to start for those entering the field.

Hopkinson, R.G., and J.D. Kay, "The Lighting of Buildings", New York: Frederick A. Praeger, 1969.*

Basic lighting and visual concepts are covered in the early chapters of this book. A chapter is dedicated to daylighting. The last half of this book examines different lighting strategies for various building types. Residential, schools, factories, and other building types are covered.

Lynes, J.A., "Principles of Natural Lighting", London: Elsevier Publications, Ltd, 1968.*

This is a good general source on daylighting. The chapter "Instrumentation for Daylight Studies," (pp. 62-89) is especially useful, covering daylight photometry (principles of photoelectric instruments, and precautions necessary to their proper use), scale models, and artificial skies. The principles and implications of illuminated-vault and mirrored-box skies are considered. It includes a bibliography.

Hopkinson, R.G., Petherbridge, P., and Longmore, J., "Daylighting", London: Heineman, 1966.*

This is an excellent resource for daylighting research and design methods, including sections on sky luminance, daylight photometry, models, and artificial skies. Chapters 13-15 (pp. 333-394) should be required reading for those considering the construction of an artificial sky. This text is dated. It does not include current I.E.S. methods. Good bibliographical references are presented at the conclusion of each chapter.

Larson, L., "Lighting and Its Design", New York: Whitney Library of Design, 1964.*

This book is almost exclusively devoted to artificial illumination, but includes many fine examples of architectural achievements in illumination design.

Phillips, D., "Lighting in Architectural Design", New York: McGraw-Hill, 1964.*

This book covers lighting from a design viewpoint. Principles and criteria useful in establishing design goals are discussed as well as natural and artificial strategies. Computation techniques are also covered, but are dated.

Hopkinson, R.G., "Architecture Physics: Lighting". London: Her Majesty's Stationery Office, 1963.*

A general approach to lighting, including daylighting are covered. Much of the information is based on studies performed in the 40s and 50s on the effects of lighting on people. The daylighting calculation chapters are based on the Daylight Factor method, with examples included. Model making is also presented as a recommended daylighting analysis. In general, it is a good source book, but not valuable for the practitioner.

Walsh, W.T., "The Science of Daylight", London: Pitman Publishing Corp, 1961.

This work is a good general source of daylight photometry, daylight illumination and sky luminance, and model studies. Chapter 8: "The Use of Models" includes the topics of scale models for daylighting studies, illumination measurements inside with photovoltaic cells, and artificial skies.

Kohler, W., and Luckhardt, W. "Lighting in Architecture", New York: Reinhold Publishing Company, 1959.*

Architectural implications of lighting are presented here. Many black and white, and color photographs help convey the thesis. This book is a good source of general, although dated, information.

2. General

Flowers, L.T., Groff, G.C., "Application of Solar Technologies in Buildings", 2d World Congress on Heating, Ventilating, Refrigerating and Air Conditioning, Sarajevo, Yugoslavia, Aug-Sep 1989.

The objective of the building energy research carried out at SERI is described as follows: to provide the building industry with technological innovations in materials, components, and systems that enable them to reduce the usage and cost of including advanced windows, storage material composites, advanced insulation, desiccant cooling, air management, and active water heating. This paper outlines the benefits, the results to date, and current research activities associated with these eight different technology options.

Oatman, P.A., Robbins, C.L., "Daylighting and Passive Solar Energy Systems in Commercial Buildings", Energy Engineering, Vol. 86, No. 1, Jan 1989, pp. 6-20.

Information on passive solar concepts is presented, emphasizing the use of appropriate passive solar concepts in non-residential buildings for the U.S. Air Force. The paper discusses the analytic process used to evaluate the various passive solar strategies considered and provides results for one climate region.

Johnson, C.A., Besant, R.W., Schoenau, G.J., "Energy Economic Trade Off Studies Recommended to Enhance the Use of Daylighting in Large Office Buildings in Canada, Renewables - Clean Energy Solution", Conf. Proc., 15th Annual Conf. of the Solar Energy Society of Canada, Penticton, June 1989.

New energy economic research studies on daylighting for Canadian office buildings are identified. To illustrate proposed computer simulations, a study is presented which includes the analysis of a daylit building in terms of lighting control schemes, window area and glazing types. The building performance and economic analysis of a daylit building is compared to the same non-daylit building for four North American locations and two utility rate structures. In most cases, the daylit building had the lowest life-cycle cost but more studies are required to reduce the risk and uncertainty of daylighting design in Canada where weather and solar irradiance conditions are worse than those in the U.S.

Fanchiotti, A., "Recent Advances on Daylighting: European Concerted Action Programme, Bioclimatic Architecture, Energy conservation and Environmental Quality: Prospective and Applications in the Design and construction of Public Buildings and Schools". Proc. of the ISES Meeting Held in Rome (Italy), 9-10, Nov 1988.

The program described is intended to provide designers with updated and reliable information and tools to use daylighting concepts and components in designing large, non residential buildings, with predominantly diurnal occupations, to improve the visual quality of the working environment, and save energy generated from non-renewable sources. The paper describes the expected final results and presents findings in the various research areas, based on work during the first three semesters.

Johnson, C.A., Besant, R.W., Schoneau, G.L., "Daylighting in Large Office Buildings: Energy Economic Parameters and Opportunities", Energy Solutions for Today, 14 Annual Conf. of the Solar Energy Society of Canada, Inc. Ottawa, Can. June 1988.

Recent literature on daylighting is reviewed and computer simulation packages for daylighting analysis are compared. Life cycle costs are analyzed for a large office building in Saskatoon, Saskatchewan, with and without daylighting in new office buildings in Canada are estimated. The paper concludes that daylighting may lead to significantly lower operating and life cycle costs and to high levels of occupant satisfaction.

Wulfinghall, D.R., "Hidden Problems in Daylighting", Construction Specifier, Vol. 40, No. 6, June 1987, pp. 92-95.

Factors that cause a net increase in energy consumption by using daylighting are examined. These include: visual desensitization, inadequate artificial lighting control, irrational window treatment, and lack of effective thermal shutters and shading. Looking ahead, the problems of shading and insulation could be simplified by two developments: glazing materials with high thermal resistance, and glazing materials with highly variable capacity. A design obstacle unique to daylighting is the difficulty of visualizing conditions inside completed buildings.

Luginbuehl, R., "Intensive Use of Daylight in Office Buildings - Measurements", Status Seminar on Energy Conservation in Buildings, Zurich, Switz, Oct 1986.

Research findings on intensive use of daylight at work are presented. The study, comprises four phases: comparison of systems, model experiments, demonstration plants, evaluation. The goal was to reduce lighting costs by at least 30% in offices and industrial buildings with work places 1 to 6m distant from the window. This goal was reached and even exceeded. Even at a distance of 3.75m from the window, artificial light can be turned off for at least 60% of the working hours.

Mac Gowan, D., Emery, A.F., "Window Architectonics in the Automated Office", 10 CIB Congress on advancing Building Technology, Washington, DC, Sep 1986.

This paper reviews the early work of Hopkinson, which led to the current international inter-institutional findings and directions, and implications for lighting design. It describes the impact of his research on the architectural and ergonomic design of large-scale automated offices, by defining criteria for window size, contact with the exterior, interior space, discomfort glare, apparent daylighting, and building energy use. The paper describes luminous environmental designs appropriate for video display terminal equipped automated office work stations. It includes comments on the influence of age and visual disability, and the limitations imposed by employing "norm" based luminous design criteria.

Gardner, P., "Practical Lessons in the Use of Energy Management Systems for Improving Overall Management of Building Services", The Factory Efficiency Show and Conf., Birmingham, UK, Sep 1986.

The principal sources for energy cost reduction obtainable with advanced monitoring and control systems are described. The UK Department of Energy has encouraged the application of the latest systems with its Energy Efficiency Demonstration Scheme (EEDS). Twenty-nine demonstrations of the latest electronic energy management techniques are under way. About one-third of them involve dedicated control techniques, including automatic switching of lighting in office buildings, schools, and factories, on the basis of working time patterns and ambient daylight levels.

Gordon, H.T., Rittelmann, P.R., Estoque, J., Hart, G.K., Kantrwoitz, M., "Passive Solar Energy for Non-Residential Buildings: Performance Overview", Advances in Solar Energy, An Annual Review of Research and Development, Vol. 3, American Solar Energy Society, 1986, pp. 171-206.

A major research and development effort to advance the-state-of- the-art of knowledge of passive solar design for non-residential buildings is summarized. In 1979, the DOE launched the Non-residential Experimental Buildings Program to investigate the potential of passive solar technologies to meet the heating, cooling, and lighting requirements of non-residential buildings. After five years, 19 buildings have completed the design and construction phases. Results have been compiled on energy consumption, economic performance, and occupancy effects.

Ander, G., et al., "Daylighting, Performance and Design", Rosemead, CA: Southern California Edison, 1986.*

A good introduction to daylighting, lighting control strategies, design tools and methods is presented. Included are nomographs developed by Edison from LBL data that can provide designers with a quick method of predicting KWH reduction in electric lighting systems when daylighting is used in southern California latitudes.

McCluney, R., "Daylighting in America" Lighting Design and Application, July 1985, pp. 36-38.*

Reasons are given to explain why daylighting is perceived to be complicated, difficult and costly. Fifteen guidelines for fenestration placement and sizing are presented, and discussed in the Appendix. Suggestions are made that building design professionals obtain a sunpath diagram for the chosen site, become familiar with various fenestration products, and develop a good understanding of discomfort and disability glare.

Germer, J., "State of the Art: Daylighting," Solar Age , Dec 1984, pp. 15-16.*

The controversy over the energy saving effects of daylighting with respect to improving efficiency of artificial lighting and poor daylighting designs is explored. The paper stresses the importance of building energy loads, climate, site, and design. Several design tools are mentioned; for example, DOE2, ab, MICROLITE, Daylight, and CADlight. Controlling glare and contrast, integrated daylighting and electric lighting are listed as common design obstacles.

Brown, J.P., "Evolutionary Trends for the Graphic Daylighting Design Method" Proc. of the 9th National Passive Solar Conf., Boulder, CO: ASES, Sep 23, 1984.*

The graphic daylight design method developed by Millet and Bedrick utilizes computer-generated overlays based on three basic ratios. These overlays can be graphically manipulated to generate isobars of proportional illumination. This paper discusses evolutionary trends in using this system.

Bowen, A, and Yannas, S., eds., "A Systematic Graphical Procedure for Determining Window Dimensions" Passive and Low Ecotechniques, Elmsford, NY: Pergamon Press. Presented at Conf. on Passive and Low Energy Alternatives, Mexico City, Aug 6, 1984.*

A graphical procedure is developed to aid the designer in deciding on appropriate dimensions and location of windows in buildings. Assuming that providing natural light in a space is a major window function, the procedure builds on lighting level calculations including the external reflected component, internal reflected component, shading coefficient, type of glass, and type of frame. The function of the space determines the required lighting level and alternative values are given for window sill and top height. The depth and width of the internal space are also considered. The final determinant in the procedure is the window width.

Sweitzer, N., and Johnson, R., eds., "Obstacles to the Use of Exterior Fenestration and Daylighting Control Systems in the U.S." Presented at Windows in Building Design and Maintenance Conf., Gothenburg, Sweden, June 13, 1987.*

Exterior fenestration and daylighting control systems can provide excellent control of solar gain and glare while being visually satisfying elements of building envelopes. However, U.S. building industry experience with exterior fenestration and daylighting control systems suggests that durability and system functioning is often unsatisfactory. Yet in Western Europe, exterior systems are a proven, cost-effective, and aesthetically accepted fenestration design element. Contrasting operating experiences reflect differences in prevailing U.S. Western European approaches to building design, construction, and operation. Three representative U.S. buildings are examined; each describing the application of exterior fenestration/daylighting control components previously untested as a system. Some unsatisfactory consequences are described.

McCluney, R., "Daylighting: A New Use for an Old Source" Proceedings of the Utilities and Lighting Seminar, San Francisco, CA, May 23, 1984.*

Electrical lighting of interior building spaces is a relatively recent innovation, reaching its peak during the period of low electrical costs in the 1950s and 1960s. With rising electric utility rates, building designers are again turning to the sun as an inexpensive illumination source. To be effective, old daylighting design principles must be relearned, recent research results improving old design methods must be exploited, and new design tools developed. The science and art of daylighting design have been improved. At the heart of daylighting design (and also important for most naturally ventilated buildings) is fenestration. Fenestration is defined as any glazed aperture (opening) in a building designed to control the admission of solar radiant heat and light. A fenestration system is a set of individual fenestrations organized to provide overall illumination of a building's interior spaces. Typical fenestration elements include: windows, skylights, clerestories, roof monitors, glass doors, and glass brick walls.

Gillette, G., "The Case for Daylighting" The Construction Specifier, Vol. 37, No. 3, Mar 1984.*

The importance of integrating daylighting design with total building design is stressed. Suggestions are given for using computers to predict energy performance, and methods for selecting aperture treatments and sizing. Peak electric load reductions are also discussed.

McCluney, R., and Houston, M. "Shading and Daylighting Design of Building Fenestrations," Principles of Low Energy Building Design in Warm, Humid Climates, Cape Canaveral, FL, Florida Solar Energy Center, 1984.*

Solar radiation can be the major source of overheating in buildings located in a warm, humid climate. Analysis indicates that on a 'design day', more than half of the cooling load for a home in central Florida results from solar radiation striking building surfaces and entering windows. Both surface and window shading are important to good building design in overheated climates. The design of building fenestrations is discussed.

Crowley, J.S., and Zimmerman, L.Z., eds., "Fenestration Guidelines: The Design and Placement of Windows" Practical Passive Solar Design, New York: McGraw-Hill, 1984.*

The relationship of climate to passive solar housing design is discussed. Descriptions of the four broad climate regions of the U.S. identify the general conditions to which solar dwelling and site design must respond. Climate-specific recommendations for window U-values may be achieved by using one of the following combinations: double or triple glazing; double glazing with night insulation; double glazing plus storm sash or low emissivity coatings and films. Charts are presented, showing the effects of window orientation and window glazing on energy consumption for three climate regions.

Lindsey, L., and W. Hallagan, "Solving the Mysteries of Natural Lighting" Solar Age, Sep 1983, pp. 27-33.*

This article includes the Design Tools Workshop, Models and Micros, Advanced Tools at the International Daylighting Conference. in Phoenix. The advanced tools described include MICROLITE for Apple and IBM-PC,, LUMEN-MICRO, DAYLITE, SOLITE, SUPERLITE, DOE 2.1b. It includes an overview of some papers presented.

Treado, S.J., and Gillette, G.L., "Effective Use of Daylighting", Final Report. Presented at the 10th Energy Technology Conf., Washington, DC, Feb 28, 1983, pp. 647-655.*

Daylighting design considerations, procedures, and guidelines for effective fenestration utilization are described in this paper. Daylighting is effective because the luminous efficacy of solar radiation is greater than electric lighting. Use of skylighting, toplighting, clerestory windows, and reflective louvers are discussed. Dimming and switching lighting control system options are compared and specified. Procedures to evaluate fenestration options range from simple charts, graphs, and design day analysis, to programmable microcomputers, to energy analysis computer programs with integrated daylight calculation capabilities. Examples of the latter - from NBSLD-2 to DOE-2- are given. Design guidelines for the Washington DC area are listed.

Wade, H., Cook, J., and Labs, K. "Passive Solar: Subdivisions, Windows, Underground", New York: ASES, 1983.*

A collection of papers illustrating the use of passive solar design is presented. Solar design is traced for the last 100 years. Discussed are design considerations for the mass market, products which enhance the application of passive solar techniques, and market and financing problems. Window design is discussed in terms of glass, air infiltration, air movement, thermal transfer and use as solar collectors. The use of underground buildings is presented from an historical perspective, with consideration for structural design, economics and quality of life.

Millet, M., "Slice of the Sun" Passive Solar: Subdivisions, Windows, Underground, New York: ASES, 1983.*

In the first section of the paper, the influence of climate on daylight design is discussed briefly. Daylighting issues related to energy conservation in large buildings are presented in the second part, and in the final section some new directions in daylighting design are discussed.

Harmon, R.B., ed., "Control of Solar Radiation in Buildings: A Selected Bibliography", Monticello: Vance Bibliographies, 1982.*

Fenestration design synthesizes many factors, including solar radiation control, daylight illumination, direct and reflected glare, the view out, services, and the building structure and fabric, in terms of energy conservation and costs. The review includes books and articles related to these aspects of fenestration design in various types of structures.

Ne'eman, E., and Selkowitz, S., "Efficient Daylighting in Thermally Controlled Environments," Proc. of the Int'l. Passive and Hybrid Cooling Conf. Newark: University of Delaware, 1981.*

Design considerations for a design team to maximize the use of daylight to reduce electric lighting loads and associated building energy consumption, are reviewed. A thorough analysis of heating and cooling loads inside the building and the heat exchange through the building envelope are needed. Data on local climate and sunshine availability also must be considered. Although energy aspects recently have dominated design considerations, daylight's influence on human well-being is gaining importance. The variability of daylight, the quality of its spectral composition, the view out, and health effects, are among the aspects to be considered when determining appropriate daylighting designs in energy-efficient buildings.

Heschong, L., "An Interview with William Lam" Solar Age, Aug 1980, pp. 30-33.*

William Lam has been a lighting design and buildings systems consultant for the past 19 years. This article presents several interesting views on daylighting design and resultant environments.

"Use Solar Daylight & Heat", Pittsburgh Paint and Glass Industries, Pittsburgh, PA, 1980.*

This is a short publication by a glass manufacturer on energy and daylighting. Practical findings are presented in lay terms. The emphasis is on products sold by PPG.

"Recommended Practice of Daylighting", New York: Illuminating Engineering Society of North America, 1979.*

This is a good source of daylighting information. The appendix presents typical examples of the I.E.S. method. Charts and tables required for this procedure are included.

3. Energy Saving Design

Kristensen, P.E., Esbensen, T., "An Innovative Commercial Building-Passive Solar With Optimized Daylighting", Sun at Work in Europe, Vol. 8, Oct 1989.

The design discussed illustrates how the use of fossil fuels in the industrialized world can be reduced by 50% during the coming 50 years with good visual and thermal comfort.

Johnson, C.A., Besant, R.W., "An Analysis of Building Shape and Window Orientation on Energy Performance and Economics for Non-Daylit and Daylit Office Buildings", 15th annual Conf. of the Solar Energy Society of Canada, Penticton, Canada, June 1989.

The effect of building shape and window orientation on energy performance and economics for a daylit or non-daylit office building is investigated. Consideration is given to the effect of varying window area, orientation, and climatic conditions, on building loads. Local energy billing schemes and capital costs are used to determine life-cycle costs and for the daylit building, payback periods. The DOE 2.1C building analysis program is used to determine thermal loads and energy requirements.

Treado, S.J., "Illumination Conditions and Task Visibility in Daylit Spaces", National Institute of Standards and Technology, report No. NISTIR-88/4014, PB-89-189237, Gaithersburg, MD, Mar 1989.

Illumination conditions are evaluated in typical building spaces based on detailed computer simulations, to characterize and quantify the effects of daylighting on task visibility. Examined are the effects of fenestration location and task contrast under daylit, electric-lit and combined conditions. The implications of the illumination conditions with daylighting on lighting and daylighting system design are discussed.

"Evaluation Procedure for Building Energy Performance Prediction Tools: Final Report", Building Energy Design Tool Development Council number 914, Washington, DC, DOE/CE/30752-T3, Nov 1988.

The activities conducted under by the Building Energy Design Tool Development Council (BEDTDC) are summarized. The focus of this work was the development of a rigorous, user oriented procedure to evaluate building energy performance prediction tools. Evaluation reports resulting from the application of this procedure will allow the user to select the most suitable design tool. Professional organizations and individuals carry out the following background research and documentation efforts: 1) survey the state-of-the-art of building energy design tools, 2) review previous building energy design tool evaluation and categorization methods, and 3) develop a design tool categorization method.

Roberson, B.F., Harkreader, S.A., "Focus Group of Daylighting Practices", Pacific Northwest Lab., Richland, WA, Report No. PNL-6740, Nov 1988.

This document is a report of the findings from meetings of focus perceptions and attitudes about daylighting systems.

Julian, W.G., "Considerations in Modern Lighting Design", Light. Aust. (Australia) Vol. 8, No. 4, Aug 1988, pp. 14-23.

The need for lighting systems to provide good seeing conditions and create a suitable atmosphere in buildings is discussed. Difficulties encountered in modern buildings - responding to demanding visual tasks, with simple, overhead lighting systems are noted. The need to consider the integration of daylight and electric lighting is noted. Over-emphasis on energy conservation design, at the cost of visual considerations, rarely produces satisfactory results. Mention is made of developments in lamp and luminaire technology, methods of control, and the assistance available from CAD systems.

Jones, L., Gray, D.B., "Potential Savings Through the Use of Daylighting Strategies", Energy Solutions for Today, 14 Annual Conf. of the Solar Energy Society of Canada, Ottawa, Canada, June 1988.

Potential energy savings associated with daylighting strategies in office buildings, specifically with the reduction and/or elimination of electric lighting when daylight can provide adequate illumination, are described. The authors employed the DOE 2.1B energy analysis modelling techniques using the DOE 2.1B program. Daylighting simulations were first carried out for buildings with no daylighting strategies; then they were remodeled, using three different light switching strategies.

Wilke, D.A, "Cost Effective Daylighting for Large Industrial Buildings", Proc. of Solar 88, the 13th National Passive Solar Conf., Cambridge, MA, June 1988.

Large single level buildings can optimize daylighting use when the roof plane is designed effectively with skylights.
To assure uniform high level illumination with cost effective cooling and heating, balancing the total building architecture and supporting artificial lighting system should be considered. The design should minimize the energy used for electrical lighting during periods of peak utility loading associated with higher rates for users. Multiple sky-lights with triple dome diffusing glazing and a well insulated reflective roof, with variable high pressure sodium variable lighting, will reduce energy loading.

Sullivan, R., Arasteh, D., Papamichael, K., Kim, J.J., Johnson, R., Selkowitz, S., McCluney, R., "An Indices Approach for Evaluating the Performance of Fenestration Systems in Non residential Buildings", ASHRAE annual meeting Ottawa, CA., June 1988.

Results are presented from the first phase of a project to develop a fenestration performance design tool for builders, designers, architects, and utility auditors. The design tool concept is defined, as are experimental and analytical methodologies required to achieve the project goal. Five fenestration performance indices are defined, which, when combined with user specified weighting factors, yield a single figure of merit. Three indices concern the effects of fenestration on building energy performance: fuel and electric use and peak electric demand. The others are related to thermal and visual comfort. The authors derived index values and correlations to window design parameters by creating a data base consisting of a large number of building modules, using the DOE-2 computer simulation program. Four glazing types and two shading devices were combined in several ways to obtain a representative sampling of realistic fenestration systems.

Vio, M., "An Evaluation of Lighting and Energy Efficiencies of Buildings - Energy Alternative", (Italy) Vol. 10, No. 51, Jan-Feb 1988, pp. 23-39. (Italian)

Building shape has a considerable influence on the glazed surface necessary to ensure a given level of daylight for interior illumination. The amount of glazed surface also influences energy consumption for lighting, and the energy efficiency of a building. The implications for lighting and energy efficiencies of some typical buildings are discussed and analyzed.

Jarrell, R.P., Payen, F.W., "Natural Daylighting - an Energy Analysis, Integration of Efficient Design Technologies", Fairmount Press, Inc., Lilburn, GA, 1988.

To promote energy conscious design, a study was undertaken to analyze the implications of using daylighting in designing a structure. Demonstrating how decisions made during the design stages affect the energy efficiency of a structure was a secondary goal. An existing office building was selected for this analysis. Its construction features, materials and equipment were determined and usage data were obtained through owner interviews and on-site investigations. From these data, present energy consumption was estimated using LOADCAL, a computer analysis program based upon ASHRAE methodology. Present daylighting levels were estimated using the procedure developed by Libbey-Owens-Ford.

Dubin, F.S., Bernaden, J.A., Neubauer, R.E., "HVAC Lighting and Other Design Trends in Intelligent Buildings", The Intelligent Building Sourcebook, The Fairmont Press Inc., Liburn, GA, 1988.

Intelligent building design requires: a building envelope which reduces heat loss and gain through insulation and thermal mass; moisture control, achieved by properly locating vapor barriers and external shading devices to reduce glare and solar heat gain; properly located windows, equipped with insulating glass, heat rejection glazing, and light shelves or other devices capable of reducing glare and reflecting daylighting into the building's space; double or triple glazing, to prevent window condensation; vertical shafts for duct work and power and communication cables, larger than those typically used, and strategically located, to reduce horizontal distribution runs.

Campbell, J., O'Sullivan, P., "Use of Passive Solar Energy in Offices", Passive Solar Energy in Buildings, Elsvier Applied Science Publishers, London, GB, 1988, pp. 23-33.

The optimal use of daylight to reduce energy consumption is considered. The topics covered include building design and form, shading of windows to control solar gain and features, such as atria. Careful design can reduce or eliminate the need for air-conditioning while retaining the advantages of solar gain.

Treado, S.J., Holland, D.B., "Fenestration Design for Office and Residential Buildings", National Bureau of Standards, Gaithersburg, MD, NBSIR-86/3489, Jan 1987.

The influence of fenestration design on energy performance and illumination conditions in office and residential buildings is examined, and recommendations given for effective design of fenestration systems to meet occupant requirements. Particular emphasis is given to various shading strategies, such as blinds, shades, light shelves and fins, and their impacts on interior daylight levels and distribution, illumination quality an energy requirements. A comparison is made between the total daylight gain into the building and 'useful daylight' - defined as being potentially useful in offsetting electric lighting requirements. Significant improvements in daylighting, electric lighting, and thermal performance, are shown to be possible with various fenestration designs.

Bobenhausen, W., Lewis, S., Daylighting. Part II: "A Comparison of Differing Strategies for Two University Projects", Journal of Environmental Systems, Vol. 16, No.3, 1986-1987, pp. 195-200.

Comparisons are made of daylighting strategies and analytic techniques employed in designing two university buildings. Siimilar performance levels were achieved within the context of two different sets of architectural aesthetics and client requirements. The buildings discussed have comparable hours of occupancy and are located in climatically similar cities.

Bobenhausen, W., Lewis, S., "Daylighting. part I: Impacts of Daylighting on Electrical and Cooling Peak Demands in Commercial Buildings", Journal of Environmental Systems, Vol. 16, No. 3, 1986-1987, pp. 187-194.

This article illustrates the effects of daylighting as a major conservation and load management strategy for a theoretical eight story office building of 120,000 gross square feet. Holding the basic building design constant, daylighting benefits are analyzed for five different cities (New York, Phoenix, Chicago, West Palm Beach and San Francisco) and their utilities. Detailed analysis is limited to implications for New York City, with an existing stock of over 250 million square feet of office buildings.

Ruck, N.C., "Letting in the Daylight", Building Research and Practice, Vol. 14, No. 5, Sep-Oct 1986, pp. 294-300.

In an earlier paper the author described the work of the Lighting Research Unit in the Architectural Faculty of the

University of New South Wales, Australia, which used of a prismatic panel to beam daylight into buildings. Here, this research is placed into a broader context, reviewing developments world-wide, designed to optimize window use in building design - minimizing energy costs while improving the visual environment.

Maitrya, V.K., Sharma, M.R., "Energy Optimized Fenestration Design for Office Buildings", CID'86: Advancing Building Technology, United State National Committee for CIB, Washington, DC., Sep 1986.

This article addresses the thermal problem caused by fenestration systems by considering the total energy balance of exposed surfaces. Estimating the time integrated heat intrusion for various transparency ratios is a useful parameter to determine the optimum fenestration area. The OTR values are considered useful in determining the optimum size of the glazed area to minimize energy requirements.

Arasteh, D., Johnson, R., Selkowitz, S., Connell, D., "Cooling Energy and Cost Savings with Daylighting in a Hot and Humid Climate", Sunworld, Vol. 10, No. 4, 1986, pp. 104-109.

The study describes the results of building energy simulations, and discusses lighting energy savings from daylighting and the effects of fenestration parameters on cooling loads, total energy use, peak demand, chiller sizes, initial and operating costs. The impact of daylighting as compared to electric lighting on cooling requirements is described as a function of glazing characteristics, location, and shading systems.

Steadman, P., Brown, F., Hawkes, D., Owers, J., Rickaby, P., "Estimating the Exposed Surface Area of the Domestic Stock", Proc. of an Int'l. Seminar on Urban Built Form and Energy Analysis, Cambridge, UK, June 1986.

A method to estimate the total area of exposed surface (walls and roofs) given data on floor areas and a specified mix of dwelling types is described. Studies of house plans from the city of Cambridge, broadly representative of the British stock as a whole, show strong similarities between the relationship of exposed wall area to floor area for different dwelling types. The paper also considers the relationships of: roof area to floor area for different dwelling types and, glazed area to exposed wall area.

Aydinli, I.S., "The Responsibility of the Optimization of Daylight and Solar Radiation in the Interior", Int'l. Symposium on Energy and Building Envelope, Thessaloniki, Greece, Apr 1986.

Optimizing building design with respect to costs and energy consumption is possible only if electric lighting cooling and heating are taken into account together with daylight and solar radiation in the interior. The main optimization parameter is window size, where a minimum size is necessary for an acceptable view out. Larger window areas decrease energy consumption for electric lighting but increase cooling and heating costs. Artificial lighting, heating and cooling systems are described, which are responsive to different sky conditions, while optimizing daylight and solar radiation in interiors.

Usibelli, A., "Technologies and Strategies for Savings Commercial Sector Energy", 13th Annual Energy Technology Conf. and Exposition, Energy Technology, Vol 13, Mar 1986., pp. 1276-1287.

Key findings of an extensive study sponsored by two California utilities are presented. Commercial sector opportunities for electric energy and peak load savings are noted. Selected energy conservation technologies are examined for major end-uses in commercial buildings including cooling ventilation refrigeration, electric motors, electric lighting, and daylighting. For each conservation technology or strategy, the costs, applicability, energy and power savings potentials, lifetime, and other key characteristics are investigated, emphasizing real world installations, wherever possible. This work attempts to analyze numerous commercial conservation technologies in a consistent and comparable framework. The major emphasis is on electricity conserving technologies in California climate, but many results apply throughout the U.S.

Selkowitz, S., "Influence of Windows on Buildings Energy Use", Proc. of Windows in Building Design and Maintenance, EI Conf. no. 10000, 1987.

Window system design and operation have a major effect on energy use in buildings and on occupant thermal and visual comfort. Window performance is a function of optical and thermal properties, window management strategies, climate and orientation, building type and occupancy. In residences, heat loss control is a primary concern, followed by sun control in more southerly climates. In commercial buildings, the daylight provided by windows may be the major energy benefit.

Becker, E.D., "Daylight and Architecture. A Feasible Way to Save Energy and Add to the Quality of Life", Mueller, Karlsruhe, Germany, 1986. (German)

Natural lighting is suggested as an alternative to artificial illumination and sophisticated air conditioning of public and commercial buildings. Fundamental daylighting knowledge and results obtained in the U.S. and in the Federal Republic of Germany are described. A methodological model uses reflectors to divert the daylighting radiation in offices to work areas for individuals and teams.

Moore, F., "Concepts and Practice of Architectural Daylighting", Lighting Design and Application, Vol. 16, No. 3, Mar 1986, pp. 58-64.

Examples of daylight utilization in the architecture of ancient Egypt, Greece, Rome, Byzantium, medieval Europe, the Renaissance and the industrialization period are given. The post-industrial and post-modernist architecture is also briefly characterized. The author makes a plea for more responsible concern for energy conserving building designs.

Arasteh, D., et al., "Cooling Energy and Cost Savings with Daylighting in a Hot and Humid Climate" Presented at the Hot Humid Climate Conf., College Station, TX, Sep 24, 1985.*

Fenestration performance in non-residential buildings in hot climates is often a large cooling load liability. Proper fenestration design and using daylight-responsive dimming controls for electric lights can reduce lighting energy, lower cooling loads, peak electrical demand, operating costs, chiller sizes, and first costs. The author describes the use of building energy simulation programs DOE-2.1B and DOE-2.1C to discuss lighting energy savings from daylighting. The effects of fenestration parameters on cooling loads, total energy use, peak demand, chiller sizes, initial and operating costs are also discussed. The impact of daylighting, as compared to electric lighting, on cooling requirements is examined as a function of glazing characteristics, location, and shading systems.

Johnson, R., Arasteh, D., and Selkowitz, S., "Energy Reduction Implications with Fenestration" Presented at the World Congress on Heating, Ventilating and Air Conditioning, Copenhagen, Denmark, Aug 25, 1985.*

The authors discuss results from several parametric analyses of energy and cost influences of fenestration in a prototypic office building. The energy sensitive parameters of fenestration, daylighting, and electric lighting were systematically varied in several climates using the DOE-2.1 energy simulation program to determine net annual results. Results are presented for two climate extremes: one heating-load dominated and the other cooling-load dominated. Changes in net annual energy consumption and peak electrical demand due to fenestration is demonstrated. Daylighting is the single most important strategy to reduce energy use, but can be an energy and cost liability. Conditions under which these liabilities occur are discussed, and optimal design solutions for minimizing energy costs are suggested.

Halldane, J. F., "Designer-Scientist Approach to Describing the Light from the Sun, Sky, and Cloud", Lighting Design and Application, Vol. 15, No. 6, June 1985, pp. 44-53.

Various complications affecting daylighting designer's evaluations of lighting levels under clear sky and cloudy conditions are discussed. The possibilities of errors of lighting models are explored.

Selkowitz, S., Arasteh, D., and Johnson, R., "Peak Demand Savings from Daylighting in Commercial Buildings" Presented at the American Council for an Energy-Efficient Economy, Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA, Aug 14, 1984.*

To determine optimum design strategies to control electrical demand, the often conflicting impacts of fenestration on lighting and cooling loads must be understood. This report uses an hour-by-hour energy simulation model (DOE 2.1B) to evaluate peak demand components and net effects in daylit and non-daylit buildings. More than 500 parametric simulations were generated for prototypic office building modules containing both horizontal and vertical glazing, located in 16 U.S. cities. From these simulations, conclusions are drawn about the effects of daylighting on peak demand for a range of climate types, orientations, fenestration areas, glazing shading coefficients and visible transmittances, U-values, lighting power densities, and lighting control strategies. Results for Los Angeles are compared to results from the climatic extremes, Louisiana (cooling-dominated), and Wisconsin (heating-dominated), and then discussed in detail. The paper also describes on-going studies measuring peak load impacts of fenestration using an outdoor test facility and occupied buildings.

Selkowitz, S., "Influence of Windows on Building Energy Use" Presented at the Windows in Building Design and Maintenance Conf., Gothenburg, Sweden, June 13, 1984.*

Window system design and operation have major effects on building energy use and on occupant thermal and visual comfort. Window performance is a function of optical and thermal properties, window management strategies, climate and orientation, and building type and occupancy. In residences, heat loss control is a primary concern, followed by sun control, in more southerly climates. In commercial buildings, the daylight provided by windows may be the major energy benefit, but solar gain must be controlled so increased cooling loads do not exceed daylight savings. Reductions in peak electrical demand and HVAC system size may be possible in well-designed daylighted buildings. Improved analytic tools and more extensive experimental data on window performance in buildings are necessary to improve design decisions and guide new product development.

Johnson, R., Sullivan, R., and Selkowitz, S., "How Fenestration Can Significantly Affect Energy Use in Commercial Buildings" Presented at the Cogeneration and Energy Conservation Seminar, San Francisco, Mar 5, 1984.*

Conclusions from a series of computer analyses of annual energy use and electrical peak demand in two climates as functions of fenestration parameters are presented. Particular attention is given to daylighting and its associated energy tradeoffs. The study includes the effects of climate, orientation, glazing area, U-value, shading coefficient, visible transmittance, lighting power density, and lighting control strategy. The analyses suggest that for a simple office module, fenestration can provide annual net energy savings in all climates, if daylighting were used. Solar gain control is critical to realizing energy daylighting benefits. Fenestration and daylighting design strategies that reduce net annual energy consumption also can reduce peak electrical demand. The optimum combination of fenestration variables is a function of climate, orientation, and electric lighting power density.

Selkowitz, S., Choi, S., Johnson, R., and Sullivan, R., "The Impact of Fenestration on Energy Use and Peak Loads in Daylighting Commercial Buildings" Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, 1983.*

This paper reports the conclusions of a series of computer analyses in two climates to determine the energy use and demand impacts of fenestration in commercial buildings. Particular attention is paid to the trade-offs involved in using fenestration to daylight perimeter zones. The study includes the effects of climate, orientation, window area, U-value, shading coefficient, visible transmittance, lighting power density, and lighting control strategy.

Johnson, R., Sullivan, R., Selkowitz, S., Nozake, S., and Conners, C., "Building Envelope Thermal and Daylighting Analysis in Support of Recommendations to Upgrade ASHRAE/IES Standard 90", Final Report, Berkeley, CA: Lawrence Berkeley Labs, Sep 1983.*

This study was designed to isolate and quantify the energy effects of fenestration and electric lighting design, and develop simplified analytic tools for compliance use for the building envelopes section of ASHRAE/IES standard 90. Envelope thermal conductivity, fenestration design, and electric lighting characteristics are parametrically varied through a wide range of values in a diversity of climates. Annual energy consumption is calculated with the DOE-2B energy analysis program. The results are collected and stored on tape. From this data base, a statistical analysis is performed using multiple regression techniques, leading to simplified correlation expressions characterizing annual energy performance trends for cooling, heating, and cooling peak so users can easily ascertain the energy implications of design options for fenestration, daylighting, and electrical lighting.

Moran, C.M., and D.E. Buffington, "Effectiveness of Various Window Treatments for Energy Conservation", Presented at the American Society of Agricultural Engineers Summer Meeting, Bozeman, MT., ASAE Technical Paper, Vol. 83-4050, June 1983, p. 11.*

Computer analyses of residential energy consumption are verified with experimental investigations of a full-scale residential structure at the University of Florida. Computer analyses are performed to simulate the effectiveness of the various window treatments. Economic analyses of each window treatment to determine the most cost effective treatment are discussed.

Magnusson, M., "Window Configuration: Designing for Daylighting and Productivity" Presented at the Int'l. Daylighting Conf., Phoenix, AR, Feb 16, 1983.*

To minimize energy use in the Social Security Administration/Northeast Program Service Center (SSA/NEPSC), scheduled for construction in 1983, an analysis of window energy use and daylighting potential in various window alternatives was undertaken. Eight possible windows were studied; three were selected for complete analysis as generic solutions to deal with energy issues. The options selected were analyzed for energy use, first cost, and effects on the interior environment. The window which maximized high daylighting glazing, provided the lowest energy use, lowest first cost, and greatest occupant benefit was the clerestory configuration with view windows.

Choi, U.S., Johnson, R., and Selkowitz, S., "Impact of Daylighting on Peak Electrical Loads" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

A prototypic five-zone office module was designed to provide a configuration, representative of commercial office construction. The daylighted zone is limited to perimeter offices 4.8 m (15 ft.) deep. The energy performance of this module under varied fenestration treatments was analyzed for a range of representative climatic conditions in the contiguous U.S. The principal parameters relating energy consumption to daylight utilization are installed electric lighting power, lighting control strategy, and design illuminance levels in the space. Daylight illuminance levels in the space are a function of fenestration properties, window management strategy to control solar gain and glare, and room characteristics. Thermal performance depends on the thermal properties of the fenestration and other characteristics of building design and operation. The interplay of these factors is examined to enhance understanding of peak load components.

Johnson, R., Sullivan, R., Selkowitz, S., Nozake, S., and Conners, C., "Glazing Energy Performance and Design Optimization with Daylighting" presented at the 1983 Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

Technical performance data are provided, suggesting how various aspects of fenestration performance may be interrelated. Cases where thermal performance is the primary concern and others, in which a combination of thermal and daylighting effects are critical issues, are included. DOE-2.1B is the primary simulation tool. A multiple regression analysis is used to examine results from a large set of data and establish correlations among the relevant variables. To study the effects of fenestration design on building energy performance, a prototypic five-zone module was designed to represent commercial office design. The design details were developed by means of studies in which basic building design and operating parameters were varied systematically and then fixed for the base case.

Meckler, M., "Manual Computation Methods for Estimating Energy Requirements in Non residential Buildings" Energy Conservation in the Built Environment, Dublin: An Foras Forbartha. Presented at the 3d Int'l. Symposium on Energy Conservation in the Built Environment, Dublin, Ireland, Oct 1, 1982.*

The development and use of a manual computation method to determine energy requirements in proposed small non residential buildings is described. The proposed method is based on information normally required for design heat loss and heat gain calculations. Included also is local weather data. The procedure first determines the annual basic energy requirements of the building without regard to supply characteristics. Energy supply system factors are then incorporated into the calculations to determine annual energy input. Tables and formulas, developed to facilitate data entry on calculation forms, are discussed. The method was verified by an in-house computer program. Detailed discussions of insulation factors, solar loads and gain factors, outdoor air sensible/latent heat, basic equipment efficiencies and relevant fenestration factors are also presented. The example described is a twelve-story office building in Los Angeles, California.

Al Diasty, R., "Investigation of Window Systems for Reduced Energy Consumption", Montreal, Quebec: Concordia University, 1982.*

The use of mechanical cooling, heating, and electrical lighting to compensate for inappropriate window and external wall design, is no longer acceptable. In an effort to meet energy conservation demands, two detailed models for thermal and daylight calculations for windows are presented. In the transient, three-dimensional thermal model, heat transfer through windows and walls is calculated, using a finite difference approximation. The model allows for varying the external surface coefficient of heat transfer with wind speed and direction. The solar heat absorbed in the external layer of walls and in all window layers, is considered. An empirical formula for air infiltration heat loss, as a function of wind speed, is obtained. A correlation between the surface convection coefficient and wind speed for eight major directions was established. This study provides a realistic basis for assessing the energy effectiveness of windows for design purposes.

Johnson, R., et al., "Glazing Optimization for Energy Efficiency in Commercial Office Buildings" Report # LBL-122764, Berkeley, CA: Lawrence Berkeley Laboratory, Oct 1981.*

This paper describes the results of a study in which annual energy consumption, with and without daylighting, in an office building module modeled parametrically for a wide range of glazing properties. The results suggest optimal combinations of glazing properties, frequently resulting in lower energy consumption than opaque insulated walls.

Selkowitz, S., "Daylighting as a Design and Energy Strategy: Overview of Opportunities and Conflicts" Proc. of the Symposium on Energy and Big Building Design, Philadelphia, PA, May 25, 1981.*

The potentials and problems associated with using daylight to improve visual performance and interior aesthetics and reduce electrical lighting energy consumption and peak electric loads are reviewed. Using daylight as a design strategy is not always synonymous with effective use of daylighting as an energy-saving strategy unless both approaches are jointly pursued by the design team. Criteria for visual performance, disability and discomfort glare, historical perspectives on daylight utilization, building strategies, luminous efficacy of daylight versus efficient electric light sources, comparative thermal impacts, peak load and load management potential, and non-energy benefits are reviewed. In most cases a solid understanding of the energy and design issues should produce energy-efficient and pleasing working environments.

Selkowitz, S., and Johnson, R., "The Daylighting Solution" Solar Age, Aug 1980, pp. 14-20.*

The electricity consumption for lighting of residential and office buildings is reviewed. The paper examines the economics involved in saving electricity by reducing lighting loads, and discusses daylight.

Gillette, G., "Energy Potential of Daylighting in a Classroom" Presented at the Conf. of Thermal Performance of the Exterior Envelopes of Buildings, Orlando, FL, Dec 3, 1979.*

An analysis is presented of a classroom of prescribed size and occupancy. Various fenestration designs are applied, and the resulting thermal and daylighting energy performance calculated. An attempt is made to relate the heating/cooling requirements of a window opening with its potential as a source of natural light. The parameters of glass area, glass type (double-pane, reflective, etc.), and ceiling height are evaluated for a classroom in Ann Arbor, Michigan operated during a 9-month school year. Comparisons are made between the performance of a design based on ASHRAE standard 90-75 and alternative fenestration designs. Although the computerized thermal analysis and the daylight had to be done separately, weather data and corresponding daylight readings for Ann Arbor are used for both. Results show a potential energy savings when daylighting is integrated into the building's envelope design, especially for southern exposures, but savings will be realized only when applied with the other energy variables.

Griffith, J.W., "Benefits of Daylighting - Cost and Energy Analysis" ASHRAE Transactions, Vol. 83, Part 2, Nov 1977, pp. 1-4.*

A rationale for daylighting vs. heat gains in buildings is provided. Economic issues and cost formulas are discussed. Some economic analyses of daylighting vs. artificial lighting strategies are given.

4. Tools - Design and Research

Hayman, S., "Sky Scanning Luminance Meters: Proposal Using Fiber-Optic Photocells", Lighting Research and Technology, Vol. 21, No. 4, 1989, pp. 195-196.

Current proposals for sky scanning luminance meters are restricted by limited sensitivity, calibration difficulties, aiming problems, complexity of scanning mechanism, lengthy scan time and high cost. A scanner is proposed, based upon fiber-optic detectors, which could overcome a number of these constraints.

Schuman, J., Sullivan, R., Selkowitz, S., Wilde, M., Kroelinger, M., "Daylight Design Tool Using HyperCard on the Macintosh", National Conf. on Microcomputer Applications in Energy, Tucson, AZ, USA, LBL-26263, Nov 1988.

HyperCard is described as a new electronic information system, more powerful and flexible than traditional written methods. It is characterized by unique abilities to interlink data in non-linear sequences, radically altering how we use reference tools. The LBL is developing a daylighting design guide in HyperCard. The intent is to first supplement, and eventually replace, written manuals and other references which are too cumbersome or forbidding to be used in a typical design process. The tool is intended to be a guide for design and education tasks.

Siminovitch, M., Navvab, M., Kowalewski, H., "Full Scale Photometric Simulation Facility for Evaluating the Luminous Environment in Office Work Applications", Conf. Record of the 1988 IEEE Industry Applications Society Annual Meeting 23rd, Pittsburgh, PA, Oct 1988.

A simulation facility and experimental procedures used for the photometric study and evaluation of office lighting design and system applications are described. This facility was developed to obtain quantitative photometric information on how different office lighting systems and design approaches affect visual quality and comfort within typical work environments.

Hraska, J., "On Daylight Availability in Interior Spaces", Proc. of Solar 88, the 13th National Passive Solar Conf., Cambridge, MA, June 1988.

Advance in standardization of typical light climate conditions have been utilized in computer analysis of availability of skylight in a typical side lighted living room, according to probabilities of occurrence of cloudy, partially cloudy, and clear days, in each month of the year in Bratislava, Czechoslovakia. The analysis predicts the effect of the orientation of the window wall on daylighting interior environment.

Ryiochi, S., Yasuo, N., "A New Apparatus for the Evaluation of Daylight Environment", Journal of Architecture, Planning and Environmental Engineering, Mar, 1988, pp. 18-24.

Green, R.A., Moore, F., Andrejko, D.A., Hayes, J., "Daylighting Design Guidelines: East-West Roof Monitor With Exterior Vertical Baffles", Proc. of the 12th Passive Solar Conf., Portland, OR., July 1987.

The development of daylighting guidelines for an east-west roof monitor with reflective baffles is described. Research results can be used as a tool designing daylighting roof monitors.

Selkowitz, S.E., Papamichael, K.M., Wilde, G.M., "A Concept for an Advanced Computer-Based Building Envelope Design Tool", Int'l. Daylighting Conf., Long Beach CA, LBL-20545, Nov 1986.

A concept for a computer based building envelope design tool, designed to overcome many limitations of existing ones is presented. It addresses daylighting design in the context of overall building envelope design, covering environmental qualitative and quantitative aspects of lighting and energy use. It could be useful throughout the design process, construction and occupancy and is intended to provide important feedback information, often missing between those stages of the building's life cycle. A cost effective tool with these performance features is not technically at present. The authors have studied the features and capabilities required in such a tool, as well as several key areas such as the design process, computer graphics, imaging systems, expert systems and building science data bases.

Weaver, N.L., Robbins, C.L., Hunter, K.C., Cannon, T.W., "Development of a Second-Generation Video-Based Luminance Mapper for Daylighting Research", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

A new microcomputer/solid state camera-based system with expanded graphic and high speed data manipulation capabilities is described. Preliminary calibration specifications for the system and applications are included.

Baumann, F.S., Place, J.W., Thornton, J., Howard, T.C., "An Integrating Window Pyranometer for Beam Daylighting Measurements in Scale-Model Buildings", ASHRAE Semi Annual Meeting San Francisco, CA, Jan 1986.

An experimental device has been developed to measure the total amount of solar radiation transmitted through glazed apertures in scale-model buildings. The device, an integrating window pyranometer (IWP), has two distinguishing characteristics: 1) it provides a measure of transmitted solar radiation integrated over a representative portion of the glazing, accounting for non-uniform radiation distributions; and 2) it is spectrally independent. In applications to scale model daylighting experiments, the IWP, together with photometric sensors mounted in the model, allows the direct measurement of the fraction of transmitted solar gains reaching the work plane as useful illumination - a convenient measure of daylighting system performance. The devices have been developed as part of an outdoor experimental facility to perform beam daylighting measurements in scale model buildings. The IWP is described, calibration test results presented and evaluated; advantages and limitations are discussed.

"Daylighting Design Tool Survey", Sunworld, Vol. 10, No. 4, 1986, pp. 110-114.

Design tools currently used with microcomputers to assist in designing energy efficient daylighted buildings are presented. The information was gathered during a telephone survey of design tool developers. There were five "tool" categories: matrices, nomographs, protractors/tables, minis and main frame computer programs. Information is provided to encourage interested design professionals, educators and students to communicate directly with design tool representatives.

Tapponi, R.R., and Hassan, A.A., "A Systematic Graphical Procedure for Determining Window Dimensions" Passive and Low Energy Ecotechniques, Elmsford, New York: Pergamon Press. Presented at the Conf. on Passive and Low Energy Alternatives, Mexico City, Mexico, Aug 6, 1985.*

A graphical procedure is developed to aid the designer in deciding on the appropriate dimensions and locations of windows in buildings. Since providing an appropriate amount of natural light in a space is a major window function, the procedure builds on lighting level calculations, considering the external reflected component, internal reflected component, shading coefficient, type of glass and frame. The function of the space determines the required lighting level, and alternative values are given for window sill and top height. The depth and width of the internal space are also given attention. The final determinant in the procedure is the width of the window.

Willman, A.J., "Development of an Evaluation Method for Passive Solar Design Tools" Proc. of the Solar Buildings Conf., Washington, DC, July, 1985.*

The DOE Passive Solar Energy Program has produced several new methods (tools) to analyze passive solar heating, cooling and daylighting strategies for residential and commercial applications. Private researchers and designers have expanded upon this work by developing other methodologies. Despite these research efforts in design tool development, the building industry has been slow to accept these products. Reasons for this limited progress are discussed. To overcome this problem, the Building Energy Design Tool Development Council (BEDTDC) was formed in 1981. One of its first projects is to assess the state-of-the-art of passive solar design tools, and recommend test, and evaluation procedures for them. This study discusses the development of a systematic procedure to investigate, evaluate and report the capabilities of design tools, relative to user's needs and criteria.

Selkowitz, S., "Application of Daylighting Research Tools to Fenestration and Building Design Optimization" Presented at Research and Design '85 Conf., Los Angeles, Mar 14, 1985.*

Neither research nor design is simple; each has a rich and complex set of procedures with its own internal structure, activities, and traditions. The increasingly difficult task of optimizing building design to meet occupant, client, and societal needs can be facilitated by a better understanding of building science research directions and the application of selected building research tools, with appropriate modifications, for design purposes.

Moore, F., "How to Design Roof Monitors for Daylight" Solar Age, Sep 1984, pp. 34-37.*

The advantages of toplighting are discussed. North and south-facing monitors are compared with respect to light and heat. The paper includes graphic methods for designing north/south and east/west facing monitors, both with clear glazing. The baffles are the light diffuser. Methods to minimize glare and evenly distribute light to the far corners of the space are discussed.

Willman, A.J. "Development of an Evaluation Method for Passive Solar Design Tools" Proceedings of the Annual Meeting of the American Solar Energy Society, Anaheim, CA, Boulder, CO: ASES, June 5, 1984.*

This paper discusses the development of a systematic procedure to investigate, evaluate, and report on the capabilities of design tools relative to a user's needs and criteria. The definition of design tool employed is "any device which assists the user in formulating and/or evaluating energy efficient strategies for buildings, new or existing." An important distinction made is that tool evaluation does not mean validation in technical rigor, cost and expedience. Instead, it is intended to provide a reasonable means to determine a tool's capability and to select one best suited for a particular application.

Robbins, C.L., and Hunter, K.C., "A Graphical Method for Determining Interreflected Daylight in Clear Climates" Progress in Passive Solar Energy Systems, New York: American Solar Energy Society. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, 1983.*

An extension of the Daylight Factor method of analysis, including a graphical method to determine Interreflected light in clear climates is presented. The interreflected component of daylight, called the internal reflectance component (IRC), has been determined for overcast skies in research performed in the UK. The technique developed by the Building Research Establishment (BRE) is based on determining an average IRC for a given room or space. Using a daylight availability model developed at SERI, a similar average IRC analysis technique for clear skies was established. The results of applying the SERI daylight availability model suggest that a critical element in determining the IRC under clear sky conditions is the ratio of global to diffuse (G/D) illuminance on a horizontal surface. This graphical technique for determining clear sky IRC values is expected to enhance the accuracy of daylighting system design by simplifying the format used in clear sky computations.

Bryan, H.J. "Development of an Integrated Daylighting Design Methodology," Progress in Passive Solar Energy Systems, New York: ASES, 1983. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 1983.*

Six daylighting calculation procedures developed by the author are presented: sky vault projection, tabular, graphic, protractor, programmable calculator, and microcomputer procedures. Analyzing these procedures reveals they lack important qualities. An alternative model is proposed; the procedure becomes part of a learning experience, integrated with the design process, enabling the designer to use his or her knowledge and experience.

Rundquist, R.A., "Simplified Method of Calculating the Interaction of Daylighting and Building Energy" Presented at the 1983 Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

A hand-calculation procedure is described to calculate the daylighting and energy impact of windows. The procedure, and examples of its use, are given. It is designed for use in schematic designs, to make early quantitative decisions on glazing types, sizes and daylighting controls. Included are calculations of interior daylighting levels for a given window and yearly lighting, cooling, and heating energy costs attributed to windows, relative to a solid wall. Workplace daylighting levels and lighting-savings-fractions are calculated for June 21 and December 21. Yearly energy cost is calculated, so various fenestration alternatives can be compared for total economic impact.

Sain, A.M., Rockwell, P.G., and Davy, J., "Energy Nomographs as a Design Tool for Daylighting" Presented at the 1983 Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

Decisions about daylighting must be made early in the design process; therefore, an effective design tool is needed to determine the effects of various daylighting options quickly and accurately. Energy nomographs are suggested as such a tool. They can be used to determine the net decrease or increase in annual energy consumption (including heating, cooling, lighting, etc.) of most daylighting design options early in the design process. They can aid designers in making cost effective decisions about many energy features. This paper explains their general use and provides a demonstration case study.

Burkett, R.J., "The Use of Computer Graphics in Daylighting Design and Analysis" Proc. of the Gateway Energy Conf., St. Louis, MO: the University of Missouri Press, 1983.*

Several currently available computer graphics software packages used to model solar conditions are presented. Techniques to generate three dimensional sun position building views, shadow projections, solar exposure paths and solar availability contours are presented. Case studies are used to illustrate program applications to daylighting design problems typically encountered.

Selkowitz, S., "Design Tools for Daylighting Illumination and Energy Analysis", LBL-14863, Berkeley, CA: Lawrence Berkeley Laboratory. Presented at the Designing and Managing Energy Conscious Commercial Buildings Conf., Denver, CO, July 19, 1982.*

The problems and potentials for using daylighting to illuminate building interiors are reviewed. Design tools to incorporate daylighting into the building design process are described. The paper also presents state-of-the-art methods to analyze daylighting impacts on lighting controls, lighting energy consumption, heating and cooling loads, and peak power demand.

Selkowitz, S., "Daylighting Design Overlays for Equidistant Sun-Path Projections" Presented at the Int'l. Passive and Hybrid Cooling Conf., Miami, FL, Nov 11, 1981.*

Projections of the sun's daily and seasonal paths frequently are used to solve building design problems involving site obstructions and shading of fenestration. In the U.S., equidistant projections are the most widely used (compared to other sun-path projections) because of the commercial availability of sun-path diagrams for a range of useful latitudes. This paper describes the development of a set of overlays, designed for use with sun-path projections to predict illumination on any building surface throughout the year for standard climatological conditions. Illumination is calculated for clear and overcast skies and direct sunlight, using algorithms recommended by the Commission Int'l. e de L'Eclairage (CIE). Values for illumination incident upon the surface, as well as that transmitted through single and double glazing, can be calculated. Similar overlays for solar radiation are being developed.

Millet, M., Adams, C., and Bedrick, J., "Graphic Daylighting Design Method: Including Clear Sky Conditions" Proc. of the 5th National Passive Solar Conf., Amherst, MA, October 19, Vol. 5.2, Oct 1980, pp. 1183–1187.*

The University of Washington Graphic Design Method (GDDM) was developed as a graphic tool for architects to assess both qualitative and quantitative aspects of daylighting design. Use of the methods is based on a catalog of patterns of daylight distribution in isolux contours over a horizontal reference plane from window and skylight openings. This paper reports directions being pursued to extend the use of GDDM under critical design conditions.

Bryan, H.J. "A Simplified Procedure of Calculating the Effects of Daylight from Clear Skies" Journal of I.E.S., Vol. 9, No. 3, Apr 1980, pp. 142-151.*

Using the Daylight Factor method, the author has reworked the method recommended by the C.I.E. for use with clear sky conditions. This lack has been the major hindrance to the use of the Daylight Factor method in the United States, since the method was developed using overcast or uniform sky conditions. The paper outlines the theory and procedure.

"Estimating Daylighting in Buildings, "Building Research Station Digest, Parts 1 and 2, Jan 1977, pp. 1-7.*

The Daylight Factor method of analysis is outlined. This is an excellent condensation of the basic principles first presented in Hopkinson's 'Daylighting'. Some useful sample calculations are presented.

Libby-Owens-Ford, "How to Predict Interior Daylight Illumination", Libby-Owens-Ford Co., Toledo, OH, 1976.*

Daylighting calculations (essentially the I.E.S. method) are explained. Nine examples are worked out to clarify the procedures.

4.1 Design Tools - Electric Light/Daylight

Guide on Interior Lighting", 2nd ed., CIE 29.2, 1986.

The recommendations given apply to interiors in which photopic vision is required. Various approaches to lighting design and the appearance of interiors are described, and recommendations given to achieve optimum efficiency from lighting installations. Lighting design, as it relates daylight factors to building thermal performance and maintenance issues, are discussed.

Ross D. and Baruzzini, Inc., "Lighting and Thermal Operations: Energy Conservation Principle", Report No. 154. Washington, DC: Federal Energy Administration, 1975.*

This report presents a detailed investigation of the relationships between office lighting (specifically levels and orientation with respect to task) and visual task performance. Its conclusions present strong arguments for reduced light levels and more careful lighting design.

"An Interim Report Relating the Lighting Design Procedure to Effective Energy Utilization" Committee on Design Practice of I.E.S., Lighting Design and Application, Vol. 5, No. 9, Sep 1975, pp. 34-37.*

This report, relating lighting design procedures to energy conservation was compiled by the Design Practice Committee of the IES to assist lighting designers in analyzing lighting problems, help generate solutions, determine the relationship of lighting to other environmental features, and optimize energy use for lighting. Procedures to aid the designer in following a logical step-by-step approach to reach a decision are described.

McNamara, A.C., "Lighting Efficiency or Comfort: A New Method of Comparison" Lighting Design and Application, Vol. 2, No. 3, Mar 1972, pp. 6-11.*

The paper discusses tradeoffs between the quality of electric illumination and the energy conversion efficiency of the system.

"I.E.S. Guide for Reporting General Lighting Equipment Engineering Data" Committee on Testing Procedures, Journal of I.E.S., Vol. 1, No. 2, Jan 1972, pp. 175-178.*

A reference guide to design report forms is suggested as well as a practical format and terminology to present the information obtained from a typical photometric test. Test reports are discussed for general lighting luminaires. Computer methods of calculating many values are discussed.

Taylor, G.J., and Bradley, R.D. "Visual Comfort and Cost Analyses for Production Lighting" Illuminating Engineering, Vol. 51, No. 4, Apr 1956, pp. 293-306.*

The importance of quality lighting in industry is being applied on a wide scale. Luminaires, with adequate uplighting, white ceilings, attractive color schemes and light interior finishes combine to give high visual comfort. This paper is a follow-on to an earlier one by the authors, concerned with cost and comfort evaluation of industrial lighting systems.

5. Control Systems

Rubinstein, F., Ward, G., Verderber, R., "Improving the Performance of Photo-Electrically Controlled Lighting Systems", Journal of the Illuminating Engineering Society, Vol. 18, No. 1, Winter 1989, pp. 70-94.

The major components of a typical control system are described. The operation of three different control algorithms is discussed, and each algorithm expressing the total illuminance as a function of the control photosensor signal is derived. Using a scale model, the authors measured the relationship between the signal generated by various ceiling mounted control photosensors and workplane illuminance for two room geometries under real sky conditions. The measured data were used to determine the performance of systems obeying the three control algorithms under varying daylight conditions. Control systems employing the commonly used integral reset algorithm supplied insufficient electric light, failing to satisfy the control objective regardless of the photosensor used. Systems employing an alternative, closed loop proportional control algorithm, achieved the control objective under virtually all tested conditions when operated by a ceiling-mounted photosensor shielded from direct window light.

Verderber, R.R., "Photoelectric Control of Daylight-Following Lighting Systems: Daylight sensing Photocell Placement". Electric Power Research Institute, report no. EPRI-CU-6243, Mar 1989.

This study evaluated control strategies and documented the ability of different control systems to maintain proper workstation lighting for various daylight levels and room geometries. Since daylight availability coincides with peak demand times for many utilities, shifting part of the lighting requirement from electricity to daylight can support load management efforts. To reduce power demand while maintaining illumination at the design level, photoelectric controls must dim the electric lighting systems in precise response to the available daylight. This study explores the equipment and methods required to achieve this balance.

Dubin, F.S., "Energy Efficient Building Design Innovative HVAC-Lighting Energy Management Control- Fenestration", Int'l. Seminar on Energy Saving. Proc., Rome, Italy, Sep. 1988.

Practical advice on how energy saving measures can be implemented in buildings in a cost effective way is provided here. Emphasis is given to district heating systems and community planning to reduce building loads.

Peterson, D., Bernaden, J.A, Neubauer, R.E., "Integrated Lighting Management", Intelligent Building Sourcebook, Fairmount Press Inc, 1988.

An overview of the requirements for a lighting control system in office buildings is presented as is an evaluation of typical approaches used to address these needs. A lighting control system should provide the proper amount of light, where and when needed. This objective must be viewed from two perspectives: that of the occupant and the building manager. Controls also must be examined from the context of the lighting system intended for the space.

Van Paassen, A.H.C., "Passive Solar Energy in Intelligent Buildings", Proc. of the ASHRAE, 1988 Winter Meeting, Dallas, TX, Vol. 94, Part 1, Jan 1988.

Digital control systems are proposed for buildings and dwellings which can manage the passive solar gains, natural ventilation, heating and lighting to minimize energy consumption and provide good thermal and integrated control system for window devices (blinds, windows, etc.) and traditional lighting and heating systems. Design concepts and techniques are described. These include optimal control strategies derived from adaptive models of building components and the weather. Similarities to the 'intelligent building' or 'smart house' concepts are noted.

Jones, N., "Lighting Energy Savings for the Small Business", Electrotechnology,- Vol. 15, No. 1, Jan 1987, pp. 20-21.

The author discusses the technique of energy control and presents a number of systems, flexible and easy to operate.

Knisley, J.R., "Lighting Control Techniques Reduce Unnecessary Energy Use", ECMAEM, 1987.

The paper discusses a variety of lighting control devices that offer opportunities to achieve appreciable savings, including switching control. timing devices, automated switching. power line carrier control, incandescent dimming systems, and daylight compensating dimming.

Papamichael, K.M., Rubinstein, F., Selkowitz, S., Ward, G., "The integration of operable shading systems and electric lighting controls", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986, LBL-20536.

Results from measurements in a scale model under real skies are presented. The model was designed to better understand the integration of fenestration and lighting controls. A typical office space was represented, equipped with motorized venetian blinds. Three ceiling-mounted control photosensors were used to operate the electric lighting system, and two control strategies were examined to change venetian blind settings. Two ground-plane reflectances and two window orientations were examined. Results indicate that the signal from a ceiling-mounted control photosensor, shielded from direct light from the window, correlates best with daylight work-plane illuminance, regardless of ground plane reflectance or venetian blind slat angle, for all slat angles not allowing penetration of direct solar radiation. The venetian blind control strategies considered may result in using different slat angles than those typically employed, resulting in different daylighting work-plane illuminances and electric lighting requirements, especially when the ground-plane reflectance is high.

Warren, M., Selkowitz, S., Morse, O., Benton, C., Jewell, J.E., "Lighting Systems Performance in an Innovative Daylighted Structure: An Instrumented Study", Int'l. Daylight Conf., Architecture and Natural Light, Long Beach, CA, LBL-20538, Nov 1986.

Conclusions from a one year instrumented study of an innovative daylighted commercial building in San Francisco are presented. The building has several architectural features specifically developed to admit daylight into interior office zones. These are complimented by continuously dimmable fluorescent lighting system that supplement available daylight under the control of open-loop ceiling-mounted photosensors.

Chapin, H.D., Chapin, F.W., "Assessment of the Need for New Controls for Solar Buildings", ABL Technologies Ltd., Victoria, BC., Canada, Aug 1986.

The use of controllers for solar buildings is assessed in the context of existing control strategies and recent trends in solar building design. The study outlines the state-of-the-art of controllers for solar buildings and suggests requirements for new controllers to optimize energy use and comfort in solar buildings. Data were obtained by surveying the solar building industry and microprocessor controller technology. The findings indicate an increasing emphasis on solar building design, combining several energy strategies. Occupant comfort is an important factor in control systems. Programmable controllers, which can manage daylighting, in addition to heating and cooling, were advantageous for many buildings. However, their use is hampered by problems with the available technology concerning reliability, limited control logic, and user interface. Requirements for new controllers for solar building are suggested. The authors conclude that control technologies rapidly changing and a combination of more accessible information and improved controllers promise a significant increase in energy efficiency and comfort for solar buildings.

Noone, S., "New Look at Photoelectric Controllers and Their Energy Saving Potential", Light Journal, Vol 51, No. 2, June 1986, pp. 90-92.

A photoelectric control unit is used to switch power to a lantern according to the surrounding brightness. To do this, it must monitor light levels, switch heavy reactive loads and withstand difficult environmental conditions. The relay assisted triac, is considered for automatic light switching with a light dependent register as a sensor. Other types of solid state devices are also used. Some mechanical components can be used to lower the initial price when cost effective, with some sacrifice of reliability.

Selkowitz, S., Griffith, J.W., "Effective Daylighting in Buildings - Revisited", Lighting Design and Application, Vol. 16, No. 3, Mar 1986, pp. 34-47.

Some new technology achievements are mentioned. Research progress is summarized with figures and discussions. The results shown are based on detailed building energy simulation studies using the DOE-2.1C computer program.

Verderber, R.R., "Review of Lighting Control Equipment and Applications: Minimizing Energy Consumption While Properly Lighting for Use of Space". Lighting Design and Application, Vol. 16, No. 2, Feb 1986, pp. 45-49.

This paper attempts to provide a basis for selecting the control equipment and the control strategies (light reduction, scheduling, tuning, lumen deprecation, daylighting, load shedding) most appropriate for an application and presents the important cost factors to be considered for each application.

Blake, F., "Daylighting and the Age of Computerized Lighting Controls", Proc. of American Solar Energy Society 1986 Annual Meeting, 1986.

Lighting systems are designed to minimize initial costs because builders do not operate buildings after construction. Energy efficiency is rarely considered in determining building's value. Increased lighting efficiency is possible at minimal cost using available tools. Manufacturers of energy management systems should be encouraged to adopt energy savings strategies in their designs.

Boyce, P.R., "Lighting Controls: the User's Point of View", Electricity Council Research Centre, Capenhurst (UK), ECRC/M-1914, May 1985.

Field studies of people's use of, and reaction to, control systems of various types for commercial lighting installations are reviewed. Opinions on lighting control systems vary widely ranging from how well the control system matches users expectations to how the building is used. Guidelines on important aspects of different control system are derived. These guidelines indicate that: a) the use of manual switching is a matter of individual initiative, governed by peoples' definition of 'public' and 'private' lighting, b) time control in the form of switching off lighting at set times is acceptable provided it occurs when the space is occupied, c) occupancy control is acceptable because the switching off only occurs when others are not present, d) daylight control, in the form of frequent switching of electric lighting, in response to daylight variation, is likely to cause dissatisfaction to occupants.

Rubinstein, F.M., Karayel, M., "The Measured Energy Savings from Two Lighting Control Strategies", IEEE Transactions of Industrial Application, Vol. 1A-20, No. 5, Sep 1984.

Andersson, B., Adegran, M., Webster, T., Place, W., Kammerud, R., Albrand, P., "Energy Effects of Electric Lighting Alternatives in Response to Daylighting", Proc. of the ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Aug 1984.

Results are presented from a study of south facing roof apertures on two buildings from the DOE's Non-Residential Experimental Passive Buildings Program. The study investigated the effectiveness of manual control of electric lighting systems and its effects on the heating, cooling and daylighting energy consumption of small daylit non-residential buildings. Data were collected, using physical models of two buildings and from the buildings. The building energy analysis program BLAST was used for the energy analysis. Results provide quantitative information on the performance of several electric lighting control strategies in response to natural lighting, including continuous dimming, on/off switching and manual controls currently in use. In both buildings, manual control provided similar or better energy performance than automatic control strategies. Factors explaining these findings are discussed. Daylighting strategies have shown substantial energy savings for similar, non daylit, buildings.

Ander, G., and Navvab, M.,"Daylighting Impacts of Fenestration Controls" Progress in Passive Solar Energy Systems, New York: ASES. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, 1983.*

The California Energy Commission established, and periodically updates, energy efficiency standards for new buildings. Performance and prescriptive standards are being developed. Daylighting impacts were calculated using QUICKLITE for typical office characteristics. Although QUICKLITE as well as manual calculations can be modified for horizontal shading devices (i.e., equivalent room concept), vertical fenestration controls such as fins cannot be easily modelled. To access the daylighting impacts of commonly used fenestration control systems, physical model testing was conducted in the sky simulator at LBL. Four common control strategies were selected, using recommendations from the AIA, ASHRAE, IES, and other industry groups. These devices include vertical fins with two reflectances (/RHO/=.88, /RHO/=.67), an overhang and a light shelf design with clear glass above and heat absorbing glass below the light shelf. Each strategy was tested parametrically with scaled models; solar altitudes were set up at 30 square feet, 50 square feet and 70 square feet. Sky conditions also were varied, including overcast and clear conditions, to cover most variables affecting daylighting performance.

Coleman, F.W., "Energy Effective Lighting Controls for the Office", Electr. Rev., London, UK, Vol 212: 4. Jan 1983, pp. 33-34.

Otsuka, H., Ishii, S., Koizumi, N., Mizuhara, H., Kono, N., "Automatic Lighting Control System", Included in Mitsubishi Denki Giho, Vol. 57, No. 2, 1983, pp. 17-22. (Japanese)

Aitken, D.W. , "The Neglected Half of Commercial Daylighting Design Reporting: Selecting the Controls, Fixtures, Bulbs, and Ballasts" Progress in Passive Solar Energy Systems, New York: ASES, 1983.*

An overview is provided of the features of electric lighting controls, lighting fixtures, bulbs and ballasts relevant to daylighting design. Emphasis is placed on daylight controlled dimming, on the desire to limit the amount of dimming to 5% or less (for economy purposes), and to permit the use of a wide spectrum of illumination schemes and hardware. Advantages of dimmers, independent of daylighting usage, are stressed. The effectiveness of air-return ceiling-mounted luminaires on lighting fixture heat collection and on bulb luminosity is examined. The status of fluorescent bulb and ballast technology is briefly reviewed, as is the matching of bulbs to ballasts and dimmers. The importance of a working knowledge of these practical concepts by the designer is emphasized.

Smirnov, A.I., "Fully Integrated Lighting and Methods for its Control", 5. Int'l. Conf. on the Rational Use of Electric Energy for Illumination, Varna, Bulgaria, 1981, pp. 47-48.

Pelkmann, B., Vogel, D., Kern, M., "Modern Lighting Control with Integrated Dimmer Circuits", Simens, Munich, Germany, 1978. (German)

Crisp, V.H.C., "Preliminary Study of Automatic Daylight Control of Artificial Lighting", Lighting Research and Technology, Vol. 9, No. 1, 1977, pp. 31-41.

Hunt, D.R.G., "Simple Expression for Predicting Energy Savings from Photo-Electric Control of Lighting", Lighting Research and Technology, Vol. 9, No. 2, 1977, pp. 93-102.

Fukuda, T., Okada, K., Norieda, T., "Dimmer Equipment Using Minicomputer", Toshiba Review (International Edition) No. 94, Nov-Dec 1974, pp. 23-26.

6. Models

6.1 Models - Computer

Sullivan, R., Selkowitz, S., "Fenestration Performance Analysis Using an Interactive Graphics-Based Methodology on a Microcomputer", Thermal Performance of the Exterior Envelopes of Buildings, Orlando, FL, LBL-26070, Dec 1989.

The authors show the development and implementation of a new methodology designed to evaluate the energy and comfort performance of fenestration in non-residential buildings. The methodology is based on the definition of a fenestration system 'figure of merit'. The figure of merit is determined by considering five non-dimensional performance indices representing heating energy, cooling energy, cooling energy peak, thermal comfort, and visual comfort. These indices were derived by performing a regression analysis of several thousand hour-by-hour building heat transfer simulations of a prototypic office building module using the DOE-2 simulation program.

Al Diasty, R., Shapiro, M.M., Fazio, P., "Time Dependent Concept for Daylight Calculation part I; the Direct Component", Journal of the IES, Vol. 18, No. 2, Fall 1989, pp. 52-64.

This paper discusses dynamic sky modelling, favoring the Kittler clear sky equation for luminance distribution and Fesenkova's zenith luminance equation for converting to absolute luminance. The intent is to provide a computer programmable technique for computing sky luminances and in turn interior illuminances for use in time varying conditions.

McCluney, R., "Window Energy Performance Comparison Program for Non-Residential Buildings", Proc. of Building Simulation 1989, Toronto, ON, Can., June 1989.

A new computer program has been written to compare the annual energy and economic performances of different window systems in non-residential buildings. The program, CSHADE, performs a side-by-side hourly energy performance simulation of a test window system compared to a reference one. A comprehensive report is printed at the completion of each simulation. Computer program findings are reported, comparing the performances of seven different window systems installed in buildings in Miami and Chicago.

Fanchiotti, A., Matteoli, S., "An integrated Thermal and Luminous Energy Analysis Program." Proc. of Solar 89, the 14th National Passive Solar Conf., Denver, CO, June 1989.

A simple integrated energy analysis code HEATLUX developed within the framework of the European Concerted Action Program on Daylighting is presented. The integration of the thermal and luminous aspects is obtained by including the heat corresponding to the artificial lighting requirements among the heat gains in a simplified thermal analysis code. SMECC is the thermal analysis code used. HEATLUX computes the levels of illumination provided by natural light integration, converts it to heat, and performs the thermal analysis including heat gains, together with gains due to other sources.

Baker, M.S., "Modeling Complex Daylighting With DOE2.1 C", The 14th National Passive Solar Energy Conf., Denver, CO, June 1989, pp. 159-165.

This paper describes a daylighting analysis technique using some powerful and generally unused features of the DOE2.1C computer program in combination with scale building models and/or detailed daylighting calculations. This method was used to model and analyze various daylighting options in several new utility office buildings in Oregon. A comparison of modeled and preliminary monitored building data is presented.

Littlefair, P.J., "Average Daylight Factor: A Simple Basis for Daylight Design", Building Research Establishment, Watford, England, report No. INIS-GB-182; BRE-IP-15/88, Nov 1988.

The use of formulae developed at BRE to enable average daylight factor to be calculated quickly and accurately is described. It should be of interest to architects and engineers involved in window design.

Matsuo, A., Inoue, T., "Natural Lighting and Thermal Insulation Through Windows", Joint Convention Record of Institutes of Electrical and Information Engineers Nigata, Japan, Oct 1988.

Computer simulation and software simulation are described for the quantitative investigation of the effect of artificial and natural lighting, to improve the comfort and energy saving by the proper use of venetian blinds. A program called HASP-L was developed. It is a modified version of an earlier dynamic thermal load computing program. It contains an added function to calculate and compute daylight. Outlines of the building design data, outside conditions, skylight illuminance calculations, artificial light illuminance calculations, dimming methods and logic, and details of the output are presented. Examples of calculations performed in Tokyo and Sapporo, are shown. In both cases, the power consumption was considerably reduced. If both heating and cooling loads were combined, the loads decreased by 3-4% in Tokyo, and increased by 3-4% in Sapporo. The state-of-the-art of the blinds was investigated to study the role and control effect of venetian blinds.

Agnoletto, L., Romagnoni, P, "Correlation Between Solar Radiation and Maximum Natural Lighting Value Inside of a Room", 43rd ATI (Italian Thermotechnics Association) National Congress, Vol. 1, Sep 1988.

Using room natural lighting, data are calculated by a suitable computer program. A procedure is described, based on a concept which allows the definition of a solar radiation boundary value, over which glare phenomena are caused.

Stix, G., "Digitized Sunshine Aids Architects", IEEE Spectrum, Vol. 25, No. 3, Mar 1988, pp. 46-49.

The author explains how computers are used to help architects design buildings to apply natural lighting. The aim is to reduce energy usage by using less electric lighting. To help analyze distribution of natural light in a scale model, digitized images and computer models are used to determine surface brightness. Mainframe computer programs calculate light distribution and model the interaction of daylight with electric lighting systems. This article explains how daylighting is used at the Olympic Oval built for the Winter Games in Calgary, Canada and at Seattle's Pacific Museum of Flight.

Frame, I., Birch, S., "Architects Can See Daylight", Construction Comput. (UK), No. 19, Nov 1987, pp. 22.

This paper describes a program which allows a rectangular room with vertical glazed windows to be described and evaluated for daylight distribution. The program is menu driven with options displayed at appropriate stages. The program is expected to be of particular interest to those working in an education environment. The program can be run on microcomputers.

Hassan, E, A, Lindsey, J.L., "Validation of Skylight Computer Modeling", ISES Solar World Congress 1987: Advances in Solar Energy Technology, Book of Abstracts. Vol. 2, Hamburg, Germany, Sep 1987.

Fontoynont, M.R., Bloss, W.H., Pfisterer, F., "Simulation of Complex Window Components Using a Ray-Tracing Simulation Program", Advances in Solar Energy Technology, VOL. 4, Proc. of the Biennial Congress of the Int'l. Solar Energy Society, Hamburg, Germany, 13-18, September 1987.

A ray tracing program GENELUX is described; it simulates the process in which natural light enters a building through complex window components. It deals with diffusing or specular glazing and can handle reflection on indoor and outdoor reflectors. It is meant to be used as a graphic design tool for architects, and offers a compromise between the power of ray tracing techniques and rapid computing time. The program has been used to test the performance of sunlighting systems such as light chimneys, lightshelves and reflective blinds. Some results are presented.

Barton, C. K., "Development of LITE- A graphic Module for Lighting Analysis in the Computer-Aided Engineering and Architectural Design System", Technical Report, US Army Corps of Engineers, E-87-02, Mar 1987.

The development and use of the graphic module LITE is presented; it is a subsystem of the Computer-Aided Engineering and Architectural Design System. LITE was developed to assist lighting engineers performing analyses during the concept design phase. The program can do IES zonal cavity calculations internally and can build a Conservation of Electric Lighting (CEL-1) input deck for comprehensive daylighting studies. Also described is the LCHG program, developed to maintain the luminaire data base file used by LITE for illuminance calculations.

Aschehoug, O., "Daylight Design for Glazed Spaces", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

The daylight distribution of glazed streets has been studied using a physical model in an artificial sky and computer calculations with SUPERLITE program. The parameters governing daylight conditions in the adjacent buildings were the street width/building height ratio, window sizes and reflectances. An optimum glazing percentage can be found, giving priority to rooms on lower floors. In narrow, deep atria, the surrounding facade glazing functions much as mirrors, bouncing daylight down to the street level.

Arasteh, D., Johnson, R., Selkowitz, S, "Definition and Use of a Daylight 'Coolness' Index", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

This paper examines the relationship between lighting energy savings from daylighting and daylight imposed cooling loads from DOE2.1C simulation results for specific commercial buildings and glazing options. For any daylit or electrically lighted space, the cooling load from natural or artificial lighting space can be broken into three component factors. Each factor can be expressed mathematically and as illumination levels within the space. These three constants can be combined into a single daylight coolness index. Thus, from illuminance measurements for a proposed daylighted space, a designer can compare the relative cooling load impacts of different daylighting designs.

Eriksson, C., Francelet, P.A., Gay, J.B., Morel, N., "Insolation and Natural Lighting", Status Seminar on Energy Conservation in Buildings, Zurich, Switzerland, Oct 1986. (french).

The authors present a method to calculate the lighting intensity at a given point inside a room from the horizontal global radiation. A simplified method to determine the lighting system energy demand is described.

Walton, G.N., "Modeling Window Optics for Building Energy Analysis", National Bureau of Standards, Washington, DC, NBSIR-86-3426, July 1986.

The report discusses modeling the optics of windows to simulate building energy requirements or daylighting availability. The theory to calculate optical performance of conventional windows is reviewed. Simplifications commonly employed in creating computation models are described. Some possibilities for more complex windows are analyzed. The type of model and data necessary to simulate windows in a building energy analysis program are determined. The optical performance of different window types can be simulated with models requiring various amounts of memory or computing time. The author concludes that an energy analysis program should contain all available models, and use the most efficient one for any given window.

Boyer, L.L., "Daylighting Prediction and Measurement in an Earth Covered Residence", Proc. of the 11th National Passive Solar Conf., Vol. II, Boulder, CO, June 1986.

The center module of a 3-dome concrete structure receives exterior lighting only from the south-southeast facade. A row of high windows under a generous overhang and two sets of patio doors admit light into the center module space which is 8.5m long and 5.5m deep. Sunlighting, passive solar heating and daylighting are selectively admitted during winter. The new daylighting analysis software program DAYLITE, was used to simulate the center module of the existing building. Clear and overcast sky conditions were simulated using available exterior illuminance data for the city of Denver, which is 320 km northeast of the site. On an overcast morning in December, the median predicted level is about 410 lux and for a diffuse clear sky condition for corresponding level is about 1280 lux. Actual measurements seemed to equal or exceed these levels. Reasons for the differences are presented. No attempt was made to analyze the performance of the two end modules.

Egger, W., "Computer Assisted Daylight and Artificial Lighting Planning", Tech. Bau (Germany) Vol. 19, No. 11, Nov 1980, pp. 898-900.

The Cophos software describes an interreflection method which takes into account the objects in rooms and allows for the establishment of an illuminance/lighting-density transformation to present calculated lighting densities on high definition color graphic screens. 'Cophographies' are obtained, which demonstrate the planned light characteristics of a room in a realistic manner.

Higgs, F.S., "Integrating Energy and Natural Lighting Simulation: The DEROB (Dynamic Energy Response of Buildings) Approach", Council for Scientific and Industrial Research, Pretoria, PB-88-207535/XAB, 1987.

The approach by which the DEROB system has been extended to simulate natural lighting within buildings in a manner fully integrated with the existing thermal flux simulations is discussed. The system offers scientists and designers a means to integrate these often conflicting design considerations into a building's design.

Treado, S.J., Holland, D.B., Remmert, W.E., Pierpoint, W., "Building Energy Analysis with BLAST and CEL-1", National Bureau of Standards, NBSIR-85/3256, PB-86-189891/XAB, Oct 1986.

The capabilities of the BLAST and CEL-1 computer programs and the procedures for using a hybrid version are discussed. Both programs are being incorporated into a single design and analysis tool. Details on assembling the required information to develop the input files and the execution of the hybrid program are covered. The program allows detailed simulation of actual lighting systems using CEL-1 including daylighting effects while providing BLAST with lighting energy modifiers on an hourly basis. The procedure is demonstrated using a sample building.

Fontoynont, M., Szabo, E., Fontanel, H., Rigo, P., "Method to Assess Visual and Energetic Performances of Natural Lighting Systems", INTERSOL 85: Proc. of the Ninth Biennial Congress of the Int'l. Solar Energy Society, Montreal, Canada, June 1985.

A method is proposed to evaluate illuminance levels inside a building, said to reduce indoor illuminance prediction errors, and evaluates the performance of complex aperture designs. The approach consists of defining beam and diffuse daylight factors as the ratios of indoor illuminance at specific indoor locations to external horizontal illuminance respectively, for direct beam radiation and diffuse radiation. These parameters are used as input in a simulation program which permits computation of illuminances at chosen indoor points, from the values of outside horizontal diffuse and direct radiation data.

Bryan, H.J., and M. Hoshino, "Thermal-Lite: A Microcomputer Program for Thermal and Daylighting Analysis" Proceedings of the Ninth National Passive Solar Conf., Boulder, CO: ASES. Presented at the Ninth National Passive Solar Conf., Columbus, OH, Sep 23, 1984.*

A microcomputer program called Thermal-Lite, designed to predict energy savings attributed to daylighting use is described. Thermal-Lite consists of four major subprograms: data input, thermal calculation, daylighting calculation and output. The data input program is organized around fourteen options, where design parameters can easily be created, stored, replaced or changed to process. The thermal calculation used was a public domain program (ASEAM), capable of predicting peak and annual building energy use by utilizing the ASHRAE TC 4.7 modified bin algorithm. The output can take two forms: peak values and annual energy consumption. Future plans to increase the program's effectiveness for designers are also discussed.

Jansen, J., Arnold, G., and Reeves, B., "ECAP: A Comprehensive Energy and Cost Analysis Procedure for Microcomputers" Presented at the American Meeting of the American Solar Energy Society, Anaheim, CA, June 5, 1984.*

ECAP, a test of microcomputer programs designed to perform a comprehensive energy and cost analysis on the energy-related systems of building designs, is presented. The structure of ECAP is explained, as are the tasks performed by each program module. The unique and innovative features of the procedure, particularly the solar heat gain and daylighting routines, are emphasized.

Ahmed, S.F., "Survey of Microcomputer Based Design Tools for Building Energy Calculations" Proc. of the Annual Meeting of the American Solar Energy Society, Boulder: American Solar Energy Society (ASES), June 1984.*

The results of a recently completed survey of microcomputer-based buildings energy design tools are presented. Only design tools developed in the U.S. are considered. The method of categorization of design tools is given. Areas for further work are identified.

Bryan, H.J., and Krinkel, D.L., "Validation of the MICROLITE I Daylighting Model". Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

A validation study of MICROLITE I is described. Results have been validated against test data from an extensive series of physical scale model measurements, as well as results from a large mainframe computer program.

Milne, M., Liggett, R., Campbell, C.L., Lin, L.C., and Tsay, Y.T. "Interactive Computer Graphic Daylighting Design Tool" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

A fast, simple interactive computer program which plots daylight curves was developed for hands-on use by architects at the beginning of the design process. The program calculates daylight illumination levels using the IES/LOF method. The most important feature is its friendly interface. Designers with no computer literacy can easily describe their building and quickly progress through as many design modifications as desired. The program is self-instructional, giving first-time users a demonstration of its various features. The program is written in FORTRAN IV and runs on a Tektronix storage tube graphics terminal.

Selkowitz, S., and Winkelmann, F.C., "New Models for Analyzing the Thermal and Daylighting Performance of Fenestration" Proc. of the ASHRAE/DOE Conf. - Thermal Performance of the Exterior Envelopes of Buildings II, Las Vegas, Dec 5, 1982.*

New daylighting and thermal modeling capabilities in DOE-2.1B and planned additions is described. DOE-2.1B contains a preprocessor-based daylighting model, sensitive to daylight availability, site conditions, room glazing parameters, window management for glare and solar control, and lighting controls. To model more complex designs, the next version of the DOE-2.1 program will have a daylighting model based on stored or user-input coefficients of utilization. A lighting program, named SUPERLITE, provides detailed data on illuminance and luminance distribution throughout interior spaces. Because the solar gains through sophisticated daylighting designs are not now adequately calculated, a procedure based on a library of new heat-gain coefficients is being developed. Using sun and sky simulators, these coefficients will be determined from direct measurements of solar optical properties of architectural devices. The major experimental procedures and analytical models, along with validation studies of DOE-2.1B and

SUPERLITE and sample results from these new modeling tools, are described.

Emery, A.F., Heerwagen. D.R., Johnson. B.R., Kippenhan, C.J., and Lakin, J.E. "A Study Method for Evaluating Fenestration Assemblies Considering the Control of Solar Heat Gain and the Provision of Daylighting" Progress in Passive Solar Energy Systems, New York: ASES. Presented at the 7th National Passive Solar Conf., Knoxville, TN, Aug 30, 1982.*

Controlling admission of solar radiation and encouraging daylighting use for internal load dominant buildings are considered. A method for conducting tradeoff analyses between these competing design strategies is presented. The use of three computer programs - UWLIGHT, SUNSXN, and OFFICE - to model illumination levels, and the selective switching of lighting fixtures, is described. A case example displaying the application of these programs and noting how a trade-off analysis may be conducted, is shown.

Bryan, H.J., and Krinkel, D.L. "MICROLITE I: A Microcomputer Program for Daylighting Design" Progress in Passive Solar Energy Systems, New York: American Solar Energy Society. Presented at the 7th National Passive Solar Conf., Knoxville, TN, Aug 30, 1982.*

A simplified procedure for calculating interior daylight illumination known as QUICKLITE I has been developed. This paper describes an enhanced version of QUICKLITE I for microcomputers called MICROLITE I. The program is intended as to be a useful tool for designers at the early stages of a building design. It was developed using a set of input menus, where design parameters can easily be created, stored, replaced or changed to determine the effects of design alternatives. The program output offers several graphical formats in the familiar architectural representation of plan, section and axonometric projection. Plans to increase the program's power and usefulness to the designer are also discussed.

6.2 Models - Scale

Brentrup, D.A., Bozeman, MT, Montana Sky, Proc. of Solar 89, The 14th National Passive Solar Conf., Denver, CO, June 1989.

Montana Sky is a studio based tool for the physical modeling and simulation of the design attributes of daylight, sunlight and electrical lighting. This paper delineates the key elements in developing an integrated design oriented curriculum. The discussion focuses on the overcast mirrored sky element and on two areas of primary consideration: the equipment and the nature of the pedagogy.

Crenshaw, R., Gisbert, M., "The Design and Construction of a Mirror-Box Artificial Sky", Proc. of Solar 89, the 14th National Passive Solar Conf., Denver, CO, June 1989.

This paper reports on a large mirror-box artificial sky built this year at a cost of $10,000 by the School of Architecture at Florida A&M

University. The paper discusses, and provides details, of the construction and instrumentation of the sky. It describes the procedures used for calibrating the sky, and reports on a series of tests performed to examine the effect of tall buildings on plant growth under them.

Rojek, G.M., Prafcke, C.A., Ubbelohde, M.S., "A Mirror Box Artificial Sky for Teaching", Proc. of Solar 89, the 14th National Passive Solar Conf., Denver, CO, June 1989.

The design, construction and testing of a mirror box artificial sky for daylighting modeling at the University of Minnesota School of Architecture is described. The paper offers insights into problems encountered and contains drawings and photographs to clarify major issues for those contemplating the design and construction of a mirror sky. It also raises some technical design and modeling issues.

Tregenza, P.R., "Daylight Measurement in Models: New Type of Equipment", Lighting Research and Technology, Vol. 21, No. 4, 1989, pp. 193-194.

Standard laboratory methods to predict daylight illumination in buildings involves model testing in large artificial skies. Usually, only one sky luminance distribution can be simulated. In the equipment described here, the sky is divided into a large number of zones, and daylight coefficients are measured. The illuminance beneath any sky luminance distribution can be determined by multiplying the coefficients by the appropriate sky luminance values. The equipment serves also as a computer controlled heliodon which permits measurement of building illuminance under direct sunlight.

Coffin, W.L., Skelton, A.M., Jackson, H.A., "Light levels in Multispan Greenhouse Models", Canadian Agricultural Engineering, Vol. 30, No. 1, Jan 1988, pp. 143-149.

The transmittance of solar radiation into scale models of multispan greenhouses was measured for one year, under a wide variety of climatic conditions. Models of conventional greenhouses were oriented east-west or north-south and glazed with clear or diffuse glass and compared with models of two prototype multispan insulated greenhouses oriented east-west with the north-south during the winter months. The insulated greenhouses had moderate reductions in light levels in the winter when compared to conventional models.

McCubbin, I., Bloss, W.H., Pfisterer, F., "Daylighting and Thermal Design - an Integrated Approach to Dynamic Simulation Modelling", Advances in Solar Energy Technology, Vol. 4, Proc. of the Biennial Congress of the Int'l. Solar Energy Society Held at Hamburg, Permagon Press, Oxford, GB, Sep 1987.

Improved daylighting design in U.K. for non-domestic buildings is predicted to save between 0.4 and 0.8 million tons of coal equivalent of primary energy by 2020. Heating and lighting energy loads interact, requiring optimum energy efficient design solutions to account for both.

A facility to model this interaction and its application within design studies is presented. Future plans for daylighting studies within the program are outlined.

Lechner, N.M., Andrejko, D.A., Hayes, J., "The Integrating Sun Simulator", Proc. of the 12th Passive Solar Conf., Portland, OR, July 1987.

The Integrating Sun Simulator is a unique type of sun machine (heliodon). Besides the normal functions of a sun machine, it can also predict the performance of windows and skylights over a whole season. Other sun machines only simulate the instantaneous effect of the sun, while this one integrates the effect of many sun positions. It can do this because it uses 120 lamps instead of the single lamp used by other sun machines.

Stupole, S.P., Lynes, J.A., Littlefair, P.J., "Luminance Pattern Simulation: Design of An Artificial BRE Average Sky", Lighting Research and Technology, Vol. 19, No. 4, 1987, pp. 105-113.

The outcome of a feasibility study to design an artificial sky to simulate the BRE Building Research Establishment Average Sky is described. The problem is one of producing a particular luminance distribution within a space, and is therefore relevant to other lighting design problems where a controlled pattern of luminance is required. The difficulties of setting up a luminance pattern are briefly discussed. These include internal reflection and parallax errors which occur when the luminance pattern is viewed from different points within the space. Two alternative designs for the artificial sky are outlined.

Kuchkarov, R. A., Mirbobaeva, D.Kh., Valiev, A., "Consideration of the Opposite Building in Calculating Natural Illumination Under Conditions of a Clear Sky", Applied Solar Energy, Vol. 22, No. 5, 1986, pp. 54-59.

A procedure is described to calculate clear sky illumination based on brightness factors obtained in relation to levels of opposite vertical illumination and a parameter LAMBDA, introduced for the degree of shading. To study illumination conditions in residential districts in clear weather, instrumental observations were conducted on mock-ups of four-story residential buildings made on a scale of 1:10.

Fontoynont, M., Szabo, E., Fontanel, H., Rigo, P., "A Method to Assess Visual and Energetic Performances for Natural Lighting Systems", Proc. of Intersol 85, Montreal, Canada, June 1985.

To determine the beam daylight factor (BDF), one needs to simulate the various positions of the sun in the sky, relatively to the building aperture. This is done by fixing the building scale model on top of a heliodon, designed to work with a light source situated at its zenith. The heliodon is a three angle system permitting direct reading of latitude, solar declination, and hour angle. The light source, situated almost 10 meters from the model, is a powerful arc-type lamp with a high color temperature. Various illuminance measurement sensors are positioned inside the model and one sensor is located outside, to record illuminance on the simulated horizontal earth surface. Values of BDF are computed through a data acquisition unit on an hourly basis, for specific dates, relatively to a given latitude.

Ander, G., and Wilcox, J.S. "Fenestration Modeling Techniques" Proc. of Research and Design '85, Los Angeles, CA, Washington, DC: AIA, Mar 1985.*

A methodology to analyze complex fenestration systems and complex room geometries is discussed. This procedure can be used in conjunction with an hourly simulation program to determine impacts to lighting, mechanical and peak loads.

White, R., "The Calibration and Error Analysis of an Artificial Sky Converted to a Clear Sky Luminance Distribution", Energy and Buildings, Vol. 6, No. 3, 1984, pp. 229-240.

Neubeck, K.M., "A Review and Analysis of 24 Daylighting Solutions" Progress in Passive Solar Energy Systems, New York: ASES. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5 1983.*

Twenty-four daylighting models were designed and built by the graduate studio in energy conscious design at Arizona State University. Each scale model represented a 9.1m x12.2m (30ft. x 40ft.) office space. The models were displayed at the 1983 International Daylighting Conference; however, no documentation was presented. This paper explores the assumptions and specifics of each design in an effort to expand the library of daylighting designs available to architects and designers.

Hallagan, W.B., Lindsey, L.L., and Snyder, M.K., "Daylighting Design Analysis", Washington, DC, U.S. Department of Energy, Feb 1981.*

Detailed scale model studies regarding daylighting aspects of the passive/hybrid solar test building located at Butler Research Center in Grandview, MO are discussed. The product development program is aimed at providing passive/hybrid system building alternatives for commercial, industrial, and community purchasers of pre-engineered metal buildings. Scale models of several alternative design configurations, including that of the test building in Grandview, were built and tested. Major design alternatives, test results, and conclusions are described.

Evans, B.H., and Nowak, M., "Effects of Direct Sunlight on Building Interiors and Subsequent Skylight Studies," Illuminating Engineering, Vol. 54, 1959, pp. 715-721.*

This article discusses a procedure for using a dome sky in conjunction with a separated sun machine for superimposing results to obtain daylighting predictions.

Vezey, E.E. and B.H. Evans, "The Study of Natural Illumination by Means of Models Under Artificial Sky" Illuminating Engineering, Vol. 50, Aug, 1955, pp. 367-374.*

This article includes a very brief description of the dome sky at the Texas Engineering Station (19 feet in diameter), and explains procedures regarding models, instrumentation, and model testing.

6.3 Models - Mathematical

Igawa, N., "Daylight Simulation of Fabric Structure", Kuki Chowa Eisei Kogaku, Vol. 63, No. 2., Feb 1989, pp. 103-110. (Japanese)

The daylighting calculation is intended to first devise a calculation formula for a configuration factor and then evaluate the fabric in terms of spectral characteristics, transparency directional characteristics and specular change. In the simulation method, to obtain the illuminance distribution, the coordinates of horizontal plan walls of the building, those of fabric plane to be the light source, calendar date and time, when calculating solar position when doing illuminance outside the building are put in. The results of the calculations are utilized to evaluate environmental conditions. By using the above simulation method, the illuminance distribution on the floor plane of fabric structure was calculated and coincided well with that actually measured.

Rossi, G., Vio, M., "Solar Energy and Daylighting Availability for Bioclimatic Buildings: Two Simple Graphical Calculation Methods, Bioclimatic Architecture, Energy Conservation and Environmental Quality: Perspectives and Applications in the Design and Construction of Public Buildings and Schools", Proc. of the ISES meeting, Rome, Italy, Nov 1988. (Italian)

A graphical method to calculate daylight illumination is described. It is based on an analytic expression which defines, at a point in a horizontal plane, the direct factor as a function of azimuth angles and elevation angles subtended by the point itself and the outer limits of the source. This analytical approach permits the tracing of a family of curves with which the calculation of daylighting is possible when the two sets of angles are known. The graphical method to calculate direct solar radiation is based on well known geometrical relationships which describe reciprocal earth-sun positions, the equations expressing the component of direct solar radiation as a function of the angles, characteristics of the sun positions, and the orientation of the design environment. Not intended for analyses involving many different environments and long time durations, these graphical methods give quick and rapid indications on analyses made on few local samples or when it is necessary to compare different solutions.

Calderaro, V., Bloss, W.H., Pfsiterer, F., "Simulation Model for the Hourly Evaluation of the Thermo-Hygometric, Energetic, Lighting and Acoustic Behavior of Buildings", Advances in Solar Energy Technology, Vol. 4, Proc. of the Biennial Congress of the Int'l. Solar Energy Society Held at Hamburg, Sep 1987.

A simulation model is described, which permits the evaluation of all kinds of building performance. The model is a composite of three different models. The first was developed under the sponsorship of the

National Alternative Energies Agency (ENEA) and implemented to optimize the energy aspects of bioclimatic solar greenhouses. It was tested by a prototype located in the Casaccia area near Rome. The second model calculates the daylighting of rooms, and was drawn out for the PFE project of the National Research Council, while the last model analyses the rooms' sound insulation. The general purpose simulation model, consists of a main program and three subroutines, which evaluate respectively, the thermo-hygrometric and energetic behavior of rooms, their illumination design, and acoustics.

Brunello, P., Bloss, W.H., Pfisterer, F., "Transfer Functions Method for Daylighting Calculations", Advances in Solar Energy Technology, VOL. 4, Proc. of the Biennial Congress of the Int'l. Solar Energy Society Held at Hamburg, Germany, Sep 1987.

Simulations of daylighting levels inside a building under actual weather conditions are made possible by suitable transfer functions. For their evaluation, the use of a detailed computer model, based on a Monte-Carlo approach, is proposed.

Hraska, J., Rybar, P., Andrejko, D.A., Hayes, J., "A Simplified Procedure for Calculating Reflected Daylight", Proc. of the 12th Passive Solar Conf., Portland, OR, July 1987.

The split flux method, frequently chosen for quick calculations of internally reflected component of daylight factor, is correct for only some reflection factors of interior surfaces and only for determined portions between daylight aperture and interior space. After analyzing luminous flux transmitted through windows, a new procedure for calculating the average internally reflected component inside lit rooms under CIE overcast sky was developed. This paper describes the derivation of the new procedure to predict the average reflected daylight. The results obtained are consistent with real-world findings.

D'Cruz, N.A., Radford, A.D., "Multicriteria Model for Building Performance and Design", Building Environment (UK), Vol. 22, No. 3, 1987, pp. 167-179.

A multi-criteria model is described to assist designers in the choice of form and construction of parallel piped open plan office buildings at the preliminary stage of building design. The model considers four performance criteria: thermal load, daylight availability, planning efficiency and capital cost. Pareto optimal dynamic programming optimization is employed. The model's form and implementation and some typical results are described.

Kim, J.J., Papmichael, K., Selkowitz, S., "Development of Regression Equations for a Daylight Coefficient of Utilization Model", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

A new coefficient of utilization (CU) model for daylighting is described, that combines the ease of use of CU models with the ability to predict illuminance under a wide range of conditions. The model consists of seven regression equations normalized to exterior vertical surface illuminance. These equations describe daylight illuminance as a function of room position and are sensitive to all of the significant design variables. The equations are derived from parametric analysis using a mainframe daylighting computer model (SUPERLITE). The authors describe how these equations were developed and their physical and theoretical background. Comparisons between direct calculation and CU results for sample room are demonstrated.

Kim, J.J., Papmichael, K.M., Selkowitz, S., Spitzglas, M, Modest, M., "Determining Daylight Illuminance in Rooms Having Complex Fenestration Systems", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

The authors describe a new approach that combines measured luminance distribution for complex window systems with a flux transfer calculation within the space. This method resembles the calculation of illuminance from electric light fixtures where the candlepower distribution of the fixtures is measured and used as an input to the calculation. Based on the variable luminance characteristics of the window system, the SUPERLITE program calculates illuminance at the workplane over the entire space. The measurement techniques and mathematical implementation in the SUPERLITE program are described. This approach allows a wide range of complex and shading systems to be evaluated without continuous changes in the computational program. A special apparatus for measuring the bi-directional transmittance of window systems has been built in conjunction with this approach. Sample results from the program are compared to measurements made in scale models in a sky simulator.

Nishita, T., Nakamae, E., "Continuous Tone Representation of Three Dimensional Objects Illuminated by Sky Light", Computer Graphics, Vol. 20, No. 4, Aug 1986, pp. 125-132.

The paper proposes an improved model for natural lighting calculations that adequately considers both direct sunlight and scattered light caused by clouds and other forms of water vapor in the air. The advantage of the proposed method is particularly apparent when simulating lighting under an overcast sky or when rendering surfaces that fall within a shadow cast by an obstruction lit by direct sunlight.

Sullivan, R., and Selkowitz, S., "Residential Window Performance Analysis Using Regression" Presented at the Building and Energy Simulation Conf., Seattle, WA, Aug 21-22, 1985.*

The development of a simplified algebraic expression that can be used to predict the effects of various window parameters on residential energy use is documented. A comprehensive parametric study of a prototypic single-family ranch-style house was performed using the DOE-2.1B energy analysis simulation program. The data base generated for the study consists of the heating, cooling, and total energy requirements and subsequent costs due to changes in the fenestration characteristics of orientation, size, conductance, and shading coefficient. Incremental effects due to shade management, night insulation, and overhangs are also part of the data base. Climate sensitivity was established by considering results from four geographic locations representative of the climate extremes in the continental U.S. Multiple regression techniques are used to generate a simplified algebraic expression that relates energy use to the parameters varied. This representation could form the basis for a simplified design tool for selecting optimal fenestration parameters.

Robbins, C.L., Hunter, K.C., "Daylighting Data Compendium", Passive Solar Journal., Vol. 3, No. 2, 1986, pp. 191-206.

This paper describes the results of a research effort at SERI to develop a mathematical model to describe the daylight resource in various cities and to publish the resulting data in a format useful to architects, engineers, and lighting designers.

Van der Voorden, M., "Determining the Rate of Solar Irradiation in the Built Environment", Intersol 85: Proc. of the Ninth Biennial Congress of the Int'l. Solar Energy Society, Montreal, Can., June 1985.

A methodology is described which allows accurate large scale calculation of irradiation quantities without restrictions as to shape, orientation and position of present obstacles and openings. Some primary sources of diffuse radiation calculation are mentioned.

Kireev, N.N., "Development of Theoretical Methods for Determining the Reflected Component of Internal Daylight", Svetotekhnika, No. 2, 1982.(Russian)

Chou, C.P., "Mathematical Model of Building Daylighting Based on First Principles of Astronomy", Solid Geometry and Optical Radiation Transfer, Dissertation, Microfilms order No. 87-21, 1987.

This dissertation describes the theoretical development and computer implementation of a mathematical approach to analyze the distribution of direct and diffuse daylight. It examines light transfer from extraterrestrial space to the inside of a room based on the principles of Astronomy, solid geometry, and radiation transfer. This study discusses and analyzes certain aspects critical to developing a mathematical model for evaluating daylight performance and compares the results of the proposed model with 48 scale-model studies to determine the validity of using this mathematical model to predict the daylight distribution of a room. Subsequent analysis revealed no significant variation between scale-model studies and this computer simulation.

Powell, G.L., "Estimating Monthly Average Values of Fenestration Solar Heat Gains" ASHRAE Journal, Vol. 24, No. 2, Feb 1982, pp. 229-312.*

Equations for computing solar heat gain factors (SHFG) under cloudless conditions and tables of hourly clear day SHGF for the 21st day of each month for selected orientations and latitudes are included. These data, representing maximum probable gains for the reference system, have been used to determine cooling loads under summer design condition.

Rundquist, R.A., "Daylighting Energy Savings Algorithm" ASHRAE Transactions, Vol. 88, Part 1, 1982, pp. 343-373.*

The development of a simple method for calculating the annual lighting, cooling, and heating energy used in a building, as affected by daylighting is described. It is intended for use as a design tool at an early building design stage to make preliminary decisions on fenestration or to evaluate changes in existing components, such as glazing or daylighting controls. The procedure is described, first in general terms; then step by step. The "first principles" approach is discussed. A capital cost analysis, a computer program, and nomogram treatment are described. Several examples are shown. Justifications for all algorithm steps and inputs are given. To simplify the procedure, a number of assumptions and approximations are made, which approximate actual practice. The methodology is designed to be modified for special cases.

7. Skylight Research and Applications

Serres, A.W. and Murdoch, J.B. "Intensity Distributions of Skylight/Well Systems that have Prismatic Lenses", IES Annual Conference, Baltimore, MD, Aug 1990.

A skylight incorporating a flat prismatic lens is suggested as an alternative to a conventional double-domed transparent over translucent skylight. The prismatic lens offers a higher transmittance than translucent material, but still provides good diffusion. The paper examines the effects of three commercially available prismatic lenses on the intensity distributions of transparent and translucent skylights mounted on a 60 degree well under clear and overcast skies and compares their performances with that of standard double-domed transparent over translucent skylights.

Serres, A.W. and Murdoch, J.B. "On the Efficiency of Skylight Wells", IES Journal, Winter 1990.

The validity and limitations of the current IES skylight well efficiency graph are examined. Flux transfer techniques are used to compute the efficiency of square vertical and splayed skylight wells. The efficiencies calculated for square vertical wells are compared with values published in the IES well efficiency graph. The efficiencies for square splayed wells are compared with calculated efficiencies of an approximate vertical model of the splayed well. Calculated efficiencies are provided in tabular format as a function of well height-to-width ratio and well angle.

Parent, M.D. and Murdoch, J.B. "Skylight Dome-Well System Analysis from Intensity Distribution Data", Lighting Research and Technology, Vol. 21, No. 3, 1989.

Intensity distribution data for 18 skylight dome-well combinations were taken for clear and overcast skies and a wide range of solar altitudes. These data are used in two ways: 1) To calculate coefficients of utilization for skylight systems so that these systems may be treated in the same manner as ceiling-mounted electrical luminaires, 2) To compare skylight systems on the basis of dome transmittance, dome diffusion, dome height-to-width ratio, well reflectance, well angle, well height-to-width ratio, and direct sun shielding.

Parent, M.D. and Murdoch, J.B. "Expansion of the Zonal Cavity Method to Include Skylights", IES Journal, July 1988.

Data were collected for skylight models, using a microprocessor controlled skylight test chamber. Horizontal illuminances on the exterior of the skylight and skylight intensity distribution curves (in four phases) were obtained for a variety of skylight dome, well configurations and sky conditions. This paper discusses the formulation of coefficients of utilization and luminous exitance coefficients for the above mentioned data, and the subsequent expansion of the Zonal Cavity Method to include skylights.

Parent, M.D., Murdoch, J.B. "Analysis and Comparison of Skylights Based on their Intensity Distribution Curves", CIBSE National Lighting Conference, Cambridge, 1988.

A test facility for obtaining skylight intensity distribution curves is in operation on the roof of the engineering building at the University of New Hampshire. Intensity distribution data for 32 skylight dome-well combinations have been taken for clear and overcast skies and a variety of solar altitudes. This paper analyzes these skylight systems based on their measured intensity distributions and the calculated illuminance distributions. Skylights are compared with respect to dome transmittance, dome diffusion, dome height-to-width ratio, well reflectance, well angle, well height-to-width ratio, and direct sun shielding.

Bodmann, H.W., Ederbach, K., Reuter, P., "Roof Lighting and Sun Protection", Energy and Buildings, Vol 11, No. 1-3, Mar 1988.

On the basis of a radiation model of the sky and direct sunlight, glare and heat loads can be calculated for different roof light systems. To avoid overheating, a maximum daily energy input through roof lights of 0.65 kwh per square meter of floor area is suggested, whereas the glare limit is set by a maximum luminance of 6000 cd/m2. With these criteria, the efficiency of various roof light system is evaluated in terms of annual hours of daylight use with a set minimum of the interior illuminance. Energy savings with roof lighting depend on the required lighting level and on the electric lighting switching scheme.

Duber, J.R., Moore, F., Andrejko, D.A., Hayes, J., "Daylighting Design Guidelines: Roof Monitor With Adjacent reflector Wall", Proc. of the 12th Passive Solar Conf., Portland, OR, July 1987.

The design guidelines described are derived from experiments performed with a daylighting system model consisting of a roof monitor with an adjacent reflector wall. Test results were measured and recorded by a data acquisition system and plotted as a graph on a sectional drawing of the model. The guidelines presented in this paper include: 1) a discussion of the system illuminance performance based on model tests, 2) the relative effect of the variables, considering their daylighting performance as measured on the horizontal work plane, and 3) suggested methods and materials for various effects offered by the system described.

Place, W., Coutier, P., Fontoynont, M., Kammerud, R., Andersson, B., Bauman, F., Carroll, W.L., Wahlig, M., Webster, T.L., "The Impact of Glazing Orientation, Tilt and Area on Energy Performance for Roof Apertures", ASHRAE Meetings, New York, NY, Jan 1987.

An investigation was made of the potential reductions in electric lighting and associated thermal impacts of replacing electric light with sunlight admitted through rooftop glazing on a single-story, prototypic office building. Experimental scale models are used to determine the fraction of the solar radiation entering the aperture reaching the work plane as useful illumination. This information is used in a developmental version of the building energy analysis computer program BLAST-3.0 to predict reductions in lighting electricity and the impact on energy consumption for heating and cooling the building.

Bauman, F., Place, W., Andersson, B., Howard, T.C., Thornton, J., "The Experimentally Measured Performance of a Linear Roof Aperture Daylighting System", ASHRAE Meeting, New York, NY, LBL-19590, Jan 1987.

Illumination and solar radiation measurements were made on a scale model building containing sloped, south facing double pane roof glazing. To control glare and properly disperse the beam sunlight over the work plane a good diffusing glazing was used for the inside pane of the roof aperture. Measurements were made to investigate the performance of this system under clear sky conditions in response to changes in a variety of interior design options. The results indicate that with modest glazing areas, the roof aperture system provides a work-plane illuminance, more than adequate in quantity and uniformity. Among the interior design options with significant effects on daylighting system performance are interior surface reflectances, overhead obstructions, and interior partitions. The outdoor experimental facility and scale model building are described and the results of experiments, presented and discussed.

Arasteh, D., et al., "Skylight Energy Performance and Design Optimization" Presented at the Windows in Building Design and Maintenance Conf., Gothenburg, Sweden, June 13, 1984.*

Proper skylight utilization can significantly lower energy requirements and peak electrical loads for space conditioning and lighting in commercial buildings. This study systematically explores the energy effects of skylight systems in a prototypic office building and examines the savings from daylighting. The DOE-2.1B energy analysis computer program with its newly incorporated daylighting algorithms was used to generate more than 2000 parameters, including skylight-to-roof ratio, shading coefficient, visible transmittance, skylight well light loss, electric lighting power density, roof heat transfer coefficient, and type of roof/skylight characteristics to minimize total energy or peak electrical load requirements.

Nettleton, J., Murdoch, J.B. "Determination of Total External Illuminance on a Sloped Surface from Sunlight and Skylight", IES Journal, July 1983.

Easy to use tables of external illuminance values for sloped surfaces can contribute to building designs using skylights in a pitched roof. The number, area, orientation of skylights and other factors are more easily determined for the predetermined level of illumination required when the external illuminance on the skylights' surfaces is known. Equations such as the one by Moon-Spencer (overcast sky luminance distribution) and Kittler (clear sky luminance distribution), are utilized to develop mathematical models to determine the exterior illuminance values.

Lewis, D., "Good News on Skylight Performance" Solar Age, Vol. 8, No. 2, Feb 1983, pp. 22-25.*

The effects of skylights on heating, cooling and lighting loads are examined using both winter and summer energy analyses. It is concluded that, in mild climates, skylights can save energy in summer and winter; in colder and cloudier climates, energy might be lost in the winter but saved in the summer. The optimum skylight area is discussed for home and commercial applications. Glazing options (single, double, or triple), heat loss, air leakage, and condensation control are considered as well as a ratio of glazing area to roof opening area, installation requirements, operation, and cleaning. A sample skylight analysis is conducted for a supermarket in Arizona. A list of skylight manufacturers and a source of additional information are provided.

Dietz, P.S., Murdoch, J.B., Pokoski, J.L., Boyle, J.R. "A Skylight Energy Balance Analysis Procedure", IES Journal, Oct 1981.

This paper provides a systematic method to calculate the total, net differential energy balance observed when sections of a building roof are replaced with skylights. Numerous mathematical models have been developed to approximate the heat transfer and illumination energy gains associated with installing skylights. The procedure described is especially well suited to be implemented on microcomputers. Among the topics discussed are the effects of solar gain, dome and curb conduction heat transfer, equivalent roof area heat transfer, infiltration heat transfer, artificial lighting energy requirements, and illumination savings from skylights. The paper also provides supplementary data needed to complete energy calculations. This information appears in the form of appendices, tables and graphs.

Murdoch, J.B. "A Procedure for Calculating the Potential Savings in Lighting Energy from the Use of Skylights", IES Journal, July 1977.

A procedure is presented to calculate the lighting energy that can be saved by turning off some or all of the electrical lighting in a room with skylights. It is designed to determine the lighting energy tradeoffs between electrical lighting and skylighting, based on the ability of each approach to provide average horizontal footcandles on a work plane.

8. Atria

Degelman. L.O., Molinelli, J.F., Kim, K.S., "Integrated Daylighting, Heating and Cooling Model for Atria", ASHRAE Proc., 1988 winter meeting, Vol. 94, Part 1., pp. 812-825, 1989.

The development and testing of a model to assess the energy savings from the integrated effects of daylighting, heating and cooling in building atria are presented. Several prototype atrium configurations within a standard building are addressed to derive an analytic process to describe daylighting energy performance. Multistory atria of the three sided square and linear types are considered as are warming and cooling functions. The model is first developed as a set of algorithms for use in hour-by-hour simulation procedures which then generate data to derive simplified algorithms. Model validation is accomplished by comparing daylight measurements in scale models and actual buildings. The software was written to be run on a variety of microcomputers or on a mainframe, using FORTRAN.

Gillette, G. "Atrium Roof Glazing: Energy and Daylighting Implications", Construction Specifier, Vol. 42, No. 3, Mar 1989, pp. 44-51.

Study results involving a simple prototype atrium and attached building are presented. When the atrium glazing is treated as an integral part of the building, it can make the atrium space as energy conserving as a similar space without glazing, but the benefits lie largely with the effective use of daylighting. From this viewpoint it is important to evaluate atrium glazing with the 'zone of influence' to account for the benefit of supplementary lighting in the surrounding spaces. The increased peak cooling loads introduced by the atrium glazing is an important issue that must be carefully addressed. If large roof glazing areas are desired, solar screening devices or lower-transmittance glazing should be considered, even for cooler climates.

Kainlauri, E.O., Spears, R.E., "Interfacing of Daylight and Artificial Light in an Atrium", Proc. of Solar 89, The 14th National Passive Solar Conf., Denver, Co. 1989, pp. 169-176.

Research conducted at Iowa State University is described. The College of Design atrium is being used as a laboratory to develop a model for atrium performance. The model is to be tested at other ISU buildings containing atria. Since 1987, the atrium has been monitored for daylighting and artificial lighting, direct sun irradiation, temperature, humidity, air velocities and air quality in terms of CO and Co/su2/ concentration and radon content. DOE 2.1C software is used in a VAX system. Calculations have been run for some of the proposed improvements.

Boyer, L.L., Oh, M.S., "Computer Prediction and Measurement Comparison of Daylighting Performance in Selected Atrium Buildings Using the SERI Algorithms", ASHRAE Proc., 1988 winter meeting, Vol. 94, part 1, Dallas, Texas, 1988.

Daylight prediction algorithms developed at SERI and incorporated into existing software are utilized to determine daylight distribution patterns and levels in eight Texas buildings. Predictions are made for clear and overcast sky conditions, for different size atrium spaces and two lightshelf spaces, of which similar units adjoin atrium spaces courts. The six atrium spaces include sidelighting and toplighting configurations. Distribution patterns are then compared among these building configurations. Daylight measurements are made in each space and the results compared on an intra-building basis to the applicable prediction patterns. The evaluation period utilized in the analyses was 12 noon at the equinox period.

Gillette, G., Treado, S., "The Daylighting and Thermal Performance of Roof Glazing in Atrium Spaces", ASHRAE Proc., 1988 winter meeting, Vol 94, part 1, pp. 826-838, 1988.

The effect of large area of roof glazing in atrium spaces is assessed using site energy and peak demand loads as performance measures. Special attention is given to the role of daylighting in the net performance of the glazing system. A detailed thermal transport and daylighting analysis computer program provides data on three aspects of roof glazing performance: 1) the effects of the atrium alone, 2) the atrium and its surrounding daylighting zone of influence, and 3) the atrium and the coupled building as a whole. The results are presented in term of comparative performance, using a base case building configuration without glazing. The net change in performance due to the inclusion of the roof glazing is systematically evaluated. The results demonstrate the benefits of roof glazing in reducing the lighting energy requirements and in turn, reducing site energy. These benefits are tempered somewhat by the increased peak demand loads.

Kainlauri, E.O., Heilkema, T.H., Spears, R.E., Proc. of Solar 88, the 13th National Passive Solar Conf., Cambridge, MA, June 1988.

This research is intended to develop a model to investigate and analyze atrium energy performance. Using the College of Design Building at Iowa State University, measurements of temperature and lighting levels were taken. Diurnal patterns of the sun insolation were observed, and recorded by photography. Weather data and simultaneous sky conditions are included. The purpose of the model is to evaluate the effectiveness of an atrium in relationship to the following aspects: 1) interfacing artificial lights and daylight 2) ventilation to prevent air stratification 3) avoidance of the direct sun and glare in workspace and 4) effective building energy management.

Kim, K.S., Boyer, L.L., "Daylight Prediction and Measurement for Three-Sided Multistory Atria Under Overcast and Clear Skies", ASHRAE Proc., 1988 Winter Meeting, Vol. 94, Part 1, Dallas, TX, 1988.

Daylight prediction algorithms were empirically developed for three-sided generic atrium types under various sky conditions with a series of scale model studies in a university sky simulator. Algorithms are developed to predict light levels normal to the vertical wall surfaces at the middle floor of high rise atria with opaque and transparent roof systems.

These algorithms are then compared to the actual measured performance of two buildings for noontime conditions at the equinox periods of the year. Measurements were conducted at two buildings in Houston and San Antonio to produce full-scale building tests; horizontal and vertical illumination levels were obtained. Horizontal light levels were measured on the atrium floor while illumination levels were measured normal to the vertical wall surface.

Kim, K.S., "Development of Daylighting Prediction Algorithms for Atrium Design", Texas A & M University, Ph. D. thesis, Microfilms order No. 87-20, 913, 1987.

This research analyzes the daylighting performance in actual building atria including 4-sided, 3-sided and linear atria. Algorithms are also developed and validated to predict daylight levels in these atria under various sky conditions. Daylight patterns of three generic forms of building atria are tested through extensive actual building measurements in combination with scale model tests, and first principle theories. Measured data are correlated with scale model findings. Algorithms are developed to predict daylight levels at the wall and on the ground floor of the atrium, enabling conventional techniques to be used to calculate daylight levels in perimeter offices adjoining the atrium. Final algorithms based on the scale-model tests are calibrated by comparing with actual building measurement data for selected buildings in the Texas region. Office lighting performance and energy performance were not dealt with, but constitute a logical extension of this work.

Treado, S.J., Holland, D.B., Bean, J.W., Gillette, G.L., "Fenestration for Building Atria", National Bureau of Standards, Gaithersburg, MD., NBSIR-87/3594, Sep 1987.

The influence of fenestration design on building energy performance is evaluated based on measurements in four atrium buildings and a series of detailed computer simulations using TARP and CEL-1. The impact of glazing area and solar optical properties is examined for a linear and central atrium building for eight geographical locations. The usefulness of automatic solar shading and heat storage strategies is also investigated. Guidelines are presented for effective design of atrium fenestration.

Balcomb, J.D., Weaver, N., Anderjko, D.A., Hayes, J., "Photometric Measurements in Atria Using the Luminance Mapper", Proc. of the 12th Passive Solar Conf., Portland, OR, July 1987.

Preliminary data are presented based on measurements using a luminance mapper in an atrium in Denver, Colorado. This photometric instrument is a digital video scanning system that records luminance values from the image plane of a fish-eye lens. Analysis of these data reveals that the predominant source of illumination on the atrium floor was from the diffuse sky; however, 20.3% was from non-glazed enclosing surfaces, indicating that interreflections make an important contribution. The lack of consistency of the data suggests that improvements in the experimental technique are needed; however the value of the luminance mapper as a photometric tool was clearly demonstrated.

Erwin, B., Andrejko, D.A., Hayes, J., "Light well to Atrium Conversion: A Case Study investigating the Daylighting Issues", Proc. of the 12th Passive Solar Conf., Portland, OR, July 1987.

A case study, investigating the daylighting issues involved in converting an existing light well into an atrium is described. It includes an evaluation of the effects of natural light on the atrium floor and the adjacent spaces. The building studied is the John Radcliffe Hospital in Oxford, England. The study was conducted in three parts: 1) analysis of existing daylighting conditions in the light well and adjacent rooms, 2) constructing a scale model of the building for testing in the Polytechnic of Central London artificial sky, and 3) the design and analysis of potential glazing systems for the retrofitted atrium.

Kainlauri, E.O., Natural System of Solar Energy, "Daylighting and Ventilation in Buildings with Atria," ISES Solar World Congress 1987: Advances in Solar Technology, Hamburg, Germany, Vol. 2- Absts, 1987.

9. Daylight/Sunlight Measurements

Olseth, J.A., Skartveit, A., "Observed and Modelled Hourly Luminous Efficacies Under Arbitrary Cloudiness", Solar Energy, Vol. 42, No. 3, 1989, pp. 221-233.

The luminous efficacy of solar irradiance under a cloudless sky is calculated by a spectral radiative transfer model. Based on model runs with input data from Bergen, Norway, the beam and diffuse luminous efficacies are parameterized in terms of solar elevation and clearness index. An overall model is presented, yielding the luminous efficacy at arbitrary cloud conditions by a tuned interpolation between the efficacies for the overcast and the cloudless case. This model yields small deviations from observations, relative to the luminous efficacy variations caused by variations in solar elevation and cloudiness.

LeBaron, B.A., Michalsky, J.J., Larsen, N.R., "Comparison of Sky Luminance Maps with Instantaneous All-Sky Images." Solar 88; American Solar Energy Society Annual Meeting and 13th National Passive Solar Conf., Cambridge MA., June 1988.

A qualitative comparison of contour maps generated from a series of point measurements around the sky dome, and concurrent instantaneous all-sky photographs is described. Three minutes are required to complete and qualitatively depict the luminance distribution, even under rapidly changing cloud conditions. The models examined performed reasonably well for the clear and overcast sky when conditions were symmetric and stable, but were unsatisfactory for the anisotropy exhibited under partly cloudy skies. The comparisons suggest that scanning instruments can quantify the essential features of a luminance distribution for conditions of high anisotropy.

"Luminance Mapper Model 2", Corp. Source Codes: 000137000. Department of the Army, SERI/SP-260-2734/R-3, Apr 1988.

This paper summarizes an announcement of technology available for utilization. Luminance mappers provide information on lighting conditions in both outdoor and indoor environments. The device consists of a viewing assembly, a solid-state video camera, and a computerized workstation. It is designed to evaluate light in architectural scale models and predict interior lighting problems such as glare. It may be used in existing buildings to determine the most efficient use of light.

Littlefair, P.J., "Measurements of the Luminous Efficacy of Daylight." Lighting Research and Technology, Vol. 20, No. 4, 1988, pp. 177-188.

The results of a year's measurement of luminous efficacy at Garston, Hertfordshire, U.K. are presented. Direct sunlight efficacies increase with solar altitude. Diffuse sky efficacies exhibit a roughly linear relationship with cloud cover. The paper contains empirical functions and data tables to enable daylight data to be generated directly from the most common types of solar radiation data.

McArthur, L.B., Morris, R.J., Wardle, D.I., "Observing and Modelling Sky Radiance and Potential Applications to Daylighting Design", Annual Conf. of the Solar Energy Society of Canada, Ottawa, Ontario, 1988, pp. 32-36.

A multi-waveband sky scanning radiometer was developed to measure radiance in 10 wave bands between the ultraviolet and the near infrared, including 5 between 300 and 700nm. The design and operation of the instrument is reviewed. Analyses of individual sky radiance maps or significant wavebands are presented to illustrate change imposition. The potential application of a luminous efficacy model, developed and/or verified in part by the sky scanner data, and the provision of natural illumination data sets for fenestration and energy systems design in buildings, is discussed.

Miyach, Iwo, Yoda, Masayuki, Suzuki, Yoshihiko, "Environmental Characteristics on Spectral Irradiance of Solar Energy", Shomei Gakkai Zasshi (Japan) Vol. 72, No. 10, 1 Oct 1988.

The spectral irradiance data of solar energy, accumulated for five years from 1982, are reported as the basic data for technological uses such as a daylight building system or photovoltaic power system. A spectro-radiometer is used to measure the irradiance, which automatically tracks the sun to receive the sunlight perpendicularly to its sensing surface. The diurnal irradiance variation in the morning and afternoon, and of visible and near infrared radiation, are shown. The relationships between the typical irradiance and energy input at 550nm spectrum and the irradiance and sun altitude, are discussed. Basic spectral characteristics of scattered light are also given.

Secker, S.M., Littlefair, P.J., "Daylight Availability and Lighting Use: Geographical Variations", Lighting Research and Technology, Vol. 19, No. 2, 1987, pp. 25-34.

This paper describes a study of the magnitude of regional variations in climate and latitude in lighting energy use, based on the model of manual switching in daylight spaces derived by Hunt. Analysis of meteorological daylight data for five locations has produced for the first time, curves which can be used to predict hours of use of manually controlled lighting in daylit building in various parts of the U.K. These curve are presented, together with an analysis of the regional differences in lighting use for various example situations. The significance and probable causes of these variations are discussed, and the need for more daylight measurements in different parts of the country is explored.

Kelton, W.H., Murdoch, J.B. "Sky Luminance Measurement and Analysis", Second International Daylighting Conference, Long Beach, CA, Nov 1986.

Data collected with the University of New Hampshire Sky Luminance Meter, and analyses performed during its first year of use are presented. The use of the sky luminance data in calculating horizontal illuminances are discussed. Computer-graphic generated sky luminance maps are compared with fish-eye lens photographs of relevant skies. The use of luminance data and maps are advocated to replace the categorization of skies as 'overcast', 'clear', or 'partly cloudy'.

Treado, S.J., Remmert, W.E., Bean, J.W., "Sky Luminance and Direct Beam Illuminance". National Bureau of Standards, NBSIR-85/3251, Mar 1986.

Measurement of sky illuminance, sky luminance, direct beam illuminance and direct beam irradiance are analyzed and discussed. The data base consisted of an annual set of integrated hourly measurements made at the National Bureau of Standards, Gaithersburg, Maryland. The relationship between diffuse sky illuminance and luminance of selected portions of the sky dome is examined. Measured sky luminances are compared to luminance calculated using equations for three standard sky types-clear, partly cloudy and overcast. The results indicate that the luminance distribution of actual skies varied considerably from the standard skies.

Leuscher, F.W., "Clear-Sky Luminance Distribution as a Function of Solar Altitude and Turbidity Factor", Pretoria University, Ph.D. thesis, South Africa, 1986.

The author designed and constructed a computer controlled sky scanner to collect simultaneous data on the luminance distribution of a clear sky, as well as global and diffuse illuminance. He also studied clear sky luminance distribution at Pretoria as a function of solar altitude and turbidity.

Murdoch, J.B., Levin, R.E., "A Portable Sky Luminance Meter", Energy and Buildings, No. 6, 1984.

The development of an instrument to collect sky luminance data over an extended time period, and store it on a cassette tape is described. Data are collected automatically by positioning a photometer using stepping motors under microprocessor control. The instrument consists of five major components: a power supply, positioning hardware, photometer, interface hardware, and microcomputer. The elevation motor, photometer sight tube and sensor, are located on the elevation support assembly. All other components are housed in a base assembly. The instrument can be carried by one person.

Ubbelohde, M.S., Brown, G.Z., and Reynolds, J.S., "Approach to Teaching Calculation Procedures for Passive Design" Presented at the 6th National Passive Solar Conf., Portland, OR, Sep 8, 1981.*

Described is the development, testing and revisions of workbook design procedures for daylighting, passive solar heating and cooling, which emphasizes the integration of calculation procedures with the building design process.

10. Fenestration Systems - Design and Construction

Chahroudi, D., "The Future of High Performance Glazings" Solar Age, Feb 1986, pp. 21-26.*

This paper discusses transparent insulation options. It compares transparent insulations according to the number and type of coatings and number of glazing layers. Entries are rated according to their performance in three categories: conservation, heating, and lighting.

Norville, H.S., and Minor, J.E., "Strength of Weathered Window Glass," American Ceramic Society Bulletin, Vol. 6564, Nov 1985, pp. 1467-1470.*

The phenomenon addressed in this article is strength of window glass deterioration with exposure to environment under in-service conditions. This phenomenon is termed "weathering." The results of destructive tests are presented for several sets of both new and weathered window glass plate specimens under uniform lateral pressure. An analytical and statistical procedure which considers all parameters that govern behavior of these plates is used to determine the strength of sample sets. Reports cited in this paper suggest significant strength degradations occur with natural weathering of in-service window glass plates.

Anderson, J.B., "A Method for Finding Engineering Properties of Sealants" Journal of Engineering Mechanics, Vol. 111, No. 7, July 1985, pp. 882-892.*

Typical insulating glass units consist of two glass plates separated by a perimeter spacer. The use of insulating glass units in buildings prompted the development of methods to predict their behavior under temperature and pressure changes. This paper describes methods developed to generate stress-strain properties to use in existing theoretical models which characterize the structural mechanics behavior of insulating glass units. This method does not consider stress-strain properties due to temperature change.

Spetz, J., "How Fabricators Can Prevent Insulating Glass Unit Failures," Glass Industry, Feb 1985, pp. 10-13.*

Procedures and tests to prevent early insulating glass failure are described. Desiccant, sealant adhesion, sealant application, and unit designs are discussed.

Granquist, D.G., Hamberg, I., and Svensson, J., "Window Coatings with Selective Radiant Properties" Industrial and Engineering Chemistry Product Research and Development, No. 24, 1985, pp. 93-95.*

The first part of the paper discusses transparent and heat-reflecting films of indium-tin oxide. Fabrication by reactive e-beam evaporation, optical transmittance and reflectance in the 0.25-50 mm wavelength range, complex dielectric function and results from a quantitative theoretical model for the optical properties are covered. In the second part, electrochromic switching films based on tungsten oxide, are addressed. Two designs with liquid and solid electrolytes are included. Fabrication techniques and optical properties are discussed.

Reed, D.A., and Simiu, E., "Wind Loading and Strength of Cladding Glass" Journal of Structural Engineering, Vol. 110, No. 4, Apr 1984, pp. 715-729.*

A procedure to investigate glass cladding behavior under arbitrary loads is presented. The procedure accounts for the fact that internal stresses are nonlinear functions of the external loads in accordance with basic fracture mechanics laws. Numerical examples are presented, and corresponding probability distribution curves are calculated, indicating failure of a specified panel subjected to one-minute constant loads. Work is being conducted at the National Bureau of Standards.

Cassidy, V.M., "Vinyl Challenges Aluminum for Window Market Supremacy," Modern Metals, 1984, pp. 12-32.*

The advantages and disadvantages of PVC are discussed. Comparisons are made of market trends of aluminum, wood, and PVC. Window makers, extruders, resin firms, and equipment builders are interviewed.

Godfrey, K.A., "Window Glass in Extreme Winds: Design for Flying Debris" Civil Engineering, Vol. 54, Jan 1984, pp. 66-68.*

Highlights of a debate on whether to change window glass design procedures and building codes are presented. The topic was discussed at the ASCE's Houston convention, which identified the key cause of damage during Hurricane Alicia as window breakage from flying roof gravel and flying broken glass. Other concerns include weakening of glass due to scratching and pitting, and weathering. The Australian building code is discussed. Design alternatives against windborne missiles included solar louvers and screens, and laminated glass.

10.1 Fenestration - Energy

Lynes, J.A. and Littlefair, P.J. "Lighting energy savings from daylight: Estimation at the sketch design stage", Lighting Research and Technology, Vol. 22, No. 3, 1990, pp. 129-137.

Determining the energy implications of window design requires knowledge about the effects of interior daylight on electric lighting use. Current methods for predicting lighting energy usage cannot be used at the initial design stage because they require details of lighting layout, control sensor location and window shape and position. The paper describes how lighting energy savings can be predicted from the average daylight factor in the space, using photoelectric or manual controls. The methods do not require calculations of point daylight factors, knowledge of luminaire layout or control sensor positions.

Koester, H., Bloss, W.H., Pfsisterer, F., "Energy Facade for a Multistory Building", Advances in Solar Energy Technology, Vol. 4, Proc of the Biennial Congress of the Int'l. Solar Energy Society, Hamburg, Germany, Sep 1987.

Kurkowski, T., "Solar Research for the Next Decade", Construction Specifier, Vol. 40, No. 6, June 1987, pp. 44-49.

In order for designers to specify products that make solar energy work in a building, a research program for sophisticated solar building materials was born. Solar researchers conclude that a primary need is for cost-effective, controllable glazing, and thermal storage systems that resemble the curtain wall skins or stud wall interiors traditionally used but that admit, store, and release solar heat and daylight as needed by the building. Such a product is described in this article.

Wiebke, S.H., "Influence of Glazing Systems on the Energy Performance of Low-Rise Commercial Buildings" Masters thesis. Wright-Patterson AFB, OH: Air Force Institute of Technology, May 1985.*

The impact of variations in glazing parameters on building energy consumption is examined for a typical low-rise commercial office building. The net annual effect depends on a complex interaction among climatic conditions, building design features, and building operating characteristics. The goal of this study was to segregate the energy effects of fenestration design, quantify these effects, and develop simplified analytic tools for building designers. Economic parameters are integrated to analyze total performance results in diverse energy regions of the country. This study includes a simulation of annual building energy performance and thermal response, using the DOE-2.1A energy analysis program, generating a data base for the multiple regression statistical investigations, and a life-cycle cost analysis. A representative range of commercial glazing systems, through the primary parametric glazing properties (U-value, shading coefficient), is considered. A base single clear glass is compared to ten insulated systems for ten climatic regions in the United States. Guidance is developed for effective glazing systems in low-rise office buildings, for energy performance and cost-effectiveness.

Arasteh, D., and Selkowitz, S., "Prospects for Highly Insulating Window Systems" Presented at the Conf. on Conservation in Buildings: Northwest Perspective, Butte, MT May 20, 1985.*

Windows and other fenestration systems are often considered the weakest links in energy-efficient residences. This opinion is reinforced by building standards, audit guidelines, and standard window performance evaluation techniques designed to size building HVAC equipment. This paper explores the possibility of designing highly insulating windows with high solar transmittances (SC 0.6) and developing "super windows" to outperform the best insulated wall or roof for any orientation, even in northern climates. Reviews of several technical approaches suggest how such a window system might be designed and built. These include using multiglazed windows, having one or more low-emittance coatings, and gas-filled or evacuated cavities and using a layer of transparent silica aerogel, a microporous material, with a conductivity in air of about R7 per inch. Data are presented on annual energy performance in a cold climate for a range of "super windows."

Carlson, A.R., "Window Treatment for Cold Climates" American Society of Agricultural Engineers Technical Paper, Paper No. 83-4064, St Joseph, MI: American Society of Agricultural Engineers. Presented at the Am. Society of Agricultural Engineers Summer Meeting, Bozeman, MT, June 26, 1983.*

Design considerations for energy conserving window treatments to avoid condensation-related maintenance problems are discussed. The window heat losses, dewpoint temperatures and allowable relative humidities at which condensation may occur on interior glass surfaces at an interior temperature of 65 degrees F and exterior temperatures from -50 to 30 degrees F, are calculated by computer. Vapor pressures are also computed to show the importance of vapor (air) tight weather stripping and coverings for window treatments.

Rubin, M., "Solar Optical Properties of Windows" Int'l. Journal of Energy Research, Vol. 6., 1982, pp. 123-133.*

To properly calculate dynamic solar gain in buildings, one must know the optical properties of the window in detail. In this paper, a complete set of calculation procedures for determining the solar transmittance, reflectance, and absorption of a window composed of an arbitrary number of partially transparent layers are developed. Any layer may have a thin-film multilayer coating, such as an anti-reflection coating to increase solar transmittance, a solar control film to reduce solar heat gain, or a transparent heat-reflecting mirror to improve thermal resistance. The results of sample calculations are given for a range of incidence angles for conventional and advanced energy conserving window designs.

Sherwood, L.T., "Glass to Moderate Glare and Heat from Windows" Illuminating Engineering, Vol. 32, No. 6, June 1937, pp. 665-686.*

Different types of glass (real and hypothetical) are discussed to reduce transmission in the infrared and visible spectra. Glare is decreased by reducing transmission (as low as 40%). No method of assessing the needs is given except in very general terms. Glass color and its psychological effects are discussed.

10.2 Fenestration Materials

Murdoch, J.B., Oliver, T.W., Reed, G.P. "Luminance and Illuminance Characteristics of Translucent Daylighting Sandwich Panels", IES Annual Conference, Baltimore, MD, Aug 1990.

Translucent sandwich panels are used extensively in architectural daylighting applications. This paper describes three metrics to quantify the luminance and illuminance characteristics of spaces lit by such panels under clear and overcast skies. Measurements of three daylighting sandwich panel installations were taken during the summer of 1988 to form the data base for the study.

Goldner, R.B., Seward, G., Won , K., Haas, T., Foley, G.H., Chapman, R., Schulz, S., "Completely Solid Lithiated Smart Window", Solar Energy Materials, Vol. 19, No. 1-2, Sep 1989, pp. 17-26.

Yadoya, M., Taiyo Enerugi (Japan) Vol 15: 1, June 1989, pp. 13-21. (Japanese)

Windows, though generally equipped with a venetian blind to avoid the direct projection of daylight, can reflect daylight from ground objects, to the ceiling to help light the room interior. There are several devices to produce this effect. Also, one can collect daylight by a heliostat on the roof and transmit it into the room interior through a vertical duct. This method promises to become more effective by using endothermic glass or film or glass with vapor deposition of high substance in reflection ratio of radiation at specified wavelengths.

Goldner, R.B., Hass, T.E., Seward, G., Wong, K.K., Norton, P., Foley, G., Berera, G., Wei, G., Shulz, S., Capman, R., "Thin Film Solid State Ionic Materials for Electrochromic Smart Window Glass", Solid State Ionics, Vol. 28-30, Sep. 1988, pp. 1715-1721.

The optical transmissivity of a multilayer elctrochromic smart window glass structure can be reversible, modulated by an electrical current pulse, and the modulation is spectrally selective. This is important for building and vehicle windows and other electro-optical applications. Thin film solid state ionic materials are the key elements of such a structure. Their roles and some current developments at Tufts are described. Also discussed is the state of development of prototype solid state, electrochemically reversible five layer window devices.

Valdes, N., "Low E Glass increased Performance/Greater Design Freedom", Construction Specifier, Vol. 41, No. 8, Aug 1988, pp. 73-78.

This article discusses low-E coatings and applications, specifying low-E glass, and other aspects of the subject.

Papamichael, K., Klems, J., Selkowitz, S., "Determination and Application of Bi-directional Solar-Optical Properties of Fenestration Systems", Solar 88: American Solar Energy Society annual meeting, Cambridge, MA, June 1988.

Accurate determination of the luminous and thermal performance of fenestration systems that incorporate optically complex components requires detailed knowledge of their radiant behavior. The authors describe a large scanning radiometer used to measure the bi-directional transmittance and reflectance of fenestration systems and components. They present examples of measured data obtained for simple non-specular samples. They also describe a method of obtaining the overall properties of fenestration systems by calculation from scanning radiometer measurements of fenestration components. Finally, they explain the application of bi-directional solar optical properties of fenestration systems to determine their luminous and thermal performance with respect to building energy consumption and occupants' comfort.

"Advanced Building Envelope Materials Technology", NTIS source code 055665000, June 1988.

This bibliography contains citations concerning building envelope and double envelope materials and tests for thermal efficiency. Included are references to insulation and superinsulation, ventilation and condensation, type and configuration of heating and cooling systems, relation of materials and design to climate, fenestration and double glazing and air tightness. Envelope technology is applied to test houses, new construction and retrofit of existing houses and buildings.

Furler, R., Williams, P., Kneubul, F.K., "The Relation Between IR and VIS Spectral Properties of Glasses and the Energy Transfer through Windows", Proc. of SPIE-Int'l. Society of Optical Engineering, Vol. 1039, pp. 348-9, 1988.

Sato, N., Kimura, S., "Measuring Integrated Amount of Daylight in the Greenhouse with Anthracene-Ethyl Alcohol Actinometers", Shizuoka Agricultural Experiment Station, Shizuoka, Japan, Dec 1987.(Japanese).

An experiment is described, designed to study the method of measuring the solar irradiation with the anthracene-ethyl alcohol actinometer in a greenhouse, covered by glass and double skin acrylic sheet for the cultivation of muskmelons. 30 ppm anthracene in ethyl alcohol had high absorption spectrum with five peaks around 350 nm wavelength of light. There was a negative linear correlation between the logarithm of the absorbance of the anthracene-ethyl alcohol solution at 350nm and the integrated solar irradiation. The correlation is expressed as log/sub 10/d=AxI+B. Where D= absorbance of anthracene-alcohol solution exposed to sunlight, I= the integrated solar irradiation calculated from the changes in absorbance of anthracene-ethyl alcohol solution, and A and B=constants.

Cogan, S.F., Plante, T.D., McFadden, R.S., Rauh, R.D., "Solar Modulation in a-WO/sub 3/a-Iro/sub 2/ and c-k/sub x/WO/sub 3+(x/2)//a-Iro/sub 2/

complementary electrochromic windows", Materials and Optics for Solar Energy Conversion and Advanced Lighting Technology Conf. San Diego, CA, USA Aug 1986, Solar Energy Materials, Vol 16, No. 5, Nov 1987, pp. 371-38.

The electrochemistry and optical switching of complementary electrochromic windows based on a-Iro/sub 2//a-Wo/sub 3/ and a-Iro/sub 2//cK/sub x/WO/sub 3+(x/2) are reviewed. Optical spectra in the 350-2000 nm wavelength range are used to calculate the solar attenuation obtainable with the windows.

Anon, "Window Shopping- Looking at Current Glazing Market Trends", PPG industries Inc., June 1987.

This article based on information received from PPG Industries Inc, USA, identifies some of the different glazing types currently available and the particular benefits of each.

Polato, P., Bonicatto, G., "Reflectance Measurements on Coated Architectural Glasses Using Commercial Spctrophotometers With Integrating Sphere Accessories", Glass Technology, (UK) Vol. 28, No. 4, Aug 1987.

The decomposition of thin films on clear or colored flat glass is used to give solar control and/or thermal insulation. The daylight, solar, and thermal parameters of the products have to be determined for a complete assessment of their performance. Various standards recommended that this be accomplished by calculations starting from the transmittance and reflectance curves in the visible (380-780nm) solar (300-2500 nm) and thermal (3-50 mu..m) ranges. Daylight reflectance and direct solar reflectance can be determined by integration of the curve obtained with specular reflectance accessory or an integrating sphere, both of which may be used with spectrophotometers.

Ian, R., King, E., "Holographic Glazing Materials for Managing Sunlight in Buildings", Journal of Architectural and Planning Research, Vol. 4, No. 1, Mar 1987, pp. 1-6.

Some applications of holographic films under consideration include direct sunlight into multistory buildings by means of holographic glazing superimposed on window surfaces or through hollow light guides in a plenum space or air shaft. These glazings will be capable of tracking the sun over a wide range of azimuths and altitudes, transferring sunlight from the path which it would ordinarily follow, and redirecting it to a location more useful for heating or lighting purposes.

Sweitzer, G., Arasteh, D., Selkowitz, S., "Effects of Low-Emissivity Glazing on Energy Use Patterns in Non-residential Daylighted Buildings", ASHRAE Meeting, New York, Jan. 18, 1987.

This paper presents the authors' assessment of energy use effects of low-emissivity (low-E) versus conventional glazing for a range of window-to-wall ratios in a daylighted office building in representative hot and cold climates. Low-E glazings transmit 'cooler' daylight than their conventional counterparts because for a given visible transmittance, they reflect a much larger fraction of incident solar infrared radiation.

Dahlen, R.R., "Low-E Films for Window Energy Control", ASHRAE Transactions, Winter Meeting 1987, Vol 93, Part 1, 1987, pp. 1517-1524.

The key to the design of low-E films for retrofit application is the protective cover for the low emittance, thin metallic coatings. Infrared transparent materials, which provide good physical and chemical protection, have been incorporated, yielding a minimum of five years life expectancy in retrofit environments. Window manufacturers are also using low-E films in the construction of new high performance windows.

Goldner, R.B., Capman, R.L., Foley, G., Goldner, E.L., Hass, T., Norton, P., Seward, G., Wong, K.K., "Recent Research Related to the Development of Electrochromic Windows", Solar Energy Materials, Vol. 14, No. 3-5, Nov 1986.

Results of recent research on each layer of a solid state multilayer structure for electrochromic windows are reviewed. This includes a review of the requirements of the multilayer structure for building windows and especially the need to have an electrochemically balanced system.

Papamichael, K., Winkelmann, F., "Solar Optical Properties of Multilayer Fenestration Systems", Int'l. Daylighting Conf., Long Beach, CA, Nov. 5, 1986.

This paper describes a mathematical model for the calculation of the bi-directional solar/optical properties of multi-layer fenestration system, using the bi-directional solar optical properties of each layer. The model is based on the representation of the bi-directional solar/optical properties using matrices. Matrix operations are then used to calculate the directional solar/optical properties of any combination of layers, considering the interreflections between them.

Jorgenson, G.V., Lee, J.C., "Doped Vanadium Oxide for Optical Switching Films", Solar Energy Materials, Vol. 14, No. 3-5, Nov 1986.

Cogan, S.F., Plante, T.D., Mc Fadden, R.S., Rauh, R.D., Lampert, C.M., Holly, S., "Optical Switching in "Complementary" Electrochromic Windows, Material and Optics for Solar Energy Conversion and Advanced Lighting Technology", SPIE Technical Symposium on Optics and Opotoelectronic Engineering, San Diego, CA, Aug 1986.

The electrochemical and optical switching characteristics of a variety of variable transmittance complementary electrochromic windows are presented. The complementary coloring amorphous WO/ Sub 3/ and Crystalline K/sub x/WO/sub 3+(x/2)/ combined with anodically coloring Iro/sub 2/. The optical switching characteristics are discussed in terms of the complementary device structure and the electrochemistry of the individual eletrochromic layers.

An ion beam sputtering system is used to deposit doped vanadium dioxide that decreases the transition temperature (T//t) from that of stoichiometric VO//2. The objective is to synthesize a material that will passively switch between a heat-transmitting and a heat reflecting state at specific design temperatures. The technique is reactive ion beam sputtering of vanadium and a dopant, in a well controlled atmosphere of Ar with a partial pressure of o//2. The films are deposited at elevated temperature onto glass and sapphire substrates for spectrophotometric evaluation above
and below T//t. The longer range goals of this research are to develop the material for: 1) thin film application to building glazing and 2) pigments for opaque wall coatings.

Lampert, C.M., Holly, S., "Materials and Optics for Solar Energy Conversion and Advanced Lighting Technology", Proc. of SPIE Technical Symposium on Optics and Optoelectronic Engineering, San Diego, CA, Aug 1986.

This conference encompasses topics in the fields of optical switching materials, photovoltaic materials, holographic films and solar optical materials, as well as insolation, and illumination testing and measurement technologies, light source hardware and applications, novel optical techniques in illumination, and the production of lighting effects in the entertainment industry. Attention is given to thermochromic and electrochromic materials for optical switching and energy efficient windows, tin oxide anti-reflection coatings, holographic solar concentration and greenhouse lighting, long lived glass mirrors for space, exposure testing of solar absorbers, optical projection equipment, medium and short arc metal halide lamps, and non-imaging optics for illumination.

Lee, J.C., Jorgenson, G.V., Lin, R.J., Lampert, C.M., Holly, S., "Thermochromic Materials Research for Optical Switching, Materials and Optics for Solar Energy Conversion and Advanced Lighting Technology", SPIE Technical Symposium on Optics and Optoelectronic Engineering San Diego, CA, USA Aug 1986.

Reactive Ion beam sputtering (RIBS) is used to deposit doped vanadium dioxide (v/sub 1-x/M/subx/O/sub 2/), where M is a dopant that lowers the transition temperature (T/sub t/) from synthesize a material that will passively switch between a heat transmitting and a heat reflecting state at specific heat design temperatures in the human comfort range. The films are sapphire substrates for spectrophotometric evaluation above and below T/sub t/. Then by analyzing the deposited films via EDAX, correlations between film composition and passive solar switching performance are made. Concepts for synthesizing suitable crystallites of such materials are also described. These crystallites could act as switchable pigments for thermochromic solar paint.

Dahlen, R.R., and Hill, B.K. "Sophisticated Window Films" The Construction Specifier, Vol. 39, June 1986, pp. 60-67.*

Cost and savings of solar control films are discussed, with examples of payback on investment. Formulas for Solar Heat Gain Coefficient, Shading Coefficient and Luminous Effectiveness Factor are also given. The paper also addresses other benefits of window film including ultraviolet reduction, shatter resistance, aesthetics, privacy and scratch resistance.

Potter, T.F., Benson, D.K., "Recent Results: SERI's Development of Advanced Glazing", ACEEE (American Council for an Energy-Efficient Economy) 1986 Summer Study on Energy Efficiency in Buildings: Vol. 2, DOE/CE/27460, 1986.

Progress since new window designs were presented at the 1984 ACEEE summer study is described. Laboratory tests of stress failure and thermal conductance of the R-10 vacuum window are continuing. Current results confirm previous conclusions based on simulations that such a glazing configuration is: 1) possible and 2) a significant improvement over current low emittance (low-E) window designs. Improved economic analyses are also presented. Further progress in developing solid state electrochromic window coatings is also described. Such coatings can provide automatic, electronic control over the admittance of daylight and solar heat gains through widows. A recent achievement in obtaining a neutral gray electrochromic coatings, significant in the optimization of daylighting benefits, is discussed.

Tait, D.B., Yellott, J.I., "Prediction of Ground-Level Sunbeams for Specular Reflective Glass", ASHRAE Transactions, Vol. 92, Part 2A, 1986, pp. 268-279.

The development in the early 1960s of techniques for applying reflective metallic coatings to architectural glass and polymeric films has given a new degree of aesthetic freedom to architects and new sun control capabilities to HVAC engineers. By using such coatings and films, the admission of light and heat through fenestration can be controlled over a wide range, but some unforeseen consequences have been encountered. Among these is the creation of reflected sunbeams of unprecedented intensity. This paper shows how the direction, intensity, and length on a horizontal surface of such sunbeams can be predicted, and in some cases, controlled.

Granquist, D.G., Hamberg, I., and Svensson, J., "Window Coatings with Selective Radiant Properties" Industrial and Engineering Chemistry Product Research and Development, No. 24, 1985, pp. 93-95.*

The first part of the paper discusses transparent and heat-reflecting films of indium-tin oxide. Fabrication by reactive e-beam evaporation, optical transmittance and reflectance in the 0.25-50 mm wavelength range, complex dielectric function and results from a quantitative theoretical model for the optical properties is covered. In the second part, electrochromic switching films based on tungsten oxide, are addressed. Two designs with liquid and solid electrolytes are included. Fabrication techniques and optical properties are discussed.

Johnson, T.E., "Cool Windows" Solar Age, Aug 1984, pp. 28-31.*

Coated glass that lets daylight in and blocks solar heat is discussed. Four representative types of glass coating (low-E-coating on green cover plate and on bronze cover plate) and HM55 with clear cover plate and with green cover plate, are rated for transmission, unit thickness, winter U-value, and shading coefficient. Also, eight glazing options are rated for transmission, solar rejection, and summer and winter U-values. Energy savings with the B glazings are discussed with reference to heating, cooling, and lighting of a model office in three cold climate cities and three warm climate cities.

Berning, P.H., "Principles of Design of Architectural Coatings" Applied Optics, Vol. 22, No. 24, Dec 1983, pp. 4127-4141.*

This surveys design considerations involved in developing architectural thin film coatings. The first part deals with design factors influencing the thermal performance of windows; the second deals with aesthetics, especially color. Heat transfer analysis as it applies to glazings is discussed. Finally, sample graphs of heat transfer properties of coated glass and computed examples of various coating design types are presented.

Lampert, C.N., "Solar Optical Materials for Innovative Window Design" Int'l. Journal of Energy Research, Vol. 7, No. 4, Oct 1983, pp. 359-374.*

New and innovative optical materials and coatings can greatly improve the efficiency of window energy systems. These materials and coatings increase energy efficiency by reducing radiative losses in the infrared, or reducing visible reflection losses or controlling overheating due to solar gain. Current progress in heat mirror coatings for glass and polymeric substrates is presented. Highly doped semiconducting oxides and metal/dielectric interference coatings are reviewed. Physical and optical properties are outlined for anti-reflection films and transparent aerogel insulation media. The potential for optical switching films as window elements includes discussions of electrochromic, photochromic and other physical switching processes.

11. Shading Devices

Lynes, J.A., Cuttle, K., "Bracelet for Total Solar Shading", Lighting Research an Technology, Vol. 20, No. 3, 1988, pp. 105-113.

The solar bracelet is a shading device which prevents the entry of direct sunlight, but admits direct light from the cones of sky which the sun never enters. It thus has optimal shading properties. Applications of the bracelet to protect windows of different orientation and slope, at different geographical latitudes, are described. Various forms of geometrical redundancy, which mainly affect other shading devices, are identified. The first built embodiment of the solar bracelet principle in a New Zealand art gallery, is described.

Kuns, M., Kunz, B., Bloss, W.H., Pfisterer, F., Agero, A.,"'First Rol' Energy and Light Efficient Window System", Advances in Solar Energy Technology, Vol. 4, Proc of the Biennial Congress of the Int'l. Solar Energy Society Held at Hamburg, Sep 1987.

It is of great advantage if a window can adjust to the changing requirements due to daily and seasonal changes in the solar radiation, especially in a temperate climate. Changing climate and light conditions require a window system with dynamic properties. A roller blind system, with a metallized polyester film inside a double pane insulated panel is a promising approach. Compared to conventional dynamic systems or static systems, this system combines all requirements: heat protection, thermal insulation, glare protection and thermal comfort. Furthermore, the roller-blind insulated panel combination is practical, can be manufactured economically, and constructed as a prefabricated unit for standard window or door frames.

Critten, D.L., "Light Enhancement Using Reflectors Arranged on a Venetian Blind Configuration", Solar Energy, Vol. 37, No. 6, 1986, pp. 445-456.

A set of experiments are described in which the daily light gains during the second half of the winter period 1984/1985 produced by a continuous set of venetian reflecting assemblies suspended from the range of the southerly span of E-W twin span greenhouse are measured. The period is divided into three parts. Decreasing light gains are demonstrated as the sun's elevation increases with the season. An approximately symmetric distribution of light about the greenhouse axis is achieved, though because of minor undulations along the louvre, afternoon gains are lower than morning gains. Initially, gains are referred to the predictable direct beam irradiance on which beam the gain is assumed to depend. Subsequently, enhancements under natural conditions are predicted, using meteorological data for the ratio of direct to total irradiance.

Kitchen, P., "Automated Louver Systems, Strategic Planning for Cogeneration and Energy Management", Assn of Energy Engineers, Oct 1985.

The paper asserts that the term 'fixed shades' can be extended to include any strategy special glass or films, for example - whose properties are fixed. The value of operable louver systems rests on the variability of the sky, not from season to season, but throughout the day, even moment to moment, on partly cloudy days.

Kinney, L., and Reynolds, D., "Daylighting and Shuttering: Reflective Insulating Blind Systems,"Alternative Energy Sources, Washington: Hemisphere Publishing Co, 1985.*

The system described consists of a series of horizontal louvers, approximately four inches wide by one-half inch thick, placed in an array inside of a frame, mounted with magnetic seals on the inside of existing windows. The upper surface of each element is a specular reflector with a concave curvature. Rib elements are operable by a hand crank which permits a range of degrees of openness between elements. Curvature, spacing, and opening differentials are chosen to provide for good distribution of light across a ceiling while controlling for glare in the work place. Thirty-two prototype rib systems have been fabricated and installed for testing at the Oak Ridge National Laboratory, the National Bureau of Standards, and the Syracuse Research Corporation. Preliminary test results are given along with plans for further development.

Kinney, L., and Reynolds, D., "Daylighting and Shuttering: Rib System Mechanical Design and Preliminary Performance Data" Presented at the Miami Int'l. Conf. on Alternative Energy Sources, Miami Beach, FL, Dec 12, 1983.*

Peck, J.F., Thompson, T.L., and Kessler, H.J., "Windows for Accepting or Rejecting Solar Heat Gain", Final Report, LBL-15440, Berkeley, CA: Lawrence Berkeley Laboratory, Sep 1982.*

Ordinary fenestration may be modified at low cost using various combinations of windows, duotone venetian blinds, and drapes to control solar heat gain. In the winter, solar radiation may be absorbed by dark blinds and transferred to the air, minimizing fading of furnishings while collecting useful energy. In the summer, more than 90 percent of the total potential window heat gain may be reduced by exhausting evaporative cooled air over the blinds. The performance of several window configurations has been theoretically analyzed, modeled on a computer, and verified experimentally.

The reflective, insulating blind (rib) system is a flexible, user-controlled daylighting device, with thermal advantages: it can reject a considerable portion of summer sun while retaining an adequate daylighting function. It can also serve as a moveable insulation to significantly decrease thermal losses through fenestration during evening hours. Twenty-nine systems were installed immediately inside existing south-facing windows of an energy-efficient office and dormitory at ORNL. The building is a heavily-instrumented, passively solar heated structure for which reliable performance data was gathered and analyzed before adding the rib systems, thus facilitating the interpretation of "after rib" performance data.

Kluck, M., "Shadow Angle Charts for a North-South Profile" Presented at the 5th National Passive Solar Conf., Amherst, MA, Oct 19-26, 1980.*

A method and charts are presented to help visualize and determine shadow angles in the plane of a north-south cross section through a building.

Pennington, C.W., Morrison, C.A., and Ingley III, H.A., "Analysis of Double Draped Fenestration Configurations" ASHRAE Transactions, Vol. 82, Part 1, 1976, pp. 742-752.*

The use of double drapes is increasing. Their effect on heat loss through the window and the shading coefficient is discussed and estimated. The shading coefficient of two drapes (window side drapery of an open-weave material, room side drapes of a opaque material of high reflectance) was higher than with the opaque drape acting alone. The addition of a second plate of clear glass (double glazing) decreased the shading coefficient only slightly. A test program to verify this analysis (based on experience, assumptions, and theory) is recommended).

Keyes, M.W., "Analysis & Rating of Drapery Materials Used for Indoor Shading" ASHRAE Transactions, Vol. 73, Part 1, Paper 2040, 1967.*

The use of different drapery materials to achieve the various objectives of view, privacy, moderation of brightness and radiation, sound control, and appearance are discussed. Classification of drapery fabrics (used by ASHRAE) is explained. Methods to analyze the fabric to predict installed performance are given in sufficient detail to allow the reader to duplicate the tests and analyses.

12. Delivery Systems - Sunlight/Daylight

Cole, R.J., "The Quantitative and qualitative Performance of Reflective Daylighting Strategies", Renewable- A Clean Energy Solution, Conf. Proc., 15th Annual Conf. of the Solar Energy Society of Canada, June 1989.

The quantitative and qualitative performance of reflective systems which deliver natural light deep into building interiors are evaluated. Illuminance measurements and observations were made within the interiors of large physical models under clear and overcast conditions for the full seasonal range. Almost any reflective system can deliver useful natural light deeper into building interiors than traditional windows. If an electric lighting strategy can capitalize on the natural lighting contribution, significant energy savings can be achieved. However, the quality of the resulting luminous environment is critical to the widespread acceptance of interior reflective systems as lighting strategies.

Ishida, M., Takahashi, N., Kabushiki, K., "Study on a System Utilizing Solar Beam Natural Lighting", Abstracts of 1988 JSES-JWEA, Joint Conf., Japan Solar Energy Society, Tokyo, Dec 1988. (Japanese)

An internal reflection light duct system is examined, and its fundamental characteristics investigated. A system was designed to improve light collecting efficiency by installing a composite prism at the light collecting opening and the characteristics of the system examined. Hard urethane reflection boards were used for the light duct. A rain tight cover was set on the light collecting opening, the duct, about 8m long, with its inner size of 120x270mm, was installed at the ceiling of the second floor of a three story experimental house, and measurements were made. Because of repeating reflections caused by the reflection films of the internal surface of the light duct, decay of the light was substantial.

Lighting Sciences Inc, "Research and Development of a Static Optical System to Reduce the Apparent Motion of the Sun", Final Report, Report No. DOE/SF/17301-T1-APP, Nov 1988.

Kama, H., Yamashita, K., "Sunlight Applications System by reflection of Light", Papers on Lectures for Joint Conf. of Societies Related to Electricity and Information, Sep 1988. (Japanese)

A sunlight application system by reflecting light, and the calculations for illuminance prediction are outlined. Sunlight can be introduced in three ways: 1) to shady areas, 2) in courtyards and stairwells, or 3) in basements. Representative devices to achieve the objectives are introduced. The daylight changes hour by hour, largely varying its quality and amount. When reflection of direct sunlight is used, simulation for the illuminance prediction is performed by a large scale computer using the light path tracking method. Equipment, calculation formulas, flow chart of the prediction simulation, and some examples of illuminance prediction are shown.

Ruck, N., Smith, S.C., "Passive Daylighting of Building Interiors", Architectural Science Review, Vol. 31, No. 3, Sep 1988, pp. 87-98.

This study investigates collection, concentration, and transport systems and their applicability to transmitting daylight. Systems to transmit concentrated natural light to deep interiors and the concept of an ideal collector with high capture and concentration ability need further examination. Reflective hollow light guides and optic fibers have considerable potential in terms of luminous efficacy. Other design issues investigated include the interface between the concentrator and the light guide, The analyses were carried out primarily in terms of concentration and transmission efficiency as a basis for assessing the technical and economic feasibility of daylighting deep interiors.

Littlefair, P., "Innovative Daylighting Systems", Building Services, Vol 10, No. 7, July 1988, pp. 27-29.

Methods of using sunlight to light areas of rooms several meters from the window are discussed. The light pipe is one method which can operate over long distances. Sunlight can, in principle, be channelled into virtually any area of the building. As well as using free sunlight to reduce electric lighting costs, this approach can reduce cooling costs since much of the sun's heat can be removed in the piping process. Mirror systems, prismatic systems, holographic diffracting systems and light shelves are among the techniques considered.

Charles, E., "Let The Sun Shine In", Electr. Rev., London, UK, Vol. 221, No. 10, 1988, pp. 20-23.

Careful lighting design eliminates for always using lights; offices at the building's perimeter can use daylight. Using sunlight saves electricity in two ways; some lights are off and secondly, the air conditioning load is lessened. Two methods of bringing natural light into offices are discussed. Lightpipes catch sunlight on a building's roof using a heliostat and beam it into a building, using hollow tubes or bundles of optical fibers. This method is costly, however, and requires reliable sunlight. A control system is also needed to set the lighting level. An alternative is a daylighting system in which optical properties of windows are adjusted to disperse or reflect the light entering a room. Daylighting techniques are described, including fixed louvers, reflective sills and scoops, prismatic systems and holographic diffracting systems.

Elicalbe Urriol, J.J., Lara, M.A., Piacentini, R.D., "Passive Solar Light Ducts", Applied Energy, Vol. 28, No. 2, 1987, pp. 95-105.

The transmission of solar radiation through a cylindrical static light duct with an inner specular reflective surface is analyzed. Theoretical results for the beam, diffuse, and global transmission efficiencies are presented and compared with experimental data. Applications are suggested.

Mori, K., "Solar Energy Utilizing Technology for Future Cities", Nenryo Kyokai-Shi (Japan) Vol 66, No. 11, Nov 1987, pp. 948-95. (Japanese)

Solar energy, utilizing technologies for future cities, centering on a system that uses fresnel lenses and optical fiber cables, are proposed. This system selects out beams in the visible range and the energy can be distributed constantly, as long as sunlight is available. Optical energy is concentrated 4000 fold. The system can provide long distance projection of parallel rays. It will be helpful for efficient utilization of light in cities and can increase the degree of freedom in carrying out urban development. The total efficiency for the introduction into optical fiber can be up to 40%. With no heating coil incorporated, there is no danger of fire. The standard size of a light condenser is 2m in dome diameter and 2.5m in height. Auxiliary artificial light is used for backup purposes when it is cloudy. Heat pumps operating on solar thermal energy are employed to maintain air conditioning for 24 hours a day. Seven automatic solar light collection and transfer systems are currently in use at the Arc Hills building complex in Tokyo. The combination of Fresnel lens and optical fiber is more than six times as high in efficiency as a reflecting mirror.

Learn, M., Bloss, W.H., Pfisterer, F., "New Economics for Solar Energy: Core Daylighting With Heliostats and Light Pipes", Advances in Solar Energy Technology, Vol. 4, Proc. of the Biennial Congress of the Int'l. Solar Energy Society Held at Hamburg (DE) 13-18, Sep 1987.

The authors propose a mechanism to achieve concentration of 17 square meters of daylight with processing and distribution capability worth $15,000 per year in San Diego, CA.

Yamashita, K., Kurosaki, A., Ishii, H., Nakagawa, M., "Sun Light Collecting System Control Using Light for the Future", Shomei Gakkai Zasshi, (Japan) Vol. 71, No. 4 1987, pp. 232-237.

This report describes construction design harmonized with natural light collection into high rise buildings and other light collection methods for artificially introducing light. Places requiring more light include places shaded by buildings, courtyards, wells, inner parts of buildings and basements. There are four major light collecting methods: 1) automatic tracking, 2) manual tracking 3) use of ducts and 4) use of fiber optics.

Hawley, C., "Bright Future for Solar Lighting", Ontarion Energy, Network, Vol. 7, No. 5, June 1987.

A windowless office near Toronto uses heliostats supplying sunlight to a light pipe system to illuminate the building interior. The heliostats are located in a rooftop greenhouse and deflect light into eight prism light guides, which are four-sided acrylic tubes made in a precise sawtooth pattern that transmits light by total internal reflection with little or no absorption loss. Auxiliary light is provided by two electric halide lamps coupled into the light pipe system. Using light pipes, the offices can be lit by sunlight for about half the year. Net cost savings are estimated at $800/yr, too low for a quick payback. The light pipe would be useful in other applications, such as in large arenas where highly efficient high-intensity discharge lamps could be used as the light source. Fewer fixtures, placed at convenient locations, would be needed, resulting in less maintenance.

"Solar Light Pipe Replaces Light Bulbs", Sunworld, Vol. 11, No. 1, 1987, p. 16.

A light pipe is described, based on the total internal reflection of light along precisely machined and optically perfect sawtooth ridges. The 45 degree corrugation does not absorb light but releases about 5% of the sunlight with each bounce along the conduit.

Wilox, J., Cunningham, C., "Strategies for Direct Beam Daylighting", Sunworld, Vol. 10, No. 1, 1986, pp. 11-12.

Direct beam daylighting overcomes many of the difficulties of using natural light for illumination in large buildings. This article examines a number of different systems used in employing this form of sunlight.

Johnson, K., Selkowitz, S., "Light Guides Design Principles", Int'l. Daylighting Conf., Long Beach, CA, Nov 1986.

A general theory of optical transport system has been developed, to be used to determine preliminary design specifications for light guide systems. Several generic light guide types are analyzed, including hollow reflective light guides, prism light guides, and open light wells. Minimum theoretical aperture requirements are determined from each type as a function of the specified optical transport efficiency and design parameters.

Zastrow, A., Wittwer, V., Lampert, C.M., Holly, S., "Daylighting with Mirror Light Pipes and with Fluorescent Planar Concentrators: First Results From The Demonstration Project Stuttgart Hohenheim", Materials and Optics for Solar Energy Conversion and Advanced Lighting Technology, San Diego, CA, Aug 1986.

The authors discuss the properties of daylighting systems based on either fluorescent planar concentrators and transparent light guiding plates or light pipes coated with a highly reflective silver coated plastic film (3M Silverlux film).

Hill, G.E., "Daylight Penetration Through a Light Plenum", Proc. of the 11th National Passive Solar Conf., Vol. 2, Boulder, CO, June 1986.

The paper addresses the amount of light which can be transferred "to the rear" of the room, and how different plenum opening configurations affect those light levels. The results imply that a hung ceiling light plenum can provide adequate light to the rear of the room to balance the high brightness ratios created by unilateral sidelighting. Also, certain plenum opening configurations are more advantageous for given sky conditions and orientations, while others offer no benefit.

Kleinwaechter, H., Kleinwaechter, J., "Heliostats for Intensive Utilization of Daylight", Sonnenenergie Waermepumpe, Vol. 11, No. 3, May-June 1986. (German)

A heliostat system is described, which features mirror diameters of 1.4m, mounted on the roof of an inner-yard building where it directs a concentrated light beam onto a fountain located in a dark inner yard when the sun is shining. The heliostat is controlled by stepper motors which align the suns rays to the polar star after their reflection. The authors report on two other systems which direct beams through a window onto the ceiling of a room in an upper story, where they are directed by deviation mirrors onto dispersing glass prisms. The heliostat position is controlled by computer aided azimuth and elevation motors.

O'Mahony, T., "Luxfer Prisms", Lighting Design and Application, Vol. 16, No. 3, Mar 1986, pp. 14-16.

The history of luxfer prisms used for daylighting began 100 years ago. White flint prismatic glass blocks were installed to catch the sunlight and reflect it to dark corners. The glass was used in skylights, in the roofs and walls of offices, banks, factories, store front windows, transoms, and in awing-like canopies over windows. Sidewalk prisms brightened basements; prisms on the deck of ships lit galleys and frequently the tops of coal chutes were studded with one inch prismatic circles, called bulls eyes to reflect light to the bottom of the barrel.

Ruck, N.C., "Beaming Daylight into Deep Rooms: Use of a Fresnel Lens Panel", Building Research and Practice, Vol. 13, No. 3, May-June 1985, pp. 144-147.

Research is reported on the beaming of direct sunlight into deep rooms by refraction using transparent prismatic panels.

Whitehead, L.A., Scott, J.E., "Demonstration of Illumination with Sunlight Distributed in Light Pipes", Intersol 85: Proc. of the Ninth Biennial Congress of the Int'l. Solar Energy Society, Montreal, Quebec, Canada, June 1985, pp. 23-29.

A new type of light pipe known as a prism light guide is described and its use in two prototype installations is presented. Both systems use prism light guides to distribute concentrated sunlight, combining the advantages of daylighting with the practicality of even light distribution, characteristic of conventional electrical illumination. Most importantly, the light distribution is unchanged whether sunlight or the supplementary electric source is used. The results are reviewed and the implications for further developments in large scale interior illumination with guided sunlight are discussed.

Rittlemann, P.R., Scanlon, P.W., Sain, A.M., Ahmed, S.F., Davy, J.E., "Thermal and Optical Performance of Light Shelves in Buildings", NTIS **PB88-160965/XAB, Feb 1985.**

Research is described to determine the performance characteristics of commonly used light shelves and to develop a product to improve the thermal/optical performance of reflective light shelves in buildings. The conclusions reached include: the light shelves currently used do not significantly improve the energy efficiency of daylighting systems, however, they improve the quality of light in perimeter zones. The two most promising technologies are a combination of scaled-down parabolic concentrating collectors and linear fresnel lenses and systems using fiber optics to physically distribute collected daylight to interior office zones.

Mirkovich, D., "Light Plenum: Concept in Office Building Design" Progress in Passive Solar Energy Systems, New York: ASES. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, 1983.*

Using modelling techniques, the "light plenum" concept is investigated to determine daylighting patterns in office lightshelf applications. This includes an enlargement of the conventional mechanical plenum to form a light trap. The trapped light reflected within the plenum is transmitted into the office space through a translucent ceiling pattern integrated with the electrical lighting system. Under sky conditions for the Pacific Northwest (the results taken at Pullman, WA), daylighting controls allow adequate, uniform task lighting levels. This daylight contribution for task lighting could allow significant reduction in electrical lighting demands in office building design.

Kimsey, S., Helfrich, C., Hill, J., Hicks, T., and Smith, R. "Economical Light Shelf Design for Daylighting in Three Schools" Progress in Solar Energy, Vol. 6, Boulder: ASES, 1983.*

Through the Tennessee Valley Authority's (TVA) Technical and Design Assistance Program, staff members assisted regional designers in the using daylight in three new school designs. Design issues and final design concepts are presented.

Eijadi, D.A., "Passive Solar Optics: Development and Implementation" Progress in Solar Energy, Vol. 6, Boulder, CO: ASES, 1983.*

The problem of introducing sunlight into deep interior spaces of large and mid-sized commercial and institutional structures by using a passive and active solar optic tracking system is discussed. The passive solar optic system is functioning on the Civil/Mineral Engineering building at the University of Minnesota, a 150,000 sq. ft. laboratory/classroom building designed as a comprehensive earth-sheltered energy demonstration building. By optically compensating for the sun's altitudial motion, the system delivers sunlight fixed in one axis to floor areas, one and three stories below grade. Though two-axis tracking is possible, it was not economically feasible for the first prototype. This system is a new form of fenestration control which reduces the aperture size to lighted floor area ratio and therefore sunlight. The existing system represents the first half of an innovative concept for distributing sunlight in multistory buildings.

Eijadi, D.A., "Solar Optics: Development and Implementation" Presented at the 1983 Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

Two types of solar tracking systems were developed and tested. A full size model of the active solar optic system was mathematically modeled, built and tested by graduate students from the University of Minnesota. The sunlight was guided through four sharp turns and subjected to a total of 13 transmission losses over a total projection distance of 60'. The maximum light transmission efficiency achieved with this prototype system was 28%. A theoretical 30% maximum was possible for this system. The average efficiency between an extremely dirty system and a freshly cleaned system was concluded to be 17%. Based on the findings, efficiencies as high as 60% are expected for future systems. It is principally a new form of fenestration control which reduces the aperture size to lighted area ratio and delivers sunlight fixed in one or two axes. Both systems have the capability of incorporating a high-efficiency central source of artificial lighting - such as Zenon Arc - to provide a system independent of the sun.

Selkowitz, S., Navvab. M., and Matthews, S., "Design and Performance of Light Shelves" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

Light shelves have been used with windows for many years to reduce sky glare while admitting reflected skylight and sunlight. Researchers are experimenting with designs that provide control of direct sun penetration, enhanced daylight distribution deeper in a room, and control of sky glare. Many designs are so complex that they cannot be modelled analytically, so most studies are based on scale models. Little test data have been published on this subject. In the study described eight windows were studied; three were selected for complete analysis as generic solutions to deal with various energy issues. These were analyzed for energy use, first cost, and effect on the interior environment. The window which maximized high daylighting glazing provided the lowest energy use, lowest first cost and greatest benefit to the occupants, was the clerestory configuration with view windows.

Bennett, D.J. and Eijadi, D.A., "Solar Optics: Light as Energy; Energy as Light" Underground Space, Vol. 4, No. 6, May/June 1980, pp. 349-354.*

High technology means to beam light and images to underground spaces is reviewed. State-of-the-art concepts are reviewed as are possible tests for a design application.

Eacret, K.M., "Beamed Daylighting: Historical Review, Current Testing, Analysis and Design Options" Newark, DE: American Section of the Int'l. Solar Energy Society. Presented at the 5th National Passive Solar Conf., Amherst, MA, Oct 19, Oct 1980.*

Beamed daylighting refers to techniques for beaming daylight deep within building interiors, beyond the perimeter zone in which diffuse light from the sky is available. The results of testing of various beamed daylighting prototypes, the findings of a review of patent documents in the field, and some options for design using beamed daylighting techniques are discussed.

Rosenfeld, A.H. and Selkowitz, S., "Beam Daylighting: An Alternative Illumination Technique" Energy and Building, Vol. 1, Jan 1977, pp. 43-50.*

This article is concerned with energy savings and peak power reduction associated with the maximum use of natural light. The general characteristics of diffuse daylighting are discussed in terms of a standard office plan. An innovative technique of daylighting using direct beam radiation from the sun is treated in some detail.

13. Responses to Light

13.1 Human Factors/Post Occupancy Evaluations

Sullivan, R., Selkowitz, S., "Development of a Methodology to Evaluate the Energy and Comfort Performance of Fenestration", Proc. of Building Simulation 89, Vancouver, CA., June 1989.

A new concept for analyzing the performance of fenestration systems is described. Five indicators can be combined in a variety of ways to describe total fenestration performance. These indicators include qualitative and quantitative findings and consist of three related to energy: fuel (heating), electric (cooling), and peak electric demand and two to comfort: thermal and visual. Performance comparisons of different systems are made by introducing a non-dimensional, user defined, weighting function that specifies the relationship between the five indices. A figure of merit is then calculated by combining the index values and weighting factors to provide a direct comparison between fenestration systems. The indices were derived by performing a multiple regression of several thousand, hour-by-hour, building heat transfer simulations for a prototypic office building module using the DOE-2 simulation program. From this regression analysis a series of simplified algebraic expressions which related fenestration performance to configuration variables, were derived. This methodology was incorporated as the computational engine within a prototype fenestration design tool on a microcomputer.

Kim, J.T., "Subjective Evaluation on the Thermal Luminous Environment of Middle-School Classrooms in Seoul Korea", Proc. of Solar 89, the 14th National Passive Solar Conf., Denver, CO, June 1989.

The effects of daylighting on subjective responses in classrooms were examined. Typical classroom shapes of middle-schools in Seoul were used, and 278 students were asked to rate their responses to the interior luminous environment, the luminous environment of working areas, glare, and interior finishing colors. The data were analyzed by probit analysis, analysis of variance, and factors affecting both the interior luminous environment and the luminous environment of working plane.

Pasini, I., "Illumination Evaluation", Public Work Canada, Information and Research Library Services. (french), 1988.

Methods for assessing the illuminated environment of office buildings are described. Interiors, exteriors, electric lighting and daylighting are discussed along with techniques given for their analysis. The three stages of assessment described are discussed in terms of both quantity and quality issues. Issues addressed include: light source efficacy, reflectance and transmittance of materials, and luminance and illuminance surveys, daylighting issues and strategies, maintenance, video display terminal areas, energy audits, photometric data, laboratory testing, and emergency lighting. Appendices contain detailed survey methods, along with examples and reference tables.

Wineman, J.W., "Natural Lighting in the Office: the Worker's Perspective", Proc. of the Environmental Design Research Association, 1987.

Although natural lighting has recently emerged as an attractive strategy for energy conservation in office buildings, its beneficial and instrumental effects for worker comfort and productivity are unclear. This paper presents a review of relevant literature, suggesting the importance of quantitative and qualitative aspects of lighting design schemes, and the potentially valuable contribution of user control for both energy conservation and worker comfort/productivity.

Warren, P.R., Parkins, L.M., "Window Opening Behavior in Office Buildings", Lighting Research and Technology, Vol. 5, No. 3, 1984, pp. 89-101.

In countries such as the United Kingdom with a temperate climate, most buildings are not air conditioned but depend upon natural ventilation and relatively simple heating systems. Openable windows are used to reduce the incidence of summertime overheating. Housing studies have indicated that windows are frequently opened during the heating season, resulting in substantial heat loss and consequent energy consumption. This paper describes the results of an initial investigation to determine whether the same phenomenon occurs in office buildings. Observations were made under several weather conditions. The proportion of window openings was highly correlated with external air temperature and also influenced by solar gain and wind speed. A more detailed analysis suggested two modes of window use, one related to maintaining adequate indoor air quality and the second, to control indoor air temperature.

13.2 Subjective Responses

Verderber, S., "Human Response to Daylighting in the Therapeutic Environment" Presented at the Int'l. Daylighting Conf., Feb 16, 1983.*

The relationship between the human spirit, daylight, and architectural form is intimate. Daylight introduces life, change, and drama into otherwise static spaces. Interior daylighting, as transmitted through one of the oldest architectural devices - the window aperture symbolizes spirituality, openness, and freedom from the prison-like confinement and intensity that characterizes windowless spaces. The windowless room functions as a perceptual barrier that inhibits the fundamental need in humans to endeavor to effectively process information essential to coping. View, fresh air, involvement with the day-to-day drama of human life, and daylight, offer rewards in terms of helping one to feel that one occupies an important niche in the larger scheme of things.

Rubin, A., Collins, B.L., Tibbott, R.L. "Window Blinds as a Potential Energy Saver - A Case Study", NBS Building Science Series 112, May 1978.

Window usage at the National Bureau of Standards was studied by photographing venetian blind positions in offices at different times of the day and year. Blind positions were altered systematically to determine the responses of building occupants. Significant differences were observed among blind positions depending on compass orientation of the window, view type, season, and nature of experimental treatment. The greatest determinant of blind position was orientation, with blinds on north-facing windows being more open than on the south. The results suggest that energy savings programs which rely on the activities of building occupants may be feasible. Suggestions are made for improvements in blind usage and design.

Keighley, E.C. "Visual requirements and reduced fenestration in offices - A study of window design and provision of a view", Journal of Building Science, Vol. 8, 1973, pp. 321-331.

Preferences for a window limited to 20% of the window wall, in a small-scale open plan office were studied. Subjects selected aperture settings which produced wide, rather than tall windows. This preference is attributed to the desire for the best lateral scan of the view beyond the window.

Cooper, J.R., Wiltshire, T., Hardy, A.C. "Attitudes toward the use of heat rejecting/low light transmission glasses in office buildings", Proc. CIE Conference on 'Windows and their function in architectural design', Istanbul, Turkey, 1973.

This paper describes a study of 11 office buildings, glazed with different types of solar absorbing and solar reflecting glass. For the most part, the glazing material had no effect on the reported pleasantness, brightness of the view or on interior colors. The only glazing causing major complaints had light transmission in the 12% to 15% range.

Longmore, J., Ne'eman, E. "The availability of sunshine and human requirements for sunlight in buildings", Conference on Environmental Research in Real Buildings, NIC Committee TC 3.3, Cardiff, UK, 1973.

A survey revealed that preferences for sunlight varied from 90% of dwelling residents and hospital patients, 73% of office personnel, to 42%

of school occupants. The percentage of those considering sunshine to be a nuisance ranged from 62% of hospital staff, 52% of school occupants, 24% of office workers, to only 4% of dwelling residents. The differences appear to be related to the individual's ability to use shading to control excessive solar heat gain and glare.

Wilson, L.M. "Intensive care delirium; the effect of outside deprivation in a windowless unit", Arch Internal Medicine, Vol 130, 1972, pp. 225-226.

Two intensive care units are described; one with windows and the other without them. Although both groups of subjects were similar in terms of age, treatment, physical condition, anesthesia and medication, the author found that more than twice as many people in the windowless environment developed post-operative delirium than in the unit with windows. In addition, there was a greater incidence of post-surgical depression in the windowless setting. The author concludes that windows provide essential benefits to hospital patients.

Ludlow, A.M. "The broad classification of the visual scene: A preliminary study", Vision and Lighting, Report 3 (GIB), Nov 1972.

Study results are presented where slides represent views seen through a window by occupants seated 2.7m from a window. Subjects expressed preferences for views which are complex, varied, and contain far and mid-distant scenes. Another finding was that viewers prefer a feeling of detachment rather than involvement with the scene being witnessed.

Ne'eman, E., Hopkinson, R.G. "Critical minimum acceptable window size, a study of window design and provision of a view", Lighting Research and Technology, Vol. 2, 1970, pp. 17-27.

Using scale model simulation techniques, the authors found that subjects could consistently define a 'minimum acceptable window size' using a small scale model, except when the view outside is uniformly bright and featureless. Results with a full scale model revealed that view, distance from the window, window height, and visual angle, all affected the subjects' judgments of acceptable window size. Subjects preferred wider windows for nearby views than for distant views. Acceptable window width was found to be directly proportional to a subject's distance from a window.

Wells, B.W.P., "Subjective Responses to the Lighting Installation in a Modern Office Building and Their Design Applications," Building Science, Vol. 1, 1965, pp. 57-68.*

The perceptions of daylight adequacy vs. actual daylight illumination in an office situation were examined. Subjects overestimated the proportion of daylight available, at increasing distances from the windows. The subjective evaluation of daylight was based more on the apparent window brightness as seen from the individual's workstation. The Permanent Supplementary Artificial Lighting Installation (PSALI) method of lighting deep buildings assumes a predominant need for daylighting. This method, developed by the BRS in England, is discussed in terms of the author's findings. The recommendation for designing large buildings is that deep buildings (high ratio of floor area to external wall area), should use artificial light, since this design is cheaper, more energy efficient (heating/cooling) and can be more densely occupied. However, a window view should be provided for all people, to satisfy the psychological need for daylight.

Aston, S.M., and Bellchambers, H.E. , "Illumination, Colour Rendering and Visual Clarity" Lighting Research and Technology, Vol. 1, No. 4, 1969, pp. 259-261.*

The paper contains a discussion on different types of light and how they make objects and colors appear to the eye. Highly energy efficient lamps may give little or no color perception.

Finch, D.M., "The Effect of Specular Reflection on Visibility: Part I-Physical Measurements for the Determination of Brightness and Contrast" Illuminating Engineers, Vol. 54, No. 8, Aug 1959, pp. 474-481.*

Changes in visibility occur when visual tasks are viewed under various lighting conditions even though the illumination at the task may be constant. These changes in visibility are related to the change in the brightness patterns of the detail and background and the contrasts that result. The author attempts to define more precisely the parameters involved in the contrast changes.

13.3 Physiological Responses

Ulrich, R.S., "View Through a Window May Influence Recovery from Surgery," Science, April 27, Vol. 224, 1984, pp. 420-421.*

Records of recovery after cholecystectomy in a suburban hospital between 1972 and 1981 were examined to determine whether assignment to a room with a window view of a natural setting might have restorative influences. Twenty-three surgical patients assigned to rooms with windows looking out on a natural scene had shorter post-operative hospital stays, received fewer negative valuation comments in nurses' notes and took fewer potent analgesics than 23 matched patients in similar rooms with windows facing a brick building wall.

Heerwagen, J.H., and Heerwagen, D.R., "Some Reflections on Psychological Comfort and Its Application to Energy Conscious Design" Progress in Passive Solar Energy Systems, New York: ASES. Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, Sep 1983.*

A biological basis for human psychological comfort is proposed, and its evolutionary origin is hypothesized in relation to the satisfaction of basic human needs. Environments which support these needs are experienced as pleasurable, attractive, psychologically and physically comfortable and are sought out. Environments not meeting these needs, or demanding too great a psychological or physical adjustment, are experienced as unpleasant, unattractive, uncomfortable, and often stressful. Implications for energy conscious fenestration design are discussed in terms of the impact on view, access to sunlight and daylight, and responses to major lighting sources.

Hughes, P.C., and Neer, R.M., "Lighting for the Elderly: A Psychobiological Approach to Lighting" Human Factors, Vol. 23, No. 65, 1981.*

The advantages of full-spectrum light simulating natural sunlight are discussed in view of recent research.

Oddo, S., "Surprising Discoveries about Why You Need More Natural Light" House & Garden Magazine, Feb 1976.*

According to a researcher at the Veteran's Administration, exposure to the whole visible and near-visible spectrum affects the rate at which our bodies absorb calcium. Another study concludes that sexual maturity and growth rates are linked to light. Some researchers think the pigment epithelial cells in the retina of the eye, with no vision function, may send messages to the pituitary and pineal glands buried deep in the brain. Russian research indicates that certain ultraviolet radiation, available insolar radiation, improves attention, concentration, and brain performance.

Wurtman, R.J., "The Effects of Light on the Human Body" Scientific American, Vol 233, No. 1, July 1975, pp. 68-77.*

Topics of discussion include the effects of sunlight on the skin (skin tanning and vitamin D3 production); the use of drugs that photosensitize the skin for treatment of herpes and psoriasis with sunlight; the use of sunlight to help cure neonatal jaundice in babies; how calcium is more efficiently absorbed in humans exposed to ultraviolet light; and the biological rhythms in humans and animals and how different spectra of light affects them.

"Effects of Spectral Difference in Illumination on Fatigue" Journal of Applied Psychology, Vol. 59, No. 524, 1974.*

Exposure to full-spectrum, high color-rendering index, daylight-simulatinglight sources seems to have a positive impact on an individual's well-being.

Ott, J.N., "Health and Light: The Effects of Natural and Artificial Light on Man and Other Living Things", Old Greenwich: Devon-Adair Co. 208 pp, 1973.*

An entertaining, if somewhat controversial, account of the author's investigations of the effects of light on living organisms over a number of years.

"The Treacherous Light Bulb" Massachusetts Institute of Technology, Reports on Research., Apr 1970.*

This paper discusses man's move from sunlight to fluorescent light and its effects.

Neer, R.M., "Stimulation by Artificial Lighting of Calcium Absorption in Elderly Human Subjects," Nature, Vol. 229, 1971, pp. 225-227.*

Data suggest that exposure to natural light increases efficiency of intestinal calcium absorption in people who normally receive no ultraviolet rays from the sun.

Schutrum, L.F., Stewart, J.L., and Nevins, R.G., "A Subjective Evaluation of Effects of Solar Radiation and Re-Radiation from Windows on the Thermal Comfort of Women" ASHRAE Transactions, Vol. 74, Part II, 1968 pp. 115-130.*

This study describes the subjective reactions to thermal environments in an office environment with large windows. Responses are recorded by sedentary women in street clothes, subjected to transmitted solar radiation on clear and overcast days. Votes of warmth and comfort correlated well with predicted responses using earlier thermal comfort studies.

Wurtman, R.J., "Biological Implications of Artificial Illumination" Illuminating Engineering, Vol. 63, No. 10, 1968, pp. 523-528.*

The author discusses the biological effects of lighting on health and well being.

13.4 Glare

McCluney, R., "A Daylighting Checklist" Solar Age, Apr 1985, pp. 84-85.*

This paper addresses disability glare and discomfort glare. It offers guidelines to designers to avoid glare and other serious mistakes in designing for daylighting.

Bedocs, L., and Simons, R.H. "The Accuracy of the I.E.S. Glare Index System" Lighting Research and Technology, Vol. 4, No. 2, 1982, pp. 80-89.*

The authors describe a new computer program to calculate glare indices directly from the Building Research Station (BRS) formula. The original program used by the I.E.S. contained inaccuracies corrected in this new program. The new computer program also improves the calculations by correcting the calculation of the background luminance. Comments on the paper by the I.E.S. Technical Committee defends the original program.

Einhorn, H.D., "Discomfort Glare: A Formula to Bridge Differences" Lighting Research and Technology, Vol. 11, No. 2, 1979, pp. 90-94.*

The international glare situation is unsatisfactory: methods adopted in different countries give discrepant predictions. To break the deadlock, a glare formula is proposed, based on the best information available. The formula allows for luminances, solid angles and positions of glare sources in a similar way as existing formulae, but takes account of the increase in glare experienced when glare sources are added in a room in

spite of the correspondingly increased vertical illuminances at the eye and inserting them suitably into a 'co-variance/adaptation' factor.

Fischer, D., "The European Glare Limiting Method" Lighting Research and Technology, Vol. 4, No. 2, 1979, pp. 97-100.*

The bases and development of the glare system now adopted in several European countries are described. From the original Sollner curves, which provided a means to evaluate glare in interior lighting installations, a glare limiting system, useful in lighting design practice, is described. The procedure for estimating the glare rating value of an installation and comparing it with the limits adopted, is given. The method is intended for use in working interiors only.

Ahmed, I., and Bennett, C.A., "Discomfort Glare: Duration-Intensity Relationship" Journal of I.E.S., Vol. 8, No. 1, Oct 1978, pp. 36-39.*

An experiment to evaluate the effect on the borderline between comfort and discomfort (BCD) of duration and intensity of a glare source was conducted. Empirical equations were formulated which describe these relationships.

Bennett, C. A., "Discomfort Glare: Concentrated Sources - Parametric Study of Angularly Small Sources" Journal of I.E.S., Vol. 7, No. 1, Oct 1977, pp. 2-15.*

Experiments were conducted to investigate discomfort glare as a function of source size and field luminance for the range from typical interior levels to conditions typical of roadways. This work extends earlier research.

Bennett, C. A., "The Demographic Variables of Discomfort Glare" Lighting Design and Application, Vol. 7, No. 1, Jan 1977, pp. 22-24.*

Are older people more sensitive to discomfort from overly bright lighting systems than young people? The answer is yes according to the author. The average population is more sensitive in direct proportion to their age from below the 20's to the 70's. Also, blue-eyed people are more sensitive than brown-eyed, and indoor workers have greater sensitivity than outdoor workers. The results of a several year study may point to lower brightness luminaires for commercial and industrial interiors, especially where older people live and work.

Goodbar, I., "A Simplified Method for Determining the Acceptability of a Luminaire from the VCP Standpoint" Journal of the I.E.S., Vol. 6, No. 1, Oct 1976, pp. 21-28.*

The method described forms the basis for criteria established in RQQ Report No. 3. The author presents the method that permits the simplified evaluation of a luminaire from the standpoint of Visual Comfort Probability (VCP). The derivation of the basic concept of dividing the ceiling into zones and sectors, the procedure for deriving a value from the Guth formula and the use of a graph for computing are shown.

Fry, G. A., "A Simplified Formula for Discomfort Glare" Journal of I.E.S., Vol. 6, No. 1, Oct 1976, pp. 10-20.*

The method covered in this article is the basis for the criteria established by RQQ Report No. #3 'An alternate simplified method for determining the acceptability of a luminaire from the VCP standpoint for use in large rooms.' The basis equation used in this method to assess discomfort glare is known as the "Guth formula." Here, the author's purpose is to show the basis for computing a luminance value, '*V*', and to show how the method of assessing glare is related to the Guth formula.

Beggs, S.S., "Prediction of Discomfort Glare" Light and Lighting, Vol. 60, No. 8, Aug 1976, pp. 245-253.*

This article gives a number of procedures constructed during separate studies on glare prediction. Formulas from these studies are provided.

DiLaura, D.L., "On the Computation of Visual Comfort Probability" Journal of I.E.S., Vol. 5, No. 4, July 1976, pp. 207-217.*

A computer program (in Fortran-IV) was developed by the author, based on RQQ Report No. 2 (1972), to calculate the VCP for any observer position in a room. The program provides a unified system of coordinates and mathematical techniques for the VCP and other properties of a lighting system.

Fry, G. A., and King, V.M. "The Pupillary Response and Discomfort Glare" Journal of I.E.S., Vol. 4, No. 4, July 1975, pp. 307-24.*

A four-part study on pupillary fluctuations as an index of discomfort glare. A method was developed for analyzing minute fluctuations in the diameter of the pupil into four components. Results of a study on the sensation of glare relative to fluctuations in pupil size is described.

Levin, R.E., "Position Index in VCP Calculations" Journal of I.E.S., Vol. 4, No. 2, Jan 1975, pp. 95-105.*

Position Index (P), the spatial sensitivity factor used to determine the index of sensation for a source, is not unambiguously defined for all directions in the visual field. The working definition is a set of curves indicating contours of constant position index. Numerical values have been tabulated for the standard room tables of VCP and serve as a precise definition for a limited number of directions in the visual field. It is desirable to define the position index by a functional relation over the entire field of view. Here, four analytical representations are considered in terms of spatial coverage, errors with respect to known representations, simplicity, and the like.

Bellchambers, H.E., Collins, J.B. and Crisp, V.H.C. "Relationship Between Two Systems of Glare Limitation" Lighting Research and Technology, Vol. 7, No. 2, 1975, pp. 106-12.*

The glare ratings of seventeen commercial luminaires have been calculated and compared for the British and German systems of discomfort glare limitation. For some circumstances considerable differences exist between the two systems but simple conversion tables are derived relating to room surface-reflectance and flux fraction ratio, which when applied enable a basic linear relationship between the two glare ratings to be used for most practical circumstances.

"Determination of Effective Candlepower of Modular and Linear Regressive Systems: Appendix to RQQ Report #2 (1972)" Committee on Recommendation of Quality and Quantity of Illumination, Journal of I.E.S., Vol. 2, No. 4, July 1973, pp. 504-505.*

This paper illustrates the derivation of the formula in the RQQ Report #2 (1972) which calculates the effective luminous intensity of modular and linear regression systems.

Levin, R.E., "An Evaluation of VCP Calculations" Journal of I.E.S., Vol. 2, No. 4, July 1973, pp. 355-361.*

There have been many indications that VCP values calculated at various laboratories may differ significantly. The objectives of this paper are: 1) to illustrate the magnitude of such differences under the present state-of-the-art, 2) to describe the more important causes of such differences, and 3) indicate steps which can be taken to reduce such differences in the future.

Lewin, I., "The Determination of Luminaire Projected Area" Journal of I.E.S., Vol. 2, No. 4, July 1973, pp. 418-421.*

Calculation techniques (based on trigonometry) are presented to determine projected areas of luminaires for use in calculating VCP. Derivation of the calculation method is included.

"Outline of a Standard Procedure for Computing Visual Comfort Ratings for Interior Lighting - RQQ Report #2, (1972)", Committee on Recommendation of Quality and Quantity of Illumination, Journal of I.E.S., Vol. 2, No. 3, Apr 1973, pp. 328-344.*

Lewin, I., "New Concepts in Direct Glare Control" Journal of I.E.S., Vol. 2, No. 3, Apr 1973, pp. 209-215.*

The application of a simplified I.E.S. recommended method for evaluating discomfort glare to the design of a new optical system for fluorescent troffer lights is described. This system meets the minimum VCP level while increasing the coefficient of utilization over the conventional fluorescent troffer design. A simplified VCP technique is described, the "Equal Area Equal Glare System," is used as a design tool, not simply as a rating system, as originally intended.

Lewin, I., March 1973, "Visual Comfort Probability - for All Luminaires" Lighting Design and Application, Vol. 3, No. 3, pp. 54-60.*

Suggestions are offered for computing VCP of luminaires that are not flat-bottomed and without luminous sidewalls.

Stone, P.T., and Harker, S.D.P. "Individual and Group Differences in Discomfort Glare Responses" Lighting Research and Technology, Vol. 5, No. 1, 1973, pp. 41-49.*

Discomfort glare conditions were generated in an experimental viewing cubicle supplied with a variable luminance glare source operated by a manually controlled dimmer. Repeated settings of the four I.E.S. discomfort glare criteria were made by 41 volunteer subjects, recruited from three different industries and a wide range of employment categories. After 20 days of practice, large differences in the settings were found among subjects for each glare criterion and differences also emerged among the three industry groups. These wide variations are consistent with other studies on sensory discomfort. The paper concludes that many factors are likely to cause such variability and further research is required to understand why people are sensitive to glare and other aspects of the physical environment.

"An Alternative Simplified Method for Determining the Acceptability of a Luminaire from the VCP Standpoint for Use in Large Rooms" Committee on Recommendation of Quality and Quantity of Illumination, Journal of I.E.S., Vol. 1, No. 39, Apr 1972, p. 256-260.*

This report is an approved alternate simplified method for determining the acceptability of a luminaire (the VCP). Its applicability is restricted to flat-bottomed, non-luminous sided equipment. This report supplements Report #2, which takes precedence. A graphical procedure and a mathematical procedure are given.

Boyce, P.R., "A Comparison of the Accuracy of Methods of Calculating the I.E.S. Glare Index" Lighting Research and Technology, Vol. 4, No. 1, 1972, pp. 31-34.*

Glare indices were calculated by the full I.E.S. method (I.E.S. Technical Report No. 10), by Lawson's simplified procedure (1962) and a circular slide rule (calculator) technique based on an extension of the Lawson approach. Differences were statistically analyzed, and found to be insignificant in practice. The "calculator" method is more limited in scope, but can be used for most conditions found in practice.

Sampson, F.K., and Jones, B.F. "Prediction, Evaluation and Specification of Visual Comfort and Performance in Classrooms" Journal of the I.E.S., Vol. 2, No. 2, January 1972, pp. 153-165.*

This paper is part of a project to specify the performance of five basic environmental factors in a classroom, visual comfort and performance being one factor. Windows are judged to be more bad than good with regard to lighting quality. Transparent, neutrally-colored, low (10-15%) transmittance glass should be used to minimize glare and still allow a view outside. Computed base values of VCP are presented, based on standard classroom conditions. Modifications to accommodate changes from standard conditions are given. The method allows the evaluation of a lighting system, in conjunction with the classroom environment, while both are in the design stage. Comfort and lighting adequacy are considered separately but are equal in importance. Complete calculation procedures are given in the Appendices.

"A Practical Method of Extending VCP Calculations to Luminaires with Distribution in the 90 Degree to 180 Degree Zone" Journal of I.E.S, Vol. 1, No. 1, Oct 1971, p. 42.

The procedure described extends the RQQ Report No. 2 standard procedure for computing the VCP to include luminaires of any distribution, instead of the RQQ restriction to luminaires with distribution in the 0-90 degree zones. The 90-180 degree zone accounts for the upward flux between the ceiling and the horizontal axis of the luminaire.

Ballman, Thomas L. "A Practical Method of Extending VCP Calculation to Luminaires with Distribution in the 90 Degree to 180 Degree Zone" Journal of IES, Vol. 1, No. 1, 1971, pp. 42-44.*

RQQ Report No. 2 outlines the standard procedure for computing VCP. This report is only applicable to luminaires with distribution in the 0 to 90 degree zones. McGowan and Guth proposed a method of extending these calculations to units with luminous side panels and a distribution in the 90 to 180 degree zone. This paper shows how the standard procedure described in RQQ No. 2 can be extended to encompass luminaires with any type of distribution.

"A Statement Concerning Visual Comfort Probability (VCP): Naive vs. Experienced Observers" Committee on Recommendation of Quality and Quantity of Illumination, Illuminating Engineering, Vol. 64, No. 9, Sep 1969, p. 604.*

This is a short note on the IES VCP system responding to concerns expressed about the system.

Fry, G. A., "Limits of the Field of View" Illuminating Engineering, Vol. 64, No. 5, May 1969, pp. 403-406.*

IES glare determination procedures refer to an observer field of view. This paper defines this field of view explicitly.

Einhorn, H.D., "Analytical Expression for the Glare Position Index" Illuminating Engineering, Vol. 64, No. 4, Apr 1969, p. 228-229.*

This paper offers a formula for the Luckiesh-Guth glare position index appearing previously only in graphical or tabular form.

McGowan, T.K., and, Guth, K., "Extending and Applying the IES Visual Comfort Rating Procedure" Illuminating Engineering, Vol. 64, No. 5, Apr 1969, pp. 253-70.*

This research paper describes the extension of the I.E.S. VCP system to luminaires of more general design.

Einhorn, H.D., "A New Method of Assessment of Discomfort Glare" Lighting Research and Technology, Vol. 1, No. 4, 1969, p. 247.*

The author proposes a simplified method for determining a glare index, based on the British system and including aspects of the American and German approaches. The method assumes that the glare factor is proportional to source size, and that increasing the number of fittings on a room does not affect glare substantially since the adaptation luminance increases proportionally.

Rodseth, T.R., "Seeing and the Degree of Glare" Lighting Research and Technology, Vol.1, No. 4, 1969, pp. 257-258.*

The relationship between glare and the adaptation response in the eye is examined.

Fry, G. A., "The Scissors Curve Method of Evaluating Discomfort Glare," Illuminating Engineering, Vol. 63, No. 9, Sep 1968, pp. 477-484.*

An improvement in Guth's glare formula is proposed.

Fry, G. A., "The Discomfort Glare Produced by a Continuous Luminous Ceiling" Illuminating Engineering, Vol. 63, No. 8, Aug 1968, pp. 411-414.*

This paper compares four methods of assessing discomfort glare produced by a continuous luminous ceiling. The first three methods utilize Guth's formula but differ from each other in how the ceiling is subdivided into smaller elements. These methods can be identified as the Guth method, the Bradley-Logan method and the Goodbar method. The fourth one uses Guth's method of subdividing the ceiling and Fry's formula for computing glare.

"Further Studies of Line Sight and Direct Discomfort Glare" Illuminating Engineering, Vol. 63. No. 1, Jan 1968, pp. 26-31.*

Jones, B.F., "A Flexible System of Evaluating Luminaire Brightnesses" Illuminating Engineering, Vol. 62, No. 3, Mar 1967, pp. 143-153.*

The author attempts to build on the accepted scissor curve of determining visual comfort to develop a system which would allow more flexibility without requiring time-consuming calculations for answers to glare problems.

Allphin, W., "Influence of Sight Line on BCD Judgment of Direct Discomfort Glare" Illuminating Engineering, Vol. 61, No. 10, Oct 1966, pp. 629-633.*

"Visual Comfort Ratings for Interior Lighting" Committee on Recommendation of Quality and Quantity of Illumination, Illuminating Engineering, Vol. 61, No. 10, Oct 1966, pp. 643-666.*

This is the first IES standard practice for determining visual comfort probability in a space illuminated by electrical means only.

Guth, S.K., "Computing Visual Comfort Ratings for a Specific Interior Lighting Installation" Illuminating Engineering, Vol 61, No. 10, Oct 1966, pp. 634-642.*

Application of the IESVCP system for glare assessment to lighting situations for which VCP tables are not available.

Bodmann, H.W., G. Sollner, and E. Senger, "A Simple Glare Evaluation System" Illuminating Engineering, Vol. 61, No. 5, May 1966, pp. 347-352.*

Following a series of experiments with twenty six lay persons, a new method is proposed for evaluating glare from electrically lit luminaires.

Logan, H.L., and Siegel, J.R. "Direct Glare Evaluation by the Visual Comfort Probability Method" Illuminating Engineering, Vol. 61, No. 4, Apr 1966, pp. 177-88.*

This paper evaluates and explains the I.E.S. VCP system of glare assessment. It includes an early attempt to extend this system to side-lighting with windows.

Bradley, R.D., and Logan, H.L., , "A Uniform Method for Computing the Probability of Comfort Response in a Visual Field" Illuminating Engineering, Vol. 59, No. 3, Mar 1964, pp. 189-206.*

The IES Visual Comfort Probability method of assessing lighting glare is described.

Guth, S.K., "A Method for the Evaluation of Discomfort Glare" Illuminating Engineering, Vol. 58, No. 5, May 1963, pp. 351-64.*

Data and analyses involving a wide variety of experimental conditions, including simulated rooms, small model rooms and actual rooms, show that a previously developed variable exponential method provides useful and logical discomfort glare ratings. It can be applied to lighting systems ranging from a few luminaires to a luminous ceiling. It also has been found that the way large luminous areas are subdivided has no effect upon computed ratings. A new analysis in terms of 210 observers provides an improved chart for converting ratings into discomfort glare estimates. A discussion of various problems associated with calculations of discomfort glare is included.

"The Development of the I.E.S Glare Index System" Luminance Study Panel of the I.E.S. Technical Committee, Illuminating Engineering Society Transactions (London), Vol. 27, No. 1, 1962, pp. 9-26.*

This report of the work of the Luminance Study Panel of the I.E.S. covers the period 1958 through 1962 which led to the adoption of the I.E.S. Glare Formula based on the BRS formula. The paper describes the considerations of the study panel in developing the glare formula, including summaries of panel deliberations on each issue. A computerized system of calculating the glare formula was developed. The advantage of this evaluation system is that instead of limiting the surface brightness of lighting units as seen from predetermined room positions, this method limits only the total glare constants for the installation, the limiting total value dependent on the application. The intent of this glare index system is to consider the whole environment and not just the lighting units.

Lowson, J.C., "Simplified Method of Estimating Glare Index" Light and Lighting, Vol. 55, 1962, pp. 291-295.*

A shortcut method is proposed to estimate the I.E.S. Glare Index 'within' errors of usually + 0.5 glare units. The flux fraction ratio (ratio of upward to downward light from the combined effect of the lighting fittings) and the room reflectance are subtracted from the I.E.S. tables to extract a new set of conversion terms. These data are graphed to eliminate interpolation. The I.E.S. tables can then be compressed and tabulated or graphed, to simplify the procedure (including required interpolations) to calculate an approximate Glare Index.

Allphin, W., "Further Appraisals of Luminaire Brightness" Illuminating Engineering, Vol. 56, No. 12, Dec 1961, pp. 701-707.*

Research results are reported, in which observers adjust luminaire brightness to the BCD level. Indices of Sensation (Guth formula) and Glare (Harrison - Meaker formula) are calculated. Critique and rebuttal follow the main article.

Allphin, W., "BCD Appraisals of Luminaire Brightness in a Simulated Office" Illuminating Engineering, Vol. 56, No. 1, Jan 1961, pp. 31-44.*

The concept of BCD is shown to be a meaningful concept for most inexperienced observers, who were able to consistently appraise discomfort glare.

Guth, S.K, and McNelis, J.F. "Discomfort Glare from Multiple Sources" Illuminating Engineering, Vol. 56, No. 1, Jan 1961, pp. 46-57.*

Using twelve observers and the Discomfort Glare Evaluator, the experimenters measured BCD levels to "calibrate" observers (against those in previous investigations) and compare the brightness of a luminous ceilingand a glare source. The ceiling is treated as a separate element, to evaluate the additive effects of multiple sources. Several analytic methods are considered, but none recommended, due to data limitations.

Chorlton, J.M., and Davidson, H.F., "The Effect of Specular Reflection on Visibility: Part II-Field Measurements of Loss of Contrast" Illuminating Engineering, Vol. 54, No. 8, Aug 1959, pp. 482-488.*

Field studies were conducted for several years, commencing in 1955, to determine if specular reflections in written and printed visual tasks resulted in a measurable loss in contrast and consequent loss in visibility.

Goodbar, I. "The Effect of Specular Reflection on Visibility: Part III- New Charts for Brightness Contrast Calculations" Illuminating Engineering, Vol. 54, No. 8, Aug 1959, pp. 489-499.*

Studies of contrast from reflections of overhead lighting units (or local lighting units) in the details and background of reading, writing, and drafting tasks have shown that contrast losses seriously affect visibility. Lighting quality, in terms of candlepower distribution from luminaires, can strongly influence task contrast and the amount of light necessary to see clearly. Since each lighting system produces its own task contrast, it is necessary to predict the losses that occur, and determine task contrast at any room location. This paper develops methods of predicting task contrast, and loss of contrast, under different lighting systems.

Hopkinson, R.G., "Evaluation of Glare" Illuminating Engineering, Vol. 52, No. 6, Aug 1959, pp. 500-504.*

This paper summarizes work (1955-1956) on glare at the BRS in England. Research in the U. S. also is discussed, in conjunction with studies in the U.K. & Holland, towards achieving international agreement. An analysis of the basic glare formula is presented, with an examination of the exponents in the formula in particular. The author investigated the effect on differences in observers (e.g., number of observers on the team), experienced (scientific vs. general population), and the influence of the experimentation method (momentary exposure vs. steady exposure to the source of glare). Additivity of glare is discussed, distinguishing between addition of the stimuli and addition of the sensations.

Hopkinson, R.G., and Bradley, R.C., "The Estimation of Glare Sensation" Illuminating Engineering, Vol. 54, Aug 1959, pp. 500-504.*

Experiments were conducted to appraise the magnitude of glare discomfort sensation. The observers were consistently able to judge magnitude concepts such as "twice as bright" or "twice as glaring".

"Evaluation of Direct Discomfort Glare in Lighting Installations" Committee on Standards of Quality and Quantity for Interior Illumination, Illuminating Engineering, Vol. 54, No.7, July 1959, pp. 463-468.*

The Committee on Standards of Quality and Quantity for Interior Illumination give their recommendations for predicting discomfort glare including formulas. It is concluded that although more testing is required for accurate determinations of glare, current methods are needed until unknown glare factors can be studied.

Guth, S.K., and McNelis, J.F., "A Discomfort Glare Evaluator" Illuminating Engineering, Vol. 56, No. 6, June 1959, pp. 398-406.*

A discomfort glare evaluator was designed and constructed. Data from 50 observers for several combinations of luminaires are presented. The relative discomfort evaluation obtained with five combinations of luminaires is consistent and relatable with computed ratings. This apparatus is believed to make research outside of a laboratory both possible and valid.

Rowlands, E., "Discomfort Glare in Interior Lighting Installation-Comparison of Appraisals and Calculated Values" Light and Lighting, Vol. 52, No. 3, Mar 1959, pp. 102-107.*

The results of appraisal tests of direct discomfort glare in interior lighting installations are compared with those calculated by the Harrison-Meaker method and by the formula suggested at the CIE meeting in 1955, with terms for the immediate background luminance and the positions of the sources. The comparison shows a marked disagreement for some installations, and suggests the need for a different approach to evaluate direct discomfort glare.

Putnam, R.C., and Bower, K.D. "Discomfort Glare at Low Adaptation Levels - III. Multiple Sources" Illuminating Engineering, Vol. 53, No. 5, Apr 1958, pp. 174-184.*

This investigation continued the studies of how BCD change with angle (10, 20, or 30 degrees above horizontal) for varying background brightnesses (adaptation levels from 0.0001 to 1.0 foot lamberts) typical of night, source sizes, and combination of multiple sources. The glare sources used were the visual size of typical street lights and were incandescent, fluorescent or combinations of both (for "multiple sources").

Putnam, R.C., and Gillmore, W.F. "Discomfort Glare at Low Adaptation Levels - II. Off-Axis Sources" Illuminating Engineering, Vol. 52, Apr 1957, pp. 226-232.*

This paper studies glare values at or near the threshold of discomfort glare for a single light source.

Fry, G. A., "The Evaluation of Discomfort Glare" Illuminating Engineering, Vol. 51, No. 11, Nov 1956, pp. 722-728.*

This paper explains the relationship between the glare rating and BCD index, and describes how to compute one from the other. The relationship between the Luckiesh-Guth position index and the Harrison-Meaker location coefficient is explained. Several differences (e.g. exponents, coefficients, etc.) between the various formulae remain, but much of the work done by the earlier researchers is shown to be consistent with one other.

Fugate, J.M., and Fry, G. A. "Relation of Changes in Pupil Size to Visual Discomfort" Illuminating Engineering, Vol. 51, No. 7, July 1956, pp. 537-549.*

An investigation of pupil constriction associated with brief exposures of light, and its relationship to visual discomfort is described. Paralysis of the iris (by the drug homatropine) modifies (usually increases) the BCD, but results in extreme discomfort when the subjects are exposed to bright sunlight due to a desire to blink, squint and tense other extraocular muscles.

Guth, S.K., "Quality of Lighting" Illuminating Engineering, Vol. 50, No. 6, June 1955, pp. 279-285.*

Experimental data on discomfort glare (from Vermeulen and deBoer, Luckiesh and Guth, and Petherbridge and Hopkinson) are reviewed and compared, with regard to the work of the IES Committee on Standards of Quality and Quantity. The limitations of each method for evaluating the relative comfort of luminaires are discussed.

Bradley, R.D., "The Layman's Use of Glare Factors" Illuminating Engineering, Vol. 50, No. 5, 1955, pp. 213-216.*

This article attempts to explain and simplify methods of glare prediction conceived by others, stating that most engineers now have to deal with problems of glare.

Meaker, P., "Discomfort Glare and Glare Factor Calculations" Illuminating Engineering, Vol. 50, No. 2, Feb 1955, pp. 82-85.*

This paper presents a step-by-step procedure for calculating discomfort glare by the Glare Factor Method (the Harrison-Meaker formula), and the assumptions and compromises necessary.

Fry, G. A., and Alpern, M., "Effects of a Peripheral Glare Source Upon the Apparent Brightness of an Object," Illuminating Engineering, Vol. 50, No. 1, Jan 1955, pp. 31-38.*

This article attempts to show that the combined effect of a number of glare sources in different parts of the visual field can be predicted by adding the equivalent veiling brightnesses falling on the eye from the individual sources.

Lowson, J.C., Dresler, A., and Holman, S. "A Practical Investigation on Discomfort Glare" Illuminating Engineering, Vol. 49, No. 10, Oct 1954, pp. 497-500.*

A summary of test and analyses by the I.E.S. of Australia. A calibration (applicable to Australia) of the Harrison-Meaker Glare Factors is desired. A test team of lighting engineers visited selected installations and evaluated each site as comfortable, just comfortable, slightly uncomfortable, etc. Results were close to (slightly above) the calculated Glare Factors, confirming the Glare Factor tables.

Petherbridge, P., and Longmore, J. "Solid Angles Applied to Visual Comfort Problems," Light and Lighting, Vol. 47, No. 6, June 1954, pp. 173-177.*

A review is made of a number of existing equal-area space projections with which solid angles can be calculated. To evaluate discomfort glare, a semi-sinusoidal (cylindrical) projection is shown to several advantages. A basic diagram and its accompanying droop lines are described, as is a modification to the droop lines to allow for the reduced glare effect of light sources located off the line of vision. Descriptions are given of the operating principles of two steradian gauges with which solid angles subtended by lighting fittings can be measured.

Fry, G. A., "A Re-Evaluation of the Scattering Theory of Glare" Illuminating Engineering, Vol. 49, No. 2, Feb 1954, pp. 98-102.*

The scattering theory of glare is discussed in reference to the light transmission through the ocular media of the eye.

Spencer, D.E., "Comparative Analysis of Comfort and Glare" Illuminating Engineering, Vol. 49, No. 1, Jan 1954, pp. 39-49.*

The author presents a caustic review of previous work in BCD, glare rating methods, the zonal flux method, and the visual comfort chart. She states that all major lighting and glare studies are erroneous, and that the only valid way to design good lighting is to use the 3:1 adaptation helios ratio recommended by the first Committee on Standards of Quality and Quantity of Interior Illumination (1944). The author compares interpretations of experimental results and "comfortable" outdoor scenes, and concludes that the 3:1 ratio "directs us toward the most comfortable conditions found in nature."

Maisonneuve, J., "The French Approach to Visual Comfort" Light and Lighting, Vol. 46, No. 5, May 1953, pp. 179-180.*

Reactions and opinions of French lighting engineers on human visual comfort are given, although no studies on this subject have been conducted in France.

Guth, S.K., "BCD Brightness Ratings in Lighting Practice," Illuminating Engineering, Vol. 47, No. 4, Apr 1952, pp. 184-194.*

The paper discusses the biological effects of light on a person's health and "well being."

Gilleard, G., and Weibel, W. "Glare Factors - New Guides to Eye Comfort" Illuminating Engineering, Vol. 47, No. 3, Mar 1952, pp. 119-23.*

This paper explains that when the method of predicting glare factors written by Harrison and Meaker is used correctly, an accurate approximation of glare can be obtained.

Logan, H.L., and Lange, A.W. "The Evaluation of Visual Comfort Data" Illuminating Engineering, Vol. 47, No. 4, Apr 1952, pp. 195-205.*

The authors review and compare available data and formulae to develop a visual comfort chart based on the efforts of Luckiesh and Guth, Holladay, Harrison, Petherbridge and Hopkinson, and Moon and Spencer. This Visual Comfort Chart allows different light sources to be "transformed" into an equivalent brightness and size so the overall brightness and size (in percent of field of view) of room lighting can be determined. (Sources of unequal brightness can be added to compute

the size of an equivalent single source.) The Visual Comfort Chart provides a predicted value for percent of observers comfortable in a given lighting situation.

Putnam, R.C., and Faucett, R.E., "The Threshold of Discomfort Glare at Low Adaptation Levels" Illuminating Engineering, Vol. 46, No. 10, Oct 1951, pp. 505-510.*

Data from experiments similar to earlier ones by Luckiesh and Guth support the results of earlier studies. This study investigated low adaptation levels and very small glare sources (e.g., night conditions).

Guth, S.K., "Comfortable Brightness Relationships for Critical and Casual Seeing" Illuminating Engineering, Vol. 46, No. 2, Feb 1951, pp. 65-75.*

This paper reports the results of work to evaluate brightness of sources (the concept of BCD) and the relationship to "critical seeing". BCD brightness can be calculated from the physical characteristics of the lighting elements.

Harrison, W. "Progress in Glare Evaluation" Light and Lighting, Vol. 43, No. 12, Dec 1950, pp. 437-442.*

The effects on glare of multiple sources of light, brightness of the source and the surrounding area, and the source shape are discussed.

Luckiesh, M., and Guth, S.K. "Brightness in Visual Field at Borderline Between Comfortand Discomfort (BCD)" Illuminating Engineering, Vol. 44, No. 11, Nov 1949, pp. 650-670.*

The experiments described are follow-ons to earlier studies by Luckiesh and Holladay. This paper discusses standard BCD brightness (borderline between comfort and discomfort), influence of field brightness, influence of size of source, multiple sources, position of the source in the visual field, and the configuration of the sources.

Darley, W.G., "An Analysis of Reflected Glare" Illuminating Engineering, Vol. 43, No. 1, Jan 1948, pp. 85-103.*

The effects of reflected glare in a drafting room are discussed. The author suggests that the eyes fixate on a relatively bright reflection and discusses satisfactory binocular fixation (fixation by both eyes) to minimize strain.

Harrison, W., and Meaker, P., "Further Data on Glare Ratings" Illuminating Engineering, Vol. 42, No. 2, Feb 1947, pp. 153-179.*

The authors discuss refinements to a glare factor formula in order to improve its rating scheme.

Luckiesh, M., and Guth, S.K, "Discomfort Glare and Angular Distance of Glare-Source" Illuminating Engineering, Vol. 41, No. 6, June 1946, pp. 485-492.*

The work by L.L. Holladay, who retired before his latest experimental data could be analyzed and reported is summarized. The experiments measured the relative brightness of glare sources located at various horizontal angles to one side of the line of vision, and at various angles above the line of vision. Empirical relationships from these experiments are shown as extensions of the Holladay formula.

Crouch, C.L., "The Relationship Between Illumination and Vision" Illuminating Engineering, Vol. 40, No. 11, Nov 1945, pp. 747-784.*

The effectiveness of illumination depends on the brightness produces on the task; therefore, brightness (light reflected to the eye) and not illuminating power of the luminaires is the key factor in visual acuity. On glare, previous work by Holladay and Stiles is summarized, including their formula for "equivalent brightness" (including glare effect) and "surround factor". Disability glare occurs when the equivalent brightness of the background exceeds that of the task, i.e., the contrast of the brightness of the glare with that of the background is a critical factor. Discomfort glare (Holladay formula) is discussed.

Harrison, W., "Glare Ratings" Illuminating Engineering, Vol. 40, No. 9, Sep **1945, pp. 525-57.***

A rating scheme for lighting installations is proposed. All principal glare factors are evaluated in terms of equivalent source size. The author proposes that discomfort glare varies as (area x brightness2)/(distance2 x angle2 x surrounding brightness 0.6). Several examples of the application of this formula are included. In the discussion following the paper, the scheme is critiqued.

Crouch, C.L., "Brightness Limitations for Luminaires" Illuminating Engineering, Vol. 40, No. 7, July 1945, pp. 427-449.*

This paper explains that when the method of predicting glare factors written by Harrison and Meaker is used correctly, an accurate approximation of glare can be obtained.

Carne, J.B., "Avoidance of Glare" Light and Lighting, Vol. 38, No. 55, May 1945, pp. 61-64.*

Studies are presented of the effect of glare on visual acuity, dazzle and discomfort of glare, and the variation of glare by angular separation and brightness of the source. Suggestions on how to best avoid glare are also given.

Luckiesh, M., "Brightness Engineering" Illuminating Engineering, Vol. 39, **No. 2, Feb 1944, pp. 75-92.***

Glare is said to be not always preventable and increasing the illuminance on a subject makes 'favorable' glare increase more rapidly than unfavorable glare. Solutions for best indoor lighting techniques are discussed.

Fowler, E.W., and Crouch, C.L., "Glare and Lighting Design" Illuminating Engineering, Vol. 36, No. 11, Nov 1941, pp. 897-916.*

This document includes papers by Luckiesh and Holladay (1925) and L.L. Holladay (1925-26), which deal with artificial lighting and resulting glare and brightness limits. Each author's formula for calculating glare is presented and compared. Also included are papers by Potter and Meaker (1931) and Potter and Darley (1941) dealing with brightness and comfort levels of artificial lighting.

Alexander, H.W., Lee, F.B. and Ickis Jr, L.S., "Glare a Serious Problem in Lighting in the Hospital" Transactions I.E.S., Vol. 33, No. 6, June 1938, pp. 523-544.*

The authors present the results of studies in a number of hospitals. Particular attention is given to the unusual need for glare-free and shadow-free illumination in areas occupied by patients, to lighting requirements for hospital routine tasks, and to proper color treatment of interiors to create comfortable seeing conditions. Fundamental data are presented involving brightness contrasts and relative visibility in the surgery, which led to formulating quantity and quality requirements for surgery lighting.

Hopkinson, R.G., and Bradley, R.C., "The Nature and Effects of Glare" Illuminating Engineer, (London) Vol. 22, No. 11, 1929, pp. 299-300.*

An early discussion of glare is presented, including definitions of discomfort and disability glare, mainly from an earlier paper by W.S. Stiles. (The Illuminating Engineer, Vol. III, 1910, pp. 99-130, 170-190, 247.)*

Cobb, P.W., and Moss. F.K., "Glare and the Four Fundamental Factors in Vision" Illuminating Engineering, Vol. 23, No. 11, Nov 1928, pp. 1104-1120.*

Experimental data on glare, comprising measurements of visibility, are presented. The authors discuss differences in results from "discomfort" tests vs. "visibility" tests of glare. The variables of importance are: 1) size of critical detail (expressed as "minutes of the visual angle"); 2) contrast between the object and its background; 3) brightness level to which the object is illuminated; and 4) the time during which the object is allowed to rest upon the retina of the eye.

Colquhoun, J.F., "Test of Glare and Visibility in Present Addresses" The Illuminating Engineer (London), Vol. 21, No. 8, Aug 1928, p. 222.*

A short description of some tests of glare and visibility using human observers in a prescribed evaluation procedure.

Luckiesh, M., "General Considerations and Definitions of Glare and Visibility" Illuminating Engineering, Vol. 22, No. 5, May 1927, pp. 542-546.*

This paper attempts to standardize terms and expressions relating to glare, and distinguishes between glare and visibility. Definitions are proposed for visibility, threshold, changes in visibility, glare veiling, field brightness, adaptation-brightness, contrast-brightness, and safety-factor of visual contrasts.

Hopkinson, R.G., and Bradley, R.C., "The Nature of Glare" Illuminating Engineer, (London) Vol. 19, No. 12, Dec 1926, pp. 355.*

This paper is a brief early discussion of glare, with suggestions for ways to quantify its magnitude.

Luckiesh, M., "Glare and Visibility" Illuminating Engineering, Vol. 20, No. 3, Mar 1925, pp. 221-252.*

A summary of research (1922-1924) at the Lighting Research Laboratory of General Electric Co. is provided. Seven different phases of glare and visibility are presented. The paper discusses veiling-glare, dazzle-glare, blinding-glare, irradiation, growth and decay of after-images, psycho-physiological effects of light sources, and the size of the pupil of the eye.

Hopkinson, R.G., and Bradley, R.C. "How to Avoid Glare" Illuminating Engineering, Vol. 17, No. 6, June 1924, pp. 177-178.*

Caldwell, F.C., "Glare and its Relation to Eyesight Conservation" Transactions of I.E.S., Vol. 18, No. 6, July 1923, pp. 543-548.*

Glare is defined as being caused by three different conditions. Also discussed is the seriousness of glare and efforts to mitigate its effects.

"Report of the Subcommittee on Glare on the Research Committee I.E.S.", Committee on Glare of I.E.S., Transactions of I.E.S., Vol. 17, No. 10, Dec 1922, pp. 743-750.*

The subcommittee defines three types of glare, depending on the nature of the particular interference with vision produced: veiling glare ("fogging" effect), dazzle glare (partial obscuring of vision),and scotomatic glare (blinding). Experiments were conducted to quantify these types of glare. Dazzle glare was found to cause the greatest visual impairment, since scotomatic glare is usually caused by small light sources. Scotomatic glare increases with source size, and should be investigated further. Quantitative research on all types of glare is recommended.

Harrison, W., "Glare Measurements" Transactions of I.E.S., Vol. 15, No. 1, Feb 1920, pp. 34-45.*

Tests indicate that a rough classification of lighting installations into groups according to the sensation of glare as registered by a small instrument can reflect a human basis of comparison for glare discomfort.

"Interior Illumination", Committee on Glare of I.E.S., Transactions of I.E.S., Vol.11, No. 1, Feb 1916, pp. 36-39.*

This report shows practical applications of some of the principles set forth on glare. Tentative figures are given indicating safe limits of contrast brightness in a field of vision to help avoid glare.

"General Report on Glare", Committee on Glare of I.E.S., Transactions of I.E.S., Vol. 10, No. 9, Dec 1915, pp. 1000-1014.*

The work of the committee for the entire year is summarized, including twelve supplementary reports on the subject of glare. Formulas are given for glare brightness and contrast.

13.4.1 Glare and Daylighting

Hopkinson, R.G. "Glare from Windows" CONRAD, The Construction Research and Development Journal, Vol. 2 and 3, No. 3,4 and 1, 1971, pp. 98-105, 169-175 and 23-28.*

This is a three-part article. Subjective estimates of glare discomfort are correlated to the glare index determined from geometric and photometric measurements made in a room. The aesthetics of the window affect judgments of discomfort glare. Greater tolerance to glare from daylighting (compared to artificial light) was found only in mild glare situations. The degree of discomfort glare from sky illuminance was predicted from a glare index based on the Cornell large source formula. Acceptability of glare depends on the ability of the occupants to move about, thereby obtaining occasional relief. View outside has a marked, but unpredictable, effect on glare discomfort. Interior surface reflections and colors are also discussed. The glare index formula proposed for a "Code of Recommended Limiting Daylighting Glare Indices" (to supplement the IES glare index for artificial lighting) is described. A table of basic glare constants for small windows is presented, and design considerations discussed.

Griffith, J. W., "BCD Judgments of Large Area Sources" Illuminating Engineering, Vol. 63, No. 3, Mar 1968, pp. 106-110.*

This paper reports the results of an early study to assess glare from large area sources such as windows.

Griffith, J. W., "Analysis of Reflected Glare and Visual Effect from Windows" Illuminating Engineering, Vol. 59, No. 3, Mar 1964, pp. 184-188.*

A research project studying the effect of reflected glare from sidewall fenestrations on various tasks is reported. The importance of the effect of reflected glare from overhead light sources on visual performance has been studied by various researchers. However, there has been very little analysis of sidewall lighting and its effect on visual performance. The direct illumination from a side window wall strikes the normal desk top task at a relatively large angle of incidence. This large angle of incidence and the fact that the field of view can be oriented away from the major source produces a desirable situation to improve the visual task by reducing the loss of contrast from reflected glare.

Hopkinson, R.G., and Bradley, R.C., "A study of Glare from Very Large Sources" Illuminating Engineering, Vol. 55, No. 5, May 1960, pp. 288-294.*

Initial findings on a study on very large glare sources are presented. Results are generalized to visual comfort.

14. Case Studies

Perry, J., "A Comparison of Two Daylit Offices in Eugene, Oregon", Proc. of Solar 89, the 14th National Passive Solar Conf., Denver, CO., June 1989.

The design process is documented, describing two new daylit office buildings in Eugene Oregon. Energy impacts are discussed and conclusions drawn about 'what worked' and 'what did not work'.

Leaver, J., McQueen, T., "Daylight Analysis with Microcomputers for School Buildings", Energy Engineering, Vol. 86, No. 1, 1989, pp. 40-43.

Several characteristic school configurations in Louisiana are described, microcomputers are used as analytical tools to develop suggestions to optimize energy use for lighting and climatic comfort. Envelope studies feature daylighting and window design strategies to reduce electricity usage and make optimal use of daylighting. Effective design of natural and artificial lighting for classrooms and offices are important factors in energy saving strategies. To test these strategies, a microcomputer version of DOE-2 is used with reasonable success to establish an image of thermal behavior in buildings.

Sweitzer, G., Johnson, R., "Obstacles to the Use of Exterior Fenestration and Daylighting Control Systems in the U.S.", Proc. of Windows in Building Design and Maintenance, Goteborg, Swed.

Exterior fenestration and daylighting control systems can provide excellent control of solar gain and glare and still be visually satisfying elements in designing building envelopes. However, U.S. building industry experience with exterior fenestration and daylighting control systems suggests that durability and proper function of these systems is often unsatisfactory. Three representative U.S. building case studies are examined, each describing the application of exterior fenestration/daylighting control component previously untested as a system and some unsatisfactory consequences of these approaches.

D'Aquanni, R.T., Ives, G., "Cost Effective Control of Daylighting and Passive Solar Gains Through Designs which Reduce Electric Utility Loads", Proc. of Solar 88, the 13th National Passive Solar Conf., Cambridge, MA, June 1988.

Two passive solar retrofit measures implemented at the Cambridge (MA) Ridge Latin School are described. The measures consist of a solar shading trellis for the school cafeteria and the conversion of a glazed overpass into a hybrid heating/cooling system. These measures are expected to achieve substantial electrical load and cost reductions at the school, where annual electric costs approximate one dollar per square foot.

Black, R., "Working in the Light, Daylighting Strategies for Fun and Profit in Corporate Architecture", Proc. of the 11th National Passive Solar Conf., Vol. 2, Boulder, CO, June 1988.

This paper examines the expansion of the corporate headquarters of the Environmental Research Institute of Michigan from its present winged office structure as it connects through a new 400 feet long "link" building and on into a former toxic chemical labs building, transformed into a working environment through energy conservation and a variety of simple daylighting strategies: skylights, perimeter wall windows, sloped and raised ceiling configurations, borrowed light interior windows, light baffles and light mirrors.

Morck, O.C., "Development of Pilot Expert System for the Design of Passive Solar Commercial Buildings", Proc. of the 13th National Passive Solar Conf. Solar 88, Vol. 13, Cambridge, MA, June 1988, pp. 173-175.

The author discusses the need for CAD systems and describes the EKSPRO Project - developing an expert system for architects. The system is to assist in designing commercial buildings, with respect to thermal comfort, daylight quality, and energy consumption, paying special attention to passive solar energy gains. The goal is to combine an existing CAD system and thermal analysis simulation models with the expert system.

Haves, P., Littlefair, P.J., "Daylight in Dynamic Thermal Modelling Programs: Case Study", Building Services Engineering Research and Technology, Vol. 9, No. 4, 1988, pp. 183-188.

A lighting facility has been included in a dynamic building simulation program (SERI-RES) used in the Department of Energy's passive solar program. Interior daylight illuminance is calculated using an extension of the daylight factor method. Usage of various lighting systems is predicted from the daylight illuminance and the thermal consequences of lighting use is included in the thermal simulation of the building.

Ives, G., "Buoyant Interiors With Daylighting", Proc. of Solar 88, the 13th National Passive Solar Conf., June 1988.

The authors explore an institutional and a residential example which demonstrate how built-in architectural features can alleviate glare, while exploiting available light and heat.

Rifki, F.A., Flannery, D.A., "A Daylight Obstruction Study in Raleigh, N.C.", Proc. of Solar 88, the 13th National Passive Solar Conf., Cambridge, MA, June 1988.

This paper shows how Raleigh, N.C., may benefit from incorporating solar/daylight access regulations into the zoning code by use of a microcomputer program. The major downtown area is examined, and daylight access criteria compared to a development under current zoning regulations. The effects of a range of daylight obstruction values (DOV) are shown by the resultant worst case streetscape of each. These findings are compared to the 'worst case' streetscape result of current zoning regulations.

Ove Arup and Partners, "Passive Solar Design Studies for Non-Domestic Buildings, pp. Case Studies", British Library Document Supply Center, report No. ETSU-S-1157-P2, 1988.

Of the passive solar designs reported, those for a light industrial building, a nurses hostel and a low rise office block, were considered cost effective. A retrofit study of a secondary school showed that incorporating passive solar measures into refurbishment could be cost effective. Designs for a sports hall and medium rise office block were considered marginally cost effective and those for a hotel bedroom block and superstore were judged not cost effective. Maximizing daylight penetration, coupled with controls on the lighting systems, produced the main energy saving. Orientation, built form, fenestration, window shape, perimeter (and overhead) daylight, and atria were primary school features. Direct gain, considered in conjunction with building weight/response factor, can contribute to a lesser degree. Trombe walls are shown to be generally uneconomic for this type of building and conservatories contributed to amenity value more than to savings.

Verderber, R., Morse, O, Jewell, J.E, "Building Design Impact on the Lighting Control System for a Daylighting Strategy", Conf. Record of the 1987 IEEE Industry Applications Society Annual Meeting, IEEE Service Center Cat. No. 87CH2499-2, 1987.

The authors discuss the unique features of a multistory office building that permits most spaces to be daylit, and the electric lights dimmed, by a cost effective centralized system. This system includes: light shelves, sloped ceilings, proper building orientation and symmetry, and supplies only the ambient illumination. Measurements of daylight illumination levels and lighting control system performance indicate that daylighting can provide over 70% of the required ambient illumination through the year. Based on the installed cast of the lighting control system, its payback period is 2.2 years.

Andersson, B., Adegran, M., Webster, T., Place, W., Kammerud, R., Albrand, P., "Effect of Daylighting Options on the Energy Performance of Two Existing Passive Commercial Buildings", Building and Environment, Vol. 22, No. 1, 1987, pp. 3-12.

Results are presented from a study of south facing roof apertures on two buildings from the DOE's Non-Residential Experiment Passive Buildings Program. This study is part of a broad effort to evaluate the energy, functional and economic performance of buildings. The work reports supplemental basic building data, with illumination data from physical models, and additional observations and measurements. Energy analyses are performed to examine the daylighting systems incorporated into the building especially as they relate to: 1) interaction between heating cooling and lighting requirements, 2) integration of the electric

lighting and daylighting systems and 3) functional effectiveness and occupant interaction with the daylighting system.

Warren, M., Benton, C., Verderber, R., Morse, O., Selkowitz, S., Jewell, J., "Evaluation of Integrated Lighting System Performance in a Large Daylighted Office Building", American Council for Energy - Efficient Economy 1986 Summer Study on Energy Efficiency in Buildings: Volume 3, Proc. from the Panel on Large Building Technologies, DOE/CE/27460-T5, Aug 1986.

The monitored performance of an integrated lighting system in an office building in the San Francisco Bay Area is described here. It presents summary findings of several building zones. Also discussed is the potential benefits of daylighting in overall building electrical energy use. Analysis of annual electricity use indicates that ambient lighting electrical circuits represent 23% of total building electricity use. Significant opportunities for energy saving by employing dimming strategies are identified, but not used in the building tested.

Benton, C., Erwine, B., Warren, M., Selkowitz, S., "Field Measurements of Light Shelf Performance in a Major Office Installation", 11th National Passive Solar Conf., Boulder, Co, LBL-21411, June 8, 1986.

The monitored performance of an integrated lighting scheme in an office structure in San Francisco is evaluated. Decentralized data acquisition systems monitored 62 different locations in the building between May 1985 and January 1986, recording average illuminance levels and corresponding ambient lighting power usage across the north and south building sections. A graphic summary of data compares the effectiveness of the building's light shelf system for north and south orientation. One counter intuitive conclusion is that the dimmer north side light shelf scheme exhibits a higher potential for electric light reduction than the brighter south side scheme.

Benton, c., Warren, M., Selkowitz, S., Verderber, R., Mc Bride, J., Morse, O., "A Field Evaluation of Daylighting System Performance", CID 1986: Advancing Building Technology, 1986.

The performance of an office building, emphasizing the use of daylighting for ambient illumination is described. The architectural scheme includes ceiling that slope from 4.25m to 2.75m , light shelves, and a central atrium. An electric lighting system supplements available daylight, using fluorescent fixtures with continuously dimming ballasts controlled by photocells. Between 8 AM and 6 PM on an average summer day, the building's southern half can potentially maintain the target illuminance of 350 lux with an electric lighting load of 44% full power. The northern half of the building would require less electrical lighting; 31% of full power.

Boyer, L.L., "Daylighting Performance of an Earth Covered Dwelling at High Altitude", Int'l. Earth-Sheltered Buildings Conf.: Advances in Geotechnical Design, Minneapolis, MN., 15 June 1986.

The center module of a 3-dome concrete structure receives exterior lighting only from the south-southeast facade. A row of high windows under a generous overhang and two sets of patio doors admit light into the center module space which is 8.5m long and 5.5m deep. Sunlighting, passive solar heating and daylighting are selectively admitted during the winter season. The new daylighting analysis software program DAYLITE is used to simulate the center module of the existing building. Both clear sky and overcast sky conditions were simulated using available exterior illuminance data for the city of Denver. Calculations were made at 28 points in the center module on 1.2 by 1.2m grid pattern, and compared with actual measurements made in the space. Actual measurements equaled or exceeded calculated values. Reasons for the differences are presented.

Boyer, L.L., Grondzik, W.T., "Sunlighting, Daylighting and Passive Solar Heating Earth Covered Dwellings", Int'l. Earth Sheltered Buildings Conf.- Advances in Geotechnical Design Minneapolis, MN, June 15 1986.

This paper delineates the critical features of a combination of good daylighting, sunlighting and passive solar heating, incorporated into an earth sheltered building, and to show how to achieve the desired integration of the major factors involved. In addition to the performance aspects of each attribute, the aesthetic, functional, and structural implications are also considered.

Rising, P.S., "Steilacom High School, A Study in Energy-Conscious Design" Presented at the 1983 Int'l. Daylighting Conf., Phoenix, AZ, Feb 16-18, 1986.*

Normally the lighting load for an educational facility is approximately 40% of the total energy consumption. At Steilacom, this fraction is higher, due to very low HVAC loads. The artificial lighting load was substantially reduced by using daylight.

Warren, M., Benton, C., Verderber, R., Morse, O., Selkowitz, S., Jewell, J., "Instrumentation for Evaluating Integrated Lighting System Performance in a Large Daylighted Office Building", Field Data Acquisition for Building and Equipment Energy-Use Monitoring National Workshop, Dallas, TX, LBL-20087, Oct 1985.

The instrumentation used to monitor the electrical energy consumption and illumination levels in an office structure in the San Francisco Bay Area is described. Interfacing of the temperature, electrical and illumination measurements to the data loggers is described. A brief description of the building, and issues addressed in this monitoring project is given. The instrumentation installed to measure lighting levels and electric power consumption are described. Typical results using this instrumentation are presented.

Winkelmann, F., Lokmanherkim, M., "Sun Control Options in a High-Rise Office Building", Energy and Buildings, Vol. 8, No. 1, Feb. 1985, pp. 1-13.

The DOE-2 building energy analysis computer program was used to study the life-cycle cost and annual energy use for a wide range of glazing and sun-control options in a 25-story office building with 50% glazing. Four climates in the U.S. were analyzed: Miami, Los Angeles, Washington, D.C., and Chicago. The impact of daylighting in the perimeter zones for the various sun-control options was also investigated. Double glazing had little effect on energy use in Miami and Los Angeles, but reduced energy use 11-23% in Washington, D.C. and 16-32% in Chicago.

Gordon, H.T., Estague, J., Hart, K., and Kantrowitz, M., "Non-Residential Building Program Design and Performance" Passive and Hybrid Solar Energy Update, Washington, DC., Sep 1984.*

In 1979, the DOE began a research program to investigate the potential of passive solar technologies to meet commercial building energy requirements. Two overview studies focus on the design and performance characteristics of the 19 projects performed during this five year program. The overview study identified several important design principles. Intuition cannot be trusted in commercial solar design, especially in identifying building energy requirements and costs; and using solar elements with multiple functions is the best way to integrate design solutions. The performance overview study documents findings relative to energy use, economics, occupancy, and their interaction. Solar heated and daylighted buildings use less energy without incurring cooling penalties that offset benefits. Passive solar building costs fall within the same range as non-solar buildings; the more expensive buildings (relative to similar, non-solar buildings) are not necessarily the best performers; and building performance is significantly sensitive to its operation and use.

Shanus, M.D., et al., "Going Beyond the Perimeter with Daylight," Lighting Designand Application, Vol. 14, No. 3, Mar 1984, pp. 30-34, 36-40.*

An office building in Sunnyvale, California was built with extensive use of daylight. Numerous design features are described. The success of the deep daylighted building described is attributed to the careful integration of three basic design components: architectural configuration and fenestration placement, electric lighting and dimming design, and careful attention to the HVAC system.

"Daylighting for Office Building Cuts HVAC Load and System Size" Air Conditioning, Heating, and Refrigeration News, Feb 1984, p. 23.*

An energy conservation award was given to a firm for designing an administrative headquarters. Central to the design is daylighting, which helped reduce estimated annual energy requirements for the 30,000 square foot, two-story building to 20,707 Btu/ft 2. This is 47% of the requirement for a standard building design, meeting California non-residential energy standards for similar application and location. The daylighting was so effective that the building functioned for two months without supplemental lighting equipment, which was delayed in delivery.

Hayes, J. and Andrejko, D.A., eds. "Passive Solar Performance of a Large Mixed Building Complex" Presented at the 8th National Passive Solar Conf., Santa Fe, NM, Sep 5, 1983.*

This study assessed the environmental behavior of the St. Enoch Square Development. The architectural concept comprises a glass envelope enclosing a variety of structures, to maximize the passive use of the natural environment to reduce the demand for auxiliary energy and fossil fuel consumption. The study calculates temperature and humidity for representative spaces within the envelope exposed to both "typical" conditions (95% of the time). From this, requirements for natural or mechanical ventilation, auxiliary heating and cooling are determined for typical spaces. Requirements for solar control or shading are also obtained. Daylighting studies and physical model testing were conducted on several proposed office fenestration designs to provide an empirical basis for estimating daylighting performance and benefits.

"Dual Daylighting Design Limits Office's Energy Use" Energy Management Magazine, May 1983, p. 43.*

A recent analysis by DOE indicates that passive solar energy strategies, especially daylighting, are important features of buildings designed for high energy efficiency. Tampa Electric Company's TECO Plaza, completed in 1981, is designed to put 93% of the nine-story building's floor space within 32 ft. of natural daylight. This natural lighting helps limit the building's lighting energy requirements to 1.5 W/ft^2, well below the 2.7 W/ft^2 level cited in the Florida Model Energy Code. This reduced lighting has also help limit air-conditioning levels.

Rizzuto, J., "Daylighting Demonstration", New York State Energy Research and Development Authority, Final Report. New York: The Ehrenkrantz Group, May 1983.*

Energy for lighting accounts for up to 50% of energy costs in commercial office buildings. Photoelectrically controlled dimming systems, which dim fluorescent lighting in response to natural daylight levels in a space, can limit energy costs. Three dimming systems were installed in the top floor of a pre-World War II office building in Manhattan. Electrical consumption for lighting was substantially reduced with all three systems. The original lighting scheme consumed 4.8 W/sq. ft. Higher performance replacement light fixtures dropped this to 2.4 W/sq. ft., with greater usable illuminance levels at the visual task. Monthly electrical consumption data showed that using only two of three rows of luminaires closest to the windows produced significant savings. Using these two rows, additional energy savings from lighting ranged from 14% for mid winter to 40% in spring and summer.

Boyer, L.L., Roush, R.W., and Duke, B.W., "Application of Daylighting in Commercial and Industrial Buildings" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

Daylighting design procedures, physical modeling, and as-built results are addressed for two recently constructed award-winning projects. A typical four-office module, utilizing a common lightcourt, was studied in

Ponca City, Oklahoma. Perimeter offices and toplighted interior laboratories were reviewed for a Research and Development Center in Duncan, Oklahoma. Other projects are identified and reviewed. The use of scale models with analytical evaluation at the concept design stage are shown to be a valuable technique for determining the relative distribution of daylight illumination and for estimating illumination levels. Distribution predictions were accurate, while light level predictions were within the safety factor normally utilized in technical design disciplines.

Windheim, L.S., Riegel, R.J., Davy, K.V., Shanus, M.D., and Daly, L.A., "Case Study: Lockheed Building 157 Deep Daylight/Innovative Lighting Concepts for a Large Office Building" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

A Lockheed Missiles and Space Company building, a 600,000 square foot energy-efficient technical engineering office building in Sunnyvale, California is described. The paper discusses the building's deep daylighting design to reduce energy consumption, integrate daylighting with the indirect fluorescent lighting system, the design methodology, and annual energy performance. Daylighting features include sloped ceilings, interior and exterior light shelves, exterior shading devices, and a large interior "litetrium." A task ambient fluorescent lighting system is used to complement, and be integrated with, the daylighting scheme. Light levels are controlled automatically by photocells. A comprehensive daylight modeling effort involved 1/8" and 3/8" - scale models, and a full scale mock-up used to test electric lighting alternatives and fine-tune design solutions. Daylighting model testing was accomplished for both clear sky and overcast sky conditions. Annual energy building performance was forecast using the DOE 2.1 computer program at a level less than half that allowed by California's title 24 energy budget.

Bryan, H.J., and Bazjanac, V., "Daylighting Design for New California State Office Building Site 1-C" Presented at the Int'l. Daylighting Conf., Phoenix, AZ, Feb 16, 1983.*

The daylighting features used in designing a 160,000 square feet California State Office Building are described. The building integrates simple proven daylighting concepts that contribute to an energy efficient design. Covered are implications for building configuration, office space layout, fenestration design and artificial lighting/control alternatives. Various daylighting features considered are discussed, and solutions highlighted.

Watson, D., "Johnson Controls Branch Office Building, Salt Lake City, Utah - Passive Solar Energy Analysis and Design" What Works: Documenting Energy Conservation in Buildings, Washington, DC: American Council for an Energy Efficient Economy. Presented, Santa Cruz, CA, Aug 22, 1982.

Key aspects of the energy design process for a branch office building of Johnson Controls, Inc., in Salt Lake City, Utah, are summarized. The analysis begins with studies of a base case of building design, similar to those normally built for branch offices. The process follows these steps: 1) based on an analysis of local climate, a number of passive solar and energy conservation options are compared with the base case, utilizing hour-by-hour computer simulations of the building heating and cooling loads; 2) low evaporative (mechanical) cooling is possible, so energy costs for the increased cooling load due to daylighting and passive solar features can be met more efficiently than with conventional refrigerant cooling; and 3) a detailed design of the fenestration and light-shelf system is made, using physical models for daylighting analysis. The energy analysis process establishes guidelines for building design. Energy use in the building is being monitored. Many energy design features in this building have not been adopted in subsequent branch offices.

Kroner, W.M., "Passive Solar Commercial Building: New Applications of an Old Technology Leads to Architectural Innovations" Presented at the 6th National Passive Solar Conf., Portland, OR, Sep 8, 1981.*

The Visitors Information Center (VIC) at RPI, Troy, N.Y., includes passive solar heating, cooling, and daylighting systems. These features supply 64% of the annual heating load, 80% of the annual cooling load, and 61% of the daylighting. The most innovative design elements are the building's multi-energy flow systems for heating, cooling, and daylighting constantly searching for free energy before actuating back-up systems. The energy systems are integrated with personalized technologies designed to provide the occupants' sensory needs, rather than just those of the building. The building applies familiar passive technologies in new ways, suggesting a new architecture, one that depends on a building's occupants as well as its systems for energy conservation.

White, C.S. and Converse, A.O., "Case Study of the 424 West 33rd Street Apartment House" Solar Thermal Utilization: Space Heating and Cooling, Upton, NY, 1981.*

The case study of a proposed retrofit project - the conversion of an old industrial loft in midtown Manhattan to an apartment building - shows that dramatic energy economies are possible by renovation techniques. The building is projected to yield savings of 80 to 85% in space heating over the average pre-war New York City apartment building. The background and existing conditions; architectural design; evaluation of building design through simulated thermal performance; heating, ventilation, and air conditioning system design; embodied energy, active solar system evaluation; and solar access litigation and legislation are discussed.

"Daylighting Design Analysis", Project Status Report, No. 2, Grandview, MO: Butler Mfg. Co. and Princeton, NJ: Princeton Energy Group, Mar 1980.*

Detailed scale model studies regarding daylighting aspects of the passive/hybrid solar test building located at Butler Research Center in Grandview, MO, are discussed. The product development program is aimed at providing passive/hybrid system building alternatives for commercial, industrial, and community purchasers of pre-engineered metal buildings. Occasioned by recognition that daylighting could strongly influence annual energy consumption in these buildings, scale models of several alternative design configurations, including the test building in Grandview, were built and tested. Major design alternatives, test results, and tentative conclusions are described.

Caudill, W.W., and Reed, B., "Geometry of Classrooms as Related to Natural Lighting and Natural Ventilation", Texas Engineering Experiment Station Research Report No. 36. College Station, TX: Texas A&M University, July 1952.*

Results of small-scale and full-scale tests of illuminance distribution in daylit classrooms are presented.

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This report is an annotated bibliography of Daylight research and practices. It is a compilation of two draft bibliographies, one compiled by the Florida Solar Energy Center, and the other by the National Institute of Standards and Technology. Both were the result of research projects conducted for the Electrical Power Research Institute. The topics covered are as follows: general treatments of daylight, energy saving design, research and design tools, control systems, computer, scale, and mathematical models, skylight research and applications, atria, fenestration systems and materials, shading devices, delivery systems -- daylight and sunlight, and finally, the responses of people to light.

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