

THREE ADVANCED DAYLIGHTING TECHNOLOGIES: Potentials in Private Office Workplaces

Glenn Sweitzer
The Royal Institute of Technology
Architectural Lighting
Sweden

Abstract

The parade of daylighting technologies that evolved in the wake of the energy crises of the 70s has closed ranks. Various-coated low-emissivity insulating glazings have emerged as the leaders and currently enjoy widespread market penetration and user acceptance. Several less-conventional examples, including light pipes, prismatic panels, and electrochromic glazings, are meanwhile still undergoing development in order to overcome barriers concerning architectural integration, cost, and user acceptance.

These barriers were considered for each of the above three developing technologies in the context of a daylighted private office workplace (that includes display unit tasks) and an adjacent corridor. The lighting control strategy for each case includes both automatic and manual controls, including window, room, and task lighting controls from the display unit operator position. Assumptions concerning manual switching of room lighting are based on a recent study of daylighting potentials in similarly-sized and -furnished office workplaces.

Office and corridor ceiling heights, configurations, and finish surfaces appear to be critical to both architectural integration of and light distribution from light pipe and prismatic panel systems. Integration of electrochromic glazings meanwhile appears to be limited by wiring needs and glazing appearance in its reflective (colored) state. The costs for each of these technologies remain high and cannot at this time be justified by electricity savings alone. It appears however that electrochromic glazings, which are expected to be commercially available within two to three years, hold the greatest potentials for both personal control of lighting and thermal conditions in addition to electricity savings. Occupant response to these technologies, however, has not been adequately assessed.

INTRODUCTION

New as well as revived daylighting technologies have evolved in the wake of the energy crises of the 70s^{1,2}. Of these, insulating glazings variously-coated with low-emissivity films^{3,4} have emerged as the leaders, having matched or exceeded expectations concerning energy performance⁵, market penetration, and user acceptance. Meanwhile, less conventional technologies have been used sparingly, often for reasons concerning architectural integration, cost, or user acceptance.

Architectural integration of unconventional daylighting technologies can involve, for example, unexpected structural and code considerations⁶ in addition to appearance^{7,8} and related lighting effects. In addition, costs for most of these technologies remain high and, in many cases, cannot provide an acceptable payback based on electricity savings alone. User acceptance is also critical; where it has failed, lighting systems have been misused, altered, disused⁹, and even sabotaged¹⁰. Such outcomes thereby diminish support critical to further development of these technologies.

In practice, each outcome is context dependent. Accordingly, in order to consider the benefits and costs of alternate technologies, the context must be held constant. The purpose of this study therefore is to independently explore three developing technologies, light pipes, prismatic panel systems, and electrochromic glazings, in one context, a sidelighted private office workplace and adjacent corridor.

A sidelighted private office has been selected for several reasons. First, it is again commonplace following a nearly three decade long emphasis on open or landscaped office workplaces. Secondly, private offices extend the potential for both personal choices and responsibilities, including the control of day- and electric lighting, to satisfy personal preferences as well as task needs. It is in part the tasks and the means available to control lighting, however, that distinguish contemporary private office workplaces from their earlier counterparts.

Most office workplaces now include—or are expected to—display unit tasks. Lighting needs for these more or less vertical tasks contrast sharply with traditional, more or less horizontal, reading and writing tasks. At the same time, contemporary private perimeter offices throughout Europe are often smaller, longer and more narrow in proportion, in order to optimize the number of units with window exposures. Furnished, these offices typically include two zones, a private work area near the window and a semi-private interior area where visitors can be accommodated. The work zone usually includes a display unit located within either the direct or reflected field of view of a window.

Under such conditions, window shading may be required to provide satisfactory display screen viewing conditions¹¹. Accordingly, shading diminishes daylighting potentials in the interior zone and electric lights are often switched on—usually from a location near the door—in response. Once turned on, however, electric lighting is rarely turned off, regardless of changes in task or daylighting potentials¹². It is assumed that this is due to both the location of the switch¹³ as well as visual adaptation. Both of these factors were considered in developing the lighting strategy for the reference office (Figure 1) in this study.

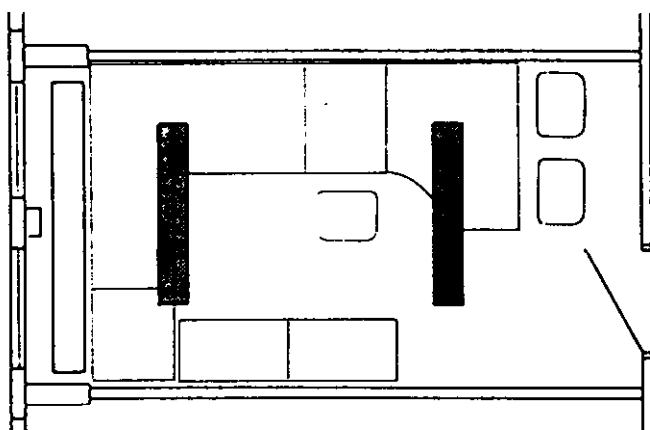


Figure 1 Reference office floor plan (not to scale; reproduced from reference 14)

This office includes a pair of symmetrically placed (openable) windows, corresponding to an (interior) window-to-wall ratio of about 0.50. Each window includes clear insulating glazing and an interior roller blind in addition to conventional track-mounted drapes. Each requires standing in order to reach and adjust.

Electric lighting is provided by two suspended fluorescent luminaires (shown shaded in Figure 1), each with up- and downlighting components, one above the window zone and one above the interior zone. Each includes energy efficient lamps but not high frequency ballasts, providing an installed power density of 13.6W/m^2 (this retrofit solution was judged best among several alternate energy efficient lighting options that were installed and studied in several similarly-sized and -furnished offices¹⁴). The switches for each zone are located side-by-side just inside the door.

The adjoining double-loaded corridor is also illuminated by ceiling-mounted fluorescent luminaires. All units are kept on during building occupancy, as the only access to other lighting is via open office doors.

The lighting control strategy developed for the reference office includes both automatic and manual controls, including window, room, and task lighting controls from the display unit operator position. In addition, assumptions concerning manual switching of room lighting are based on a study of daylighting potentials in similarly-sized and -furnished office workplaces¹², as follows:

- * On/off switching of (continuously dimmed) room lighting, by zone, at a location inside the door as well as from the window workplace position.
- * On/off switching of an adjustable and dimmable task light for display unit tasks only from the workplace position (this control could also be coupled to the display screen in order to provide either pre-programmed or recommended luminance ratios in response to changing room lighting conditions as well as to automatic window shading controls).
- * Sensor-controlled dimming of corridor lighting in response to available daylight admitted via transom windows or distributed via light pipes.

Following are descriptions of the three advanced daylighting technologies in the context of the reference office.

LIGHT PIPES

Concept

Light pipes have been explored and a system patented (in the US) as early as 1881¹⁵. Although the idea did not catch on, the currently available systems hold exciting potentials because of the relatively long distances (ca 30-100 meters) over which they can operate. The most basic pipe is an empty shaft along which a light source can be transmitted. The success of any system, however, depends on means to efficiently collect and concentrate, transport, as well as distribute the light source¹.

Efficient collection requires a strongly collimated light source, such as direct sunlight. In addition, collector size and solar tracking capabilities along with means to filter (infrared) heat buildup are critical. Light pipes are not efficient, however, under overcast conditions or where direct access to sunlight is not available.

The most common forms of light pipes with good transmission characteristics are reflective, lens, and prismatic panel guides in addition to fiber optics, acrylic rods, and fluid filled tubes (Figure 2). Except for reflective and lens guides, all use the principle of total internal reflection. The thin fiber cables are efficient but expensive while the solid guides are bulky and heavy. The options therefore narrow to reflective or prismatic guides².

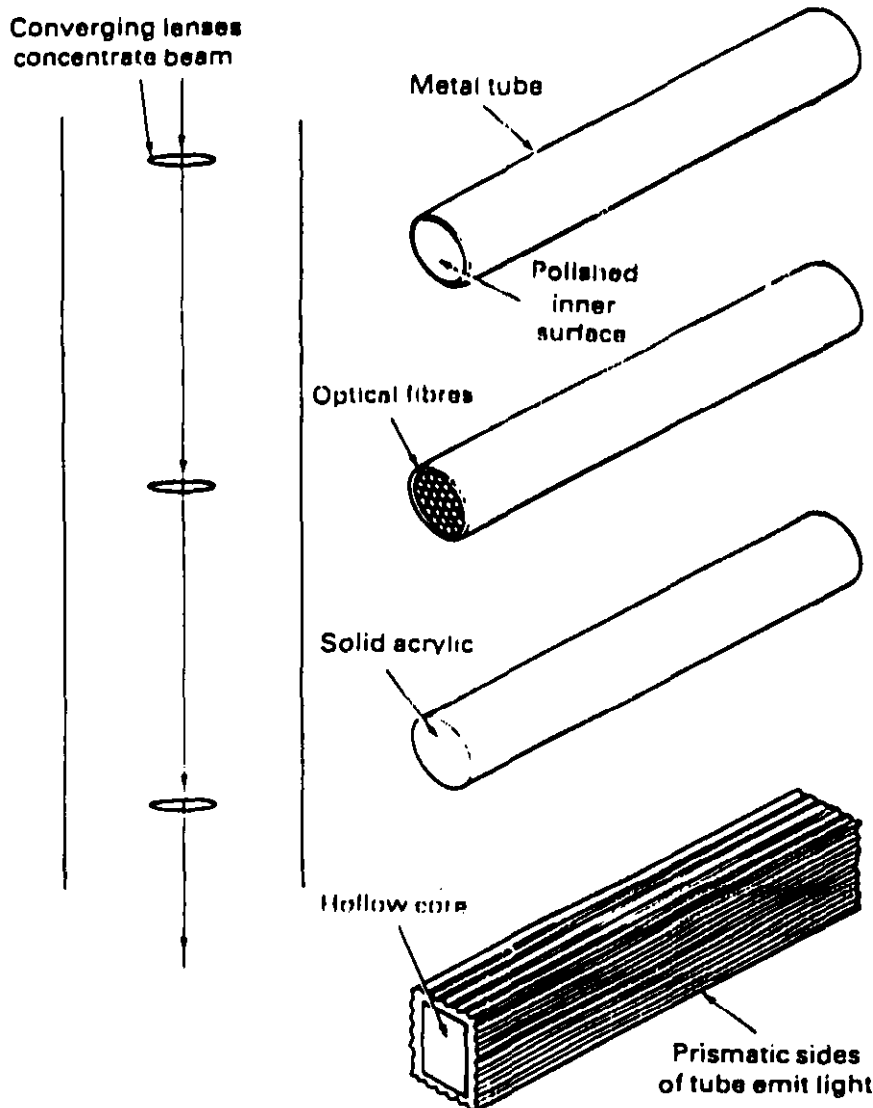


Figure 2 Various types of light pipes. On the left, a lens guide; on the right, from top: a reflective metal tube; a fiber optic bundle; an acrylic rod; and a prism light guide. (Reproduced from reference 1 by permission of the Controller of HMSO)

Applications

Prismatic guides are available commercially, in rectangular and tubular shapes, in uninterrupted lengths of up to ca 25 meters^{16,17}. Each includes an internal prismatic light guide film with a backing of diffuse reflecting film. Although their predecessors were developed to guide daylight, the current systems feature electric sources, most often metal halide lamps; one 250W lamp is required about every 14 meters. The light emitting sector for a tube can be varied between 90° and 240° while, for a rectangular section, one or two entire faces can emit light.

Interior applications include areas above water (where relamping is difficult); where radio and magnetic interference (generated by luminaires) can impede the accuracy of sensitive electronic equipment; and in hazardous rooms where spark potential from light sources is critical. Exterior applications include highlighting of building elements, especially in hard to relamp rooftop or exterior locations. The cost for both indoor and outdoor system components (only) is currently about 400 ECU per lineal meter. This includes the luminaire, lamp, and conventional ballast (the warm-up time is 5-10 minutes). If continuous dimming is desired, for example, in response to daylight, another (more expensive) ballast is required.

Reference Office

It is proposed to use a tubular light pipe to illuminate the corridor and, via sloped transom glazing, the interior office zone. (Figure 3). Sunlight would be concentrated into a light pipe at one end of the corridor and supplemented as necessary with (dimnable) metal halide lighting. The light would be emitted upwards, from a 180° wide angle and spread by the concave ceiling surface above, thereby balancing surface luminances while preventing line of sight to the source from any location in the hallway or office. Modelled trim around the transom window openings would prevent otherwise sharp shadows on the office walls¹².

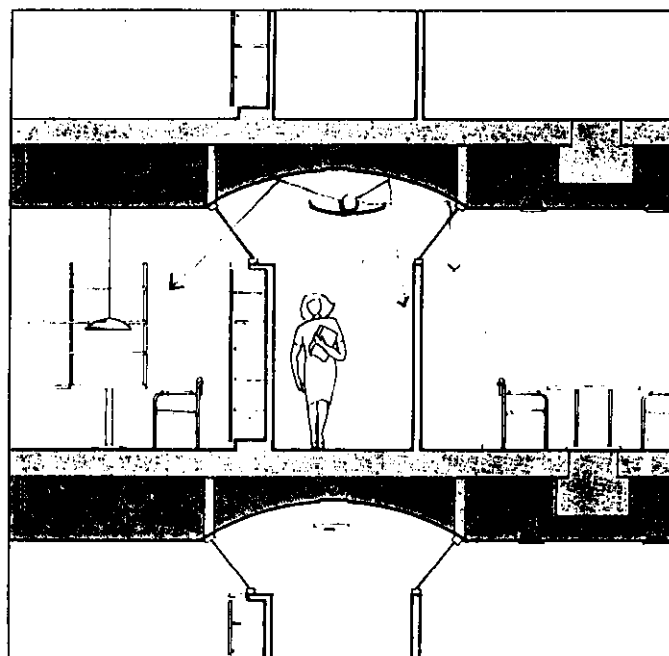


Figure 3 Section of corridor and adjacent private perimeter offices (Reproduced from Project Magazine 16, Partek OY, Helsinki)

This system, at an installed power density of 12.5W/m² for the 1.5 meter wide corridor alone, is not particularly energy efficient. However, because the system can at the same time provide partial room lighting for the interior office zones (on both sides of a double-loaded corridor) it can provide additional benefits. For example, it could limit or eliminate the need for switching on of additional lighting (upon arrival) in the interior office zone when the window zone is adequately daylighted or, even when it is not. These potentials will of course vary by latitude as well as by climate¹⁸ and building exposure.

PRISMATIC DAYLIGHTING PANELS

Concept

Prismatic panel systems have developed as a means to distribute daylight deeper into building perimeter zones while preserving view to the outside. Side- or toplighting systems can be designed to reject direct sunlight and solar radiation while directing skylight to the interior, thereby moderating both glare and overheating. The basic principle behind these panels is that the direction of incoming daylight can be altered by refraction as well as by reflection.

The system developed by Siemens AG^{19,20} includes two panels, each composed of 20cm x 20cm prismatic elements. The flat exterior face of each fixed sunshielding panel has a metallized specular surface while its movable counterpart has a non-specular surface. The opposite face of each of these panel types is configured to provide specific sunlight cut-off and skylight transmission angles, according to each window exposure. The interior light-guiding panels have no special surface treatments and are most often vertically fixed although they have been used in tandem with movable exterior panels (Figure 4).

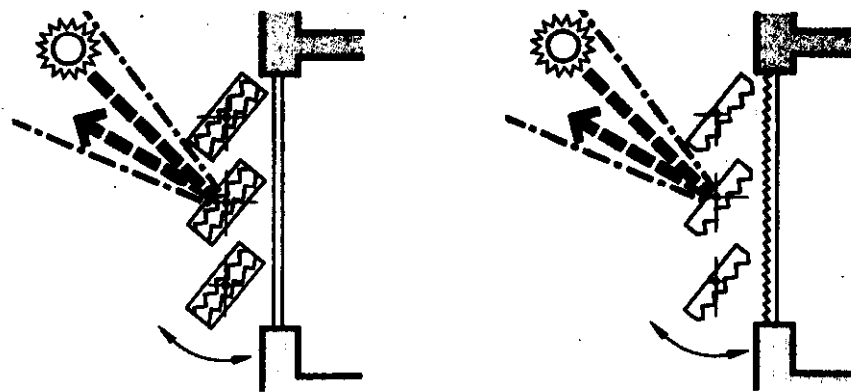


Figure 4 Sun- and skylight ray paths through two types of prismatic sidelighting panels; left - with movable light guide; right - with fixed light guide (Reproduced from reference 20)

Placement and extent of these panels is also critical. In order to preserve view to the outdoors, panels are typically located in upper window areas, above conventional insulating glazing. In addition, this upper panel position usually provides unobstructed line-of-sight between incoming light and ceiling reflecting surfaces. These surfaces can be semi-specular (e.g. brushed aluminium) as well as specially configured in order to distribute the incoming light while accommodating electric lighting requirements.

Applications

Since the introduction of the Siemens system approximately 10 years ago, several variants have been installed in Western Europe. Each includes prismatic panels integrated into the window wall as well as highly reflective and configured ceiling systems to distribute day- and electric lighting in perimeter spaces. The critical effects produced by three of these systems, each in a different bank office building in Germany, have been reported²¹.

The critical effects included the distribution of reflections and shadows on ceiling and wall surfaces in addition to the uniformity of horizontal illuminances at the work-plane. In each case, however, the electric lighting was not being dimmed or switched off in response to available daylight. Finally, in the bank which included perimeter offices similar in size to the reference office, hung pendant reflectors (shown dotted in Figure 5) appeared to be limiting daylighting potentials to the adjacent corridor, connected by transom glazing.

Reference office

It is proposed to use a sidelighting system that includes movable exterior and fixed interior prismatic panels, in order to provide a fixed angle of distribution. The pendant-hung reflector, however, would be removed in order to improve daylight distribution to the corridor. In addition, the two hung luminaires may need to be replaced with tubular lamps (as shown above) or lowered (or the ceiling raised if the existing luminaire height is critical) in order to prevent shadowing that would limit daylight penetration to the interior room surfaces and corridor. In response to daylight admitted to the corridor, the fluorescent lighting could be continuously dimmed.

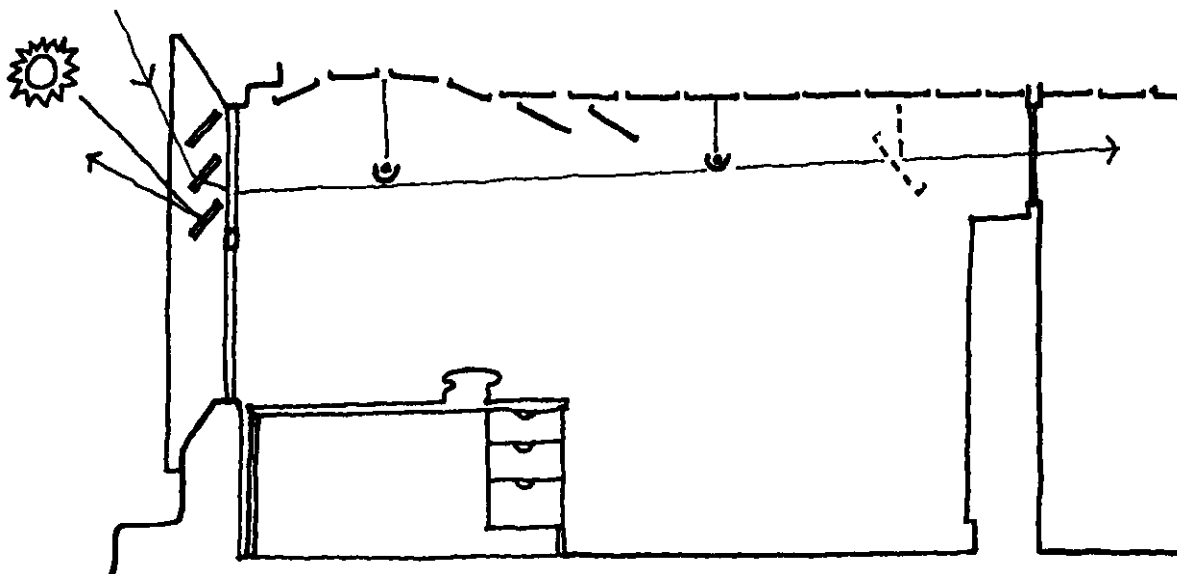


Figure 5 Section of reference office with prismatic panel sidelighting system (Based on drawing provided by Lichtplanung Christian Bartenbach)

ELECTROCHROMIC GLAZINGS

Concept

Electrochromic glazings can control the transmittance of visible as well as near infra-red and ultraviolet radiation. In response to an electrical charge, a five-layered sandwich located between two layers of conventional clear glass can change, in a persistent and reversible manner, between transmissive (bleached or clear) and reflective (colored) states. These changes can be triggered automatically in response to temperature or light intensity or, manually²², to suit individual preferences, for example.

Of the five layers, the outer two are transparent electrodes, electrical conductors. Between them are the active electrochromic layer and its (ion storage) counterpart, the passive counterelectrode. Between these layers is an electrolyte, a non-metal conductor of electricity (Figure 6).

The active electrochromic layer is currently most often tungsten trioxide (although several other metal oxides can also be used). Changing the direction of the electric current moves lithium atoms between the electrochromic and the passive counterelectrode layers, through the electrolyte. When lithium atoms are in the passive counterelectrode, the layers become transmissive (bleached). When they are moved to the electrochromic layer, they react with the tungsten trioxide thereby rendering the layers reflective (colored)²³. The time required for moving from a bleached to a colored state can be matched to the time necessary for the human eye to accommodate to the change, about one minute.

The amount of electricity required to trigger these changes is negligible. In theory each panel works as a capacitor and no electricity is required to move the charges back and forth. In practice, the losses are small, totaling less than $1\text{kWh/m}^2/\text{year}$ ²⁴.

Applications

Outside of the laboratory, one of the first test applications for electrochromic glazings has been for automobile sunroofs²⁵. By blocking incoming solar radiation, cooling loads—and therefore air conditioning system size—can be reduced. In this case, the glazing appeared blue in the colored state.

It is expected that electrochromic glazings for architectural applications will be commercially available within two to three years. It is currently estimated that material costs will be in the range of 190 to 380 ECU/m² but, ultimately, not more than 20 ECU more than a standard window²⁶. Then, it is argued, that these windows can be justified by offsets in cooling system and window shading system costs as well as modest electric lighting and cooling operating costs. Again, the magnitude of these savings will vary case by case.

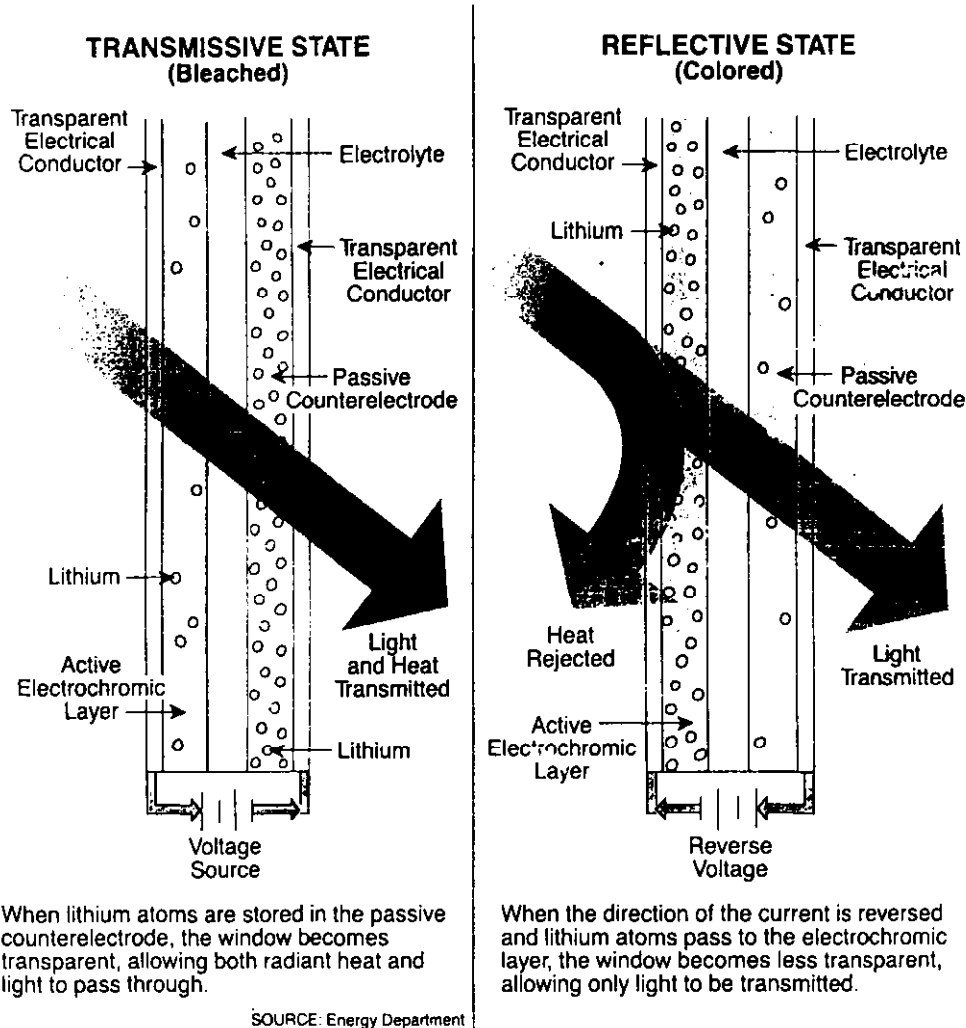


Figure 6 Operation of an electrochromic window (Reproduced from reference 23)

Reference office

It is proposed to use electrochromic glazings in each of the two windows in the reference office. In addition, it is proposed to provide individual as well as automatic control over partitioned areas within each pane of glass (with necessary wiring concealed under muttins on the inside surface, for example). This would simultaneously permit view and shading in response to changes in solar radiation as well as visual needs in the window zone.

In the case of visual display screen tasks, the light sensors could also be connected to the display screen contrast and electric task lighting controls in order to balance surrounding surface luminances, for example, according to personal preference or pre-programmed criteria²⁷. The default control could otherwise automatically limit solar heat gain in order to minimize cooling loads.

Alternatively, prismatic daylighting panels could be located above electrochromic units. In this case, cool zenith light could be directed deeper into the office and corridor (as described earlier) while the electrochromic glazing units could optimize lighting and thermal conditions in the window zone.

CONCLUSIONS

- * The use of light pipes, prismatic panel systems, and electrochromic glazings should be considered case by case, concerning daylight availability, architectural integration, costs, and user acceptance.
- * Office and corridor ceiling heights, configurations, and finish surfaces need to be carefully integrated in order to optimize daylight distribution from light pipes and prismatic panels.
- * Conceptually, electrochromic glazings hold the greatest potentials for electricity savings as well as widespread use (the glazings can be fitted into existing insulating window frames and they require

- negligible electricity to operate).
- * Electricity savings alone cannot—at this time—payback the investment costs for any of the technologies studied.
- * User acceptance has not yet been adequately studied for any of these technologies

DISCLAIMER

The commercial products and trade names referred to in this report are included for information purposes only and do not constitute an endorsement or recommendation by the author, the Royal Institute of Technology, or the sponsors of this work.

ACKNOWLEDGEMENTS

I would like to thank Liliana Beltran and Steve Selkowitz, Lawrence Berkeley Laboratory, Martin Klingler, Lichtplanung Christian Bartenbach, and Lorin Whitehead, TIR Systems Ltd., for background information; Paul Littlefair, The Building Research Establishment, and Hans Allan Löfberg, The National Swedish Institute for Building Research, for review comments; and the Swedish Council for Building Research and National Board for Industrial and Technical Development (NUTEK), for funding.

REFERENCES

- [1] P. Littlefair. 1988. "Innovative Daylighting Systems--A Critical Review", *Proceedings of the National Lighting Conference and Daylighting Colloquium*, Lighting Division of the CIBSE, Cambridge, pp. 367-391.
- [2] S. Selkowitz and L. Beltran. 1991. *Technology Review: Daylighting Optical Systems*, California Institute of Energy Efficiency, pp. 1-7..
- [3] C.G. Granqvist. 1990. Window Coatings for the Future, *Thin Solid Films* 193/194, pp. 730-741.
- [4] C.G. Granqvist. 1991. Solar Energy materials: Overview and Some Examples, *Applied Physics A* 52, pp. 86-87.
- [5] G. Sweitzer, D. Arasteh, and S. Selkowitz. 1986. "Effects of Low-Emissivity Glazings on Energy Use Patterns in Nonresidential Daylighted Buildings", *Proceedings of the ASHRAE Winter Meeting, Symposium on Fenestration Performance*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.
- [6] R.P. Leslie. "Core Daylighting: Building Code Issues", *Proceedings (II) of the International Daylighting Conference*, Long Beach, CA, pp. 314-324.
- [7] G. Sweitzer, and R. Johnson. 1984. "Obstacles to the Use of Exterior Fenestration and Daylighting Control Systems in the US", *Proceedings of the Windows in Building Design and Maintenance Conference*, Gothenburg, Sweden.
- [8] P. Gujral, R. Clark, et al. 1982. *Windows: Technology and Resource Transition*, Environmental Study Group, Skidmore, Owings & Merrill, Chicago, IL, pp. 14, 29.
- [9] E. Ne'eman, G. Sweitzer, and E. Vine. 1984. Office Worker Response to Lighting and Daylighting Issues in Workspace Environments: A Pilot Survey, *Energy and Buildings* 6, pp. 159-171.
- [10] G. Sweitzer. 1985. "Building Case Studies", in A. Usibelli, S. Greenberg, et al, Commercial-Sector Conservation Technologies, Lawrence Berkeley Laboratory Report No. 18543, pp. 6.76-6.94.
- [11] S.L. Sauter. Preliminary Edition. Improving VDT Work - Causes and Control of Health Concerns in VDT Use, Department of Preventive Medicine, University of Wisconsin, WI, USA, pp. 59-60.
- [12] G. Sweitzer. 1990. "Daylighting Potentials for VDU Office Workplaces in Sweden: A Pilot Study", *Proceedings of the International Daylighting Conference*, Moscow.
- [13] J.R. Cole. 1986. "Justifying Daylight: A Question of Cost", *Proceedings (II) of the International Daylighting Conference*, Long Beach, CA, pp. 104-110.
- [14] L. Carlsson. 1989. *Utvärdering av belysning i kontorsrum* (Evaluation of Lighting in Office Rooms), The Swedish State Power Board, Räcksta, Sweden, pp 13, 18, 24-25.
- [15] P. Littlefair. 1986. Beam Lighting: A Pipe Dream?, *Electrical Design* 5, pp. 31-33.
- [16] Lightpipe™ Interior Lighting System. 1988. Product Brochure, TIR Systems LTD, Burnaby, British Columbia.
- [17] Lightpipe™ Building Highlighting System. 1988. Product Brochure, TIR Systems LTD, Burnaby, British Columbia.
- [18] S. Secker and P. Littlefair. 1986. "Geographical Variations in Daylight availability and Lighting Use", *Proceedings of the National Lighting Conference*, Lighting Division of the CIBSE, Cambridge, pp. 214-229.
- [19] Daylight System. 1987. Product Brochure No. A19199-J22-A222-X-7600, Siemens AG, Traunreut, Germany, pp. 12-13.
- [20] Daylight System. 1987. Product Brochure No. A19199-J22-A223-X-7600, Siemens AG, Traunreut,

- Germany, pp. 4.
- [21] G. Sweitzer. 1991. Prismatic panel Sidelighting Systems: Daylighting Distribution and Electric Lighting Use Patterns in Perimeter Office Workplaces, *Proceedings of the 1st European Conference for Energy-Efficient Lighting*, National Board for Industrial and Technical Development, Stockholm, Sweden.
 - [22] C.G. Granqvist. 1990. Chromogenic Materials for Transmittance Control of Large-Area Windows, *Solid State and Material Sciences* 16-5, pp. 291-308.
 - [23] Holtzman, David. 1986. A Solution Almost Clear as Glass, *Insight* 9, pp. 53-55.
 - [24] C.G. Granqvist. 1989. "Energy-Efficient Window: Options with Present and Forthcoming Technology", in T. B. Johansson, B. Bodlund, and R.H. Williams, eds., *Electricity-Efficient end-Use and New Generation technologies, and Their Planning Implications*, Lund University Press, Lund, Sweden, pp. 105-107.
 - [25] T. Kase, M. Kawai, and M. Ura., 1986. A New Electrochromic Device for Automotive Glass—The Development of Adjustable Transparency Glass, *Proceedings of the SAE Passenger Car Meeting & Exposition*, The Society of Automotive Engineers, Inc.
 - [26] Personal communication, Steve Selkowitz, Lawrence Berkeley Laboratory, Berkeley, CA, November 7, 1991.
 - [27] G. Sweitzer. 1990. "Adjustable Luminances for VDU Tasks in Office Workplaces" in L. Berlinguet and D. Berthelette, eds., *Work With Display Units 89*, Elsevier Science Publishers, B.V. (North-Holland), pp.81-88.