Keywords: alternative energy, environment, solar lighting, solar tracking, daylight, poultry processing, illumination, colour rendition, microbial control, mold, luminaires, optical guide

A Case for Hybrid Lighting of Poultry Processing Workplaces

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1 Background

Increasing variety, efficiency, shortage of space, process complexity and concern for excluding airborne contaminants in the industrial workspace have contributed towards our ever-growing dependence on artificial lighting. Building designs have become more and more complex so that out-facing windows, clerestories, monitors and skylights are no longer very relevant in workplace illumination – instead they are now increasingly viewed as external architectural aesthetic features.

Concern for energy efficiency, workers' welfare and the environment, cost of artificial lighting, the ever-threatening oil cartel and unsatisfactory colour rendition of luminaires now force us to focus once again towards using sunlight to augment artificial lighting of interiors. Emerging new materials and technologies facilitate this.

Particularly with reference to humid workplaces such as those prevailing in slaughterhouses, solar illumination also once performed a cleansing function. The solar ultraviolet (UV) rays killed bacteria and mold. As workplaces became more organized, tucked away inside industrial buildings in pursuit of hygiene and environmental concern, are we losing these natural advantages?

Above all, did we turn our backs upon daylight itself, once proclaimed the very essence of architectural pursuit?

The history of architecture is the history of the struggle for light. The struggle for windows.
- Le Corbusier

2 Solar Illumination – Is it adequate?

2.1 Every second the sun converts over 657 million tonnes of hydrogen into 653 tonnes of helium. The missing 4 million tonnes of mass is converted and radiated as energy. The earth receives only about one two-billionths of this. Yet it has been estimated that in 15 minutes our sun showers upon the earth as much energy as mankind consumes in all forms during an entire year.

Sounds comforting. But total solar irradiance includes heat and other unwanted forms of energy. Even before examining whether solar munificence upon the rooftop of your processing plant is adequate for your needs, we need to know the latter.

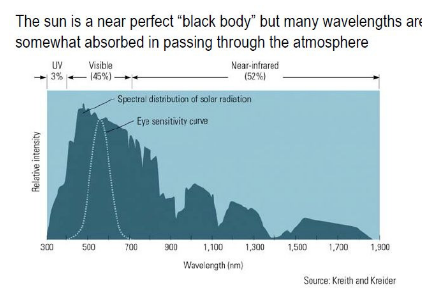

Fig 1 Humans see only a limited portion of the solar spectrum

2.2 **Standards.** USDA standards for illumination[1] in a poultry processing workplace mandate 200 foot-candles with a colour rendition index of 85[2] in places where inspection occurs, and a level ranging from 50 to 30 foot-candles on other work surfaces. General lighting is permitted at 5 foot-candles when measured at a height of 30 inches (762 mm) from the floor.

EU directives[3] recommend illumination intensity of 1000 lux at the point of veterinary inspection, 200 lux in working areas and 110 lux in storage areas.

Exactly what these units connote can be judged from this table which shows comparative illumination intensities observed and experienced by all. The more mathematically minded readers are referred to the general references[4] which contain leads to websites showing how modern units of illumination are inter-related to the archaic FPS measures that the US continues to use.

Table 1

Situation	Illumination (Lux)
Sunlight	100000-130000
Daylight, indirect sunlight	10,000-20000
Cloudy day	1000
Office	200-400
Very dark day	100
Twilight	10
Dark twilight	1
Full moon	.01
Quarter moon	.001
No moon, clear sky	.0001
No moon, clouded	.00001

Source: Wikipedia, as excerpted in Meyn Information Guide

2.3 **Workplace Safety.** In addition to the above, illumination at the workplace should also be considered subject to OSHA (Occupational Safety and Health Administration, US Department of Labor) guidelines which relate to workers comfort, safety and health. Pl see *Suggested Reading,* item 10.

2.4 In order to meet these illumination criteria, we need to consider just how much solar illumination is available for us to plan using it for this purpose when we design a slaughter building.

2.5 **Available Solar Illumination** Michael R. Cates[5], in making a case for the illumination level on a cloudless day in continental United States, with the sun high in the sky, states that the amount of sunlight falling on the surface of the earth is more than 1000 watts per square metre in the visible wavelengths. Taking the lighting (not heating) effect of this light, one square metre of bright sunlight, then, is equivalent to turning on about fifty-five 100-watt light bulbs. Most offices or small rooms can be very well lit by two or three light bulbs; consequently, a square metre of sunlight could theoretically light about 20 rooms or offices. If the roof area of a building is taken to be approximately the floor area of any one of its floors, enough light strikes the roof on a sunny day to light every room in the building even if it's more than a hundred stories high! The problem is collecting the light, then getting it where you want it to go.

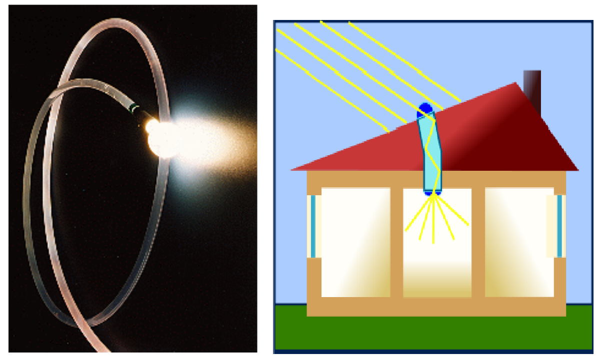

Fig 2. Left - An optical bundle shows a dummy bulb being lit by light travelling from the hidden end, and Right - basic principle of lighting using a sun-tube. **Sources:** Picture on the left is from Hybrid Lighting by Michael R. Crates and right is from Wikipedia.

2.6 Of course, the important difficulties are (a) directing the sunlight into building interiors which are not necessarily adjacent to the ceiling or wall – conventional glazed windows and skylights can provide daylight only some 5 metres into a building- after which it decreases asymptotically with distance from the fenestration and (b) changes drastically as the sun moves relative to the earth.

Mechanical trackers have the ability to collect and direct sunlight even as the sun moves relative to the earth. These are feasible for exotic applications such as solar power generators and solar furnaces, but they are expensive. They form the basis of some of the systems discussed here in paras 3.3, 3.4 and 4.2.

A third difficulty is getting sunlight after the sun has set. You need some form of storage of the sun's energy. HLS systems (para 3.3) use one approach to solve this problem. But this last difficulty, important as it is, does not form the basis of discussion in this paper. Here we are concerned only with the problem of using available sunlight for illumination of building interiors, while the sun shines.

2.7 **Mold Control** is an important role of sunlight in characteristically moist and dark areas such as the interior of poultry processing plants. UV radiation and the heating and drying effects of strong sunlight are both responsible for killing mold. The rather more germicidal UV light is in the wavelength band 200nm to 280nm, also labelled UV-C, and within the C band the most destructive wavelength for microbes lies between 254nm and 265nm.

Table 2. Characteristics of solar ultra violet rays[6]

Ultraviolet radiation from the sun is a component of the electromagnetic (EMR) spectrum. All forms of EMR are classified by wavelength. A common unit of measurement of wavelength for electromagnetic radiation is the nanometre (nm) which is 1,000,000,000th (thousand millionth) of a metre. The UV range is traditionally divided into:

UV-A (320 - 400nm)	- long wave or black light. Causes tanning. Generally not harmful
UV-B (285 - 320 nm)	- middle wave or sunburn radiation - primary wavelength range causing health hazards. Includes 253.7 nM used as germicidal UV
UV-C (200 - 285 nm)	- short wave/germicidal radiation/electric arc welding "Vacuum" UV=100 - 200nm. Generally not harmful

Although molds are everywhere and typically their presence should not elicit a hysterical response, their presence in a processing plant is unacceptable from the hygiene, food safety and health points of view. Mold do not require light for survival and growth and will find enough nutrition on walls, and other surfaces that have the minutest layer of nutrients such as blood and tissue debris, fat, dirt, dust and even soap residue. Almost all typical surfaces of buildings inhabited by humans, including those that are conscientiously scrubbed and cleaned, would qualify as suitable for the growth of moulds.

Molds grow best between 25 and 30°C, and relative humidity above 70%. It should be remembered however that surface humidity is almost always different from ambient humidity. Since the relative humidity of air increases with decreasing temperature, surfaces colder than room air will have higher relative humidity. Additionally, it is also possible for molds to **begin growing** in conditions of high relative humidity and temperature and then **continue growing** in environments with significantly lower relative humidity and temperature. However molds need 1 to 2 days of uninterrupted high humidity conditions to reproduce, so a regimen of drying the workspace after every shift and during weekends constitutes the least cost strategy for abatement of this nuisance.

Research institutions, Oak Ridge National Laboratories included, are working on potential applications for solar UV light, with one of its primary uses as an air purifier, as these wavelengths are able to kill molds and other airborne pathogens. This is a future application, depending on the development of the specific UV-resistant plastic optical fibres able to transmit "deep UV wavelengths" in sufficient strength to have the desired lethal effect on pathogens. At present such fibres are still too expensive for the general market.

Till these problems are cost-effectively overcome, the best defence against mold in such applications, specially in the tropics, is to acknowledge their existence at the time you design a building. Your design should incorporate carefully selected artificial UV light sources and ozonators to be used in conjunction with HVAC to kill mold spores.

Abatement and control of mold in slaughterhouses by means other than UV radiation is the subject of another paper to appear later on this website.

3 Available Technologies

A comprehensive compilation of available technologies with emphasis on suitability according to climate, impact (if any) on external architectural character, commercial availability of the system, quality of illumination and reach in terms of depth into the buildings, is presented in *Daylight in Buildings*[8]. This publication lists 28 technologies, ancient and modern, classified under two main heads. However, this classification, while serving their author's immediate urge to pigeonhole the concepts, is not easy to follow.

A more intuitive approach occurs in an *Energy & Resource Solutions, Inc*[9] publication that lists longitudinal monitors, saw tooth monitors, clerestories, skylights, dedicated visual and daylight glass, reflective light shelves, redirected beam day-lighting and movable baffles and louvers as essentially architectural features designed to these ends. Architects interested in designing efficient slaughterhouses are urged to refer this publication.

For the present exercise, as our process buildings are deep, we discard technologies that only illuminate work spaces adjacent to an external wall. Next, we ignore technologies and methods that relate mainly to ambient lighting and therefore are not relevant in the present context. This leaves virtually only those technologies that I discuss below. They allow work-location-wise lighting, deep within the building, augmented by artificial lighting where necessary, to meet illumination needs specified by international standards.

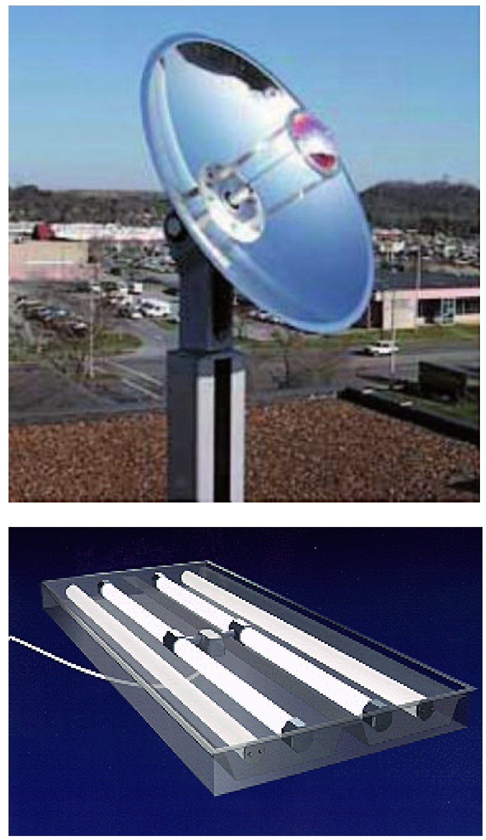

Fig 3. THGS and anatomy of an HSL heliostat system. The top of this figure shows the Sunlight Direct model HSL 3000. This dish is 4 feet in diameter, and lights 1000 square feet inside the building, minus the UV rays. Expected lifetime: 20 years. The bottom picture shows a hybrid lighting fixture. Sunlight is routed through an optical fibre to two central "dummy" tube-lights which radiate the captured sunlight. The other two are genuine 40-watt tubes whose illumination level is controlled by varying their current and voltage to produce a total illumination level satisfactory to sensors mounted in the room[7].

3.1 **Tubular Daylight Guidance Systems (TDGS)** are suitable for guiding sunlight from rooftop or window/skylight into the interior using a tubular sun-pipe. These are usually good for areas that cannot be directly illuminated by conventional glazing. Collection of sunlight is done by an active or passive daylight collector mounted on the roof.

Figure 3 (top) is an example of such a system using a double mirror sun-tracking collecting system. Because it concentrates sunlight, the most efficient mode of transmitting it in this case is a non-imaging optical bundle comprising cheap plastic optical fibres. Such fibre bundles are approximately the size and weight of the electric wiring now common to modern buildings and can be bent. A liquid sun-pipe may also be used. **Figure 2** shows a gel-filled fibre with a frosted glass bulb attached to the end. The bulb glows not from any electrical power supplied to it, but from the sunlight piped through the fibre. TDGS are effective under both clear and overcast skies..

For the **heliostat type of piped lighting** the following efficiency data attributed to *Advanced Environmental Concepts Pty Ltd*[10] is relevant:

- 70,000 Lux from sun
- 80% efficiency of heliostat
- 80% efficiency within sun-pipe or optical bundle
- 90% efficiency in diffusing and distributing the light within the space.

3.2 Another variation is the **Passive Zenithal TDGS**, an example of which is shown alongside. It is *passive* because there is no tracking device. *Zenithal* because it collects primarily from the center of the sky, although the domed collector may be tilted by latitude to correspond to the displaced zenith. The collecting surface consists of a UV protected polycarbonate dome. The UV protection ensures that there is no long-term degradation of the dome through the action of solar UV rays. The polycarbonate dome allows excellent transmission from above and sides. In addition it collimates more light within the *acceptance cone* [11] so that the rays experience total internal reflection inside the tube and are thus propagated along its axis. The dome is followed by a condensation trap and an ABS flashing to protect the exposed sun-pipe as it passes through the roof. The pipe is 600 mm in diameter and straight lengths connect with elbows of 45 degrees. There is much leeway about the number of pipes and elbows that may be installed. Finally the sun-pipe enters the false ceiling (drop ceiling) to illuminate the workspace in terminations of polycarbonate diffusers. The sun-pipe is sealed to inhibit entry of moisture and loss or gain of heat. Elbows interrupt convective flows that could contribute to transfer of solar heat into the building interior.

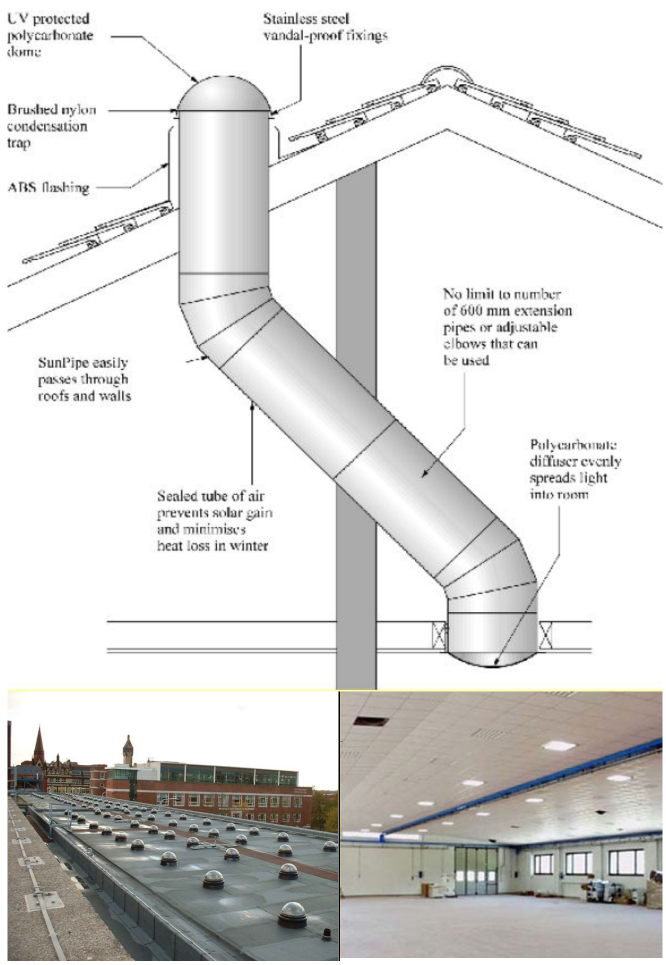

Fig 4 Passive Zenithal Tubular Daylight Guidance System (PZTDGS)

3.3 **HLS** or **Hybrid Solar Lighting System** was developed by the US Govt Oak Ridge Laboratory for areas where direct solar radiation is greater than 4kWh/m^2/day and cooling is a major design concern. One such method, described by Jeff D Muhs[12] of the same laboratory, is to collect rooftop sunlight, split it into visible and invisible components, directing the former by sun-pipes into the building and use the latter to generate electricity with the help of photovoltaic cells. The referenced article presents AD 2000 costs in USD.

In the HLS system, the collector is a primary 1.22 m diameter parabolic acrylic sun-tracking mirror with an elliptical secondary mirror which separates the visible infrared portions of sunlight and focuses visible sunlight into bundles of 127 nos of 3 mm diameter optical fibres which deliver the sunlight to the end of a side-emitting acrylic rod located inside a conventional electric luminaire fitted with dimmable fluorescent booster lamps. A control system tracks the sun and light sensors monitor daylight levels. The luminaire delivers uniform illumination with the help of booster lamps at pre-determined levels. It is claimed that one collector can power 8-12 fluorescent or 30-40 reflector luminaires, thus lighting an area of approximately 100 SqM. An HLS collector is illustrated in Figure 3.

3.4 **The Heliobus** is a new system that integrates most of the above technologies combining it with a strikingly unusual large collector. It was developed in Switzerland. The heliobus system comprises a heliostat, an optical bundle and a diffusing element and has been used for lighting at the Potsdammerplatz in Germany besides other buildings in Europe.

4 Components

Non-imaging optics, into which class most of the hybrid lighting components fall, do two things better than their more expensive cousins, imaging optics – illumination and concentration. Examples of non-imaging optical devices include optical sun-pipes, non-imaging reflectors, non-imaging lenses or a combination of these devices. Optical bundles are typically classified under imaging optics.

4.1 **Construction of the sun-pipe** follows one of two methods. It could be built with light reflective material such as silvered film or multilayered film affording total internal reflection or be made of prismatic cross section. The **prismatic section film** has been invented by the 3M Corporation. Of course if you use any form of tracking your overall energy density is very high and you will generally use glass or plastic fibre or liquid filled bundles such as that shown in Fig 2. Such bundles can be routed much like electrical cables.

The collective name for all such devices used to take sunlight into the interior of buildings is **fibre optics**. The familiar face of fibre optics is the **optical cable** used in data transmission. It consists of a bundle of fine glass fibres, thin enough to resist fracturing when bent. Each fibre has a surface that causes total internal reflection so that the signal consisting of modulated light travels extremely long distances with very little attenuation. Optical fibres or optical bundles are made of pure silica and are consequently very expensive. The higher end of optical fibre systems are used for endoscopy, for viewing difficult-to-reach interiors such as the inside of a turbine, delivering intense light into closed spaces for specific purposes such as curing light-cured epoxy resin, cold illumination of microscope stages, and viewing internal organs of human patients.

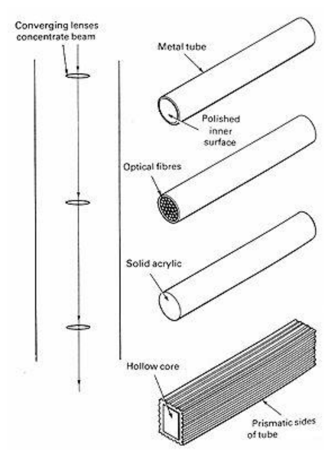

Fig 5 Various types of sun-pipes. On the left is a lens guide. On the right, from top down: a reflective metal tube, a fibre optic bundle, an acrylic rod, and a prism sun-pipe which sends light axially[13].

TIR Systems Ltd[14] developed the original commercial **light pipe or sun pipe**. It directs the point light from a luminaire through hollow light pipe having total internal reflection, to illuminate an area approximately 15 metres removed from the source. The pipe is made of extruded methyl methacrylate, a version of plexiglass or acrylic.

According to Advanced Environmental Concepts Pty Ltd, research shows that a liquid sun-pipe of 4 cm diameter with a 1m diameter **Frensel lens** collecting device has the ability to transmit enough light to provide lighting to a large conference room at an illumination level of 250Lux. In making this assertion they assume that this research was conducted for an installation not more than 10m from the light source, however, they state that the system has been tested for installations up to 60m from the solar collection source. Fresnel lenses are cast acrylic plates with virtually no thickness but significant collimating power.

The optical bundle described under ***HSL*** (Para 3.3) is much thinner than the sun-pipe and can be installed much like an electrical conduit.

4.2 **Collector.** The **Himawari collector**, a Japanese invention, is a dynamic collimating device that follows the sun and for this reason it is very expensive, although it is also efficient. See item 10 under *Commercial Sources*. Less expensive is the **double prism collector** which contains two cast acrylic discs which contain an array of prismatic surfaces which are rotated by a geared motor to deflect the sunlight along the sun-pipe. The sun tracking collector in Fig 3 (THGS) employs such a collector. Next in price and efficiency are the **fixed non-tracking redirecting devices** which have lower year-round performances. They work by selectively redirecting daylight from the regions of the sky where the sun is most likely to be. A simple example is a mirror located to the south of the sun-pipe aperture to reflect light from the north sky. Finally the **static collector** is the least expensive and has applications where the light is to be conducted only short distances from the roof. The PZTDGS shown in Fig 4 employs such collectors.

5 Heat Load, Obstructions and Objections

What about the heat in sunlight? Unlike conventional electric lamps, natural light produces little or no waste heat, having an efficiency of 200 lumens per watt, and is cool to the touch. (Compare this with the most efficient electric lights available - linear fluorescent lamps 65-90 lm/W- not counting the ballast load, and the worst, incandescent lamps at 15 lm/W). This is because the system's solar collector removes the infrared (IR) light from the sunlight – that part of the spectrum that generates much of the heat in conventional light bulbs.

What about space? Large portions of valuable plenum space – the area between the roof and drop ceiling – find little practical use, so there is little competition with other building services such as HVAC ducts, utility and firefighting pipelines and electrical conduits. In such constructions space does not appear to be the limiting factor.

And leaks? Roof penetrations are typically small and minimal, reducing the potential for leaks.

Buildings employing solar lighting are eligible for approval by many organisations worldwide. Among agencies that do lay down specifications and provide certifications are Australia's Green Star and NABERS energy rating for buildings, the British-based BREEAM and EU Energy Performance in Buildings Directive, the United States LEED rating for major renovations and the ongoing evolution of Green Buildings. Such buildings are also eligible for tax breaks in many countries.

ORNL 99-1593 EFG

Region	Building Use Scenario	¢/kWh Displaced		Years to Payback at 12.5¢/kWh	
		Current	Projected	Current	Projected
Sunbelt (9 kWh/m^2/day)	Everyday	4.5	1.9	4.9	2.0
	300 days	5.5	2.3	6.0	2.5
	250 days	6.6	2.8	7.2	3.0
Average Location (7 kWh/m^2/day)	Everyday	5.8	2.4	6.3	2.6
	300 days	7.0	2.9	7.6	3.2
	250 days	8.5	3.5	9.2	3.8
Suboptimal Location (5.5 kWh/m^2/day)	Everyday	7.4	3.1	8.0	3.3
	300 days	9.0	3.8	9.7	4.0
	250 days	10.9	4.5	11.7	4.9

Table 3. Oak Ridge National Laboratory assessment of payback periods for hybrid lighting systems[15]

I have no information about Indian laws in this context, but reference 3 under *Suggested Readings Cybertreks and design/simulation software* should direct you to the right government window

6 Economics

Mohammed Mayhoub et al[16] of the University of Liverpool have classified these systems into two main commercially successful guidance types viz the tubular daylight guidance systems (TDGS) and the newer hybrid daylight/electric systems (HLS). They compare their whole life cycle costing (WLCC) against the conventional electric lighting system (ELS) in their paper *Hybrid Lighting Systems: Costs and Benefits.*

This work is based on the lighting of a windowless modular space of 6m x 12m x 3m high, with the short edge facing south, using each system in turn. Their work was carried out in London (51^{o}N,0^{o}E), Moscow 56^{o}N, 38^{o}E), Valencia (39^{o}N,0^{o}E) and Athens (38^{o}N,24^{o}E).

Because hybrid lighting systems are customized, it is difficult to find firm price data in the literature. You either use the methods under the above reference, or call one of the sources listed under *Section 6* and obtain an estimate. More important is the pace at which prices are crashing. One cannot help noticing that this technology is definitely here to stay. Perhaps the most convenient and cost effective time to consider this option is now, while your building is still under planning.

7 Commercial Sources

I have browsed the websites of major lighting system companies such as Philips (Dynalite division), Siemens-Osram and GE and found that while they do produce some components suited for hybrid lighting of workplaces, they are not primarily engaged in delivering operating systems. Why is this so? Perhaps because the organisational synergies of such large corporations prevent them from offering highly customized services that hybrid lighting installations require, in much as the same way that leading refrigeration compressor and evaporator manufacturers are generally not involved in complete system delivery.

There are a number of companies in the highly specialized high tech application areas of light guides. Some of these are listed below.

1 **Bomin Solar GmbH** • Industriestr. 8-10 • D-79541 Loerrach Germany. www.Bomin-Solar.de Tel.: +49 (0) 7621-95960 • Fax: +49 (0) 7621 - 543 68 • Email: Info@Bomin-Solar.de . Heliostats, acrylic sun-pipes, control units, mirrors, chandeliers.

2 **Himawari Lighting System - La Forêt Engineering Co. Ltd (Mori Building Group)** Roppongi Annex 7F, 6-7-6 Roppongi, Minato-ku, Tokyo 106-0032 Japan• Tel +81-3-6406-6720, Fax +81-3-6406-6723 www.himawari-net.co.jp/• Lens focusing, automatic tracking and optical fibre transmission devices.

3 **Jain Jyot** http://www.jains.com/Solar/ • Appears to concentrate on wind and solar panel based lighting systems, not hybrid lighting

4 **Lumatec** Liquid Lightguides• Lumatec GMBH, Linienstr. 9-13, 82041 Deisenhofen, Germany• Tel +49-89-7 42 82 20, Fax +49-89-74-28-22-64• www.lumatec.de, sales@lumatec.de • Primarily in higher end applications of liquid light pipes.

5 **Passivent Limited** - Natural Daylight Solutions• North Frith Oasts, Ashes Lane, Hadlow, Kent TN11 9QU • Tel: 01732 850770 Fax: 01732 850949• info@passivent.com • Web: www.passivent.com • Components and system for hybrid lighting

6 **Philips Dynalite North Asia office** Shanghai Rep office Apollo Business Centre Room 419 Shanghai Apollo Building 1440 Yan An Road (C) Shanghai, PR China. t +86 21 6103 1637, f +86 21 6103 1637 info@dynalite.cn, www.dynalite.cn . Components for hybrid and efficient lighting

Philips Dynalite Middle East office Dubai UAE Dynalite (Dafza BR) Office 145 Building 5WB Dubai Airport Free Zone PO Box 54802 DUBAI UAE• t +971 4 214 6130 f +971 4 214 6135 • info@dynalite-online.com• www.dynalite-online.com • Components for hybrid and efficient lighting

7 Integrated Skylight Luminaire by **Rensselaer Polytechnic Institute**, NY, USA• Designed to provide general lighting for high ceiling buildings such as factories etc replacing traditional high-intensity discharge lighting systems.

8 **Sepstar**• Hybrid Lighting System uses a different technique• The Sepstar Solar-Wind LED lighting system consist of 2 Solar panels, a LED light and mounting frame, light pole, controller, rechargeable lead acid battery, AC/DC power• Sepstar's product can be seen at http://www.sepstar.com/sepstar-hybrid.html.

9 **Solatube International, Inc.**2210 Oak Ridge Way, Vista, CA 92081-8341• http://solatube.com/ • collectors, metal tube flashing for leakproofing, roof dome assembly, Spectralight® Infinity Extension Tubes , tubular diffuser, lenses, ventilation add-ons, controls etc.

10 **Sunlight Direct LLC** California, can be visited at http://www.sunlight-direct.com/ • They developed the HSL 3000, a picture of which occurs in Fig 3a. The company may offers several versions, including a hybrid with fluorescent bulbs, adjusting the fluorescent depending on the amount of sunlight available. Others may be a stripped-down sunlight-only model.

11 **Superlite Lighting Co Pvt Ltd,** 33, Guru Gobindsingh Estate, Jay Coach, Goregaon (E), Mumbai 400 063, India• http://www.superliteindia.com/index.htm • info@superliteindia.com• Tel +912226852822, Telefax +912226853027• PZTDGS, components for hybrid and efficient lighting

12 **Xtralite Rooflights**, Spencer Road, Blyth Riverside Business Park, Blyth, Northumberland NE24 5TG, UK• http://www.xtralite.co.uk/index.asp • sales@xtralite.co.uk • Tel +44 (0) 1670 354157, Fax:+44 (0) 1670 364875• Rooflights

Suggested Reading, Cyber-treks and Design/Simulation Software:

1 **Cornell University Ergonomics Web**• DEA350: Ambient Environment: Illumination and Work • http://ergo.human.cornell.edu/default.asp

2 **DMX Lighting Software** • http://www.DmxSoft.com/

3 **Energy Efficiency in Buildings** by R. V. Shahi, Secy, Govt of India, Ministry of Power. Keynote Address for India - International Energy Agency (IEA) Joint Workshop on "Energy Efficiency in Buildings and Building Codes" held on 4-5 October, 2006 at New Delhi, India

4 **GI-32** is a popular lighting designer's tool published by Lighting Analysts Inc and includes daylight modeling • http://www.agi32.com/

5 **Hybrid Daylight and Electric Lighting Systems**. David Carter, The University of Liverpool CIBSE Merseyside and North Wales Region and Society of Light and Lighting, March 2009.

6 **IESNA Handbook**, published by The IES -- Illuminating Engineering Society of North America IESNA, 120 Wall Street, 17th Floor New York, NY 10005-4001 • Phone: (212) 248-5000 Fax: (212) 248-5017 • E-mail: iesna@iesna.org • Web Site: http://www.iesna.org/ • Also Efficient Dual-function Solar/electric Light Guide to Enable Cost-effective Core Daylighting by Alexander Roseman et al.

7 **Lighting Fundamentals**, lighting upgrade manual • US EPA Office of Air and Radiation 6202J, EPA 430-B-95-003, January 1995

8 **Lighting Research Centre**. • http://www.lrc.rpi.edu/

9 **Lightscape**, published by Autodesk®, is useful for the rendering of daylighting designs. VIZ 4 software incorporates Lightscape and offers advanced modeling, rendering, and animation • http://usa.autodesk.com/adsk/servlet/item?linkID=10274604&id=6547440&siteID=123112

10 **OSHA** • http://regulation.healthandsafetycentre.org/s/GuidelinePart4.asp#SectionNumber:G4.65 • Illumination Levels, G4.66 Means of Illumination, G4.67 Brightness, Reflectance and Glare, G4.68 Illumination Measurement, G4.69 Emergency Lighting

11 **Radiance** is a suite of programs for the analysis and visualization of lighting in design. The system was developed with primary support from the U.S. Department Of Energy and additional support from the Swiss Federal Government. It is copyrighted by the Regents of the University of California. Versions for UNIX and Windows based computers (Desktop Radiance) are available. Radiance is useful for the prediction of illumination, visual quality and appearance of spaces, and to evaluate artificial and daylighting designs. • http://eetd.lbl.gov/eetd.html

12 **Skylighting and Retail Sales** An Investigation into the Relationship Between Daylighting and Human Performance Condensed Report August 20, 1999. Submitted to: George Loisos Pacific Gas and Electric Company on behalf of the California Board for Energy Efficiency Third Party Program Submitted by: Heschong Mahone Group 11626 Fair Oaks Blvd. #302 Fair Oaks, CA 95628 • Skycalc™ is a software tool designed by the Heschong Mahone Group that assists designers in developing a daylighting strategy using skylights. The program takes into account building type and use, region of the country, seasonal weather, etc. to calculate light patterns and building energy savings in terms of reduced lighting and HVAC costs. SkyCalc and accompanying guidelines are available for free on the web at http://www.designlights.org.

13 **Superlite Lighting Software**, US Department of Energy, Environmental Energy Technologies Division, Building Technologies Program, 1 Cyclotron Road MS 90R3111E.O. Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720 • http://eetd.lbl.gov/eetd.html

14 **The Lighting Library**. • http://www.mts.net/~william5/index.htm

REFERENCES

[1] **USDA** Standards for lighting for poultry processing 9 CFR Ch. III (1–1–00 Edition) PART 381—POULTRY PRODUCTS INSPECTION REGULATIONS, Subpart H—Sanitation, Para 381.52 Lighting and ventilation - states that where inspection of the bird or carcass occurs, the illumination level shall be a minimum of 200-footcandles of shadow-free lighting with a minimum color rendering index value of 85 where the poultry are inspected, to facilitate inspection. In other places in which poultry is killed, eviscerated, or otherwise processed shall have at least 30 foot-candles of light intensity on all work surfaces, except that at the inspection stations such light intensity shall be of 50 foot-candles. In all other rooms there shall be provided at least 5 foot–candles of light intensity when measured at a distance of 30 inches from the floor. The document further clarifies that the conditions of 200 foot-candles and 85 CRI may be met by deluxe cool white type of fluorescent lighting

[2] **The color rendering index** (CRI) (sometimes called color rendition index), is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light • en.wikipedia.org/wiki/Color_rendition

How colors appear when illuminated by a light source. Color rendition is generally considered to be a more important lighting quality than color temperature. Most objects are not a single color, but a combination of many colors • www.clallampud.org/conservation/res_CFL_Fixtures_Terms.asp

Lighting Fundamentals, lighting upgrade manual, US EPA Office of Air and Radiation 6202J, EPA 430-B-95-003, January 1995
The CRI is a relative scale (ranging from 0 - 100). indicating how perceived colors match actual colors. It measures the degree that perceived colors of objects, illuminated by a given light source, conform to the colors of those same objects when they are lighted by a reference standard light source. The higher the color rendering index, the less color shift or distortion occurs.

The CRI number does not indicate which colors will shift or by how much; it is rather an indication of the average shift of eight standard colors. Two different light sources may have identical CRI values, but colors may appear quite different under these two sources.

[3] **Council Directive 71/118/EEC**, covering building and equipment requirements for high capacity poultry processing plants, as reproduced in Meyn Information Guide

[4] **Relationship between the units**. Foot-candles and Lux. http://www.mts.net/~william5/library/illum.htm, http://www.theledlight.com/index.html

[5] **Hybrid Lighting: Illuminating Our Future** By Michael R. Cates who is a physicist at ORNL's Engineering Technology Division • http://www.ornl.gov/info/ornlreview/rev29_3/text/contents.htm

[6] **OHS Reps**, Govt of Australia • http://www.ohsrep.org.au/index.cfm and http://www.peakpureair.com/

[7] **Hybrid Lighting**. (ibid)

[8] **Daylight in Buildings**. ISBN 978-0-9562808-2-4, ECBCS Annex 29/Task 21 Project Summary Report edited by Kjeld Johnsen and Richard Watkins. Published by AECOM Ltd, AECOM House, 63-77 Victoria Street, St Albans, Hertfordshire AL1 3ER, UK, on behalf of the International Energy Agency • www.ecbcs.org • essu@ecbcs.org

[9] **Energy & Resource Solutions**, Inc, **Daylighting Application and Effectiveness in Industrial Facilities**, Brian McCowan Daniel Birleanu, Vice President • bmccowan@ers-inc.com Project Engineer dbirleanu@ers-inc.com • Energy & Resource Solutions, Inc. Haverhill, MA

[10] Ibid

[11] The acceptance cone is defined as the critical angle for the material which makes up the light-pipe. If the angle is larger, light will simply pass out of the walls of the pipe. If it is within the critical angle, it will propagate along its axis. For a graphic presentation see **Solar Lighting of Building Interiors**, Matthew Lam and Matthew von Schilling, The University of British Columbia

[12] **Hybrid Solar Lighting Doubles the Efficiency and Affordability of Solar Energy in Commercial Buildings**. Jeff D Muhs of the Oak Ridge National Laboratory. 2360 Cherahala Blvd. Knoxville, TN 37932 United States • Tel.: +1-865-5749328 Fax: +1-865-5760279• muhsjd@ornl.gov

[13] **Natural Lighting Opportunities** Prepared by: Advanced Environmental Concepts Pty Ltd ACN 075 117 243 Level 1, 41 McLaren Street North Sydney NSW 2060, June 03. for the Melbourne City Council Office. AESY820000\0\2\MMC30108\

[14] TIR Systems – (a 1980) from **A History of Illumination**
The commercial light pipe is a Canadian Invention, developed by TIR Systems Ltd, (Burnaby, BC). Single point source luminaires direct light into hollow linear light guides to produce, through the principle of Total Internal Reflection, lines of brilliant light. Light pipes are made of extruded, impact resistant, clear acrylic, and use a 250 watt metal halide lamp, with a life of approximately 10,000 hours. One luminaire is required for every 44 foot run of light pipe.

[15] **A Place in the Sun**. Hybrid Solar Lighting and Full Spectrum Solar Energy Systems. PPT by Jeff Muhs, Oak Ridge National Laboratory. US Department of Energy Buildings Program

[16] **Hybrid Lighting Systems: Cost and Benefits**, Mohammed Mayhoub, University of Liverpool, School of Architecture, Liverpool, UK; On leave from Al-Azhar University, Cairo, Egypt• msm@liv.ac.uk and David Carter University of Liverpool, School of Architecture, Liverpool, UK • eb09@liv.ac.uk