SINTEF REPORT

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TITLE

Lighting Systems in Smart Energy Efficient Buildings. A State-of-the-art.

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ABSTRACT

This report marks the start of subtask 2.3 “Lighting Systems” within the project “Smart Energy Efficient Buildings”. The aim of the SmartBuild project is to develop new knowledge, integrated systems and technologies which will make it possible to cover our building-related energy needs with substantially less harmful environmental emissions, while still satisfying the whole range of end-user needs such as comfort, aesthetics, costs, operability, reliability and functionality. To accomplish this, a 5-year multi-disciplinary project was initiated in 2002, combining the knowledge of a wide range of experts in the field of energy use in buildings at NTNU and SINTEF, as well as the expertise of related Norwegian industry.

The aim of this report is to form the basis for future work within the SmartBuild project, and to provide information that may be used by the other project participants in order to survey possibilities for effective integration of our different fields of expertise.

The rapport concludes, that within the SmartBuild Project it is of special interest to focus on:

1. THE HYBRID LIGHTING SYSTEM.
   The concept of integration of daylighting- and electrical lighting systems should be enlarged to comprise shading system, possibly also PV. Such a hybrid system should be optimized for both, user comfort and energy saving.
2. THE CONTROL SYSTEM
   All elements of such a hybrid lighting system should be controlled by one intelligent building-control system that could also control the heating (cooling) and ventilation in the building. The central control system should secure a comfortable indoor environment and should contribute to considerable energy savings.
3. INTEGRATION OF BIPV IN SHADING-DAYLIGHTING SYSTEM
   The integration of PV in a dynamic shading-daylighting system, especially for high latitudes.

KEYWORDS	ENGLISH	NORWEGIAN
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SELECTED BY AUTHOR	Daylight	Dagslys

Lighting Systems
in
Smart Energy-Efficient Buildings
A State-of-the-Art

A report within the research program
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1. Introduction

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   The integration of PV in a dynamic shading-daylighting system, especially for high latitudes.

2. Central Concepts

Conventional daylighting design components, i.e. fenestration systems, can normally provide adequate daylighting in the perimeter of buildings, i.e. within 4,0 m of windows or skylights. To provide daylight in a larger fraction of the building area requires one of two approaches.
The first option is to increase the fraction of the floor area that is adjacent to fenestration using architectural design strategies to alter floor plans from rectangular to reentrant forms, or by use of atria, or by stepping back upper stories of the building, etc.
The second option is to use daylighting optical systems to deliver light to building locations beyond the perimeter zone. The light transmission can be desired either horizontally or vertically through the core of a building. The daylighting techniques are often based on the use of special reflectors, louvers, baffles, reflective blinds, light deflecting materials, light shelves, etc.

Many of the optical daylighting systems require three major elements.

- First, a collection system is required to gather and redirect the available light flux, in some cases to concentrate it.
- Second, the light flux must be transmitted through a transmission system to the point of use in a building.
- Third, the light flux must be distributed in a way consistent with the end use of the lighting. In many systems several of these functions may be combined.

Through the combination and integration of one or more daylighting systems the amount of light in under-lit spaces can be considerably increased. Design of such optical systems should be optimized for the climate.
Since daylighting consists of two very different components, the diffuse skylight and the direct light from the sun that often has to be rejected, the systems can be divided in two main groups:

- <u>Daylighting systems with shading</u>
    - Systems which rely primarily on diffuse skylight and reject sunlight,
    - Systems that primarily use direct sunlight, sending it onto the ceiling or to locations above eye height

- <u>Daylighting systems without shading included</u>
    - Diffuse light-guiding systems
    - Direct light-guiding systems
    - Light-scattering or diffusing systems
    - Light transport systems

The matrix collected from Kischkoweit-Lopin (pages 6-10) gives a clear overview of advanced daylighting systems now available for the building profession.

Daylighting alone, even if distributed with the help of daylighting systems, cannot secure adequate lighting conditions for all working hours during a year and for all visual tasks. It is due partly to the limited availability of daylight during the year, partly because it is difficult to redirect diffuse daylight precisely to the desired place. Artificial lighting is much more flexible; it should supplement daylight in the periods of time when daylight level is too low or in places where a specific distribution of light is desired.

Many new fluorescent light sources developed in recent years both have a high efficiency lm/watt and a high color rendering, making them attractive supplements of daylight. They have a longer livespan than their predecessors. The electronic joints reduce the danger for flicker.

The most promising new technologies in lighting are Lighting Emitting Diodes (LEDs) and Organic Lighting Emitting Diodes (OLEDs) [Jonson]. The form of OLED sources can be quite different from current sources, allowing exciting new design uses for the products. Being diffuse sources, OLEDs are much lower in intensity per unit area than LEDs. The manufacturing process for OLEDs lends itself to shapes that can be formed to different geometries, making luminous panels or flexible luminous materials possible. Conversely, LEDs are very intense point sources which can be integrated into small spaces to create an intense source or used separately for less focused applications. High efficiency (lm/watt) is one of the most important attributes motivating scientists to work with LEDs. Another is that they produce electromagnetic radiation only in the visible part of the spectrum; i.e. they do not produce heat. Both OLED and LED sources are expected to be thinner than other comparable sources; this thinness offers additional design opportunities.

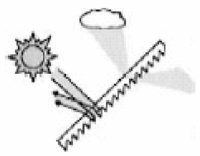
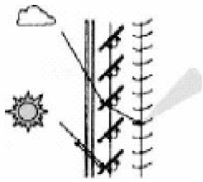
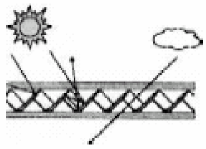
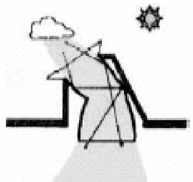
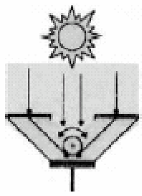
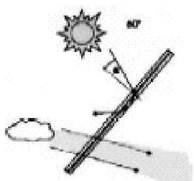
Many different control systems were developed to manage the artificial lighting systems depending on the daylighting level and the presence of occupants at working places. Most systems are optimized for energy saving. Two main concepts are actually used.

The on/off switching system switches artificial light on if the daylight level at the working place is lower than the level desired for visual task typical for the working place; it switches electrical light off if the daylighting level is high enough. The system may cause frequent on/off switching in periods when daylight level at working place varies and is close to the recommended value. To avoid this the system is designed with margins allowing daylight to increase or decrease more than the accurate value before the system reacts. There are many variants of switching systems, some of them switch light stepwise reducing the jump between each change in lighting intensity.

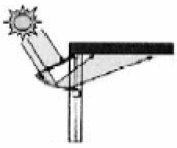
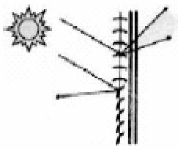
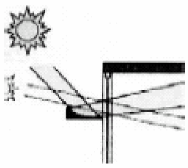
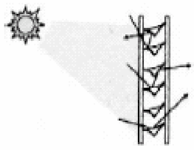
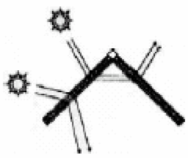
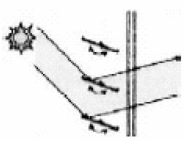
The dimming system concept relies on dimming of light flux from luminaries to the level that together with daylighting gives desired illuminance at the working place. Such systems utilize daylight to the higher degree than the switch on/off systems. The dimming systems are also more expensive, but they assure more stable visual conditions. It is not obvious that a constant light level at the working place during the day is desired by occupants.

Both systems can be supplied with switching on/off function reacting to presence/absence of occupants.

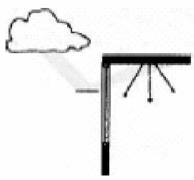
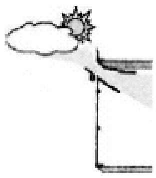
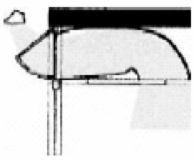
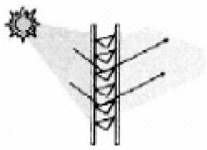
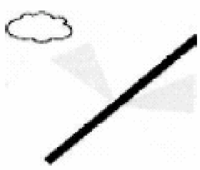
2.1 Shading systems which block direct sunlight but being transparent for diffuse skylight

System		Climate	Attachment	Criteria for the choice of elements
Prismatic panels		All climates	Vertical windows, skylights	– Glare protection (D) – View outside (D) – Saving potential (artificial lighting) – Need for tracking (D) – Available
Prisms and venetian blinds		Temperate climates	Vertical windows	– Glare protection – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Sun protecting mirror elements		Temperate climates	Skylights, glazed roofs	– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Anidolic zenithal opening		Temperate climates	Skylights	– Glare protection – Homogeneous illumination – Saving potential (artificial lighting) – Testing
Directional selective shading system with concentrating HOE		All climates	Vertical windows, skylights, glazed roofs	– Glare protection (D) – View outside – Saving potential (artificial lighting) – Need for tracking – Available
Transparent shading system with HOE based on total reflection (→ 4.2.3)		Temperate climates	Vertical windows, skylights, glazed roofs	– Glare protection (D) – View outside – Homogeneous illumi nation – Saving potential (artificial lighting) – Need for tracking – Available

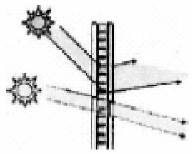
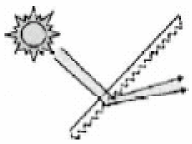
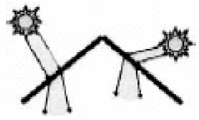
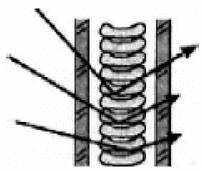
2.2 Shading systems which diffuse sunlight or redirect sunlight onto the ceiling or above the eye height.

System	Climate	Attachment	Criteria for the choice of elements
Light guiding shade 	Hot climates, sunny skies	Vertical windows above eyeheight	– Glare protection – View outside – Lightguiding into the depth of the room (D) – Homogeneous illumination (D) – Saving potential (artificial lighting) (D) – Available
Louvers and blinds 	All climates	Vertical windows	– Glare protection – Lightguiding into the depth of the room – Homogeneous illumination – Need for tracking – Available
Lightshelf for redirection of sunlight 	All climates	Vertical windows	– View outside (D) – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Glazing with reflecting profiles (Okasolar) 	Temperate climates	Vertical windows, skylights	– View outside (D) – Glare protection (D) – Lightguiding into the depth of the room (D) – Homogeneous illumination (D) – Variable solar heat gain coefficient – Available
Skylight with Laser Cut Panels 	Hot climates, sunny skies, low latitudes	Skylights	– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Turnable lamellas 	Temperate climates	Vertical windows, skylights	– Glare protection (D) – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Need for tracking – Available

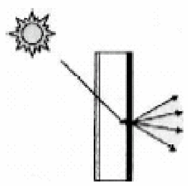
2.3 Diffuse light guiding systems

System	Climate	Attachment	Criteria for the choice of elements
Lightshelf 	Temperate climates, cloudy skies	Vertical windows	– View outside – Lightguiding into the depth of the room (D) – Homogeneous illumination (D) – Saving potential (artificial lighting) (D) – Available
Anidolic Integrated System 	Temperate climates	Vertical windows	– View outside – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Anidolic ceiling 	Temperate climates, cloudy skies	Vertical facade above viewing window	– View outside – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Testing
Fish System 	Temperate climates	Vertical windows	– Glare protection – View outside – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Zenith light guiding elements with Holographic Optical Elements 	Temperate climates, cloudy skies	Vertical windows (especially in court-yards), sky-lights	– View outside – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available

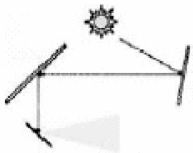
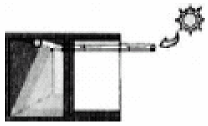
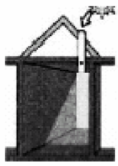
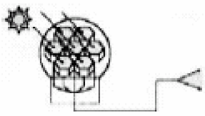
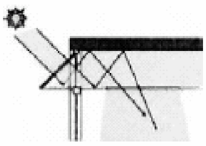
2.4 Direct light guiding systems

System	Climate	Attachment	Criteria for the choice of elements
Laser Cut Panel (LCP) 	All climates	Vertical windows, skylights	– View outside (D) – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Prismatic panels 	All climates	Vertical windows, skylights	– View outside (D) – Lightguiding into the depth of the room – Saving potential (artificial lighting) – Available
Holographic Optical Elements in the skylight 	All climates	Skylights	– View outside – Homogeneous illumination – (artificial lighting) (artificial lighting) – Available
Light guiding glass 	All climates	Vertical windows, skylights	– Glare protection – View outside – Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available

2.5 Scattering systems

System	Climate	Attachment	Criteria for the choice of elements
Scattering systems (light diffusing glass, capillary glass, frosted glass) 	All climates	Vertical windows, skylights	– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available

2.6 Light transport

System		Climate	Attachment	Criteria for the choice of elements
Heliostat		All climates, sunny skies		– Lightguiding into the depth of the room – Saving potential (artificial lighting) – Need for tracking – Available
Light-Pipe		All climates, sunny skies		– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Available
Solar-Tube		All climates, sunny skies	Roof	– Lightguiding into the depth of the room – Saving potential (artificial lighting) – Available
Fibres		All climates, sunny skies		– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Need for tracking – Available
Light guiding ceiling		Temperate climates, sunny skies		– Lightguiding into the depth of the room – Homogeneous illumination – Saving potential (artificial lighting) – Research and development

3. Technology & Market

The systems presented on pages 6-10 represent a large range of advanced daylighting systems now available to the building profession. Some of these systems are in the development or prototype stages and some systems are architectural concepts rather than products.
Daylighting systems are generally seldom used in real buildings. There are many reasons for this:

- The high price of materials used in the systems, e.g. laser cut panels, prismatic panels, specular reflectors having very high reflectance, etc.
- Necessity for supplement with electrical lighting system. The daylight system alone cannot meet the lighting demand during all operation hours, it has to be supplemented with artificial light system, but the construction cost of artificial lighting system is much higher than the energy saving for lighting due to usage of daylight during many years.
- Lack of standard designs and products/systems optimized for specific latitudes and climates on the marked
- Lack of integration between daylight- and artificial light systems
- Lack of scientifically documented results confirming the positive impact of daylight on productivity
- Lack of information for building developers and investors about the importance of daylight for health, and well-being.

The usage of daylighting systems in buildings should be justified by increased daylight level in under-lit areas, better visual environment and health and well-being of occupants. The energy saving for lighting is not strong enough argument for most of private investors.

The integration of lighting and daylighting systems in one system operated by lighting control system could reduce the construction and operation costs. Anyway, attempts have only been made in a few cases to integrate daylighting and artificial lighting into a single system or a single fixture. The reasons are:

1. Lack of expected economical profit. The development in the field of artificial lighting sources have resulted in many new energy effective products. The profit from energy savings for lighting can not justify the construction costs connected to the daylighting system, especially in Norway as long as electricity prices are low.
2. Lack of cooperation. Daylighting system is a part of façade design and could be designed by architects; artificial light is a part of electrical installation designed by electrical engineers. The integration needs a close cooperation between those two parts during the whole building design process. It seldom occurs.
3. Lack of manufacturers willing to develop combined daylight/artificial light system and put it on the marked. Designers/producers of daylighting systems work hard to sell daylighting systems; most of them have no economical potential needed for development of complex systems. Producers of luminaries are mostly interested in production of luminaries alone; they are not willing to develop products that involve façade design.

The timeliness of the idea of integration of daylight and artificial light can be illustrated by a luminaries design competition that was announced in January 2002 by the US luminaries manufacturer Lightolier [Lightolier]. The aim of the competition was to design a skylight/electric light fixture in a single product that comfortably and effectively provides both daylight and electric light under sunny and overcast skies, and at night.

4. Interaction with other SmartBuild strategies and technologies

4.1 Lighting systems and user needs

The following are the summary of the author's experience with the different stakeholder's attitude towards and experiences with daylighting systems. A lot of experience was collected during my participation in the Hybrid Lighting project curried by SINTEF Material Technology.

The Government is concerned about employment, economic growth, environmental concerns and the country's dependence on import. Any system that contributes to energy saving and occupants health/well-being is politically interesting.

Architects: are generally very positive to a smart integration of different systems in buildings. Most architects know about the positive impact of daylight for human health, well-being and productivity. Those aspects make them positive to daylighting systems as long as the system looks attractive aesthetically. They love glass for its transparency and they like to design buildings with large glazing areas, both on facades and on the roof. They may be skeptical to the systems placed on the façade, e.g. shading systems that are in conflict with the transparency of the building.
Architects are very concerned about the aesthetics and design of products, e.g. lighting fixtures have to look aesthetically attractive and trendy to be chosen by them. They are also concerned about function ability of building areas. They are positive towards the integrated lighting systems that enable more flexible utilization of floor areas. In addition they are under a constant pressure from buildings owners to design buildings with large floor area/volume coefficient.

Electrical engineers: do not know much about daylighting systems or shading systems, but they are familiar with control systems for electrical lighting. Due to very limited budgets for lighting projects they prefer to use standard products and solutions.

Contractors do not know much about daylighting systems. They are even more conservative than engineers, new solutions and new systems introduce new risks to them, which they prefer to avoid. Electricians who are responsible for installation of the electrical systems on-side are mostly concerned about easy montage.

Investors should be divided to:
-*investors* who construct buildings in order to rent or sell them
-*investors* who rent

The main goal for the first group is to construct as much floor area as possible for a given volume of the building at the lowest possible price. A high floor area per volume factor is easier to obtain in compact buildings. They should be interested in applying a hybrid lighting system if the system will enable usage of the areas lying remote to the window wall as working areas, especially if the difference in the total investment cost is not too high. A radical increase of electricity prices this winter will probably widen their interest in energy efficiency, as it will be easier to rent or sell the building areas.

The main goal of the other group is to reduce the operation and maintenance costs, subsequently to make the working areas attractive for the occupants. They prefer flexible areas.

Any system that contributes to saving of electricity costs and at the same time is acceptable for the occupants, is attractive. Easy access to luminaries, and infrequent change of light sources reduces maintenance costs.

Occupants are mostly concerned about a comfortable working/living environment, to some degree about the quality of the visual environment and aesthetics. A nice view through the window is also of great importance for them. They also value the possibility to control their environment by themselves. If any control system is to be accepted, it has to be user friendly.

They should be better informed about the very positive effect of daylight on their health, well-being and productivity.

4.2 Lighting systems and Environmental criteria

The light-transmitting daylighting systems are constructed of window glass, mirrors, acryl panes, small plastic elements etc. The light-reflective daylighting systems are made of highly reflective materials as polished aluminum and steel. As such they are not less environmental friendly than glass-façade or glass-roof systems, usually used in buildings.
Daylighting systems can give huge environmental profits by saving energy consumption for lighting in buildings operating at daytime.

4.3 Lighting systems and Indoor environment

Daylighting systems produce no air pollution. Thus, they have no direct impact on the indoor air quality. However daylighting systems fixed inside a room having horizontal elements will increase the shelf factor in the room. If not cleaned very often, they will collect dust. Even vertical inside shading systems, e.g. curtains, collect some dust and may not be acceptable in rooms with very high demand for hygiene.

Lighting systems, if not cleaned regularly, can cause combustion of dust and unwanted pollution of the indoor air. Therefore, the lighting fixtures should be designed for quick and easy cleaning.

Some light sources make noise. Users may find it irritating in spite of a low volume.

Even more important is the pulsation effect of some fluorescent light sources. For very sensitive people it will cause headaches and for very few even epileptic attacks.

The indoor environment should include the visual environment as one of the important criteria. The glare, both from the sun, the sky and from lighting fixtures, can occur if lighting designers do not pay enough attention to shading the occupants from direct view towards light sources. The glare, especially the solar glare, can be very dangerous, since it can damage the human visual system. Most occupants will evaluate an even lighting distribution in a room as boring and flat. To increase the visual interest, the luminance distribution in the room should vary. The visual task should have higher luminance than surfaces lying close around it. The luminance of light sources should not be higher than the value 20-40 times luminance of the visual task. The recommendations for maximum luminance contrasts in the working places are worked up by the international lighting committee CIE and should be followed by lighting designers and architects.

Jennifer Weitch [Weitch] the author of CIE report "*Principles of Healthy Lighting*", points to the nonvisual effects of light on human physiology, mood and behavior. According to Ms. Weitch, that the daily dose received by people in Western countries might be too low. To improve the occupant's mood and make the indoor visual environment healthier for the occupants, higher lighting exposures or/and a longer period of lighting exposure will be recommended in the future. She also points to the spectrum. Light for biological activity should be rich in the regions of the spectrum to which the nonvisual system is most sensitive. The exact spectrum is not known, but it peaks in the blue-green region. If so, the blue skylight should be extensively used in buildings. The report concludes, that a revolution in lighting recommendations is to come within the next 10-15 years, as we expand from purely visually-based recommendations to new ways of thinking about lighting. People need enough lighting exposure and periods of darkness, too.

4.4 Lighting systems and Implementation strategies

Lighting systems need clear implementation strategies. There exist too many examples of very smart products that will never be implemented. The implementation is even more difficult if the product cannot give economical profit. For example, the use of daylighting systems cannot be justified by the profit from energy saving alone.

The very important arguments for the implementation of lighting systems should be the health, well-being and productivity of occupants. Since the occupants salaries are the highest outcome for most of enterprises, even a 0,5% increase of productivity during the year can give economical profit that can justify large investment costs for daylighting systems. Unfortunately, it is not easy to document the impact of lighting on productivity, since productivity depends on a huge amount of factors. Eitherway, there are indicators pointing to a positive influence of daylight exposure on the production of cortisol hormone and on the quantity of cortisol in urine on the immune defense of the body. Which means that too small light exposure increases the probability for illness. More efforts are needed to document those connections and use them during the implementation process.

Another strategy for implementation of daylighting systems can rely on focus on an increased daylight level in areas lying away from daylighting openings, resulting in increased functionality and flexibility of those areas.

4.5 Lighting systems and Integrated design

The integration of lighting systems in buildings is an obvious objective. Despite that, it is not easy to achieve in practice, because the decision about the façade design, fenestration, shading devices, BIPV, electrical lighting and control systems are made by different decision makers and at different times during the building design- and construction process. Traditionally, architects were responsible for integration of building components and systems during the design process. The technical development of daylighting-, shading- and lighting systems resulted in a huge amount of ideas, solutions and products. If an architect would still like to play a central role in the process, he/she has to increase his/her knowledge considerably. Otherwise he/she has to cooperate with specialists. The problem occurs if the advices that specialists give contradict with the main architectural concept of the building. The scenario sketched here occurs quite often, because the architects usually have a very strong opinions about the design of the building façade.

Integration of different systems into one more complex system is a new approach.
There have been developed very few solutions which integrate daylighting with electrical lighting within a single system [Köster] [Feldmann] [Schnetz] [Mingozzi] [Ejhed] [Heliobus] [Bracale].
The process started when new daylight-redirecting components and materials were made available to the market (e.g. Siteco, Hüppe, Edmonds, Serra Glaze, 3M). The architect had to compose these components and materials into a tailored lighting system that suited the application, as shown in figure 1.

Figure 1. Hüppe Daylight Technology

The solutions are usually optimized for direct sunlight and have a limited efficiency when the sunlight is not available. The use of such systems is limited to the countries were the probability for sunlight radiation is much higher than 50% of all daylight hours during the year. The systems are often comprehensive and require major changes in the building structure if used in existing buildings. They function well, but they often lack the economic dimension, which prevents a broad commercial support.

One very promising integrated system, designed for usage in offices, was developed by Siteco, Lighting Technology GmbH [Nagel], see figure 2. The Siteco Light shelf is primarily intended for installation in the top section of the window. Below the shelf, a conventional window allows for an unimpeded view of the outside. Sunlight is collected by a light concentrator and directed onto a diffuser together with diffuse skylight. The light is further directed onto the ceiling. Workplaces are illuminated indirectly with the light reflected from the ceiling. The shelf is primarily marketed as a shading device. The solar glare from the upper part of the window is avoided since direct sunlight falling on the small area of the window is distributed on a large area of the ceiling. The shelf is meant to replace the conventional ceiling mounted artificial lighting in a cell office.

The artificial lighting component is a ceiling washer mounted in the body of the light shelf above the daylight diffuser. Depending on the illuminance requirement, the washer is fitted with one or two T5 light tubes. An integrated light control system permits adjustable dimming, and thus an energy efficient operation of the lighting system. The shelf is meant to replace the conventional ceiling mounted artificial lighting in a cell office.

Figure 2. The Siteco Light shelf.

Apart from the Light self of Siteco, we are only aware of one other compact hybrid lighting solution that has been developed by Iguzzini. It requires a light collector on the outside of the façade and an opening in the façade. The concentrated sunlight is being reflected towards an anidolic mirror. The reflected light from this mirror is directed towards the working place through a translucent diffuser. The company intends to integrate an artificial light source in the system. The product is not yet commercially available [Casalone] (figure 3).

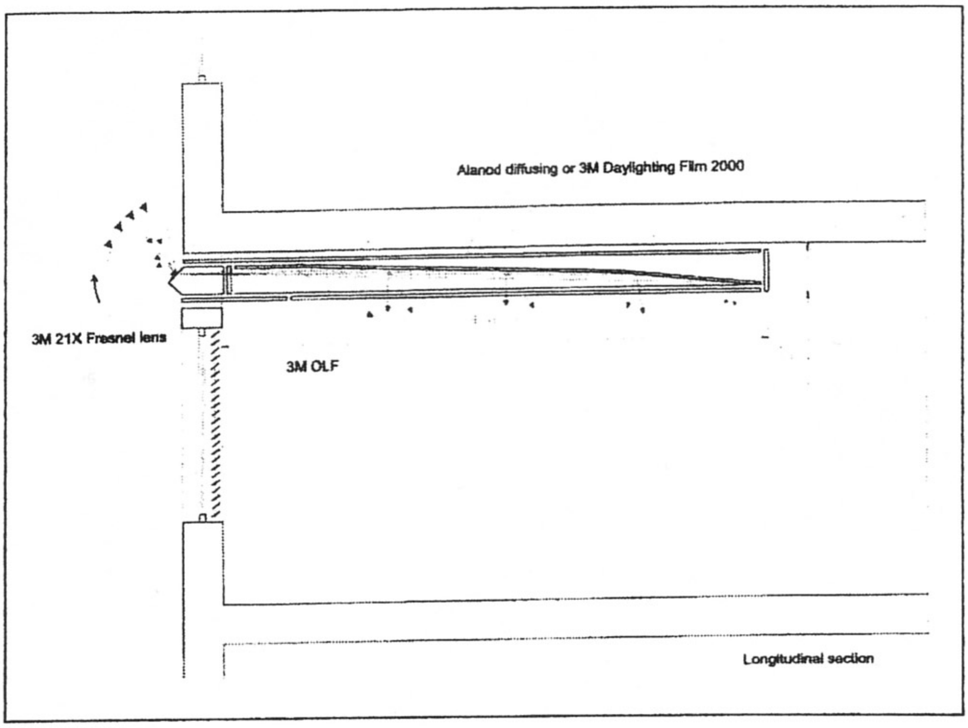


Figure 3. The Iguzzini hybrid lighting device.

Integrated daylight/electric light fixtures were developed both for sidelight and skylight. Two examples of integrated lighting system that combine sunlight, collected on the roof and distributed by a huge light tube, with artificial light source placed at the bottom of the building in a single package that allows the most effective delivery of both types of light, figures 4 and 5.

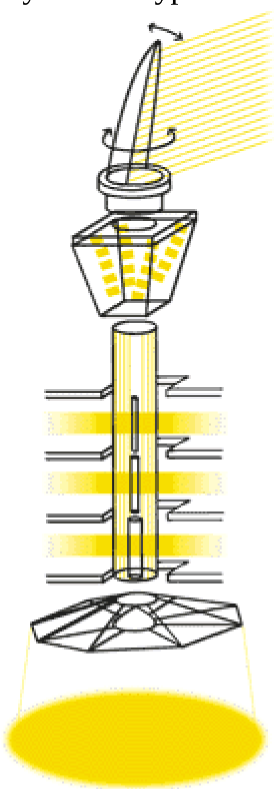


Figure 4. Heliobus

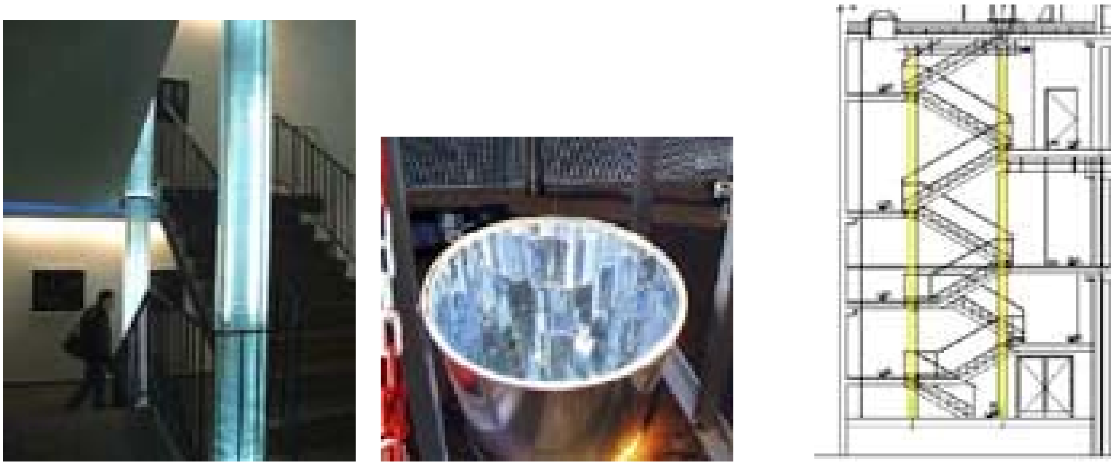


Figure 5. Arthelio Project

4.6 Lighting systems and Building integrated energy systems

Lighting is a major electricity load in most commercial buildings. The lighting is also a major contributor to the cooling load. For commercial buildings, which are occupied during daytime, the peak lighting load typically coincides with the peak solar gain, cooling load and peak casual gains from buildings activities.

4.7 Lighting systems and Building integrated photovoltaic

There are many examples of PV integration in buildings façade design and in fixed shading devices. In low latitudes the solar shading consists of horizontal elements placed at the top of the window or covering the window surface. The elevation angle of the sun is large. To shade the window, shading elements can be sloped slightly down from the horizontal plane allowing penetration of the diffuse skylight from the lower part of the sky; the view out is only partly obstructed.

A typical problem with shading in high latitudes is caused by low elevation angle of the sun over the horizon, especially during the morning and evening hours. To shade windows properly with the shading system made of horizontal slats, the slats have to be inclined nearly vertically, covering nearly all window area. The view out is totally obstructed; the daylight does not penetrate to the building and occupants use artificial lighting to compensate for very low lighting level. It is ridicules; artificial lighting is used during daytime with sunlight!

Imagine a shading system consisting of vertical, moveable lamellas. An intelligent control system changes position of lamellas during the day turning them to position perpendicular to the sunlight direction. Such lamellas, always oriented toward the sun, should be an excellent place for integrating of PV! (Apart of the fact that one lamella will shade the neighbor one under slant incident angles of sunlight). The shading system sketched here will effectively shade the window and reduce the solar glare problems; it will also enable skylight penetration during most part of the sun hours and it will produce electricity. A part of this electricity can be used for operating of the system.

Another possibility for integration of PV in shading devices is to use them at the roof of the building, on the shading devices needed for skylights or glass roofs. The principle could be similar. A dynamic shading system, functioning as a moving sun umbrella, can be utilized for fixing of PV. The possibility to avoid shading of PV's should be even better.

4.8 Lighting systems and Heating, cooling and ventilation systems

Utilization of daylight as lighting of working areas may result in significant savings in electricity consumption for lighting. [Danny] reports about 50% energy savings for lighting in a single person offices were a daylight responsive dimming system is used. The energy saving potential is mostly dependent on the daylighting level in the room, the energy saving potential is much larger in the perimeter zone than in a core of the building.

[Athienitis] reports, that in rooms with shading-, daylighting-, and dimming- control, the energy saving for lighting may exceed 75% for overcast sky and 90% for clear sky with sun, comparing to the case of no control system. The results refer to small office room with a motorized shading system consisted of highly reflective blinds between the two panes of glass. The control system adjusts the sloping of shading blinds that control the light flux penetrating to the room and redirect sunlight to the ceiling in sunny days. It also adjusts the light flux from luminaries to meet 500 lx requirement at the working area using the dimming principle. The author claims that the control system creates high quality indoor environment too. The reduction of luminaries' operation time causes the reduction of the intern heating and increasing of energy requirement for heating. The energy saving for cooling is not documented in this study, but most probable it will be much higher than additional energy use for heating.

[Sala] reports about the AIW-Active Intelligent Window designed to exploit solar radiation, outdoor air temperature and relative humidity to provide automatically controlled direct or indirect solar gains, cooling by ventilation, humidification-de humidification, variable insulation and daylighting of indoors. Each function or set of functions is automatically selected by en intelligent control system.

4.9. Lighting systems and Heat pumps

The energy consumption for lighting has an impact on the total energy consumption in buildings, also buildings heated by heat pumps. Lighting systems that utilize daylight as lighting source use less energy (for lighting) than conventional lighting systems, because the total operation time for artificial lighting is shorter. If lighting fixtures operate in shorter time, they produce less heat and the requirement for heating increases. The heat pump has to produce more heat and the effectiveness of the heat pump will probably be higher.

4.10 Lighting systems and Operation and automation

Many intelligent control systems for lighting are under development. In addition to the daylight responsive dimming- or on/off- switching systems optimized for energy saving, new approaches focus more on occupant's satisfaction. Really, the user acceptance of automated control of daylight and artificial light is a crucial objective of any control system. One of the most important conclusions of visual comfort study, conducted by [Velds] last year, was the lacking possibility to overrule the control system was the most important complain.

[Guillemin] writes about a shading control system that can operate in two different ways. If the occupant is present, priority is given to visual comfort; if the occupant is absent, priority is given to thermal aspects, i.e. energy saving for cooling or heating. It is also integrated in an optimized global controller. The artificial lighting controller is used to complete the illuminance level in the room up to the level desired by the user. The desired level is learned by the system through the user's wishes.

[Garg] reports about smart occupancy sensor that was proposed for ”human movement” of a person working at a computer and can learn the variation in activity level of the occupants with respect to the time of the day. It adapts the time delay, i.e. the time after which the lights will be switched off. Traditional occupancy sensor enables ca. 30% of energy saving for lighting compared to situation without any sensor. The smart sensor can save additionally 5%.

[Kolokotsa] reports about a new integrated control approach. The air quality, the thermal comfort and the visual comfort are all controlled by fuzzy logic control system. The system monitors also energy consumption for heating/cooling and electric lighting.

The pilot study about office workers response to automated venetian blind and electric lighting system curried by [Vine] raised a number of interesting issues with respect to occupant responses and preferences in daylighted environments.

- First, most workers appeared to prefer greater illuminance levels (more daylight and more electrical light) for their office space, even though they could see well enough to perform their tasks. The higher illuminance levels may indicate the preference of: more daylight, less-obstructed view out, for balancing the illuminance from daylighting, for more electric lighting to brighten the sides and back of the room.

- Second, even if the automated system performs well and has a high level of acceptance, occupants should be offered the ability to manually control some or all of the system operation and should be educated and trained about the proper use of the controls and the nature of the feedback system.

- Third, a large sample of people should be investigated to find answers for following questions:

    - what kind of people need to control their lighting environment,
    - how this control may influence their reactions to the lighting environment
    - what proportion of the population prefer lighting conditions that change over time, corresponding to changes in the external conditions

4.11 Lighting systems and Energy storage

The energy for lighting is most needed in the periods of low daylight level outside, i.e. in periods when the possibility for electricity production at site, e.g. from PV, is not possible. There is a need for energy storage if an on site energy production is to be chosen.

5. Lighting systems and SmartBuild

In my view, the envelope of smart building should react to the changes of the temperature, sunlight, skylight, wind, etc. outside in a similar way as human being reacts, e.g. by taking more cloths if the temperature sinks, turning eyes away from the sun if it is low over the horizon or using wind cloths in the windy weather. Such a constructed building envelope will help us to create comfortable indoor environment and at the same time enable us to save more energy, because the natural energy sources, such as daylight, solar heat etc. will be used to a greater degree.

The SmartBuild project could focus at the following:

1. THE HYBRID LIGHTING SYSTEM
   The concept of integration of daylighting- and electrical lighting systems should be enlarged to comprise shading system, possibly also PV. Such a hybrid system should be optimized for both, user comfort and energy saving.

2. THE CONTROL SYSTEM
   All elements of such a hybrid lighting system should be controlled by one intelligent building-control system which could control also the heating (cooling) and ventilation in the building. The central control system should secure a comfortable indoor environment and should contribute to considerable energy savings.

3. INTEGRATION OF BIPV IN SHADING-DAYLIGHTING SYSTEM
   The integration of PV in a dynamic shading-daylighting system, especially for high latitudes.

Many different design alternatives could be developed for different users and different building types/functions, possibly also for different climates. The concepts for both, façade and roof openings could be developed.

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Central R&D institutions

LBL
EPFL
Building Research and Technology
University of North London
Cambridge University

Industry

Glassbransjeforbundet
Solskjermingsforbundet
Luxo, Glamox
Velux
Shöco
Gasa Arkitekter
Pir II Arkitekter