EFFICIENCY OF DAYLIGHTING SYSTEMS USING LIGHT-PIPES

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Daylighting provides light that supplements or replaces electric lighting. For commercial buildings, artificial lighting and its associated cooling energy, represent 30-40% of total used energy. The addition of daylight in a space may bring benefits related to aesthetics, health, and energy savings. The synthesis of a properly daylit space and well-controlled artificial lighting system can produce lighting energy savings in the range of 30-70% in offices.

1. Introduction

Meeting the challenge of sustainable living in a world with fast-diminishing finite resources calls for a fundamental change in the way we use those resources. The use of renewable energy to power our modern lives is intended to prevent the need for damaging fossil fuels and hence slow or halt global warming. The amount of energy demand generated by the use of electric lights is considerable and gives the possibility of significant savings by daylighting. An additional saving that is associated with natural lighting is a reduction in cooling load for air-conditioned buildings. Because the luminous efficacy of natural daylight is higher than the majority of artificial light sources, fewer radiant watts of power are required for a given level of illuminance. In an artificially lit office building, a considerable percentage of the heat that requires removal is generated by the light fittings and overall savings through daylighting are significant [4].

Daylight allows people to see well and to feel some connection with their environment [5] and when allowed to express a preference, occupants choose natural over artificial light. Long-term studies have found that people prefer the varying levels of light provided by a daylight cycle to the constant light levels provided by artificial lights [3]. The same study showed that people chose high levels of natural light that corresponded to levels of light at which biological stimulation occurs. The work concluded that a wide range of health problems might be due to a lack of access to natural light throughout the day.

The use of daylight in buildings is beneficial both to human wellbeing and to productivity and also has a place in the effort to minimize the impact of human activity on the planet by reducing electricity consumption in lighting.

2. Review of daylighting strategies

Following their principal function, daylighting systems can be classified [6] as systems with shading and systems without shading.

Two types of daylighting systems with shading are discussed: systems that rely primarily on diffuse skylight and reject direct sunlight, and systems that use primarily direct sunlight, sending it onto the ceiling or to locations above eye height.

Shading systems are designed for solar shading as well as daylighting; they may address other daylighting issues as well, such as protection from glare and redirection of direct or diffuse daylight. The use of conventional solar shading systems, such as pull-down shades, often significantly reduces the admission of daylight to a room. To increase daylight while providing shading, advanced systems have been developed that both protect the area near the window from direct sunlight and send direct and/or diffuse daylight into the interior of the room.

Daylighting systems without shading are designed primarily to redirect daylight to areas away from a window or skylight opening. They may or may not block direct sunlight. These systems can be broken down into four categories; some systems can fulfill multiple functions and are therefore in more than one category.

- Diffuse light-guiding systems redirect daylight from specific areas of the sky vault to the interior of the room. Under overcast sky conditions, the area around the sky zenith is much brighter than the area close to the horizon. For sites with tall external obstructions (typical in dense urban environments), the upper portion of the sky may be the only source of daylight. Light-guiding systems can improve daylight utilization in these situations.

- Direct light-guiding systems send direct sunlight to the interior of the room without the secondary effects of glare and overheating.
- Light-scattering or diffusing systems are used in skylit or toplit apertures to produce even daylight distribution. If these systems are used in vertical window apertures, serious glare will result.
- Light transport systems collect and transport sunlight over long distances to the core of a building via fiber-optics or light pipes.

Currently, light from core daylighting systems is usually directed into a space by large diffusers that descend below the ceiling plane. Smaller diffusers and hollow light guides that resemble ordinary luminaires are also available. It is reasonable to expect that these systems will have light distributions and glare control similar to those of standard luminaires. However, most manufacturing efforts have gone into producing systems that efficiently collect light and transmit it through the building. More work is needed to produce effective methods of directing light to the work surface.

New daylighting technologies are not likely to become common until their prices drop to reduce the payback period. The light pipe is perhaps the most technologically exciting of innovative daylighting systems because of the long distances over which it can operate. In principle light pipes collect, direct, and channel sunlight into virtually any area of a building. The system consists of three main components: heliostat (collecting and concentrating unit), transport system (reflective conducts) and emitter (distributing light into the targeted space). The micro prismatic film perform total internal reflection, which is approximately ten times as efficient as typical specular metallic reflection (reflectance 0.99 compared to 0.90).

Daylighting systems can contribute to lower first costs for a building's mechanical system by lowering peak cooling load relative to that of the same building with conventional lighting design. Mechanical system downsizing is dependent on the confidence in the estimated load and the reliability of the daylighting system to reduce loads during peak periods. Since mechanical systems are offered in standard sizes, however, incremental differences in calculated capacity may not always result in a change in equipment size.

Operating costs for energy can be calculated using the local utility rate. It is important to model utility rates accurately, particularly for daylighting technologies, because savings are often realized during summer peak periods when electricity costs are the highest.

Daylighting systems should be maintained on a regular basis. Systems with operating parts or those that rely on sensors for proper operation must be tuned or recommissioned when the interior space is reconfigured or its use is redefined. If the system is static and enclosed, then maintenance costs will probably be equal to those for conventional systems. Systems that permit natural ventilation may require more maintenance because of increased exposure to weather and dirt.

3. Solutions of daylighting systems using light-pipes

Light-pipe is a secondary light source which transmits light from the primary (natural or artificial) source within interior spaces, to a specific target or on specific reflecting or transmitting surfaces.

Light transmission is done at the end of the light-pipe, where light is distributed and directed depending on task particularities, or by side transfer towards specific targets. Light-pipe transmits light radiation through total internal reflection. The inner material has a reflectance of up to 0.98 and internal reflectance is produced within the structure of the 0.5 mm thick optic film, made of transparent acryl or polycarbonate [2]. This film has a prismatic outer face and a plate inner face, concurring to totally reflect light rays.

The collecting unit is the functional device of the highest importance with respect to the amount of daylight which can be used. Using a Fresnel lens, the heliostat is built to track efficiently sun position in the sky by a simple rotation around vertical axis, as lens's collecting angle allows sunlight to be focalized for any solar angle, specific to the site latitude where this system is mounted [7]. This focalized light is than reflected by a mirror towards the vertical conduct, as close as possible to its axis. The mirror has a special design allowing collection of diffused skylight.

The lighting system should also be equipped with electric light sources, able to balance daylight permanent variability. Following aperture photocells signals, the control unit turns on the electric lamps, in order to balance or to replace daylighting in case that sky is no longer clear or after night fall.

The use of light-pipes can increase energy savings, but generally system efficiency is low because of light losses within ramification or direction changing. There are specific light-pipe systems for roof applications, known as solar tubes. These systems maximize the concept of renewable energy by reflecting and intensifying sunlight and even normal daylight, down through a highly reflective silver mirror-finish aluminum tube.

An early work on light transport [9] described a hollow light tube developed in 1978 and constructed from a prismatic polymer material that combined the high reflection efficiency of total internal reflection with the low cost and practicality of a hollow system. This device was intended both for electric and daylight transport, but only accepted light from a cone of 27.6°, precluding day-long passive solar collection for daylighting.

An example of light-transport daylighting is the ‘Heliobus’ device, which employs a hollow light guide similar to light pipes and ducts [1]. The collector was a heliostat, which was a concave mirror that collected sunlight and delivered it to the reflective duct below, of square cross-section. This section had emitters fitted to allow the removal and use of light at various heights through the building, followed by a diffuser at the end of the duct to emit the remainder of the light. The system also had three efficient electric lamps to act as backup at times of insufficient external illuminance. Monitoring of the system in the building showed that without electric lamps the system increased room illuminance by 1.5 to 3 times and overall was calculated to give energy consumption 3-4 times lower than a standard electric installation, as well as reducing the installed electric lighting capacity by half.

The very most of the micro prismatic light guides have been continuously light emitting pipes, with a continuously diffusive extractor film inside the tube. This extractor film has to be given a specific design for each different light guide length and diameter. A further step could be adjustable dynamic extractors. In a light guide system now all the discrete extractors are identical, and a light valve adjusts the light emitted from each extractor. The light valve can be an arrangement of a turnable mirror, for instance adjustable from parallel with the longitudinal axis to 45°. In this way the amount of deflected light can be varied as needed. Such a light guide system can be built from similar extractors through the whole installation, and the adjustment of light levels in each room can easily be done afterwards. This will do the manufacturing and installation of the systems much more efficient, and more cost effective.

4. Discussion on light-pipes efficiency

Although prism light guide luminaire systems work well, they are intrinsically less efficient than conventional, simple luminaires. The reason is that the light injector itself typically has efficiency similar to that of a conventional fixture, so that any inefficiency of the prism light guide luminaire represents a net loss compared to conventional lighting. Since typical overall efficiencies for prism light guide luminaires range from 0.40 to 0.80, this loss is significant, and has limited the use of prism light guide systems to situations in which the practical advantages of piping light are economically more significant than energy efficiency issues. Recently, however, there has been interest in using new light sources that have higher luminous efficacy, in conjunction with improved prism light guide luminaires, to achieve a net efficiency comparable to conventional lighting.

Whitehead developed a simple calculation method for estimating the net efficiency of prism light guide luminaire systems [8]. For several example systems, this method yields results that are in good agreement with photometric testing, but since the method involves numerous simplifying assumptions, its accuracy cannot be assured in new circumstances.

The most striking feature of the problem is the large number of loss mechanisms. For simplicity, this problem is broken into four multiplicative stages: light injector loss factor, light guide input loss factor, light guide transport loss factor, and light guide output loss factor.

This simple calculation method was used to estimate the efficiency of several light-pipe systems, found to be between 0.43 and 0.75 [8].

5. Conclusions

A significant number of applications using daylighting systems have been accomplished. The most interesting and easily adaptive solution is however represented by light-pipes. Even if light-pipe industry met a major development in the 80s, efficient systems are still expected in practice. The efficiency of such systems is difficult to be estimated with high accuracy.

Research and development work needs to be done in order to improve the global efficiency of daylighting systems using light-pipes, so that these systems finally meet large scale application demands and contribute to a safer environment.

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EFICIENȚA SISTEMELOR DE ILUMINAT NATURAL CU TUBURI DE LUMINĂ

Iluminatul natural asigură lumina necesară completării sau înlocuirii iluminatului electric. Pentru clădiri cu destinație comercială, iluminatul artificial şi energia de răcire asociată reprezintă 30-40% din energia totală utilizată. Integrarea dintre un sistem de iluminat natural corespunzător spațiului iluminat şi un sistem de iluminat electric corect conceput şi controlat poate conduce la economii de energie de ordinul a 30-70% pentru clădiri de birouri.

1. Introducere

Asigurarea vieții într-o lume cu resurse naturale finite care cunosc o diminuare rapidă necesită o schimbare fundamentală a modului în care aceste resurse sunt folosite. Utilizarea energiilor neconvenționale este menită să prevină dispariția combustibililor fosili şi astfel să diminueze sau să stopeze încălzirea globală a planetei.

Necesarul de energie determinat de utilizarea luminii electrice este considerabil şi oferă posibilitatea obținerii de economii de energie semnificative prin utilizarea luminii naturale. O economie de energie suplimentară asociată cu utilizarea luminii naturale constă în reducerea sarcinii de răcire pentru spații interioare climatizate. Deoarece eficacitatea luminoasă a luminii naturale este superioară eficacității majorității surselor de lumină electrice, asigurarea unui anumit nivel de iluminare presupune aporturi termice reduse în spațiul interior iluminat. În clădiri de birouri iluminate electric, o proporție considerabilă a căldurii ce trebuie evacuată este generată de sistemul de iluminat, iar economia globală de energie prin utilizarea luminii naturale este semnificativă [4].

Lumina naturală permite oamenilor să vadă bine şi să perceapă legătura cu mediul înconjurător [5], iar atunci când trebuie să-şi exprime preferința, ocupanții aleg lumina naturală în defavoarea luminii electrice. Studii îndelungate au descoperit faptul că oamenii preferă parametrii variabili ai luminii naturale şi nu pe cei constanți asigurați de sursele de lumină electrice [3]. Concluziile acestor studii au arătat că o serie largă de probleme de sănătate se pot datora lipsei accesului de lumină naturală de-a lungul zilei în spațiile interioare.

Utilizarea luminii naturale în clădiri este benefică atât pentru confortul ocupanților, cât şi pentru creşterea productivității, având de asemenea un rol important în efortul de minimizare a impactului activităților umane asupra mediului natural prin reducerea consumului de energie electrică pentru iluminat.

2. Strategii de iluminat natural

După funcția principală, sistemele de iluminat natural pot fi clasificate [6] în sisteme cu ecranare şi sisteme fără ecranare.

Sistemele cu ecranare sunt concepute atât pentru împiedicarea accesului luminii solare directe, cât şi pentru iluminat natural; ele pot rezolva şi alte aspecte legate de iluminat, cum ar fi evitarea orbirii şi redirecționarea luminii directe şi a luminii difuze către suprafețe de interes.

Sistemele de iluminat fără ecranare sunt concepute în principal pentru redirecționarea luminii naturale către zone îndepărtate de ferestre sau deschideri superioare. Ele pot sau nu bloca accesul luminii solare directe. Aceste sisteme pot fi clasificate în patru categorii:

- Sisteme de ghidare a luminii difuze a cerului
- Sisteme de ghidare a luminii directe solare
- Sisteme de difuzare a luminii naturale
- Sisteme de transport al luminii naturale

Tubul de lumină este probabil sistemul de iluminat natural modern cel mai interesant din punct de vedere tehnologic, datorită distanțelor lungi pe care el poate opera.

Strategiile şi sistemele avansate de iluminat natural pot produce economii de energie atunci când sunt folosite în zone climatice corespunzătoare şi pentru orientări corecte ale clădirilor, în concordanță cu analiză specifică realizată cu algoritmi şi programe de simulare a fenomenelor de reflexie, refracție şi transmisie a luminii, necesară pentru estimarea performanțelor acestor sisteme.

3. Soluții de sisteme cu tuburi de lumină

Tubul de lumină este o sursă secundară de lumină care transmite lumina de sursa primară (naturală sau electrică) în spațiul interior, către un obiectiv specific sau către anumite suprafețe reflectante sau transmițătoare. Transmisia luminii se realizează la capătul tubului de lumină, unde lumina este distribuită sau direcționată, în funcție de particularitățile sarcinii vizuale, sau prin transfer lateral către obiectivele specifice.

Tubul de lumină transmite radiația luminoasă prin fenomenul de reflexie internă totală. Materialul interior are o reflectanță de 0,98, iar reflexia internă se produce în structura de 0,5 mm grosime a filmului optic, fabricat din acril transparent sau policarbonat [2]. Acest film are suprafața exterioară prismatică şi suprafața interioară plană, conducând la reflexia totală a radiațiilor luminoase.

Unitatea de captare este echipamentul funcțional de cea mai mare importanță în ceea ce priveşte cantitatea de lumină naturală ce poate fi utilizată. Prin înglobarea unei lentile Fresnel, heliostatul este astfel construit încât să urmărească eficient poziția soarelui pe cer printr-o rotație simplă în jurul axului vertical şi/sau axului orizontal, întrucât unghiul de captare al lentilei permite luminii solare să fie focalizate pentru orice unghi de înălțime solară, specific latitudinii locului unde acest sistem este montat [7]. Această lumină focalizată este apoi reflectată de către un sistem de oglinzi către conducte verticale, cât mai aproape posibil de axul central. Oglinzile au un design special, permițând şi captarea luminii difuze a cerului.

Sistemul de iluminat trebuie să fie de asemenea echipat cu surse de lumină electrice, capabile să compenseze variabilitatea permanentă a luminii naturale, suplimentând sau înlocuind iluminatul natural atunci când este cazul.

Majoritatea sistemelor sunt echipate cu filme difuzante de extracție a luminii din interiorul tubului, care trebuie concepute în mod specific pentru fiecare lungime şi diametru de tub de lumină. Un pas ulterior ar putea fi reprezentat de extractoarele cu reglaj dinamic. Într-un sistem de ghidare a luminii, toate extractoarele sunt identice, şi o valvă reglează lumina emisă de fiecare extractor. Valva poate fi reprezentată de o oglindă rotativă, de exemplu reglabilă între 0° (paralelă cu axa longitudinală a tubului) şi 45°. Astfel, cantitatea de lumină emisă poate fi variată după necesități. Un astfel de sistem poate fi construit din extractoare similare de-a lungul întregii instalații, iar reglarea nivelului de iluminare în fiecare încăpere poate fi cu uşurință realizată ulterior. Aceasta va face aceste sisteme mai eficiente şi va determina scăderea costurilor de producere şi de instalare a acestor sisteme.

4. Discuție despre eficiența tuburilor de lumină

Deşi sistemele prismatice de ghidare a luminii funcționează bine, ele sunt în principiu mai puțin eficiente decât sistemele simple, convenționale. Explicația este că injectorul de lumină prezintă de regulă o eficiență similară eficienței dispozitivelor convenționale, astfel încât orice ineficiență a sistemului prismatic de ghidare reprezintă o pierdere netă comparativ cu iluminatul convențional. Deoarece eficiențele globale tipice ale sistemelor prismatice de ghidare – tuburi de lumină variază între 0,40 şi 0,80, aceste pierderi sunt semnificative şi au limitat gradul de aplicare al acestor sisteme în situațiile în care avantajele practice ale tubului de lumină sunt din punct de vedere economic mai importante decât aspectul eficienței energetice.

5. Concluzii

Un număr semnificativ de aplicații utilizând sisteme de iluminat natural au fost realizate. Soluția cea mai interesantă şi cea mai flexibilă este reprezentată de tuburile de lumină. Deşi industria tuburilor de lumină a cunoscut o dezvoltare majoră în anii `80, sunt în continuare necesare activități de cercetare şi dezvoltare pentru a îmbunătăți eficiența globală a sistemelor de iluminat natural cu tuburi de lumină, astfel încât acestea să cunoască cereri de instalare la scară largă şi să contribuie astfel la realizarea unui mediu mai curat şi mai sigur.