PUT YOUR DAYLIGHT WHERE THE SUN DOESN’T SHINE

METHODS FOR BRINGING DAYLIGHT DEEPER INTO BUILDINGS

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Preface

For the sake of both energy conservation and visual comfort, daylight is preferable to artificial light. There are several methods of bringing daylight to spaces in buildings where usually only artificial light would be. In this manual some of these methods are presented and explained, and examples of implementations given.

This booklet aims to be more of an informational document for architects and engineers than a strict step-by-step design guideline as there are many variables and products under constant development.

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1.1 Introduction

While daylight is generally preferred to artificial lighting in most working and living situations, it is not always possible to get a desirable amount of daylight to any given location inside a building. The total window area in a façade is generally limited, a room can be too deep so the light does not penetrate it far enough, windowless basements etcetera.

There are some methods of getting daylight to places that it usually would not reach; this manual aims to be an introduction to these methods, and how to implement them.

1.2 Methods

The easiest way to change the path of light is using a mirror. Figure 1.1 on the next page shows how incoming light in an atrium can be scattered to different directions. For catching more direct sunlight, a heliostat can be used, this is basically a mirror that follows the trajectory of the sun so that the reflected light will be constantly aimed at the same target.

Using only mirrors (be it plane or parabolic) it is possible to concentrate light on a certain point, but it requires an unobstructed path, so the application possibilities inside buildings are limited.

To transport light deeper into a building, tube-shaped mirrors, or light guides, can be used. The inside of the light...
guide has a highly reflecting (“mirror-ing”) surface so that the light that enters on one side is transported to the other end with only minimal loss.

This “tube” has a few main variants: it can literally be a tube-shaped mirror made of metal, (glass) fibre or in a special case, a prismatic hollow cylinder.

The metallic tube type is the most commonly used variant, and is generally named “light pipe” or “light tube”. It has the advantage that it is relatively cheap and does not need to be straight (see figure 1.2). It does take up relatively much space, so there might not be sufficient space in a building to implement it.

The glass tube type is not only used for transporting, but also for distributing light (see figure 1.3). As the light travels down the tube, some of it reflects further down and some of it refracts into the surroundings. As this method involves having the tube in the middle of a room or place, it is not very suitable for office or living rooms, and better suited for larger open spaces like office landscapes.

Figure 1.1: Heliostats on a ceiling
The glass fibre solution is essentially the same as a “light pipe”, but with the advantage that light can be much more concentrated (with an outdoor collector that uses prisms or parabolic mirrors), the fibre cables are smaller than tubes and flexible so this solution uses less space inside a building and can be used in more difficult to reach spots. An extra possibility is to have a system that shifts some of the ultraviolet light into the visible spectrum to boost the amount of light gained even with overcast skies.

1.3 This manual

The rest of this manual focuses mainly on the tube-shaped and fibre transport methods. Heliostats can be used for redirecting extra light to the collectors of the tube or fibre systems, but will not be considered further here.

The various methods will be viewed more in-depth, considering the implications on the architecture of the usage (reserving space inside and outside of the building, infrastructure), the efficiency c.q. light yield of the systems, and short examples of the methods being used in practice.
Figure 1.3: Glass tube, station Potzdamer Platz
2 Light pipes

2.1 Principle

A light pipe (sometimes referred to as “light tube”) is basically a pipe-shaped mirror. It is an aluminium tube with a highly reflective inner surface; light that falls in it is reflected further down the pipe with little loss of intensity (see 2.1).

It provides a simple and relatively cheap method to lead daylight into spaces where it normally would hardly or not reach. It can also be used in rooms where direct daylight access can be realised but would cause glare issues or thermal discomfort due to direct sunlight.

At the outside of the building, the tube is capped of with a dome that collects light from all directions. At its endpoint there is a luminaire that spreads the light into a room; generally a diffuser is used in this luminaire (see 2.2). Other possibilities are a blank cap for more direct light, or a fresnel-like lens.

![Figure 2.1: Principle of a light tube](image1.png)

*Figure 2.1: Principle of a light tube*

![Figure 2.2: Diffuser at the end of a solar pipe, without and with light](image2.png)

*Figure 2.2: Diffuser at the end of a solar pipe, without and with light*
Figure 2.3: *Light tube application in a warehouse*

Figure 2.4: *Application in a fire station*
2.2 Application

The pipe takes up a lot of space, which limits its applicability in existing buildings to rooms which have a more-or-less vacant spaces above or next to them, such as a storage room, attic, installation room, pipe shaft or spacious suspended ceiling.

As there is usually one dome-pipe combination per luminaire, the best application is probably for rooms right under the roof because the pipes can be kept short (2.5) and do not take up any extra space in the building.

Examples of these in practice can be seen in figures 2.3 and 2.4. These are respectively an existing warehouse where the light pipes have been retrofitted, and a newly built fire station where daylight is provided to the restroom.

The diameters of the pipes vary from 25 cm to 50 cm roughly, for application large buildings this can even be bigger. For a new design it is therefore advisable to provide daylight as much as possible with windows, and necessary to reserve the space required for the pipes in suspended ceilings or pipe shafts. Although it is possible to choose the option to let the pipes be part of the architecture, as was done in the case of the Cardiff Police Station where the pipes run in sight through the atrium to provide daylight to the holding cells (Figure 2.6).

Mostly only one luminaire is placed at the end of a light pipe, but for some cases multiple luminaires are placed on the side of the pipe, for instance vertically in a stairwell. It should be noted that further down the pipe the light intensity decreases fast.

Another special case is the prismatic, transparent acrylic tube made by 3M that distributes light evenly along its length. This is not very well suited for smaller rooms, but works well in atria (see Figure ??), train stations (1.3), large office spaces, halls etc.

Figure 2.5: Illumination of a room directly under the roof
Figure 2.6: Cardiff police station

Figure 2.7: Prismatic tube in an atrium
2.3 Efficiency

First off, it should be noted that there is a wide variety of quality (and directly related to that, price) in light pipes. The cheapest are not rigid but flexible with a harmonica-like surface so it can easily take corners, but there is a lot of light loss in it. There are rigid metal pipes that have a reflective layer glued to the inside, but the quality of this layer (and thus the efficiency of the pipe) tends to degrade over the years, which gives it a limited lifespan of about 10 years. The best (and most expensive) solution is a rigid metal pipe which has its reflective layer deposited on the inside; it has a very high reflectivity and longevity.

The efficiency of the fixed light-pipes is reduced by the absorption of the walls of the pipe. The light is repeatedly reflected as it goes through the pipe. The light loss is proportional to the length-to-width ratio of the pipe (the more times the light is reflected within the pipe, the more the light is absorbed)\[1\].

For an indication of the efficiency, M. Paroncini et al.[1] calculated a DPF (Daylight Penetration Factor, roughly equivalent to the daylight factor) of approximately 0.5%.
Light pipes
3.1 Principle

The concept of optic fibre as a means of daylight transport is similar to that of a light pipe: the light guide here is a glass or polymer fibre wire but it can still be considered a hollow mirror because of the reflective cladding around the core (Figure 3.1).

![Figure 3.1: Optical fibre](image)

The advantage of optical fibre over the tube-shaped light guides is that they take up far less space, and that light can easily be concentrated. A single collector can provide light for multiple luminaires. A collector can be a mirror(3.2) or a lens(3.3).

![Figure 3.2: Solar collector mirror](image)
3.2 Application

Collectors can be relatively small, so they can be mounted easily upon a roof (Figure 3.4) or even on a wall (3.6).

Not many special measures are necessary, there only needs to be a small opening in the roof or wall to lead the fibre cable through. In new buildings this can be designed, on an existing building only some drilling is required. Inside the building, the cables can be
led over a suspended ceiling or through a conduit. The only thing that needs extra attention is bending the cables around corners; the more the cable is bent, the more losses in the fibre. When the bending radius gets too small, the fibre core might even break.

Just like with the light tube, the luminaires can be diffusors, but also spotlights, thanks to the high directivity of the light at the end of the cable.

### 3.3 Efficiency

A bit of light intensity is lost with each reflection but also due to impurities in the fibre. Just like with the light pipe, to give a single value for efficiency is rather difficult, as it depends on too many variables: the fiber length and material, collector efficiency.

Kandilli et al. [2] reported efficiencies between 69 and 80% for their test system, depending on the bending radius in the cable.
Luminescent solar concentrator

4.1 Principle

A rather new development in daylighting is the use of luminescent solar concentrators (LSC). These optic concentrators have been in use for a while in combination with PV solar collectors; they get more sunlight on the PV-cells and thus more electricity is generated. The use in the transport of daylight is still under development; as yet at the moment of writing there is no product on the market using this technology. It is included in this manual anyway because it might become a viable product in the near future.

The light then stays trapped inside the collector/light guide until it reaches a luminaire where it is released to the surroundings, as shown in Figure 4.2. The method used in the LSC concept is roughly the same as in previously

Figure 4.1: Green LSC sheet
mentioned systems: a solar collector on the exterior of the building connected to a light guide. In this case the light is captured in fluorescent material (like in Figure 4.1), in three separate layers of the light’s primary colours red, green and blue; this is schematically presented in Figure 4.2.

When the light guides of the three colours light are terminated in the luminaire and led through a diffusor, the human eye perceives it as white light (see Figure 4.4).

The plastic sheets of the collector have a fluorescent dye added to them to trap the light. For the red light, a pink dye is used as this better matches the response of the human eye; for the blue light a violet dye is used because there are no blue dyes available that perform good enough[3]. Because the violet dye matches human eye response rather poorly and degrades quickly due to UV light, it can be replaced by blue LED lights powered by PV cells.

A method of collecting more light

![Figure 4.2: Concept of the LSC system](image1)

![Figure 4.3: Light is trapped in the fluorescent material](image2)
4.2 Application

As already mentioned, there is no viable product based on this technology yet, but as an example a prototype of the Sydney University of Technology is shown here. It consists of a collector panel with red and green LSC sheets and PV cells (see Figure 4.5); the PV cells power blue LED lights. The panel is connected to a light guide (Figure 4.6).

![Combined LSC / PV collector](image)

**Figure 4.4:** Compound light of three colours, and (dotted) the response of the human eye in the visible spectrum is to use a luminescent down-shifting (LDS) layer: a layer that absorbs light in the 300–500nm wavelength range, and re-emits light at a longer wavelength in the visible spectrum[5]. This LDS layer can be applied right on top of the LSC layers. This basically means that extra visible light is sent into the light guide, even with overcast skies.

**Figure 4.5:** Combined LSC / PV collector
This light guide takes up little space and can easily be led through a building (Figure 4.7), even existing ones. The collector panel can be easily mounted on a roof or even integrated in a façade design.

A disadvantage of this system is that the light guide must follow the shape of the collector instead of using optical fibre, which limits the range and reticulation (i.e. the possibility to have a “forked” able network structure). An alternative was devised at the University of Malaya[4] where the collector consists of fluorescent fibres with a diameter of 2mm so that regular optical fibre can be attached to it (see 4.8) but unfortunately this has not left the testing state yet.

4.3 Efficiency

The model of the University of Sydney’s model is said to be able to illuminate a remote room (10m away) by over 1000 lm of natural light with a luminous efficacy of over 300 lm/W, regardless of the sun’s position, in clear sky conditions, and a light-to-light efficiency of 6%[3].
References


Image credits

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