Contents

Chapter 1

Introduction

Human life has been dominated by daylighting ever since being early inhabitants in caves. For centuries, it has been the only light source available [1, 2]. On the one hand the sun allows human beings to distinguish day from night and on the other hand provides heat to mankind. Around the year 2800 B.C., during the time of the Ancient Egyptian civilization, daily life was equally conditioned by the use of natural light as shown in the Egyptian pyramids, which represent the religious architecture of the epoch. Greek cultures began to design their houses in such ways as to capture solar radiation during the winter and avoid the sun's heating in summer, giving priority to solar design over other considerations. Later, the Romans adopted the Greek architectural technique. The lack of natural resources used for heating for long periods conditioned the development of solar design in architecture, adapting it to the different climates of the empire [3]. The use of glass as an architectural element by Roman glassmakers was one of the most important innovations of the era and was used in pavements, plates for wall cladding and in the sealing of holes and windows fixtures [4]. With the incorporation of colourless glass towards the end of the 1st century A.D., the use of solar energy increased as a source of heat in various areas such as greenhouses or hot springs. Later, due to the rise, of Christianity in the Middle Ages (Fig. 1.1), the most important glass production was carried out in the decoration of churches [5] and temples, and standing out among the glazed elements were the iconic stained glass (windows).

In the seventeenth and eighteenth centuries great technological advances in different fields such as optics or chemistry provided improvements in the manufacturing processes. Finally, a decisive boost of growth was realized in the 19th century due to the mass production of flat glass plates that provide greater luminosity and improve the appearance of large buildings through the construction of large windows. In the nineteenth century the popularity of stoves as a heat source was so widespread that the correct orientation of the façades of buildings was neglected, eroding concerns about solar effects.

Figure 1.1. Burgos Cathedral, Spain. Night-time illumination, stained-glass windows.

In another way, artificial light is incorporated definitively at the end of the 19th century, providing new possibilities of architectural design related to the temporal and spatial independence in illumination. Architects reformulated the concept of natural lighting in order to give it an adequate use in relation to the life of the occupants. Current efects of global warming together with its aesthetic possibilities and the ability to meet man's biological needs increases interest in its use in the present century [6].

The Sun, and therefore solar radiation harnessed by the Earth in its orbit, is the main source of renewable energy within our reach, energy that is available indefinitely and in a predictable proportion, although with some variations [7, 8]. The solar constant is the amount of energy received in the form of solar radiation at the edge of the Earth’s atmosphere during a specific time and is approximately 1.35 kW/m^2 [9].

Highly variable quantities at ground level change with aspects such as latitude, seasons of the year and climatology.

Sunlight is increasingly being integrated into buildings as an architectural tool for saving energy, but the physical and psychological effects caused by illumination in humans also have to be considered as they can provide benefits as significant as that of saving energy. The beneficial effect of natural light on the health of people has been known since antiquity and thanks to advances in multiple sciences such as medicine or biology have once again come into focus to improve the health and well-being of individuals [10, 11, 12].

Natural light varies in intensity and quality at every moment of the day, and the amount of variation which is tolerable and desirable in the illumination of spaces depends on each particular use. Lighting requirements, according to the country regulations, are very strict in some cases, in some cases, for instance, in museums, and more flexible in others, such as in leisure spaces. Light sources can generate discomfort, glare in the visual field, resulting in visual irritation and reducing overall productivity in exposed humans [13] so the control of the admission of natural light within spaces requires a careful design [14]. In order to provide a good lighting, there are three basic factors to take into account: quality, quantity and distribution. An optimal natural lighting strategy regulates the level of illumination inside the building and controls the directionality of the light, optimizing the quality of the environment.

Today, natural lighting is of high importance in architecture due to the need in society for the reduction of energy expenditure in order to prevent global warming. Since the 1970s, daylight guidance systems have been one of the most important areas of study and innovation with the aim of giving it an adequate use in relation to the conservation of energy [15, 16]. The incorporation of elements usually used as windows is a fundamental part in the design of buildings. However, its use has some limitations, such as the possibility of producing discomfort glare, high contrast and excessive brightness. The light flow they provide affects mainly the close proximity of their location so they require artificial auxiliary lighting systems [17] or systems of luminous control. The increase of buildings during the last decades (Fig. 1.2 and Fig. 1.3) requires the development of innovative systems that allow distribution of natural light in inner areas where the traditional elements are not effective [18, 19].

Figure 1.2. Faculty of Optics and Optometry, University Complutense of Madrid, Spain. Natural-lighting design in architecture.

We can divide the strategies of natural lighting design development into two large groups [20, 21, 22]. The first includes lateral lighting systems, in which the light is captured from the side of the building towards the interior. Currently, there is a great variety of developments that direct and distribute light although the examples more widely used are windows. The second group includes roof lighting systems (ceiling) whereby light is captured from the top of the building and distributed inside. An example of this are skylights, which can be defined as open windows in the ceiling or in the higher segments the walls where light enters. Changing the orientation of these systems, as well as their size and location, has been able to increase their effectiveness.

Figure 1.3. Interior view of Museum of Human Evolution, Burgos, Spain. Natural-lighting design in architecture.

Innovative daylighting systems are designed to redirect the sunlight or the sky towards the places where it is required without producing glare, using developments in the fields of optics that make use of the laws of reflection and refraction in the materials. One of the main design challenges of the systems in lighting lies in optimizing efficiency. This is achieved by acting on the various elements that make up the system, such as minimizing the size of the area of capture by incorporating materials with high reflectance or transmittance and changing the geometry of the components. Innovative systems include optical elements such as mirrors, prismatic glasses, shelves, atriums and guides of light. Mirrors can be used to direct and reflect direct sunlight.

Prismatic glasses, among other applications, alter the direction of sunlight and avoid glare caused by direct light. Light shelves work with the principle of reflection and can redirect, diffuse and also direct light to avoid glare from the sky. They are usually located horizontally and on top of windows or inside buildings, reflecting the light towards the ceiling in a diffuse way, helping in this way to obtain a greater uniformity of light in the desired area. Atriums provide more light in the constructions of large dimensions, increasing the comfort of the occupants.

In 1881, William Wheeler [23] developed an illumination system based on hollow light guides. Thereafter, these systems were developed to distribute natural light in spaces where it is absent [24, 25]. Hollow light guides are considered to be the most widely applied innovative systems worldwide [26], which can provide an increase in natural light, lowering the total expense of electricity.

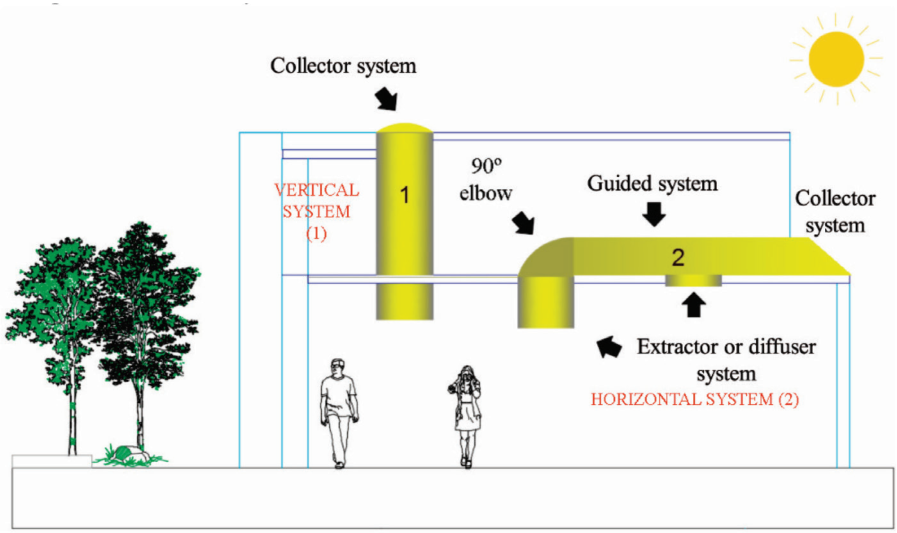

Figure 1.4. Basic components of the hollow light guides integrated into a building: vertical (1) and horizontal system (2).

In the basic guiding mechanism (shown in figure 1.4), light strikes a collector system located on the outside of the construction and is guided into the interior of the building through a tubular system, usually vertical (1) or horizontal (2), internally coated from a highly reflective material like aluminum to be expelled by means of an extractor system or diffuser. Transparent hollow light guides incorporating prismatic films have improved compared to aluminum-based ones as an increase in efficiency for certain angles of light [27]. The incorporation of hollow light guides allows to increase the luminous flux without an increase of temperature in summer or thermal losses in winter, improving on the construction and design alternatives. In this book, innovative optical designs are proposed such as the lateral extraction system and angular guides, which offer improvements in the guided light through hollow prismatic light guides. These designs allow the orientation of direct light in space using nonimaging optics, by means of dielectric materials and reflective efficiency. Through theoretical calculations and experimental models, several efficiency, analysis and colorimetric calculations have been carried out in hollow light guides of different geometries and materials. The development of a mathematical model for the calculation of the light transmission of hollow prismatic light guides, shows the efficiency of the system associated with an analysis of the prismatic film to micrometric scale. The mathematical model allows to quantify the influence of several parameters that characterize it as well as the defects that exist in the surface of the material that composes it. To quantify the topographic defects, they have been studied by means of different techniques of microscopy on a micrometric scale. The model adjustment is carried out through optimization procedures based on the obtained flux data in simulations with ray tracing software using realistic models and verifications with an experimental model. Finally, a technique is proposed of morphological analysis, using image processing algorithms to evaluate the influence of flexion on the deformation of a flexible prismatic film. This technique shows the relationship between the curvature of the film, the deformation and the flux of transmitted light.

The present work provides a quantitative estimation of the influence of numerous factors that affect the transport of light in hollow prismatic light guides in order to contribute to the prediction of light losses, such as the influence of defects or the modeling of optical systems.

The book is divided into six chapters. Chapter one contains an introduction to general lighting in architecture. Chapter two deals with the main aspects and design parameters related to artificial lighting in architecture. Chapter three presents a review of the main theoretical concepts related to light and its measurement and analyzes the advantages and disadvantages of solar light guidance systems. The current state of the art is also presented and discussed in the technology of prismatic light guides. In chapter four, various developments in guiding and extracting light by means of calculations are described, as well as theoretical and experimental analysies of efficiency. Colorimetric calculations in hollow light guides of different geometries and materials are shown, in addition to the techniques of optic analysis used and the instrumentation applied. In chapter five, the analysis and characterization of a microprism surface is shown, an experimental prototype is developed to determine the efficiency in the guides of light and, subsequently, a semiempirical mathematical model is proposed. Chapter six provides a method of characterizing the deformation produced in a prismatic film induced by changes in the curvature of the cylindrical guide that contains it. This method is based on recognition procedures and image analysis. Experimental and theoretical quantifications are also discussed as well as losses of light due to these changes through analysis of optical transmittance.