Energy and Buildings 80 (2014) 394–405

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Innovative daylighting systems' challenges: A critical study

M.S. Mayhoub*

Architecture department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 17 March 2014
Accepted 7 April 2014
Available online 5 June 2014

Keywords:
Innovative daylighting systems
Light collector
Light guide
Light diffuser
Cost
Application

ABSTRACT

The innovative daylighting systems (IDS) seek to meet the illumination requirements in buildings, where inadequate amount of daylight is provided by the conventional daylighting systems. Many IDS have been commercially launched, but challenges, such as high initial cost, utilization difficulties, and application limitations, prevent their widespread use. Most of these challenges can be overcome, but no IDS are likely to overcome all of them at once. Alternatively, a number of systems that efficiently suit different circumstances is a more practical approaches. This study reviews the IDS whether commercially released or not, and discusses the challenges associated with their utilization within buildings. Solutions and recommendations have been suggested. The study makes the capabilities and limitations of the different IDS clearer for both architects and users, and discusses the challenges and promises facing developers and lighting designers.

1. Introduction

Conventional side and top lighting techniques have been used to provide adequate amounts of daylight as long as a high skin-to-volume ratio has been sustained within the buildings. The new building forms and user needs resulted in high-rise, deep-plan and compact buildings. Consequently, maintaining the high skin-to-volume ratio that allows daylight to reach most building spaces became inapplicable. The need for *deep-plan buildings* meant that side windows are not the best choice, as they distribute flux principally up to 6 m from the window wall causing glare, high contrast, and excessive brightness, leaving the remainder of the perimeter zone and the core lacking sufficient light. The need for *high-rise buildings* meant that roof openings are not the proper solution as they are mostly inapplicable for anything other than the highest storey.

The precious *value of city land* made the provision of daylighting via central spaces, which raise the skin-to-volume ratio, an uneconomic alternative in many cases [1]. Accordingly, three new strategies have been developed to bring daylight deeper into the new building forms and to control and distribute direct sunlight by either improving the conventional techniques, developing new glazing systems, or inventing innovative daylighting systems.

In any strategy, newly developed devices and optical materials are used. The produced daylighting systems additionally contribute in conserving energy, protecting the environment, and enhancing building users' productivity and well-being.

The IDS are reviewed and criticized in this study since most of the improved conventional daylighting techniques have already been well integrated into the building fabric, and are familiarly used by building designers. The glazing technologies are more concerned with eliminating the heat transmission throughout the glazing systems, and are already a preferable façade element. Meanwhile, the IDS are relatively new and expensive. More experience, from both developers and architects, is required to produce more practically applicable and aesthetically appealing systems.

2. New daylighting system strategies

Enormous attempts have been carried out to enhance the provision of daylighting in buildings, which can be classified into three strategies as described in the following sections.

2.1. Improving the conventional daylighting techniques

This strategy seeks to improve the conventional daylighting technique capabilities to deliver daylight. This is mainly achieved throughout the use of new optical materials, elements and devices, such as overhangs, lightshelves, louvres, blinds, screens, and light filters. The use of these techniques either reduces daylighting problems, send more daylight to the back of the space, or improves the daylighting uniformity within the space [2]. They are widely available and affordable. Over the time, the older solutions, such as the overhangs, have been turned into architectural vocabularies, and

* Tel.: +20 10 14801827.
E-mail address: msmayhoub@hotmail.com

http://dx.doi.org/10.1016/j.enbuild.2014.04.019
0378-7788/

the newer ones, such as the metal louvres, have become part of the contemporary architecture image.

2.2. Developing glazing systems

This strategy seeks to achieve the daylighting goals throughout the development of the building envelope glazing system. The glazing technologies are mainly concerned with enhancing the thermal insulation properties, and thus allow more glazing area to be applied in order to admit as much daylight as possible while preventing transmission of as much solar heat as possible.

There are three fundamental approaches to improve the energy performance of glazing products. The first approach is to alter the glazing material itself by changing its chemical composition or physical characteristics. An example of this is the tinted glazing, the chromogenic glass, and the aerogel [3,4]. The second approach is to apply a coating to the glazing material surface to reduce heat gain and glare. Spectrally selective glazing is achieved by applying a microscopically thin, low-emissivity coating on the glass to improve both heating and cooling season performance [5]. The third approach is to assemble various layers of glazing, and control the properties of the spaces between them. Automated shading devices can also be included inside the glazing units [5–7].

2.3. Inventing innovative daylighting systems

This strategy is more concerned about delivering daylight into remote and windowless spaces in buildings and aims to maximize the utilization of the available daylight. Many IDS have been developed with a vast variation of technologies and solutions covering a wide range of applications. They typically consist of a light collector, light guide and diffuser, with a possibility to combine two of them in one part. Passive or active collectors installed on the building roof or attached to the building façade made of clear optical materials, mirrors or lenses are used to collect direct sunlight and/or diffused skylight. The light guide delivers the collected daylight through the building vertical voids (e.g. atrium) or via fibre optics or light pipes (ducts). Glass or plastic fibre optics maybe used. Light ducts made of/or lined with high reflective materials of transmittance which exceeds 99% per light bounce became cost-effectively available [8]. A wide variety of conventional or custom-designed light outputs are employed to suit most of the architectural lighting applications [9].

3. Innovative daylighting systems review

Many IDS have been developed over the last few decades, but few of them have found their way to the retail shelves. The IDS are classified into four groups according to their progress towards market penetration. The first includes the commercially available systems, the second includes systems developed but still under demonstration, the third includes systems in the prototype stage, and the fourth includes systems did not step beyond the theoretical idea.

3.1. Commercialized systems

Few IDS have managed to turn into commercial products. The *passive tubular daylight guidance system* (TDGS) is believed to be the most commercially available IDS, and is known as 'sun pipe', though it still has some limitations. It is mostly installed in the highest storey of the building due to difficulties in guide installation, although it is technically able to deliver daylight further [1,10]. This system delivered daylight up to 14 stories when it was applicable to install sun pipe in a building central space (Fig. 1) [11]. Some applications improve the collectors by means of active or static mirrors to increase the harvested daylight (Fig. 2) [12]. Other systems alternatively use light well and electric light sources may also be integrated.

Fig. 1. A 14-storey height sun pipe.

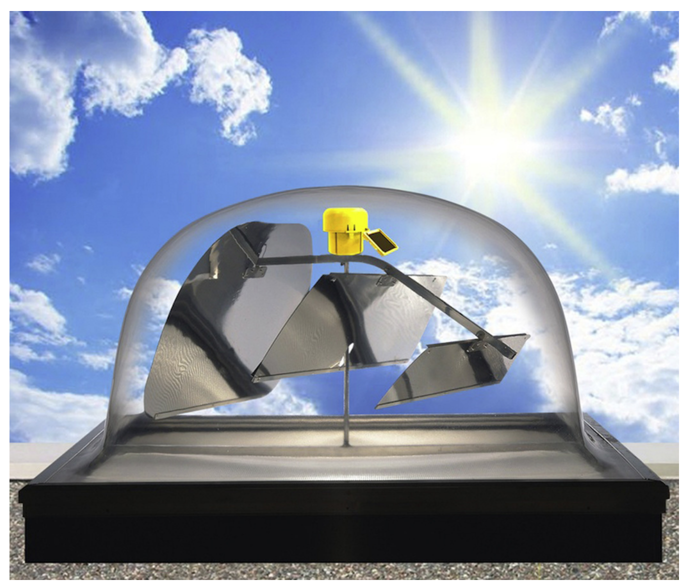

Fig. 2. Active mirrors used in the collector to increase the harvested daylight.

Many types of the *Heliostat* are produced to collect sunlight by using a set of mirrors and/or lenses, which send it into building core via vertical voids. A further set of internal mirrors may be used to distribute the daylight. The Heliostat has very different shapes and components and can be considered as a custom-designed system [13]. A small and economy type of Heliostat for residential use has been recently produced [14].

The Swiss Company *Heliobus* produced daylighting systems combined of Heliostat and sun pipes systems. The former collects