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RESEARCH ARTICLE

Comparison between lighting performance of a virtual natural lighting solutions prototype and a real window based on computer simulation

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Abstract
This article discusses the measurement and simulation of a first generation prototype of Virtual Natural Lighting Solutions (VNLS), which are systems that can artificially provide natural lighting as well as a realistic outside view, with properties comparable to those of real windows and skylights. Examples of employing *Radiance* as a simulation tool to predict the lighting performance of such solutions are shown, for a particular case study of a VNLS prototype displaying variations of a simplified view of overcast, clear, and partly cloudy skies. Measurement and simulation were conducted to evaluate the illuminance distribution on workplane level. The key point of this study is to show that simulations can be used to compare an actual VNLS prototype with a hypothetical real window under the same sky scenes, which was physically not possible, since the test room was not located at the building's façade. It is found that the investigated prototype yields a less rapidly drop illuminance distribution and a larger average illuminance than the corresponding real window, under the overcast

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(52 lx compared to 28 lx) and partly cloudy (102 lx compared to 80 lx) sky scenes. Under the clear sky scene, the real window yields a larger average illuminance (97 lx) compared to the prototype (71 lx), due to the influence of direct sunlight.

1. Introduction

Many researchers have shown the significant role of windows in buildings. Windows are important in controlling the amount of natural light admitted from the exterior environment into the buildings. It has been shown that building occupants feel windows are important due to their preference for having natural light over electric light (e.g., Hartig et al., 2003; Chang and Chen, 2005; Aries et al., 2010). Several studies have reported beneficial and restorative effects of views on a natural scene (e.g., Tennessen and Cimprich, 1995; Berman et al., 2008), whereas views on human-built environments yield effects, which are similar to having no window at all (Kaplan, 1993). Kim and Wineman (2005) showed empirically that views and windows have psychological and economic values. Moreover, a proper use of natural light would potentially save considerable amount of energy from artificial lighting use (e.g., Hammad and Abu-Hijleh, 2010; Yun et al., 2010). In a general term, the correct application of a daylighting strategy in buildings increases visual comfort and energy efficiency (Galasiu and Veitch, 2006).

Despite all of its advantages, the quality and quantity of natural light is highly variable, and its availability is limited in time and space. For instance, there is not enough or no daylight at all during nighttimes; buildings can be too deep to supply sufficient daylight throughout the space (Reinhart, 2005; Reinhart and Weismann, 2012) and some rooms are simply not provided with windows, skylights, or any form of daylight transporting systems, and therefore are not suitable for long-term working activities.

In the cases where a real natural lighting solution is absent or ineffective, for instance due to space and time limitation, the concept of Virtual Natural Lighting Solutions (VNLS) can be promising to overcome the problem of lack of daylight. VNLS are defined here as "*systems that can artificially provide natural lighting as well as a realistic outside view, with properties comparable to those of real daylight openings*".

A number of efforts have been made to imitate one or more elements of natural light inside buildings, in the form of artificial solutions. Originally, the efforts were more focused on bringing 'view' of an outside condition into the room. Attempts to create a realistic artificial view have been under development for centuries. For example, in art history, *trompe l'oeil* is known as an art technique involving realistic imagery to create the optical illusion that the depicted objects appear in three dimensions, while actually being a two-dimensional painting. This technique can be traced back to the ancient Greek era around the year 400 BC, and was well-developed mostly by Italian artists between the 15th and 17th century. Despite very inspiring, this example is not discussed further in detail, since it is not an actual light source, nor a device that can transmit light from outside environment. Nevertheless, the concept of displaying artificial sceneries of nature is still used in the later form of VNLS prototypes. Some researchers have shown that artificial views, which do not emit light themselves, can actually give positive effect on human health (e.g., Heerwagen, 1990; Ulrich et al., 1993).

Interestingly, the inverse is also true. In its intense appearance without a sufficient view, artificial bright light can give a positive effect on human well-being, particularly for healing purpose (e.g., Eastman et al., 1998; Lingjærde et al., 1998; Avery et al., 2001). Many specific lighting products had been manufactured to generate a large amount of light with a particular spectral power distribution for this application. In general, the idea behind this type of VNLS prototypes is to recreate the situation with natural light and its qualities inside a space, and to harvest the benefit it may offer.

In addition, directionality of the light is another important property that distinguishes a real window or skylight from an artificial light source. In fact, directional light is something rarely appears on the existing VNLS prototypes, since most of them only generate light in a nearly diffuse direction. Therefore, a non-diffuse, or directional, light is considered a key feature that should appear in an ideal VNLS prototype. Based on these considerations, any VNLS prototypes (that exist) and models (that do not yet exist) can be classified based on their light and view qualities, as illustrated in Figure 1, into four categories: (1) those providing relatively simplified view and mainly diffuse light, (2) complex view and mainly diffuse light, (3) simplified view and mainly directional light, and (4) complex view and mainly directional light. Examples of the first two types already exist as prototypes or real products in reality, while the last two do not yet exist at the moment and are still under development, of which building performance simulation tools have the role to predict the performance.

1.1. Prototypes with a simplified view

One of the simplest versions of a VNLS prototype is the 'light box', which is generally constructed of a series of artificial light sources behind a diffuse surface. This prototype in general displays a low resolution and largely simplified view. With regards to health application, research has shown that light boxes can be installed for healing purpose. It is known that human bodies use natural (sun-) light to regulate a variety of functions that affect mood and energy level, cure skin disorders, and make vitamin D (Begemann et al., 1997). Without enough (sun-) light, humans often feel down, lack