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# A simple tool to evaluate the effect of the urban canyon on daylight level and energy demand in the early stages of building design

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**Abstract**

Daylight is a restricted resource in urban contexts. Rooms situated in an urban context often have a significant proportion of the sky and the sun blocked out by the urban building mass. The reduced direct daylight potential makes daylight reflected from outdoor surfaces an important daylight source to the room. It is therefore important to be able to take into account the daylight reflections from the urban environment in early design stage. This paper describes a simplified method that uses a combination of ray-tracing, the luminous exitance method and the concept of the urban canyon to represent daylight levels in rooms situated in an urban setting. The method is implemented in the daylight algorithm of an existing building simulation tool capable of making rapid integrated daylight and thermal simulation. Comparisons with the more sophisticated lighting tool Radiance show a maximum relative error of 17% but it is often much lower. The accuracy of this approach is therefore considered to be adequate for the early stages of the building design process. The results from integrated daylight and thermal simulations are presented to illustrate how the tool can be used to investigate the impact of urban canyon parameters on indoor environment and energy performance.

*Keywords:* Simulation; Daylight; Energy use; Building design; Urban canyon

## 1. Introduction

Investigations by Littlefair (2001) and Li et al. (2009) show that the urban morphology has substantial impact on the amount of daylight and solar radiation received through windows. Simplified calculations document an effect of almost 10% in the relationship between urban morphology and energy consumption in non-domestic buildings (Ratti et al., 2005). More detailed simulations have demonstrated that the geometry of urban canyons has a relative impact on total energy consumption, compared to unobstructed sites, of up to +30% for offices and +19% for housing (Strømann-Andersen and Sattrup, 2011), and that the urban context significantly affects the availability and distribution of indoor daylight.

These findings make it imperative for building designers to be aware of the impact of the urban context on indoor climate and building energy performance in the early stages of the design process. Computer-based building simulation is ideal for this. Detailed simulation programmes like ESP-r (University of Strathclyde, 2011) and EnergyPlus (US Department of Energy, 2013) can link daylight and thermal simulation in an integrated manner. ESP-r is able to base the luminaire control in its thermal regime on the internal daylight distribution calculated with Radiance and the daylight coefficient method (Clarke and Janak, 1998). EnergyPlus is able to base luminaire control on calculations of

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illuminance levels in certain indoor reference points (maximum two). The illuminance is not calculated directly but by interpolating calculated daylight factors (DF) for the sky vault contribution and the direct sunlight contribution, respectively, and then multiplying by the exterior horizontal illuminance (Ramos and Ghisi, 2010). However, the use of these tools requires expert knowledge and large amounts of input data for even the simplest simulation, rendering them impractical in the early design stages where information is scarce. This calls for the development of more simple tools that are fit for the early design stages.

Rapid whole-year daylight algorithms that includes the reflections of neighbouring buildings are available (Robinson and Stone, 2006; Walkenhorst et al., 2002) but they lack interactivity with the thermal domain. There are a few attempts to integrate rapid whole-year daylight algorithms in thermal models (Hviid et al., 2008; Franzetti et al., 2004; Athienitis and Tzempelikos, 2002), but it is only the tool BC/LC by Hviid et al. (2008) that has implemented an algorithm for representing the daylight reflections of neighbouring buildings. However, the algorithm is very simplified and has critical limitations when designing buildings in an urban context. In the following, a new calculation method to account for daylight reflections from the urban context on indoor daylight levels in BC/LC calculations is described and validated. Furthermore, integrated daylight and thermal simulations are made to demonstrate how the tool can be used to investigate the impact of urban canyon parameters on indoor environment and energy performance.

## 2. Calculation method

The proposed calculation method is an addition to the algorithms already implemented in BC/LC. The full description and documentation can be found in Hviid et al. (2008) but for clarity, the method is summed up. The daylight modelling principle in BC/LC is based on a split flux approach where the daylight on surfaces in the room is split into four main contributions. The direct contribution from the sky and sun to the room surfaces is calculated using backward ray-tracing. The internal daylight reflection contributions employ the luminous exitance method (Park and Athienitis, 2003). The program thereby calculates the spatial daylight distribution in the room as illustrated in Fig. 1.

The contribution from light reflected from outside surfaces is treated in two ways: (1) reflections from building surfaces below the horizontal plane are considered a part of the average albedo, (2) the building surface of an opposing building substitutes the sky behind it creating a light source of reflected incident sky- and sunlight. However, the current algorithm does not take into account the building facade in which the room is situated. Consequently, the incident light on the opposing building surface only 'bounces' once thus ignoring the inter-reflections in the urban outdoor environment. The method described here seeks to improve the representation of the contribution from light reflected from outside surfaces to the indoor environment.

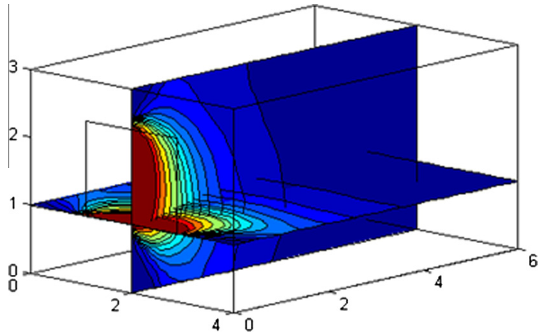

Fig. 1. Distribution of the daylight factor on a virtual horizontal plane (facing the roof) and a virtual vertical plane (facing left wall when looking out).

### 2.1. Light sources and ground-reflected light

An upper sky dome placed above the horizontal plane is used to model skylight and a lower (inverted) sky dome below the horizontal plane is used to model ground-reflected light. Both sky domes are divided into 145 patches using a discretization scheme proposed by Tregenza (1987). Each patch subtends a similar solid angle, which enables every patch to be treated as a point source with insignificant error. The sun disc is modelled as a separate point source on the upper sky dome. The illuminance on an external plane due to light from the sky dome ($E_{\text{sky}}$) is modelled using the approach in Robinson and Stone (2006):

$$E_{sky} = \sum_{i=1}^{145} L\Phi\sigma\cos\xi \tag{1}$$

where $L$ is the luminance (lm m$^{-2}$ Sr$^{-1}$) of the $i$th sky dome patch, $\Phi$ is the solid angle, $\xi$ is the mean angle of incidence (rad) and $\sigma$ ($0 \leqslant \sigma \leqslant 1$) the visible proportion of the patch. The calculation of the visible proportion of the patch ($\sigma$) takes into account the fact that geometrical obstructions may cut off parts of the upper as well as the lower sky dome.

The illuminance on an external inclined plane ($E_{\text{sun}}$) due to direct light is expressed as

$$E_{sun} = E_n \cos\xi \tag{2}$$

where $E_n$ is the direct normal illuminance from the sun.

Having determined the light sources, the reflecting ground can be represented as a luminous up-side down sky with constant brightness expressed as:

$$E_{ground} = \sum_{i=1}^{145} \frac{\rho}{\pi}(E_{sky} + E_{sun})\Phi\sigma\cos\xi \tag{3}$$

where $\rho$ is the mean ground reflectance (albedo).