THE LIGHTSWITCH WIZARD – RELIABLE DAYLIGHT SIMULATIONS FOR INITIAL DESIGN INVESTIGATION

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ABSTRACT

A web-based, non-expert daylighting analysis tool has been developed to support daylighting-related design decisions in peripheral private offices during an early design stage (http://buildwiz.com). The tool offers a comparative, reliable, and fast analysis of the annual amount of daylight in the offices (daylight factor and daylight autonomy) and the lighting energy performance of automated lighting controls (occupancy sensors, photocells) compared to standard on/off switches. Blinds are either manually or automatically controlled.

During a simulation run, pre-calculated, RADIANCE-based daylight coefficients for over 600 office designs are coupled with weather data from 285 sites in North America to yield annual daylight illuminance profiles. The annual electric lighting energy use is subsequently predicted via a model that mimics occupancy and manual lighting and blinds control in private offices.

A simulation run takes between 30 seconds to 3 minutes and yields a detailed report of the annual daylight availability and lighting energy use in the investigated office.

INTRODUCTION

The role of computerized building design tools is to supply decision makers with performance measures that support informed design choices. Given the breadth of choices and concerns a design team is constantly confronted with, various design aspects are usually competing for the team's attention. In this competitive environment, information gained through any one simulation tool are constantly weighed against the required time and financial resources necessary to obtain them, as well as information that could be gained through the use of other or no tools.

Daylighting analysis software should have a high acceptance and adoption rate within the market given that daylighting is (a) a desirable design aspect for most buildings and (b) difficult to capture through simple rules of thumb. Therefore it is surprising, that the market penetration of daylighting tools is slow. They seem to keep a "nice-to-have but too costly" stigma. A number of barriers against the wider usage of these tools have been identified in the past (Donn 1999):

- long learning curves due to the tools' complexity,
- uncertainty about the accuracy of simulation results,
- time-consuming 3D model preparation[1] and simulation times, and
- the absence of conclusive performance measures.

In addition, most tools provide analysis suitable for the full design phase, not the initial conceptual design work.

This paper introduces a new web-based analysis tool that aims to make advanced daylight simulation techniques available to a wider spectrum of users and foster their use at the initial design stage. The tool is called "The Lightswitch Wizard". Its mandate is to help:

- *building designers* to design perimeter offices with "enough but not too much" annual daylight.
- *lighting designers* to assess the energy/cost benefits of lighting and window blinds controls.

The Lightswitch Wizard design specifically addresses the barriers listed above. Its basic approach is shown in Figure 1:

Simulation input is provided via a web-based graphical user interface (*see* Figure 3) that allows the user to customize dimensions, material properties, lighting and blinds systems, and user properties for a standard peripheral office. Based on the chosen office properties, pre-calculated daylight simulation results are retrieved from a database and further processed to calculate the annual daylight availability and electric lighting energy use in the

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[1] A survey of 198 mostly North American architects and engineers yielded that 80% "always used" 2D-CAD compared to only 10% who "always used" 3D-CAD programs (Jacobs and Henderson 2002).
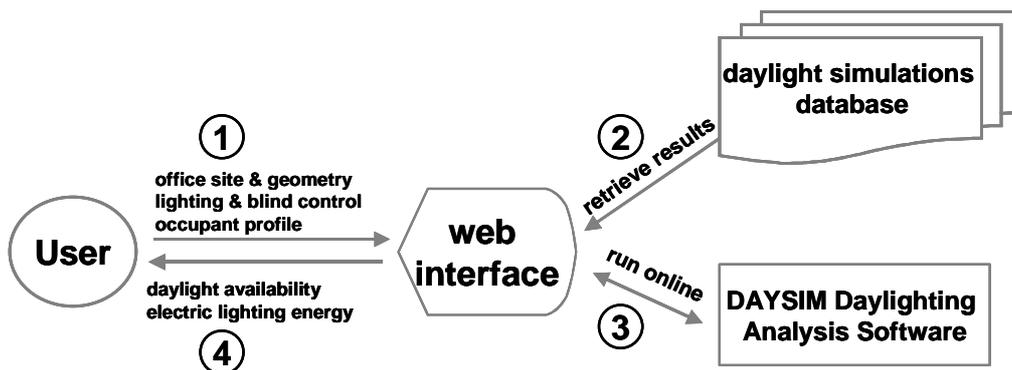
Figure1 :Basic approach of the Lightswitch Wizard.

office. A detailed simulation report (*see* Table 2) is delivered back to the user.

The simulation engine and output are described below, followed by an example application and a discussion of the merits and limitations of the wizard.

SIMULATION INPUT

Figure 3 shows a screenshot of the Lightswitch Wizard's main application window. Similar to the RADIANCE Image Database (http://gaia.lbl.gov/rid) and the Daylighting Design Variations Book (www.bwk.tue.nl/fago/daylight/), the tool offers a side-by-side analysis of two independent office scenarios at a time. Simulation input is grouped under three tabs: *site, office*, and *user*. The former two groups allow customary choices such as one out of 285 sites in North America[2], four facade orientations, and, currently, three prototype facades. Room dimensions, surface reflections, glazing type and frame proportions are entered under the *office* tab.

To reduce simulation times from hours to minutes without compromising simulation accuracy, daylight coefficients for all possible office combinations have been pre-calculated with the RADIANCE backward raytracer (Ward and Shakespeare 1998). Daylight coefficients offer a fast and reliable method to predict indoor illuminances under arbitrary sky conditions (Tregenza and Waters 1983). The Lightswitch Wizard uses the validated DAYSIM program (Reinhart and Walkenhorst 2001) to convert daylight coefficients and irradiance climate files

into 5 minute time series of the indoor illuminance distribution in the chosen office. These time series are in turn used to calculate annual daylight autonomies and daylight factor distributions (*see* Table 2).

A unique feature of the Lightswitch Wizard is a strong emphasis on the description of the occupant (occupancy and user behavior) and the lighting and blinds control systems.

User occupancy is characterized by arrival and departure times on weekdays, which are processed by a stochastic occupancy model that breaks up the working day through temporary absences from the work place (Reinhart 2001). The resulting mean occupancy probability on a weekday is shown in Figure 2 for an arrival time of 8:00 and a departure time of 17:00[3].
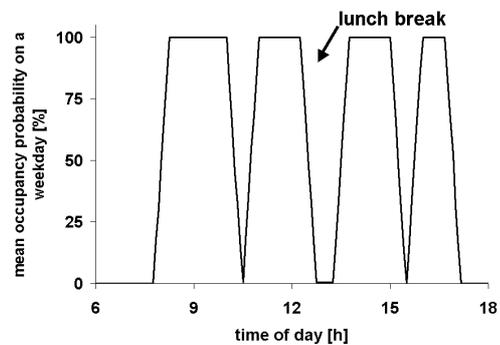

Figure 2: Mean occupancy probability on a weekday for arrival to departure times of 8:00 to 17:00.

User occupancy and daylight illuminance profiles determine the time per year when the

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[2] Hourly direct and diffuse irradiances have been taken from the Environment Canada database CWEEDS (Environment Canada, 1992) and the US database SAMSON (NCDC, 1996) for 1990 and converted into 5 minute time series using a stochstic model described in (Walkenhorst *et al.* 2002).

[3] For a working day longer than 6 hours, the occupancy model assigns a one hour lunch break and two 30 minute absences from the work place in the morning and afternoon.

occupant could principally work by daylight alone. User behavior and the lighting and blinds control system determine how much of this available daylight actually replaces electric lighting loads.

In the following the lighting and blinds control scenarios supported by the Lightswitch Wizard are described. The input variable *user behavior,* which determines how the occupant interacts with manual controls (on/off switch or manual blinds) is described further below.

The wizard features six lighting control scenarios:

- *manual on/off switch:* a standard manually controlled electric lighting system with an on/off switch near the door. According to chapter 27 of the IESNA Lighting Handbook (IESNA 2000), this is the reference system relative to which the energy savings potential of automated controls should be expressed.

- *switch-off occupancy sensor:* manually controlled on/off switch lighting system combined with an ideally located occupancy sensor with a user-specified switch-off delay time. The lighting system is switched on manually through the switch. It is switched off either manually by the occupant or automatically by the occupancy sensor. The occupancy sensor requires a standby power of 3W when the lighting system is switched on.

- *on/off occupancy sensor:* automatically controlled lighting system with an ideally located occupancy sensor with a user-specified switch-off delay time. The occupancy sensor is permanently in standby mode and activates the lighting whenever occupancy is detected. The standby power of the occupancy sensor is 3W.

- *dimming system:* ideally commissioned dimming system with a manual on/off switch near the door. A photocell dims the lighting until the total work plane illuminance (daylight & electric light) reaches a specified minimum illuminance threshold. At minimum lighting output (1%) the system consumes 15% of its full electric power. The photocell requires a standby power of 2W.

- *dimming system with switch-off occupancy sensor:* same system as above combined with a switch-off occupancy sensor. The control module (photocell and occupancy sensor) requires a standby power of 5W.

- *dimming system with on-off occupancy sensor:* fully automated dimming system that is switched on and off by an occupancy sensor. The control module (photocell and occupancy sensor) requires a permanent standby power of 5W.

The temporary setting of the blinds throughout the year determines the amount of daylight available for lighting. The following blinds control scenarios are supported:

- *manually operated blinds: s*tandard internal venetian blinds system commonly found throughout North America. Depending on the *user behavior* chosen, the blinds use is 'active' or 'passive' (Table 1).

- *automated blinds:* ideal automated blinds system. The blinds are fully lowered to avoid glare as soon as direct sunlight above 50 Wm^{-2} hits the work place. The blinds are re-opened as soon as the glare criteria is no longer met.

- *no blinds:* this scenario that is not recommended unless glare protection is realized through a static device such as a light-shelf.

To simulate indoor illuminances when the blinds are lowered, a simple blinds model has been used. The model assumes that the lowered blinds reject 100% of the direct and transmit 25% of the diffuse solar radiation (Vartiainen 2000).

A key finding from field studies on manual lighting and blinds control in single offices is, that even though occupants behave *differently*, they use their lighting and blinds controls *consciously* and *consistently* (e.g.: Lindsay and Littlefair, 1993; Pigg, Eilers and Reed, 1996; Love, 1998; Jennings *et al.*, 1999; Reinhart and Voss, 2003). The latter finding confirms that manual lighting control is not arbitrary and constitutes the theoretical foundation for models (such as the Lightswitch Wizard) that aim to mimic how occupants interact with their controls. To account for individual differences between occupants, the wizard allows to specify the occupant's *user behavior* concerning lighting and blinds use. To simplify this choice for the software user, lighting and blinds use have been termed either 'active' or 'passive' (*see* Table 1).

Table 1: Input parameters for user behavior in the Lightswitch Wizard (Reinhart 2002).

lighting use

active	User operates the electric lighting in relation to ambient daylight conditions.
passive	User who keeps the electric lighting on throughout the working day.
mix of both	mix of both behaviors for an *ensemble* of offices

blinds use

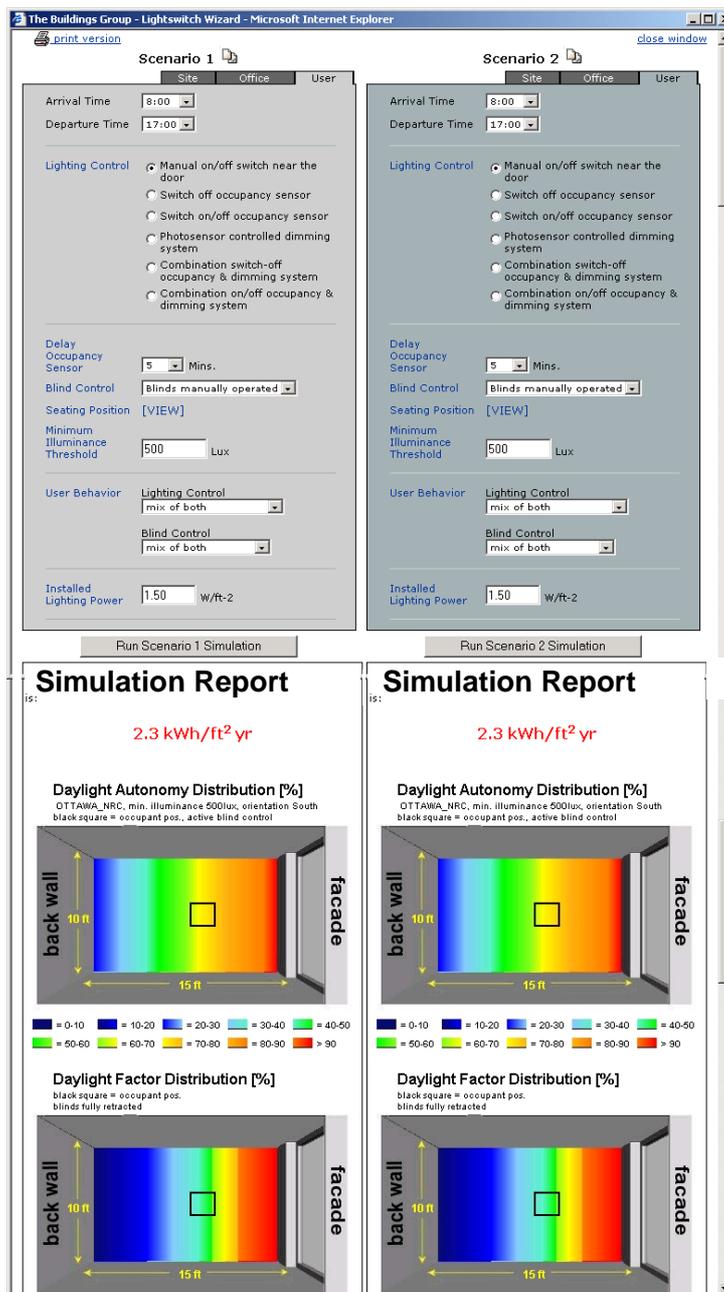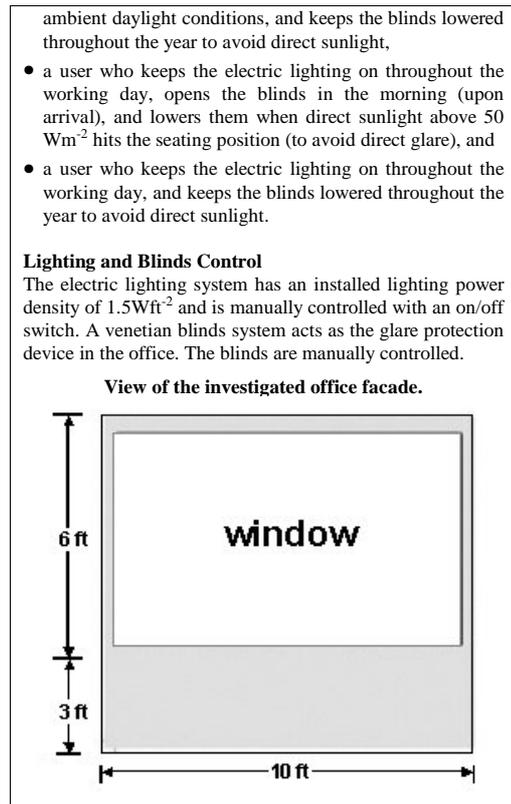|	
active	User opens the blinds in the morning upon arrival and partly closes them during the day to avoid direct sunlight.
passive	User keeps the blinds partly closed throughout the year to avoid direct sunlight.
mix of both	mix of both behaviors for an *ensemble* of offices

Figure 3: The Lightswitch Wizard offers a side-by-side comparison of the electric lighting use and annual daylight availability in two independent perimeter offices. The main application window is divided into four parts: Two upper input sections and two lower simulation report sections. The two left input and simulation report sections refer to office scenario 1. The two sections on the right refer to office scenario 2. Simulation input is organized into three groups: Site, Office and User.

The lighting and blinds control algorithms in Table 1 are a combination of various stochastic switch on/off probability functions that depend on occupant arrival, departure and indoor illuminances. The algorithms have been described in (Reinhart 2002). They are based on individual behavioral patterns that have been observed in field studies (Reinhart and Voss 2003). The electric lighting energy uses for identical offices and lighting systems can differ considerably for different *user behaviors*.

How can a designer choose an adequate lighting system for a particular project? For an individual office, it is impossible to predict the user behavior of the occupant. If, on the other hand, the office

Table 2: Example Simulation Report.

Simulation Report

The predicted annual electric lighting energy use in the office is:

$$2.3 \text{ kWh/ft}^2 \text{ yr}$$

Daylight Autonomy Distribution [%]

OTTAWA_NRC, min. illuminance 500lux, orientation South
black square = occupant pos., active blind control

= 0-10	= 10-20	= 20-30	= 30-40	= 40-50
= 50-60	= 60-70	= 70-80	= 80-90	> 90

Daylight Factor Distribution [%]

black square = occupant pos.
blinds fully retracted

= 0-1	= 1-2	= 2-3	= 3-4	= 4-5
= 5-6	= 6-7	= 7-8	= 8-9	> 9

Site Description

The office is located in OTTAWA_NRC (N 45º, W 75.67º). Daylight savings time lasts from April 1st to October 31st.

Office Description

The office has a facade facing due South. The facade glazing has a visual transmittance of 72.0%. The window unit has a frame proportion of 15.0%. The facade is unobstructed by surrounding buildings or landscape. The office has a floor to ceiling height of 9ft, is 10 ft wide and 15ft deep. The diffuse reflectances of the ceiling, walls and floor are 80%, 50%, and 20%, respectively. A view of the office facade is shown below.

User Description

The office is occupied Monday through Friday from 8:00 to 17:00. The occupant leaves the office three times during the day (30 minutes in the morning, 1 hour at midday, and 30 minutes in the afternoon). The occupant performs a task that requires a minimum illuminance of 500 lux. The predicted electric lighting energy use of 2.3 kWh/ft^2 yr corresponds to the mean energy use in an *ensemble* of indentical offices that are occupied by four user types:

- a user who operates the electric lighting in relation to ambient daylight conditions, opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm^{-2} hits the seating position (to avoid direct glare),

- a user who operates the electric lighting in relation to ambient daylight conditions, and keeps the blinds lowered throughout the year to avoid direct sunlight,

- a user who keeps the electric lighting on throughout the working day, opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm^{-2} hits the seating position (to avoid direct glare), and

- a user who keeps the electric lighting on throughout the working day, and keeps the blinds lowered throughout the year to avoid direct sunlight.

Lighting and Blinds Control

The electric lighting system has an installed lighting power density of 1.5Wft^{-2} and is manually controlled with an on/off switch. A venetian blinds system acts as the glare protection device in the office. The blinds are manually controlled.

View of the investigated office facade.

investigated by the Lightswitch Wizard is one out of many identical offices in a large building, the average energy demand for this *ensemble* of offices is the design criteria of interest. In this case, the relevant question becomes: What is the frequency distribution of the different user types in the building? Unfortunately, there is no data currently available to meaningfully answer this question. A straightforward engineering approach is to assign equal frequencies to all four combinations in Table 1 (active/active, active/passive, passive/active and passive/passive). This choice corresponds to the *mix of both*-option for lighting and blinds use.

SIMULATION OUTPUT

Table 2 shows an example simulation report. These reports are displayed in the main application window in Figure 3 below the input section. The influence of the different input parameters can be assessed through a side-by-side comparison of the simulation reports for two different scenarios. The main simulation results are presented up front:

- The annual electric lighting use is expressed in kWh/ft^{2}yr. Depending on the user behavior chosen, it either refers to the energy use of a particular user type or to the mean energy use of an *ensemble* of identical offices.

- The amount of daylight available in the office is expressed through false color maps of the
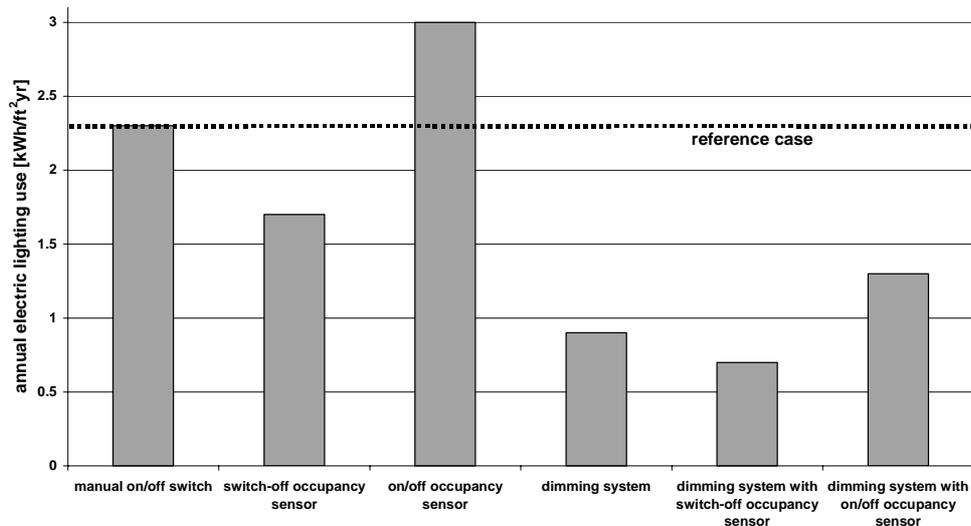
Figure 4:Example application for the office described in Table 2 for various lighting

daylight factor and daylight autonomy distributions. The daylight factor is defined as the ratio of the indoor illuminance on the work plane to the outdoor horizontal illuminance under an overcast CIE reference sky. It is a common parameter to characterize the daylight situation in a building as it is an intuitive quantity that can be measured or calculated. Nevertheless, its explanatory power as a design performance measure is limited as it ignores building orientation and geographical latitude, and is based on a single overcast sky condition.

- The daylight autonomy in a building is defined as the percentage of the occupied times per year, when a minimum illuminance level can be maintained by daylight alone. It is a performance measure that considers all sky conditions throughout the year when the office is occupied. It captures daylight availability, user occupancy and illuminance requirements in a single number. It is independent of the installed electric lighting system so that a high daylight autonomy is a *necessary requirement* but not a guarantee for lighting energy savings due to daylight.

For quality assurance purposes all simulation assumptions are documented in the simulation report in a format that can be copied and pasted into documents prepared by the users of the software.

EXAMPLE APPLICATION

Assume a designer working on an office building in Ottawa, Canada. The office has no external obstructions. All perimeter offices are private and have the dimensions of the example office in Table 2. In the reference scenario, all offices have standard on/off lighting switches and manually

operated venetian blinds. Table 2 informs the designer that the mean energy use in the offices facing south is 2.3 kWh/ft^{2}yr.

The designer is interested in estimating the energy saving potential of installing automated lighting controls. A few runs quickly lead to the results shown in Figure 4. All investigated automated lighting controls except for the on/off occupancy sensor are likely to yield energy savings with respect to the reference scenario. The on/off sensor hinders all users to ever work by daylight alone. This effectively nullifies energy savings for those users in Table 1 who would operate the electric lighting in relation to ambient daylight conditions. The largest electric lighting energy savings (70%) can be expected from a dimming system combined with a switch-off occupancy sensor. These savings are largely due to the dimming system and the high daylight autonomy of 70% near the work place[4]. Depending on the installation costs for the different automated lighting systems, Figure 4 allows the designer to quantitatively weigh projected payback times against initial costs. Of course, the same kind of analysis is also possible for the remaining three facade orientations.

DISCUSSION

As laid out in the introduction, the intention of the Lightswitch Wizard is to bring daylight simulation

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[4] The black square in the daylight autonomy distribution figure in Table 2 depicts the seating position of the occupant. This is one of the simulation inputs.

techniques closer to the mainstream design practice by aiming at the initial conceptual phase and combining a smart simplified GUI with a sophisticated calculation engine. This section discusses the extent to which the wizard overcomes the barriers identified above, and what its limitations are:

- <u>long learning curves:</u> Compared to the time required to proficiently learn RADIANCE, the wizard provides instant access to reliable simulation results for standard peripheral offices. The users of the software will have to invest some time into familiarizing themselves with the daylight performance measures provided. It will probably take a number of runs until the user develops a feeling of what is a *high* daylight autonomy or annual electric lighting use. On the other hand, "acquiring a systematic understanding of the relationships of architectural precedents to the environment" (Donn, 1999) –in our case room design and daylight availability– constitutes a useful exercise for a designer in itself.
- <u>time-consuming 3D model preparation and simulation times:</u> The time necessary for a user of the software to enter the building data and getting daylight simulation results is small compared to having to create a 3D model, import it into RADIANCE and run a simulation. This time savings on the users' side have been realized through a substantial simulation effort on the developer's side[5]. This effort has limited the number of prototype facades that are presently offered. More facades can be added as/if the wizard further evolves. In the meantime, the expert simulation software DAYSIM offers more ambitious users a way to get the same simulation output for arbitrary complex building models[6].
- <u>accuracy of simulation results:</u> All simulation results stored in the Lightswitch Wizard database are based on the RADIANCE simulation engine that has been validated for comparable sidelit rooms (Mardaljevic 1995). A comparison of the daylight autonomy measurements and calculations in a full scale test office showed that results were identical within a two percentage-point range (Reinhart and Walkenhorst, 2001). Despite these encouraging findings are daylight simulation results of the Lightswitch Wizard based on a number of approximations:
  - (a) Shading due to external objects is presently discarded.

(b) Mullions are not explicitly modeled. Instead the window transmission is simply scaled down depending on the frame to window area ratio specified by the user.
(c) As explained above, blinds are generic and not explicitly modeled.
(d) No furniture is considered.
(e) The ground reflectance is set to 20% throughout the year, ignoring snow cover in the winter.
(f) The dimming system is considered to be ideally commissioned which does not necessarily reflect current practices (see e.g. Floyd *et al.*, 1995; Love, 1995)

Of all these approximations, neglecting surrounding external objects can lead to the most drastic errors especially in dense urban settings. Using a generic instead of an explicit blinds model –which can lead to substantial simulation inaccuracies at individual time steps– usually becomes less crucial considering a whole year. The reason for this is that our present knowledge of how occupants use their blinds is limited and does not include what slat angles are routinely chosen or how far the blinds are lowered. In the model, blinds are either 'up' or 'down'.

The main simulation uncertainty lies in the user behavior model. As discussed in (Reinhart 2002) the current Lightswitch model offers a snapshot of current knowledge of office occupant interaction with their lighting and blinds controls. The model is currently being validated through field studies that are carried out in the context of the International Energy Agency Task 31, *Daylighting Buildings in the 21st century* [7].

- <u>conclusive performance measures:</u> Despite the uncertainties of the Lightswitch Wizard, the tool provides a set of relevant performance parameters that can be directly used to guide design choices. A limitation of the wizard is that it presently does not consider thermal energy balances for heating and cooling. This limitation might be overcome in the future. It bears the risk of a designer optimizing "one dimensionally" towards an adequate use of daylight while at the same time introducing unwanted heating and cooling loads.

CONCLUSIONS

This paper describes a new web-based daylight simulation tool to assist the implementation of daylighting measures in perimeter offices. Applications and limitations of the tool are discussed. Required simulation times are short and

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[5] The daylight coefficient data for one facade variant require about 1.5 GB of disc space and 9000 hours of CPU time to generate them.

[6] http://irc.nrc-cnrc.gc.ca/ie/light/daysim.html

[7] http://www.iea-shc.org/task31/index.html

pre-set input options largely draw on standard and readily available design choices. The simulation output provides innovative but intuitive performance parameters that can be seamlessly integrated into the design process. The tool has the potential to contribute to a wider usage of daylight simulation techniques at an early design stage. As this design support service is breaking new grounds, challenges lie ahead regarding its adoption by industry. A sustained effort to reach product maturity is planned for the near future.

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