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LIGHTSWITCH: A MODEL FOR MANUAL CONTROL OF LIGHTING AND BLINDS

Christoph F. Reinhart[*1], Denis Bourgeois[2], Francois Dubrous[3]

1 National Research Council Canada, Institute for Research in Construction

1200 Montreal Road, Ottawa, ON, K1A 0R6, Canada

2 Université Laval, École d'architecture
1 côte de la Fabrique, Québec, PQ, G1K 7P4, Canada

3 Natural Resources Canada, The Buildings Group – CANMET Energy Technology Centre
580 Booth Street, Ottawa, ON, K1A 0E4, Canada

ABSTRACT

A simulation algorithm and its implementation into three building simulation programs are presented. The algorithm predicts the lighting energy performance of manually and automatically controlled electric lighting and blind systems in perimeter daylit offices. Algorithm inputs are annual profiles of user occupancy and work plane illuminances. These two inputs are combined with probabilistic switching patterns, which have been derived from field data, in order to predict the status of the electric lighting and blinds throughout the year.

Assumptions underlying the model are currently being validated and refined through a series of field studies which are carried out within the International Energy Agency's Task 31, *Daylighting Buildings in the 21st Century.*

The algorithm has been linked to three simulation programs:
- Lightswitch Wizard: An online design support service (www.buildwiz.com) for daylighting and lighting control related design decisions in perimeter offices.
- Daysim: An advanced, Radiance-based version of the Lightswitch wizard that allows to model arbitrary building geometries (http://irc.nrc-cnrc.gc.ca/ie/light/daysim.html).
- Esp-r: In order to yield more holistic energy predictions, the integration of the model into the Esp-r whole building simulation engine is currently underway.

ZUSAMMENFASSUNG

Ein neuer Simulationsalgorithmus (Lightswitch) wird beschrieben, der das manuelle Schaltverhalten von Büronutzern für das Kunstlicht und einen Blendschutz beschreibt. Eingabegrößen sind Nutzeranwesenheit und minimale Beleuchtungsstärke am Arbeitsplatz. Diese Größen werden mit in Feldstudien beobachteten Verhaltensmustern verknüpft, um den Status des Kunstlichtes und Blendschutzes zu jedem Zeitpunkt des Jahres vorauszusagen. Diese Verhaltensmustern werden im Rahmen der International Energy Agency Task 31, *Daylighting Buildings in the 21st Century,* validiert und erweitert werden.

Bisher wurde der Algorithmus in drei Simulationswerkzeuge implementiert:

[*] corresponding author: Tel.: ++1(613) 993-9703; Fax: ++1(613) 954-3733, email: christoph.reinhart@nrc-cnrc.gc.ca

- Lightswitch Wizard: Ein Online Planungswerkzeug, das die Tageslichtplanung in Bürogebäuden unterstützt und das energetische Einsparpotential von Anwesenheitssensoren und tageslichtabhängig gesteuerten Kunstlichtsystemen vorhersagt (www.buildwiz.com).
- Daysim ist eine "Expertenversion" des Lightswitch Wizard, die es erlaubt, eine Tageslichtanalyse für beliebige Gebäudegeometrien durchzuführen (http://irc.nrc-cnrc.gc.ca/ie/light/daysim.html).
- Um den Einfluss des Nutzerschaltverhaltens auf den Gesamtenergiebedarf eines Büros quantifizieren zu können, wird der Lightswitch Algorithmus derzeit in das Gebäudesimulationsprogramm Esp-r implementiert.

INTRODUCTION

According to chapter 27 of the IESNA Lighting Handbook [Rea 2000], lighting controls in buildings are installed to provide occupants with "aesthetic and energy management control" over the electric lighting system. Since their first appearance in the 1987 edition of the Application Volume of the Lighting Handbook, lighting controls have been promoted based on the assumption that "local automated control techniques can be more cost effective than the usual reliance on manual operation of lights" (page 27-1) [Rea 2000].

Under what circumstances do lighting controls actually save energy and how much? The Lighting Handbook declares that "it is incumbent on the engineer and lighting designer to be aware of the wide variety of electronic lighting controls available and to correctly apply them to the project at hand" [Rea 2000]. In order to "correctly" apply these sensors, the handbook proposes a cost analysis by "adding the cost of the control system [including commissioning costs] to the rest of the equipment costs and determining how the controls affect operating costs". The Handbook acknowledges that "while cost information for lighting controls are easily available, performance information are not as available and may be very site dependant [...] with savings depending on indoor daylight levels, size of space, work schedules and occupant activities as well as occupants' attitude and training." Another complicating factor is the uncertainty of "actual blind usage in buildings". The Lighting Handbook does not further discuss the exact nature of these dependencies so that the lighting designer ultimately has to judge the "correct" lighting system based on personal experience, anecdotal evidence and/or computer-based simulation models.

Simulation models offer a comparative analysis of the energy performance of different lighting control systems. The energy performance of automated controls is relatively straightforward to model as it is based on deterministic correlations between physical quantities like the illuminance at a photocell and the status of an electric lighting system. The more challenging task is to model a conventional one-level manual switch which constitutes "the most common practice and should function as a reference system, relative to which energy savings of automated lighting controls should be expressed" [Rea 2000].

This paper presents the basic approach of a new manual lighting and blind control algorithm called Lightswitch that mimics manual lighting and blind control of occupants in private perimeter offices based on field study data. Following a brief description of the model, its future validation and implementation in three simulation tools are discussed.

BASIC APPROACH OF THE ALGORITHM

Figure 1 shows the basic Lightswitch approach. Model inputs are: measured or simulated 5-min annual profiles of user occupancy, and work plane illuminances due to daylight. The latter can nowadays be reliably predicted using dynamic daylight simulation methods such as Esp-r [Janak 1997], DLS [Mardaljevic 2000], and Daysim [Reinhart, Walkenhorst 2001], that combine a daylight coefficient approach with the Perez sky model.

Figure 2 details how the Lightswitch algorithm processes occupancy and illuminance input data series with a 5-min resolution. At each time-step the electric lighting and blind status are set according to the outcome of the loop in Figure 2(a). The gray "set blinds" procedure is described in Figure 2(b). The occupancy profile determines which switching decision applies. Afterwards a random process is initiated to determine whether the switching decision is followed by a switching event or not. All stochastic processes in Figure 3 have been extracted from field study data [Reinhart, Voss 2003]. Underlying assumptions, limitations and an example application of the Lightswitch algorithm are presented in [Reinhart 2002].

VALIDATION THROUGH IEA TASK 31 FIELD STUDIES

Even though the Lightswitch algorithm is based on scientifically sound methods, it is still of "preliminary" nature as are the underlying behavioral patterns. Both will need to be refined in the future as behavioral research on manual lighting control advances. One platform for these validation is through the field studies that have been carried out in the context of IEA Task 31 *"Daylighting Buildings in the 21st century"* (http://www.iea-shc.org/task31/index.html).

LIGHTSWITCH WIZARD

The algorithm has been implemented into an online RADIANCE-based daylighting analysis tool called the *Lightswitch Wizard* www.buildwiz.com [Reinhart, Morrison, Dubrous 2003]. The tool has been developed to support daylighting-related design decisions in commercial buildings during an early design stage. It offers a comparative, reliable, and fast analysis of the amount of daylight available in peripheral private offices as well as the lighting energy performance of automated lighting controls (occupancy sensors, photocells) compared to standard on/off switches. Blinds are either manually or automatically controlled.

The focus user group consists of building and lighting designers. A user of the software does not require any previous knowledge of daylight simulation techniques as all simulation inputs are explained in the online technical background, and glossary sections. Simulation results are based on pre-calculated RADIANCE simulations which are coupled with an empirical model that mimics manual lighting and blind control in single offices.

IMPLEMENTATION INTO DAYSIM

The algorithm has further been implemented in version 2.0 of the Daysim software (http://irc.nrc-cnrc.gc.ca/ie/light/daysim.html). Daysim simulates the annual daylight availability and electric lighting use for arbitrary building geometries. It combines the forward raytracer Radiance [Ward 1998] with a daylight coefficients approach [Tregenza 1983]. The underlying sky model to calculate annual illuminance profiles is the Perez all weather sky model [Perez *et al.*1993]. A stochastic model [Olseth, Skartveit 1989] has been adapted to calculate the short-time-step development (down to 1 minute) of indoor illuminances based on hourly mean direct and diffuse irradiance values [Walkenhorst *et al.* 2002].

To date, Daysim has been downloaded by 250 individuals from 44 countries affiliated to 95 architectural and consulting firms and 69 research institutions.

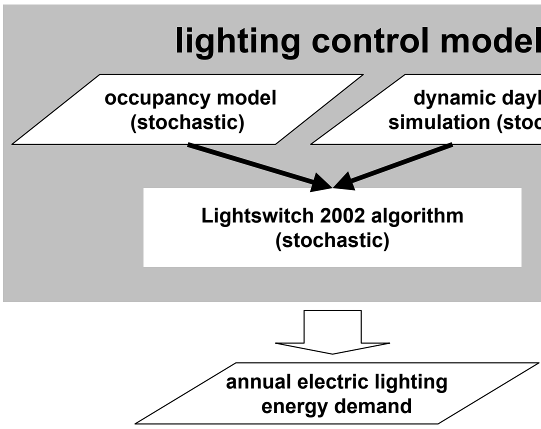


Figure 1: Basic approach of the Lightswitch-2002 model.

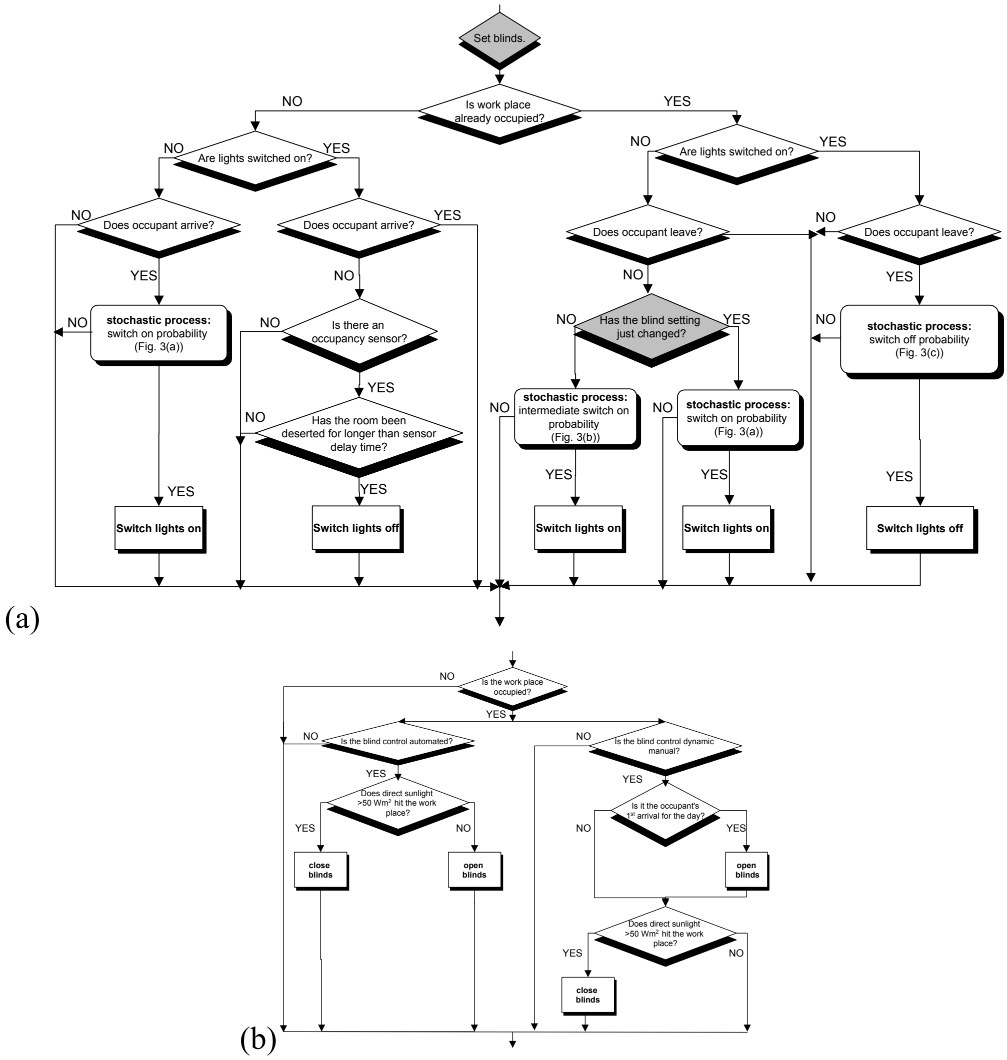
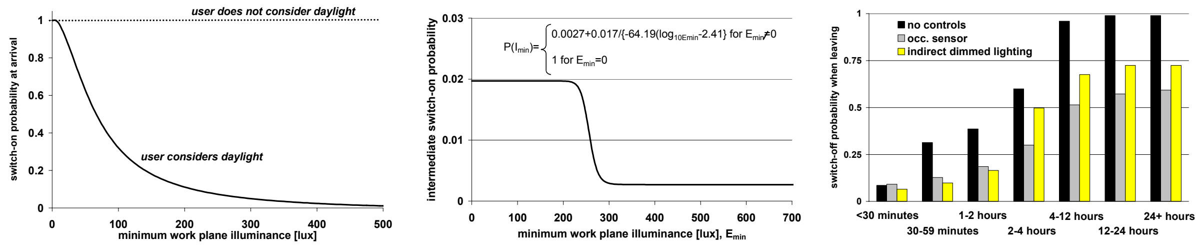


Figure 2: (a) The Lightswitch-2002 algorithm for electric lighting and blind. (b) The "set blinds" procedure).



(a) (b) (c)

Figure. 3: (a) Measured switch-on probability function upon arrival. Hunt's original function [Hunt 1979] (solid line) describes the average switching behavior of a group of users. The dotted line models the switching behavior of a user that keeps the electric lighting activated throughout the working day. (b) Intermediate or within-day switch-on probability for electric lighting [Reinhart, Voss 2003].(c) Measured switch-off probabilities for different times of user absence for a lighting system without controls, with an occupancy sensor and for a dimmed, indirect lighting system[Pigg 1996], [Reinhart, Voss 2003].

INTEGRATION INTO ESP-R

A limitation of the aforementioned two daylighting analysis tools is that they do not consider thermal energy balances for heating and cooling. This limitation 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. To overcome this barrier, the Lightswitch algorithm is currently being coupled with the Esp-r building simulation engine [Clarke 1997]. The approach chosen is to transform the Lightswitch algorithm into a module that can be linked with different building simulation programs. At each simulation time step the "host" total building simulation program feeds physical quantities such as indoor illuminances, occupancy, and direct sunlight at the work place to the module which returns the status of the electric lighting and blinds. It is expected that this modular approach will allow for a smooth updating of the software as the algorithm evolves over time. An extension of the module to also include manual window opening patterns is planned in the near future.

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