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Solar control: A general method for modelling of solar gains through complex facades in building simulation programs

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ABSTRACT

This paper describes a new general method for building simulation programs which is intended to be used for the modelling of complex facades. The term 'complex facades' is used to designate facades with venetian blinds, prismatic layers, light re-directing surfaces, etc. In all these cases, the facade properties have a complex angular dependence. In addition to this, such facades very often have non-airtight layers and/or imperfect components (e.g. non-ideal sharp edges, non-flat surfaces, . . .). Therefore building planners often had to neglect some of the innovative features and to use 'work-arounds' in order to approximate the properties of complex facades in building simulation programs. A well-defined methodology for these cases was missing. This paper presents such a general methodology.

The main advantage of the new method is that it only uses measureable quantities of the transparent or translucent part of the facade as a whole. This is the main difference in comparison with state of the art modelling based on the characteristics of the individual subcomponents, which is often impossible due to non-existing heat- and/or light-transfer models within the complex facade.

It is shown that the new method can significantly increase the accuracy of heating/cooling loads and room temperatures.

1. Introduction

1.1. Solar control – general statements

Transparent components are essential to the design and performance of a building. They influence its indoor comfort and energy budget in many diverse ways: daylight illuminates indoor rooms throughout the year [1], solar energy can be used to heat buildings passively, excessive solar gains can cause glare and overheating. The amount of heat which enters modern buildings by conduction via opaque areas of the envelope is usually small due to the small temperature differences in summer and the level of thermal insulation which is already common in many countries. Conductive gains may still be relevant in warmer climates with less need for thermal insulation. For example, inadequately insulated roof areas in the older building stock present a main cause of solar gains in upper storeys: dark-coloured roofing materials are significant in increasing cooling loads in air-conditioned buildings during sunny summer days [29]. Dark-coloured facade claddings may also increase cooling loads especially in buildings with facade integrated openings for continuous ventilation. This paper concentrates on control of solar gains only; an overview of current work on glare protection for daylight conditions is given in Ref. [34]. The amount of transmitted heat, or solar gain, due to transparent areas of a building envelope is determined primarily by [28]:

- The size of the glazed areas.
- The orientation of the glazed areas with respect to the sun.
- External obstructions by surrounding buildings and trees.
- The glazing properties.
- The properties of sun-shading devices, and how they are operated.

1.2. Evaluation of complex facade components

A combination of measurements and numerical models is the best choice for determining performances. Measurements are needed for validation. Modelling is needed in order to reduce the cost for the measurements by reducing the necessary number of measurements.

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Nomenclature

Angle definitions (numerical values of angles are specified in degrees throughout this publication)

γ acade orientation (0° := south, west positive)
γ_s solar azimuth angle (0° := south, west positive)
γ_f $\gamma_f := \gamma_s - \gamma$ (facade azimuth angle, 0° parallel to facade normal)
α_s solar altitude angle
γ_p solar profile angle $\alpha_p[\alpha_s, \alpha_f] = \arctan\left(\frac{\tan(\alpha_s)}{\cos(\gamma_f)}\right)$ [6]
α_{in} angle of incidence $\alpha_{in}[\alpha_s, \gamma_f] = \arccos(\cos(\alpha_s)\cos(\gamma_f))$ [6]
β_k tilt angle of the slats of a Venetian blind or – in the case of facades with switchable properties – a parameter field which characterises the switching state

Properties of glazing and blind

$A^x_{y,d,e,z}$ $A = [\tau/\rho/\alpha/g]$ for [transmittance/reflectance/absorptance/g-value (or TSET or solar factor)]; $x = [{}'/\text{nothing}]$ when [radiation is incident on the inner surface/otherwise]; $y = [_e/_v]$ for [solar/light] properties; $d = [_{dif}/\text{nothing}]$ for [diffuse irradiation/otherwise]; $e = [_{eff\text{-}m}/_{eff\text{-}h}]$ for [monthly/hourly] effective (average) values; $z = [_{gzg}/_{bid}/_{tot}$ or nothing] for [glazing/blind/combination]

Thermal resistances

U U-value
R_x $x = [e/i]$ for [external/internal] convective and radiative surface resistances and [s] for the thermal resistance of the sample. $1/U = R_e + R_s + R_i$

Other

λ wavelength [nm] for spectral properties $\Rightarrow$ $A^x_{\lambda,d,z}$ or $A^x_{d,z}[\lambda]$ respectively

Examples

$\rho'_{v,diff,gzg}$ diffuse light reflectance of the inner surface of glazing without blind
$\rho'_{gzg}[\lambda]$ spectral reflectance of the inner surface of glazing without blind
$\alpha_{tot}[\alpha_s,\gamma_f]$ total absorptance in the facade
$g_{tot}[\alpha_s,\gamma_f]$ total solar energy transmittance g of glazing and blind
$\alpha_{gzg}[\alpha_{in}]$ total solar energy transmittance g of glazing without blind

For the case of venetian blinds, the characterisation of glazing, blinds and combinations of glazing and blinds has been described in detail in Refs. [17,18].

However, in many building simulation programs like for example [4,8,9] or [31] it is difficult to include the results of such facade measurements and facade simulations. A new solution to this problem is the topic of this paper.

2. The new method "black-box model" for building simulation programs

2.1. General

The general idea is to create an interface for building simulation programs (e.g. [4,8,9] or [31]) or which allows the properties of complex facades to be integrated without any modelling of the details within the building simulation program itself. The reasons for this approach are the following:

- There are always new facades which are too complex for the internal models which are included in the building simulation program itself. It is important for the success of new developments that the advantages of innovations can be demonstrated by building designers. The lack of an interface for these new products often slows down the market penetration of new daylighting and solar control systems.
- In some cases, the thermal and optical properties of facades cannot be described by models with sufficient accuracy. This is especially the case when the real component deviates significantly from the ideal design. An example could be a glazing unit with multiple integrated prismatic or light re-directing layers with imperfect edges and imperfect surface flatness of the light re-directing surfaces.
- Semi-empirical models have been developed for facades with venetian blinds which are able to describe the angle-dependent properties of the facade accurately, without needing too many (expensive) measurements [17]. However, to study the impact of such complex facades on overall building performance, it is necessary to integrate these models into a building simulation program.

Therefore a method was implemented in a whole building simulation program which requires only data which is measurable on the complete glazing unit. As input, the new method needs only the angle-dependent g-value/solar factor and solar transmittance of the total facade unit. If available, the solar reflectance ρ_e (for solar radiation incident on the outer surface of the facade unit) can also be used as input, which improves the accuracy of modelling the external surface temperature. It is important to notice that it is not always necessary to measure g, τ_e and ρ_e: in some cases these properties can be calculated with mathematical models (for example, with the models given in Ref. [17] for the case of facades with venetian blinds).

The general idea of the model is to describe every complex facade with a two-layer model. Each of the two virtual layers has an effective solar absorptance with the desired angular dependence. Between the two layers, there is a temperature-dependent thermal resistance. This idea is quite similar to the ideas behind the γ-model which was developed by Rosenfeld [27] for the correction of non-standard boundary conditions during calorimetric g-value measurements.

2.2. Description of the model

2.2.1. Input data

The starting point of the model is a set of measured or externally calculated values. Each data set i is valid for different directions of the incident light and different settings of the control parameter β_k. The model needs the following input:

- g-Value $g_{tot}[\alpha_{s,i},\ \gamma_{f,i},\ \beta_{k,i}]$ (mandatory). In addition to the g-value, it is necessary to specify the thermal boundary conditions (surface resistances R_e and R_i) which have been used for the determination of g_{tot}.
- U_{tot}-Value (mandatory). The centre-of-glazing U-value of the total facade (i.e. glazing + blind) is required for the same thermal boundary conditions as the g-value.
- Solar transmittance $\tau_{e,tot}[\alpha_{s,i},\gamma_{f,i},\beta_{k,i}]$ (mandatory).
- Solar reflectance $\rho_{e,tot}[\alpha_{s,i},\gamma_{f,i},\beta_{k,i}]$. (Optional. Needed only for accurate modelling of the temperature of the external surface,