Computational investigation of the performance of window blinds

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ABSTRACT

Solar gains are one of the most important factors of design for energy efficient buildings. While "catching the sun" in winter is a main strategy, protecting the building from the excessive solar heat gains in summer is even of greater significance. In parallel, the use of daylight in buildings, in order to reduce artificial lighting power consumption is nowadays a parameter integrated in the design of buildings.

In this context, this paper refers to the use of blinds as a solar control strategy for achieving thermal and optical comfort in buildings. The performance concerning the illuminance levels of indoor spaces with and without thermal mass, for three different window blinds is investigated, with the use of EnergyPlus computer simulation design tool. At the same time, the thermal performance of the space is estimated, in an attempt to couple its thermal and visual behaviour, as a function of the window blinds and the thermal mass of the space.

1. INTRODUCTION

Bioclimatic design of buildings demands a great interaction of the building shell with the sun. While "opening" the building to the sun in winter is a main goal of sustainable architecture, protecting it in summer is an equivelent requirement. In parallel, high solar radiation availability results to unpleasant illuminance levels, giving to solar control strategies more emphasis on their integration in the building's design.

Nowadays the use of internal and external window blinds is gradually embodied in the design of energy efficient buildings and has become an object of intensive research around the world. Following the effort to decode the performance of window blinds as an effective solar control strategy (Kuhn 2006), this paper points out the potential of using energy simulations with computer programs to determine thermal and optical conditions in building design, as well. A "zone" representing a room with typical office design is simulated with EnergyPlus; by taking account the illuminance levels and the thermal loads of the zone, general conclusions of the performance of window blinds are extracted.

2. SIMULATION MODEL

2.1 Program

The well known and widely used program for building energy simulation EnergyPlus (E+) is used for this paper. E+ is the evolution of two computer programs: Blast and DoE (Crawley et all, 1999) and has been extensively validated and tested (Henninger et all, 2006).

The program is a powerfull calculation engine, where the analysis of energy simulation is done by using weather data in an hourly basis, while the capability of sub-hourly simulation exists. Geometry and construction characteristics of the "zone" are defined in detail as inputs to the program and the simulation of blinds is performed by using the shading and the solar geometry, which is daily calculated.

2.2 Model – Base Case

The model used for the computational evaluation of blinds has been designed in order to represent typical office rooms with a full facade window. In order to include variations in daylight simulation and to assist future study and design of real test cells for daylight measurements, the model consists of a two room building where each room is a separate thermal zone, allthough only one room is examined. Both rooms are the same and thus no thermal exchange between the two zones exists (concession of adiabatic partition wall). The dimensions of each room are: 3.0 m width, 7.0 m depth and 3.0 m height (Fig. 1). The building is modelled as a concrete chamber of high thermal mass, with external thermal insulation and the main facade facing south. Rooms have a direct solar gain system attached at the south side covering the total facade (3.0 m x 2.7 m), accounting for the 30% of the ground plan of the room. The fenestration consists of a clear double glazed window. Each room has also a north facing window and a door located on the wall opposite the partition wall.

For the study no internal loads (artificial lighting, people, equipment, etc) are taken into account. For the base case, the room is considered to perform with high thermal mass and without any solar control.

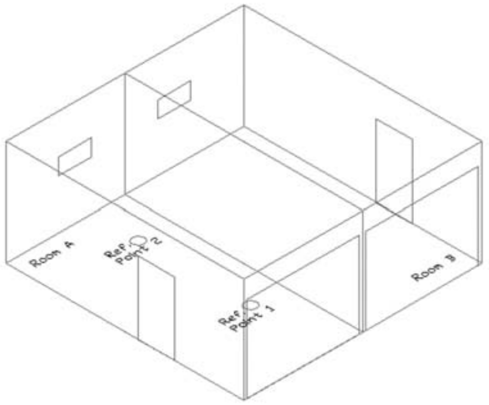


Figure 1: South-west 3D view of the model. Circles inside the

room A indicate the two reference points for daylight calculations. (EnergyPlus drawing file)

2.3 Models of the parametric study

Further in the simulation process the room is modelled with external blinds attached at the southern direct gain window, covering the total area of the fenestration. Blinds are placed in three different angles: 135°, 120° and 60° (fig. 2). In parallel, three values of solar reflectivity of the blinds are examined:

− *blinds of high reflectivity* (80% reflectance),
− *blinds of medium reflectivity*, (50% reflectance) and
− *blinds of low reflectivity* (20% reflectance).

In all cases the slats are 20 cm wide, separated by a distance of 18.75 cm (Fig. 2) and assumed to have zero solar transmittance. The simulations were carried out considering the room with hight mass.

Next, the above nine design alternatives are recalculated for the test cell without mass. More specifically all walls, the floor and the ceiling of the room are modelled with thermal insulation being placed at the inner side of the zone, resulting to a construction of a low thermal mass model.

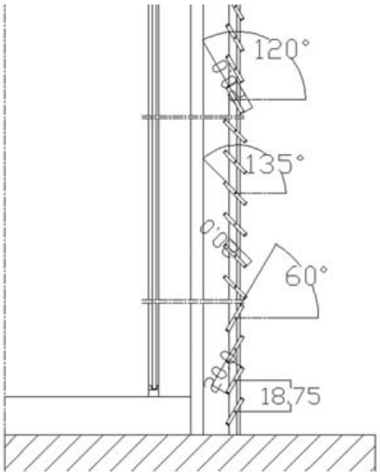


Figure 2: Window blinds and their definition geometry.

2.4 Climatic data

All models of the parametric study are simulated for weather conditions of the city of Thessaloniki, Greece (latitude: 40.67E and longitude: -22.83N). The international weather for energy calculations (IWEC) file is directly used from the weather files available online at the US DoE site (*http:// www.eere.energy.gov*).

3. SIMULATION RESULTS

3.1 Overview

EnergyPlus offers a wide range of output variables. In this paper outputs referring to illuminance levels and thermal loads of the room models are used to draw conclusions.

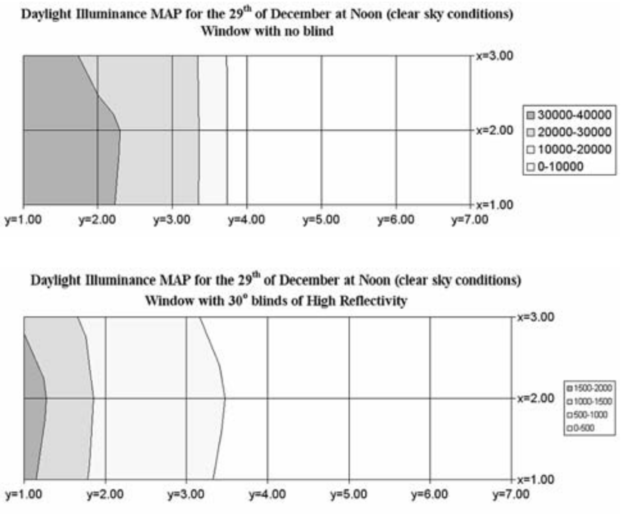


Figure 3: Winter illuminance maps for room A.

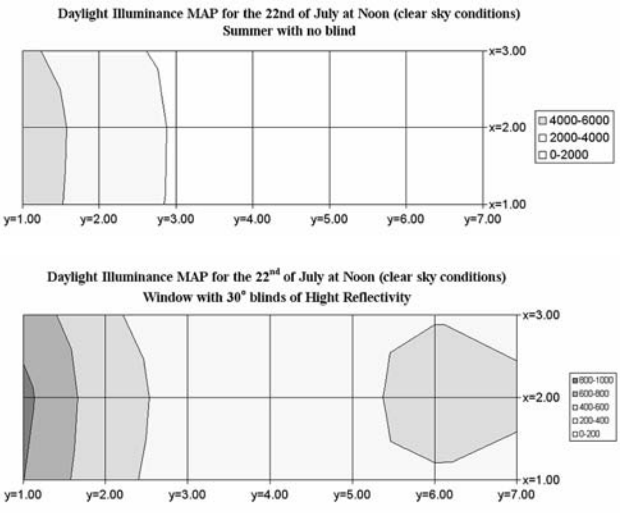


Figure 4: Summer illuminance maps for room A.

Outputs are taken in an hourly basis, furthermore thermal loads are calculated for the whole year, both for heating and cooling. According to the directive of the Greek Technical Chamber (GTC 1982) the winter design temperature for offices is 21 °C, while the respective summer design temperature is 26 °C. Thermal loads are calculated taking into account a 24 hour/day achievement of the design temperatures, assumed to be covered by a simple air HVAC system. It is considered that the cooling period starts at May 1st and ends at October 15th while the rest of the year is the heating period, where heating loads of the zone are calculated.

Illuminance levels (lux) are computed in an hourly basis for two reference points (Fig. 1). Reference point 1 is located at a distance of 1.60 m from the window wall, while reference point 2 at a distance of 5.00 m from the window. Both points are elevated at a height of 0.80 m above floor level, representing desks' working plane in offices. Also illuminance maps with a grid of 1.0 m x

1.0 m are generated (Fig. 3, 4).

The contribution of the various shading installations to the daylight distribution in the room is examined for 3 different sky types ranging from clear sky to overcast conditions.

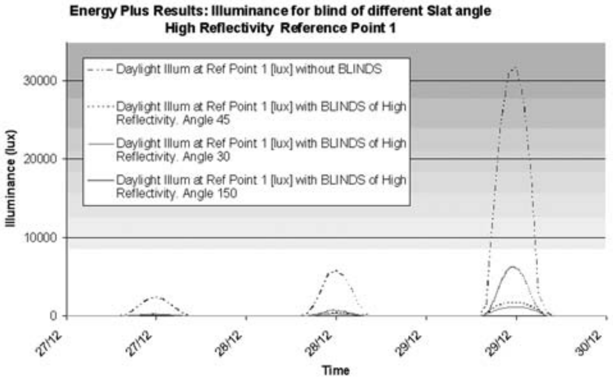


Figure 5: Illuminance at reference point 1 for blinds with high reflectivity tilted at various angles.

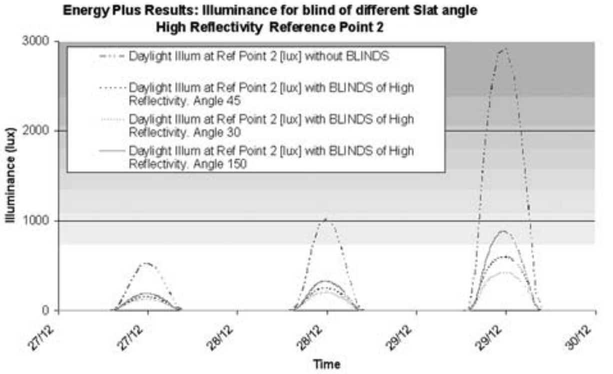


Figure 6: Illuminance at reference point 2 for blinds with high reflectivity tilted at various angles.

3.2 Comments

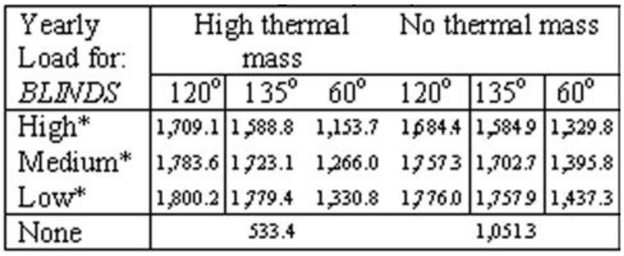
The base case outputs, as mentioned before, refer to the performance of the room without any solar control. The application of blinds result to an immediate impact on thermal and visual behaviour of the zone and this is evident in the results that are discussed bellow.

3.2.1 Thermal behaviour

Altering the conditions of the space influences the thermal loads:

− *Heating loads* of the room are increased when using blinds that intercept solar radiation and diminish solar gains. Thermal loads rise up to 3.34 times with regards to the base case, when using blinds of low reflectivity with slat angle 120^o.

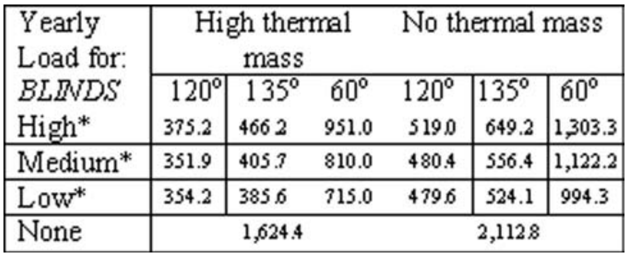
Table 1: Thermal heating load (kW/h) for room A



Yearly Load for:	High thermal mass			No thermal mass		
BLINDS	120°	135°	60°	120°	135°	60°
High*	1,709.1	1,588.8	1,153.7	1,684.4	1,584.9	1,329.8
Medium*	1,783.6	1,723.1	1,266.0	1,757.3	1,702.7	1,395.8
Low*	1,800.2	1,779.4	1,330.8	1,776.0	1,757.9	1,437.3
None	533.4			1,0513		

*Reference on the reflectivity of the blind

Table 2: Thermal cooling load (kW/h) for room A



Yearly Load for:	High thermal mass			No thermal mass		
BLINDS	120°	135°	60°	120°	135°	60°
High*	375.2	466.2	951.0	519.0	649.2	1,303.3
Medium*	351.9	405.7	810.0	480.4	556.4	1,122.2
Low*	354.2	385.6	715.0	479.6	524.1	994.3
None	1,624.4			2,112.8		

*Reference on the reflectivity of the blinds

− *Heating loads* increase when the thermal mass of the space is minimized, since no mass exist to store the admitted solar gains. Loads of the alternative without mass and without solar control rise 97% over the base case. On the contrary, when integrating solar control on the model without mass, the heating loads do not differ more than 1.5% from the loads of the base case with blinds (Table 1). The lack of solar gains in both cases is the determinant factor in the calculation of the heating load of the zone.

− *Cooling loads* on the other hand decrease directly and effectively in the model with blinds compared to the base case where no solar control is applied. The cooling load of the zone with blinds of medium reflectivity and slat angle 120^o account only for 22% of the base case's respective load (Table 2), since by blocking out solar radiation the fenestration's direct solar gains are avoided. It's also worth mentioning that the lack of thermal mass causes an additional increase of 35% to 40% of the cooling load.

3.2.2 Visuall behaviour

Firstly, as expected, no changes at illuminance levels are noticed for the room with or without thermal mass, stating once more the fact that daylighting of spaces depend on the geometry and optical properties of the surfaces that form the space.

Illuminance levels for all the models are dominated by the size of the window of the study (full facade) and this is the factor that determines the values observed. The use of blinds has a positive effect on visual comfort by reducing and normalizing the distribution of daylight in the zone.

− Illuminance levels dectrease with the use of blinds. Reference point 1 (near the window) reaches 30.000 lux without blinds for clear sky conditions in winter (Fig. 5), while the use of blinds, regardless of their slat tilt and their reflectivity, reduces illuminance to 30% of the base case.

− The use of blinds contributes to an evenly distribution of daylight in the room. Daylight illuminance at reference point 2 at the back of the room is increased (fig.4), while excessive illuminance values are only recorded at the front zone of the room in a depth of a half meter from the window (Fig. 3 and 4).

3.2.3 Optical and thermal coupling

Optical and thermal properties of the zone change simultaneously in a polyparametric way, directly coupled with the climatic conditions. The current analysis is an approach for studying the interaction between visual and thermal factors and can give preliminary conclusions only. A multi statistical analysis is required to access the problem in greater detail. Bearing this fact in mind and processing the results of this paper, the following points can be highlighted:

− Climate conditions of Thessaloniki favour the use of blinds with high reflectivity and slat angle 120^o in the summer. Cooling loads are decreased by 77% (Table 2), while illuminance levels are evenly distributed in the room (Fig.4) with a range of 400-600 lux.

− For the winter season the need for solar gains in order to reduce heating loads has to counterbalance with the excessive illuminance levels (30.000 lux at reference point 1 without blinds. Fig.5). No solar control is wanted regarding the heating load, but as far as the visual comfort is concerned the use of blinds is necessary. This is a problem that needs to be redefined and solved with the use of movable blinds.

4. CONCLUSIONS

4.1 Overview and discussion

The objective of the current paper is to approach the influence of window blinds to the thermal and optical conditions of spaces. An EnergyPlus model of two identical rooms was created and different arrangement of window blinds were simulated and reviewed by means of thermal loads and illuminance. The results of this study point out the fact that thermal and visual comfort are opposite driving forces as far as energy consumption is concerned. High solar gains in winter can lead to unwanted illuminance levels and glare problems, while daylight demand in summer increase cooling loads. The optimization of these two parameters lies in the determination of comfort requirements and solar control strategies in symphony with the principals of bioclimatic design and sustainable architecture.

4.2 Further study

As pointed out in the beginning of the paper thermal and optical comfort is of great importance for the design of energy efficient buildings. At the same time, achieving thermal comfort can lead to unpleasant visual conditions in a space and vice versa. The use of solar control systems like window blinds can contribute towards the coupling of the two contradictory requirements of building design and this is the purpose of various studies world wide (Kristl 2007), (Kuhn 2006). As studies are carried out, effort has to be given in the creation of an algorithm for correlating the thermal and optical comfort with the window blinds used. Material properties and geometry of the blinds in combination with building shape can be used as a base for rules of thumb when designing a solar control system with window blinds. At the time no such "design tables" exist, while the potential of using them does.

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