Optical and thermal design and modelling of architectural shading systems

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Abstract
The use of shading elements in building façades is a common resource when an energy efficient building is designed, moreover in warm climates. Nevertheless, commonly used building thermal modelling tools, only allow a simplified definition of the shading element geometry. In order to design better performing shading elements, an accurate characterization of the geometry and the optical and thermal performance of the elements should be carried out and their effects on the energy efficiency of the building simulated.

This study describes the thermal and optical characterization and modelling of a 3D shaped metallic façade shading element and the resulting new Type for TRNSYS. This Type enables the simulation of the energy performance of the shading element when placed in building façades. Energy performance simulations for office buildings, for different façade orientations and in several climatic zones in Europe have been carried out. The results are compared and the most appropriate and performing applications of these elements are assessed.

1 Introduction

In the past decades, state of the art construction techniques have allowed an increase in the glazed area in building envelopes across Europe. This trend has led to situations where excessive solar gains create user discomfort in summer. In the past, increasing the cooling power of the HVAC equipments would have been enough to solve this problem, but, in a society with increasing energy costs and limited fossil-fuel available, this is not a sustainable solution.

Shading elements are a usual solution to overheating problems. These devices are located in front of windows in a way that provide shading. By correctly locating shading devices, cooling loads can be significantly reduced while providing glare protection.

Figure 1: Metallic Shading device over a glazed façade in Labein-Tecnalia headquarters.

In order to achieve a better understanding of the performance of shading devices, a steel shading system was selected for a parallel-mounted installation. A geometrical radiation analysis was performed and a computational implementation was made in TRNSYS.

Shading modelling was previously modelled for cases such as photovoltaic and solar thermal collector arrays. For building-integrated aplications, overhang and wingwall shading was modelled in TYPE34. A more general aproach was also available through shading masks such as the ones modelled in TYPE 64, which allowed shading calculation for parallel-mounted installation.

The shading device selected being a 3D shaped shading device, independent direct and diffuse shading modelling was required. As the previously defined types don’t make a difference between beam and diffuse radiation, a purpose specific type was programmed.

The programmed solution handles independently beam and diffuse radiation, as well as the thermal calculations, which can not be calculated by using other available trnsys types.

2 Shading element modelling

A mathematical model of the thermal and energy performance of a metallic shading element has been carried out and introduced in a TRNSYS Type. The mathematical model assumes that the solar shading device is infinitely wide and that full surfaces are shaded by the device. The model needs input data provided by TRNSYS about the solar position, incident radiation and temperature. The output of the model provides information about the transmitted radiation through the element, and the absorbed heat and temperature of the element.

The Type of the shading elements is defined by the position parameters of the element (azimut and slope), and a file containing the absorption coefficient, thermal loss coefficient and the beam and diffuse transmittance as a function of the angle of solar incidence. These data can be adapted to any other element.

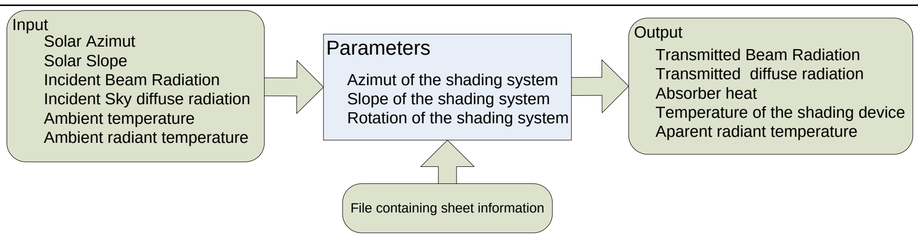

Figure 2: Input-Output scheme of the developed model

The modelled shading device is an expanded steel plate which generates a 3D hole with a hexagonal geometry. The optical model implemented is based on a Montecarlo Ray-Tracing method. While a steady-state thermal balance is used for temperature calculations.

The Montecarlo Ray-tracing method is used to model the geometry of a set of adyacent holes in the expanded metal sheet. In the ray-trancing process a great number of photons are launched against the shading device, where specular and diffuse reflectance are taken into account.Measured reflectance data was used for the geometric modelling. A collecting surface is located behind the shading device. Photons reaching that surface are accounted as “transmitance”, while those absorbed in the surfaces of the shading device are accounted as “absorptance”.

No thermal loss coefficient has been found to allow a fully detailed thermal model of the shading device. ISO 6946 states 25 W/m2K for vertical opaque envelopes. As this shading element is exposed on both sides and the holes in it allow a better heat transfer to air, a 40 W/m2K value has been chosen. If better data would be available, the thermal model is defined in a way that a new coefficient can be introduced in the data file.

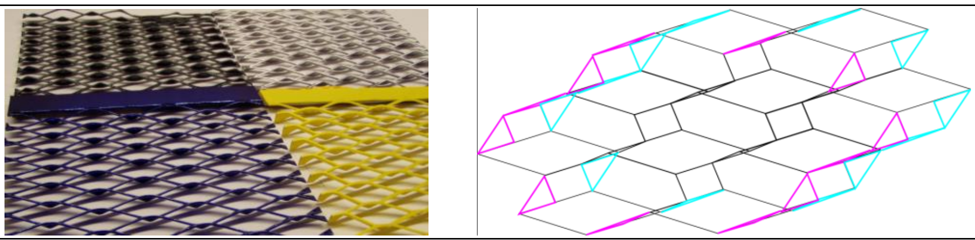

Figure 3: Actual shading element and the modelled simplified geometry.

These outputs can be coupled to any kind of building to simulate the effect of the shading element. A simplified project has been introduced in TRNSYS in order to perform the simulations.

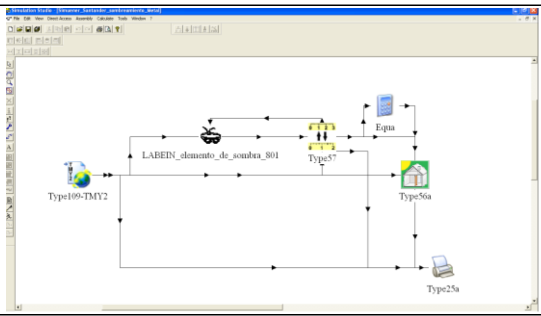

Figure 4: Resulting TRNSYS project

3 Temperature of the shading system

Shading devices get heated by the absorbed solar radiation, increasing their temperature. Two surface finishes (grey and black) have been modelled in order to achieve a better understanding of the thermal processes involved. The solar absorption values have been measured, and the resulting mean value for the total radiation and wavelengths is 53% for the grey element and 95% for the black element.

South facing installations in Madrid and Berlin have been studied. In both locations the element temperature increase comparing to ambient temperature has reached 20ºC. In Berlin it happened in the month of September, while in Madrid it was in January. In Madrid the temperature increases are bigger in winter than in summer, this is caused by the solar geometry that affects the incidence angle.

In summer in Madrid the element temperature was 10ºC higher than the ambient temperature reaching to 45ºC as shown in Figure 5. The results also showed that overheating in “black” devices is around 30% higher than in “grey” ones due to the higher solar absorption.

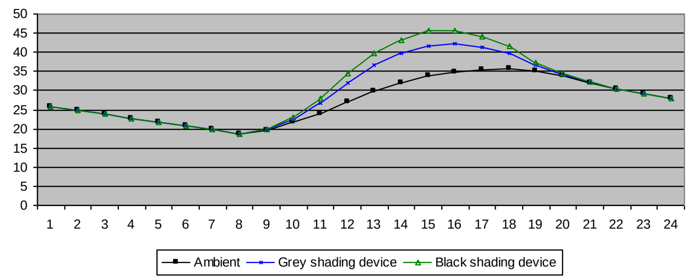

Figure 5: Shading device temperature in summer time Madrid.

4 Heating and cooling needs in office buildings

A simplified situation has been simulated for assessing the effect of the shading device. A reference office consisting on a small area in a much larger building with similar use profiles. Only one wall is externally exposed (U=0.65 W/m2K), where a double 6/8/6 glazing window is located (U=3.21W/m2, g=0.722).

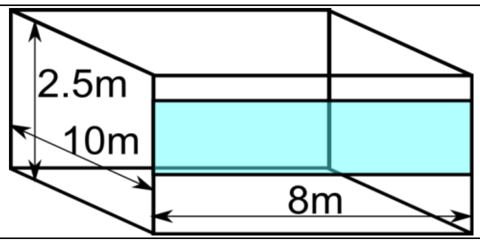

Figure 6: Geometric configuration of the simulated thermal zone.

An orientation-dependant analysis has been performed, by means of a triple modelling with an alternatively east, south or west-facing externally exposed façade. The analysis has been expanded to different percentages of glazed façade. The analysed configurations are: a moderately glazed (30%) and a fully glazed (90%) building. Two European locations have been studied in order to obtain a better understanding of the geographical variation of shading performance. The following locations have been selected for latitude and climate reasons: Berlin (52ºN, Central Europe) and Madrid (40ºN, Southern Europe).

User profiles have been selected to represent a moderately dense open space office. A 0.11pers/m2 user density has been selected with a Monday through Friday 7h to 19h working profile. Combined total internal loads represent a 40W/m2 heating power. During the working time a 1.7 ach ventilation rate is used. This use profile leds to high cooling loads in summer, while not too high heating loads are produced in winter.

For these situations three shading situations have been studied:

- Base case: no shading applied.
- Full Shading: whole year shading with the grey-finished shading device.
- Variable shading: Variable shading has been defined as a dynamic shading system that provides shading in summer while allowing full isolation in winter. Shading is provided in summer with the grey-finished shading device.

The resulting data should be enough to establish the effectiveness of shading devices in different climates. Generally speaking, South orientation presents lower heating demands followed by east and west orientations. In some cases heating load is even unelectable for South-facing zones. For clearness, only East orientations are plotted in this paper.

Figure 7 shows the yearly energy needs in an office in Berlin for east oriented with 30% and 90% glazed façades. In these graphs a bar diagram is shown with cooling (blue) and heating (red) demands in absolute figures. Variations over the base case (no shading) are shown in a line graph for cooling (blue), heating (red) and total (orange) thermal demands. The scale on the left is used for absolute figures [kwh/m2*year], while the scale on thhe right is used for variations over the base case [%].

Compared to the base case, the Full shading situation reduces the cooling energy demand while increases the heating demand.

The Variable shading performs as the combination of the previous cases: In the heating period, it performs as if no shading device was installed, while in the coling period shading is provided as in the Full shading case.

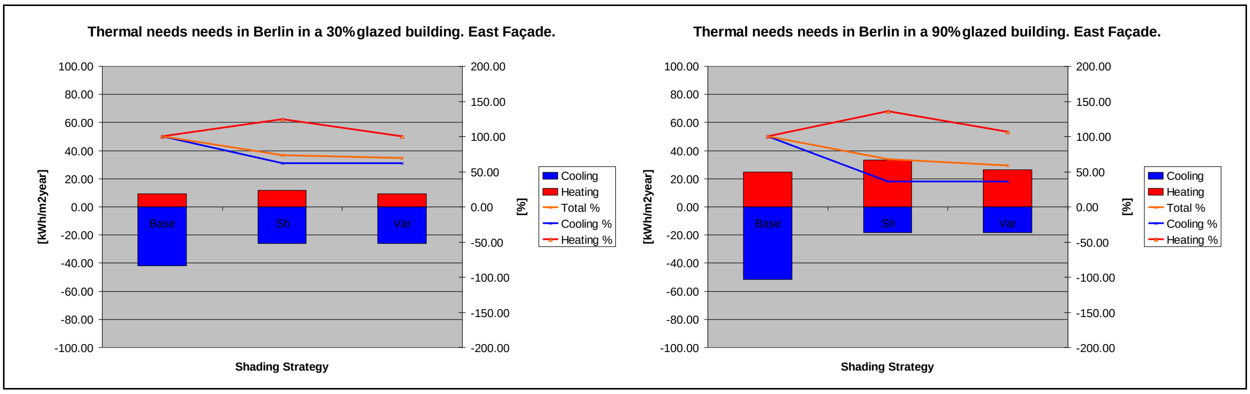

Figure 7: Yearly heating and cooling demands in Berlin for East-facing zones.

In order to define the operation months of the Variable Shading a monthly analysis should be carried out. Figure 8 shows the heating (in positive values) and the cooling (in negative values) needs for each month.

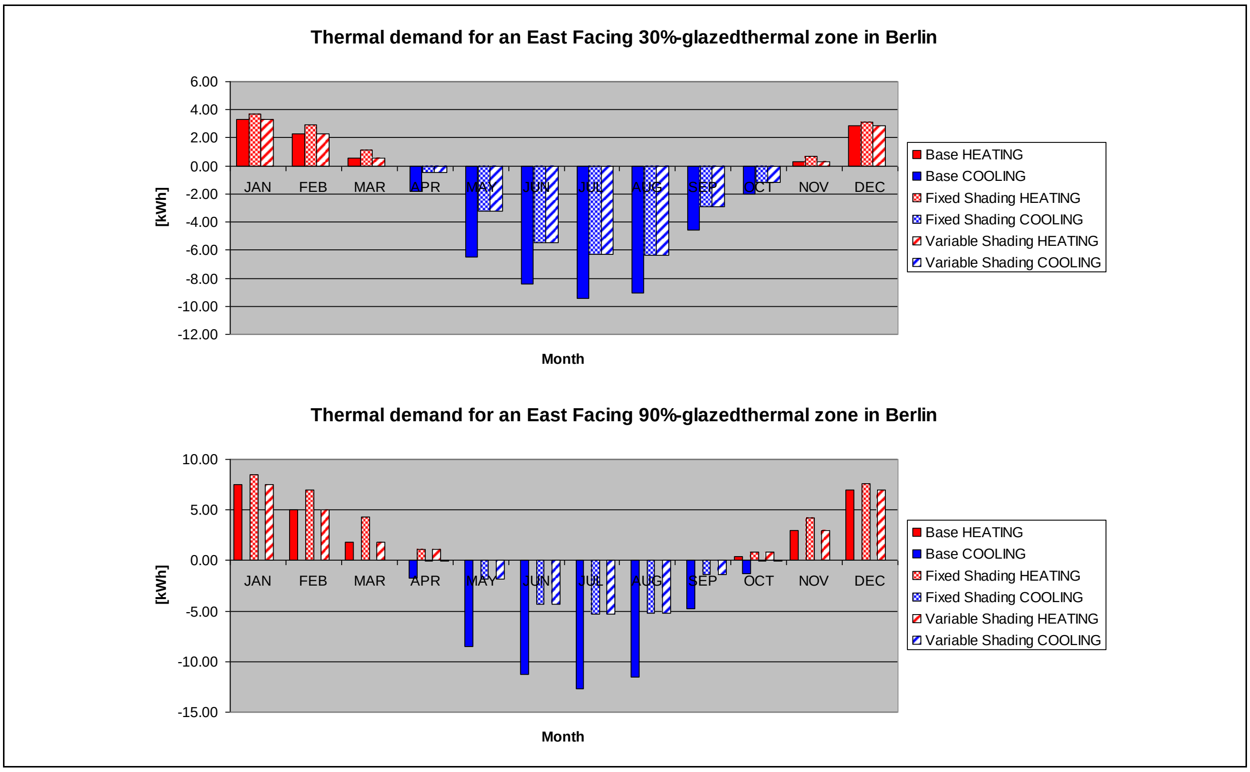

Figure 8: Monthly heating and cooling demands in Berlin for East-facing zones.

As simulations state, the full shading device reduces cooling demand and increases slightly heating demand. Seasonally variable shading strategies does not seem interesting for the case studies done, being only of a slight interest for the highly glazed solution (90%). Considering the monthly demands, the shading period can be optimized. In this case the April-October period should be selected.

Figure 9 shows the same analysis performed in Madrid. There isn't any heating demand for the base situation. This is due to the selected simplified reference office where only one façade has glazing while the rest are opaque (so thermal losses are low) and the relatively high intenal gains considered. The cooling demand is drastically reduced with the shading device, this is very obvious in the 90% glazed façade situation. The percentage of heating need increase is very high with the shading device, but this is due to a very small demand in the Base situation.

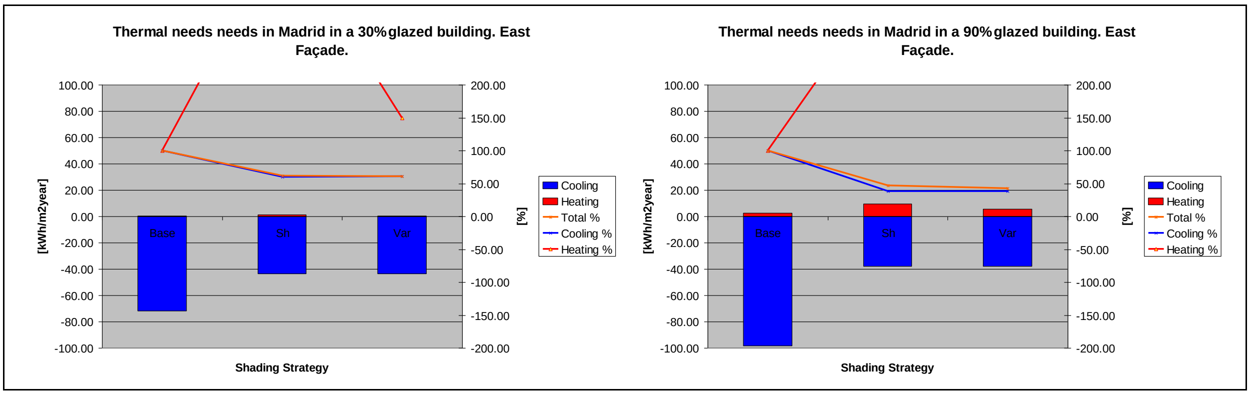

Figure 9: Yearly heating and cooling demands in Madrid for East orientations.

The monthly analysis shown in Figure 10 allows the optimisation of the variable shading device operation. It is stated that the working period should be from February to November in Madrid.

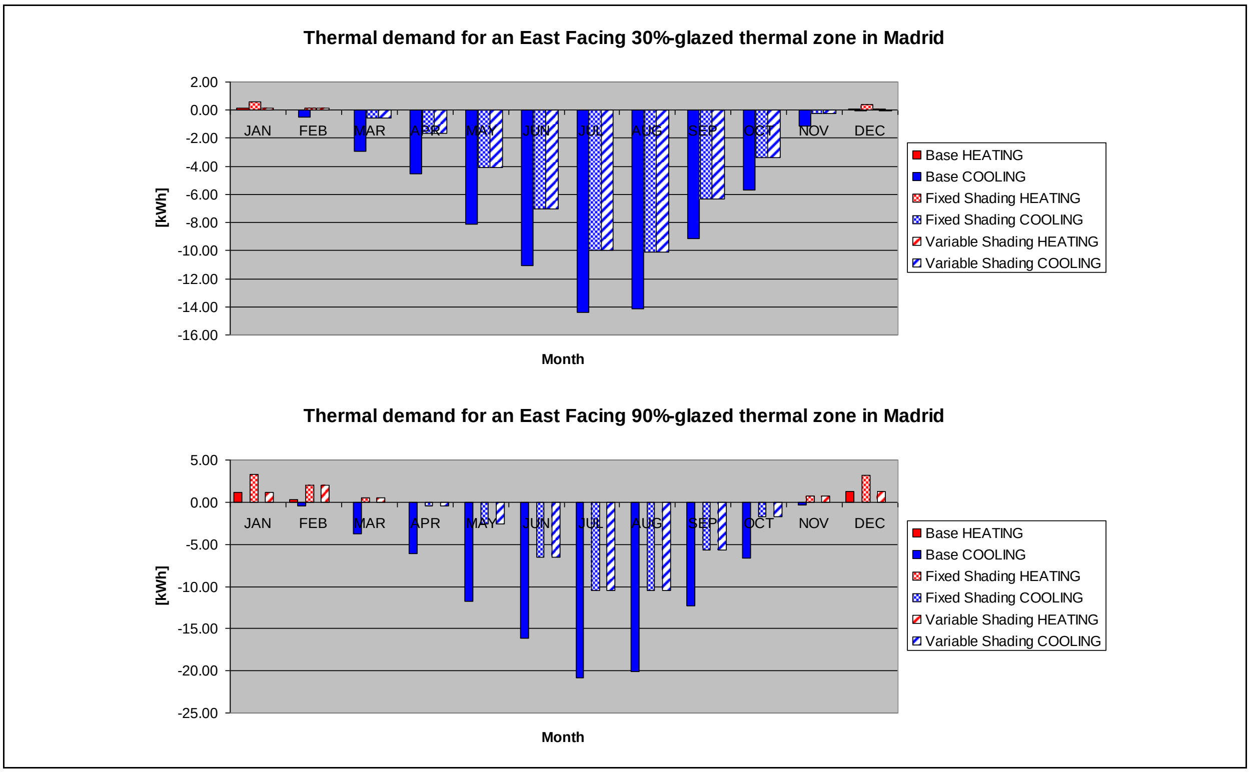

Figure 10: Monthly heating and cooling demands in Madrid for East orientations.

5 Conclusions

The simulated buildings are mainly affected by cooling loads. This is caused by high internal and solar gains. These gains are not too efficiently removed form the building, by other means than the cooling system.

In some cases, an increased ventilation rate would lead to reduce the cooling load in mild periods, but the building chosen did not allow this kind of load-reducing strategies. External shading devices seem a good option to reduce the cooling loads associated to the selected buildings even if the heating demand is increased.

The suitability of variable shading devices (only in operation during cooling season) has been assessed. In general this is not a necessary option except for highly glazed façades with heating demands, as is the case in Berlin.

Concerning shading system temperature, it is only relevant if the system is installed at ground level in a publicly available area. As winter ambient temperatures are relatively low, the resulting system temperatures are not too high. The resulting element temperatures in summer can reach peak temperatures around 45ºC, so measures should be taken to avoid direct contact in installations in the ground floor.

User visual comfort can lead to less intensive shading. In this case, partial shading can be used instead of full shading. The resulting load reduction will be different than the one in the studied case.

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References

[1] AENOR. UNE-EN 673 *Vidrio en construcción. Determinación del coeficiente de transmisión térmica, U. Método de cálculo* (1998).

[2] AENOR. UNE-EN 13363. *Dispositivos de protección solar combinados con acristalamiento* (2008).

[3] ISO. ISO 6946. *Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation method* (1996).

[4] ISO. ISO 9845 *Solar energy. Reference solar spectral irradiance at the ground at different receiving conditions* (1992).

[5] Incropera F.P. & DeWitt D.P. *Fundamentos de transferencia de calor*. Prentice Hall, 1999.

[6] Solar energy Laboratory. University of Wisconsin-Madison. TRNSYS 16. Programmers guide (2007).

[7] Yunus A. *Transferencia De Calor Y Masa, un enfoque práctico*. Mc Graw Hill, 2007.