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# Metal mesh as shading devices and thermal response of an office building: parametric analysis

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**Abstract**

Windows are the most important part of the building façade to control solar gains, thermal losses and visual comfort. Office buildings usually have medium-high WWR (window to wall ratio value) and high internal gains (due to users, lighting and appliances). For this reason, they require a good balance between thermal and visible performances of transparent façades and shading control strategies to avoid overheating, optimizing daylighting aspects. A sensitivity analysis was assessed to evaluate primary energy use for heating, lighting and cooling for conventional Italian single office units equipped with static metal mesh shading devices with different geometries and openness factor values. Different location (Milan, Palermo), orientation (south and west) and WWR (33% and 100%) were analyzed. Hence shading devices alternatives as venetian blinds and sun control windows are proposed as a comparison.


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*Keywords:* Metal Mesh, Shading devices, Energy efficiency, Office, Building Envelope, Angular solar and visible transmittance measurements.

## 1. Introduction

The shading devices design and optimization process allows different procedures and alternatives. One of these consists in study and use of lightweight materials with three-dimensional structure, able to reduce solar gains, redirecting sunlight. The most promising and interesting materials can be obtained, with a technological transfer

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approach, from different industrial sectors [1]. We collected over 200 suitable as alternative materials for shading devices. Part of them (86 samples) were already tested, the other ones will measured during next months. This paper presents some measurement and simulation results for three sample of metal mesh used for window shading. Metal meshes are used in new and renovated buildings as an external second skin for the building envelope to enhance architecture design, to filter daylight and to reduce solar gains. Their effectiveness as shading devices depends on their geometry, texture, and application [2,3], and on the spectral [4] and directional optical-radiative response of the materials they are made of (i.e., lambertian, specular, or retro-reflective [5]).

## 2. Materials and experimental

The three samples herein presented and analyzed are part of a broader experimental session carried out with the aim of determining the angular light and solar transmittance properties ($\tau_v$, $\tau_e$) of shading materials with standard or large 3D texture geometry structure. Because of the of samples texture and pattern an integrating sphere apparatus is required [6]. The optical spectral properties were measured in accordance with [7] for incidence angles between normal (0°) and 60° with a step of 15°, for wavelength between 300 and 1700 nm, covering the 92.7% of the solar spectrum. The data collected were integrated to obtain visible and solar transmittance values in accordance with [8].

a) b)

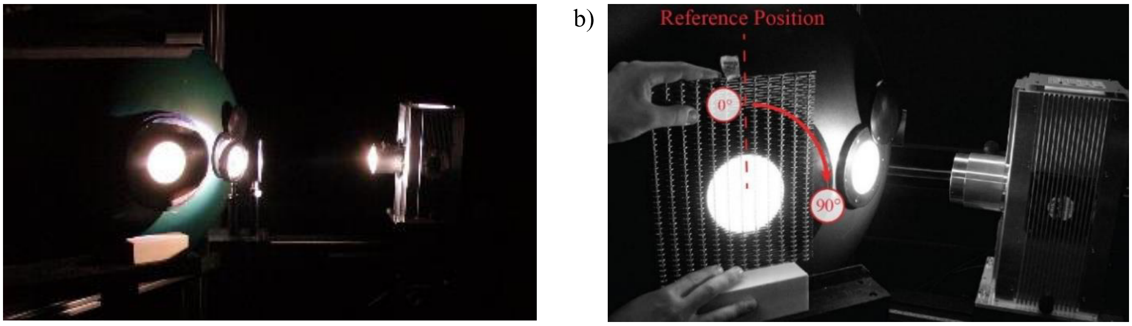
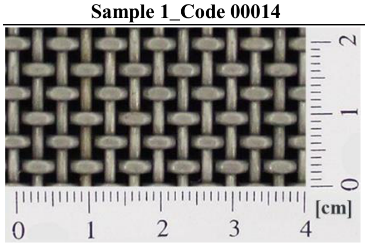



Fig. 1 – a) Integrating sphere apparatus. b) Standard for sample rotation on the sample port 0° and 90° are the reference measurement positions.

If the texture of the analyzed sample does not present symmetry regarding the main axis of a hypothetic arrangement plane of the sample, the measurement should be repeated for any axis of symmetry. The standard rule for such procedure consists of incremental 90°clockwise rotations over the sample port as shown in Fig. 1-b.

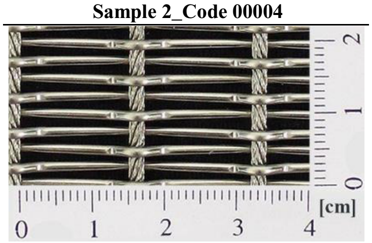
Tab. 1 – Metal mesh grid samples, from left to right: sample 1 (a), sample 2 (b) and sample 3 (c).

**Sample 1_Code 00014**



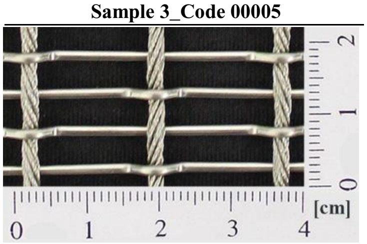

| | |
|---|---|
| Warp diameter [mm] | 2,3 |
| Warp spacing [mm] | 2 |
| Weft diameter [mm] | 2,3 |
| Weft spacing [mm] | 2 |
| Openness factor [%] | 24 |
| Thickness [mm] | 3,2 |
| Material | Steel |

**Sample 2_Code 00004**




| | |
|---|---|
| Warp diameter [mm] | 2,5 |
| Warp spacing [mm] | 15 |
| Weft diameter [mm] | 1,5 |
| Weft spacing [mm] | 1,5 |
| Openness factor [%] | 40 |
| Thickness [mm] | 4 |
| Material | Stainless Steel |

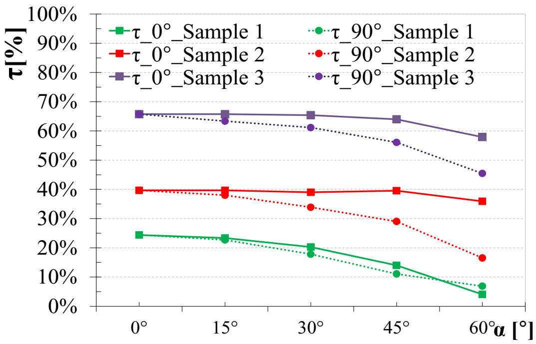
**Sample 3_Code 00005**




| | |
|---|---|
| Warp diameter [mm] | 2,5 |
| Warp spacing [mm] | 15 |
| Weft diameter [mm] | 1,5 |
| Weft spacing [mm] | 4 |
| Openness factor [%] | 66 |
| Thickness [mm] | 4 |
| Material | Stainless Steel |

Sample 1 (Tab. 1) is made by steel weft and warp wire with the same diameter (2.3 mm) and the same spacing (2 mm). Sample 2 and sample 3 (Tab. 1) are made by stainless steel wire: weft wire have a diameter of 1.5 mm while warp wire of 2.5 mm. Both have the same warp spacing (15 mm) but different weft spacing (respectively 1.5 mm and 4 mm). The sample orientation on the sample port does not affects the measured angular solar and light transmittance values (Fig. 2). On the other hand, for sample 2 and 3 the increasing spacing between the vertical wires shows a progressive increasing gap between the transmittance values for the two orientations and for incident angles of the radiation beam. This means that the vertical wire, necessary for this 3D large texture geometry based materials, affects transmittance values only for angles, between light source and sample, higher than 45°.

a)




b)

| | Light source incidence angles (α) | | | | |
|---|---|---|---|---|---|
| | 0° | 15° | 30° | 45° | 60° |
| $\tau_e$ _0°_Sample_1 | 24% | 23% | 20% | 14% | 4% |
| $\tau_e$ _90°_Sample_1 | 24% | 23% | 18% | 11% | 7% |
| $\tau_e$ _0°_Sample_2 | 40% | 40% | 39% | 40% | 36% |
| $\tau_e$ _90°_Sample_2 | 40% | 38% | 34% | 29% | 17% |
| $\tau_e$ _0°_Sample_3 | 66% | 66% | 65% | 64% | 58% |
| $\tau_e$ _90°_Sample_3 | 66% | 63% | 61% | 56% | 45% |

Fig. 2 – a) Graphic of angular solar transmittance values $\tau_e$ for Sample 1, Sample 2 and Sample 3. b) Table of angular solar transmittance values for Sample 1 (00014), Sample 2 (00004) and Sample 3 (00005). The angles 0° and 90° identifies the orientation of the sample on the sample port.

The samples revealed a different angular transmittance dependency arising from a change in their orientation on the sample port. In this paper we focused on metal mesh solution similar to sample 2 and 3 (Fig.1 and Fig. 2).We performed energy simulations to evaluate the performance of these materials if used as shading devices.

## 3. Calculation

Two conventional Italian office units located in the north and in the south of Italy (Milan and Palermo) were modeled in EnergyPlus [9] in order to estimate and compare their primary energy use for heating, cooling and lighting under different weather, orientation (south and west) and envelope conditions. The dimensions of the units are 3x4x3m (W x L x H) with one wall (having area of 3x3 m) facing outdoors.

The simulations were performed:

- with a standardized Single–Zone Variable Air Volume System cooling and heating system (VAV);
- with an efficiency of 0.87 for Gas Heater;
- with a Coefficient of performance (COP) of 3 for Cooling;
- using simulation parameters listed in Tab. 2.

Tab. 2 - Parameters used for energy simulations. Temperature and humidity set point and airflow rate are in accordance with [10] for standard office buildings.

| Parameter | Winter | Summer | Units |
|---|---|---|---|
| Schedule for people presence, plants and appliances on | From 8:00 to 18:00 | From 8:00 to 18:00 | [h] |
| Number of person for office | 1 | 1 | [-] |
| Lighting loads | 12 | 12 | [W/m$^2$] |
| Equipment loads | 10 | 10 | [W/m$^2$] |
| Air temperature set-point (Air temperature set-back) | 20.0 (18.0) | 26.0 (30) | [°C] |
| Air Flow rate | 0.015 | 0.015 | [(m$^3$/s)/person] |
| Relative humidity | 50.0 | 50.0 | [%] |
| External air infiltration rate (constant 24 hours) | 0.1 | 0.1 | [ach] |

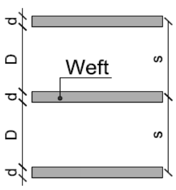
Primary energy use was calculated from estimated building final energy use, referring to Italian conversion factors that are 1.00 for gas and 2.18 for electricity. Energy demand for lighting is related to people presence and a minimum illuminance level requested on a work plane (500 lux), dimmed in the room by a stepped light control [11]. The light reflectance values $\rho_v$ used for internal surfaces are: 50% for internal walls, 25% for floor and 80% for ceiling.

The standard reference parameters used for the wall facing outdoors are:

- WWR that reproduce typical office conditions: 33% (that refers to a ribbon window with a net glazing area of 26%) and 100% (that refers to a curtain wall with a net glazing area of 80%);
- an opaque part of the façade with a thermal transmittance value of 0.3 [W/m$^2$K];
- a glazing systems (LE) coupled with a frame that satisfy law requirement for the different WWR and location (Tab. 3);
- the thermal bridge due to the coupling of glass and frame equal to 0.08 [W/(m K)] [12].

The following simulations were carried out in order to evaluate, with a parametric approach, the effectiveness of different Metal mesh texture (whose features are described in Tab. 3) coupled as a shading device with a Low Emissivity high selective glazing system (LE). These are featured by horizontal wire with a diameter (d), a net spacing between wires (D), a spacing between the axis of wires (S) and an openness factor (v/p). In accordance with the angular transmittance measurement carried out the vertical wires are not included in our model because of their low impact.

Tab. 3 - Metal mesh (a) and Glazing systems Features (b).

| Metal mesh shading systems | | | | | | |
|---|---|---|---|---|---|---|
| D [mm] | S [mm] | D [mm] | d/D [-] | v/p [%] | ID | Scheme |
| 2 | 12 | 10 | 0.20 | 83% | M_0.2 |  |
| 2 | 8 | 6 | 0.33 | 75% | M_0.3 | |
| 2 | 7 | 5 | 0.40 | 71% | M_0.4 | |
| 2 | 6 | 4 | 0.50 | 67% | M_0.5 | |
| 4 | 10 | 6 | 0.66 | 60% | M_0.6 | |
| 2 | 4.6 | 2.6 | 0.77 | 57% | M_0.8 | |
| 2 | 4 | 2 | 1.0 | 50% | M_1 | |



| Glazing systems typologies | | | | | |
|---|---|---|---|---|---|
| Low energy glazing systems | $U_w$ [W/m$^2$K] | $U_f$ [W/m$^2$K] | $U_g$ [W/m$^2$K] | g [-] | $\tau_v$ [-] |
| Milan_33%_LE | 1.80 | 1.80 | 1.48 | 0.54 | 0.71 |
| Milan_100%_LE | 1.30 | 1.50 | 0.98 | 0.49 | 0.66 |
| Palermo_100%_LE | 1.70 | 2.00 | 1.22 | 0.48 | 0.66 |
| **Sun control glazing systems** | | | | | |
| Milan_33%_SC | 1.80 | 1.80 | 1.47 | 0.28 | 0.63 |
| Milan_100%_SC | 1.30 | 1.50 | 1.01 | 0.27 | 0.63 |
| Palermo_100%_SC | 1.70 | 1.80 | 1.26 | 0.29 | 0.69 |

The reflectance value used for both metal mesh and venetian blind used for simulations were measured with a standard Perkin Elmer Lambda 950 Spectrometer for wavelength between 250 and 2500 nm. The mean values arising from two measurements of samples of metallic sheets conventionally used for shading systems were $\rho_e$ 0.496 and $\rho_v$ 0.490). These same samples have also been used for determining the mean infrared emissivity value of 0.4.

The shading alternatives used as a comparison were two: a static venetian blind shading system (with horizontal 45° tilted strip, a ratio between height and width of 0.2, a strip spacing equal to their width and the same reflectance and emissivity of metal mesh; a standard sun control glass (SC) with the properties listed in TAB 3 (b).

The simulations do not consider the impact of aging on the optical-radiative performances, which can be relevant as demonstrated by other studies with long-term environmental exposure of roofing membranes and ETFE [13,14].

## 4. Results

The graphics in Fig. 3 and Fig. 4 shows the different primary energy use for the defined scenarios with different WWR (33% and 100%), location (Milano and Palermo) and orientation (south and west). The effectiveness of metal mesh shading systems, coupled with a Low-Emissivity glazing system (LE), is compared with a Solar control glazing system (SC) without shading devices, a Low-Emissivity glazing system (LE) without shading devices and a Low-Emissivity glazing system coupled with a standard Venetian Blind shading system (VB).

Analyzing Fig. 3 is possible to observe that generally the $EP_c$ (primary energy requirement for cooling) decrease for increasing d/D while the $EP_l$ (primary energy requirement for lighting) and $EP_h$ (primary energy requirement for heating) increase.

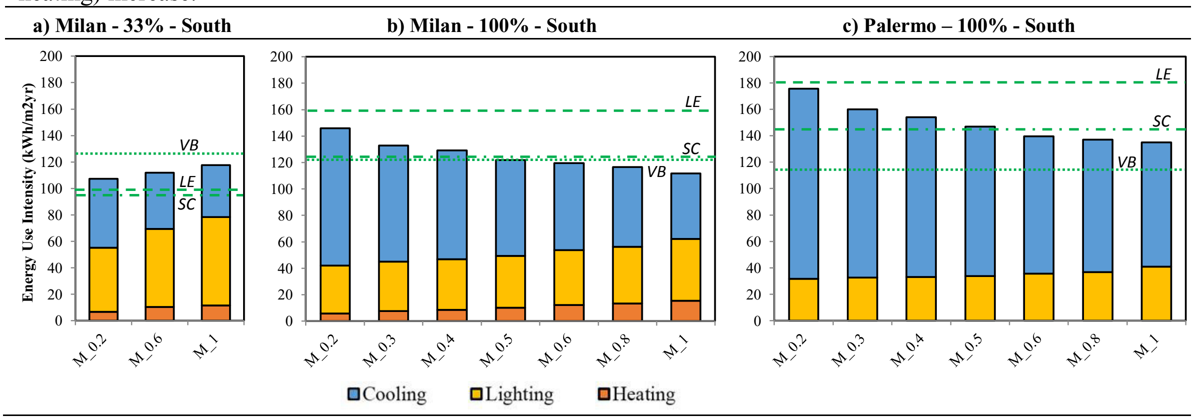



Fig. 3 – a) EP for Milan office with WWR of 33% and south exposure. b) EP for Milan office with WWR of 100% and south exposure. c) EP for Palermo office with WWR of 100% and south exposure.

For Milan, south exposure with WWR of 33% the shading systems (both metal mesh and venetian blind) performs worse than glazing system alone (both LE and SC). Analyzing only the metal mesh is possible to see that for increasing d/D the annual primary energy requirement increase. For Milan, south exposure with WWR of 100% generally the impact of $EP_c$ is higher than $EP_l$ and $EP_h$. For d/D higher than 0.6 the metal mesh system is the best alternative while for lower values the SC and VB systems perform better. For Palermo, south exposure with WWR of 100% generally the effect of $EP_c$ is higher than $EP_l$. The metal mesh system is never the best one. However this system performs better than glazing systems alone for d/D higher than 0.6.

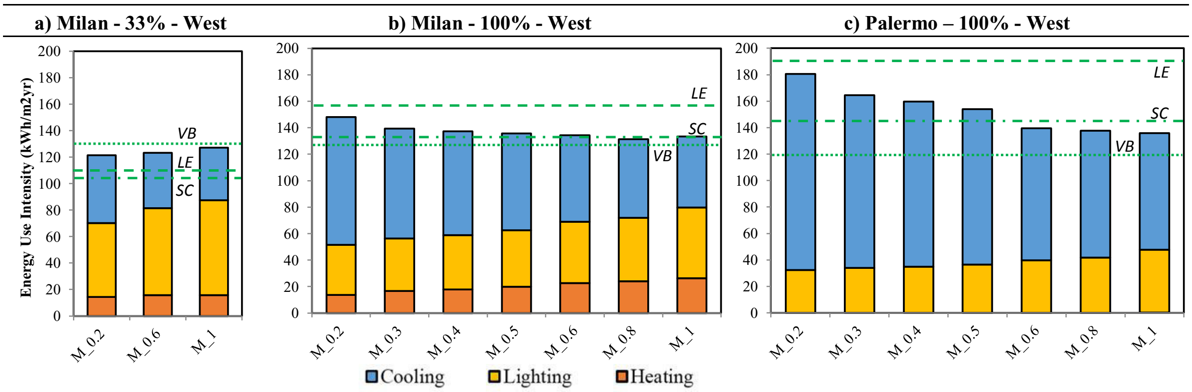



Fig. 4 - $EP_h$ for Milan office with WWR of 33% and west exposure; $EP_h$ for Milan office with WWR of 100% and west exposure; $EP_h$ for Palermo office with WWR of 100% and west exposure.

Analyzing Fig. 4 is possible to observe that generally the energy requirement tendency (in term of mutual behavior among the various control systems) for the different solar control systems are similar to the south one except for the increasing values of $EP_h$ (primary energy requirement for heating). Furthermore for West exposure the metal mesh systems are never the best solution, neither for Milan with WWR of 100%.

## 5. Conclusions

The analysis shows that the same shading alternatives for metal mesh, applied in different climate conditions, produce different results in term of primary energy use. For WWR 33% (Milan and Palermo) the shading systems (both metal mesh and venetian blind) generally performs worse than the glazing systems alone (both solar control and low emissivity). Metal mesh systems with high d/D are the best solar control solution for WWR 100%, in Milan and south exposure. The venetian blind are the best alternative, for west exposure, showing low values of $EP_c$ and high values of $EP_l$. This is a consequence of the venetian blind self-shading effect, due to their equal spacing and width. Comparing venetian blind with metal mesh with d/D higher than 0.4 the difference in term of final energy use is lower. A metal mesh systems with wide spacing is an alternative for ensuring both a good outside view and a low energy use, excluding the glare analysis, which will be performed later and presented in another paper. On the other hand metal meshes are never the best solar control strategies for Palermo, but for d/D higher than 0.6 performs better than glazing system alone both (LE) or (SC).

## 6. Acknowledgements

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