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# Effects on Correlated Color Temperature by using Luminescent Solar Concentrators integrated in the building envelope

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# Agenda



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2. Methodology
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    - 3.1. LSC prototypes
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4. Scaled physical model analyses
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# Introduction



•Luminescent Solar Concentrators (LSCs) represent a very promising field for R&D about solar components, especially the semitransparent ones, suitable for building integration.

•These components can likely represent an effective way to produce renewable energy preserving the transparency of the building envelope, by using a wide amount of surfaces which are at the moment neglected, as windows, skylights, shading devices, etc.

•The LSC yellow prototype can substitute parts of the exposed façades of a building in which people have to complain a visual task during all the day, changing the quality of light that becomes warmer.

Sports and Leisure Center in Saint-Cloud, Paris, France, Arch. Christophe Ouhayoun & Nicolas Ziesel (Koz) (source: Koz Architects ® Stephen Lucas)

# Introduction

•The LSC red prototype results more critical in designing the installation in daily occupied working spaces although some cases can be found in modern architecture.

•Analyses have to be carried out to assess the effective impacts of the color in visual comfort and perception in indoor spaces. The purpose of the study is to assess how the application of LSC plates, installed in a convenient position to produce electrical energy can also be used as interactive windows involving visual comfort parameters.

•Experimental measures on the LSC plates and their application on a scaled model were carried out on a single office space with two configurations of transparent south façade and discussed.

Library Sandro Penna, City of Perugia, Italy, Arch. Italo Rota (source: Italo Rota ® Italo Rota).

# Methodology

•The two LSC samples developed by ENI were characterized considering them as simple elements by experimental measurements. The LSC yellow sample was also analyzed as functional component integrated in a simple office space, using a scaled physical model.

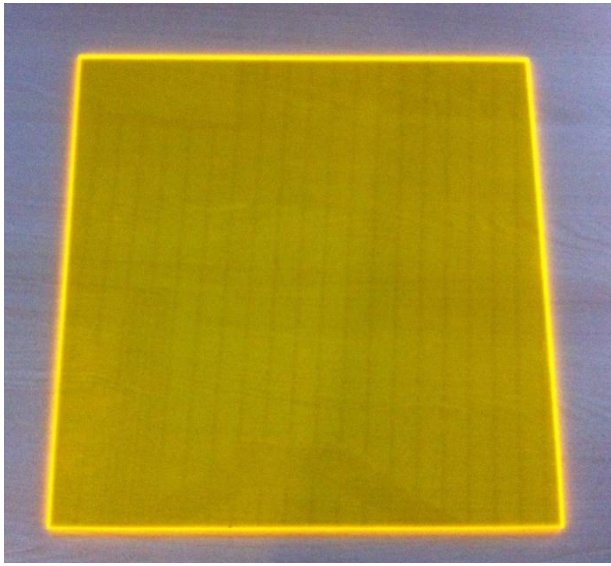
•The two prototypes are realized with transparent plastic polymethylmethacrylate (PMMA) in which dyes are dispersed shifting the spectrum of solar radiation.

•LSCs were submitted to spectral characterization.

•The LSC yellow sample has dimensions 50x50 cm and the LSC red one is a small sample 9.8x9.8cm. Due to red sample dimension it couldn't be used for the scaled model measurements

| Optic characteristics | Standard | Units | Value |
|---|---|---|---|
| Light transmission (thickness 3 mm); (wavelength 380-780 nm) | DIN 5036 | % | 93.5 |
| Refractive index | DIN 53491 | nD 20 | 1,491 |

Visible light transmission and refractive index of the PMMA.



Plates with the two dyes analyzed (source: ENI Donegani Institute).

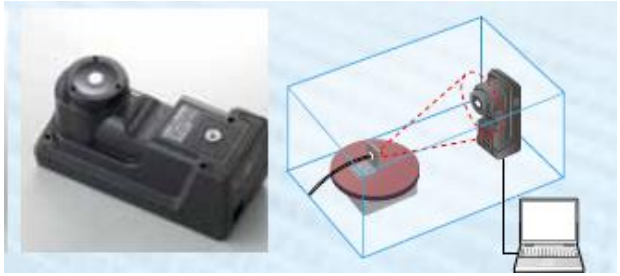
# Measuring instrument data sheet



•Analyses on the two LSC sheets were performed with an illuminance spectrophotometer Konica Minolta CL 500A.

•The CL-500A is a compact, lightweight illuminance spectrophotometer that can be used not only for illuminance measurements but also for spectral evaluation by using multiple sensors and an optical grating.

•The sensor based detector allows displaying spectral distribution in graphical form.



| Specifications | |
|---|---|
| Model | Illuminance Spectrophotometer CL-500A |
| Illuminance meter class | Conforms to requirements for Class AA of JIS C 1609-11:2006 "Illuminance meters Part 1: General measuring instruments" Conforms to DIN 5032 Part 7 Class B |
| Spectral wavelength range | 360 to 780 nm |
| Output wavelength pitch | 1 nm |
| Spectral bandwidth | Approx. 10 nm (half bandwidth) |
| Wavelength precision | ±0.3 nm (Median wavelength of 435.8 nm, 546.1 nm, and 585.3 nm as specified in JIS Z 8724 |
| Measuring range | 0.1 to 100,000 lx (chromaticity display requires 5 lx or more) |
| Accuracy (Standard Illuminant A) | $E_v$ (illuminance): ±2%±1 digit of displayed value<br>xy: ±0.0015 (10 to 100,000 lx)<br>xy: ±0.002 (5 to 10 lx) |
| Repeatability (2σ) (Standard Illuminant A) | $E_v$: 0.5%+1 digit<br>xy: 0.0005 (500 to 100,000 lx)<br>xy: 0.001 (100 to 500 lx)<br>xy: 0.002 (30 to 100 lx)<br>xy: 0.004 (5 to 30 lx) |
| Visible-region relative spectral response characteristics ($f_1'$) | Within 1.5% of spectral luminous efficiency V (λ) |
| Cosine response ($f_2$) | $E_v$: Within 3% |
| Temperature drift ($f_T$) | $E_v$: ±3% of displayed value; xy: ±0.003 |
| Humidity drift ($f_H$) | $E_v$: ±3% of displayed value; xy: ±0.003 |
| Storage temperature/ humidity range | -10 to 45°C, relative humidity of 85% or less (at 35°C) with no condensation |
| Dimensions (WxDxH) | 70x165x83 mm |
| Weight | 350 g |

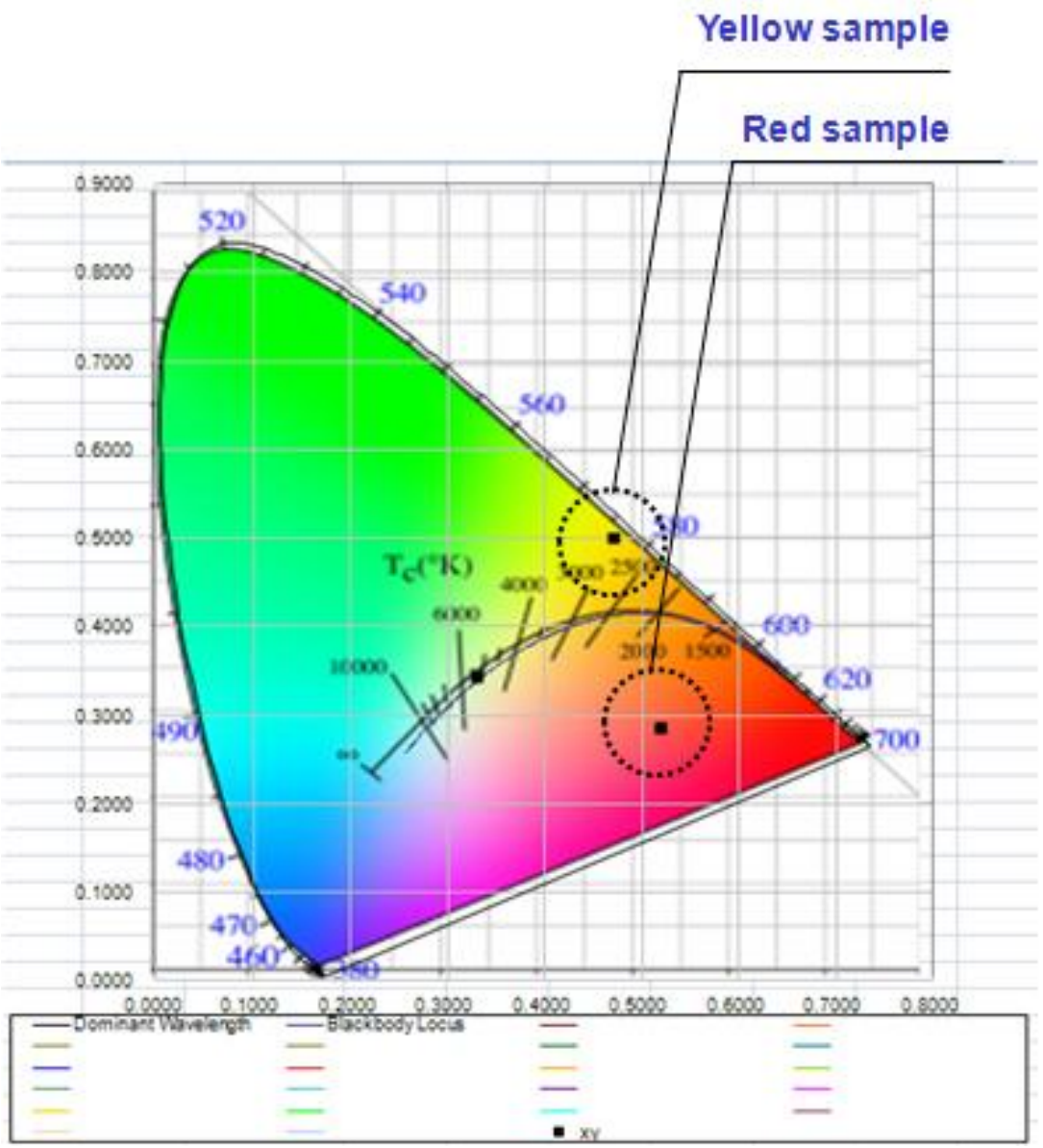
# Spectral characterization of the LSC plates

•Spectral Analyses were performed in overcast sky (i.e. snowy day sky).

•Photometric units are also recorded including:

- illuminance [lux],
- correlated color temperature (CCT) [K],
- chromaticity coordinates (xy, u'v'),
- distance from blackbody locus (BL) $D_{uv}$
- dominant wavelength [nm].

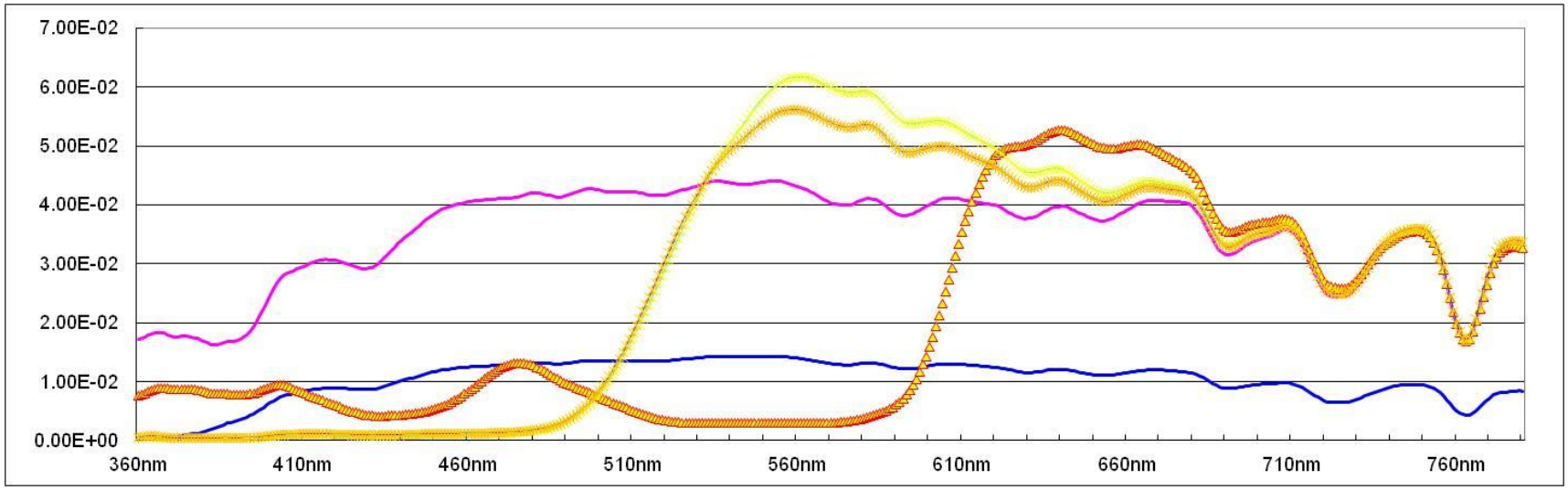
• Data are recorded with the instrument standard data management software (CL-S10w).




CIE 1931 chromaticity diagram: localization of the two samples.

# Spectral characterization of the LSC plates

Two measurements for the main case of the LSC yellow sample and a measure on LSC red sample were recorded and plotted in comparison with a clear glass and the sky values.

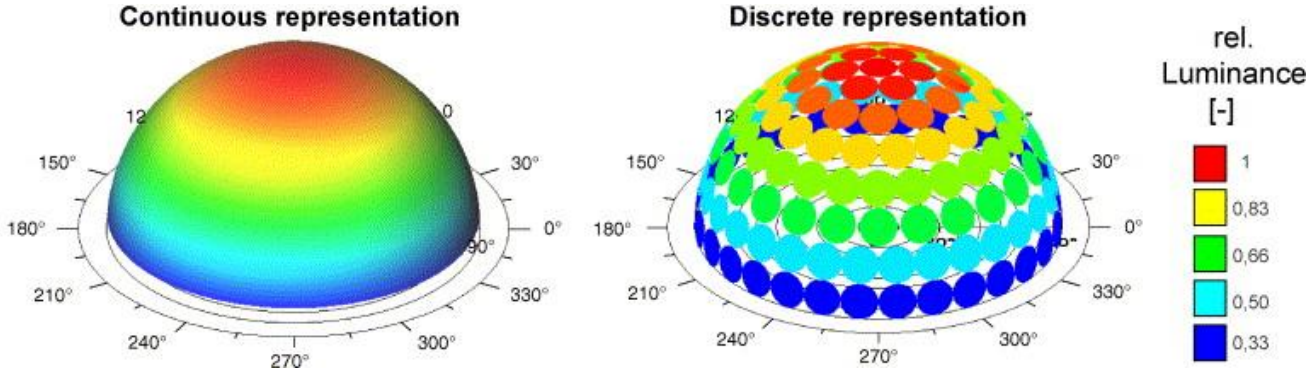



Spectral irradiance values of the two samples analyzed in comparison with the overcast sky and clear glass. Pink line=overcast sky; Blu line=clear glass; Yellow/Dark Yellow lines= Yellow LSC; Red line= red LSC.

Data recorded shown that the clear glass reduces the sky illuminance of about 68% and the LSC red sample reduces this value of 74% whereas the LSC yellow sample improve it of about 5-12%. The CCT varies of about 40% (i.e. 42.6-41.3%) for the LSC yellow sample. The yellow sample thus increases the CCT value without reducing illuminance level. In overcast sky conditions the CCT is higher than 5000 K and the value obtained with the yellow sample lead the color of the light into the range of the warm and intermediate white acting an enhancement of the visual comfort.

# Spectral characterization of the LSC plates

Overcast Sky conditions




| Parameters | Symbol | Units | Overcast sky | Clear glass | LSC Yellow Sample | | LSC Red sample |
|---|---|---|---|---|---|---|---|
| | | | | | Record 1 | Record 2 | |
| Illuminance | $E_v$ | lux | 3034 | 972 | 3398 | 3192 | 794 |
| Chromaticity coordinates | x<br>y | - | 0.3354<br>0.3515 | 0.3361<br>0.3592 | 0.4761<br>0.5000 | 0.4715<br>0.5014 | 0.5186<br>0.2874 |
| Correlated Color Temperature CCT | $T_{cp}$ | K | 5385 | 5364 | 3091 | 3159 | - |
| Distance from BL | $D_{uv}$ | - | 0.0040 | 0.0074 | 0.0286 | 0.0296 | - |
| Peak Wavelength | DW | nm | 553 | 552 | 561 | 559 | 640 |

Measured data on the elements.

# Scaled physical model analyses



•Results in term of illuminance average value, spectral distribution, peak wavelength and CCT in a model of office space (5x4m; h. 3m) with two façade configurations integrating the LSC yellow sample are reported.

•The first model has a transparent window (1/8 of the floor area) with a the yellow LSC surface placed above as a fanlight ($FL_y$) and the second model has a façade with the same configuration in which is added the LSC yellow plate also in the lower part of the window as a transparent yellow parapet increasing solar active surface and daylight penetration ($FL+P_y$).

•The two facade configurations integrating the LSC yellow sample were compared with the same façade configurations without any colored portions, simulating simple glazed facades ($FL_t$ and $FL+P_t$).

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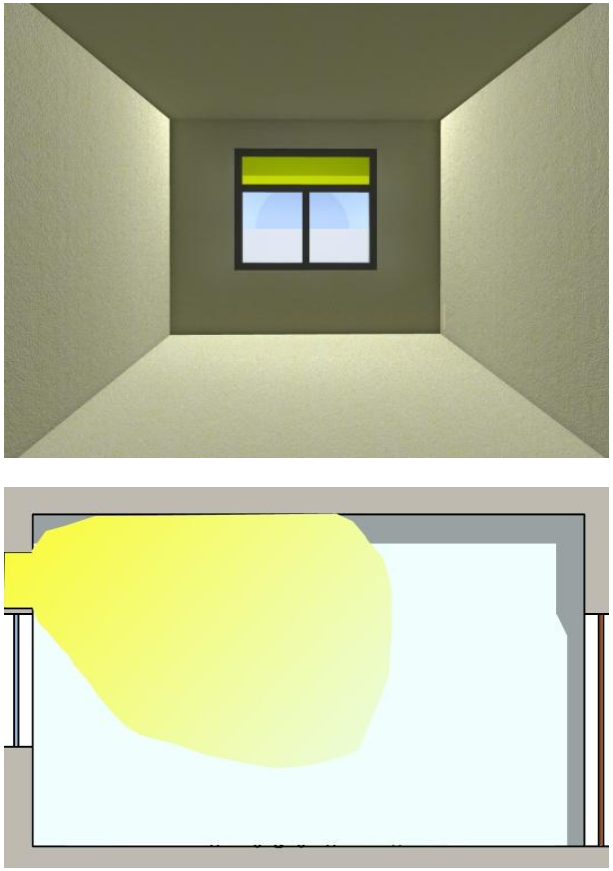
Office models: in the left $FL_y$ facade and on the right $FL+P_y$ facade.

# Scaled physical model analyses



| Dimensions of the openings | Units | Value |
|---|---|---|
| Transparent window | | |
| length | m | 2.0 |
| height | m | 1.2 |
| Fanlight ($FL_y$) | | |
| length | m | 2.0 |
| height | m | 0.5 |
| Parapet ($P_y$) | | |
| length | m | 2.0 |
| height | m | 0.5 |

Dimensions of the openings of the two facades configurations

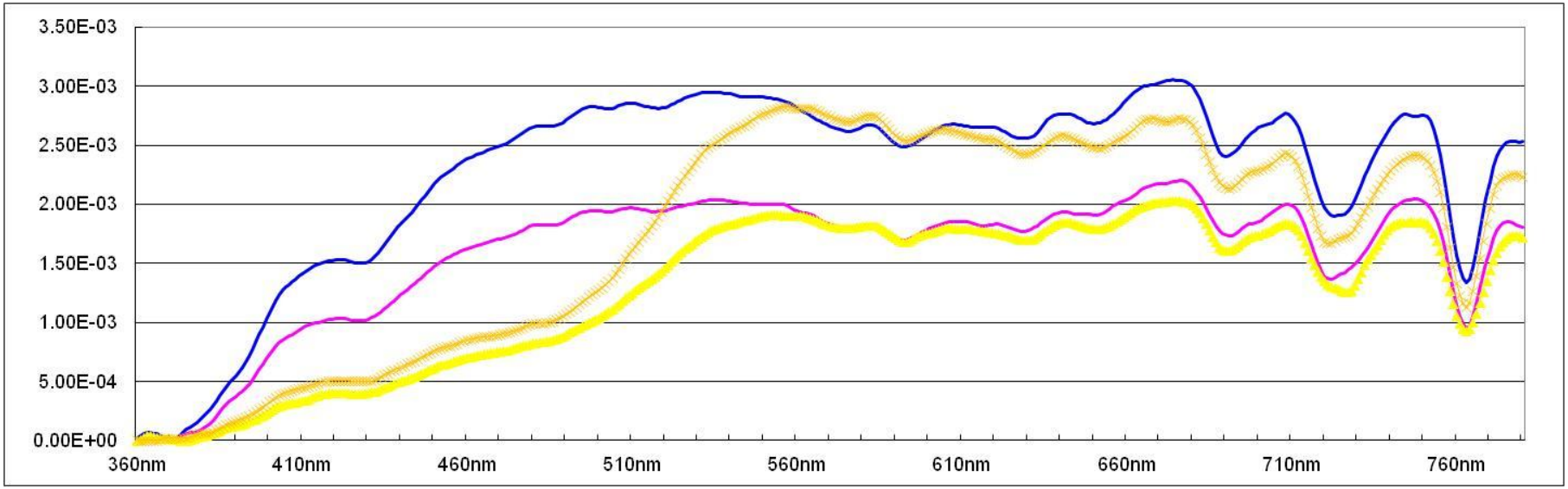


Effect of the fanlight with indirect light.

# Scaled physical model analyses



Two measurements for the main case of the LSC yellow sample and a measure on LSC red sample were recorded and plotted.



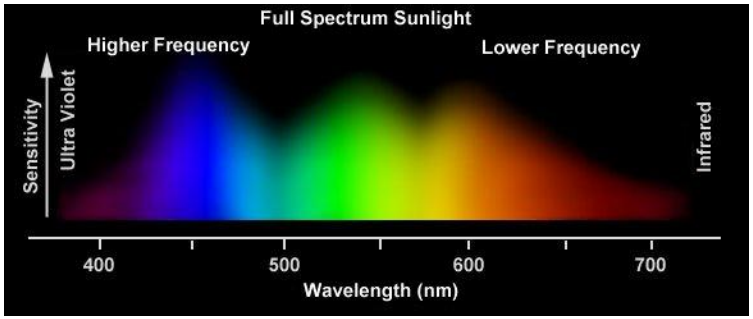

Spectral irradiance values of the two models integrating the yellow sample in comparison with the same configurations equipped with clear glass surfaces:

Pink line=$FL_t$;

Blu line=$FL+P_t$;

Yellow line= $FL_y$;

Dark yellow line= $FL+P_y$.



# Scaled physical model analyses



•Results reported in the first analysis are confirmed in the scaled physical model setup.

•Illuminance values are lower due to model configuration however the enhancement of the CCT is reconfirmed and supported by this analysis.

| Parameters | Symbol | Units | $FL_t$ | $FL+P_t$ | $FL_y$ | $FL+P_y$ |
|---|---|---|---|---|---|---|
| Illuminance | $E_v$ | lux | 201 | 138 | 123 | 177 |
| Chromaticity coordinates | x<br>y | - | 0.3449<br>0.3688 | 0.3464<br>0.3701 | 0.4062<br>0.4298 | 0.4175<br>0.4394 |
| Correlated Color Temperature CCT | $T_{cp}$ | K | 5060 | 5014 | 3765 | 3609 |
| Distance from BL | $D_{uv}$ | - | 0.0084 | 0.0085 | 0.0161 | 0.0173 |
| Peak Wavelength | DW | nm | 674 | 676 | 674 | 556 |

Measured data on the scaled physical models.

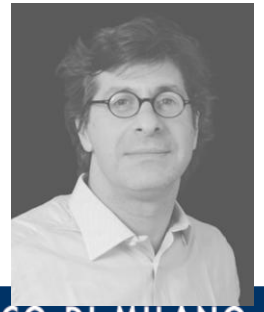
# Conclusions



•The most interesting result of this preliminary study is the improvement on light quality under diffuse daylight conditions achieved with the LSC yellow plate installation.

•It can be appreciate that the use of colored LSC sheets affect the characteristic parameters of incoming light producing an upgrading of color temperature becoming warmer and more pleasant for the users (i.e. from 5000 K to 3300 K), without reducing illuminance levels.

•This means that the installation of the LSC yellow plate in the façade enhances the visual comfort inside the office space without producing an increase of electrical consumption to achieve the illuminance levels required by the national standards.



## Thank you very much for your attention!

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