Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 70 (2015) 719 – 728
Energy Procedia

International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2014

Lean strategies for window retrofit of Italian office buildings: impact on energy use, thermal and visual comfort

Andrea Giovanni Mainini[a]*, Daniele Bonato[a], Tiziana Poli[a], Alberto Speroni[a]

[a]*Politecnico di Milano - Architecture, Built environment and Construction engineering Dept., P.zza Leonardo da Vinci 32, Milano 20133, Italy*

Abstract

The aim of this paper is to explore lean retrofit strategies for transparent envelope of existing Italian office buildings, to improve their performance and to ensure low energy use and a good thermal and visual comfort. Solar and light control is necessary to prevent overheating in office buildings those generally present high internal loads. The effectiveness of solar window films use in Italian buildings context is here investigated, in comparison with other strategies like the use of internal roller blinds and the substitution of the existing window panes with high performance ones. A sensitivity analysis was assessed to evaluate the office unit primary energy use under different retrofit solution, weather conditions and window to wall ratio. A conventional existing office unit was modeled in EnergyPlus and LBNL Radiance to assess heating, cooling and lighting energy demand coupled with visual comfort parameters. Thermal comfort was evaluated hourly in accordance with ISO 7730. The results are presented with a cost - benefit analysis to understand the best retrofit solution.

Peer-review by the scientific conference committee of SHC 2014 under responsibility of PSE AG

Keywords: Window films, transparent building envelope,human comfort, primary energy demand

1. Introduction

Energy standards and certifications request high performance for transparent and opaque envelopes in new buildings to minimize the energy consumption. Windows are the most important part of the building façade to control solar gain and thermal losses. Their performance are also relevant for visual and thermal comfort. Office

* Corresponding author. Tel.: +39 0223996015; fax: +390223996020.
E-mail address: andreagiovanni.mainini@polimi.it, mainini.andrea@gmail.com

Peer-review by the scientific conference committee of SHC 2014 under responsibility of PSE AG
doi:10.1016/j.egypro.2015.02.181

buildings, that generally have medium-high WWR (window to wall ratio value), high internal gains due to users, lighting and appliances need a good balance between both thermal and visible performance of transparent facades and between static and dynamic shading control strategies to avoid overheating and to permit optimal use of daylight [1],[2],[3].

In Italy over than the 75% of existing office buildings have more than 25 years and present inadequate or obsolete façades technologies and systems. The opaque part of the envelope is generally with low or no insulation and the transparent façade has single glasses or double pane clear glasses filled with air[4].

Hence is important to elaborate strategies able to improve the transparent envelope performance of existing office buildings that can be easily implemented, without compromising building use and reducing retrofit costs to minimum. We considered and compared lean retrofit alternatives for the transparent part of the envelope i.e.: the substitution of existing window panes with high performance ones, the use of internal shading devices (roller blind with on-off control on solar irradiance) and window films application (Table 1). Each solution permits to optimize, in different ways, several aspects like building consumption during the hot and warm season or to improve thermal and visual conditions in working environments. The analysis was implemented on two office buildings models with different energy needs and located in Milan (Cold Winter – Hot Summers) and Palermo (Warm Winters – Hot Summers). Milan is in the North of Italy (45°27′50″N - 9°11′25″E) and Palermo is in the South (38°07’00”N - 13°22'00"E).

2. Model description

The two conventional representative models of Italian office units were modeled in EnergyPlus to estimate and compare their primary energy use under different weather, and envelope conditions. The dimensions of the units are 3 x 4 x 3 m (W x L x H) and they have only one wall facing outdoors and oriented South, modeled alternatively with different window to wall ratio representative for ribbon window and curtain wall systems. The proposed solutions have a WWR (window to wall ratio) from 50 to 100% (corresponding to a glass area of 42% and 80%). The wall is considered as non-insulated. The standard reference case for transparent surfaces is the double pane clear glass filled with air (DC). The analyzed retrofit alternatives are listed in Table 1-2 and consist in:

- glass substitution with a double pane low-e selective/ solar control glass control filled with air (LowE_X codes, with X from 1 to 3 representative of the three low-e glass alternatives).
- the use of reflective/selective/solar control window films on the existing double clear glass (DC+Y codes)
- The use of an internal automated roller blind with an on- off control based on irradiance and a set point of over 300W/m^2

Table 1. Thermal and optical properties of the double pane clear glass (DC), the double pane Low-e glasses (LowE_X, where X is a number used to identify the LowE glass alternatives) and the Double pane clear glass coupled with window films from type A to type D (DC+Y, where Y is a number used to identify the LowE glass alternatives). Visible transmittance (tvis), Solar Heat Gain Coefficient (SHGC) and Thermal transmittance (U-factor) were calculated and reported in the table.

	DC	**LowE_1**	**LowE_2**	**LowE_3**	**DC+A**	**DC+B**	**DC+C**	**DC+D**
τ_{vis} [-]	0.786	0.698	0.521	0.701	0.686	0.534	0.355	0.176
SHGC [-]	0.704	0.452	0.299	0.382	0.644	0.454	0.320	0.164
U factor [W/m^{2}K]	2.703	1.674	1.651	1.651	2.733	2.727	2.727	2.727

Table 2. Thermal and optical properties of window films (A clear, B Selective, C and D Solar control) and roller blind.

	τ_{vis}	τ_{sol}	ρ_{vis}	ρ_{sol}
Film A	0.76	0.673	0.09	0.09
Film B	0.59	0.414	0.11	0.12
Film C	0.39	0.29	0.22	0.17
Film D	0.19	0.13	0.57	0.54
Roller blind	0.26	0.28	0.4	0.57

Solar spectral transmittance and reflectance values for glasses, solar films and shading devices were determined with LBNL Optics 5.0 Software [5], from the International Glazing Database IGDB [6] or measured with a Perkin Elmer Lambda950 Spectrometer and then computed in LBNL Window 7.2 Software [7]. Soiling of transparent surfaces in urban area is not considered in this study, but it can cause a reduction in optical and solar properties from 3 to 10%, depending on the transparent material or interface [8].

We have considered a standardized Single–Zone Variable Air Volume System cooling and heating system (VAV) to estimate the Primary energy use for heating (Gas Heater) and cooling (Electric Heat Pump). We assumed an efficiency of 0.87 for Gas Heater and a Coefficient of performance (COP) of 3 for Electric Heat Pump. The used simulation parameters are listed in Table 3

Table 3. Parameters used for energy simulations. Temperature and humidity set point and air flow rate are in in accordance with [9] for standard office buildings.

Parameter	Winter	Summer
Schedule for people presence, plants and appliances on (h)	From 9:00 to 18:00	From 9:00 to 18:00
Air temperature set-point (°C)	20.0	26.0
Air temperature set-back(°C)	18.0	30
Air Flow rate [(m^3/s)/person]	0.015	0.015
Relative humidity (%)	50.0	50.0
Number of person in office (-)	1	1
External air infiltration rate (vol/h) – constant 24 hours	0.1	0.1
Lighting loads (W/m^2)	10	10
Equipment loads (W/m^2)	15	15

Energy demand for lighting is related to schedule for people presence and illuminance level requested on work plane. A stepped light control [10], located in the center of the room, is used to ensure 500 lux on the work plane during working hours [9].

3. Results

3.1. Window films alternatives choose

There are several typologies of window films on market, differenced by thickness, metal density, color, installation side, etc. Solar and visual transmittance of 84 different window films were collected or measured, and then simulated in Energy Plus [10], for the two buildings and weather alternatives, to obtain total primary energy use for lighting, cooling, heating and fans.

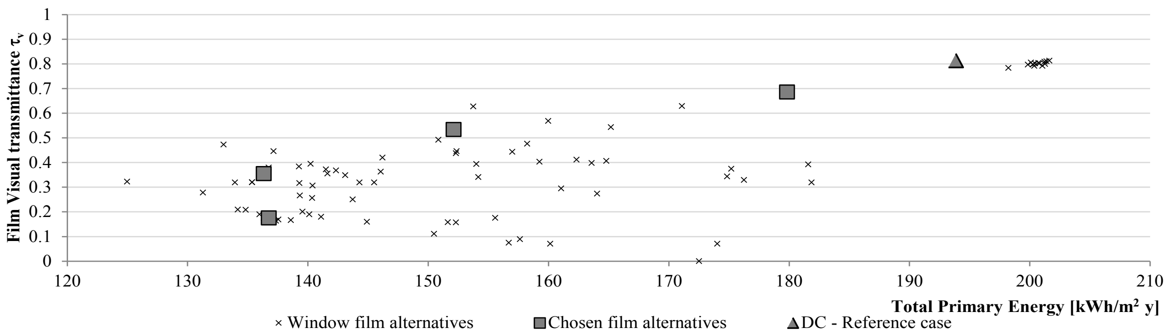

Fig. 1 Visible transmission and total primary energy consumption correlation for 84 window film tested in Milan WWR 50% -Ribbon window

The results presented in chapter 3.2 refer to the most representative window film alternatives (A,B,C,D) between all the modeled scenarios. In Fig. 1-2-3 total primary energy use for all the 84 film alternatives applied on existing DC glass, for Milan, ribbon window WWR 50% scenario, are presented in comparison with film visible transmittance value and, alternatively, to primary energy use for lighting and cooling.

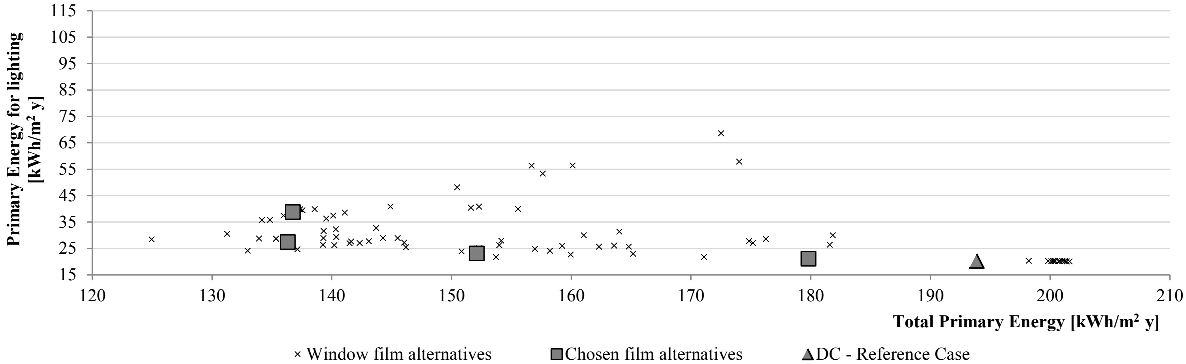

Fig.2. Primary energy for Lighting and total primary energy consumption correlation for 84 window film tested in Milan WWR 50% -Ribbon window

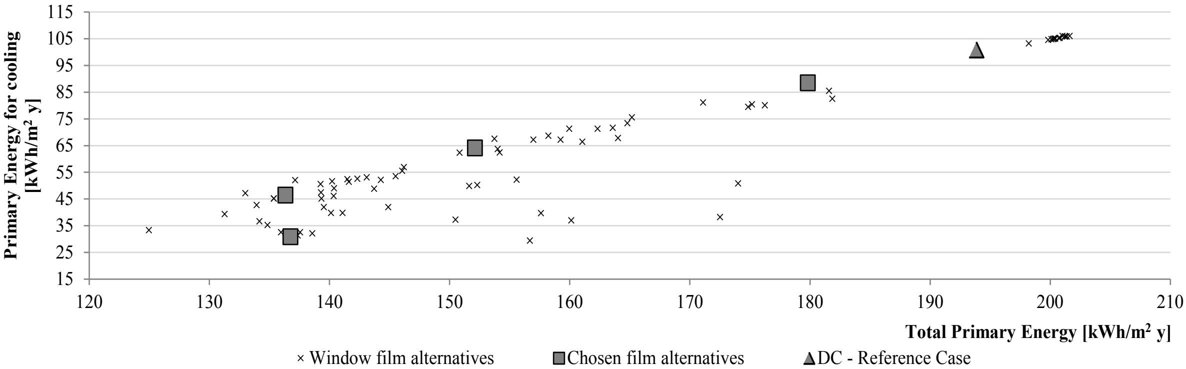

Fig. 3. Primary energy for Cooling and total primary energy consumption correlation for 84 window film tested in Milan WWR 50% -Ribbon window

3.2. Primary energy use

Annual primary energy use (in kWh/m^2 year) for the two office units with some of the proposed transparent envelope solutions is presented in detail in the following figures and tables for Milan and Palermo. Primary energy was evaluated from building final energy use, referring to Italian primary energy conversion factors that are: 1.00 for gas and 2.18 for electricity. Total Primary energy use reduction in comparison with DC standard case is presented in Table 4 and in Table 5, respectively for the ribbon window and curtain wall façade.

All the proposed solutions, except for DC+A, permit a good energy consumption reduction level. The average reduction percentages are maximized in the case of WWR 100% (Fig. 5) compared to WWR 50% scenario. We also observe that the automated internal roller blind (DC+sh) provides a cooling consumption reduction similar to the glass substitution strategies. Also reducing the irradiance activation set-point for blinds from 300 W/m^2 to 150W/m^2 it is not possible to decrease efficiently cooling loads. Better results can be obtained using external automated blinds. Other strategies like LowE_2, DC+C, DC+D permit to achieve better energy performance. DC+D sample, despite of its efficiency, has a low light transmission that could potentially interfere with the visual comfort of the users inside the office. The glass substitution with a well-performing one is particularly convenient in cold climates like Milan, because of the improvement in thermal transmittance and the reduction in heating loads.

Table 4. Primary energy use reduction, for WWR 50%, in comparison with transparent envelope reference case DC double clear glass)

	DC	DC+sh	LowE_1	LowE_2	LowE_3	DC+A	DC+B	DC+C	DC+D
Milan	0%	-23%	-18%	-33%	-27%	-7%	-21%	-29%	-29%
Palermo	0%	-27%	-16%	-35%	-26%	-9%	-28%	-40%	-45%

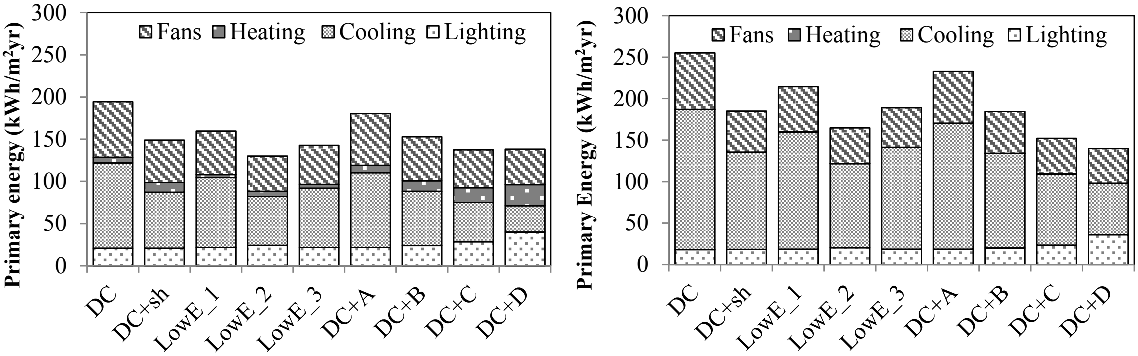

Fig. 4. Primary energy use comparison for Fans, Heating, Cooling and Lighting for the proposed retrofit solutions in Milan (a) and Palermo (b). --ribbon window- Window to wall ratio 50%.

Table 5. Total primary energy use reduction, for WWR 100%, in comparison with transparent envelope reference case (DC double clear glass)

	DC	DC+sh	LowE_1	LowE_2	LowE_3	DC+A	DC+B	DC+C	DC+D
Milan	0%	-28%	-24%	-43%	-34%	-8%	-26%	-38%	-44%
Palermo	**0%**	**-31%**	**-19%**	**-44%**	**-31%**	**-11%**	**-33%**	**-50%**	**-66%**

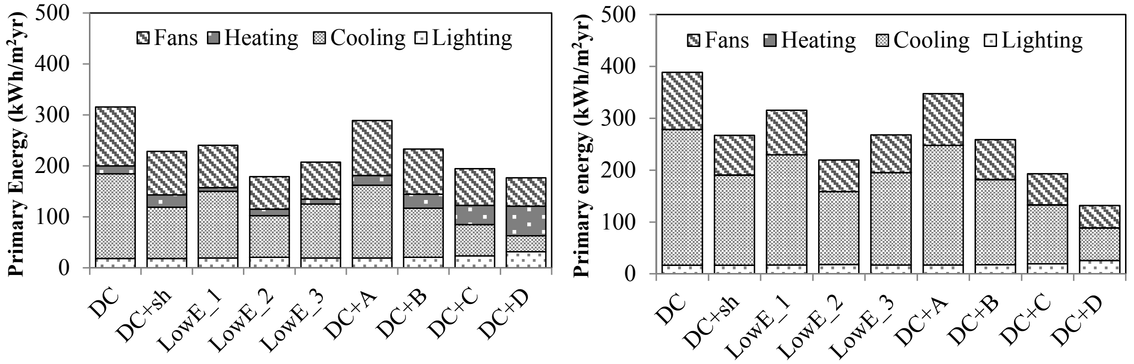

Fig. 5. Primary energy use comparison for Fans, Heating, Cooling and Lighting for the proposed retrofit solutions in Milan (a) and Palermo (b). --curtain wall window- WWR Window to wall ratio 100%.

Among the proposed alternatives we chose the most efficient ones for every typology, in reducing total primary energy consumption. Figures 6 to 8 compare the monthly primary energy use in Milan and Palermo for Heating, Cooling and Lighting, for DC+sh, LowE_2 and DC+C alternatives for both weather conditions and only for WWR 50% scenario. Analogue variations are obtained for WWR 100% scenario. Primary energy use for heating is not significant for Palermo, but is relevant for Milano in every of the proposed alternatives. The use of solar films on existing DC windows in Milan determine an increase in primary energy use for heating because of the high thermal transmittance and the reduction in solar gains, that is higher than the one obtained using an automated shading device, with the same glass technology. Glass substitution is a more effective solution in this case.

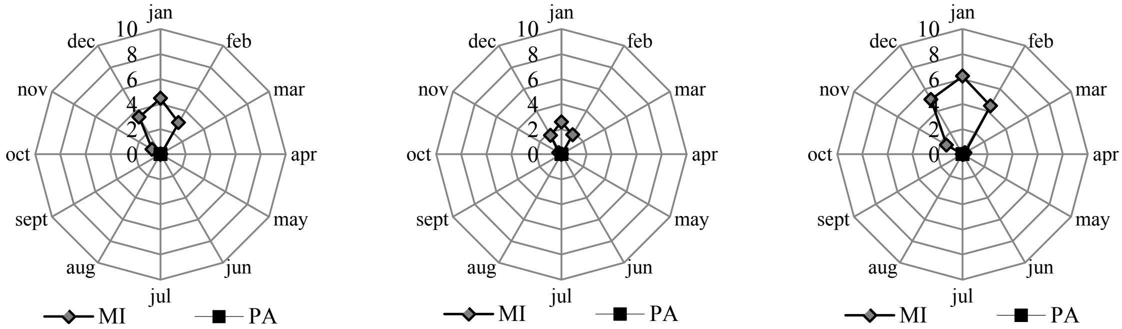

Fig. 6. Monthly primary energy use comparison for Heating - [kWh/m^2], for the proposed retrofit solutions in Milan (MI) and Palermo (PA): (a) DC+sh (b) LowE_2 (c) DC+C. Ribbon window – window to wall ratio 50%

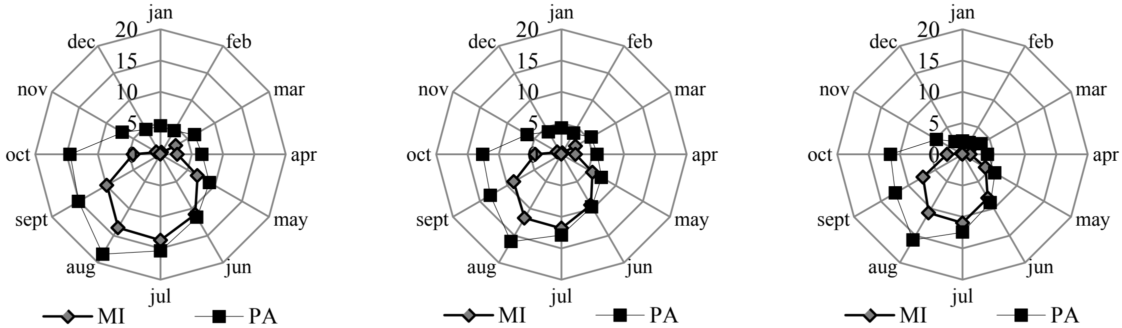

Fig. 7. Monthly primary energy use comparison for Cooling - [kWh/m^2] for the proposed retrofit solutions in Milan (MI) and Palermo (PA): (a) DC+sh (b) LowE_2 (c) DC+C. Ribbon window – window to wall ratio 50%

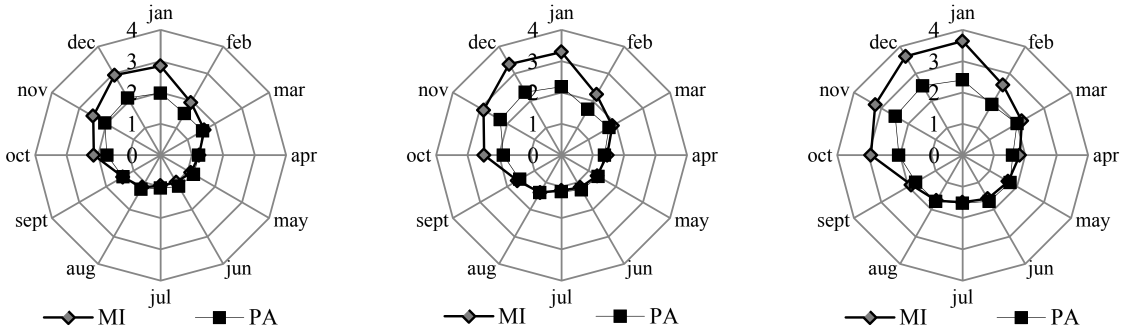

Fig. 8. Monthly primary energy use comparison for Lighting [kWh/m^2] for the proposed retrofit solutions in Milan (MI) and Palermo (PA): (a) DC+sh (b) LowE_2 (c) DC+C. Ribbon window – window to wall ratio 50%

Solar films are more effective in reducing primary energy for cooling than the other alternatives proposed, but determine an increase in primary energy use for lighting, due to the reduction in visible transmittance. Movable shading devices are the best solution for reducing primary energy use for lighting. The primary energy reduction, or increase of every strategy and in comparison with the standard DC case are presented in Table 6 and 7.

Table 6. Primary energy use percentage reduction for cooling and increase for lighting and heating for the selected envelope alternatives (DC+sh, Low_2 and DC+C) in comparison with the reference DC case values. WWR 50%, Ribbon Window

	DC+sh				Low_2				DC+C			
	Heating	Cooling	Lighting	**Total**	Heating	Cooling	Lighting	**Total**	Heating	Cooling	Lighting	**Total**
Milan	67%	-34%	0%	**-23%**	-8%	-43%	17%	**-33%**	153%	-54%	37%	**-29%**
Palermo	19%	-31%	2%	**-27%**	-43%	-40%	12%	**-35%**	42%	-49%	30%	**-40%**

Table 7. Primary energy use percentage reduction for cooling and increase for lighting and heating for the selected envelope alternatives (DC+sh, Low_2 and DC+C) in comparison with the reference DC case values. WWR 100% Curtain Wall

	DC+sh				Low_2				DC+C			
	Heating	Cooling	Lighting	**Total**	Heating	Cooling	Lighting	**Total**	Heating	Cooling	Lighting	**Total**
Milan	58%	-39%	0%	**-28%**	-16%	-51%	12%	**-43%**	146%	-63%	26%	**-38%**
Palermo	28%	-34%	0%	**-31%**	-53%	-46%	8%	**-44%**	161%	-57%	18%	**-50%**

3.3. Thermal comfort

We evaluated hourly thermal comfort (Predicted Mean Vote – PMV and Predicted Percentage of Dissatisfied - PPD) in accordance with [11]. Some average monthly values are presented in Fig.9 for ribbon window and in the Fig. 10 for curtain wall scenario.

Table 8. Parameters for human thermal comfort evaluation

Parameter	Winter	Summer
Clothing (clo)	1.00	0.7
Air temp. (°C)	20.0	26.0
Activity (met)	1.2	1.2
Air speed (m/s)	0.10	0.10
Relative humidity (%)	50.0	50.0

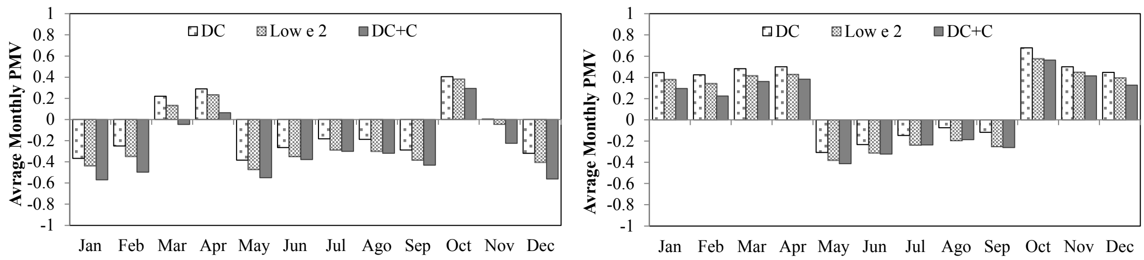

Fig. 9. Average Monthly PMV values for the proposed retrofit solutions in Milan (a) and Palermo (b). WWR 50% (ribbon window).

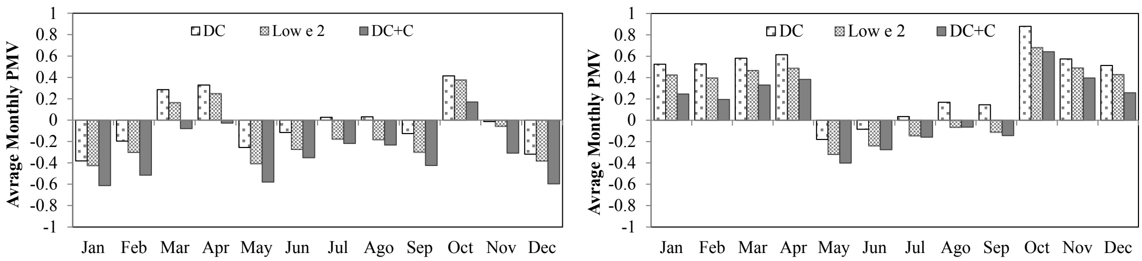

Fig. 10. Average Monthly PMV values for the proposed retrofit solutions in Milan (a) and Palermo (b). WWR 100% (ribbon window).

Figures do not show significant thermal comfort index variation between different window to wall ratio scenarios. Furthermore the algorithm used to calculate the PMV and PPD, according to the Fanger model, do not consider the direct and diffuse radiation hitting the human body as in [12]. Both comfort indexes are influenced only by the Mean Radiant Temperature MRT, evaluated from surface temperatures around the user in the middle of the office unit and the differences between each alternative for every scenario. More significant results are obtained comparing north and south Italy scenarios. In Palermo, there is only one inversion in Predicted Mean Vote values between the hot and cold season while in Milan the inversion in values is only during transitional seasons.

3.4. Glare and visual comfort

Visual comfort was calculated hourly with Radiance [13] and Energy Plus [10]. In Fig.8 we present an extract of the results for two critical days in Milan, characterized by different seasonal solar height and radiation value.

We computed the hourly Daylight Glare evaluation Index (DGI) value for a standard user in the middle of the office unit, facing wall, with window on the left side of the body, for:

- 26th June, hottest day of the year
- 22nd December, the day with the peak irradiance value on horizontal surfaces for December in Milan

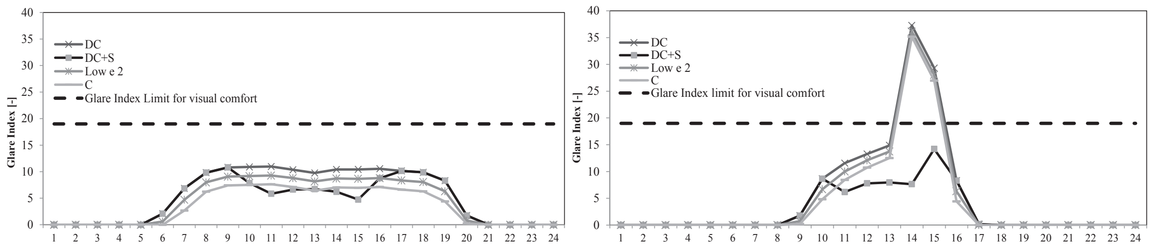

Fig 11. Hourly DGI value, in Milan for South facing window, on June the 26th and (a) on December the 22nd (b).

Fig 11a shows how each strategy, during the cooling season, satisfies the glare requirements, probably because of the position of the user inside of the office unit. During winter season, as it is shown in the Fig. 11b, only the internal roller blind (DC+S) permits to control efficiently solar radiation avoiding Glare.

Fig 11a shows how each strategy, during the cooling season, satisfies the glare requirements, probably because of the position of the user inside of the office unit. During winter season, as it is shown in the Fig. 11b, only the internal roller blind (DC+S) permits to control efficiently solar radiation avoiding Glare. The LowE_2 and the DC+C static alternatives do not permit to module efficiently the light entering the room and require an additional internal or external dynamic screen to ensure glare control. In the following figures luminance values are presented for LowE_2 and DC+2 in comparison with standard DC case. The figures are not representative of the Glare evaluation process, but are used only to present the performance of the different alternatives under variable conditions and seasonal sun altitudes

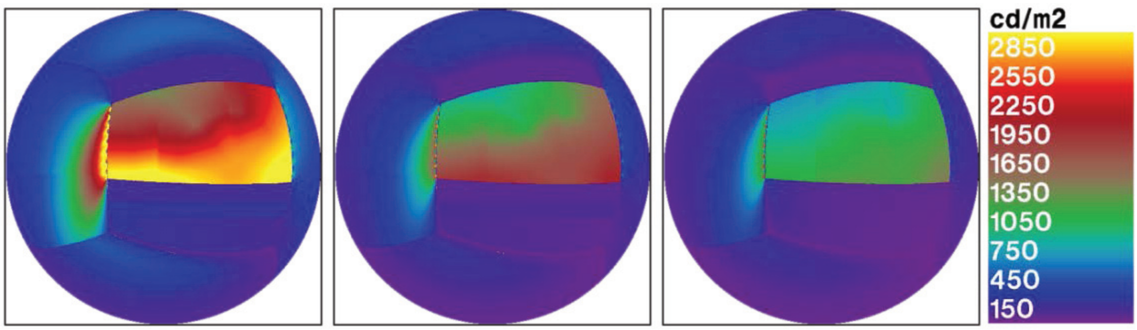

Fig. 12. Luminance distribution, in Milan for South facing window, on June the 26th at the 15pm for each solutions:(a) DC (b) LowE_2 (c) DC+C

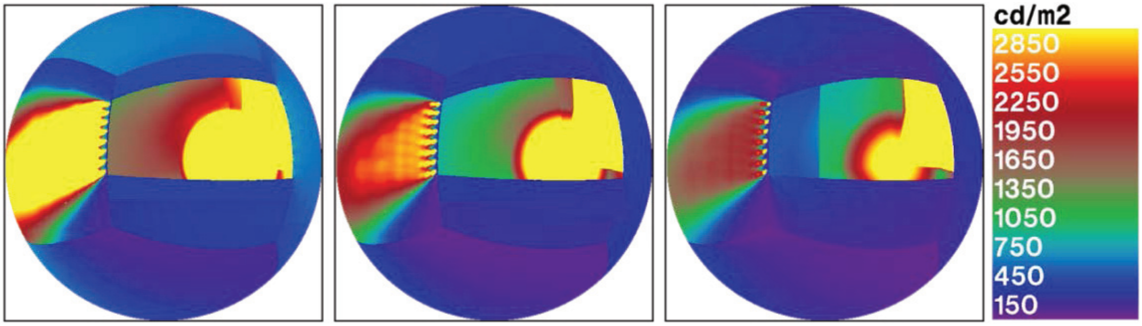

Fig. 13. Luminance distribution, in Milan for South facing window, on December the 22nd at 15pm for each solutions: (a) DC (b) LowE_2 (c) DC+C

3.5. Cost analysis

We elaborated an economic correlation to make a comparison between different retrofitting solutions. For each option, the NPV, Net Present Value, has been calculated considering an interest rate of 2%. To calculate the cash flow, the Italian energy price increasing tendency has been estimated, considering the spread during the last ten years and assuming an initial cost of 0.188 €/kWhEE for electricity and 0.873 €/m^3 for Gas. We have also estimated retrofit cost for the most effective alternatives proposed and in particular for:

- (DC+sh) Automated Internal roller blind: 130 €/m^2
- (LowE_2) Glass substitution with a double pane low-e glass: 105€/m^2
- (DC+C) Window film application: 85€/m^2

Evaluating the annual energy saving, we have calculated the BEP, Break Even Point and the Payback time. The Fig. 14 shows the results of economic analysis for each lean strategy in different climate zone and with different window to wall ratio.

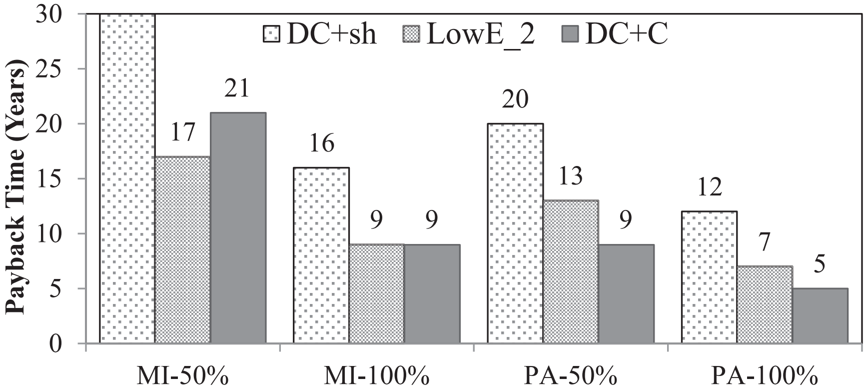

Fig.14. Break-even point of each solution in Milan (MI) and Palermo (PA) for different window to wall ratio value.

4. Conclusions

There are several technology alternatives for solar-protection that can be easily used for existing buildings envelope retrofitting. Our research shows how the same energy saving strategies applied in different climate conditions produce deeply different results in term of primary energy consumption.

The application of solar films (DC+Y) is very effective in primary energy use reduction and thermal comfort improvement for existing transparent low performance envelopes, especially in hot climate and during cooling seasons. The short break-even point achievable through their use provides a further important demonstration of their value. The cost effectiveness increase in accordance with window to wall ratio increase.

Window films are the cheaper options between the above mentioned technologies, but don't represent a substitution, but se they are part of a lean requalification process. However, they are static solar control systems, which can determine a decrease in daylight availability and an increase in heating and lighting loads. The substitution of the existing glasses with the Low-e Sun control ones (LowE_X) is the more cost-effective solution for mixed cold and hot climates like Milan. To avoid glare Phenomena both solar films alternatives and low-e solar control glass need to be combined to an additional sun control system. Roller Blind alternative (DC+sh) permits to obtain good thermal and visual comfort and a primary energy use, that is comparable to the other retrofit alternatives. The Payback time is not convenient and the break-even point is reached later than the other solution because of the higher initial cost of the system, considering blind automation devices. Presenting different technologies and strategies, we have highlighted some aspects that can influence the choice of a particular requalification method, with a focal point on energetic and economics issues. Related future works will present additional results on visual comfort, thermal comfort (considering solar radiation in Mean Radiative Temperature calculation) and on user behavior and lighting consumptions profiles.

References

[1] Ochoa C., Aries M.B.C., van Loenen E. J., Hensen J. L.M., Considerations on design optimization criteria for windows providing low energy consumption and high visual comfort, Applied Energy 2012;95:238-245.

[2] da Silva P. C., Leal V., Andersen M., Influence of shading control patterns on the energy assessment of office spaces, Energy and Buildings 2012;50:35–48.

[3] Tzempelikos A., Shen H., Comparative control strategies for roller shades with respect to daylighting and energy performance, Building and Environment 2013;67:179-192.

[4] Citterio M. Analisi statistica sul parco edilizio non residenziale e sviluppo di modelli di calcolo semplificati. Report RSE 2009-161, 2009.

[5] LBNL, Optics 6.0, Retrieved from http://windows.lbl.gov/software/Optics/optics.html; 2014.

[6] IGDB. (2014). "International Glazing Database ", Retrieved from http://windows.lbl.gov/materials/IGDB/; 2014.

[7] LBNL, THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual; 2013.

[8] Mainini A. G., Poli T., Paolini R., Zinzi M., Vercesi L., Transparent Multilayer ETFE Panels for Building Envelope: Thermal Transmittance Evaluation and Assessment of Optical and Solar Performance Decay due to Soiling, Energy Procedia 2014;48:1302-1310.

[9] EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics; 2007.

[10] ENERGYPLUSTM, EnergyPlus Engineering Reference The Reference to EnergyPlus Calculations, 2014.

[11] EN ISO 7730 Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria; 2009.

[12] La Gennusa M., Nucara A., Rizzo G., Scaccianoce g., "The calculation of the mean radiant temperature of a subject exposed to the solar radiation—a generalised algorithm," Building and Environment 2005;40:367–375.

[13] Ward G. J., "The RADIANCE Lighting Simulation and Rendering System,"Computer Graphics (Proceedings of '94 SIGGRAPH conference); 1994. p. 459-472.