SIMULATION OF THE THERMAL BEHAVIOUR OF BUILDINGS EQUIPPED WITH LOW-EMISSIVITY GLAZED COMPONENTS. A PERFORMANCE ANALYSIS

Mario Cucumo, Vittorio Ferraro, Dimitrios Kaliakatsos, Valerio Marinelli

Department of Mechanical, Energetics and Management Engineering
University of Calabria
Via P. Bucci, Cube 44/C
Tel. +39 0984 494603 - Fax +39 0984 494673
E-mail: dimitri@unical.it

ABSTRACT

In this paper, the authors want to highlight the different kinds of thermal behavior under dynamic conditions of buildings based on the use of two different types of glass for the windowed components: in the first type under consideration a double-standard 4-12-4 glass is adopted, while in the second a low emissivity glass of equal thickness is used with the presence of a coating on the inner face of the window.

The analysis focuses on the determination of the indices of thermal comfort in the environment, both in free and in forced evolution, and consumptions of the HVAC plant when the system is functioning. For the evaluation of the above parameters, the analysis is initiated by determining the time profile of the internal temperature, of the internal surface temperature of the window and the time profile of the mean radiant temperature after properly defining the computational grid for the software. The simulations to evaluate the energetic advantage of the types of windows analysed, were carried out for two different case studies and in three different climatic zones through the use of Ecotect software.

After determining the temperature profiles mentioned above and calculating the indices for the thermal comfort PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) in accordance with the UNI EN ISO 7730:2006, the annual energy required for the air conditioning system and for the maintenance of the temperature set point within the environment were evaluated.

Subsequently, the energy certification for the second case study was performed on the basis of the indications of the technical specifications UNI TS 11300-1:2008 and 11300-2:2008, with the objective of determining what benefits are obtained from the point of view of the energy class, simply by changing the properties of the windows.

1. INTRODUCTION

The dynamic simulations for the calculation of temperature profiles were performed utilising Ecotect software [1]; this software has achieved international standard thanks to the many drawing and analyses that its tools provide the user, as well as to the accuracy of its calculation results.

The various simulations were performed for two different periods of the year (one in the winter, the other in summer) and for three different localities: Milan (climate zone E), Pescara (climate zone D) and Trapani (climate zone B).

The building was analysed for all four principal orientations by appropriately rotating the models created in Ecotect, both in free evolution and in controlled evolution of an air conditioning system. Obviously, the calculation of all the parameters involved in this study was carried out bearing in mind the technical specifications dictated by the energetic laws applied to the building.

Two case studies were considered:

- ✓ a studio subjected to restructuring: it is an existing building in which only the properties of the glass were changed, passing from one climate zone to another;
- ✓ a newly-built villa on one floor, with more complex geometry than in the first case study, for which the limitations imposed by Legislative Decree 192/2005 [2], and by Legislative Decree 311/2006 [3], as amended, were taken into account.

In this regard, it is right to highlight how, especially in the cold climatic zones F and E, it is almost impossible to make a comparison between the two different types of glass. In these climatic zones, in fact, it is impossible irrespective of a low-emissivity glass.

After determining the temperature profiles already mentioned, the indices relating to thermal comfort, PMV and PPD in accordance with the standard EN ISO 7730 [4], and the necessary energy to the air conditioning for the maintenance of the set point temperatures inside the environments tested, the second case study was subjected to energy certification according to the specifications UNI TS 11300-1 [5] and UNI TS 11300-2 [6], with the aim of determining whether it is possible to obtain advantages in this sense simply by changing the properties of the windows of the house in question. The Legislative Decrees [2] and [3] represent the implementation of the Directive 2002/91/EC of the European Parliament and Council on the energy performance of the buildings in Italy [7]. The Technical Specification 11300-1 [5] defines the modalities for the implementation in Italy of the norm EN ISO 13790:2008 [8] with reference to the monthly method for calculating the thermal energy needs for heating and cooling, while the Technical Specification 11300-2 [6] is the Italian version of the norm EN 15316-1:2007 [9], for calculation of system energy requirements and system efficiencies.

2. CONSTRUCTION OF CLIMATE DATA

The first important step for the dynamic simulation of the two case studies is to provide average monthly climate data of the three selected locations in weather software tools of Ecotect.

For each month of the year hourly values of dry bulb temperature, direct and diffuse radiation on horizontal surface, relative humidity, wind speed and prevailing wind direction were included. In addition, having considered clear sky conditions, the indices of the cloudiness in tenths of sky, were put equal to zero.

As an example Figures 1, 2, 3 and 4 report some data in graphical form for Trapani.

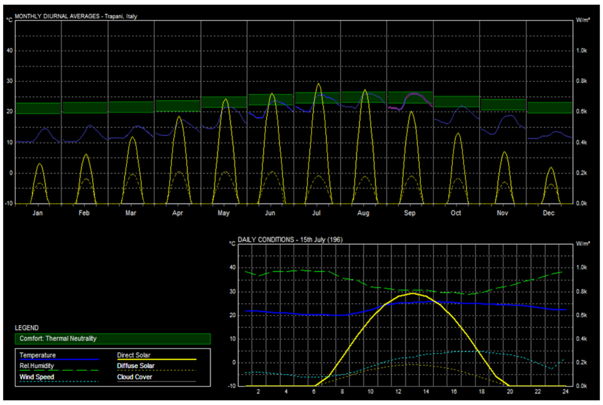

Figure 1 - Monthly values of temperature, direct and diffuse radiation, relative humidity and wind speed for Trapani

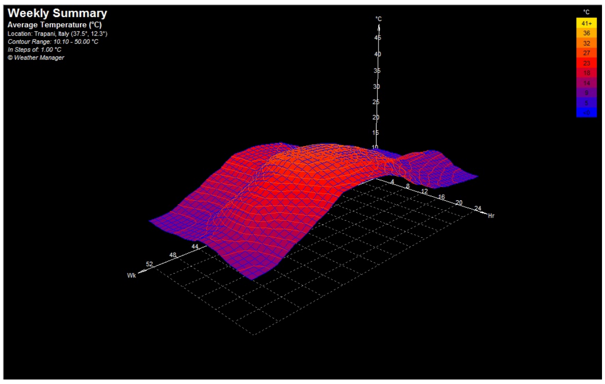

Figure 2 - Values of the average monthly temperature for Trapani

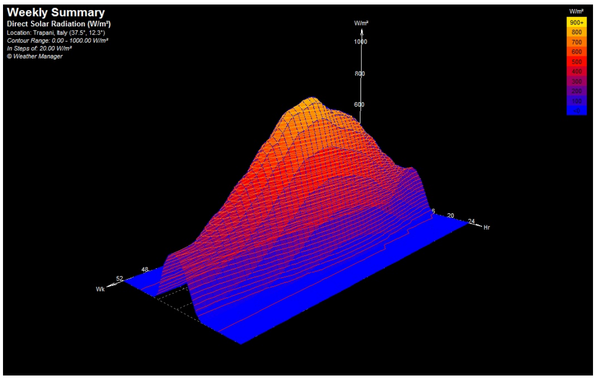

Figure 3 - Monthly values of direct radiation on horizontal surface for Trapani

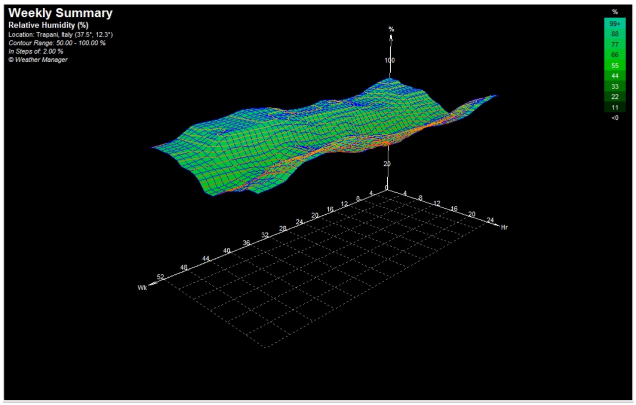

Figure 4 - Monthly values of relative humidity of the outside air for Trapani

3. ANALYSIS OF THE FIRST CASE STUDY

The studio considered was modelled in Ecotect environment (Figure 5), and has the following geometrical characteristics:

- Footprint: 4 x 6 m;
- Height: 3 m;
- Area of the glazed surface: 4 m^2;
- Distance between window and ceiling: 0.4 m;
- Distance between window and floor: 0.6 m;
- Distance between window and the side walls: 1 m;
- Door dimensions: 0.9 x 2.1 m.

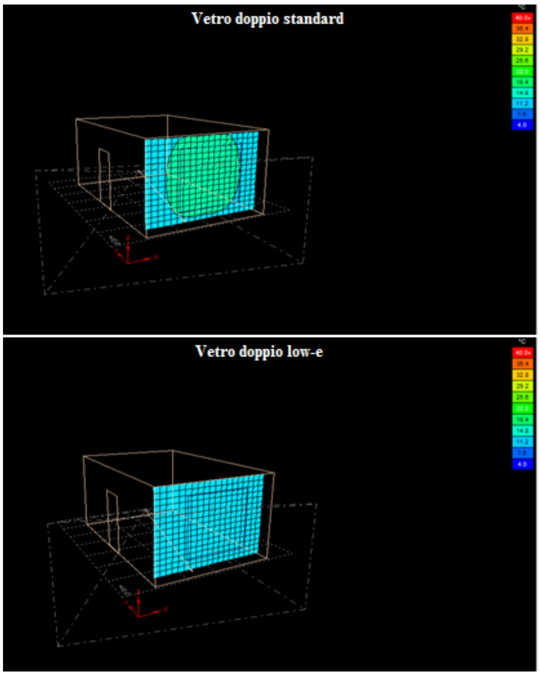

Figure 5 - Model for the first case study in Ecotect environment

Once defined the building for the first case study, the stratigraphy of the opaque vertical, floor, ceiling, window and door closures was chosen. Given that, the Ecotect software performs a dynamic analysis of the building and therefore takes account of the dynamic effects of the walls, in addition to the value of the transmittance calculated in steady state, the values of some other parameters such as dynamic admittance, decrement factor and phase shift, calculated in accordance with the standard EN ISO 13786:2008 [10] were inserted for each building element.

Tables 1 and 2 summarize the most important properties of the glassed elements used for the calculation.

Table 1 – Values of the characteristics of the double standard glass 4-12-4

Parameter	Symbol and unit	Value
Coefficient of external emissivity	ε [-]	0.86
Coefficient of internal emissivity	ε [-]	0.86
Coefficient of outside reflection	ρ [-]	0.14
Coefficient of inside reflection	ρ [-]	0.14
Transmittance	U [W /m^2 K]	2.80
Admittance	Y [W /m^2 K]	0.62
Solar gain coefficient	g [-]	0.79

Table 2 - Values of the characteristics of the double glass 4-12-4 with low emissivity coating

Parameter	Symbol and unit	Value
Coefficient of external emissivity	ε [-]	0.86
Coefficient of internal emissivity	ε [-]	0.10
Coefficient of outside reflection	ρ [-]	0.14
Coefficient of inside reflection	ρ [-]	0.90
Transmittance	U [W /m^2 K]	1.20
Admittance	Y [W /m^2 K]	0.49
Solar gain coefficient	g [-]	0.69

Observing Tables 1 and 2, the different behaviour of the two glasses is clear. In the case of standard glass, the greater solar gain permits more solar radiation to penetrate within the environment, but, the low coefficient of internal reflection makes this type of glass non-retentive of the heat emitted by the heated surfaces and it is dispersed. The low emissivity glass, however, appears to be almost opaque in the field of high wavelengths where there is emission of the heating bodies. From these considerations it follows that the latter component retains heat better within the environment and, moreover, the lowest value of the transmittance indicates less dispersion due to the temperature difference between the inner surface of the glass and the outdoor air.

For the first case study the user profile, through the appropriate tabs of building a load time profile of a typical workday in an office with a maximum load from 8:30 to 18:30, crowding and type of activity were defined. Furthermore, sensible loads and those latent per unit area were inserted and the computing grid in the Ecotect environment was created (Figure 6), for the evaluation of the mean radiant temperature. In this way it was possible to evaluate the profiles of internal air temperature, the temperature of the inner surface of the window and the mean radiant temperature for all exposures and using both types of windows.

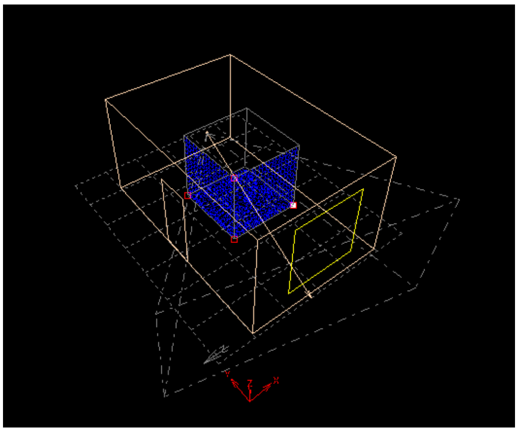

Figure 6 - Computing grid in Ecotect environment

The dynamic simulations were performed using the average monthly data of January and July, for the three localities by varying the glass element and exposure of the same.

The considerations that can be made by observing the approximately 150 temperature profiles obtained are the following: in winter the internal temperature is greater in the case in which low-emissivity glass was adopted by about half a degree Celsius; the same situation occurs for the mean radiant temperature even though, in the hours when the sun hits the glass surface directly, the two peaks tend to coincide. The internal surface temperature of the standard glass, however, far exceeds the internal surface temperature of the components low emissivity glasses in the hours when the sun's rays have a direct impact on it.

In summer, the differences between the two types of glass are more pronounced. As an example, Figure 7 shows the trend of the internal air temperature for the month of July for the west-facing window in Trapani. The indoor temperature is higher when the glass surfaces are considered to be of a low emissivity, except during the hours of direct sunlight on the window.

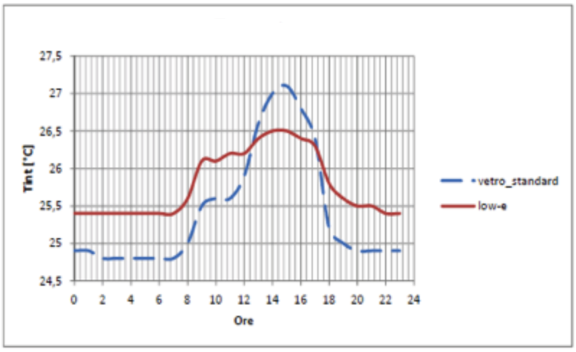

Figure 7 - Trend of the internal air temperature in July for Trapani. West-facing window.

Similar results were obtained for the internal surface temperature of the window and for the mean radiant temperature, although, the Δt measured when the peaks are reached, are superior. The major differences to the internal surface temperature of the glass are recorded in Trapani in the summer when the window is facing west (Fig. 8). Very similar results are obtained for the mean radiant temperature of the room (fig. 9).

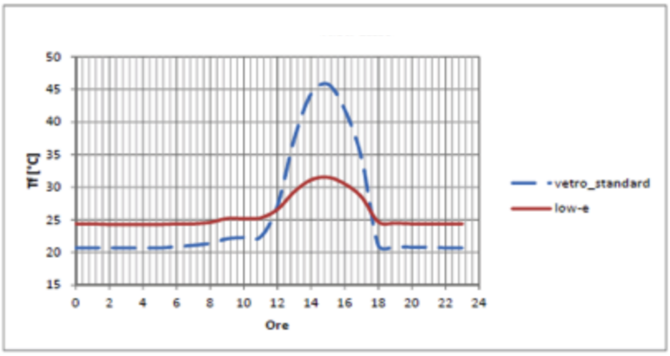

Figure 8 - Trend of the internal surface temperature of the glass in July for Trapani. West-facing window.

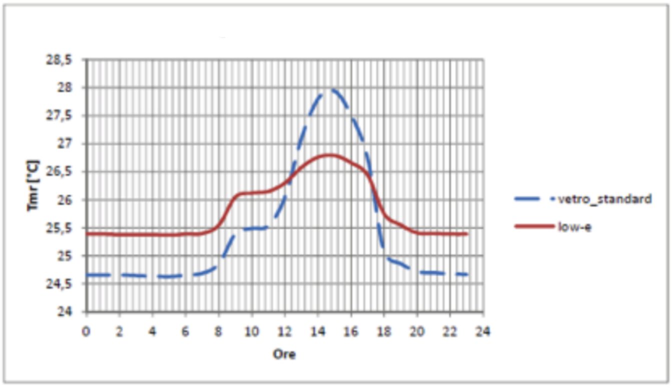

Figure 9 - Trend of the mean radiant temperature of the room in July for Trapani. West-facing window.

For north-facing position, the internal air temperature of the room and the mean radiant temperature are always higher with the low-emissivity glazing type. For the internal surface temperature of the glass, the profiles obtained are flatter compared to the previous cases. The greatest discrepancy was recorded in summer in the last hours of the day in which the sun shines directly on the window (Figure 10).

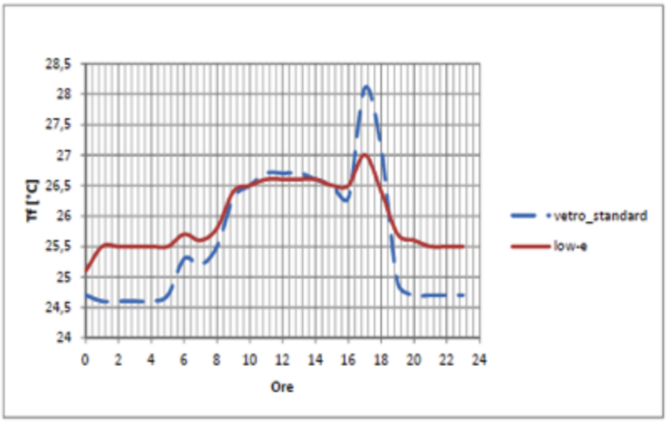

Figure 10 - Trend of the internal surface temperature of the glass in July to Pescara. North-facing.

The parameters discussed above, affect the assessment of thermal comfort indices. After calculating all the parameters involved in evaluating the thermal comfort of the environment, it is possible to say that, by varying the exposure, the difference between the values of PPD is about 5 to 7% in favour of low emissivity glass in winter, while in the summer the advantage lies with the standard glass with the same percentage difference as can be seen from Figures 11 and 12.

In Table 3, shows the data used for the calculation of thermal comfort.

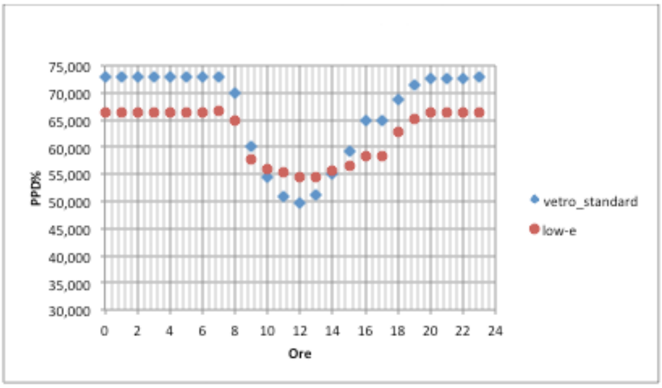

Figure 11 - Values of PPD in January for Trapani. South-facing window.

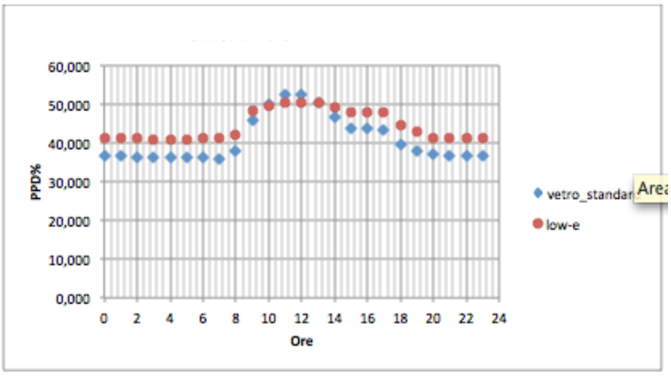

Figure 12 - Values of PPD in July for Trapani. South-facing window.

Table 3 - Values of the parameters used for the calculation of thermal comfort

	Winter	Summer
I_{clo} [clo]	1.0	0.5
f_{clo} [clo]	1.15	1.1
M [W/m^2]	70	70
U.R	50%	50%
v_{ar} [m/s]	0.25	0.15
h_c [W/m^{2}K]	4.686	6.050

However, both in summer and in winter, the temperature and humidity conditions of comfort are not obtained according to the UNI EN ISO 7730, corresponding to PPD values of less than 10%.

4. EVALUATION OF THERMAL COMFORT AND CONSUMPTION TRENDS IN FORCED EVOLUTION

With regard to the controlled environment in forced evolution, setting the set point temperature, the mean radiant temperature is around 21 °C in winter and 26 °C in summer, with minor differences for both types of glass. The largest ΔT, because of the properties of the glass, are measured as above in the hours of direct incidence of the solar rays.

As for comfort, it can be said that the environment is in thermal comfort conditions with percentage of PPD around 7% to 12% in winter and in summer for all localities and exposures. Only in Milan to southern exposure, the predicted percentage of dissatisfied in the summer is about 5%, and as a result of 7 percentage points less than the other two positions. For all exposures it is possible to incorporate all the results in a single chart (Figure 13).

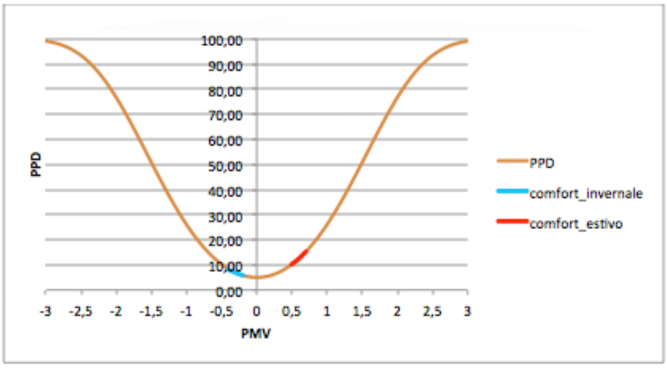

Figure 13 - PMV and PPD values for the three localities and for all exposures

The energy required to maintain the above temperature and humidity comfort conditions in the environment is different for the different situations analysed. Milan, of course, is the location where consumptions are higher due to higher thermal loads. Figures 14 and 15 show the histograms with the maximum consumptions estimated for Milan with standard glass and low-emissivity glass.

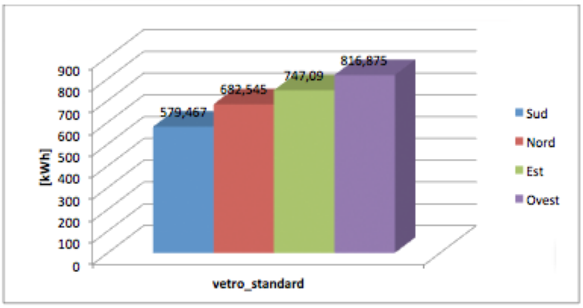

Figure 14 - Consumptions of the HVAC system in Milan with standard glass for different exposure.

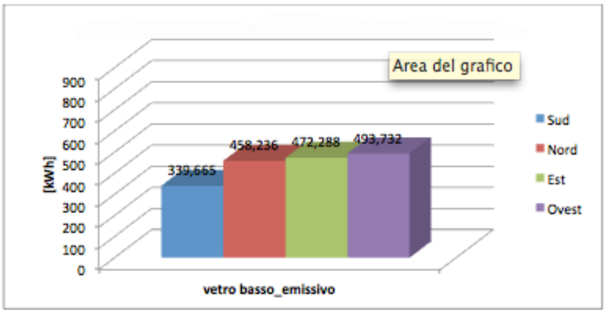

Figure 15 - Consumptions of the HVAC system in Milan with low-emissivity glass for different exposure

Table 4 summarizes the percentage differences found between the consumptions of the HVAC system with standard clear glass with low-emissivity glass obtained in the three localities for the various exhibitions.

Table 4 - Percentage differences between the consumption of the HVAC system with standard clear glass with low-emissivity glass for the three localities for the different exposures

EXPOSURE	MILAN	PESCARA	TRAPANI
SOUTH	41%	38%	36%
NORTH	32%	30%	22%
EAST	37%	35%	33%
WEST	39%	41%	42%

By carefully analysing the results obtained, we can make the following considerations:

- The maximum annual consumption is obtained for all three localities and for both types of glass for the west-facing window mainly due to higher cooling load required;
- Milan is the locality where higher consumptions are registered. This is explained by the fact that in winter the outside temperature drops low;
- The largest percentage difference relative to the use of two different windows is the south where the different properties of the standard glass and low-emissivity glass are most evident;
- The lowest percentage difference (although significant), is obtained for the north exposure, except for Trapani where it is down to 22%, because of the solar height, where taking as reference the month of the summer solstice, it appears to be 10° higher than that measured in Milan.

5. ANALYSIS OF THE SECOND CASE STUDY

The second case study considered has different characteristics than the first: it consists in a villa on one floor with floor area of about 126 m^2, gross volume of 350 m^3 and a total glazed surface area of 36 m^2 (fig. 16).

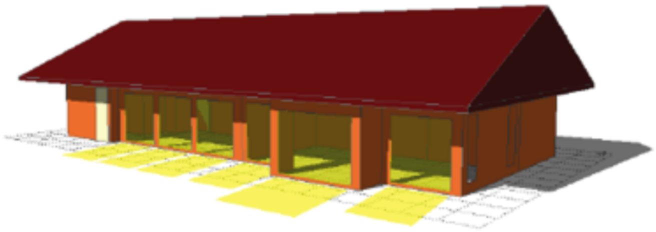

Figure 16 – The newly-built villa created in Ecotect environment

Unlike what was done for the first case study, in this case it is assumed that the structure was a new construction and, for this reason, it was necessary to adapt the transmittances of the opaque elements of the casing to the limits imposed by National Legislative Decree 311/2006.

Before the calculation of the indices of thermal comfort, the appropriate tables of thermal loads and the computing grids were created for each room. By way of example, Figure 17 shows the computing grid on the south-east facing kitchen.

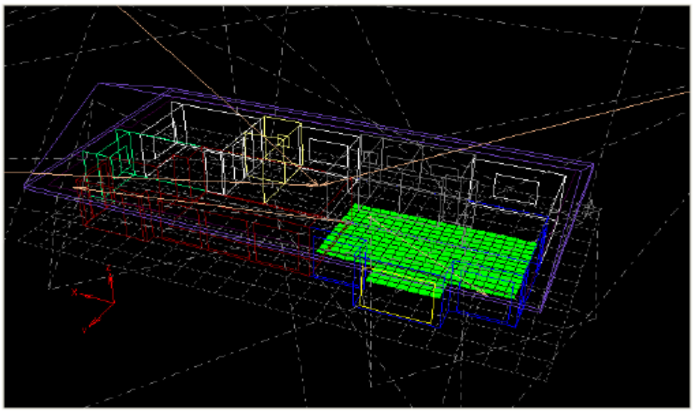

Figure 17 - Computing grid for the evaluation of the mean radiant temperature in the kitchen.

The next step was to calculate the internal temperatures for each environment, the average radiant temperature and the internal surface temperatures of the glass. The biggest differences are recorded in the kitchen because of higher loads due to internal heat sources.

Contrary to the first case study, the differences of the calculated values of PPD are remarkable. The environment is not in comfort conditions at all three localities in both summer and winter, when standard glass is used.

When the low-emissivity glass in Pescara and, above all, in Trapani is used, in free evolution during the winter calculation period, the environment is in thermal comfort conditions because the internal temperature and the mean radiant hover around 20 °C.

As an example, Figure 18 shows the performance of PPD in Trapani in the winter season.

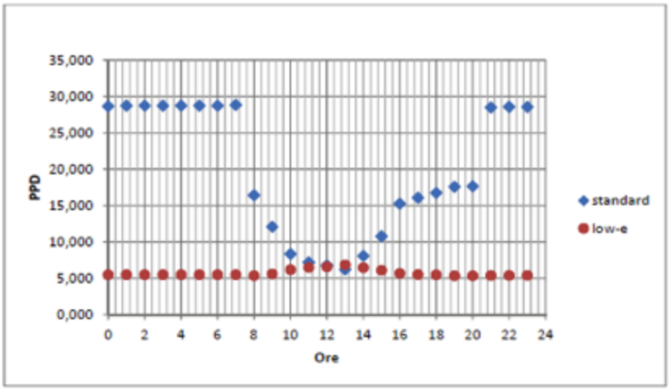

Figure 18 - Values of the PPD index in winter for Trapani

In the second case study, the increase of the internal loads made the difference between the two types of glass more marked. In this case, in fact, the properties of the low-emissivity glass to be nearly opaque to the radiation in the infrared band, is made evident by the new user profile and therefore the cooling loads arising from the use of low emissivity glass are greater (fig. 19).

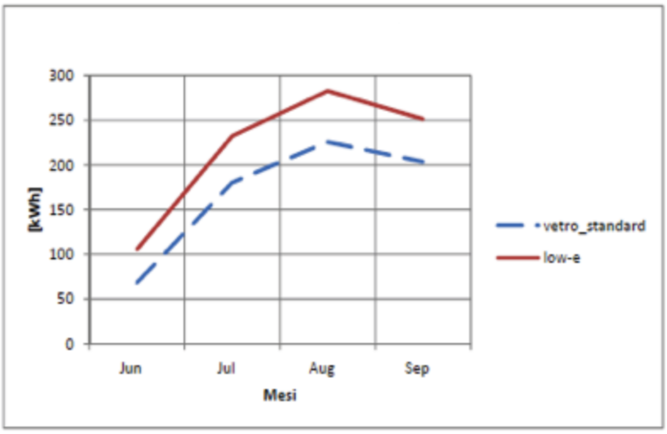

Figure 19 - Cooling load for Trapani.

When the annual consumption is taken into account, the percentage differences are greatly reduced compared to the first case study: in Milan and Pescara, when the low-emissivity glass is adopted, there is a reduction in consumption of about 4% compared to the use of a window with standard glass. In Trapani the greater irradiation weighs considerably on cooling loads so that the consumption that is recorded with the use of a glass surface with low emissivity coating is greater than 2% with respect to the use of a standard double glass.

Figures 20 and 21 report the consumptions of the HVAC system for the three localities with normal glass and with low-emissivity glass.

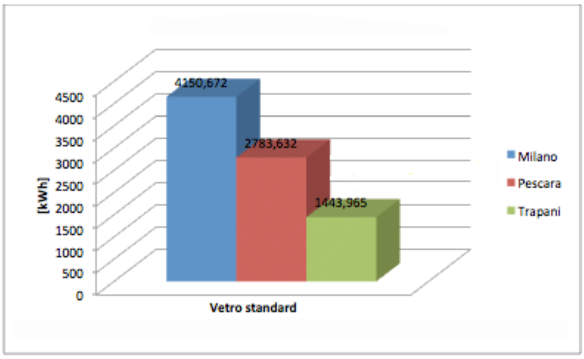

Figure 20 - Annual consumption in the three localities with standard glass

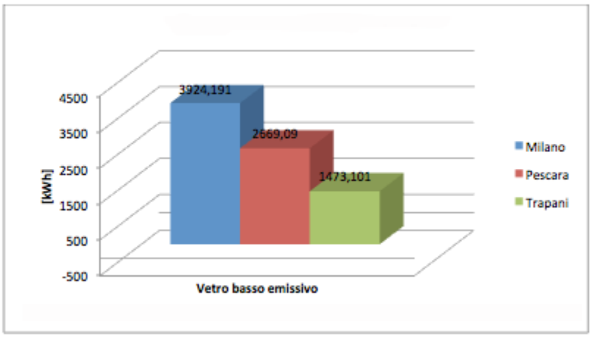

Figure 21 - Annual consumption in the three localities with low-emissivity glass

6. ENERGY CERTIFICATION

In this paragraph, following the indications of the National Technical Specifications [5] and [6], energy certification was performed for the villa created in the Ecotect environment (Figure 22). By locating the building in the three climatic zones, we aimed to assess the influence of the properties of the windows on the building's energy class, through the use of a double standard glass to a glass with low-emissivity coating.

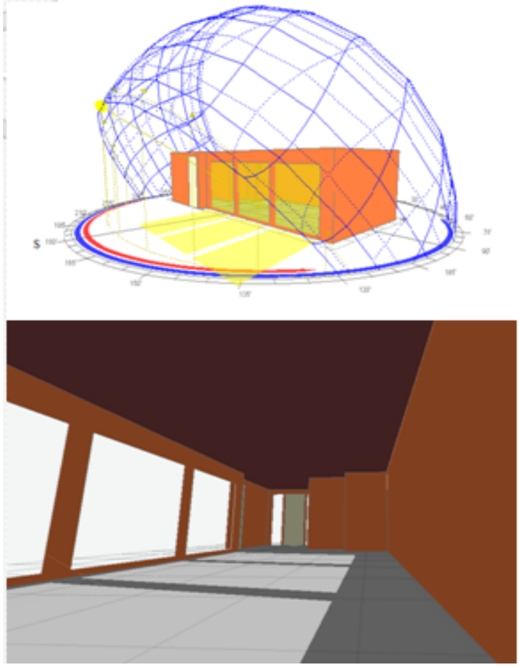

Figure 22 - Views in Ecotect environment for the living room facing south

After imposing limits on the thermal transmittance of vertical and horizontal opaque walls according to the National Law (Legislative Decree 311/2006), the first step was the determination of the geometric parameters related to the building for the calculation of the S/V ratio that, in this case, is equal to 1.7 m^{-1}. Below, the surfaces losses (opaque and glazed), the geometrical characteristics of the windows and those of the horizontal and vertical projections are determined for each exposure.

It should be noted that heat losses calculated according to the technical specification [5], the average seasonal efficiency was calculated according to the technical specification UNI TS [6], and the heat requirement for heating was estimated.

The demand for domestic hot water is the same in the three localities and is equal to EP_{acs} = 19.6 kWh/m^2 year which corresponds to the energy class $D_{acs.}$

By way of example, Tables 5 and 6 show some results of building energy certification for Trapani.

Table 5 - Results of the energy certification for the villa located in Trapani with standard double-glazing

Ideal Seasonal Heating Thermal Energy $Q_{H,nd}$ [kWh / year]	2 823
Index of Energy Performance of the building EP_i, [kWh/m^2 year]	22.4
Energy Performance Index - Limit value EP_{iLimit} [kWh/m^2 year]	44.4
Primary Energy Demand for Heating $Q_{H,p}$ [kWh / year]	3 676
Average Seasonal Efficiency of the Heating system $\eta_{g,H}$	78%
Average Seasonal Limit Efficiency $\eta_{g,H,lim}$	78%
Energy Performance Global Index, EP_I [kWh/m^2 year]	29.2
Energy Class	B+

Table 6 - Results of the energy certification for the villa located in Trapani with low-emissivity glass

Ideal Seasonal Heating Thermal Energy $Q_{H,nd}$ [kWh / year]	1 925
Index of Energy Performance of the building EP_i, [kWh/m^2 year]	15.3
Energy Performance Index - Limit value EP_{iLimit} [kWh/m^2 year]	44.4
Primary Energy Demand for Heating $Q_{H,p}$ [kWh / year]	2 507
Average Seasonal Efficiency of the Heating system $\eta_{g,H}$	77%
Average Seasonal Limit Efficiency $\eta_{g,H,lim}$	78%
Energy Performance Global Index, EP_I [kWh/m^2 year]	19.9
Energy Class	A+

By carefully analysing the results obtained for all locations, the convenience of using the low-emissivity coated glass is evident.

In Milan by passing to a double-glazed low emissivity window, a reduction in the demand for useful thermal energy and primary energy demand of about 14% is found. Despite the advantage gained, this amount is not enough to bring the building into a higher energy class.

In Pescara, the reduction of primary energy demand is around 17%. Regarding the winter heating, the building remains in class B_i with both types of glass. Things change at the global level, where there is a decline in the demand for primary energy of 12% and this leads to an improvement in the overall building energy class with low-emissivity glass (B_{gl}) against class C_{gl} with standard glass.

In climate zone B there are major differences: the reductions in energy requirements and thermal primary energy for heating in winter are around 30% and this value moves the class of the building from B_i to A+. At the global level, the jump is an energy class (from C_{gl} to B_{gl}), resulting from a decrease of 19% of the needs of the global primary energy.

CONCLUSIONS.

For the first case study, in the three localities and for all exposures, the internal temperature of the environment, both in summer and in winter, is higher when a low-emissivity glass is adopted. The same result was obtained for the mean radiant temperature.

As for the temperature of the inner surface of the glass, in the hours when the sun hits the glazed component directly, the peak reached by the window with standard glass turns out to be higher, equal to about 15 °C, when considering the west-facing window in Trapani.

Once these values are known, for the first case study, the calculation of the PMV and PPD has shown that, even though the conditions in the environment tend to improve with the adoption of low-emissivity glass, both in summer and in winter and with both types of windowed components, the environment is largely outside of the thermal comfort conditions in free evolution. It therefore appears clear that it is essential to use an air conditioning system.

The major annual consumption occurred in Milan, while the more critical exposure in all three climatic zones is the west. The energy that the air conditioning system must provide to maintain the set point temperature within the environment varies greatly from one situation to another: it is a reduction of the total annual consumption of about 40% (except for the north-facing window), when low-emissivity glass is adopted.

There is a clear energetic advantage obtained by the adoption of low-emission glass even if it necessitates a higher initial investment (about 10 euro per square meter).

In the second case study, with a different user profile, the results obtained are different. In Pescara and Trapani, in winter conditions with low-emissivity glass, the comfort conditions are achieved with the environment in free evolution mode. In summer, it is true that the PPD index is lower using standard glass, but the environment still remains in both cases out of the comfort conditions.

About the energy consumptions of the HVAC system, in summer cooling loads calculated with low-emissivity glass exceed those calculated with standard glass. Therefore, in Milan and Pescara the energy to be supplied is slightly lower when the low-emissivity glass is used. At Trapani, however, the use of the window with standard glass is preferable, even if for just a few percentage points (2%).

Globally analysing the conditions in winter and summer, also in this case the preference would fall on the low-emissivity glass even after the new limits of the Directive on the Energy Performance of Buildings.

Energy certification confirms this statement. In Pescara and Trapani there is an improvement of global energy class by passing from standard glass to low-emissivity glass. This difference improves to two classes if one considers only the calculation of EP_i in the climate zone B, in which the increasingly stringent limits of thermal transmittance give more choice.

REFERENCES

[1] Autodesk Ecotect Analysis, Sustainable Building Design Software, http://usa.autodesk.com/ecotect-analysis/

[2] Decreto Legislativo 19 agosto 2005, n. 192, Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia, pubblicato nella Gazzetta Ufficiale n. 222 del 23 settembre 2005 - Supplemento Ordinario n. 158.

[3] Decreto Legislativo 29 dicembre 2006, n.311, Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia, pubblicato nella Gazzetta Ufficiale 26 del 1-2-2007- Supplemento Ordinario n. 26, testo in vigore dal: 2-2-2007.

[4] EN ISO 7730:2005, 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.

[5] UNI TS 11300-1:2008, Energy performance of buildings Part 1: Determination of the thermal energy demand of the building for air conditioning in summer and winter.

[6] UNI TS 11300-2:2008; Energy performance of buildings - Part 2: Determination of the primary energy demand and of the efficiencies for winter heating and for the production of domestic hot water.

[7] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings, Official Journal of the European Communities, 4 January 2003.

[8] EN ISO 13790:2008, Energy performance of buildings - Calculation of energy use for space heating and cooling.

[9] EN 15316-1:2007, Heating Systems in Buildings - Method for calculation of system energy requirements and system efficiencies - Part 1: General.

[10] EN ISO 13786:2008, Thermal performance of building components - Dynamic thermal characteristics - Calculation methods.