



Retrofit of Massive Buildings in Different Mediterranean Climates. Interactions Between Mass, Additional Insulations and Solar Control Strategies

TECHNICAL ARTICLE

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ABSTRACT

In temperate climates, such as in most parts of Italy, it is necessary to limit both winter heat losses of buildings and their overheating in other periods. Moreover, in warmer Mediterranean climates the convenience of insulation against the building's thermal inertia must also be evaluated. Therefore, when the energy renovation of an old building with heavy masonry is performed the problem is to optimize the position and the thickness of the additional insulation. In presence of extended glazed surfaces, the most appropriate solar control strategy should be defined too. Both issues are present in many old Italian public buildings.

This paper deals with a computerized methodology for optimizing these choices by taking into account the interactions between thermal mass, additional insulation as well as internal and solar gains. The case study consists in a typical school building from the early 1900s. Building's thermal behavior was simulated in different Italian climates: Bologna, Roma and Palermo. The effects of various solutions on energy demand and comfort were compared. The possible effects of different types of masonry, different building's orientations and various intended uses were also explored.

Simulation results show that the optimal intervention strategy, for the considered type of building, depends not only on the climate but also on the building's intended use, which determines the internal gains and the time profile of use.

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INTRODUCTION

In temperate climates, such as in most parts of Italy, it is necessary to limit both winter heat losses of buildings and their overheating in other periods. The second requirement is particularly relevant in presence of high internal and solar gains. It is well known that, in these climates, it is not convenient to exceed the insulation thickness. In addition, in warmer Italian climates the convenience of the insulation in comparison to the building's thermal inertia must be evaluated. The two things are often seen as alternatives.

When the energy renovation of an old building with heavy masonry is performed, it is a question of optimizing the position (internal or external) and the thickness of the additional insulation according to the intended use (Sami et al. 2011; Deng et al. 2019; Stazi et al. 2015; Tzoulis et al. 2017). The usefulness of a certain insulation depends on a number of factors, such as:

- local climate, in particular the presence in it of significant day-night temperature drifts,
- building's thermal inertia,
- building's thermal balance, in particular the relevance of the energy demand for cooling compared to that for heating,
- time profile of use.

Moreover, in the case of old public buildings, large glazed surfaces are often present, which involve well-known problems: high and undesired solar gains in the cooling period, high thermal losses in the heating period as well as thermal and luminous discomfort. Also the choice of the solar control strategy is connected to the building's intended use and windows orientation (Buvik et al. 2015; Erhorn et al. 2015; Erhorn-Kluttig and Erhorn 2015).

This work presents a computerized methodology for optimizing these choices. The various retrofit strategies are evaluated with respect to their effects on total primary energy demand and on thermal and luminous comfort. The primary energy demand considered is that for heating, ventilation, air conditioning (HVAC) and artificial lighting, since insulation and solar control strategies influence these energy end uses. Furthermore, these energy end uses are linked to each other; and analyzing them separately can lead to misleading results. For these reason, the computer simulations were performed by using a specifically home made software (Ener_Lux), which simulates the dynamic thermal and luminous behaviour of a room at hourly time steps. The peculiarity of this software is that, within each calculation time step, it calculates thermal and luminous comfort index values, and, on the base of these, it simulates the feedback on the solar control devices, artificial lighting system and set-point temperatures (Carbonari 2012; Carbonari 2017).

The case study consists in in two classrooms of a typical school building from the early 1900s with a heavy structure and large glass surfaces in a climate of the Northern Italy (Bologna, 44.5°N, 20°C-base heating degree-days equal to 2259). The climate of the town is temperate with cold winter and warm summer; in all the seasons there are rather high daily temperature ranges. With regard to this building, a retrofit intervention was hypothesized; it includes the insertion of additional insulation and more efficient devices for solar control on glazed surfaces.

In order to assess the influence of internal gains, time profile of use and solar radiation, two different intended uses, i.e. offices and dwellings, and a south orientation, which is usually critical the one to the south, have been hypothesized for the same rooms. In addition, to evaluate the influence of thermal inertia, some different masonry, both heavier and lighter, were also simulated. Given the high occurrence of this type of building in the Italian territory, its thermal and luminous behavior has also been simulated in two other Italian climates, i.e. Rome (41.91°N, 20°C-base heating degree-days equal to 1415) and Palermo (38.11°N, 20°C-base heating degree-days equal to 751), which are progressively warmer, humid and sunnier climates. In addition, to evaluate the influence of thermal inertia, some different masonry, both heavier and lighter, were also hypothesized. Inoltre, per valutare l'influenza dell'inerzia termica, sono state ipotizzate anche alcune diverse murature, sia più pesanti che più leggere.

The climate data used for the three selected sites are shown in Figure 1 and in Table 1, where the meaning of the symbols is as follows:

- t_{max} : maximum daily temperature (C°),
- t_{min} : minimum daily temperature (C°),
- RU: relative humidity (%),
- I_{tot} : total daily solar radiation on the horizontal plane ($MJ \cdot m^{-2} \cdot day^{-1}$).

THE CASE STUDY

The examined building has an elongated plan, with the major axis oriented approximately nord-south (Figure 2). The classroom look out symmetrically on the two longer sides. Two identical classrooms were examined, their windows are facing approximately east (76° East azimuth), since, considering the morning time of use, this is the most critical orientation. The two examined classrooms are situated on the second and the third floor respectively; therefore, the influence of surrounding urban obstruction as regards solar gains and daylighting is different.

The school was built in 1915; it has structural internal and external brick walls (0.25 m thick) with plaster on both sides (total thickness: 0.3 m, transmittance (U-value): 2.06 $W \cdot m^{-2} \cdot K^{-1}$, front thermal capacity (C_{front}): 481 $kJ \cdot m^{-2} \cdot K^{-1}$,

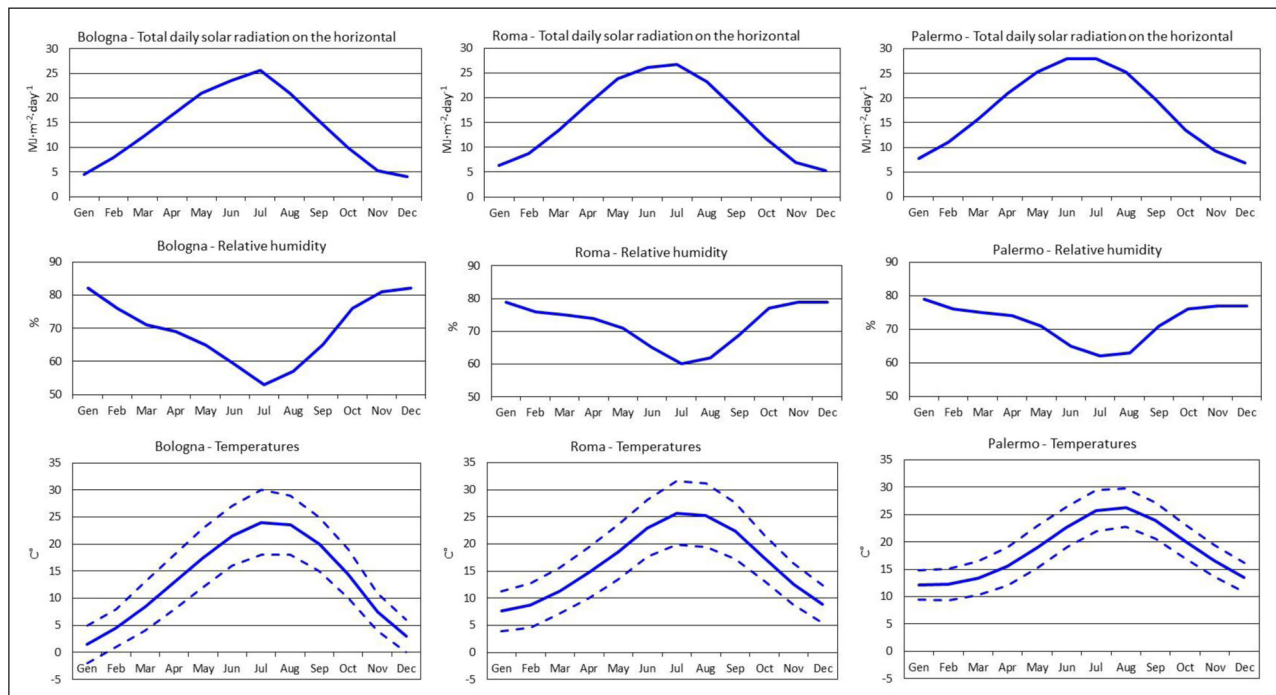


Figure 1 Climate data used for the three examined sites.

	BOLOGNA				ROMA				PALERMO			
	T _{MAX} (C°)	T _{MIN} (C°)	RU (%)	I _{TOT} (MJ·M ⁻² ·DAY ⁻¹)	T _{MAX} (C°)	T _{MIN} (C°)	RU (%)	I _{TOT} (MJ·M ⁻² ·DAY ⁻¹)	T _{MAX} (C°)	T _{MIN} (C°)	RU (%)	I _{TOT} (MJ·M ⁻² ·DAY ⁻¹)
Gen	5	-2	82	4,50	11,3	3,9	79	6,41	14,8	9,4	79	7,70
Feb	8	1	76	7,90	12,8	4,65	76	8,80	15,1	9,3	76	11,10
Mar	13	4	71	12,10	15,7	7,15	75	13,40	16,4	10,2	75	15,70
Apr	18	8	69	16,60	19,4	10	74	18,72	19	12	74	20,80
May	23	12	65	21,00	23,5	13,5	71	23,91	22,9	15,2	71	25,20
Jun	27	16	59	23,60	28,1	17,7	65	26,07	26,4	19,1	65	27,90
Jul	30	18	53	25,60	31,6	19,8	60	26,67	29,5	22	62	27,90
Aug	29	18	57	21,00	31,1	19,5	62	23,19	29,8	22,7	63	25,20
Sep	25	15	65	15,40	27,6	17,2	69	17,54	27,2	20,6	71	19,60
Oct	19	10	76	9,90	21,6	13,2	77	11,75	23,2	17	76	13,50
Nov	11	4	81	5,30	16,4	8,8	79	6,97	19,3	13,6	77	9,30
Dec	6	0	82	4,10	12,4	5,4	79	5,28	16,2	10,8	77	6,90

Table 1 Climate data used for the three examined sites.

horizontal elements in wood, with superimposed lime mortar and bricks. Vertical wide windows are present.

In Bologna, it was assumed that the retrofit intervention involves the installation of a triple glazing with 0.004, 0.006 and 0.004 m thick glass layers. The external air gap can be 0.037 m thick if it contains movable and packable slats, otherwise it is 0.018 m thick. The other air gap is 0.018 m thick and it as a low emissive layer in the external side of the internal glass (overall $U_{\text{value}}: 1 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$).

In Rome and Palermo, glazing has been hypothesized with U-values close to the limit values set by the current Italian standards, which are: $3 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ in Palermo and $1.8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ in Rome. Therefore, with only two glasses of various thicknesses and with various distances depending on the presence of devices inside the cavity. Transmittances close to the limit values have been chosen because lower values would lead to overheating problems. In all locations, the same solar control devices were simulated.



Figure 2 The examined school building in the centre of the picture. Image source: Google Earth.

In the case of classrooms, internal sensible and latent thermal gains relating to the presence of twenty-seven pupils and a teacher were taken into account. An hourly ventilation rate of 15 m^3 per occupant was assumed. It has been assumed a period of occupation from eight in the morning to one in the afternoon, and a required illuminance of at least 500 lx, in harmony with Italian regulations for schools and offices. The hypothesized light system consists of fluorescent lamps (luminous efficacy: 91 lm/W, maximum total power: 756 W). This system is divided into two zones parallel to the external wall. There are no dimmers.

In the case of offices, six occupants were hypothesized with the related equipment (six computers and one printer) in the same space as the previous single classroom, and a more localized lighting system (maximum total power: 480 W) always based on fluorescent lamps. A daily occupation period equal to eleven hours was supposed: from eight in the morning to seven in the afternoon. In the case of housing, the internal gains suggested by the Italian standard were assumed (i.e. 3.71 W/m^2 , 260 W total). To estimate the primary energy demand related to the artificial lighting system, the same type of office system has been hypothesized but sized on two occupants instead of six (therefore a power of 160 W), but during the daytime hours an average temporal presence of only one occupant was assumed.

At first two types of additional insulation layers have been hypothesized: an external insulation consisting of a layer of rock wool, with various thickness values, with an outer protective layer in plaster, and an internal insulation consisting of expanded polyurethane only 0.05

m thick, with an internal layer of plasterboard, according to current construction practice. This because a greater insulation thickness would reduce interior space without resulting in significant energy savings.

Usually Italian school buildings are only equipped with a hydronic heating system coupled with radiators. Therefore, due to the high internal and solar gains, with the exception of the colder period, classrooms are often overheated. In order to estimate the energy cost of obtaining thermal comfort in any season, it is assumed that a full air centralized heating, ventilation and air conditioning system (HVAC) is installed to eliminate overheating and improve air quality. In the HVAC system, electrically driven chillers provide the fluid for the cooling coils, while the fluid for the heating coil is primarily provided by the condensers of the chillers, integrated by gas-boilers when necessary.

Currently, the only solar control device is a diffusing curtain inside the windows. This device allows controlling glare phenomena but do not avoid unwanted solar gains and penalizes daylighting. Instead, the alternative solar control strategies examined here are based on various types of packable arrays of tilting slats: one external to the glasses and two inserted between the glasses in the outermost air gap, one of the last two has diffusing surfaces, while the other has a specular upper surface (Figure 3).

The external slats are coupled with an internal diffusing blind, which is lowered when necessary to avoid glare, while the slats inside the glasses use their inclination for the same purpose. Therefore, these devices are operated at first to minimize the thermal load but guaranteeing the required level of illuminance

even in the most disadvantaged position. Then they can be further operated to eliminate glare phenomena if they are detected. The control logic of the mirror slats differs from that of the diffusing slats because, before checking the thermal load and the glare, the slats are arranged in such a way as to redirect upwards the direct radiation as deep inside the room as possible. When necessary, all types of slats can be packed to ensure natural illuminance required, but if this causes glare phenomena they are unpacked. It is assumed that these control logics represent the actions that would be implemented spontaneously by the occupants.

In the various locations, the behaviours of hypothetical heavier and non-insulated masonry were also simulated: a brick wall 0.51 m thick and a stone wall 0.51 m thick, all with plaster on both sides. This in order to compare the performance of insulation with those of a greater heat capacity, which is characteristic of historical architecture, especially in the two southernmost, warmer climates. In order to evaluate the effect of a lower heat capacity of the envelope the behaviour of a more recent construction system was also simulated for the same

building. It consists of a point structure: beams-pillars in reinforced concrete, with hollow bricks and concrete floors 0.3 m thick and external walls in hollow bricks 0.12 m thick, including plaster on both sides. Although the U-value of the hollow bricks wall is similar to that of the current solid brick wall, in the absence of insulation, the average surface U-value of the façade (shown in Table 1) is higher. This is due to the presence of structural thermal bridges: edge beams of the floors and pillars in reinforced concrete. With regard to this configuration, the optimal insulation was sought.

The main thermos-physical characteristics of all these walls are summarised in Table 2.

METHODOLOGY

Normally this type of analysis is performed using different software to simulate the thermal and luminous behaviour of the building separately, usually these software are: *EnergyPlus* for energy simulation and *Radianc* for lighting simulation. This does not allow simulating within each



Figure 3 External slats (left) and slats inserted between glasses (right) hypothesized in the climate of Bologna. From ©Internorm catalogue.

	U-VALUE ($W \cdot M^{-2} \cdot K^{-1}$)	C_{FRONT} ($KJ \cdot M^{-2} \cdot K^{-1}$)
Current brick wall 0.25 m thick	2.06	481
Heavier brick wall 0.51 m thick	1.27	917
Heavier stone wall 0.51 m thick	2.37	1285
Hollow brick wall 0.12 m thick	2.37	199

Table 2 Main thermal characteristics of the external masonry examined.

calculation step the interactions between solar control actions and energy demand for lamps and HVAC. Therefore, a specific homemade software, *Ener_Lux*, has been used here. It is mainly aimed at supporting the design of solar control devices and related control strategies. It takes into consideration the physical system composed by a room, its glazed surfaces, internal and external solar control devices (slats, blinds, overhangs, and any element shading the glazed surfaces) as well as the surrounding urban environment (Figure 4). Urban context includes the building containing the examined room. The program simulates the dynamic thermal and luminous behaviour of the physical system at hourly time steps, and provides: sensible and latent thermal loads, primary energy demand for air conditioning and artificial lighting, evaluation of thermal and visual comfort. To do this it performs a thermal balance and a light simulation of the room with hourly step.

In the thermal field, the program uses an algorithm based on a finite difference method and heat balance of elementary zones (e.g. a single layer of a wall or a glass), a thermal grid model (Buonomano et al. 2016; Fraisse et al. 2002; Kämpf 2007; Underwood 2014; Fanchiotti et al. 1983). Each elementary zone constitutes a node of the thermal grid, it is characterized by its thermal capacity and heat transfer coefficients with the other elementary zones. For each node the program build an heat balance equation, the solution of the system composed by all these equations provides the values of nodes temperatures and heat flows changed between the nodes. The room sensible thermal load is obtained from these solutions: for instance, if an all-air system is simulated, the thermal load consists in the heat flow related to the node representing room's internal air. In other cases, the thermal load consists in the heat flow related to the nodes associated to the system's terminals.

The calculated temperature values of the nodes corresponding to the internal air and internal surfaces are also used for the calculation of thermal comfort

indices. They are the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) (Fanger 1970), that are adopted by the Italian standard (UNI 1997). The plane radiant temperature asymmetries values are also calculated.

The building elements delimiting the room have to be described from geometrical and thermophysical points of view. For each layer of each element: density, conductivity and specific thermal capacity have to be defined. For each element's surface the following radiative properties have to be specified: infrared emissivity, diffuse reflection coefficient and specular reflection coefficient. These last two coefficients are used to describe surface's behaviour toward solar radiation: the first represents the fraction of impinging energy that is globally reflected, the second represents the fraction of reflected energy that is redirected in a mirror like way. Both of these coefficients can assume two different values: one is relative to total solar spectrum and the other only to visible range. Type of glazing has to be described. Urban obstructions and any external shading elements have to be described only from geometrical and radiative point of view. At present the internal furnishing elements are described in a simplified way, as well as the external elements; they are not included in the thermal grid model but they interact with energy and luminous radiation. Other input data are: information on the use of the room, number and kind of occupants, internal sensible and latent thermal sources, time profile of utilisation, type of systems.

The primary energy demand is calculated taking into account the sensible and latent thermal loads and the type of HVAC system. Efficiency of the plant is calculated in each time step tacking into account the load factor. In the current version, the hourly values of climate data are derived from the daily data (average or total) normally available.

Starting from latitude and climatic data of the site, the program calculates Sun's position and solar energy

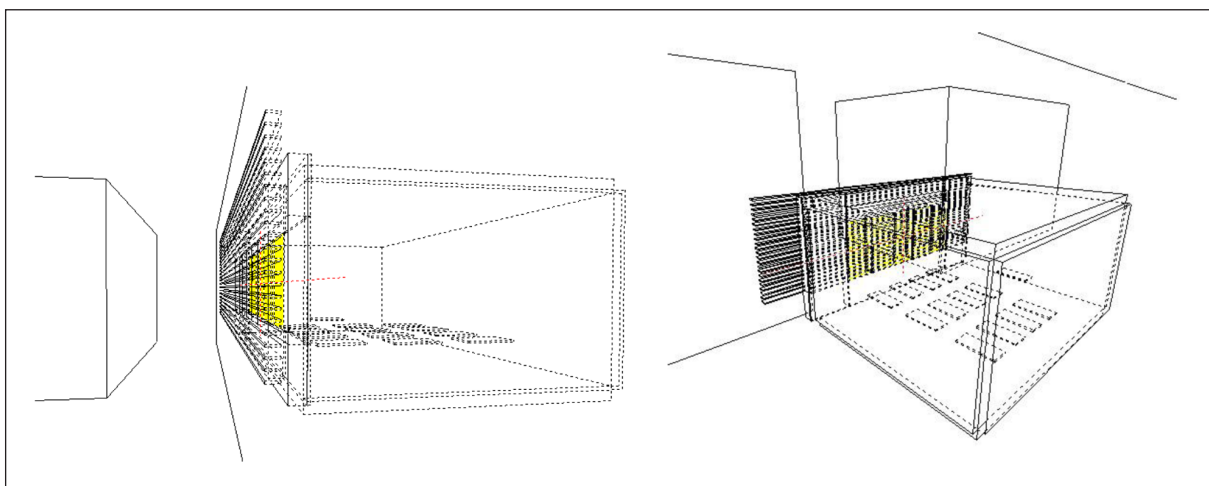


Figure 4 Geometric model of the examined room and its urban context. The size of the slats has increased and their number has been reduced compared to reality, to reduce variable sizes and calculation times.

impinging on each surface of the physical system and its energy flow is associated with the affected nodes of the thermal grid model. International known algorithms are used for calculating the instantaneous values of two radiation's components: direct from Sun and sky diffuse (Collares-Pereira and Rabl 1979; Lazzarin 1981). They are calculated taking into account any shading effects, for any surface the profile of the part exposed to direct radiation is calculated by means of a projective algorithm.

The total radiation affecting each surface also includes a part due to mutual reflections between the surfaces constituting the system, it is calculated by solving a system of linear equations (Carbonari and Rossi 1999). Each equation of this system represents a surface's radiative energy balance, in it the total radiation incident on the considered surface (unknown) is represented as its radiance divided by its diffuse reflection coefficient, the radiation from any other visible surface is represented by its energy radiance (unknown) multiplied by the relative view factor, while the radiation from the Sun and the sky, if present, are the known term. The view factors are calculated by an algorithm based on the unit-hemisphere method (Hopkinson et al. 1963). System's solution provides the energy radiance value of each surface, therefore the total radiation impinging on it.

Generally, the reflections are diffused, in case of specular reflections due to particular devices, as polished slats surfaces, the program calculates the intensity of the mirrored radiation and traces its path; it is assumed that the following reflections are diffused. The specularly reflected energy is handled as the direct component. At present only the upper part of slats can be characterised by a coefficient of specular reflection.

A similar process is used in the luminous field to calculate the illuminance value on each surface and the luminance of it. Relatively to each surface IESNA and

CSTB algorithms are used to calculate illuminance due respectively to direct solar radiation and sky (Cucumo et al. 1997). System's solution in this case provides luminous radiance value of each surface, from which the luminance value can be derived. Starting from the luminance values, and assuming a diffusing behaviour of all the surfaces, the program builds a model of the occupant's visual field where the luminance of each point is represented (Figure 5). The field of view is delimited according to the indications of Professor H. M. Traquair (Traquair 1938). The algorithm calculates the solid angles subtended by the light sources and corrects them, when required, by the Guth position index (Luckiesh and Guth 1949; Peterbridge and Longmore 1954). In this way, visual comfort is evaluated by calculating the following indices:

- Daylighting Glare Index (DGI) in case of wide light sources (Chauvel et al. 1982), this index is adopted by the Italian standard (UNI 2000),
- Unified Glare Rating (UGR) in case of smaller sources (CIE 1995; Hamedania et al. 2019),
- uniformity factor of the internal illuminances value (U_p) (DIN 1979),
- a check on disability glare (Robbins 1986) is also performed.

Controls on visual comfort are performed only when the lamps are turned off.

If the illuminance value on visual task is not sufficient it is assumed that the lighting system is activated and the related heat flow is included in room's heat balance. It is possible to take into account plant's zoning and luminous flow control by dimmer.

Within each calculation step, the program checks the conditions of thermal and luminous comfort relatively to

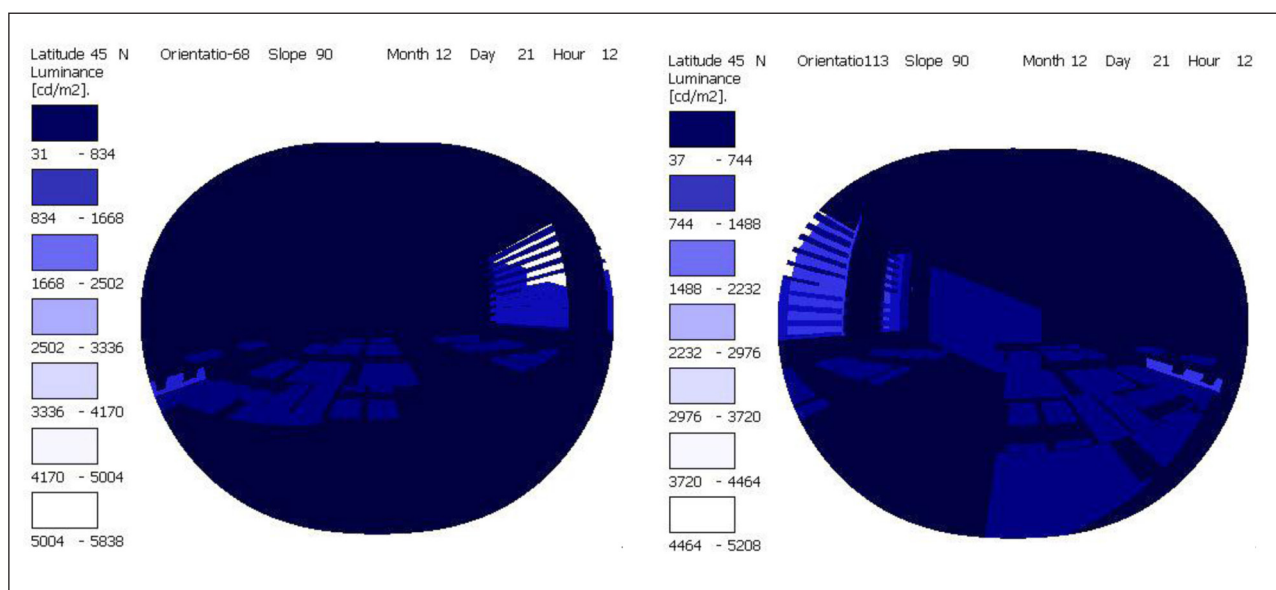


Figure 5 Samples of output of the algorithm simulating occupants visual field, in different positions inside the room.

some significant position of occupants inside the room by calculating the relative evaluation indices. These positions must be chosen in the instruction phase of the program. The position of the occupants in the room affects the calculation of the view factors between their bodies and the surrounding surfaces, therefore the values of mean radiant temperature (MRT) and asymmetries of the plane radiant temperature perceived by each occupant. The evaluation indices of luminous comfort too are related to the position and possible lines of sight of each occupant, which must be specified.

If discomfort conditions are detected any necessary feedback on the solar control devices and/or on the set-point temperatures is automatically simulated and the calculation of the hourly time-step is repeated. If adjustable devices are present, all the solar control actions, such as slats tilting or screen lowering, are simulated by modifying the digital model. When the general comfort conditions are reached, the primary energy demand for HVAC and artificial lighting is calculated (Figure 6).

ANALYSIS OF THE RESULTS

The graphs shown here are mainly referred to the two most different climates: that of Bologna and that of Palermo. In the intermediate climate of Rome, the results are closer to those of Palermo. Any change in energy demand or in the degree of comfort is evaluated

with respect to the reference case, which is constituted by the current configuration of the building.

PRIMARY ENERGY DEMAND

In the climate of Bologna, if the rooms are used as classrooms or offices, any type of additional insulation results to be useful only during the coldest period, this because of the high internal gains. In the half seasons, insulation only increases overheating, as it prevents the night's cooling of the masses (Figure 7). In the warmer period, it has no relevant effects because of the reduced heat flows throughout the envelope, due to the higher internal set point temperature (26°C). For these reasons, in Bologna, the optimal external insulation thickness value is between 0.06 and 0.07 m in the case of the classroom. The total annual energy demand decreases rapidly to this value, due to the reduction of winter losses, after which it slowly increases due to the increase of cooling loads. In the case of the office, on the other hand, this optimal insulation thickness value is around 0.02 m (Figure 8).

In the case of the office the lower number of occupants requires a lower rate of ventilation, this significantly reduces the energy demand for heating, while it reduces less that for cooling, due to the smaller temperature differences between inside and outside in the cooling period. Given the longer period of daily use and the use even in summer, the total annual energy demand is greater than that of the classroom, on average

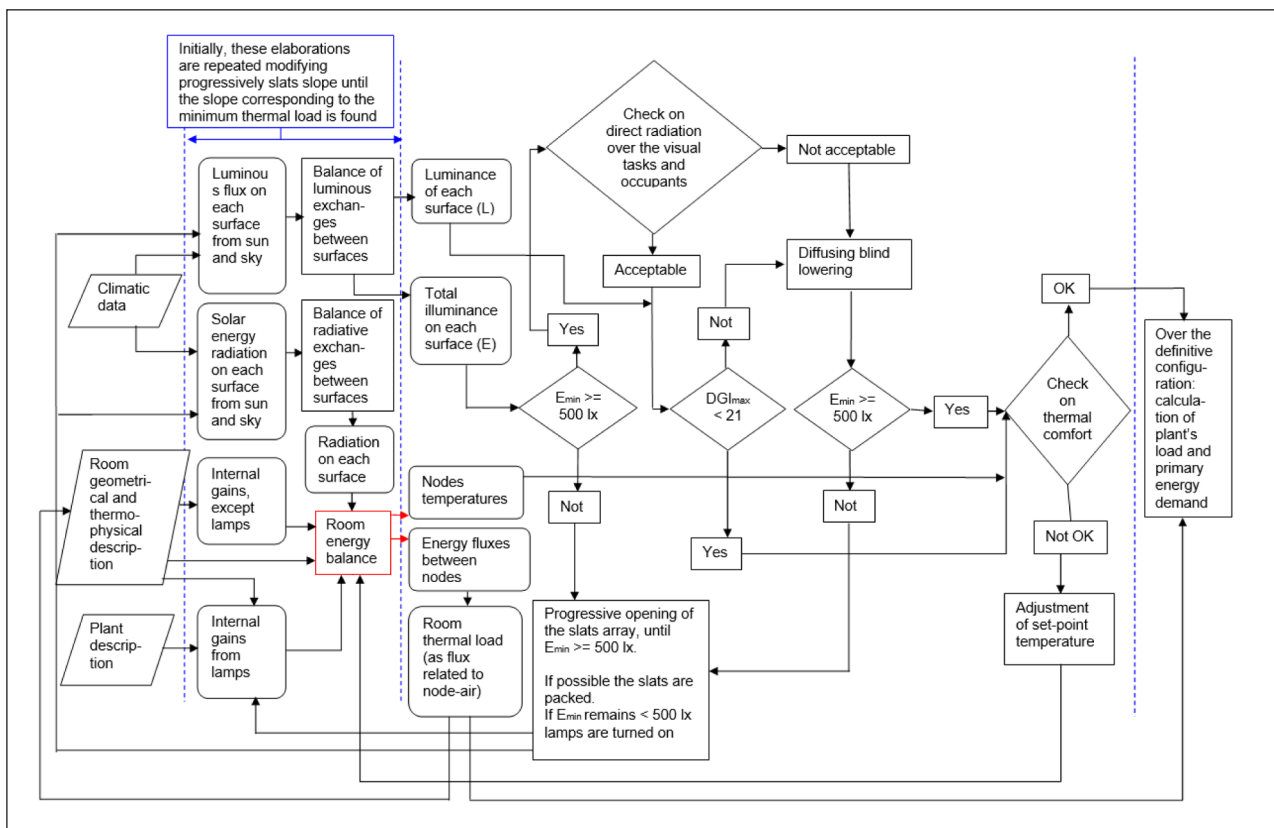


Figure 6 Flowchart of the software used, when simulating a solar control system including external slats and internal curtain.

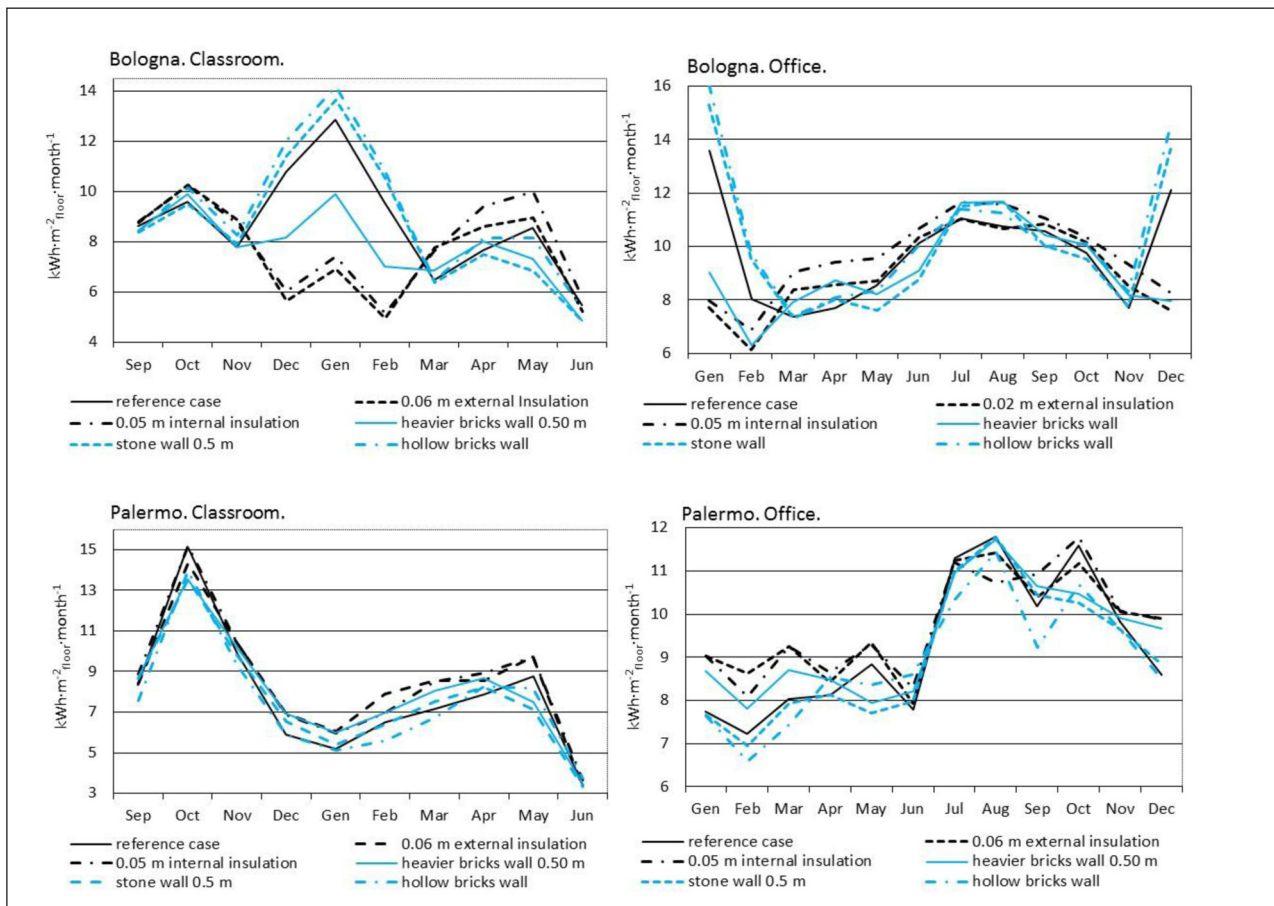


Figure 7 Monthly primary energy demand (per square meter of floor area) for HVAC and lighting systems of the room on the 2nd floor, with various walls and various types of insulation.

26–30% higher. The longer hours of use mainly affect the consumption of lamps, which almost double, despite the assumption made about the lower power of the lighting system (Figure 5).

In the case of the dwelling, heating energy demand is preponderant; therefore, it is not possible to identify a point of minimum of total energy demand, which continues to decrease as the insulation thickness increases, even if more and more slowly (Figure 5).

In the rooms of the upper floor, in Bologna, the total annual primary energy demand is generally 3–4% higher. This is due to the greater solar gains and the consequent greater cooling loads, partially balanced by lower consumption for lighting.

In Bologna, in general, internal insulation is less convenient than the external one, particularly in the case of office use, where cooling energy demand is dominant (Figure 10). This because it avoids the effect of the wall's thermal inertia (Figure 7), therefore, in warmer climates the disadvantages is even greater.

In warmer climates of Rome and Palermo, both in the case of the classroom and the office, the energy demand for cooling is much greater than that for heating, therefore any type of insulation only increases total annual energy demand, given the greater amount of useful dispersions compared to harmful ones. The

effect is greater for the classroom due to the reasons mentioned above. This does not happen in the case of residential use, where heating energy demand is dominant, even if for it the advantages of insulation are minor in warmer climates.

The heavier brick wall without insulation 0.5 m thick is characterized by lower U-value and greater heat capacity than those of the reference masonry. Therefore, in Bologna, due to the first characteristic, it slightly reduces winter consumption for heating and increase that for cooling in the hottest period of July–August, since it reduces the useful dispersions. The greater inertia slightly reduces energy demand in the mid-seasons, because it reduce cooling loads, especially in the office. For these reasons, this wall has advantages only in Bologna, for the office and, in a more accentuated way, for the classroom. However, these advantages are slightly less than those due to the optimised external insulation are, in the case of the classroom it is a question of an energy saving of 10.5% against 13%. On the other hand, this wall would be disadvantageous in the other two warmer climates examined, both for the classroom and for the office: the savings on heating do not compensate for the higher cooling costs due to the lower useful dispersions. Only in the case of housing, this wall is advantageous everywhere.

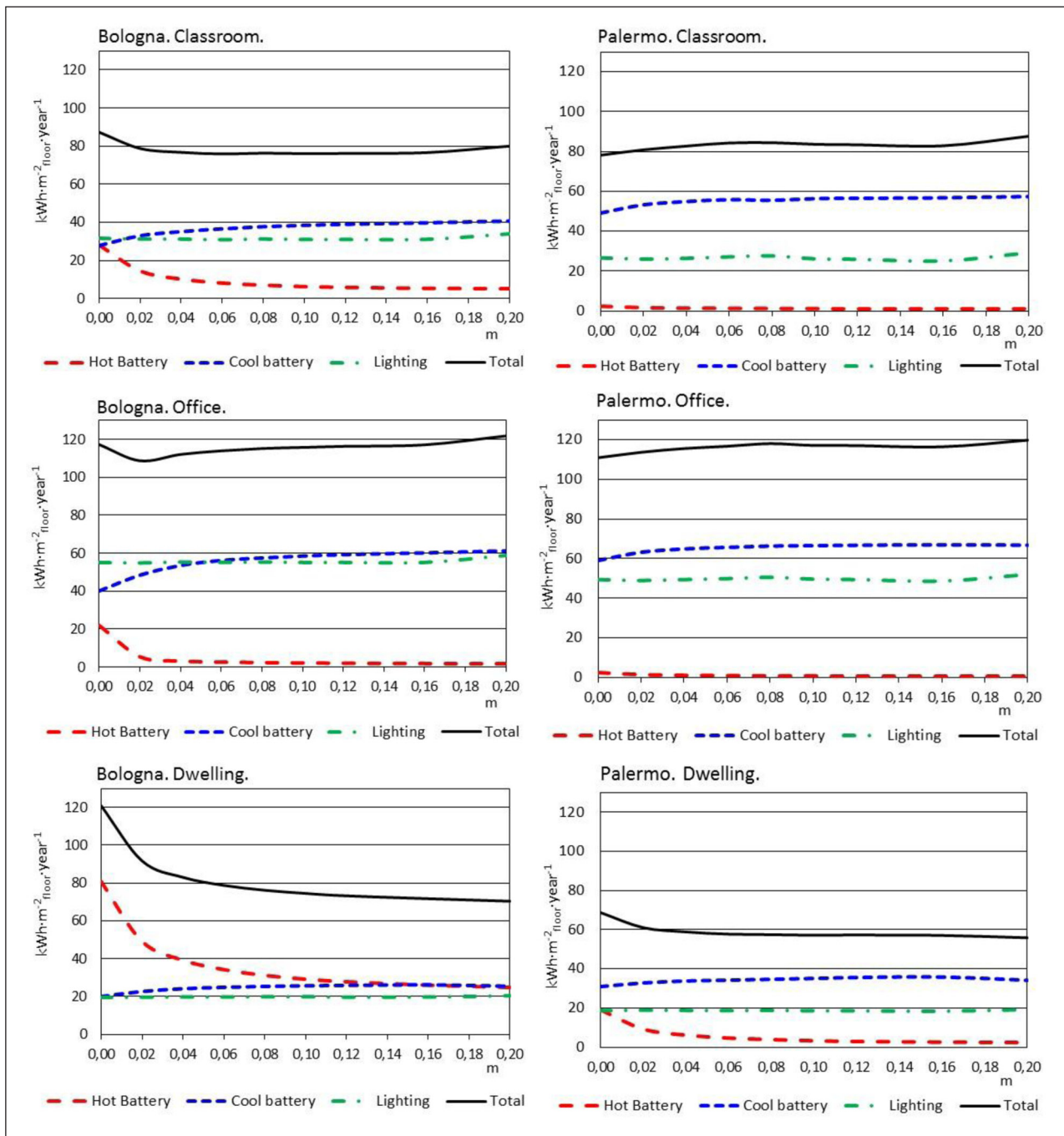


Figure 8 Room on the 2nd floor, annual primary energy demand (per square meter of floor area) for the various uses as function of external insulation's thickness.

The 0.5 m thick stone wall is characterized by increased U-value and a significantly higher heat capacity, which is equal to four times that of the reference case. Thermal inertia alone is advantageous especially in reducing cooling loads. Therefore, it would result in negligible energy savings in Bologna only for the classroom (0.52%), and in Palermo it would provide modest results for the classroom and the office (2.2% and 2.42% respectively), while it would be disadvantageous in all the other cases. Both in the case of brick and stone walls, the greater thickness entails greater consumption for artificial lighting.

In Bologna, the construction technology in reinforced concrete and hollow bricks, in the absence of insulation,

increases the total primary energy demand, essentially due to the higher consumption from heating. The thicknesses of the optimal external insulation are not significantly different from those found for the reference masonry. In warmer climates, on the other hand, this technology involves energy savings in the case of the classroom and the office, but these are essentially due to the lower consumption of the lamps, given the lower thickness of the masonry.

Here are the results relating to the combination of the various solar control devices with the external optimized insulation since this turned out to be the most efficient one (Figure 9). Compared to the use of the internal

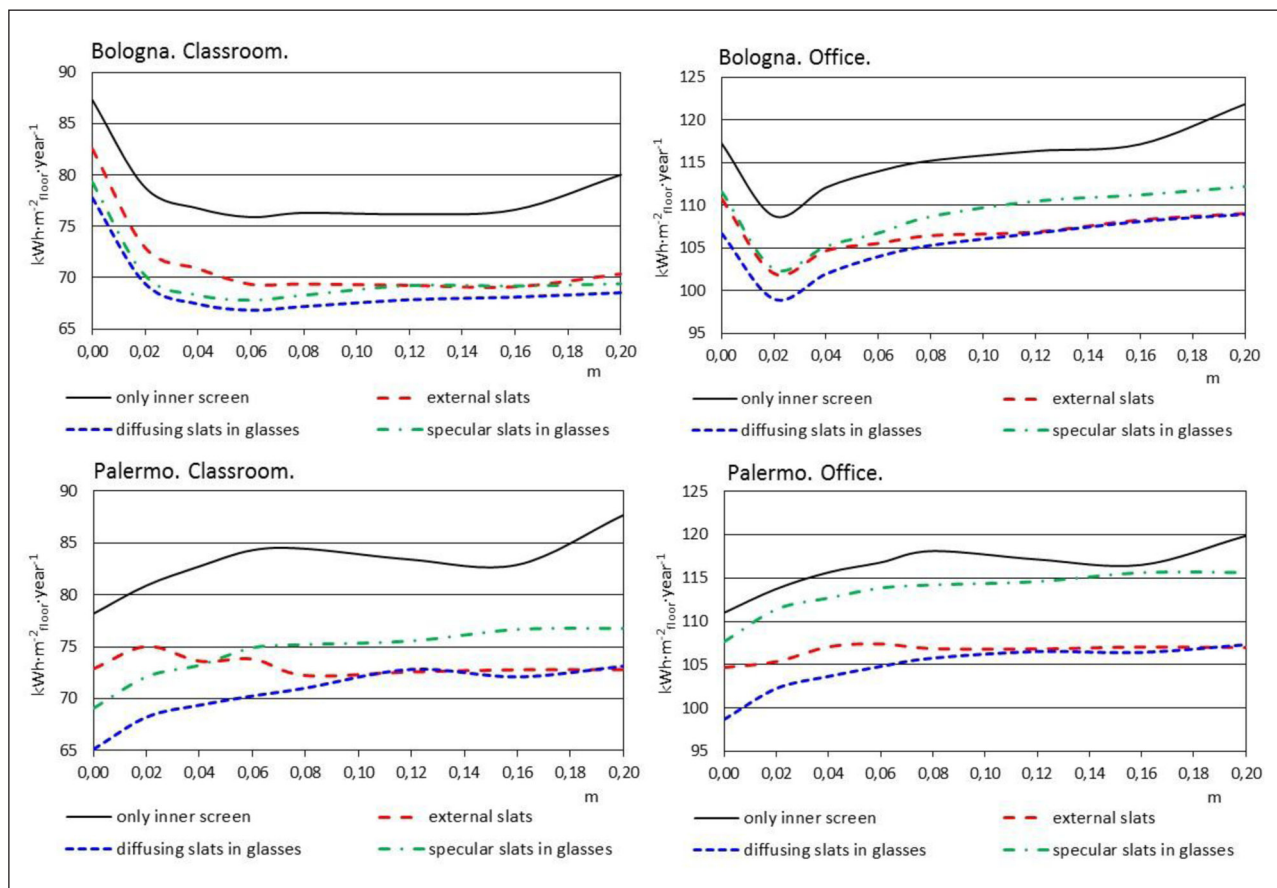


Figure 9 Total annual primary energy demand (per square meter of floor area) for HVAC and lighting systems of the 2nd floor room as function of external insulation's thickness and different solar control strategies.

curtain only, all the types of examined movable slats entail energy savings (Figures 9–10). This is because they reduce unwanted solar gains better than the internal curtain alone and avoid glare phenomena by reducing the incoming luminous flux less. Therefore, they reduce the use of lamps and the consequent thermal gains. The introduction of these devices does not change the ideal insulation thicknesses previously identified.

In general, the diffusing slats positioned between the glasses give the highest energy savings, followed by the specular ones, always inserted between the glasses. The latter reduce lamps consumption less, since a large part of the incoming luminous flux (80%) is diverted upwards and 40% of it is absorbed by the plaster. The external slats have a lower reflection coefficient and reduce the incoming luminous flux much more, thus resulting in lower savings related to artificial lighting.

In Bologna, the energy savings due to the use of the slats are of the same order of magnitude as those due to optimal insulation. In warmer climates, the percent savings due to solar control are higher but always mainly due to savings in artificial lighting (Figure 10). With office use, the total savings due to the slats also is greater in absolute value, but, given the higher consumption due to the longer time of use, the percentage savings are less remarkable. Therefore, the differences between the energy performances of the various devices are smaller.

In general, the greatest energy savings are found in Bologna for the classroom, and they are due to insulation that reduces the energy demand for heating. In Palermo the savings are generally lower and mostly due to lighting thanks to solar control devices (Figure 10).

A hypothetical facing south of the room's windowed external wall would result in a modest reduction in the total annual primary energy demand. This savings would be mainly due to the lower use of lamps, and would increase with the use of the most efficient solar control devices (slats between glasses). This effect would be greater in the case of the office, which presents greater consumption from lamps. These savings would be greater in Palermo. With the Southern orientation, the percentage savings due to all types of slats, compared with the screen alone, would increase, in particular in the case of the specular slats applied to the office. This different orientation would not alter the ideal insulation thicknesses previously identified.

THERMAL COMFORT

Thermal and luminous comfort indices were calculated with reference to six significant positions of occupants in the room. To evaluate visual comfort, two possible gaze directions for each position were examined. The results relating to the two most different climates, Bologna and Palermo, and to the intended office use are reported here, this is because the results related to office use

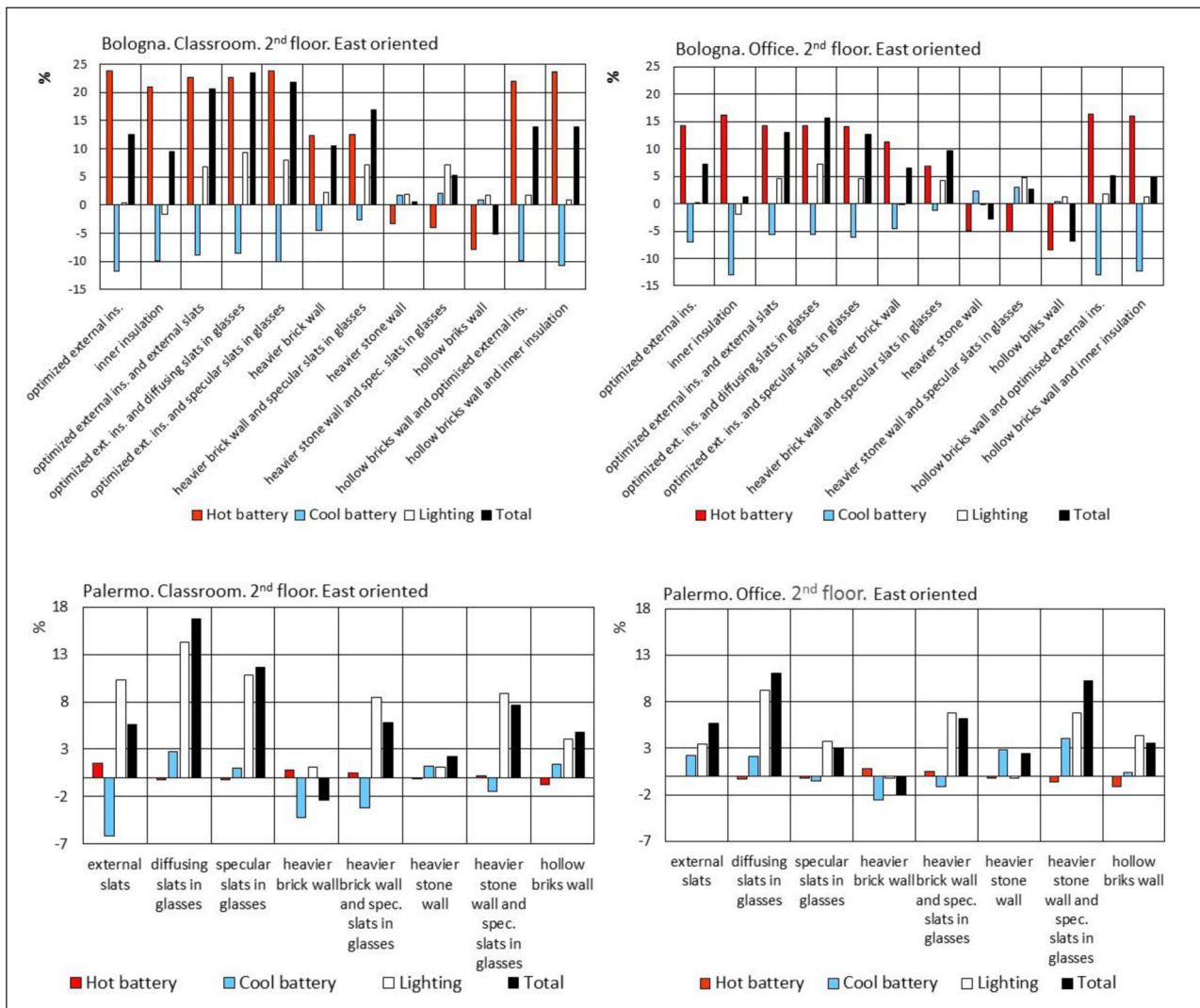


Figure 10 Percentage energy savings achievable compared to the reference configuration. The configurations with slats are combined with the optimized external insulation. In case of heavier walls or hollow bricks wall only the best performant solar control device is represented.

also include the afternoon and the summer period. The predicted mean vote (PMV) was used as the main evaluation parameter (Fanger 1970; UNI 1997).

The thermophysical characteristics of the building envelope elements essentially affect the mean radiative temperature (MRT), which in turn affect the PMV, and the localized discomfort due to the asymmetry of the plane radiant temperature (t_{pr}). In order to explore the influence of insulation, an external insulation 0.06 m thick and an inner insulation 0.05 m thick have been hypothesized in both locations, although in Palermo they would be harmful from the energy point of view. Both in Bologna and in Palermo all the insulations, in particular the external one, improve comfort throughout the year, and the results are better in the mid-seasons. Only in the warmer period, the differences with the reference case are small (Figure 11).

The heavier brick wall, 0.5 m thick, having a lower U-value than the reference one, slightly improves the degree of comfort compared to it, but in a less way than insulation. The hollow brick and the stone wall, both

not insulated, having a U-value greater than that of the reference wall, slightly worsen comfort in the cold period and in the mid-seasons, because they reduce MRT and PMV values more. However, in the hottest period the stone wall, thanks to its inertia, contains more the MRT value and provides better performance even than the insulation in Bologna. In Palermo, instead it seems not to keep the MRT value low enough, and the hypothesized insulations guarantee sensations closer to thermal neutrality.

Solar control devices mainly influence the internal temperature of the windows, therefore the MRT and the asymmetry of t_{pr} values. The diffusing slats between glasses keep this temperature a little higher in the cold period and reduce it slightly in the hottest period. The specular slats are less efficient in controlling this temperature. Given the different control logic adopted, in the cold period they tend to pack less frequently than the others; therefore, they reduce more the incoming radiation and reduce more the PMV value. Conversely, in the hottest period, when they are not packed, they assume a lower inclination and they heat up more and

heat the inner glass more. Therefore, the MRT value turns out to be slightly greater with them. In Bologna this happens only in the hottest period, in Palermo always. In all locations external slats provide better thermal comfort during the warmer period, by limiting the temperature of the internal glass.

The t_{pr} asymmetry is greater with the devices that allow the internal glass to cool more in winter (i.e. slats that pack) and make it heat more in the hot period. However, these values are always very lower than the limit values provided by the Italian standard, which is 10°C for horizontal asymmetry.

VISUAL COMFORT

The evaluation of the light comfort was carried out only in the hours of complete daylighting with both areas of the lamp set off. Two types of glare were considered here: the disability glare from direct radiation on the visual task, and discomfort glare due to exceeding contrast of luminances inside the visual field (Hopkinson 1963). This last is assessed by means of the Daylighting

Glare Index (DGI), in case of extended light sources (Chauvel et al. 1982; UNI 2000), or Unified Glare Rating (UGR) in case of smaller sources (CIE 1995). In this study, the first type of glare is considered excessive when the luminance of the task or its irradiated parts exceeds 580 cd/m² (Robbins 1986). It has been assumed that the presence of glare of any kind in one occupant’s position entails solar control actions.

The histogram on the left of Figure 9 show, for each solar control strategy, the percentage of hours-occupant in comfort or discomfort conditions on the total hours-occupant detected after the thermal load control actions, performed with the solar control devices, and before the glare control actions. The histogram on the right of Figure 12 show, for each solar control strategy, both the daylighting hours possible after the control actions of the heat load and after the light comfort control actions. The internal curtain used alone is the device that reduces the hours of daylighting the most, while the slats between the glasses penalize it less, especially the specular ones. In particular, the specular slats provide more

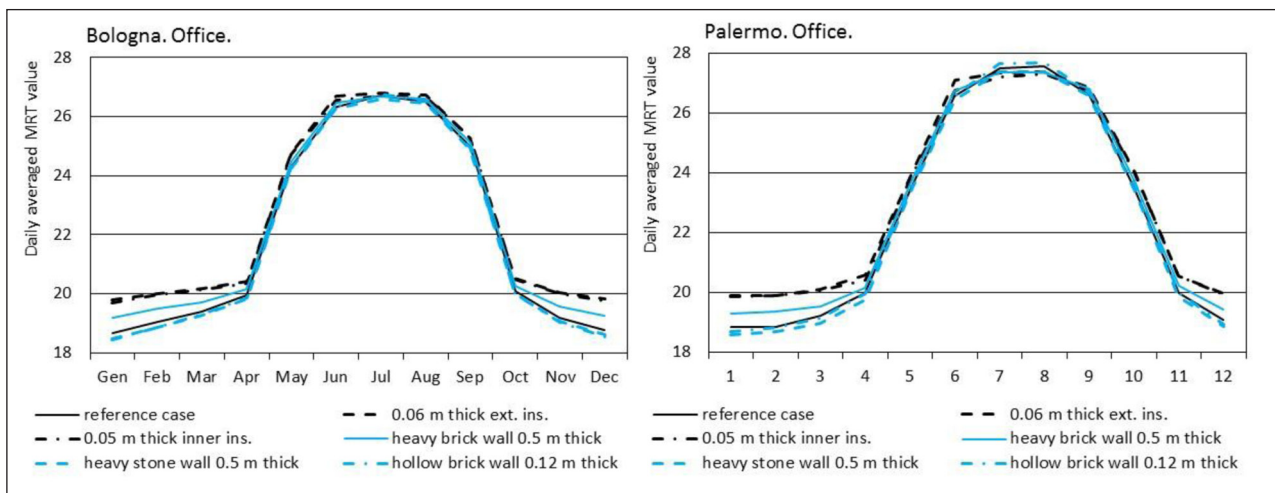


Figure 11 Office. Spatially and daily averaged MRT values in typical monthly days, with different types of insulation and constructive technologies for the 2nd floor room.

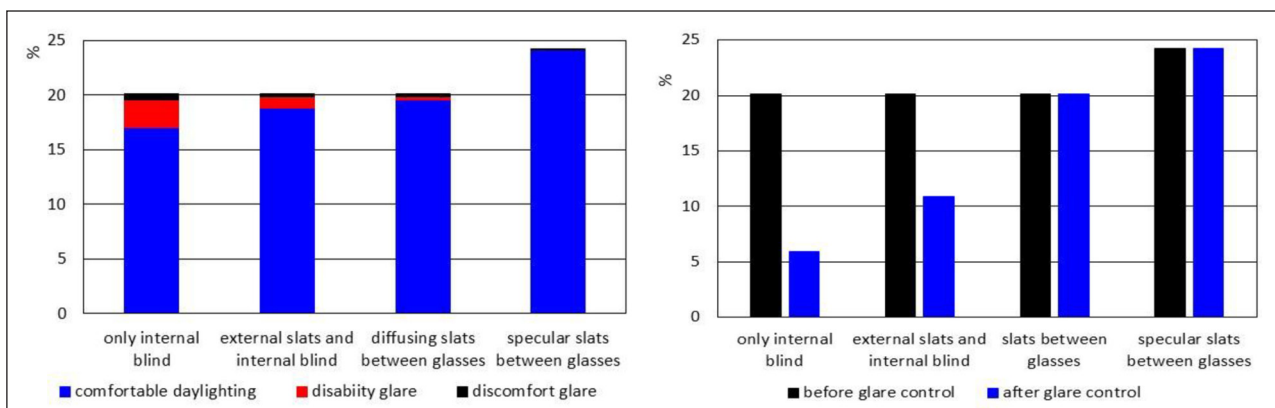


Figure 12 Bologna, office in the 2nd floor room, percentage frequency of hours-occupant in visual discomfort conditions on the total hours-occupant after the thermal load control actions, performed with the various devices, and before the glare control actions (left). Ratio between annual hours of daylighting and the total hours of use, before and after glare control actions (right).

daylighting hours, by favoring higher illumination values in the positions furthest from the windows. The fact that this does not lead to lower consumption from lamps is because, with specular slats, in many of the hours in which the lamps are used, the entire set of lamps is switched on, while, with the diffusing slats, only half of the lamps are switched on. It can be observed that, in the case of the slats between the glasses, the glare control actions do not reduce the number of daylighting hours that are possible after the load control actions.

Before the glare control actions, the most frequent type of discomfort is that due to the direct radiation on the visual task, especially in the case of the curtain used alone. In the case of the South orientation the number of daylighting hours increases, and the percentage frequency of discomfort conditions decreases, because fewer situations with low sun in the middle seasons occur, and the differences between the performances of the various devices are smaller, both in the case of the classroom and of the office. In Palermo, the number of hours of visual comfort is greater, given the greater intensity of the solar radiation.

Compared to the use of the single curtain all the types of slats improve the internal light comfort. Before the glare control actions, all the types of slats reduce the frequency of disability glare due to direct radiation on visual tasks, in particular the specular ones. After the visual comfort control actions, all the slats guarantee a greater uniformity factor of the internal illuminances (U_o) than just the curtain. The diffusing slats between glasses provide the higher value of U_o in Bologna, whereas in Palermo the external slats are the best performant, but the differences between different types of slats are lower. The U_o is defined as the ratio between the minimum illuminance value on visual tasks and their average value in the room (DIN, 1979). However, specular slats also cause higher spatial and temporal average DGI values, albeit within limits.

CONCLUSION

Simulations results show that the optimal intervention strategy depends not only on the climate but also on the building's intended use, which determines the internal gains and the time profile of use.

The dominance of the energy demand for cooling compared to that for heating reduces the optimal insulation's thickness. Therefore, insulations, in particular the external one, brings energy advantages for all the examined intended uses only in the coldest climate of Bologna. While it would retain a certain usefulness in other climates for residential use only, for which the energy demand for heating is dominant.

In all the climates, the insulations, in particular the external one, improve comfort throughout the year, and the results are better in the mid-seasons.

Without insulation, only in Bologna a brick masonry of greater thickness has the advantages of lower U-value. Even its greater thermal inertia provides advantages especially in the mid-seasons. However, these energy savings are less than those obtainable with optimised external insulation are. In the other climates examined, the disadvantages related to the minor useful heat losses are dominant. A significantly higher heat capacity, but associated with greater transmittance, as in the case of thick stone masonry, brings modest energy savings only in the warmer climate of Palermo and for destinations other than the home.

Among the solar control strategies, the most energy efficient seems to be the use of diffusing slats inserted between the glasses, followed by the specular ones always between the glasses. The specular slats provide the best conditions of luminous comfort, while those outside the glasses provide the best thermal comfort in the hottest periods.


Therefore, in the climate of Bologna, from energy point of view the best retrofit strategy consists in the external insulation with the optimized thickness combined with diffusing slats internal to the glasses, while in the other warmer climates it consists in the introduction of the same solar control device and no insulation, except for the intended residential use.

A hypothetical facing south of the room's windowed external wall would result in a modest reduction in the total annual energy demand, mainly due to the lower use of lamps. With this orientation, the percentage savings due to all types of slats would increase, especially in case of the specular slats applied to the office. Therefore, windows orientation mainly influences the choice of solar control devices. This different orientation would not alter the identified optimal insulation thicknesses.

COMPETING INTERESTS

The author has no competing interests to declare.

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REFERENCES

- Buonomano, A, De Luca, G, Montanaro, U and Palombo, A.** 2016. Innovative technologies for NZEBs: An energy and economic analysis tool and a case study of a non-residential building for the Mediterranean climate. *Energy and Buildings*, 121: 318–343. DOI: <https://doi.org/10.1016/j.enbuild.2015.08.037>

- Buvik, K, Andersen, G and Tangen, S.** 2015. Energy upgrading of a historical school building in cold climate. *Energy Procedia*, 78: 3342–3347. DOI: <https://doi.org/10.1016/j.egypro.2015.11.748>
- Carbonari, A.** 2012. Thermal and luminous comfort in classrooms: a computer method to evaluate different solar control devices and its operating logics. In: *PLEA 2012 – The 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture*. Lima, Perù, 7th–9th November 2012. Lima: PUCP.
- Carbonari, A.** 2017. Solar control of extensively glazed facades: a computer method for predicting the effects of various devices and building's thermal inertia. In: *SET 2017–16th International Conference on Sustainable Energy Technologies, Bologna*. 17th–20th of July 2017. Bologna: WSSET and Alma Mater Studiorum Università di Bologna.
- Carbonari, A and Rossi, G.** 1999. Metodologia per l'ottimizzazione energetica ed illuminotecnica degli elementi ombreggianti applicati alle facciate degli edifici (Methodology for energy and lighting optimization of shading elements applied to building facades). In: *ATI 1999 – The 54th Conference*. L'Aquila, Italy, 14th–17th September 1999. Padova: SGEditoriali.
- Chauvel, P, Collins, JB, Dogniaux, R and Longmore, J.** 1982. Glare from Windows: current views of the problem. *Lighting Research & Technology*, 14(1): 31–46.
- Collares-Pereira, M and Rabl, A.** 1979. The average distribution of solar radiation. Correlations between diffuse and hemispherical and between daily and hourly insolation values. *Solar Energy*, 22: 155 and following. DOI: [https://doi.org/10.1016/0038-092X\(79\)90100-2](https://doi.org/10.1016/0038-092X(79)90100-2)
- Commission Internationale de l'Eclairage (CIE).** 1995. Technical report 117 – Discomfort Glare in interior lighting. Wien, Österreich: CIE.
- Cucumo, M, Kaliakatzos, D, Marinelli, V and Vivacqua MD.** 1997. Metodi di calcolo della luminanza del cielo e dell'illuminamento naturale su superfici esterne (Calculation methods of sky luminance and daylighting of external surfaces). *Condizionamento dell'Aria Riscaldamento Refrigerazione*, 5: 485–496. DOI: <https://doi.org/10.1177/096032718201400103>
- Deng, J, Yao, R, Yu, W, Zhang, Q and Li, B.** 2019. Effectiveness of the thermal mass of external walls on residential buildings for part-time part-space heating and cooling using the state-space method. *Energy and Buildings*, 190: 155–171. DOI: <https://doi.org/10.1016/j.enbuild.2019.02.029>.
- Deutsches Institut für Normung.** 1979. DIN 5035 – Innenraumbelichtung mit künstlichem licht. Berlin, Germany: DIN.
- Ente Nazionale Italiano di Unificazione (UNI).** 1997. UNI EN ISO 7730: Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. Milano, Italy: UNI.
- Ente Nazionale Italiano di Unificazione (UNI).** 2000. UNI/TS 10840: Luce e illuminazione Locali scolastici: criteri generali per l'illuminazione naturale e artificiale. Milano, Italy: UNI.
- Erhorn, H, Erhorn-Kluttig, H and Reiß, J.** 2015. Plus energy schools in Germany – Pilot projects and key technologies. *Energy Procedia*, 78: 3336–3341. DOI: <https://doi.org/10.1016/j.egypro.2015.11.747>
- Erhorn-Kluttig, H and Erhorn, H.** 2015. School of the future – Towards zero emission with high performance indoor environment. *Energy Procedia*, 48: 1468–1473. DOI: <https://doi.org/10.1016/j.egypro.2014.02.166>
- Fanchiotti, A, Rossi, G, Trevisan, C and Vio, M.** 1983. Sistemi Solari Passivi – Progettazione e realizzazione di una stazione di prova di muri trombe modello di simulazione numerica confronto tra dati sperimentali e risultati numerici. Venezia: Istituto Universitario di Architettura di Venezia.
- Fanger, PO.** 1970. Thermal Comfort. New York: Mc Graw-Hill.
- Fraisse, G, Viardot, C, Lafabrie, O and Achard, G.** 2002. Development of a simplified and accurate building model based on electrical analogy. *Energy and Buildings*, 34: 1017–1031. DOI: [https://doi.org/10.1016/S0378-7788\(02\)00019-1](https://doi.org/10.1016/S0378-7788(02)00019-1)
- Hamedania, Z, Solgia, E, Skatesa, H, Hineb, T, Fernandoa, R, Lyonsa, J and Duprea, K.** 2019. Visual discomfort and glare assessment in office environments: A review of light-induced physiological and perceptual responses. *Building and Environment*, 153: 267–280. DOI: <https://doi.org/10.1016/j.buildenv.2019.02.035>
- Hopkinson, RG, Peterbridge, P and Longmore, J.** 1963. Daylighting. London: Heinemann.
- Kämpf, JH and Robinson, D** 2007. A simplified thermal model to support analysis of urban resource flows. *Energy and Buildings*, 39: 445–453. DOI: <https://doi.org/10.1016/j.enbuild.2006.09.002>
- Lazzarin, R.** 1981. Sistemi solari attivi, manuale di calcolo (Solar passive systems, a calculation handbook). Padova: F. Muzzio & C.
- Luckiesh, M and Guth, SK.** 1949. Brightness in visual field at borderline between comfort and discomfort (BCD). *Illuminating Engineering*, 44(11): 650–670.
- Peterbridge, P and Longmore, J.** 1954. Solid Angles Applied to Visual Comfort Problems. *Light and Lighting*, June 1954: 173–177.
- Robbins, CL.** 1986. Daylighting, design and analysis. New York: Van Nostrand Reinhold Company.
- Sami, AA-S and Zedan, MF.** 2011. Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass. *Applied Energy*, 88(9): 3113–3124. DOI: <https://doi.org/10.1016/j.apenergy.2011.02.036>
- Stazi, F, Bonfigli, C, Tomassoni, E, Di Perna, C and Munafò, P.** 2015. The effect of high thermal insulation on high thermal mass: is the dynamic behaviour of traditional envelopes in Mediterranean climates still possible? *Energy*

and Buildings, 88: 367–383. DOI: <https://doi.org/10.1016/j.enbuild.2014.11.056>

Traquair, HM. 1938. *An introduction to clinical perimetry*. Edinburgh: sby.

Tzoulis, T and Kontoleon, KJ. 2017. Thermal behaviour of concrete walls around all cardinal orientations and optimal thickness of insulation from an economic

point of view. *Procedia Environmental Sciences*, 38: 381–388. DOI: <https://doi.org/10.1016/j.proenv.2017.03.119>

Underwood, CP. 2014. An improved lumped parameter method for building thermal modelling. *Energy and Buildings*, 79: 191–201. DOI: <https://doi.org/10.1016/j.enbuild.2014.05.001>

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