

TECHNICAL ARTICLE

Retrofit of Italian School Buildings. The Influence of Thermal Inertia and Solar Gains on Energy Demand and Comfort

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Most of the Italian school buildings were built before the 1973 energy crisis, so they need a retrofit to reduce their primary energy demand and improve the indoor environment quality. Moreover, regardless of age, these buildings have large windows; therefore, it is generally necessary to improve the solar control strategy. The older buildings have heavy masonry; in these cases, the problem is where it is more convenient to place an additional layer of insulation: inside or outside the buildings opaque envelope elements. This work explores, only by means of computer simulations, the effects of various retrofit strategies on energy demand and comfort conditions. The examined strategies are characterized by different positions of the additional insulation and various solar control strategies. The case studies consist of two school buildings of the city of Bologna, in Northern Italy. In order to assess the influence of internal gains and time profile of use, other possible uses for the same buildings, such as offices or dwellings, have been considered. Simulations results show that the external insulation is always the most performing, but the differences with the internal one are not relevant in the case of the classrooms. Differences increase with the reduction of the internal gains and with the extension of the daily use time. Small packable slats inserted between the glasses improve luminous comfort, and reduce energy demand. Larger external slats provide less luminous comfort but better thermal comfort in the cooling period; however, they increase the energy demand.

Keywords: Buildings Energy; Retrofit; Thermal and Luminous Comfort

Introduction

In Italy, around 51000 buildings are used in whole or in part as schools. Most of them, about 64%, were built before the energy crisis of 1973, in the absence of any regulation concerning energy consumption, and less than 10% of them were built after the adoption of the Law 10 of 1991, which is the first Italian regulation introducing clear constraints on energy efficiency (JRC 2015; Legambiente 2018; Gaitani et al. 2015). Therefore, these buildings need a retrofit to reduce their primary energy demand and improve the indoor environment quality. Furthermore, most of them have only an old and inefficient heating system, and are not equipped with a ventilation and air conditioning system (Dalla Mora et al. 2017; De Santoli et al. 2014). The retrofit of this building stock and its plant adaptation can provide significant energy savings and improvements in comfort.

This situation is common to various European countries, therefore some national and community projects have addressed this issue, allocating funds for the retrofit of

existing schools and encouraging the sharing of strategies and best practices. These are projects like Schools of the Future (Erhorn-Kluttig and Erhorn 2015; Mørck, Thomsen and Jørgensen 2015), ZEMeds (Gaitani et al. 2015), VERYSchool, EnOB (Erhorn, Erhorn-Kluttig and Reiß 2015).

The main areas of intervention foreseen by these projects are improvement of building envelope's insulation, optimal handling of solar and internal gains, renovation or introduction of heating, ventilation and air conditioning system (HVAC), improvement of the efficiency of lighting and energy supply or generation systems. The optimal handling of solar gains is a relevant topic, since, regardless of age, school buildings have large windows. Therefore solar control strategies are necessary to avoid problems of visual and thermal discomfort, in particular that due to overheating, which can also occur in cold climates, when the solar gains add up to the significant internal gains (Buvik, Andersen and Tangen 2015; Erhorn, Erhorn-Kluttig and Reiß 2015; Erhorn-Kluttig and Erhorn 2016).

Buildings built before 1940 represent a considerable part of the whole stock of school buildings: about 24% (Legambiente 2018). These buildings have a heavy structure with full brick walls, in these cases, one of the main questions that arise is where it is more convenient to place an additional layer of insulation: inside or outside the

buildings opaque envelope elements. In general, it is common to think that in the case of buildings discontinuously used, such as offices and schools, it is better to place the insulation inside, in order to exclude the mass from the thermal balance of the internal environment. In this way, a low inertia system is obtained, able to respond quickly to the actions of the plant. However, in reality, the answer is not obvious; the usefulness of thermal inertia depends on a number of factors such as:

- presence in the local climate of significant daily thermal excursions,
- relevance of cooling loads compared to heating ones,
- length of the period of daily use.

As a previous research shows (Carbonari 2017), if cooling loads are prevalent, thermal capacity can be useful to take advantage of nighttime free cooling and to delay heating in the time of use. However, often there are other practical or regulatory constraints to the placement of the insulation outside, as in the case of the historical centers of the cities. Normally the Italian school buildings are only equipped with a heating system with water radiators. Therefore, because of relevant internal and solar gains, with the exception of the colder period, they turn out to be overheated. In this study, it was assumed that a full air centralized HVAC system is installed to eliminate overheating and improve air quality, and also to quantify the energy cost of thermal comfort in all seasons.

This work is aimed to explore, only by means of computer simulations, the effects of various retrofit strategies and various building's intended uses on primary energy demand and general comfort conditions. The examined strategies are characterized by different positions of the additional insulation and different solar control devices. The computer simulations were performed using the home made software "Ener_Lux" (Carbonari 2012), which allows simultaneous analysis of energy and comfort issues, taking into account automatically any solar control action. For the moment, the case studies consist of two school buildings of different ages and with different constructive technologies in the city of Bologna, in Northern Italy. In the case of the more recent building type, the behavior of two alternative construction technologies, based

respectively on steel and wood, has also been simulated. In order to assess the influence of internal gains and time profile of use, other possible uses of buildings, such as offices and dwelling, have been simulated. The climate of the city is temperate with cold winter and warm summer, in all seasons there are not negligible daily temperature ranges. In this paper some early results are presented.

The case studies

The following two school buildings are currently being examined.

Case A: the elementary school "G. Pascoli", built in 1915 (**Figure 1**), with structural internal and external walls in full bricks, 0.25 m thick, with plaster in both sides; horizontal elements are in wood beams and planks, with superimposed lime mortar and bricks. In each classroom there are three vertical wide windows. Classrooms internal dimensions are: 9.45 m on the side along the façade, 7.39 m on the other side, the height is 4.5 m.

Case B: the elementary and secondary school "L. C. Farini", built in 1975 (**Figure 2**), with reinforced concrete structure of beam and pillars, and horizontal ribbon windows. The horizontal elements are in reinforced concrete and hollow tile mixed floors, 0.4 m thick, the walls are made of hollow bricks, 0.12 m thick the external ones and 0.08 m thick the internal ones, with plaster in both sides. Classrooms internal dimensions are: 6.30 m on the side along the façade, 7.17 m on the other side, the height is 3.1 m.

All the examined classrooms are approximately east oriented, with 76° (case A) and 63° (case B) east azimuth. In the local climate, this orientation is the less favourable in the cooling period for a room used in the morning, as a classroom. Currently, in both buildings the only solar control device is an internal semi-transparent and diffusing curtain. In the simulations, its transparency coefficient was supposed equal to 0.5 in both the energy and the light field. For each building, the shading effects of the present urban obstructions were taken into account.

In reference to a classroom of each school building, the effects of the addition of two types of insulation, internal and external, have been analysed. In order to analyse the influence of the thermal capacity, for all the configurations with external insulation studied, it has been hypothesized a thickness of the insulating material such



Figure 1: The elementary school G. Pascoli, the long building in the middle of the image on the left, built in 1915. Photo: Google Earth (left), Google Street View (right).



Figure 2: The elementary and secondary school L. C. Farini, built in 1975. Photo: Google Earth (left), a collaborator of the author (right).

Table 1: Main thermal characteristics of the classrooms.

Configuration	U-value [W/(m ² ·K)]	c _{frontal} [kJ/(m ² ·K)]	c _{specific} [kJ/(m ³ ·K)]
A without insulation	2.03	481	137
A external insulation	0.29	481	137
A inner insulation	0.57	20.6	89
B without insulation	2.02	182	93
B external insulation	0.29	182	93
B inner insulation	0.65	20.6	86
B steel	0.29	15.5	47
B wood	0.29	60.3	56

as to obtain the same value of the transmittance (U-value), equal to the limit value imposed by the current Italian standard, that is $0.3 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$. Therefore, in both buildings the proposed external insulation consisted of a layer of rock wool of about 0.11 m thick, with an external 0.015 m thick protective layer, composed primarily of plaster. In the case of the older building, this was only a theoretical intervention considering the historical context, in which no modifications of the external appearance of the buildings are permitted.

Normally, when an internal insulation is used, its thickness does not exceed 0.05 m. This is due to the fact that a greater thickness would reduce the inner space without producing significant additional energy savings. However, in this study a layer of extruded polystyrene foam (XPS) with a thickness of 0.07 m has been assumed, this to avoid excessive differences in the U-values compared to the configurations with external insulation, also considering the effect of thermal bridges due to the discontinuity of the internal insulation in correspondence of the slabs. In this way the average U-value of the opaque external borders turned out to be $0.566 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ in the case A and $0.648 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ in the case B (**Table 1**). The internal insulation was covered with 0.015 m thick plasterboard. For both buildings the type of glazing that is currently more widespread and compatible with the current standards has been hypothesized: a double glazing with two 0.006 m thick glass layers and 0.012 m thick interspace, with a low emissive layer on the outer face of the inner glass (overall U-value: $1.8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$).

It was assumed that twenty-seven pupils and a teacher were present in the classroom, the related sensible and latent thermal gains were taken into account: for each occupant 50 W in sensible form and 50 W in latent form. For each occupant an hourly ventilation rate of 15 m^3 was assumed. The hypothesized light plant consist of fluorescent lamps (luminous efficacy: 91 lm/W, maximum total power: 756 W). It is divided into two areas along two bands parallel to the external wall. There are no dimmers.

To calculate the primary energy demand related to HVAC, in this work for simplicity it was assumed that the hot fluid was always supplied to the air treatment machine by a condensing gas-boiler, with reference efficiency value equal to 0.9, and the cold one by an electrically driven air to water heat pump, exchanging heat with external air, with reference coefficient of performance value (COP) equal to 4.5. With regard to these machines, the fraction of power that can be used by each classroom has been sized based on the external winter and summer design temperatures. In each time-step the instantaneous values of the boiler efficiency and of the heat pump COP have been calculated taking into account the load factor. The usual summer and winter air treatment cycles have been used in the respective seasons, while in the mid-seasons one or the other reference cycle could be used, depending on whether there was a need to dehumidify or humidify the flow of air introduced into the classroom.

As a first step, the internal air temperature was used as the indoor environment control parameter, but the use of the Predicted Mean Vote (PMV) (Fanger 1970) has also

been simulated, because this kind of control can be performed by the occupants when the manual adjustment of HVAC terminals is available. In the first case, internal set-point air temperature has been assumed equal to 20°C in winter and 26°C in summer, as prescribed by the Italian law. While in the mid-seasons its value has been obtained by interpolation between these two values. Interpolation was based on the average monthly value of the maximum outdoor air temperature. In accordance with the Italian standard (Ente Nazionale Italiano di Unificazione 1997) and the design customs the relative humidity set point has been assumed equal to 50% all over the year.

With regard to the building of the case B, it has been studied the behavior of other constructive technologies: with steel and wood structure, since their use is currently expanding. The hypothesized building with steel structure has internal and external partitions consisting of sandwich panels; the external one contains a 0.11 m thick layer of extruded polystyrene foam. The slabs are made of a corrugated steel sheet with superimposed lightweight concrete, its total thickness is 0.24 m, and a roof of paving tiles over a layer of concrete is present. The wooden building uses X-Lam technology. Its outer walls consist of a 0.057 m thick X-Lam layer and an external insulation of 0.10 m thick wood wool, with an external 0.02 m thick protective layer mainly composed of plaster, and an internal 0.015 m thick plasterboard. Even the slabs consist of a 0.30 m thick X-Lam, with superimposed 0.04 m thick concrete, and a 0.02 m thick wooden floor.

In **Table 1** the main thermo-physical characteristics of examined classrooms are resumed. The U-values shown in the table are averaged on the surface of the external opaque envelope; therefore, when the insulation is internal, the U-value include the effects of thermal bridges that are present in correspondence of the slabs. The frontal thermal capacity of the external opaque wall (c_{frontal}) and the specific volumetric thermal capacity of the classroom (c_{specific}) are also shown in the table. These last two quantities do not include the thermal capacity of the masses outside the insulation. The second includes the thermal capacity of the internal building elements that participate in the thermal balance of the classroom. The considered volume is the internal one of the classrooms.

Methodology

This work was done by means of computer simulations, using software *Ener_Lux*. This software (Carbonari, 2012) is mainly aimed at the study of solar control devices and related operating strategies. It allows investigating the interactions between the solar control actions on the glazed openings of a room, the conditions of thermal and visual comfort inside it and primary energy demand for HVAC and lighting. Therefore it takes into consideration the physical system composed by a room, its glazed surface, internal and external solar control devices (slats, blinds, overhangs and any element shading the opening) as well as the surrounding urban environment, including the building containing the room under investigation.

Once defined the kind of devices and their control logic, the program simulates the dynamic thermal and

luminous behaviour of the physical system with hourly time-steps and provides the following indexes values: Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) (Fanger 1970) and Daylighting Glare Index (DGI) (Hopkinson et al. 1963) or Unified Glare Rating (UGR) (CIE 1995), depending on the extent of the light sources. Other information about the visual environment quality are provided too (Robbins 1986). Then the program calculates sensible and latent room's thermal loads and, based on information on the type of plants, the primary energy demand for HVAC and artificial lighting. To perform room's energy balance the program use an algorithm based on heat balance of elementary zones (e.g. a single layer of a wall or a glass): a thermal grid model. When the use of adjustable devices is simulated, all the planned solar control actions, such as the progressive inclination of slats or the lowering of a curtain, are automatically simulated. In such cases, the program modifies the geometric configuration of the system and repeats the simulation of the hourly time-step. The check against visual discomfort conditions is performed only when the lamps are turned off (**Figure 3**).

Different kinds of glare are considered: disability glare due to direct radiation impinging on the visual task, big differences of luminance values between different points in the visual field, evaluated by the UGR index, and discomfort glare due to large luminous sources (typically the sky seen through the windows) that is evaluated by the DGI index. When one of these kinds of discomfort is detected, the program simulates a solar control action. The values of the indexes DGI and UGR are calculated by means of a peculiar algorithm, that simulates in a simplified way the occupants' visual field.

The program allows the use of various indoor environment control parameters, not only the air temperature but also the operative temperature (t_o) and the PMV. The **Figure 3** shows the organization of the calculation in case the use of an array of external slats combined with an internal curtain is simulated.

Analysis of the results

In the case A, the classrooms, of greater volume, they have a significantly higher thermal capacity than in the case B (**Table 1**). Moreover, in the second case, the thermal capacity is concentrated in the horizontal structures rather than in the vertical ones. In the case A two classrooms have been examined, respectively located on the second and third floor above ground, while in the case B it was only examined one classroom located on the second and last floor. In the first case, the overall area of the three vertical windows is greater than that of the ribbon window of case B (9.75 m² against 5.57 m²). Therefore, in the second floor classrooms the magnitude of solar gains is similar in both cases, despite the larger urban obstructions of case A, while in the third floor classroom of case A the solar gains are greater than 30% compared to those of the other two classrooms. In the following analysis only the classrooms of the second floors are compared. To simplify the simulation the classrooms are considered adiabatic toward the other internal spaces.

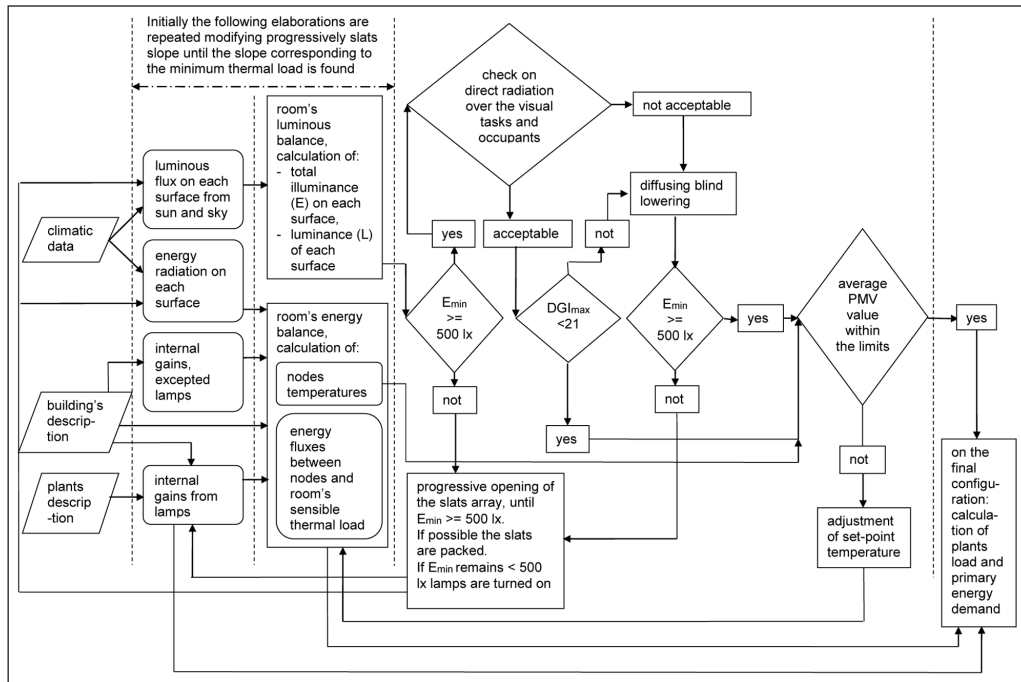


Figure 3: Scheme of the *Ener_Lux* calculation flow. The figure shows the behavior of the program when it simulates the use of an array of external slats combined with an internal curtain. E_{min} is the least value of Illuminance for an occupant of the room.

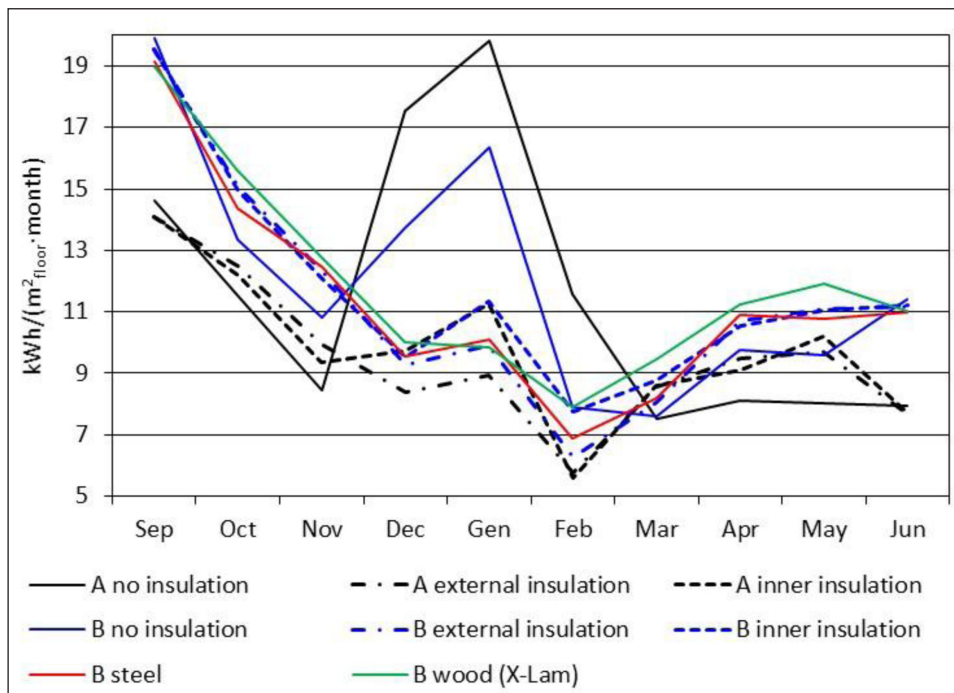


Figure 4: Monthly specific primary energy demand for HVAC and lighting plants in the various configurations.

Energy Demand

In general, with or without any type of insulation, the case A is less consuming than the case B. This is due to its higher thermal inertia that reduces energy demand for HVAC, especially that related to cooling. Only without insulation the case A is the best consuming during the heating period, because of the U-value of full bricks, slightly greater than that of hollow ones, and of its bigger inertia, which makes heating more difficult, keeping the initial temperatures lower. In all the following figures,

the primary energy demand is specific, i.e. referred to the square meter of floor.

Because of the high internal gains, both types of additional insulation, particularly the external one, are useful only during the coldest period, when they reduce the energy demand for heating. In the mid-seasons, they only aggravate the problems of overheating, since they prevent the exploitation of nighttime cooling of the masses. With external insulation this negative effect is greater (**Figure 4**). In the warmest period both types of insulation

do not have significant effects, because, due to the higher set point temperatures (26°C), the heat flows exchanged through the envelope are small. Anyway, the best performant insulation is the external one in both buildings examined, but the differences between the two types of insulation are not relevant (Figure 5).

The annual energy savings due to the insulations is lower in the case B (Figure 5), both in absolute terms and in percentage (Figure 13). This is because in the case B the energy demand for cooling is dominant and the insulation does not significantly influence it. In the case B the steel structure presents performances very close to those of the two types of insulation applied to the existing building, in particular to the external one, while the wood structure appear to be less performant. This is due to the lower diffusivity of the wooden floor, compared to the one in tiles that has been hypothesized in the other cases. The lower diffusivity causes the floor surface to heat up faster, with consequent higher cooling loads. This worsens its thermal behavior in the mid-seasons, particularly in spring (Figure 4).

Thermal Comfort

With the same insulation, in all seasons, greater inertia tends to keep the temperatures of the masses and internal surfaces lower. The temperatures of the internal surfaces are represented by the Mean Radiative Temperature (MRT), which greatly influences the PMV value. Therefore, in the configurations of the case B, characterized by lower inertia, the thermal comfort conditions, represented by the PMV values, are better in winter and worse in the other periods (Figure 6). With the same inertia the external insulation provides better comfort in winter, by means of higher TMR values, but for the same reason it provides worse conditions in mid-seasons. There are not sensible differences in the warmest period, in which the classrooms are not used.

Luminous Comfort

The evaluation of visual comfort was performed only in the hours with daylighting. When visual discomfort conditions are detected it is hypothesized the use of the inter-

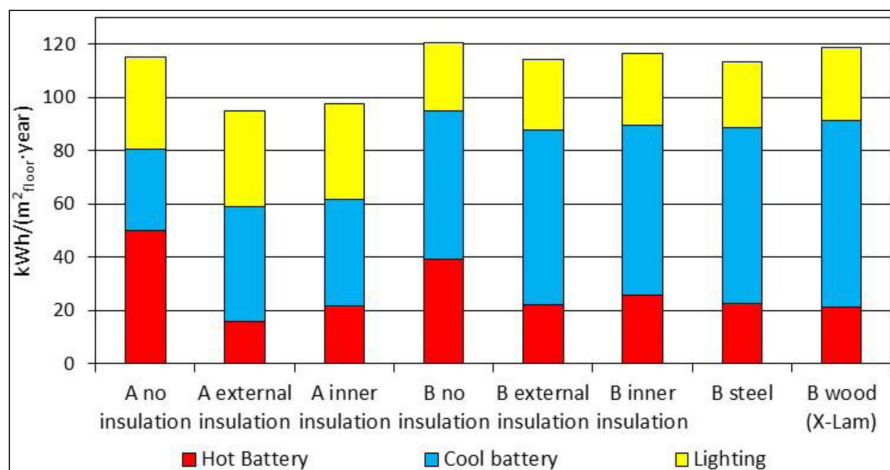


Figure 5: Annual specific primary energy demand (per square meter of floor area) for lighting plant, hot battery and cold battery of HVAC plant, in the various configurations.

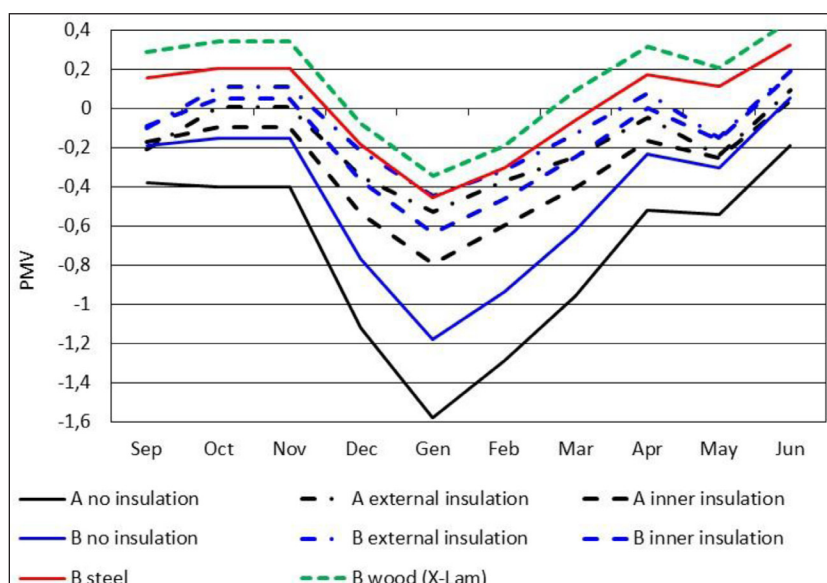


Figure 6: PMV values averaged in the room and in the hours of use of the monthly typical days, for the various configurations.

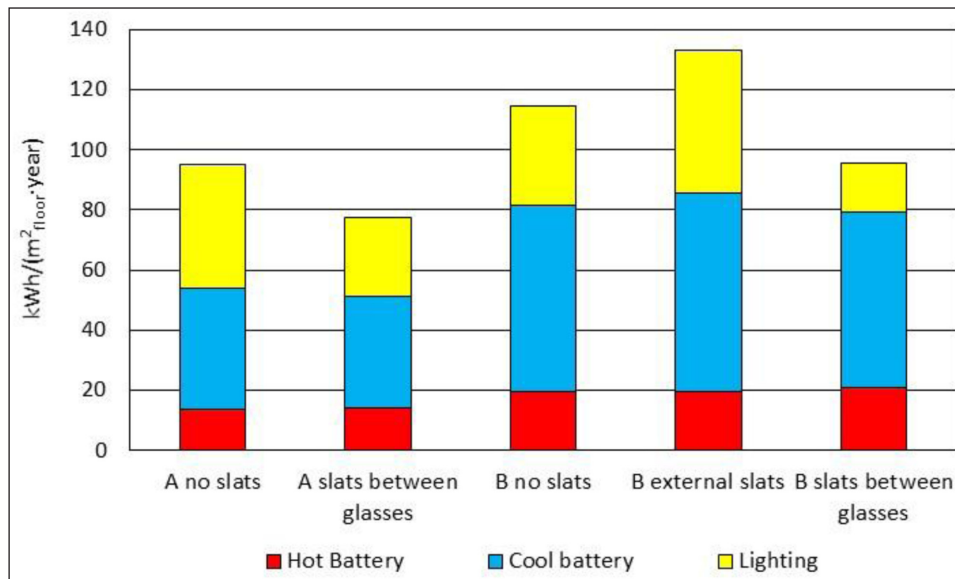


Figure 7: Annual specific primary energy demand (per square meter of floor area) for HVAC and lighting plant, in the cases A and B, always with external insulation, with different solar control devices.

nal diffusing screen, this reduce the internal average illumination and lamps can be turned on. The case B, with ribbon windows, presents a much smaller frequency of the disability glare (Robbins 1986), due to direct radiation on visual task, and of the discomfort glare, due to the sky visible through the windows (Hopkinson, Peterbridge and Longmore 1963). In fact, though the ribbon window, less extended in height, the direct radiation reaches visual tasks less frequently, and the fraction of sky visible from most places is smaller, therefore also the DGI values are lower. Consequently, the classroom of the case B uses the lamps for much less time than the classroom of the case A.

Possible Use of Different Solar Control Devices

In all the cases examined, it is desirable to use some more sophisticated solar control device than the simple internal curtain. This is to reduce unwanted solar gains more effectively and improve visual and thermal comfort.

In this work, the possible use of two types of movable horizontal slats was simulated: one external and the other inserted between glasses. Both types of slats were controlled with the following seasonal logic: in each hourly step, slats are initially inclined at an angle that allows the entering of the only solar energy fraction that can contribute to cover the sensible thermal load. Anyway the entering solar radiation cannot be lower than the one required for daylighting, ensuring a minimum illuminance value in the most critical workplace, that is 500 lx, in accordance with the Italian standard (Ente Nazionale Italiano di Unificazione 2000). If some kind of glare is detected, in the case of the external slats it is assumed that an internal diffusing blind is lowered, the same one used in the actual situation without slats. While in the case of the slats among the glasses, it is assumed that the visual comfort is obtained by increasing the inclination of the slats. After these control actions it the interior lighting may have been reduced to the point of requiring artificial lighting.

Considering the urban context, the external slats, which have considerable dimensions (normally not less than

0.3 m deep in the direction orthogonal to the facade), and its supporting structure, can be proposed only for the building of the case B, while the small slats inserted between the windows glasses can be proposed in both cases. The simulations concerning these devices are related to configurations with external insulation.

Both devices, in particular the external slats, improve thermal comfort by mitigating overheating conditions and avoiding direct radiation on occupants. The slats inserted between the glasses have a higher reflection coefficient than the external ones (equal to 0.7 in energy field and 0.78 in visible range), therefore they provide the necessary incoming luminous flux assuming a greater slope, this reduces the fraction of visible sky therefore the DGI values. Moreover, this kind of slats are packable in the hours with lower solar radiation, consequently, energy demand for lamps is not significantly modified (Figure 7). On the other hand, this type of slats leads to higher internal glass temperatures, this reduces the advantages regarding thermal comfort and increases the energy demand for air conditioning in the cooling period.

External slats, are not packable and present a lower reflection coefficient value, assumed equal to 0.6 both in energy and in luminous field, therefore, with the orientation that they have in the case study, they involve an increase in energy consumption for lamps, as they reduce the incoming luminous flux. Consequently, the energy demand for cooling also increases. These results would change significantly if dimmers were used; with the current hypothesis, insufficient daylighting in the most disadvantaged place causes the lighting of half park lamps.

There are not great differences between the performance of the various devices during the cold period with the lowest solar paths (December, January), when it is not necessary to reduce the incoming radiation (Figure 8).

Figure 9 shows the effects of the different solar control strategies on the classroom's sensible thermal balance in a typical day of mid-season that asks for cooling. It can be seen that the external slats significantly reduce the

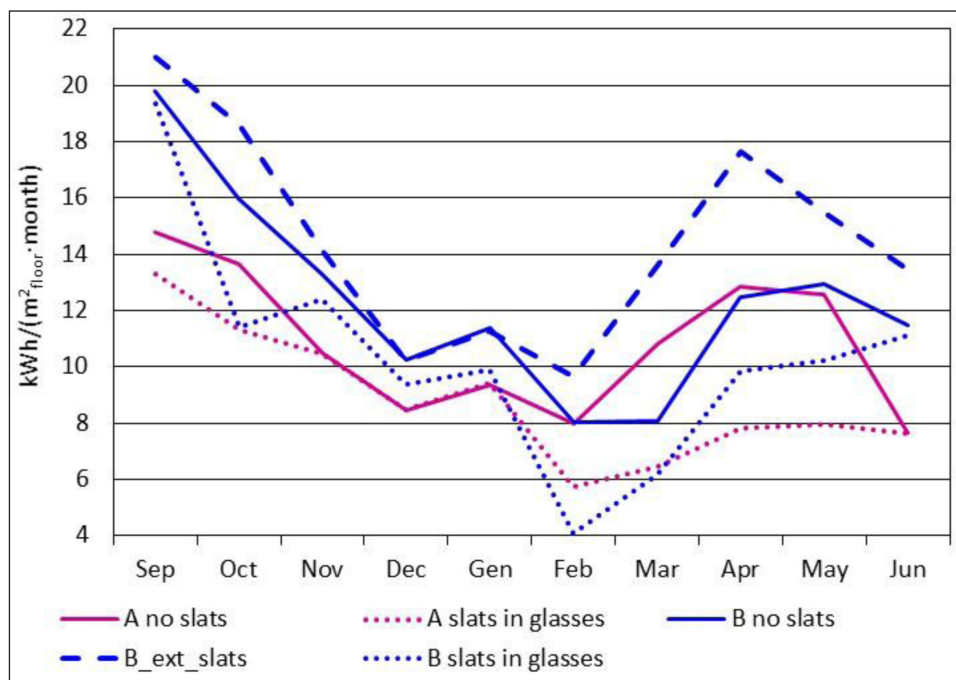


Figure 8: Monthly specific primary energy demand for HVAC and lighting in the cases A and B with different solar control strategies.

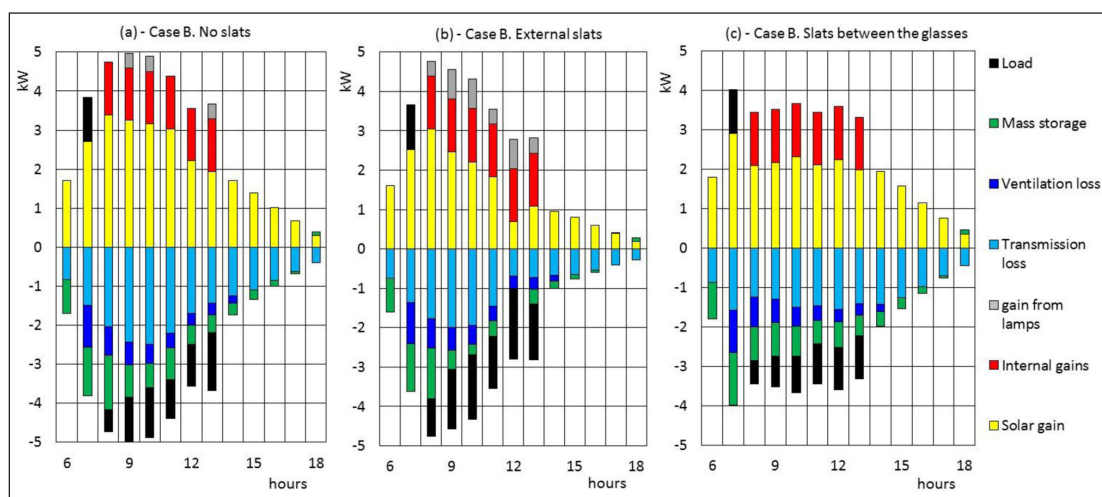


Figure 9: Case B. Classroom's sensible heat flows (W) on a typical mid-season day (April 21). (a) Configuration without slats, in which only the inner curtain is used, (b) external slats and internal curtain, (c) only the slats between the glasses. The flows from the masses (storage) to internal space are considered positive, negative in the opposite direction.

solar gains, but, in comparison with the slats between the glasses, they increase the internal gains due to the lamps. For space reasons, only the daytime hours are shown in the graphs.

Possible Reuse of Buildings as Offices or Dwellings

In order to explore the influence of internal gains and time profile of use, the possible re-use of the same buildings for other functions, such as offices or dwellings, was simulated. In these simulations, the current solar control strategy, based only on the internal curtain, was assumed.

In the case of the offices, it was hypothesized the presence of six occupants with the related equipment in the

space previously used as a classroom. A daily time of use of twelve hours was assumed: from 8 a.m. to 8 p.m. In comparison to the use as a school, given the lower internal gains, heating consumption in the winter period is significantly higher, whereas in the other seasons there are no significant differences (Figure 10). Therefore, the total annual consumption is greater than in the case of the classrooms. In comparison to the classrooms, the annual energy savings due to insulations is greater, particularly in the case A, which in absence of insulation shows the highest consumption for heating.

In the case of residential use, the building is used continuously. During the heating period the night set point temperature is reduced to 15°C. Because of the longer

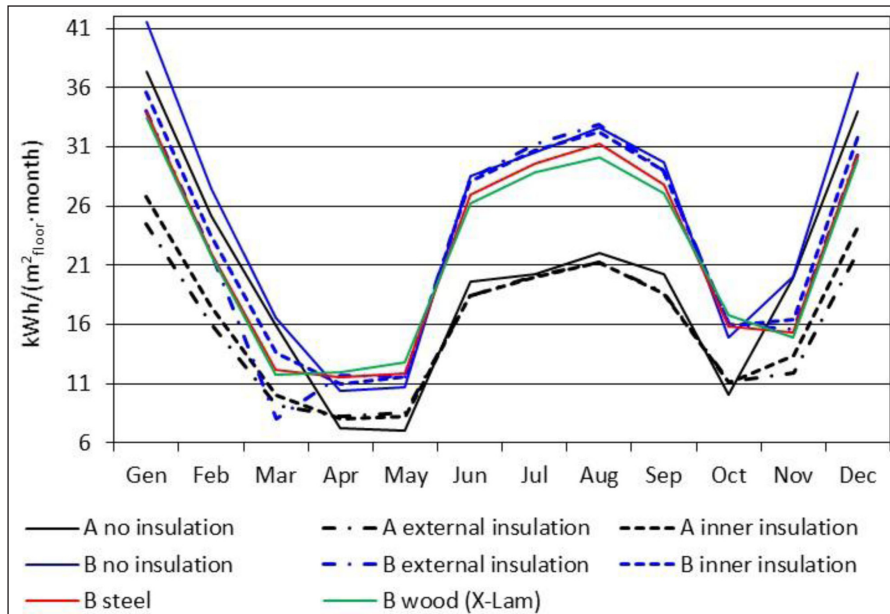


Figure 10: Office. Monthly specific primary energy demand for HVAC and lighting plant in the various configurations.

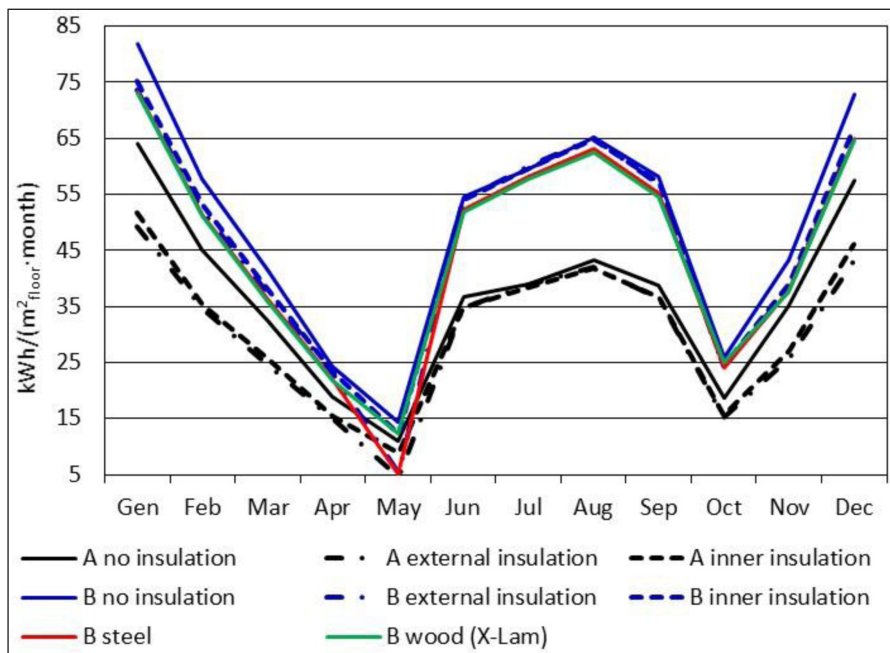


Figure 11: Dwelling. Monthly specific primary energy demand for HVAC and lighting plant in the various configurations.

usage time, the total annual primary energy demand is significantly higher, despite lower internal gains (Figure 11). The energy savings due to insulations are also greater, especially in the case A. Compared to other uses, the differences in energy savings between the various types of insulation are greater in absolute terms, but not in percentage. The external insulation is every time the most convenient (Figures 12 and 13).

Figure 12 shows the total annual specific primary energy demand related to the various configurations and to the different intended uses of the buildings. Figure 13 shows the percentage energy savings achievable with the various types of insulation. The insulation mainly reduces the energy demand for heating, therefore by means of

it the greatest savings, both in absolute and in percentage terms, are obtained in the case A, which starts from higher heating consumptions. The intended uses that leads to lower internal gains implies a higher energy demand for heating, while a longer period of daily use causes higher consumption in general. Therefore in these cases the energy savings achievable with the insulation, compared to the case of the classrooms, are always higher in absolute terms.

The energy savings achievable with the insulation decrease with the reduction of thermal inertia both in absolute and in percentage terms. In fact, the configurations of the case B have a greater total energy demand, mainly due to cooling, and the insulation has a small

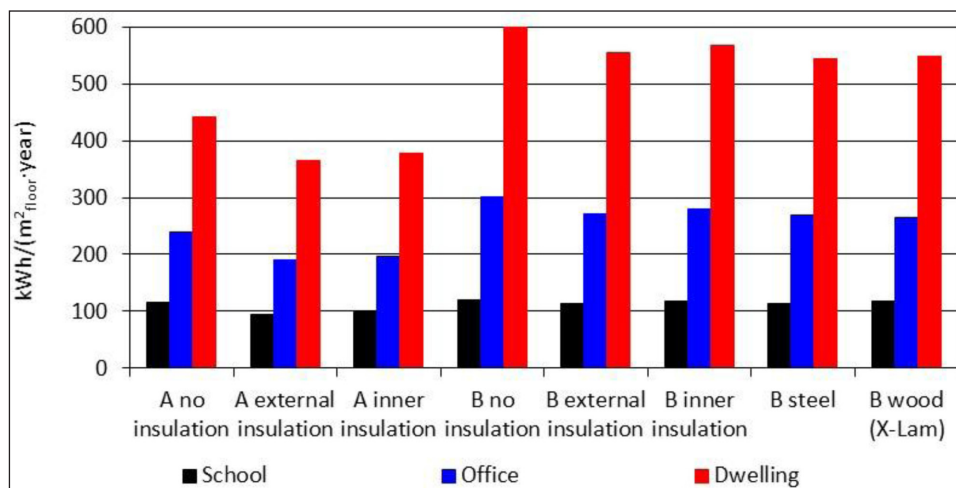


Figure 12: Total annual specific primary energy demand for HVAC and lighting plant in the various configurations and for different uses of the buildings.

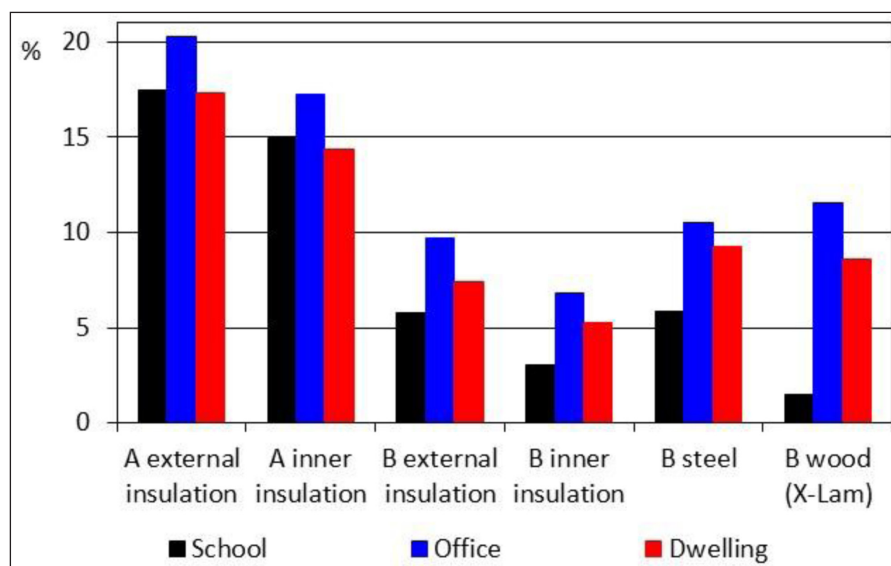


Figure 13: Percentage energy savings achievable with the two types of insulation compared to the reference configuration without insulation.

influence on it. With the increase in energy demand, due to lower internal gains and the longer periods of daily use, the relative convenience of the external insulation with respect to the internal one increases in absolute terms both in case A and in case B, in the case A it also increases in percentage terms.

Possible Use of Different Indoor Environment Control Parameters

Currently there are no indoor environment control systems based on the PMV index, however it can be assumed that the occupants, if they can control the plant terminals, do so in order to obtain in the room an average PMV value the closest possible at zero. Therefore, they would try to compensate an unsatisfactory MRT value by adjusting the air temperature.

Generally, this type of control involves a greater demand for primary energy, compared to the control based on the indoor air temperature. With the same values of the other quantities that influence the thermal comfort, the energy consumption increases with the increase of the

difference between the MRT value and the desired value of the operative temperature (t_o). This difference is mainly influenced by the thermal inertia and the time profile of use. **Figure 15** shows, for the various cases, the percentage increase in total primary energy demand due to the use of the PMV value, instead of the indoor air temperature value, as an indoor environment control parameter.

In the case of the classrooms, which are not used in the warmer months, the thermal inertia increases these differences in the winter, but in the case A it attenuates them in the mid-seasons. The external insulation mitigates this problem by maintaining higher values of the MRT. In the case B there are relevant differences in spring too, the lower thermal inertia does not keep the MRT values low (**Figure 14**).

In the case of the offices, the differences are more pronounced in the cooling period (summer and mid-seasons). In particular, the greater inertia (case A) accentuates the percentage difference in the energy demand for cooling. Only in the case of the dwellings, continuous use, even at night, means that the MRT values are closer to the

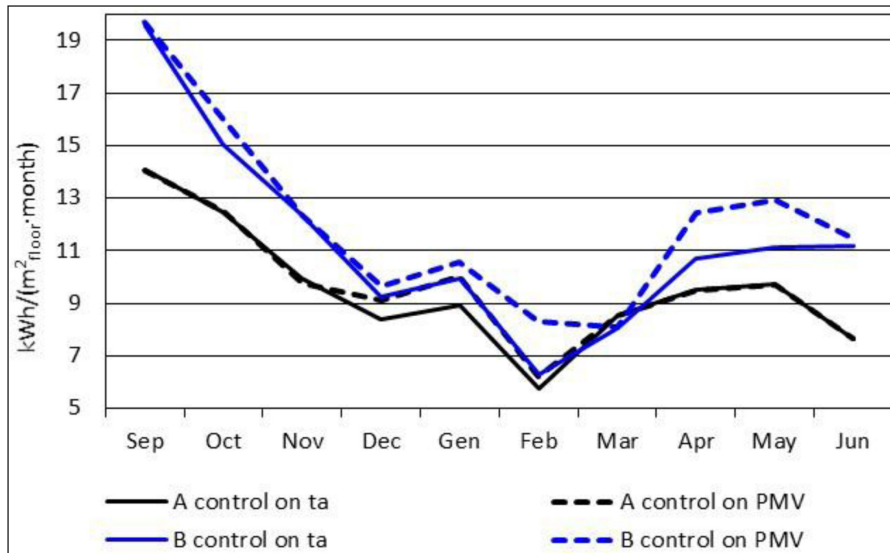


Figure 14: Classrooms with external insulation, comparison between total monthly specific primary energy demand with different indoor environment control parameters in the cases A and B.

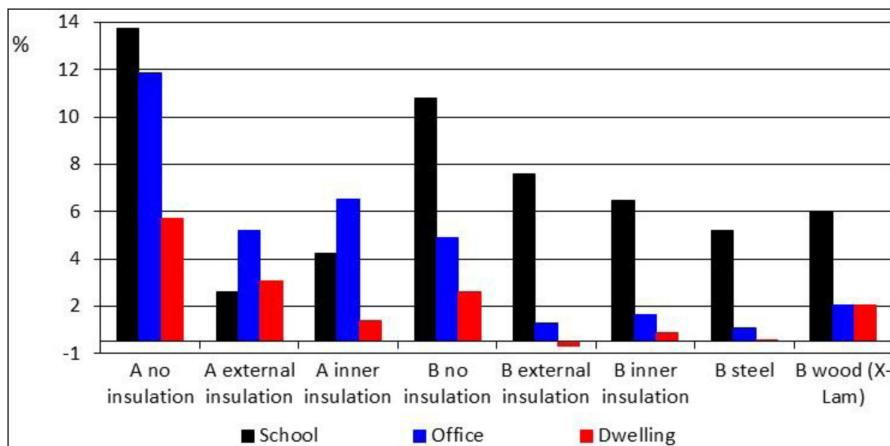


Figure 15: Percentage increase in total primary energy demand due to the use of the PMV, instead of the indoor air temperature, as a control parameter of the indoor environment, in various cases.

desired values of t_o . Therefore, the differences between the two types of control are much attenuated. Even in the case B, with external insulation, the control on the PMV becomes slightly advantageous thanks to lower summer consumption.

Conclusion

These first results show that, in the considered climate, thermal inertia is useful to reduce the energy demand for HVAC, especially that related to cooling. This is mainly due to the fact that it allows the night cooling of the masses to be exploited during the cooling period. Therefore, with the same insulation, the configurations characterized by a lower inertia have a higher energy demand.

In all the cases examined, the external insulation is more advantageous than the internal one, mainly because it is more efficient in reducing the energy demand during the heating period. In the mid-seasons, both types of insulation are counterproductive, because they prevent the exploitation of night cooling of the masses. In the hottest period, with the same inertia, both insulations seems to be irrelevant, due to the smaller amount of thermal flows

exchanged through the building envelope. In general, in the case of the classrooms, the differences between the performances of the various types of insulation are not relevant. The relative convenience of the external insulation compared to the internal one is greater for the building's uses characterized by lower internal gains and longer daily periods of use.

In general, the conditions of thermal comfort are better with greater inertia and with external insulation. With the same insulation, greater thermal inertia tends to keep the MRT values lower during the year; therefore, it can improve thermal comfort, but only during the cooling period.

In the current situation, in the absence of particularly sophisticated devices for solar control, better visual comfort conditions are obtained in the case B, with the ribbon windows. Both alternative solar control devices examined can improve thermal and visual comfort. Compared to the external slats those inserted between the glasses are more effective from the lighting point of view and less from the thermal one, since they involve higher temperatures of the internal glass. On the other hand, the external slats

penalize more the daylighting, and this causes a greater energy demand for artificial lighting and cooling.

Competing Interests

The author has no competing interests to declare.

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