Thermal and Luminous Comfort in Classrooms
A computer method to evaluate different solar control devices and its operating logics

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ABSTRACT: Frequently physical requirements related to luminous and thermal comfort conflict the ones with the others in the classrooms. In facts physical quantities values influencing comfort are sensibly variable from point to point, principally as function of the distance from windows. This work proposes a computer method aimed to forecast and to evaluate the effects of a movable solar control device and its control logic, with regard both to comfort conditions and to energy demand. A case-study, consisting in a classrooms of a school located in Verona (in the North of Italy), has been examined, and different solar control strategies has been compared.
Keywords: energy, comfort

INTRODUCTION
Frequently physical requirements related to luminous and thermal comfort conflict the ones with the others in the classrooms. In facts physical quantities values influencing comfort are sensibly variable from point to point in the interior. This variability is mainly related to the distance from windows. Consequently, e.g., the requirements concerning the lighting of an occupant located far from windows can conflict with the requirements concerning the thermal comfort of another occupant nearer to the windows. These problems are particularly evident in Italian school buildings realised during sixties and seventies years of the twentieth century. They are characterised by extended glazed surfaces, located without any care about orientation. In absence of suitable solar control devices the direct radiation can achieve a part of the occupants and their visual tasks, producing thermal discomfort and glare. Moreover, during the cold season, the presence of extended glazed surfaces can cause thermal discomfort too.

As usual, it is not possible to eliminate completely these problems due to mistakes in building’s design, but providing windows with indoor/outdoor solar control devices can improve some aspect of visual and thermal comfort. This work proposes a computer method aimed to forecast and to evaluate the effects of movable solar control devices and their control logics, with regard both to general comfort conditions and to primary energy demand. The method is based on the use of a new version of the program Ener_Lux, already presented in previous PLEA Conferences [1, 2].

A case-study is actually under examination. It consists in a series of classrooms, with different orientations, of a school building located in the city of Verona (in the North of Italy). Different solar control strategies are compared, in particular until now:
- a total absence of solar control has been simulated, with the aim to establish a reference situation,
- the strategy at present used, consisting in the lowering or raising of a roll up shutter external to the glazing,
- the use of a set of adjustable louvers external to the glazing, as first step the louvers surfaces are supposed diffusing with a medium reflection coefficient (0,5) both for total and visible radiation.

It is assumed that both the movable solar control devices are controlled by a “seasonal” logic: in each moment the device assumes the configuration that allows the entering of the only solar energy fraction that can contribute to cover the sensible thermal load, without to cause overheating. In any case the entering solar radiation can not be lower of that is required for daylighting. That is to ensure a minimum illuminance value (250 lx) in the more disadvantaged internal position. Direct radiation that impinges on the occupants or their visual tasks can cause either visual or thermal discomfort; in these cases, for all the three examined strategies, it is assumed that an internal diffusing blind can be lowered.

This work presents the first results regarding only one classroom, that is the more influenced by solar control strategy, having the windows facing South-South West (orientation: 22, 5° West).
THE SOFTWARE
To perform all the analysis of this work a new version of Ener_Lux program has been used. This software is mainly aimed to the study of solar control devices and their operating logics. Therefore it takes in consideration the physical system composed by a room, its glazed openings, internal and external solar control devices (louvers, blinds, any element shading the opening) and surrounding urban context (urban obstructions). Urban context includes the building containing the examined room.

All the elaborations of Ener_Lux are performed with hourly step. The program provides: sensible and latent thermal loads, primary energy demand for air conditioning and artificial lighting, evaluation of thermal and visual comfort. To obtain these results it executes an energy balance of the room with hourly step. The used algorithm is based on a finite difference method and heat balance of elementary zones: a thermal grid model. To evaluate visual comfort degree a model of luminous environment and occupant’s visual fields is built too (Fig. 1).

The building elements delimiting the room have to be described from geometrical, thermal and physical point 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: infra red emissivity, 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 the coefficients can assume two different values: one is relative to total solar spectrum and the other is relative 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 pieces of furniture are described in a simplified way, like external elements; they are not included in the thermal grid model but they interact with energy and luminous radiation.

Other input are: information on use of the room, number and kind of occupants, internal sensible and latent thermal sources, time profile of utilisation, type of plants.

Starting from latitude and climatic data of the site, the program calculates Sun’s position and solar energy impinging on each surface of the physical system. International known algorithms are used for calculating the instantaneous values of two radiation’s components: direct from Sun and sky diffuse [3, 4]. For any surface the profile of the part exposed to direct radiation is calculated (Fig. 2). The part of impinging radiation due to mutual diffuse reflections between surfaces is calculated solving an equation system. Each equation of it represents a surface’s radiative energy balance: the total energy impinging on the surface result from the sum of energy flows coming from other surfaces, from Sun and sky. System’s solution provides energy radiance value of each surface.

Generally the reflections are diffused, in case of mirror like reflections due to particular devices, as polished louvers surfaces, the program calculates only the intensity of the first specular reflection and traces its path; it is assumed that the falling reflections are diffused. The specular reflected energy is handled as the direct component. At present only the upper part of louvers can be characterised by a coefficient of specular reflection.
From energy point of view the total solar radiation impinging on a building element surface constitutes a heat flow provided to the node of thermal grid related to the surface. For each node the program builds a heat balance equation, the solution of the system composed by all these equations provides the values of nodes temperatures and heat flows changed between nodes. The room sensible thermal load is obtained from these solutions: for instance, if an all-air plant is simulated, the thermal load consists in the flow related to the node representing room’s internal air. In other cases, the thermal load consists in the heat flow exchanged by the nodes associated to the plant terminals. Latent load is calculated as function of occupant typology and other eventual steam sources. Consequently primary energy need is calculated taking into account room sensible and latent loads and plant typology.

Using internal air and internal surfaces temperatures values, and other necessary information (on internal activity ecc.) global PMV and PPD values are calculated [6, 9]. It is possible to calculate plane radiant temperature asymmetry too.

In luminous field the program calculates the illuminance value on each surface of the system, using a process analogous to that used for energy radiation. Relatively to each surface IESNA and CSTB algorithms are used to calculate illuminance due respectively to direct solar radiation and sky [5]. System’s solution in this case provides luminous radience value of each surface. Starting from the radience 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 (Fig. 3). This way it is possible to make evaluations on the contrast (differences of luminance between different zones) and to calculate alternatively DGI or UGR [7, 8], as function of light source’s extension.

If the illuminance value on visual task is not sufficient it is assumed that the lighting plant is activated, 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.

In presence of adjustable devices all the solar control actions finalised to maintain thermal and luminous comfort are automatically simulated. As consequence of hypotised actions, as variation of louvers tilt or screen lowering, the program modifies the geometrical configuration and repeats the simulation of the (current) hourly step.

To simulate the seasonal control logic it is necessary to calculate the entering solar radiation required value in each time step. This is obtained by means of a first
simulation where it is assumed that all the available solar radiation can impinge on the external surface of glazing. The sensible thermal load is obtained and, as function of it, the radiation required value is calculated. Its value is equal to entire available radiation value during the heating season and it is equal to zero during the cooling period; but during the middle seasons it is a variable fraction of the available radiation, and the room’s thermal load can change of sign during the day.

As a function of the radiation required value the configuration of movable solar control device is defined. In case of inclinable louvers an iterative process is necessary. In fact, varying the louvers tilt angle, the direct and diffuse components of entering radiation change their values in opposite way.

THE CASE STUDY
The examined classroom is located in a school building, of Verona, in the North of Italy, built during the seventies years of the last century. It is a middle school for children from eleven to fourteen years (Fig. 4).

The climate of the region (“Pianura Padana”) is considered “temperate”, but it is characterized by cold-humid winter and hot-humid summer. Fog is frequent during autumn and winter.

Building structure is made up by reinforced concrete. Internal walls are in perforated bricks, 0.08 m thick, with 0.02 m thick plaster on both sides. Floors are built in perforated bricks and reinforced concrete (0.2 m thickness). External walls are in perforated bricks with external insulation in fibre of wood (U value: 0.2 W-m⁻²-K⁻¹), windows have double glazing of 0.006 m thickness with 0.006 m of air gap (U value: 2 W-m⁻²-K⁻¹).

Internal gains include artificial lighting, sensible and latent heat flows from occupants (26 people x 50 W). Classroom lighting plant is composed by a group of fluorescent lamps with a total electric power of 756 W. Normally dimmer are not used in Italian school buildings, but it is assumed that the lighting plant is split up in two zones: one nearer to the windows and other farer from them.

At present the building is only heated in the cold period, using a water central heating plant with radiators placed under the windows; no ventilation or air conditioning plant are present. In this work it is assumed that the building is equipped by a centralised HVAC all air system. This with the aim to evaluate the influence of solar control strategies on theoretic global primary energy demand, for heating, ventilation, air conditioning (HVAC) and artificial lighting, during the year. Although
it is not the optimal solution, it is assumed that the warm fluid is produced by a gas-boiler and the cold fluid by a chiller.

ANALYSIS OF THE RESULTS

In a classroom the sensible and latent loads due to ventilation are predominant and they are not influenced by different solar control strategies. Moreover, in the considered climate and taking into account that Italian middle schools are closed during July and August, the annual energy demand for heating is five time bigger than the energy demand for cooling. For all this reasons not too big differences in primary energy demand are remarkable between the three different strategies.

Figure 7: Louvers controlled by seasonal logic, classroom’s sensible heat flows (W) in a winter day (January 21.)

Anyway the strategy based on movable louvers presents a little smaller annual primary energy demand related to heating and air conditioning (around 1% less) and a sensibly bigger energy demand related to artificial lighting (around 70% more). For these reasons its total primary energy demand is slightly bigger respect to the other two strategies (around 1.5% more).

During the heating period all the configurations are adjusted in a way to allow the entering of all the available solar energy, and their energy performances are similar. But the presence of louvers, although they are parallel to the solar beams, reduces in reason of ten percent the total entering radiation. In particular the diffuse components are penalised, because the presence of louvers reduces sensibly the view factors: between windows and sky, windows and landscape. This lower gain is compensated by a bigger heat flow from lamps, which are turned on for many hours. Therefore the heating load is lower and lighting load is bigger. The situation could be surely worse without splitting the plant in two zones, but it could be improved using dimmers.

In the middle seasons and in the cooling period the two devices reduce sensibly the entering solar energy (to the half part of available radiation or less). But the sensible thermal load is not reduced proportionally: its reduction is only around the ten percent when the entering radiation value is halved. This is due to the small influence of solar gain on room’s heat balance and room’s thermal inertia: without devices a big part of the major solar gain is stored in the masses of building elements; other part of it increases the losses (Fig. 7, 8). Maybe the choice of ensuring a minimum illuminance in the more disadvantaged positions involves an excessive entering radiation.

Figure 8: Louvers controlled by seasonal logic, classroom’s sensible heat flows (W) in a day of cooling period (May 21.).

Figure 9: Effects of different control logics on luminous environment quality.

Therefore the advantages of adjustable devices concern the quality of luminous environment in the room, and the thermal comfort in the positions nearer to
the windows. This is remarkable in particular for louvers. In the warmer periods, when the louvers reduce and redirect the entering radiation, DGI values in all the internal positions are lower (Fig. 9), and the CIE uniformity factor value is sensibly higher (about 30% more) (Fig. 10). The higher average daylighting values (Fig. 11) mean that in the positions nearer to the windows illuminances and solar heat flows present exceeding values. This is particularly evident in the case of the configuration without controls; these values are surely incompatible with general comfort conditions.

**REFERENCES**