DAYLIGHTING AND VENTILATION USING A DYNAMIC SKYLIGHT

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SUMMARY

This paper presents a dynamic skylight, for daylighting and ventilation in a medium size room. The device includes an heliostat with variable geometry, which can exploits direct or sky diffuse solar radiation as function of season and weather conditions. During winter the direct radiation, if present, is re-directed inside the room on diffusing ceiling. During summer device’s configuration is modified to allow the entrance of lone sky diffuse radiation that is required for daylighting. The direct radiation impinging on the exposed side of the device is used to create a solar stack effect, that contributes to air extraction and natural ventilation. Size of opening on roof, device’s geometry and control logic have been optimised by means of computer simulations for two Italian sites: Venezia and Trapani. Room’s energy balance takes into account of solar and internal gains. Optimisation is aimed to minimise the total annual energy demand for climatisation and illumination.

INTRODUCTION

Openings on the top of building’s envelope have been used in the past with multiple purposes: indoor daylighting of buildings located in high density urban tissues, modelling and scene-light in holy and representative buildings, ventilation and smoke’s evacuation [1]. In hot dry climates these openings were also used, jointly with pools, to provide ventilation, evaporative cooling and humidification [2].

Lighting from above is especially useful for particular room’s destinations as: art gallery, museum show rooms, classrooms, meeting rooms and library reading rooms. In fact on one hand it avoids discomfort glare, because the luminous sky is kept out of occupant’s visual field, on the other hand it don’t allows outside vision.

This work considers a medium size reading room of 6X6 m in plan and 4 m height equipped with a dynamic skylight aimed to daylight and to assist air conditioning. This spatial module (Fig. 1) is adjacent to other similar spaces, obviously they are situated at the last floor of a building. Roof and internal walls have a light metallic frame, and the envelope is assembled using sandwich panels containing insulation.

Presence of thirteen persons and an air change ratio of 20 m³/(h·person) are assumed. Fluorescent lamps with an efficiency of 91 lm/W and a continuous dimming regulation are applied in order to ensure 500 lx on visual tasks. Internal gain due to lamps corresponds to the absorbed electric power. The building is equipped with an air conditioning plant.

The skylight proposed in this work is actually at the planning stage, therefore all the energetic and daylighting evaluations reported in here are based on computer simulations.

OPENING’S SIZING

Opening’s functions

Any opening in the building’s envelope has to accomplish several functions often reciprocally conflicting: passive heating during the winter; daylighting; ventilation for hygienic aims; summer cooling; outside vision.

The opening size has to mediate between different requirements with the aim of minimising total energy needs and achieving global comfort conditions.

Also in the case of a roof opening optimal size is different in different seasons; therefore a moveable configuration can mediate the contrasting needs in a better way than a fixed one.

Optimal size of different kind of skylight

The first step in skylight’s design is top opening’s sizing. This size depends from the skylight’s typology and from its control logic, if moveable elements are present.

Therefore three different configurations have been compared. For each of them optimal size has been defined:

1) Simple horizontal skylight, without any control for Sun radiation, only an internal diffusing curtain to avoid glare phenomena is present.

2) The same skylight of previous point with addition of external moveable louvers in order to avoid overheating.

3) Dynamic skylight incorporating a heliostat.

Position of movable elements, in the second and third cases, is defined according to a control logic that can be resumed as follow: at any moment the device has to consent the entrance of the useful solar radiation only. This is a fraction of available radiation corresponding to:
1) a thermal power not exceeding than that requested for heating;
2) a luminous flux at least equal to that requested for lighting, in order to exploit the better quality of natural light and to contain thermal load from lamps.

Figure 1: The module.

Software and calculations

Size of aperture, device’s geometry and its control logic have been optimised by means of computer simulations. The utilised software, Ener_lux [3], calculates energetic and luminous solar radiation entering in the room throughout the skylight, calculates the level of internal illuminance and executes a simplified energy balance of the building module by hourly steps.

This balance takes into account solar and internal gains (occupants and artificial lighting). Calculating total energy demand, electric consumption for air circulation, air extraction and HVAC operation are considered. More detailed lighting analysis have been performed by means of software 3D Studio Max, based on Radiosity algorithm [4].

Three Italian sites have been considered: Venezia (44.5° N), Roma (42° N) and Trapani (39° N). For each of them device’s geometry has been optimised.

Simulation’s results

In figures 2, 3 and 4 are reported the behaviours of total primary energy demand vs top opening’s size, for different kinds of skylight. Data are referred to venetian climate.

Increasing opening’s side length all the curves present a first descending part that is due to energy saving in artificial lighting, which increases with opening’s width.

Beyond the minimum the energy demand raises as a consequence of climatisation needs. In fact heat losses in cold periods (without significant solar gains) and overheating in hot periods are rising with opening’s width. This trend is remarkable for the skylight without any radiation control, whereas it is moderate in the other two cases. Particularly for skylight with heliostat relatively to which the trend is almost flat after minimum. The control of entering radiation reduces energy demand related to climatisation, especially during the warm season.

The different position of the minimum point for each configuration is evident. Opening’s optimal size is relatively small for skylight without control devices. The relative length of square opening side is 1.75 m in the climate of Venice and 1.25 m in Trapani. The presence of control devices allows bigger side length values, less or more 4.5 m in Venice, 3 m in Trapani. This allows to obtain a higher level of daylighting for longer periods and a more uniform illumination inside the room.

Figure 2: Venice, room’s total primary energy demand as function of top square opening’s side length, for different kind of skylight

Analysing energy demand the following considerations can be made:
a) Heating load is remarkable in Venetian climate only and it is higher for device incorporating heliostat. In fact the bigger entering luminous flux provokes a lower internal gain from lamps.
b) Simple daylight presents the bigger energy demand for cooling, the other two configurations show less or more the same values. Comparing daylight with louvers and that incorporating heliostat, the second one permits a
small further economy due to the smaller thermal load
from lamps, but only for little opening’s size values.
c) With radiation control devices the entity of lighting
energy demand is comparable with that one of cooling,
but it presents an opposite trend: it decreases with
increasing of opening’s size. Differences between
different configurations are appreciable only for reduced
opening’s size values. In fact the adopted control logic
always allows the entrance of a luminous flux not lower
than request.

Comparing device’s behaviour in different Italian climates
we can observe that total energy demand increases proceeding
from North towards South. This is due to the greater
consumptions for cooling that are the more influencing one.
Referring to the opening’s optimal size this consumption in
Trapani are 7% bigger than in Roma and 30% bigger respect
to Venice. Contextually opening’s optimal size decreases, as
already observed.

Respect to energy demand not big differences between
configurations two and three are remarkable. Only for a
reduced opening’s size the heliostat allows a small economy
respect to louvers: 1% in correspondence of common optimal
size value, until 6% for smaller size. This economy is due to a
smaller energy demand for illumination.

The bigger advantages of heliostat are due to the better
quality of lighting: internal illumination is more uniform, as
shown in the rendering (Fig. 15-16), and natural lighting is
exploited for more time.

For all the configurations, referring to the optimal size, the
minimum value of total energy demand is situated in March,
whereas the maximum is between August and September (Fig.
5). Because of internal gains, energy demand for cooling is
present less or more during the entire year, except for January
if we consider the simple skylight and January-February if we
consider the other two configurations. Maximum cooling need
is observable on July.

THE PROPOSED DEVICE

The proposed device includes a heliostat with variable
geometry and other reflecting surfaces (Fig. 6,7), it allows to
exploit direct or sky-diffuse solar radiation as function of
season and weather conditions. The entire metallic frame
supporting heliostat and other reflectors can rotate around its
vertical axis to follows solar azimuth [5,6].

The heliostat, that is the first reflector, it is external to the
room and it is contained in a double glazed envelope. This
envelope is composed by two clear glazing, 6 mm thick,
spaced by 4 mm thick interstice. Envelope’s profile is
evidenced in Fig. 14.

During the cold season the direct radiation, if present,
impinges on the heliostat’s specular reflector, and it is re-
directed downward inside the room.

In the lower part of rotating frame two other plane surfaces
partially redirect horizontally the radiation to the diffusing
ceiling, and partially diffuse it downward over the visual tasks
The first reflector is a textile, reflecting on one side (reflection coefficient 0.9) and absorbing on the other side. Its inclination and its extension are adjustable, by mean of movement of one extremity, as shown in figures 10 and 11.

The second reflector (Fig. 12) is a micro-perforated fabric, reflecting on its upper side (reflection coefficient 0.8). The micro-holes allow a diffuse transmission of a rate of radiation on the other side (transmission coefficient 0.12). From room’s interior it appears translucent. It is composed by two surfaces with fixed inclination of 45° as shown in figures from 6 to 9.

All these plane reflectors can by wrapped-up around one extremity when theirs presence is not request as shown in Fig.12. In cloudy days it is necessary to exploit the sky diffuse radiation, for this reason the two reflecting surfaces that would obstruct the opening are rolled up and they “disappear”.

Figure 7: The moving frame, supporting heliostat and other reflectors, in winter configuration (Venice. 21 Feb. 12:00 a.m.). The upper dark-grey surface is the heliostat’s specular reflector, whereas the lower dark-grey surfaces are the diffusing/reflecting elements.

Figure 8: Venice. 21 February, 7:00 a.m.

During the warm season the device modifies its configuration rotating of 180° around its vertical axis. This way it exposes to the direct radiation an internal absorbing surface, which is the back side of the heliostat’s reflector, and transforms itself in a plane air solar collector (Fig. 13).

The direct radiation impinging on the device is used to create in its interior a solar stack effect that can contribute to air extraction and room’s natural ventilation. Warm exhaust air is purged throughout an opening on the device’s top.

The opposite side of the absorbing surface (facing the interior of the room) is low-emissive (specular reflecting), this characteristic reduces the infra-red re-irradiation forward room’s interior. Device’s side opposite to Sun direction is transparent and allows the entrance of sky diffuse radiation.
Optimal slope of external glazed surfaces varies as
function of Latitude. The variation of this optimal slope that one can observe moving from Venice’s to Trapani’s Latitude is evidenced in figure 14.

Figure 14: Optimal slope of external glazed surfaces for the climates of Venice (continuous line) and Trapani (dashed line).

CONCLUSION

Devices controlling the entering solar radiation allow a sensible reduction of operating energy demand respect to a simple horizontal skylight.

The energetic advantage of a device including a heliostat respect others more simple devices, like louvers, is not remarkable. The bigger advantage of the heliostat consists in a longer time of utilising daylighting and in a better quality of internal visual field.

Figure 16: Venice 21 February at 9.00 a.m. internal luminance distribution with skylight incorporating heliostat.

REFERENCES


