Ventilated Illuminating Wall (VIW): Natural ventilation and daylight experimental analysis on a 1:1 prototype scale model

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Abstract: In this paper the authors present the first experimental results about the natural ventilation obtained by a device called Ventilated Illuminating Wall (VIW), which carries out the function to introduce natural light in underground areas or that don't have facing outwards, contemporarily operating in the same areas a natural ventilation effective action necessary to guarantee thermal comfort and healthy conditions to the occupants.
The VIW is represented by a 1:1 prototype scale model, constituted by a precast removable manufactured product set to a window of a room. Such device is able both to transport the natural light, captured by the coverage, in underground areas and to introduce outside air for the required ventilation through the vents positioned both inside the room and in the retaining structure of the coverage.

Our study's objective is to verify experimentally, through air speed measurements in different points, if in every condition the indoor air quality is guaranteed.

The results about daylight performances of the system are satisfactory; besides they show that the VIW is able to assure a significant natural air ventilation, but the thermal analysis can be improved measuring the air mass flow rate and the comfort parameters for the occupants.

Keywords: *Ventilated illuminating wall, Natural ventilation, Energy efficiency, daylight, Experimental analysis.*

1. Introduction

Buildings are often equipped by underground areas in which the absence of natural light and ventilation create uncomfortable conditions for human activities. In many cases mechanical ventilation and artificial light are used to ensure comfortable conditions for the occupants. It is known that buildings use almost 40% of the world energy [1] and, obviously, a meaningful part of the whole energy consumption of an edifice is due to artificial light and mechanical ventilation of underground rooms.

Moreover, the case can be considered of buildings utilized as museums, exposition rooms or similar. These spaces need a particularly soft luminance distribution, avoiding direct solar radiations from windows or skylights or very intense reflections from shiny surfaces that may be present in the environment, which can generate the risk of glare. Besides, the paintings on display can be sensitive to light and deteriorate in the presence of high values of illuminance. Usually in museums or exhibition rooms low illuminances are preferred over the illuminated surfaces because, in this case, a favorable balance of luminances is more easily obtained between the visual task and its background.

For these reasons, in these cases any direct interface to outdoor environment through traditional windows or skylights is often avoided and artificial light is adopted all the time. The absence of windows and skylights makes it impossible natural lighting and ventilation. On the other hand it is known that the enjoyment of works of art is better in the presence of natural light than in the absence of it, and a significant energy saving can be achieved by using natural light instead of artificial light. Taking into account that every effort must be made in order to reduce energy consumption of buildings, many technological systems have been applied in architecture with the aim to ensure comfortable conditions for the occupants, concurrently providing a significant energy saving. In recent years many technical devices, such as light pipes and similar, have been proposed with the aim to introduce natural light in areas without direct interface with outwards and many papers have been published in order to explain the way to design tubular light pipes or similar technological devices [2, 3, 4, 5] .

In some cases light pipes are equipped with technological systems able to ensure air extraction from the room in which they are installed [6]. In this work the authors present an innovative device able to capture daylight from a transparent horizontal surface on the top of the device and redirect it into the room, and simultaneously allow the introduction and extraction of air. This device, called Ventilated Illuminating Wall (VIW), was built in real scale and experimentally tested in order to verify its lighting and air circulation performances, in order to reduce the use of electric light and mechanical ventilation and so diminishing the energy request of the building.

2. Description of the V. I. W.

An innovative technological system was developed by the authors named “Ventilated Illuminating Wall (VIW)”. Moving from the idea of building an apparatus able to introduce daylight in underground areas or rooms without direct interface to outdoor, simultaneously ensuring the necessary air circulation, the authors developed a multilayer boundary wall, equipped with a glass plate cover on the top able to capture daylight and a vertical interspace internally covered by a highly reflective film (3M Radiant Mirror Film) by which light is redirected to a transparent surface, like a window, and introduced into the room.

Thanks to a second exterior vertical air cavity, which allows the greenhouse effect in presence of thermal solar radiations in the case of not underground buildings, and fifteen openings with wire mesh properly practiced on the walls, air is allowed to circulate for extraction and introduction in the room so creating an effective air change able to ensure internal comfortable conditions for the occupants. The Ventilated Illuminating Wall is particularly suitable in large exposition areas, which don’t have facing outwards and need diffuse light, avoiding glare phenomena which occur when intense direct light from windows comes towards the illuminated surfaces.

3. Methodology

An experimental analysis was carried out on a 1:1 prototype scale model of the V.I.W. The tests were carried out by measuring internal and external illuminance, wind velocity and direction, and internal air velocity in various positions of the room: near the air inlet and outlet vents and in the centre of the room.

3.1. Experimental apparatus

The test room is a 5x3 m plant area room, 2,7 m high. The V.I.W. is constituted by a precast removable manufactured product placed against the window in the north-west wall perimeter of the room. In Fig. 1 some pictures of the system are shown taken during successive stages of its construction: an iron frame was applied against the window on the perimeter wall of the laboratory (a, b); an air space was created between the window and the first opaque layer, which consists of a 4 cm black painted polystyrene panel which gives the necessary thermal insulation and improves the greenhouse effect in the second vertical hole. This last is a 10 cm air space between the polystyrene panel and the external 1 cm transparent polycarbonate panel applied on a second iron frame (c). On the top of the system a glass plate cover is applied which allows daylight entering the room (d).

Fifteen openings with wire mesh allow the natural air circulation necessary to ensure favorable hygienic conditions in the room. The internal ones are shown in Fig. 1 (e) and the external in Fig. 1 (f), where the final configuration of the apparatus is shown.

Fig. 1. Realization steps of the VIW.

The experimental line used to carry out the analysis consists of four CIE Lux-meters sensors, range 0-25 klux, accuracy 3% of the reading value, for the internal illuminance, a CIE sensor range 0-100 klux, tolerance 1.5 %, for the external illuminance, a data-logger with 20 inputs, by which data are registered and elaborated; three internal hot wire anemometers, range 0-20 m/s, accuracy 0,01 m/s, 1%; one tacho-gonioanemometer with direct output.
In Fig. 2 a section of the device with a description of the principal components of the V.I.W. and a quoted section of the system are shown.

3.2. Description of the experimental test conditions

The experimental tests were carried out positioning the sensors in the room as represented in Fig. 3, in which a plant and a section of the room are shown with the position of each sensor.
The tests were carried out in summer and autumn conditions. Air temperature was measured in positions 1, in the center of the room, and in positions 2 and 3, close to the wire mesh applied on the inferior and superior openings. In the same positions air velocity was measured, while illuminance was measured in positions 4, 5, 6 and 7 (Fig. 3).
On the roof top of the building, close to the transparent glass covering plate by which light is collected from the sky, the external lux-meter and the tacho-gonioanemometer dedicated to measure wind velocity and direction were positioned.

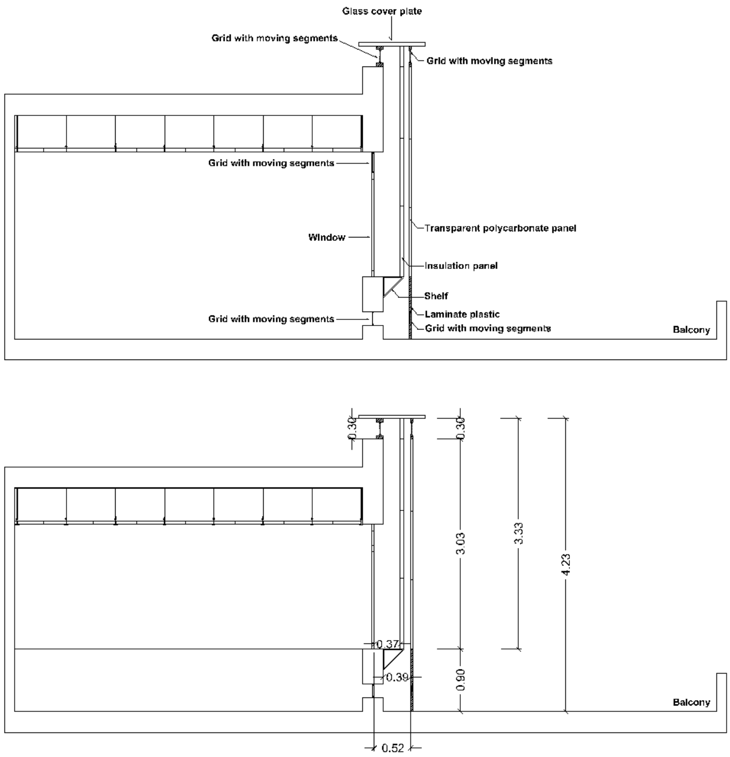

Fig. 2. Sections of the VIW.

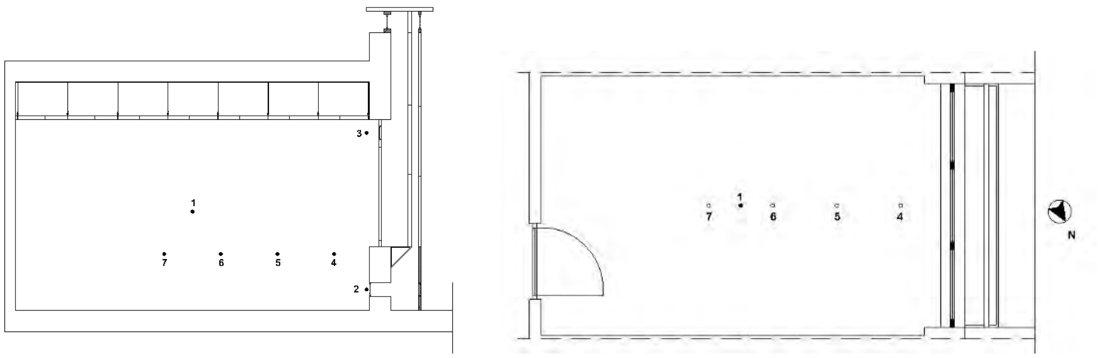

Fig. 3. Section and plant of the test room with the measure positions

4. Results

In Fig. 4 illuminance data measured on September the 16th are shown. External illuminance is referred to the right axis while the ratios between internal and external illuminance in the measure positions are referred to the left one. In this case, with a very regular trend of external illuminance, the influence of the V.I.W. on internal distribution of illuminance is significant up to quite 2 m from the system for a large range of daytime, but in the morning some very high pick values are verified in positions 4 and 5 close to the V.I.W and the influence of V.I.W. is meaningful also in positions 6, quite 3 m distant from the VIW, as shown in table 1, thanks to reflections directly coming from the Radiant Mirror Film.

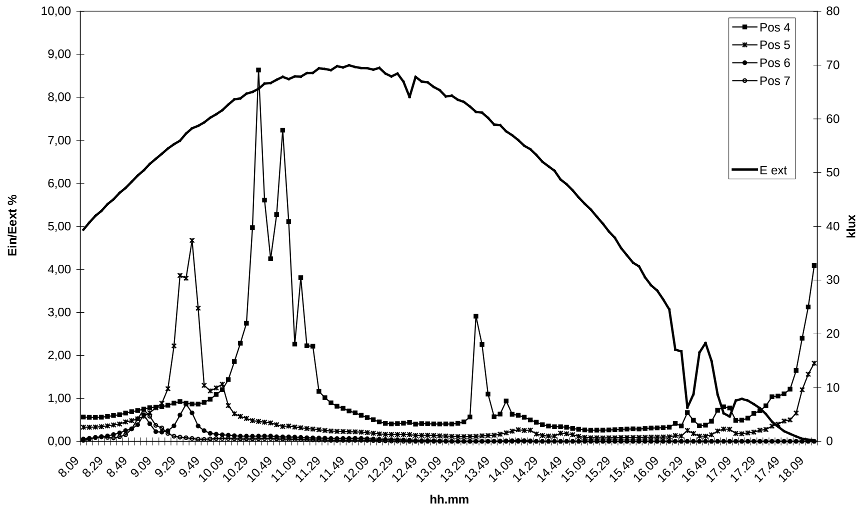

Fig. 4. Illuminance data in positions 4-7 on September the 16th

Table 1. Minimum, Medium and Maximum illuminance data in positions 4-7, on September the 16th

	Pos. 4	Pos. 5	Pos. 6	Pos. 7
Minimum (lux)	9	4	0	0
Medium (lux)	572	222	46	24
Maximum (lux)	5664	2722	497	372
Distance from V.I.W. (m)	0,5	1,3	2,1	2,9

In autumnal conditions, with lower and less regular external illuminance, in the measure positions a similar situation is verified, but pick values of illuminance in the morning are absent and the influence of the system to internal illuminance is significant up to 2 m from it, as shown in Fig. 5.

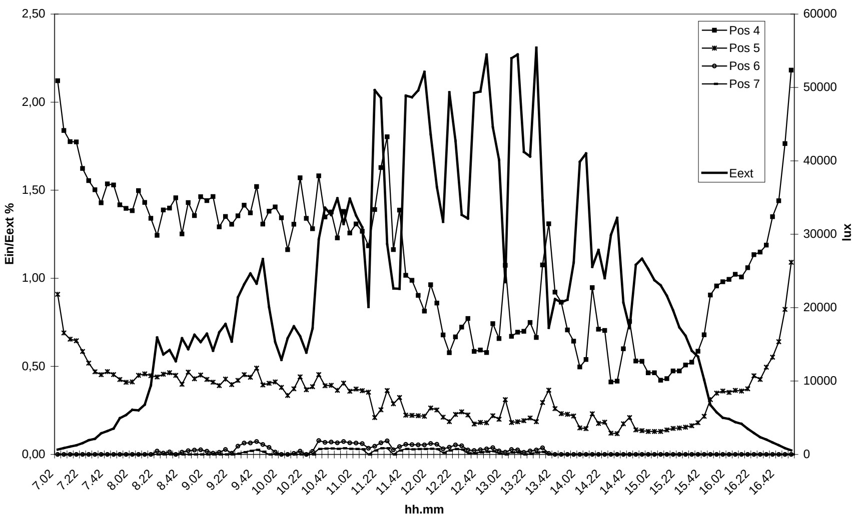

Fig. 5. Illuminance data in positions 4-7 on November the 5th

The natural ventilation allowed by the V.I.W. permits the necessary change of air in the room and different ways are traced in summer (night and day) and winter conditions. In the design phase the authors provided for the behavior of the system as shown in Fig. 6 in which a representation of expected natural ventilation in summer and winter is shown, obtained by different configurations (close/open) of the openings. In particular, the Fig. 6 (a) shows the expected natural ventilation in daily summer condition, while Fig. 6 (b) the expected natural ventilation in night summer and in winter (night and day) conditions.

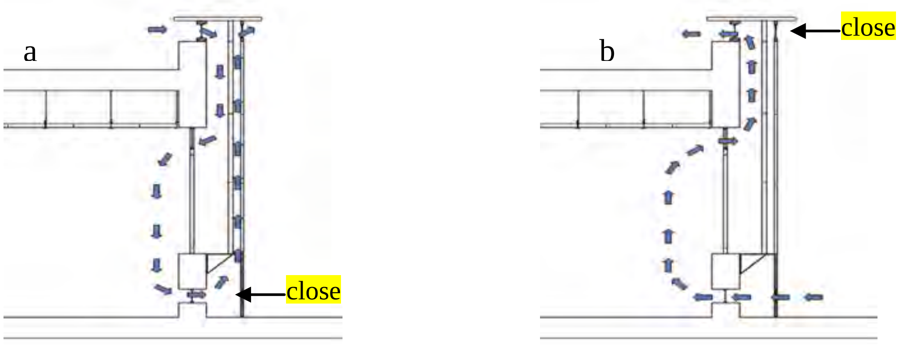

Fig. 6. Natural ventilation in daily summer conditions (a), night summer and winter conditions (b) .

In Fig. 7 data of wind direction and velocity on September the 17th are shown. Higher speeds are verified from 9 am to 5 pm with a medium wind direction angle from North of about 97°, while a medium value of about 158° is verified in night conditions, just favourable for a good air circulation. All the summer tests carried out confirm this trend, that can be considered representative of summer conditions.

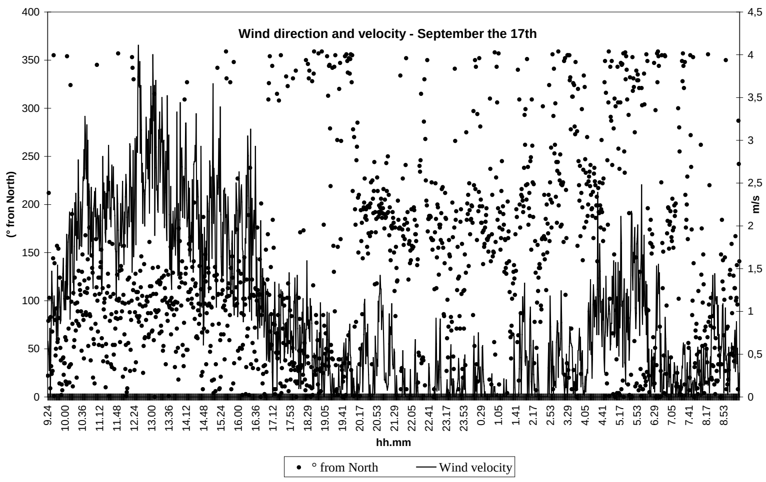

Fig.7. Wind direction and velocity on September the 17th

In Fig. 8 air speed is shown on September the 17th, measured in positions 2 and 3 close to the air inlet and outlet vents. Table 2 shows minimum, medium and maximum data. During the day the vent 2 is the outlet opening and the 3 is the inlet one, while at night the reverse situation occurs. In the centre of the room (position 1) air velocity is less than 0,03 m/s all the day with a mean value of about 0,005 m/s, while in night conditions the maximum value is the same with a lightly higher value of the mean velocity, of about 0,007 m/s.

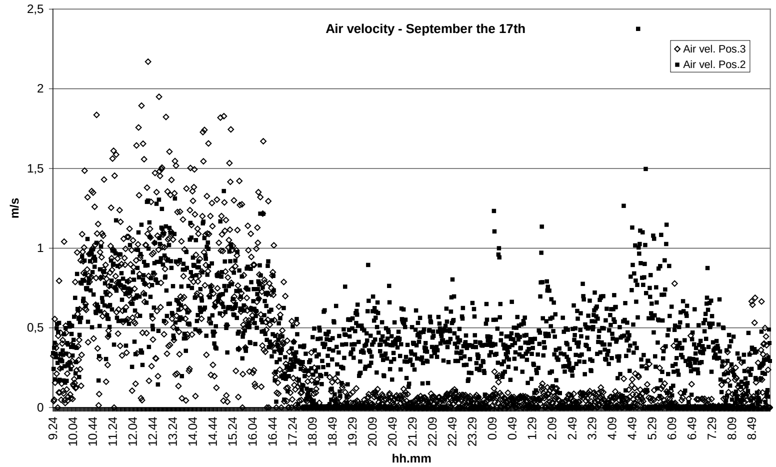

Fig. 8. Inlet and outlet air velocity on September the 17th

Table 2. Minimum, Medium and Maximum air velocity in positions 2 and 3 on September the 17th

	DAY		NIGHT	
	Pos 3 - inlet	Pos 2 - outlet	Pos 2 - inlet	Pos 3 - outlet
Min. air velocity (m/s)	0	0,021	0	0
Med. Air velocity (m/s)	0,7	0,64	0,39	0,05
Max. air velocity (m/s)	2,17	1,36	2,38	0,78

In Fig. 9 data about wind direction on November the 5th are shown. In daily conditions from 10.30 am and 6.30 pm the medium wind direction angle from North is 132°, while a medium value of about 195° is verified in night conditions. This is a less favourable situation than in summer, particularly in daily condition, nevertheless the VIW seems to assure acceptable performances also in this case, thanks to an efficacy stack effect.

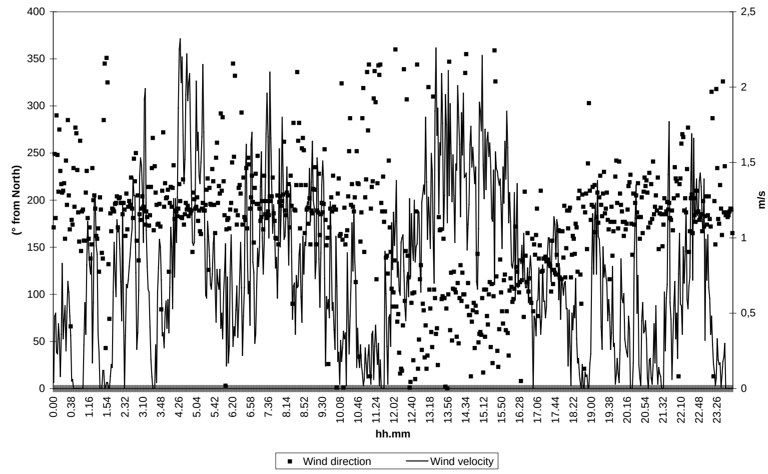

Fig. 9.Wind direction and velocity on November the 6th

In Fig 10 air speed in positions 2 and 3 are shown with winter configuration of openings. During the day the inlet and outlet air speeds are similar because they are only influenced by the difference of temperatures between internal and external environments, while during the night a more favourable wind direction allows to obtain higher values of inlet air velocity.

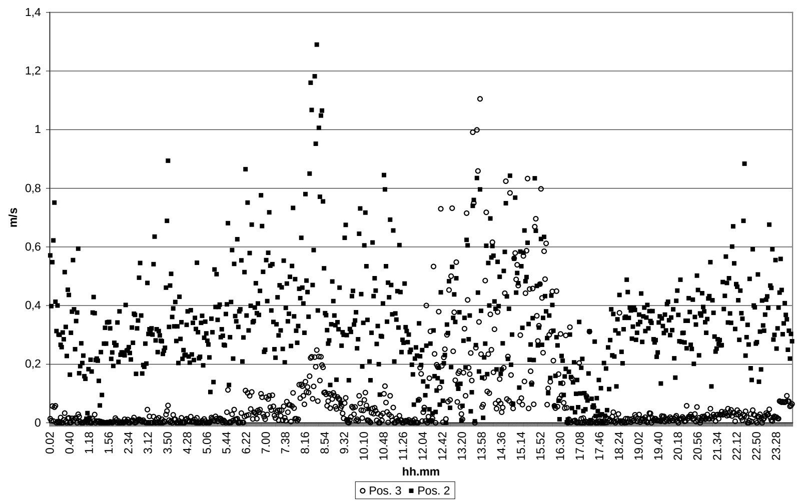

Fig. 10. Air velocity on November the 6th with winter configuration of openings

5. Conclusions

The V.I.W. is a new daylight technological device able to make also an efficacy natural ventilation in underground areas of buildings or rooms without direct outward interface. The building steps of the V.I.W. are described and the first experimental data of indoor illuminances and air speed are shown. The V.I.W. seems to allow an efficacy change of air of the test-room, although the mixing of air does not probably involve the whole environment. The daylighting efficacy is completely satisfactory in presence of high external illuminance, but must be improved with low external illuminance, by an efficient cleaning of the reflective film. The continuous monitoring the V.I.W may prove its efficacy in terms of energy saving and the spin-off uses of the system, particularly in museums or large exhibition rooms in which it may be used together with traditional or double light pipes.

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