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Introduction

Universities are universal in their approach to problems and in the way they contribute to generating solutions. Universities are universal since they connect to each other in networks. The Departments of Architecture in Delft and Bologna relate to each other through networks of collaborating teachers, researchers and scholars. This has resulted in the initiative for a seminar, in which representatives of both departments meet in order to present, discuss their research.

Early 2004 the idea took shape to organize a visit of a Delft University of Technology delegation to their colleagues of the Department of Architecture and Urban Planning (DAPT) of the Faculty of Engineering (Bologna). This publication collects twelve articles, reflecting the presentations of six researchers from Bologna and six from Delft. Based on these contributions three session themes were identified, being Retrofitting, Climate and Facade and Innovations. What they have in common is their concern with the quality and sustainability of the built environment, with a designer's focus for innovation and a technical basis.

The first session ranges from retrofitting and extending a late 19th century building on a site with an Etruscan settlement dating back to the 6th century B.C. to studies of 20th century buildings and sustainable solutions for future office buildings.

The second session deals with the climate inside buildings and the way their envelopes contribute. This session is concluded with a presentation on design and production considerations of double curved facades. This is the upbeat to the last session, which explores innovations in materials, borrowed from non building disciplines, such as aerospace, pharmaceutics and nanotechnology in new applications such as daylight guiding systems. In a similar innovative fashion the boundaries of double curved structures are explored. The session is concluded with a case demonstrating how theoretical and experimental research as presented before can be applied in new projects, such as the newly built and recently initiated Rabin Center in Tel Aviv.

We can clearly see the connections between the subjects being presented. You might find it an artificial construction that needs a bit of extra imagination. But it is this kind of imagination that lets the designing engineer see solutions, still hidden for others.

A.C. Dell'Acqua, Professor
Ype Cuperus, Assistant Professor

On Environmental Sustainability of Ventilated Façades in Italy

Luca Guardigli

Abstract

The paper will address the issue of the energy exchange in glass envelopes (facades and roofs), applied to public buildings. The opportunity is given by a recent project for a University library in Parma, where design requirements implied natural lighting solutions from above the main hall, in a very difficult site.

The paper is initially focused on preliminary investigations with the software Ecotect, in particular internal sun penetration, optimised shading design and preliminary internal light calculations; following the results of the preliminary phases, the subsequent phases of the design are monitored. Different alternatives regarding the choice of glass typologies and components (shading elements included), in relation to the environmental requirements of internal spaces, are taken into account. The design process is followed from the preliminary phases to design developments and, finally, to the construction documents. The aim of this investigation is to find the optimised solution for these envelopes, in relation to the quantity of radiation that is coming through the envelope to the main internal spaces.

The technical solutions are chosen in the Italian market of glass envelopes; the paper gives an overview of these technical alternatives for big open public spaces, with the different implications that each alternative has on internal thermo-hygrometric environments. Some information on related HVAC systems and glass envelopes costs are finally given.

1. Introduction

The aim of this paper is to address some environmental issues about the use of *ventilated walls* (or *façades*) in Italy for commercial and/or residential buildings12. Particularly, the question is if ventilated façades (VF) represent an environmentally sustainable solution for some kind of buildings and architecture.

Nowadays, ventilated walls are widely used in the form of back ventilated non loadbearing enclosures. Precise calculations on their performances are very difficult to carry out and usually not accomplished. In recent years some sophisticated analytical methods of Computational Fluid Dynamics, based on finite differences or other sophisticated techniques, have been proposed. In these cases, as a precise understanding of the components (materials and geometry of the enclosure system) and the knowledge of pressure and wind speed and direction are always required, it is always difficult to extend the results to generic situations.

Besides, no simple or efficient method to address the effects of ventilation on internal comfort and energy consumption is used in Italy by Building Regulations. On top of that, the integration of the enclosure with the overall environmental behaviour of the building is often not taken into consideration. The consequence is that the contribution of the ventilation is generally not considered. VF become very well-publicized and attractive solutions more than environmentally conscious elements.

2. Active and passive VF

Through history building *enclosures* (or *envelopes*) have always embodied complex relationships between various functions. The main ones were protection (from rain, cold/heat, wind, sun radiation, intrusions), comfort (light, ventilation, insulation), and celebration (religious and political). Between the 20s and the 70s, thousands of buildings, of any size, were constructed following a trend in which the return of the investment and the impressive and fascinating image of 'modern times' were the main issues. The driving vision for building envelopes of the XX century consisted of lightness, full prefabrication, fast track installation, and full transparency, in order to create continuity between interior spaces and external land-

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[12] **The term 'ventilated wall' (in italian, parete ventilata) is more generic than 'ventilated façade' (facciata ventilata), which is widely used, but represents specifically the front or main elevation of the building. Other similar terms, like 'ventilated envelopes', or 'ventilated skins', or 'ventilated enclosures' are often used with different meanings.**

scape. While the prefabrication of the envelope and fast track projects have become a standard after the 30s, full transparency still requires technological development, due to complex issues concerning insulation, condensation, radiation, and safety.

Shortly, two basic technological systems are now adopted for the building envelope: the *passive wall*, mainly constructed with solid and massive blocks, with or without the use of ventilated skin, and the *active wall*, essentially based on light elements and adjustable devices for lighting, ventilation and thermal comfort[13]. While in the past, the indoor comfort (natural light, absence of air draughts and excess of radiation) was not taken into great consideration, as well as the waste of energy, today users and investors (banks, insurance companies and their employees) are more demanding and evaluate the characteristics of a building in all detailed aspects. Many factors are often required to be actively controlled by users, in order to:

- make the envelope fully transparent or opaque,
- adapt insulation to external noise, pollution, wind, rain, cold and warm temperatures, and especially solar radiation,
- have natural ventilation and natural contact with the outside environment.

Other desired options are driving the natural light deeper into the room to create uniform light intensity, or shadow to work with monitors and screens, or having all perimetral walls (including the glazed areas), and possibly the ceiling and the floor, at the room air temperature, in order to avoid undesirable and uncomfortable radiating effects and air movements.

The result is a building where the envelope has strict links to the mechanical and electrical systems. For instance, the Permasteelisa project named "Blue Building" uses two combined systems: a Flexicool ® system (chilled ceiling) by ABB for cooling and Interactive Wall ® by Permasteelisa (double-glazed cavity wall). The two systems are linked to compensate solar gain and heat transmission through a glazed curtain: a patented ceiling zone near the perimeter makes the glazed curtain perfectly adiabatic. The indoor climate control is completed by a chilled ceiling and primary air to remove internal gains (fig. 1).

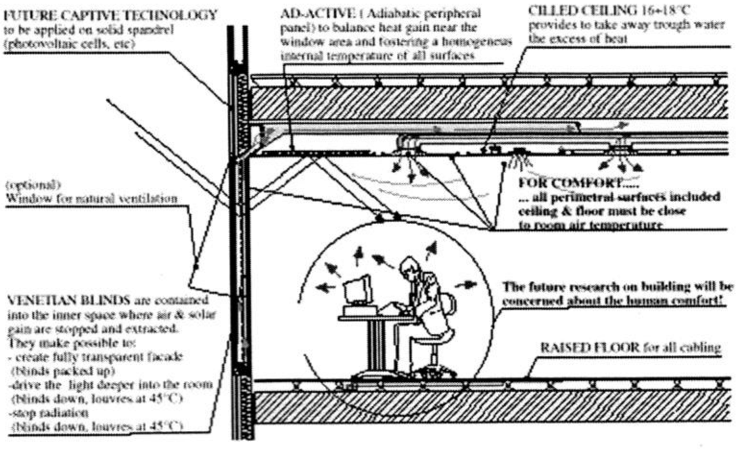

Figure 1: section of building with "Blue Building" technology.

This system provides homogeneity of inner conditions, independently from weather and distance from the perimetral wall. Designers say that this system can save 20% of energy for running costs (the mechanical room uses 40-50% less frigories and 30% less calories). Besides, the extra costs of a double wall are compensated by the reduced costs for mechanical equipment, machinery and nearly 50% of electrical energy[14]. More detailed studies on the

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[13] In this second case, the proper term should be ventilating facades; in fact there is air exchange between inside and outside.

[14] A curtain stops the sun radiation in the cavity where the passage of return air allows to collect and extract the excess of heat. A double forced ventilated facade is preferred to a highly sophisticated double glass because of the solar factor. In fact, with the most sophisticated double glass, if we

sustainability of this system should be done by the company. However, the interaction between the ventilation in the double façade and the mechanical system promotes some energy savings (fig. 2). Of course, different answers should be given according to different climates.

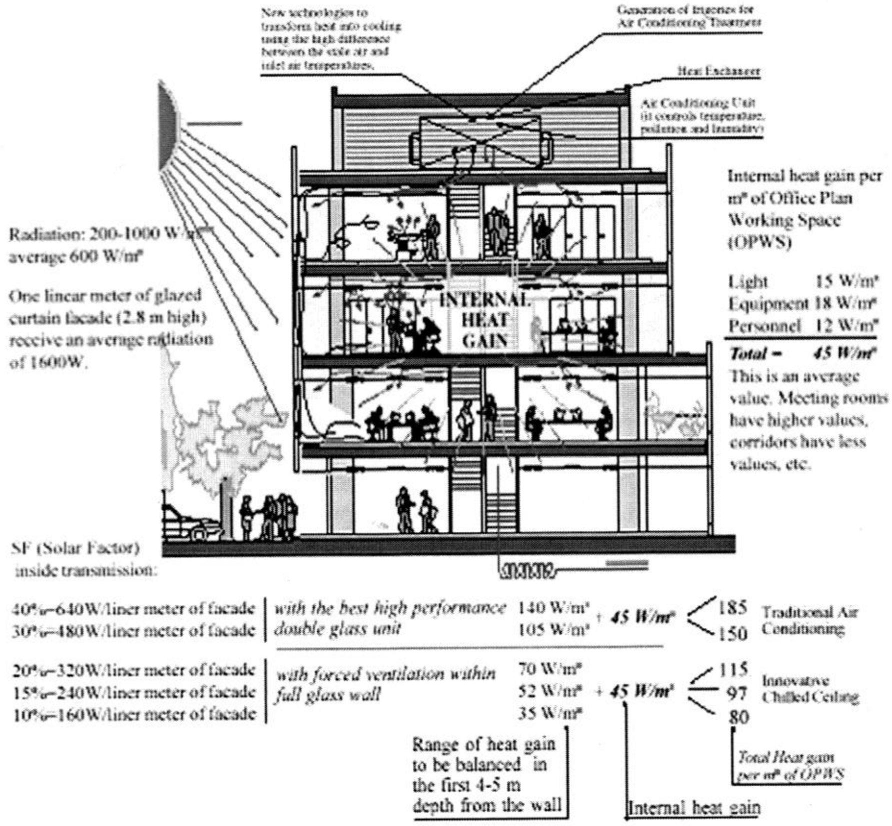

Figure 2: energy performance of the "Blue Building".

The conclusion is that active walls are the innovative technological trend, confirmed also by the market. In fact, over the 30% of the requests for the best building today are asking for a better indoor comfort with less consumption of energy and less maintenance costs. Using innovative technologies, as the ones mentioned above, we can predict an actual energy saving of 20% on new and renewed buildings. The savings can rise up to 80-90% in the next 10-15 years. The producers don't give further information about costs, which would have been very interesting. Nevertheless, these kind of buildings with active walls are almost not existing in the italian scenario.

Talking about the common use of passive walls with *enclosure back ventilation* in Italy[15], in modern buildings generic VF were initially studied for the drainage of moisture from the wall. Only recently, they started to be conceived to exploit the radiation heat gain in winter (transparent cladding) and reduce the heat flow during the summer. The second aspect is more important in Italy than in the rest of Europe. (fig. 3)

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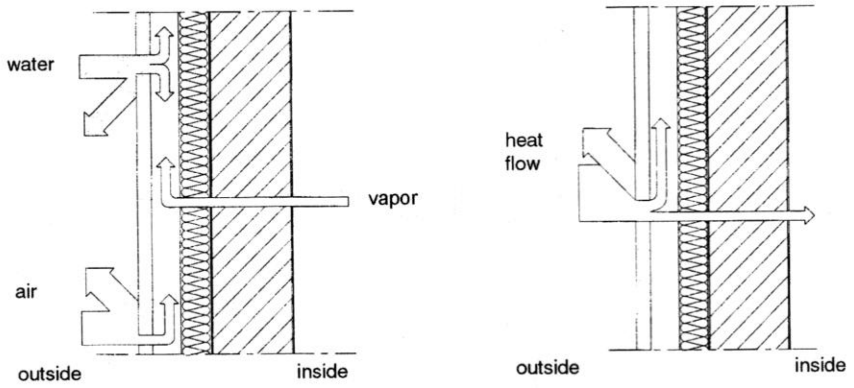
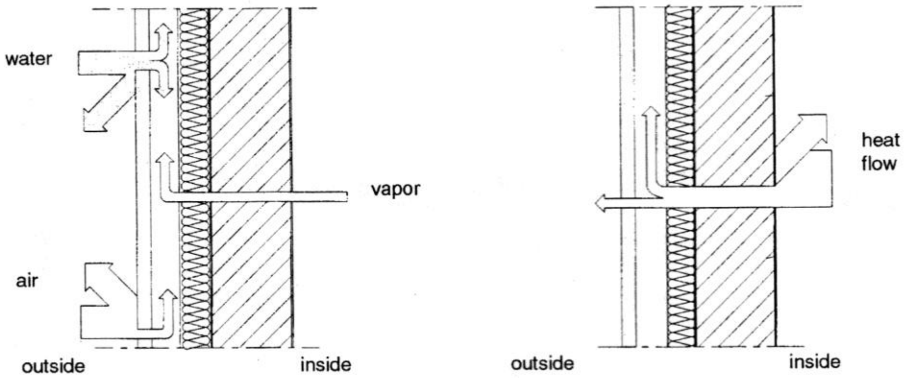
desire to have 60% of light transmission (LT) we have to accept a 32% of solar factor (SF), that is too much for the chilled ceiling technology. Furthermore, the temperature of the inner glass is too high and creates the conditions for a radiating surface.

A technological improvement of the system should be that all exhaust energy produced inside the building (by light, various equipment and persons) and approximately the 50% of radiation were collected and driven into the mechanical rooms. Some combinations of these technologies are being investigated at the Quaternario Technological Campus (near Venice), with 14 different combinations of wall technologies.

[15] **It's difficult to depict Italy as a country with homogeneous mediterranean climate, but in this paper we will use approximation.**



Summer



Winter

Figure 3: Effects of VF on heat transfer

VF can be transparent (glazed) and opaque. Opaque ones are more common in Italy[16].

Nowadays VF are considered important components of sustainable design in reducing energy consumption, enhancing internal comfort, and leading to attractive formal solutions. None of these factors prevail on the others.

Some widely publicized functional advantages of ventilated walls, compared to heavyweight brick walls, are listed below:

1. Cladding systems are easy and fast to install.
2. New cladding systems protect weak façades from atmospheric agents.
3. Ventilation promotes energy efficiency.
4. External cladding eliminates thermal bridges.
5. Air cavity eliminates moisture.
6. Maintenance is easy.

As we can notice, energy consumption is only one of the factors and is not necessarily considered as a priority. Initial costs and the formal aspect of the cladding system is often a priority. For instance, VF are often used in building rehabilitations, where preservation requirements are not present: old factories, post-war apartment blocks, degraded office buildings from the 60s (fig. 4).

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[16] Continuous search for indoor comfort is very old: it was often accomplished through the use of thick inertial insulating and resistant walls (heavyweight walls), but also through the channeling of water and air movement within the cavity. Even the ancient Romans used envelopes to actively control the room temperature through hot air that, generated from an external low chamber fire, flowed within the wall cavity and was sucked by the stack effect of properly dimensioned cavities.

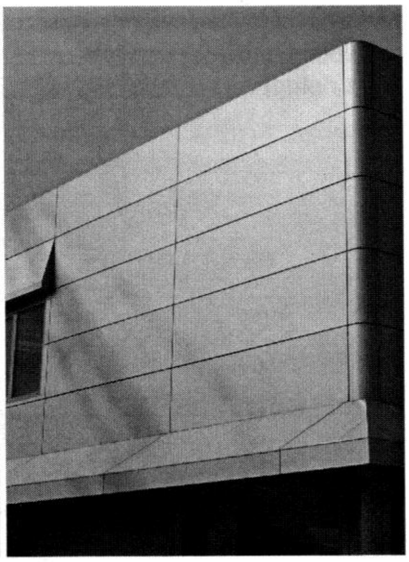

Figure 4: the results of a rehabilitation project of a commercial building, built in Bologna in the 50s.
Figure 5: detail of the previous building.

In this cases the application of cladding elements at a certain distance from the original wall modify the previous energy savings performances of the building and help in the aesthetics of the façade, but don't exploit the ventilation effect. The section of the cavity and, therefore, the air flow rate, is usually determined by the technology of the anchoring system. (Fig. 5)

Among various cladding systems, traditional ones (tile, stone) are frequently used in Italy and others, made with innovative material, (steel alloys and plastics) are rare. Recently traditional materials, like ceramics, bricks and fiber-reinforced concrete are being produced and placed in an innovative way. These materials are often preassembled in panels of various dimensions, mechanically anchored to the sovrastructure and distantiated to create expansion joints. (Fig. 6, 7, 8, 9)

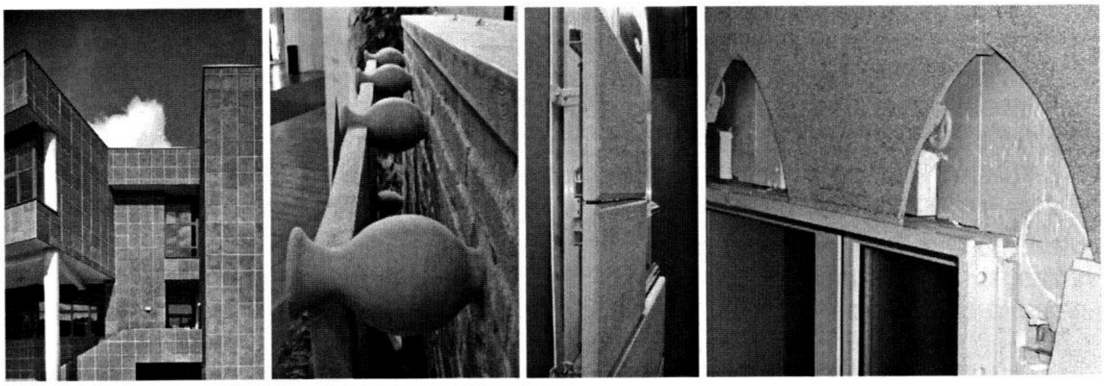

Fig. 6, 7, 8, 9. examples of cladding systems in Italy.

In a ventilated wall the insulation is fixed to the structural wall and the cladding system anchored to the wall through a specific anchoring system. Between cladding and insulation an air duct is generated, whose stack ventilation effect should activate a natural ventilation which contributes to the control of the thermo-hygrometric characteristics of the building. (Fig. 9).

Air ventilation is considered only part of the outer skin and it is independent from the internal ventilation of the building. If not properly ventilated, we should call these solutions *pseudo-ventilated façades*.

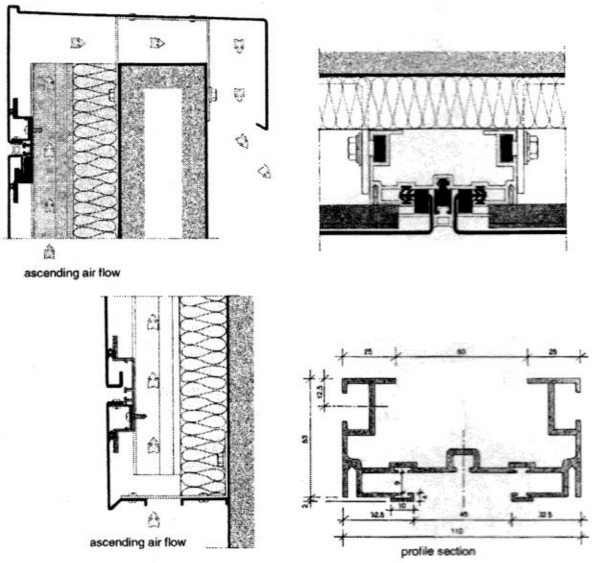

Figure 10: the natural ventilation effect in the cavity of a VF.

2. Italian technical standards

Standard solutions are represented by a functional model, which is composed, from inside to outside, by:

1. Structural wall
2. Regularization layer
3. Insulation
4. Air cavity
5. Anchoring system
6. Cladding system
7. Joints system

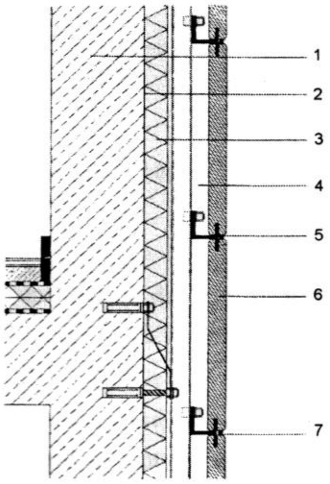

Figure 11: the standard solution for a VF.

The Italian standard UNI 11018:2003[17] "Cladding and anchoring systems for *back ventilated external enclosures of buildings* – Instructions for design, installation and mainte-

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[17] See UNI 11018-2003 (Rivestimenti e sistemi di ancoraggio per facciate ventilate a montaggio meccanico. Istruzioni per la progettazione, l'esecuzione e la manutenzione del sistema di ancoraggio). The standard makes a distinction between ventilated walls and ventilated roofs. The

nance" provides the above scheme of the wall (fig. 11) , where only the case with an opaque wall is taken into consideration. The anchoring system (safety) is again the main issue of the standard; not energy issues. It is clear that the standard reflects the Italian market of ventilated walls.

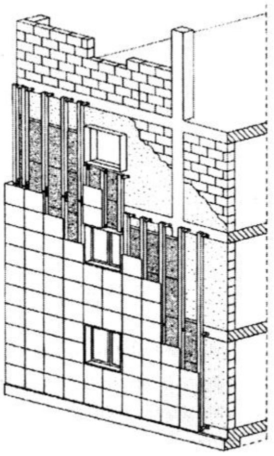

Fig. 12. Example of VF given by the Italian standard UNI 11018:2003.

According to the UNI 11018:2003, ventilated enclosures are divided into poorly ventilated, ventilated and intensively ventilated (tab. 1)

Table 1

Type of ventilation	Vertical wall or inclination > 60° S/L (m^2/m)	Inclination < 60° S/A (m^2/m^2)
Poorly ventilated	<0.002	<0.0003
Ventilated	0.002-0.05	0.0003-0.003
Intensively ventilated	≥0.05	≥0.003

S is the total area of the openings (at the top and at the bottom) per meter, L is the height of the enclosure and A is the area. The increase of ventilation depends on the fraction S/L. For instance, a 10m high vertical façade with 10cm openings and cavity is considered (normally) ventilated. According to UNI, a minimum of 2cm width is required for the cavity to drain water from rain or condensation. A vertical compartmentation is also required for fire resistance. The inclination of the wall plays an important role in the performances.

The Italian Standards reflect the French CSTB-1999, regle Th-K 77 : "Regles générales de conception et de mise en oeuvre de l'ossature et de l'isolation thermique del bardages rapportés"[18]. The heat flow is calculated, in absence of solar radiation, according to the equation:

$$\Phi_{est-int} = U_{eq} \cdot (\theta_{ae} - \theta_{ai}) W/m^2 \qquad (1)$$

where U_{eq} represents the equivalent U-value of the wall, expressed in relation to the fraction S/L. We have here the same three categories of tha italian UNI. When the value of S/L is less than 0.002 m^2/m (poorly ventilated), then the U-value is given by the following equation:

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stratigraphy of ventilated roofs are basically similar to vertical enclosures, except for the waterproofing layer.

[18] Other standards regard the same subject: ASTMC 1242-1996, Design, selection and installation of exterior dimension stone anchoring systems; BS 8298-1994, Code of practice for design and installation of natural stone cladding and lining; DIN 18516 part 3-1990 Back ventilated, non loadbearing, external enclosures of buildings, made of natural stone, design and installation.

$$U_{eq} = U_o = (1/h_e+R_e+R_{int}+R_i+1/h_i)^{-1}\ W/m^2K \qquad (2)$$

where h_e and h_i are the internal and external surface convection coefficients and R_e, R_{int}, R_i are the resistances of external wall, air and internal wall.

When the value is between 0.002 and 0.02, the U-value increases. In fact, the formula is:

$$U_{eq} = U_o+J\cdot(U_i/U_e)^2 \qquad (3)$$

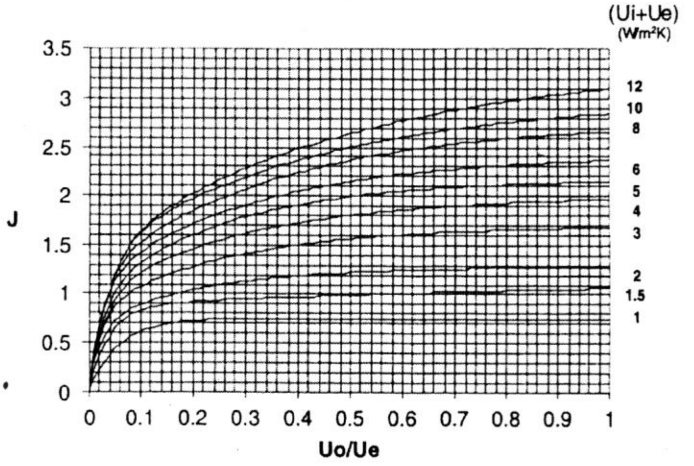
where U_o is given by the formula for poorly ventilated enclosures, and

$$U_e = (1/h_e+R_e+R_{int}/2)^{-1}\ W/m^2K \qquad (4)$$

$$U_i = (1/h_i+R_i+R_{int}/2)^{-1}\ W/m^2K \qquad (5)$$

The value of J is given by the diagram 1 shown below.

Diagram 1: the functions give the values of J



When $0.002<S/L<0.02\ m^2/m$, the value of R_{int} (thermal resistance of the ventilated cavity) is given by the table 2 below, in relation to the nature of the surface (emissivity) and the thickness of the cavity.

Table 2

	Thickness (mm)				
surfaces	5-7	7-9	9-11	11-13	>14
$\varepsilon_1 = \varepsilon_2 = 0.9$	0.11	0.13	0.14	0.15	0.16
$\varepsilon_1 = 0.2\ \varepsilon_2 = 0.9$	0.18	0.24	0.28	0.30	0.35
$\varepsilon_1 '= \varepsilon_2 = 0.2$	0.20	0.26	0.32	0.37	0.43

When $0.02<S/H<0.05\ m^2/m$, J is given by the value obtained from diagram 1, multiplied by 1.35. Finally, when the value of S/L is more than 0.05, the contribution of the outer skin is negligible and the equation is:

$$U_{eq} = (1/h'+R_i+1/h_i)^{-1}\ W/m^2K \qquad (6)$$

with the condition that $(1/h'+1/h_i)^{-1} = 0.22\ W/m^2K$, which allows to calculate $1/h'$ knowing the value of $1/h_i$.

3. Energy efficiency of VF

To test the above mentioned equations, we decided to set up a case-study: in a building renewal project a ventilated enclosure is applied to an existing wall (see table 3 below)[19].

Table 3

	Material	Thickness (m)	Density (kg/m^3)	L (W/mK)
1	1. gres porcelain tiles	0.06	2300	1.00
2	2. air cavity	0.10	-	-
3	3. cellular glass insulation	0.03	150	0.06
4	4. plaster 1.5cm	0.015	2000	1.40
5	5. internal wall, 25cm	0.25	800	0.32
6	6. internal plaster, 1.5cm	0.015	1400	0.70

For a typical 10cm thick air cavity, with bottom and top openings of the same size, if we put:

$$1/h_e = 1/25 = 0.04 \text{ m}^2\text{K/W} \qquad (7)$$

$$1/h_i = 1/7.7 = 0.13 \text{ m}^2\text{K/W} \qquad (8)$$

R_e (thermal resistance of the enclosure) = 0.5 m^2K/W,

R_i (thermal resistance of the internal wall) = 1.0 m^2K/W,

R_{int} = 0.14 m^2K/W,

we have the value $U_o = 0.552\ W/m^2K$. The value is valid for a poorly ventilated façade (L>10m), which represents a fairly good solution in terms of U-value. However, when the height of the VF is between 1m and 10m (very common in buildings) the performance gets worse. In this interval, the U-value is fixed: $U_{eq} = 0.552+1.25\,(0.83/1.63)^2 = 0.552+0.324 = 0.975\ W/m^2K$. The negative contribution of ventilation in increasing the U-value is very significant (almost 60%). The heat flow, considering approximately the same temperature difference in the two cases, should be increased almost by the same amount. Although in this case moisture is prevented, better performances, in terms of U-value, could be given by other solutions; for instance, adding a thicker insulation layer (it could be a natural material) to the previous wall[20]. Of course, the wall would not be that transparent and wouldn't avoid condensation problems so easily. But it could be cheaper; therefore, more sustainable. Besides, we gave an answer only to the winter situation, where the air contributes to the heat loss. UNI is not giving any support for summer climate, and we know for sure that in Italian climates VF should not be chosen only to reduce heat loss during the winter.

Therefore, we tried to understand the behaviour of VF, considering the positive contribution of ventilation in subtracting heat from the cavity during the summer. In fact, as we noticed before, cavities are present in new cladding systems, but often not properly ventilated. As ventilated walls are built as a remedy for pre-existing not ventilated, old façades, we wanted to address the positive contribution of the air flow compared to the performance of the cavity without effective ventilation.

According to some recent studies (Mazzarella, 2000), it is possible to compare the two situations (ventilated or not-ventilated walls) quite easily. In the first case (stationary regime) the thermal flow is given by the formula:

$$\Phi_{est\text{-}int} = U_o \cdot (\theta_{op,e} - \theta_{op,i}) + N_{I,0} \cdot \alpha_0 \cdot G_T\ W/m^2 \qquad (9)$$

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[19] See Farinelli I., Analisi termofluidodinamica delle pareti ventilate, rel. Prof. Luca Guardigli, correl. Prof. Marco Spiga, Università degli Studi di Parma, A.A. 2003-2004.

[20] In this paper we won't address some issues related to thermal inertia. This is not significantly increased by VF.

where N_I is the absorbed solar radiation factor $=U/h_e$, α is the surface absorbance, G_T is the solar irradiance (W/m^2), and $\theta_{op,e}$ and $\theta_{op,i}$ are the external and internal ambient operating temperatures. U_o is calculated in a classic way (UNI EN ISO 6946).

In the second case (ventilated wall), we have the formula:

$$\Phi_{est\text{-}int} = U_v \cdot(\theta_{op,e}-\theta_{op,i}) + N_{I,V}\cdot\alpha\cdot G_T + \Delta U_V \cdot(\theta_{ae}-\theta_{op,i})\ W/m^2 \qquad (10)$$

where N = U/h

Mazzarella applies both equations in winter and summer. Without going into details for the calculation of U_v (primary U-value for the VF), we can remember that ΔU_V is a further contribution of ventilation, which depends on the air thermal capacity (c_p), on the cavity surface coefficient h_{cv}, and on air mass flow (m, expressed in kg/s), itself depending on the air pressure around the wall. The value is very complicated to determine, unless the external air temperature θ_{ae} is substituted by the operating one, $\theta_{op,e}$.

According to this set of equations, and using the previous type of wall, the ventilated solution has worse thermal performances than the non ventilated one.

Using the previous wall, we have: the value of h_{cv} is set between 0.1 and 2.6 W/m^2K; external temperature (T_e) = 30°C, internal temperature (T_i) = 24°C; solar gain (G_T) = 400 W/m^2.

Air characteristics: specific heat capacity (cp) = 1006 J/kgK, dynamic viscosity μ $18.5\cdot10^{-6}$ Pa·s, density ρ = 1.16 kg/m^3, thermal conductivity (λ) = 0.0258W/m°K, the air flow (m), which is essential for the calculation of the heat gain, is very difficult to determine21.

Using the value of air flow (m) = 0.5 kg/s, in case of static air cavity U_0 = 0.5871 W/m^2K and, in case of ventilation: $0.5910<U_{VS}<1.1519$ in the interval $0.1<h_{cv}<2.6$ W/m^2K, which is coherent with the solution give by the Italian and French standards. The U-value can increase up to 300%.

On average, according to the previous equations, to reach the same U-values in winter, the insulation should be raised by 2-4% with poorly ventilated façades, 6-8% with ventilated, and by 10-12% with intensively ventilated façades. This is very significant, because it confirms the bad behaviour of thick cavities during the winter. The opposite behaviour happens during the summer, where the contribution of the solar radiation is smaller with a bigger air flow. Considering the same air mass flow (m), raising the insulation thickness, the effect of the flow is reduced, but non linearly because of the thicker insulation which raises the temperature and promotes the stack effect. Mazzarella concludes that the insulation is very important.

Unfortunately the equation does not give consistent results. In fact the value $N_{I,V}$ should be smaller than $N_{I,0}$, but we didn't come to this conclusion.

Not satisfied by all these results, we tried to address the ventilation issue with a system of 5 and 6 simple equations. This model compares the efficiency of the ventilated façade during the summer and it is based on the following hypotesis: stationary system, transcurable conduction in solids, air flow (m) or w known; constant physical properties.

The system with sealed cavity can be studied through 5 equations:

$$q = \alpha G_T - h_e(T_1 - T_e) \qquad (11)$$

$$q = (T_1 - T_2)/R_1 \qquad (12)$$

$$q = (T_2 - T_3)/R_{int} \qquad (13)$$

$$q = (T_3 - T_4)/R_2 \qquad (14)$$

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21 The calculation of air mass flow is very difficult unless automated iterative calculations are carried out: nevertheless, regarding the optimal air flow during the summer, the Technical Agreement of UEAtc helps in determining the ventilation openings in relation to the height of the building; the prescribed solution is ≥ 50cm2/m for a 3m high building, 65 for a 6m high building and 100 for a 18m high building.

$$(T_3 - T_4)/R_2 = q_{int} = h_i(T_4 - T_i) \qquad (15)$$

The second system with a ventilated cavity can be studied through 6 equations.

$$q = \alpha G_T - h_e(T_1 - T_e) \qquad (16)$$

$$q = (T_1 - T_2)/R_1 \qquad (17)$$

$$q = h(T_2 - T_b) \qquad (18)$$

$$q = q_{asp} + h/10 \cdot (T_b - T_3) = mc_p/A \cdot (T_b - T_e) + h/10 \cdot (T_b - T_3) \qquad (19)$$

$$h/10 \cdot (T_b - T_3) = (T_3 - T_4)/R_2 \qquad (20)$$

$$(T_3 - T_4)/R_2 = h_i(T_4 - T_i)$$

Where T_b is the fluid temperature coming out form the cavity, R_1 (thermal resistance of the skin) = 0.5m^2 K/W, R_2 (thermal resistance of the internal wall) = 1.0m^2 K/W, R_{int} = 0.16m^2 K/W. (fig. 13)

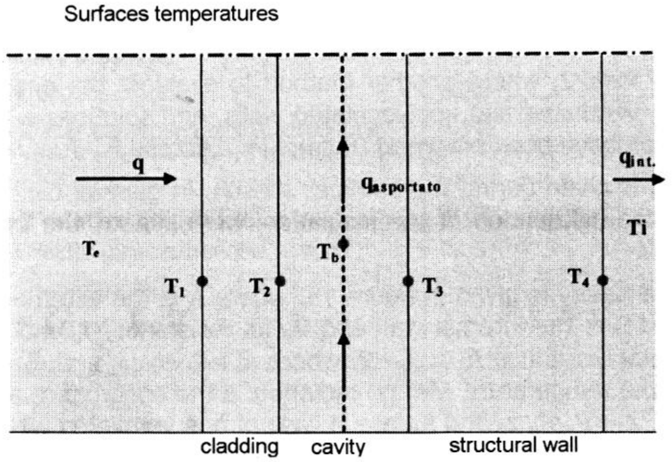

Fig. 13. Adopted model for the VF

Using the value 0.01Kg/s for the air flow and $h = 30\ W/m^2K$ (heat transfer coefficient), the solution of the systems has given interesting results, shown in the following table 4.

Table 4

m = 0.01 h = 30	T with ventilation (°C)	T without ventilation (°C)
T_e	30	30
T_1	42.6892	43.1716
T_2	31.3048	37.816
T_b	30.5458	-
T_3	29.0546	36.1022
T_4	24.581	25.3911

The drop in temperature is actually only of approximately 1°C, which does not change much the internal comfort (transparency is also important). However, the effect of ventilation is very big in terms of heat transfer. The heat on the surface of the wall is 22.79 W/m^2, but only about 15% ($q_{int} = h_i(T_4 - T_i) = 4.47$ W/m^2) is transferred inside, while the quantity taken away (q) is 18.29 W/m^2 . In a non ventilated wall $q_{nonvent.}$ = 10.71 W/m^2= constant. Well ventilated wall are strongly recommended during the summer.

The diagram 2 below puts *m* in relation with the fraction $q_{int}/q_{nonvent}$. As we can see, over a certain point, it is not necessary to increase the thickness of the air cavity. On top of that, the fraction varies significantly from 10 to 50 depending on the flow. This also demonstrates the positive effect of ventilation in the cavity during the summer.

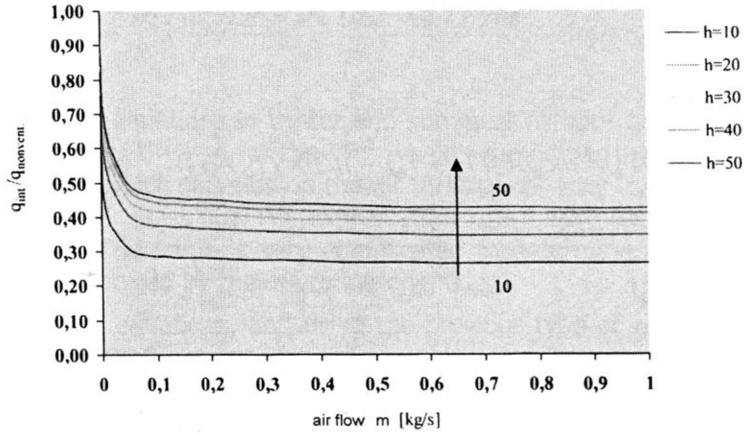

Fig. 14. Effects of air flow on heat loss

As a better conclusion for these energy issues we would like to report the results of a study atthe University of Pisa22, where another method to evaluate the energy performances of the VF, comparing ventilated and not ventilated walls, and solutions with forced ventilation or natural ventilation have been proposed (Ciampi M., Leccese F., Tuoni G., 2002).

The energy saving is given during the summer season, in general conditions, in relation to the cavity width, the distribution of the insulation, the air flow, the insulation and, in the roof, the inclination.

The scheme for the cavity is given in figure 15, where A is the external cladding and R_A its thermal resistance; B is the internal wall and R_B its resistance; r_e and r_i the surface resistances. Also the total resistance $R_t = R_e+R_i$, where $R_e=R_A+r_e+r_1$ and $R_i=R_B+r_i+r_2$. $Te = T_0 + \alpha r_e I$, where T_0 is the temperature with no radiation, a the absorbance and I the intensity of the solar radiation. $z = R_e/R_t$. z_0 and R_{t0} are in case of non ventilated wall.

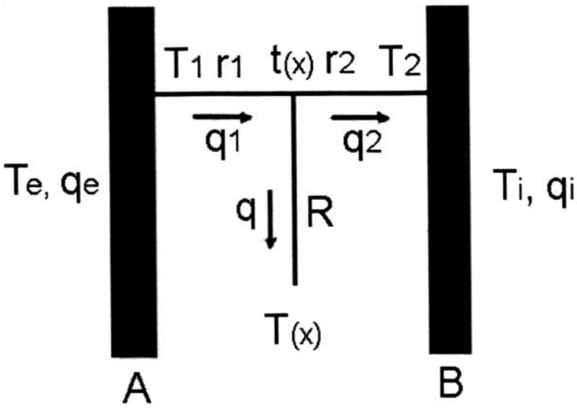

Figure 15. Model for the VF

Two main equations, which give the temperature and the thermal flow entering the internal wall, are:

$$dT/dx = \lambda(T_m-T)/L \qquad (21)$$

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22 **Ciampi M., Leccese F. Tuoni G., "Sul comportamento termico di facciate e coperture ventilate", La termotecnica, gennaio-febbraio, 2002.**

Integrating this equation we have

$$T(x) = T_m+(T_0-T_m)\cdot e^{-\lambda x/L} \qquad (22)$$

and

$$Q = (1/L)\cdot\int q_2 dx = (t-T_i)R_t - zc\cdot(T_u-T_0) \qquad (23)$$

where T_u is the temperature at the exit of the cavity, $z = R_e/R_t$ and $c = GC_p/lL$ (G is the mass flow, C_p is the specific heat at a constant pressure and lL the exchange surface)

The performance of the walls are given by 5 parameters, but the most significant are:

$S = (Q_0-Q)/Q$, or the percentage in savings due to ventilation, $\phi = (T_0-T_m)/(T_0-T_m)$ and $\chi = R_{e0}/R_t$ where $R_{e0} = R_A+r_e+r_0/2$ in case of no ventilation.

Some walls (ventilated façades) have been tested. (Table 5)

Table 5

		Thickness (m)	density	K (W/mK)
P1	Stainless Steel	0.003	8000	17
R_{t0} = 1.523	Air (ventilation cavity)	0.10	-	-
Z_0 = 0.085	Cellular glass	0.03	150	0.06
	Concrete grout	0.015	2000	1.4
	Concrete blocks	0.25	1200	0.39
	Mortar composed of hydrated lime	0.015	1400	0.70
P2	Brick	0.08	8000	17
R_{t0} = 1.619	Air (ventilation cavity)	0.10	-	-
Z_0 = 0.278	Cellular glass expanded	0.03	150	0.06
	Concrete grout	0.015	2000	1.4
	Concrete blocks	0.30	1200	0.39
	Mortar composed of hydrated lime	0.015	1400	0.70
P3	Ceramic tiles	0.06	8000	17
R_{t0} = 1.723	Air (ventilation cavity)	0.10	-	-
Z_0 = 0.110	Cellular glass expanded	0.03	150	0.06
	Concrete grout	0.015	2000	1.4
	Concrete blocks	0.25	1200	0.39
	Mortar composed of hydrated lime	0.015	1400	0.70
P4	Brick	0.08	600	17
R_{t0} = 1.119	Air (ventilation cavity)	0.10	-	-
Z_0 = 0.402	Concrete grout	0.015	2000	1.4
	brick	0.30	1200	0.39
	Mortar composed of hydrated lime	0.015	1400	0.70

The used values were: r_i = 0.13 m^2K/W, r_e = 0.04 m^2K/W; $\varepsilon_1 = \varepsilon_2 = 0.9$; the other climatic conditions were the same applied before.

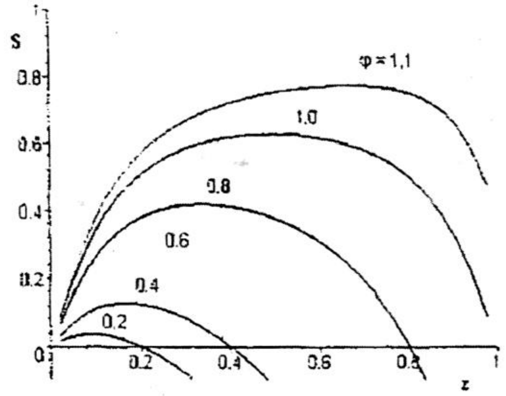
The results are: shown in Table 6.

Table 6

	P1	**P2**	**P3**	**P4**
c R_{t0}	9.778	6.561	9.663	4.263
z	0.0546	0.266	0.0866	0.395
c	1.075	1.052	1.060	1.073
S	24.6	41.5	34.6	31.4

It is particularly important to notice the value of S, which represents the percentile savings during the summer of a VF, in terms of heat loss, compared to a non ventilated façade. This improvement can reach 40%. This demonstrates the importance of a good ventilation in Italy during the summer season. Some diagrams help the design of the VF, playing with these parameters S, z and ϕ. We choose one of them (Diagram 3).

Diagram 2



Parameters for VF design

3. Conclusions

VF are widely used in Italy for many purposes, especially in renewal projects, but their environmental performances are not usually addressed. They usually improve the previous situation, but they don't represent a satisfactory sustainable solution, as their cost does not balance the energy savings (related to U-values). In this paper we didn't take into consideration the nature of materials, which is also an important aspect for sustainability. For a better behaviour, VF should be adjusted according to different climates depending on the seasons, in order to reduce the negative effects of ventilation during the winter. Basically, VF should turn into active walls. During the summer, which is a key season for the Italian climate, an effective ventilation should, in fact, always achieved. Unfortunately, this doesn't happen in most of the projects. An interaction with the overall control of the building should also be particularly stressed in the next future.

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