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# Thermodynamic analysis of ventilated façades under different wind conditions in summer period

A. Gagliano*, F. Nocera, S. Aneli

*Department of Industrial Engineering, Viale Andrea Doria 6, 95125 Catania, Italy*

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ABSTRACT

The main benefit attributed to opaque ventilated facades (OVF) is the reduction of cooling load for the building Heating Ventilation and Cooling (HVAC) achieved through ventilation led by natural convection in the ventilated chamber and the protection from solar radiation given by the outer layer of the façade.

This research investigates the thermal behavior of an opaque naturally ventilated façade through Computation Fluid Dynamics (CFD) simulations during summer days. The CFD simulations have been performed in order to analyze the behavior of DSF components under different wind conditions in the summer period, utilizing the weather data of Catania city (Italy).

For the different investigated scenarios, the authors have calculated the temperature and air velocity profiles inside the air gap of the façade, highlighting the different effects of buoyancy and wind forces.

The results show that the wind forces in conjunction with the buoyancy forces affect significantly the performance of OVF components.

Further, the reduction of the heat flux during the summer period has been evaluated by comparing the thermodynamic performance of a naturally ventilated and an unventilated façade with the same geometry and thermo-physical characteristics.

The behavior of the naturally ventilated façade is an improvement in terms of passive cooling of the building compared to the non-ventilated façade since it allows the peak load to be shifted whilst offering energy savings in the range of 47% to 51% depending on climate.



## 1. Introduction

Buildings cause half of energy consumptions in European countries, and their energy needs continue to grow worldwide [1], mainly for satisfying the energy demand for heating, ventilating and air conditioning (HVAC).

In this context, the 2010/31/EU Directive on the energy performance of buildings (EPBD) [2] has stated the urgency of developing new solutions to improve the efficiency and the energy savings in the building sector. Therefore, it is encouraged the advancement of refurbished buildings into very low energy buildings, emphasizing the importance of avoiding overheating during summer season not only in the warmest regions, but throughout the European countries. The building envelope directly affects the annual energy consumption and, consequently, the operating costs for heating, cooling, and for the humidity control of the indoor spaces. Moreover, the dynamical thermal behavior of the building envelope also determines the peak loads and, consequently, the power of the energy generation equipments and their initial cost. Currently, a multiplicity of construction techniques allow the improvements of the thermal performances of the building envelopes providing reliable opportunity for reducing the annual energy demand [3–5]. Between these technics, it is possible to include the ventilated building envelopes, which are able to reduce the energy needs and the peak cooling load [6,7], especially in southern Europe regions where the highest levels of solar radiation [8–11] are encountered. Ventilated building envelopes reduce the solar gains by the exploitation of natural ventilation and guarantee temperatures of the outer shell close to the ambient temperature. The most common configuration of an Opaque Ventilated Façade (OVF) consists of an outer shell anchored to the wall surface of the building, an insulating material and an air gap between the cladding and the insulating material. The air gap between the two layers has an inlet opening, from where the outdoor air stream comes in, and an exhaust opening from where the air stream goes to the outdoor environment, or is driven in the indoor environment. The buoyancy and/or the action of the wind allows the air stream to move within the ventilated chamber.

* Corresponding author.
*E-mail address:* agagliano@dii.unict.it (A. Gagliano).

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**Nomenclature**

| | |
|---|---|
| $C_p$ | Specific heat at pressure constant [J kg$^{-1}$K$^{-1}$] |
| ES | Energy saving rate [%] |
| $F_{W-sky}$ | Wall sky view factor |
| $h_i$ | Heat transfer coefficient at the inside of the internal wall [W/m$^2$ K] |
| $Q_{OVF}$ | Heat fluxes incoming through the ventilated façade |
| $Q_{UVF}$ | Heat fluxes incoming through the unventilated façade |
| $R_{OVF}$ | Is thermal resistance of the layer of the ventilated façade starting from the ventilated cavity [m$^2$ K/W] |
| $R_{UVF}$ | Is thermal resistance of the layer of the unventilated façade starting from the external layer[m$^2$ K/W] |
| $T_o$ | Air temperature of the outdoor environment [K] |
| $T_i$ | Air temperature of the indoor environment [K] |
| $T_{si(vc)}$ | Superficial temperature of the inner layer of the ventilated cavity [K] |
| $T_{so}$ | Superficial temperature of the outdoor layer of the unventilated façade [K] |
| $T_{sky}$ | Sky temperature, [K] |
| $U_r$ | Wind speed at reference height [m/s] |
| $U(z)$ | Wind speed at "z" height [m/s] |
| $z$ | Height [m] |
| $z_r$ | Reference height [m] |

*Greek symbols*

| | |
|---|---|
| ß | Tilt angle of surface measured from horizontal |
| $\gamma$ | Coefficient that taking into account of the surrounding environment |
| $\varepsilon$ | Emissivity |
| $\lambda$ | Thermal conductivity [W/m K$^{-1}$] |
| $\mu$ | Dynamic viscosity [kg m$^{-1}$ s$^{-1}$] |
| $\rho$ | Density [kg m$^{-3}$] |
| $\sigma$ | Stefan-Boltzmann constant [W/m$^2$ K$^{-4}$] |
| $\tau$ | Time [hour] |

Moreover, opaque ventilated façades have several benefits, such as excellent finishing of the walls, control of the humidity, insulation protection and energy saving.

Many studies, which have investigated the performance of ventilated structures, have shown that ventilated façades significantly reduce the cooling load [6,12,13], the problems caused by moisture in buildings, and they can be performatives during the winter period [14].

The prospective of combining ventilated façade with photovoltaic (PV) modules, provides a bracing chance for producing renewable energy, increases the energy performance and the aesthetic of the building envelope [15]. Indeed, the ventilated photovoltaic façade acts as a pre-heating device in winter and a natural ventilation system in summer that reduces PV module temperatures [16]. An experimental study and a dynamic thermal model for building with integrated natural or mechanically ventilated PV façade have been developed by [17–19].

Diarce [20] studied a ventilated façade containing a Phase Change Material (PCM) in its outer layer that allow storing energy by latent heat of fusion. The aim of this development is to increase the thermal inertia of the external layer and, hence, the energy efficiency of the ventilated façade as one previous study has highlighted [21]. In addition, thermal response of a ventilated facade with PCM within the air chamber for cooling applications was studied in [22,23].

Energy performances of ventilated façades are governed by several parameters, such as cavity thickness, exposure, characteristics of components materials, weather conditions (solar radiation, air temperature and wind speed), which continuously vary during the day and throughout the year [24,25].

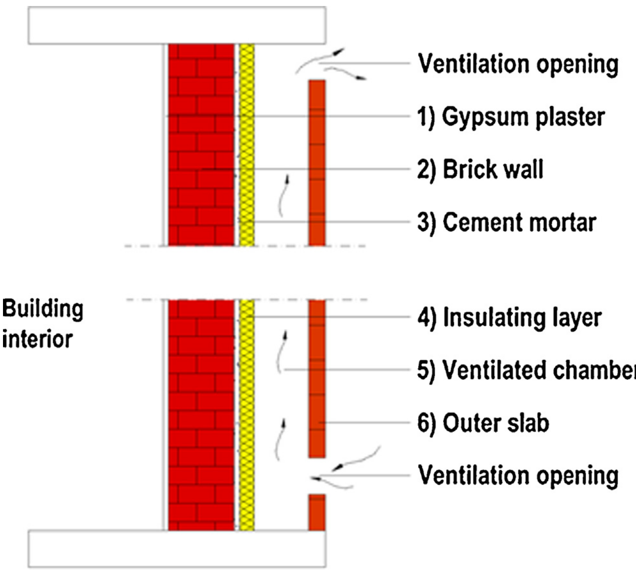


**Fig. 1.** Schematic section of the OVF.

The CFD approaches has been broadly extended for simulating the thermal behavior of the ventilated façade [20,26]; recently authors like Baldinelli [27] and Coussirat [28], investigated the thermal response of double glazed ventilated facades by means of CFD techniques and validated the numerical results with experimental data coming from real facades. CFD models were also applied to predict the effectiveness of PCM clay boards in ventilated and unventilated situations [29].

Coussirat [28] reported that the RNG k–e turbulence model and the DO (Discrete Ordinates) radiation model performed better than other turbulence models tested in terms of predicting heat transfer when there are zones of low velocities within the façade configuration.

However, many of the above-mentioned studies were developed only for steady state conditions and did not take in account the effect of the wind forces. The aim of this study is to assess the dynamic thermal behavior of an opaque ventilated façade (OVF) considering different wind scenario (velocity and direction) in south Europe countries during the summer period. Thereby, a Computational Fluid Dynamic analysis of an opaque ventilated facade, not mechanically ventilated, has been performed using the Fluent software for "a summer day-type" under the action of 24 h weather conditions.

## 2. Methodology

In this study, the opaque ventilated façade was modeled as a two dimensional system considering that, for a given height, the temperature difference along the width of the façade was not significant [20].

Therefore, the modeled system is constituted by an inner and an outer layer separated by an air gap where the airflow can freely enter through the opening placed at the bottom and exit through the opening placed at the top of the outer layer (Fig. 1).

If the wind velocity is zero, the air flow rates through the air gap is driven only by the natural convection phenomenon otherwise, for wind velocity higher than zero, the flow rates induced within the air gap is due to wind and buoyancy forces. As consequence, the airflow rate will depend mainly by wind vector.