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A Numerical Study on the Effect of Exit Section on Inclined Ventilated Roofs

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Abstract
In this work, a prototypal ventilated roof for residential use is numerically investigated. The roof is a symmetric structure, both in geometrical and thermal terms, so only a single flap of the roof is studied. Thermofluidodynamics characteristics of the roof are analyzed as a function of geometric parameters: the inclination of the roof, the width of the ventilation layer and the height of the ridge. The model is analyzed as two-dimensional thanks to the commercial code Ansys Fluent. It is evaluated in air flow, considering a k-ε turbulence model to give the governing equations. Results are function of an assigned heat flux on the top wall of the ventilation layer. Results are analyzed thanks to distributions of temperature and air velocity and profiles of wall temperature and air velocity along the cross sections and longitudinal sections of the ventilated layer to consider the different effects of the various geometric configurations. The objective is to study the thermal and fluid dynamic behaviors of a ventilated roof for different values of some geometrical parameters: the channel gap, the inclination of the roof and the height of the ridge. In particular, the reference configuration is compared to a ventilated channel without the ridge. Finally, ventilated roof configuration is related to other types of roof.

Keywords – ventilated roof; energy saving;heat flux; heat transfer model; numerical investigation

1. Introduction

The reduction of energy consumption is one of the most important goal that our society wants to reach. Data inform that the civil sector utilizes about 30% of global energy and the residential sector causes the main part of this percentage. In particular, residential heating in Italy implicates about 25% of annual energy consumption. The analysis of residential consumption shows that energy demand is mainly ascribable to environmental conditioning systems and a careful building design can reduce their use. In particular, the roof design should respect comfort and energy saving, considering that climatic conditions change depending on seasons and territories. In the winter period, the top cover should contain heat losses. In the summer period, the top cover should reduce the heat gain from the ambient to limit the consumption of the energy essential to the air conditioning system. A ventilated roof has a good configuration for energy purposes. It is composed by a series of layers, as shown in Fig. 1. The outermost layer is the roof cover; immediately under the mantle, there is the ventilation layer: a cavity which goes from the eaves to the ridge. Thermal insulation of the roof is obtained thanks to one o more panels of insulating material; rainwater infiltration and condensation percolation are prevented thanks to waterproof panels. Lastly, the structure is the element that holds permanent loads, accidental overloads and it resists to exceptional events.

Main papers related to ventilated roof are shortly reviewed in the following. In [1-3], ventilated roofs are described as a good solution to reduce thermal loads and it is compared to the same not ventilated structure. A forced ventilated cavity can be arranged in different ways [4], and, in particular, double-skin roofs are studied in [5, 6]. The thermal performance of a ventilated roof is studied in [7, 8], as a function of many construction parameters: the height of the air gap, the use of a radiant barrier in the air gap, the slope of the roof, cavity size and shape. Different roof constructions, roof tiles and paints are studied in [9, 10]. Numerical investigations have been accomplished employing different techniques as in [11-13]. New roofing technologies are studied: combining amorphous silicon PV laminates with the metal panels of a ventilated solar roof [14]; using a pool as a layer of the roof [15]; composing a system by a plenum, a green roof and a sensor operated fan [16].

In this work, a prototypal ventilated roof for residential use is numerically investigated. The roof is a symmetric structure, both in geometrical and thermal terms, so only a single flap of the roof is studied. Thermofluidodynamics characteristics of the roof are analyzed as a function of geometric parameters: the inclination of the roof, the width of the ventilation layer and the height of the ridge. The model is analyzed as two-dimensional thanks to the commercial code Ansys Fluent. It is evaluated in air flow, considering a k-ε turbulence model to give the governing equations. Results are function of an assigned heat flux on the top wall of the ventilation layer. The objective of this work is to study the thermal and fluid dynamic behaviors of a ventilated roof for different values of some geometrical parameters: the channel gap, the inclination of the roof and the height of the ridge.

Fig.1. Ventilated roof outline

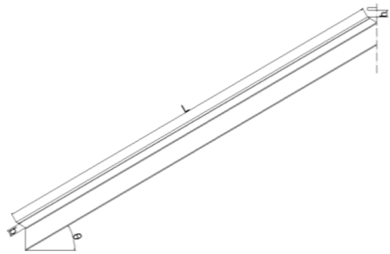


Fig. 2. Two-dimensional model of the ventilated roof

2. Mathematical Model

The physical domain under investigation has a two-dimensional configuration and it is shown in Fig. 2. The model is composed by an inclined channel and some parallel layers constituted by several materials. The length of the channel, L, is 6.00 m and its inclination, θ, is from 15° to 30°. The width of the channel, b, is 0.05 m - 0.20 m and the height of the ridge, h, is between 0.05 and 0.15 m.

The flow in the channel is two-dimensional, the working fluid is air, the turbulent regime is steady state with viscous dissipation negligible. Thermophysical properties are constant with temperature, except for air density (Boussinesq approximation), which gives rise to buoyancy forces. They are assigned for each material layer constituting the roof. Thermophysical properties are calculated at 300 K. The governing equations are: conservation of mass, conservation of momentum, conservation of energy and the k-ε turbulent model [17] is employed.

The computational domain used in this investigation has finite dimensions, since the roof is placed in an infinite medium. It is consists of a finite-extension computational domain composed by the ventilated channel and two reservoirs located at the inlet and the outlet of the channel. The two reservoirs permit to know what happens far away from the region of the thermal disturbance caused by the heated layer simulating the free-stream condition of the flow. Their dimensions are Lx=5b and Ly=L/4 because some computational tests proving that the variations of velocity and temperature inside the channel is small for a larger size of the storages. On the top layer of the roof a heat transfer toward the external ambient is considered. On the bottom layer of the roof, the interface with the internal environment is simulated adiabatic. For the simulation, the discrete transfer radiation model (DTRM) is applied. Surfaces are simulated diffuse [18], so the reflection of incident radiation at the surface is considered isotropic with respect to the solid angle. DTRM simulates the radiation leaving a surface element, in a certain range of solid angles, as a single ray. The net radiative heat flux from the surface is equal to the sum of the reflected fraction of incident and emitted heat fluxes. The scattering effect is considered negligible, all the walls are gray. The convergence criteria for residuals of velocity components and energy are 10^{-6} and 10^{-8}, respectively.

3. The Numerical Solution

The geometric model and the mesh of the computational domain are realized thanks to the software Gambit. In particular, to create the mesh, several grids were realized and compared depending on Richardson's extrapolation equation [19], so the chosen grid counts 228427 calculation cells. The choice of the mesh used for simulations, depends on the right compromise between the accuracy of the simulation and calculation time.

The governing equations of the simulations are coupled, non-linear and partial differential and their numerical solutions are obtained using the commercial code Ansys-Fluent 12.2 [20]. On the top of the roof, an uniform heat flux is applied and it is equal to 800 W/m^2.

4. Results and Discussion

The objective of this work is to study the thermal and fluid dynamic behaviors of a ventilated roof for different values of some geometrical parameters: the channel gap, the inclination of the roof and the height of the ridge. The channel gap is equal to 5 cm, 10 cm and 20 cm, the inclination is equal to 15°, 30° and 45° and height of the ridge (the distance between the channel and the roof tile) is equal to 5 cm, 10 cm and 15 cm. The reference configuration is a ventilated roof with the channel gap equal to 0.10 m, the inclination f equal to 30° and the height of the ridge equal to 0.10 m.

Air velocity and temperature profiles are reported for three channel sections, at 0.1 m, 3 m and 5.9 m from the entrance, and along three longitudinal sections: the top line (interface between wood and air) the bottom line (interface between the cement mortar and the air) and the channel axis.

The Fig. 3 shows the velocity field in the ventilated roof. The values increase in the center part of the channel with the distance from the inlet section whereas they decrease near lateral surfaces because of the border effect. The maximum value is reached near the outlet section of the heated channel: there is a feeble slowing down due to the variation of the outlet section. The influence of the ridge on the velocity field is shown in the Fig. 4. The air velocity is affected by the heating along the channel: when the temperature increases, the density of the air decreases, so the fluid is lighter and tends rising faster the channel.

The Fig. 5 (a) presents temperature profiles along the transversal section of the air channel. The lower value of the fluid temperature within the channel is along the transversal section in the central zone of the section and the bottom surface is heated by the radiative heat transfer. The maximum value is in the outlet section, on the upper wall of the channel, which is the hottest part of the ventilated roof. In Fig. 5 (b), temperature profiles are shown along three different longitudinal directions: the walls and the axis of the channel. Profiles increase along the two solid surfaces, the upper and the bottom wall of the channel, and the temperature increases mainly in the lower zone. In central zone of the channel, the increase of air temperature is about linear.

4.1 Width of ventilation layer effect

The reference configuration is compared to two other configurations in which the channel width is the half and the double of first considered. In Fig. 6 (a), temperature profiles along the outlet section of the channel are shown for the three considered channel gap of the roof. Air temperature profile is strongly dependent on the distance between the solid walls, the upper and the bottom ones for all configurations. The difference of

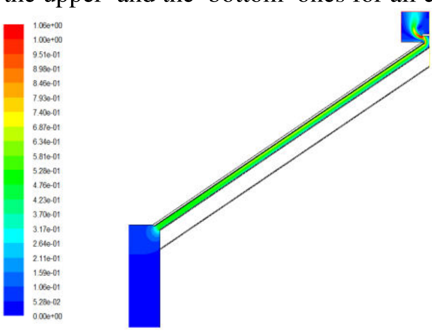


Fig. 3. Velocity field of the ventilated roof

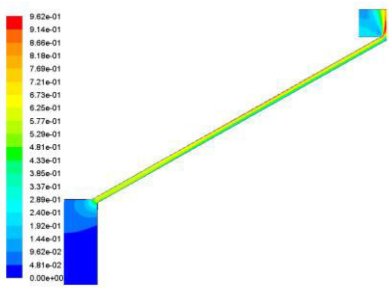
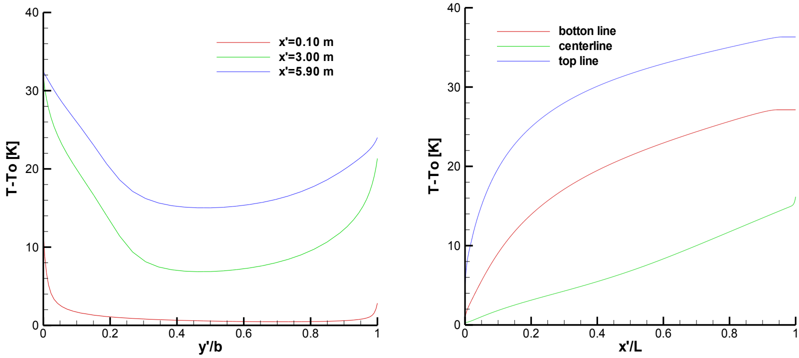


Fig.4. Velocity field of the ventilated roof without the ridge



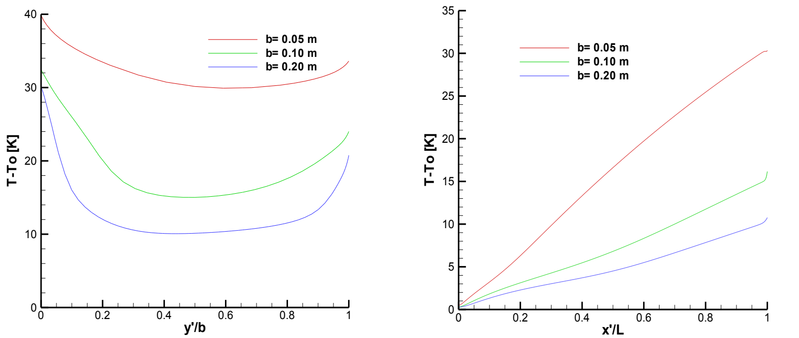
(a) Transversal section of the channel (b) Longitudinal directions of the channel

Fig. 5. Air temperature profile in the channel along: (a) transversal sections and (b) longitudinal directions

temperature between the walls and the fluid increases with the channel width. The effect of the width on air temperature along the longitudinal section of the channel is shown in Fig. 6 (b). The difference between the three temperature profiles is negligible in the inlet section of the channel, but in the outlet sections the difference is more noticeable halving and doubling the opening of the reference configuration.

4.2 Inclination effect

The reference configuration is compared to other two configurations in which the inclination of the channel gap is decreased or increased of 15°. Fig. 7 shows, respectively, the temperature rise at the outlet section, Fig. 7 (a), and along the channel axis, Fig. 7 (b). The difference is more marked



(a) (b)

Fig. 6. Air temperature profile in the channel along: (a) transversal sections and (b) longitudinal directions

when the inclination decreases, and the reason is the weaker chimney effect in the configuration with a smaller slope. Temperature difference is negligible when the inclination increases from 30° to 45°. Then, in warm season it is better a roof with a higher inclination, conversely in cold season it is better a roof with a smaller inclination.

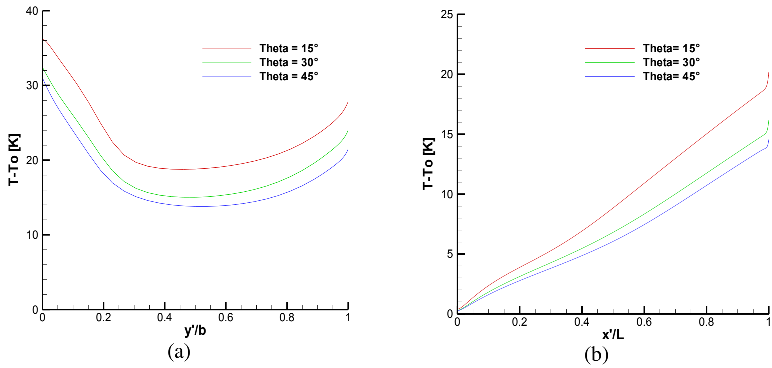


Fig. 7. Air temperature profiles: (a) outlet section, (b) along the channel axis

4.3 Height of the ridge effect

The last results concern the distance between the outlet section and the roof tile. The examined configurations are characterized by a height equal to 5 cm, 10 cm and 15 cm. Fig. 8 shows the velocity vectors of the fluid at the exit section of the channel. In all configurations, the fluid reaches the highest velocity values in the zone near to the lower wall of the ridge. Increasing the height of the ridge, the vortex near the outlet section moves toward the external ambient and it produces a reversal flow of the air motion inside the channel. The maximum value decreases as the ridge height increases, as shown in Fig. 9. Along the roof sections, velocity decreases near lateral surfaces because of the border effect. The maximum value is reached near the outlet section of the heated channel. Furthermore, as Fig. 10 shows, there is not a vortex near the outlet section, but the air moves vertically toward the external ambient.

4.4 Comparison with other types of roof

A comparison between different types of roof can demonstrate the benefits caused by the installation of a ventilated roof. The parameters under analysis are the temperature and heat flux exchanged by the lower surface of the roof and a configuration with a non-adiabatic lower surface is studied

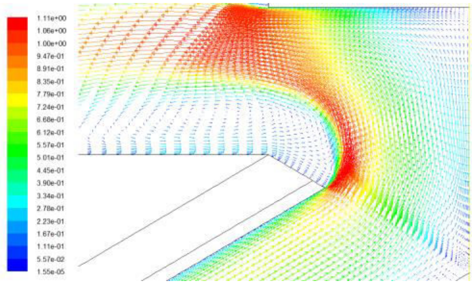


Fig 8. Velocity vectors at the outlet section for h equal to 10 cm

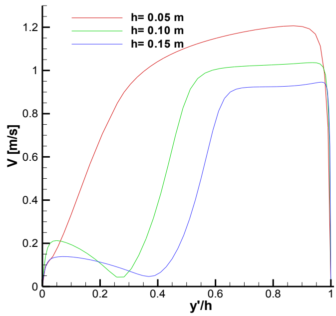


Fig. 9. Air velocity profile near the ridge

too. The operating condition are a heat transfer coefficient h equal to 10 W/m^2K and a temperature of the room under the bottom surface equal to 300 K. The base configuration, roof not-insulated and ventilated, R-NI-V, is compared with other three configurations: roof not-insulated and not-ventilated (no cavity), RNI-NV-NC; roof not-insulated and not-ventilated (with cavity), RNI-NV-WC; roof insulated and not-ventilated, R-I-NV.

In the first case, the roof is composed by only solid materials and there is not a channel or a cavity under the upper surface. In the second case, the inlet and the outlet section of the channel are closed so there is not the ventilation because of the presence of two gratings of aluminum. In the third case, the roof has an insulation panel of glass wool that covers the entire thickness (0.1 m) of the channel. The highest values of temperature and exchanged heat flux are related for the first and the second case, as shown in Table 1. In particular, the ventilated configuration presents the highest temperature and heat flux values and it is preferred because of the lower cost of installation and maintenance. Furthermore, a ventilated roof allows

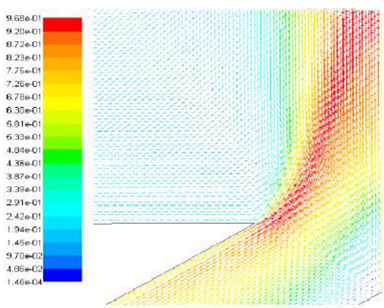


Fig. 10. Velocity vectors at the outlet section of the channel without the ridge

Table 1. Bottom layer temperature and incoming fluxes for the studied typologies of roof

	R-NI-V	RNI-NV-WC	R-I-NV	RNI-NV-NC
T-Ti [K]	2.5	8.3	1.8	10
Heat Flux [W/m^2]	27	84	17	102

to eliminate all effects related to the formation of condensation.

5. Conclusions

Changing geometrical parameters involved in the phenomenon, the analysis has revealed that the variation in opening channel changes strongly the fluid dynamics behaviors. The flow throttling is as pronounced as the distance between the walls of the channel is reduced. It causes a drastic reduction of the air mass flow rate in the channel, the air velocity increases, downstream the outlet section, due to a lower pressure drop. About thermal behaviors, the lowest temperature on the channel bottom surface is reached for channel gap is of 20 cm. The inclination effect on thermal behaviors, at constant opening and ridge height, indicates that an inclination angle increase determines benefits in terms of fluid dynamic behaviors, given higher mass flow rate and velocity. The channel internal temperature decreases because of an increasing chimney effect. If the ridge height is bigger than 10 cm, thermal and fluid dynamic behaviors have very low variations, at constant channel gap and heat flux. The differences are substantial for the lower height and, in this case, there are an increase of air velocity and a reduction of mass flow rate. The presence of the ridge can penalize the roof thermal performance, but the ridge is an important architectural element, above all to protect the channel from bad weather. The comparison between the ventilated roof and three other configurations shows that the lowest value of temperature and heat transfer rate toward the internal room, under the roof, are verified when the roof is isolated and not-ventilated. However, a ventilated roof allows reducing costs of installation and maintenance and eliminating water condensation problems.

Nomenclature

b	channel width, m	q	Heat flux, W/m^2
h	hipped roof height, m	Pr	Prandtl number,
k	kinetic energy of turbulence	T	Temperature, K
L	channel length, m	T_o	Environment temperature, K
L_x, L_y	reservoir dimensions, m	θ	Roof inclination, °

References

[1] M. Ciampi, F. Leccese, G. Tuoni. Energy analysis of ventilated and microventilated roofs. Solar Energy 79 (2005) 183-192.
[2] A. Dimoudi, A. Androutsopoulos, S. Lykoudis. Summer performance of ventilated roof component. Energy and Buildings 38 (2006) 610-617.
[3] G. Villi, W. Pasut, M. De Carli. CFD modelling and thermal performance analysis of a wooden ventilated roof structure. Build Simul 2 (2009) 215-228.
[4] B. Cerne, S. Medved. Determination of transient two-dimensional heat transfer in ventilated lightweight low sloped roof using Fourier series. Building and Environment 42 (2007) 2279-2288.
[5] P.H. Biwole, M. Woloszyn, C. Pompeo. Heat transfers in a double-skin roof ventilated by natural convection in summer time. Energy and Buildings 40 (2008) 1487-1497.
[6] K.T Zingre, M.P. Wan, S.K. Wong, W.B.T. Toh. Modelling of cool roof performance for double-skin roofs in tropical climate. Energy 82 (2015) 813-826.
[7] A. Dimoudia, S. Lykoudis, A. Androutsopoulos. Thermal performance of an innovative roof component. Renewable Energy 31 (2006) 2257-2271.
[8] S. Lee, S.H. Park, M.S. Yeo, K.W. Kim. An experimental study on airflow in the cavity of a ventilated roof. Buildings and Environment 44 (2009) 1431-1439.
[9] M.B Ozdeniz, P. Hancer. Suitable roof constructions for warm climates – Gazimagusa case. Energy and Buildings 37 (2005) 643-649.
[10] N.L. Alchapar, E.N. Correa. Aging of roof coating. Solar reflectance stability according to their morphological characteristics. Construction and Building Material 102 (2016) 297-305.
[11] S. Tong, H. Li, K.T. Zingre, M.P. Wan, V.W.C. Chang, S.K. Wong, W.B.T. Toh, I.Y.L. Lee. Thermal performance of concrete-based roofs in tropical climate. Energy and Buildings 76 (2014) 392-401.
[12] S. Tong, H. Li. An efficient model development and experimental study for the heat transfer in naturally ventilated inclined roofs. Building and Environment 81 (2014) 296-308.
[13] S. Ebrahim, A. Alshyji. Reducing solar heat gain from inclined buildings' roof by using radiant barrier system. Excerpt from the Proceedings of the 2013 COMSOL Conference in Rotterdam.
[14] J. Kosny, K. Biswas, W. Miller. S. Kriner. Field thermal performance of naturally ventilated solar roof with PCM heat sink. Solar Energy 86 (2012) 2504-2514.
[15] S.N. Kharrufa, Y. Adil. Upgradng the building envelope to reducing cooling loads. Energy and Buildings 55 (2012) 389-396.
[16] P. La Roche, U. Berardi. Comfort and energy savings with active green roofs. Energy and Buildings 82 (2014) 492-504.
[17] B.E. Launder, D.B. Spalding. The numerical computation of turbolent flow. Comput Meth Apll Mech Eng 3 (1975) 269-289.
[18] Fluent Incorporated, Fluent 6.1. User manual. Lebanon(2003). New Hampshire.
[19] W.M. Rohsenow, J.P. Hartnett, Y.I. Cho. Handbook of Heat Transfer. McGraw-Hill Handbooks, Third Edition. McGraw-Hill.
[20] ANSYS-Fluent Inc. Ansys-Fluent 12.2 manuals. Ansys ed. 2012.