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Study of a particular stack performance in a building.

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Abstract. Natural ventilation has gained prominence in recent times as a method of ventilating buildings. The two fundamental principles of natural ventilation are stack effect and wind driven ventilation. This paper describes a particular stack performance realized in a building (school) at real scale by computation of the wind induced ventilation and a comparison of the stack performance (airflow rate extracted and wind speed) respect to other systems (wind catcher, wind jetter and wind turbine) are also showed. The realization of the system, actually working, shows the synergy between a plant design and installation using traditional energy sources with innovative engineering techniques providing for the use of integrative energy. In this case, the wind action plays an important role for the conditioning of the school, integrating and giving a significant energetic contribution to the air cooling system. The school building (a nursery) has been built in Modena and is actually working.

Key words

Wind driven ventilation; stack; airflow.

1. Introduction

The energy saving and the use of renewable energies inside the buildings is the principal argument of the new "Parlament and European Council executive on the energetic efficiency in building", which sets the lowest objectives in terms of energetic efficiency of the buildings with an integrate approach. This approach takes in account not only the quality of the thermal insulation but also the kinds of system used, the possibility of cogeneration, the use of integrative energies, the natural ventilation systems and others.
In our country, almost the 30% of the total energy produced is used by the civil area. This situation underlines the good potentiality of performance in this area, considering also that the most of the buildings built during the years 1960/70, (which in Italy represent a big percentage of the actual buildings), had been erected without taking in account the necessary devices to limit the energy consumptions. The efficient use of the energy in buildings, together with the application of technologies using renewable sources, are today the key-instruments to improve the energy efficiency and to reduce the consumption of the fossil fuels and consequently the environmental pollution.
Therefore, it's important to evaluate the strategies to highly limit the needs of energy using not only passive techniques to optimize the contribution due to the climatic agents but also using materials and technologies which guarantee an high-level of performances in terms of thermal insulation and comfort. With this point of view the realization of the school cooling system , after a wind and climatic study on the in area, gives the chance to use wind energy directioned through particular air stacks. Therefore, the study has been focused to reach an efficient "free cooling" which gives the possibility to remove the heat inside the rooms.
Ventilation is changing of air in enclosed space. In domestic buildings the primary ventilation method is renewable in the form of air infiltration and natural ventilation through windows and openings. Natural ventilation uses the natural forces of wind pressure and stack effect to aid and direct the movement of air through buildings . The pressure differences inside and outside the building will drive airflow. Stacks effects are caused by temperature difference between the inside and the outside of buildings. This effect is dominant during periods of low wind speed and decreases in summer period when temperature differences are minimal. Several authors investigated about ventilation techniques. Khan showed a classification of wind driven ventilation types with their application and their typical airflow rates.
In the past to dissipate exhaust air into the atmosphere, chimneys were used and at their top were placed exhaust cowls using wind induction and stack effect. Cowls could be stationary or rotate about an axis so as to always have the opening facing the leeward side. This takes advantage of the partial negative pressure created when winds blow across openings or if cowl rotates. This paper shows an example of a wind chimney with a suction cowl placed at the top. This cowl has been executed taking into account the designs used in the past.

2. Materials and methods

The project of the nursery school built in Brodano, Vignola (Modena), has been thought on the basis of those principles. The SUD/NORD exposure of the more extended areas: the destination of the rooms SUD exposed as classrooms and nursery for children and (the destination) of the room NORD exposed as bathrooms (Fig.1); the realization of a portico in SUD direction with such a dimensions to guarantee, in summer, the shade on the glass surfaces and, in winter, their exposition to the sun; walls not only well-insulated but also with an high thermal capacity; a roof not only well insulated but also not absorbing the incident sun flow owing to a metallic cover; an air-chamber, with dimensions wider than the building perimeter, realized under the floor; these are all the solutions adopted with aim to limit as much as possible the active work of the system. Therefore, the systems dimensioned to realize inside the rooms the thermoigrometric conditions of project, had been thought with the idea to substain and to integrate the "passive" behaviour of the building. The good insulation of the whole building, realized by ecologic panels in fibrewood, requires a very low thermal power to the heating which very well agrees with the system typology chosen; not only, but the radiant panel is a "warm" element for the "cool" air which flows under the ground-floor floor and, therefore, the panel provides to warm it.

The ventilation system works to permit to the external air to flow freely not forced inside the rooms and (to permit) that the ventilation system starts only as support or integration to the natural circulation only in case that this natural ventilation is stopped.

The air flow from the stacks determines the entrance of the air flow from the lower zone through the air inlets placed in the SUD exposed rooms. The passage realized under the floor, become a real channel through the which the air flows from the NORD zone towards the SUD zone where two big air inlets are positioned.

The temperature of the air flow inside the rooms is checked and if it's value doesn't reach the fixed value (22°C in winter), the thermoventilation system starts. In the other areas, less frequented, the ventilation is realized through the opening of the glasses. The air flow inside the air stack is due to the different temperature which occurs between the chimney core and outside. The air flow is also conditioned by the effect of the resistence R and therefore the mechanical energy equation in this case is:

$$g \cdot \Delta H \cdot \frac{v_i - v_e}{v_e} = w_u{}^2 / 2 + R$$

(J/kg)

where:

DH is the height of the stack (m)

g is the gravity acceleration = 9.81 (m/s^2)

v_i is the specific volume of the air inside the stack (m^3/kg)

v_e is the specific volume of the air outside (m^3/kg)

w_u is the air flow leaving the stack (m/s)

R is the concentrated and/or distributed head loss (J/kg).

Neglecting the specific volume variations due to the pressure and taking in account the variations due to the temperature differences we obtain the section value of the stack in function of the volumetric rate $\dot{V}$ by the equation:

$$\mathbf{A = K}\ \dot{V} / \sqrt{\mathbf{DH}}$$ where:

K is the empiric coefficient which takes in account the differences of temperature inside and outside, the head loss inside the stack and the wind effect.

Fig.2 shows the cowls used and placed (on the roof of the building) at the top of the chimneys. The cowls consisted of a metallic flue, throat and wind vane. The throat and wind vane rotated around a vertical axis, always backing the wind while the flue is fixed. The cowl is 2.00 m above the ground roof. The diameter of the flue is 0.5 m. The cowl is also equipped by a nozzle (length 0.5 m) placed at the back see Fig.3. The nozzle, facing the wind, acts balancing the cowl position respect to the variation of the wind direction and also improves the stack effect enhancing the air suction. The software used for modelling is Fluent 6.1. Simulation is carried out to evaluate the field motion and to determine the cowl performance and to compare it with other ventilation systems.

The general result as expected is that the ventilation performance is primarily influenced by wind speed and direction .

3. Results

Simulations are carried out to evaluate the field motion, to determine the cowl best performance and to compare it with other ventilation systems. Simulations have been carried out varying the stack design to determine it's best performance. Therefore: a) different inlet and outlet rays of the nozzle; b) different wind speeds; c) different lengths of the flue have been simulated to obtain the best performance respect to the air rate extracted. The stack is assumed to extract air from an environment at a constant atmospheric pressure. The amount of air for unit of time (kg/s) has been measured taking into account the extracted air rate (pressure inlet), the inlet section of the nozzle (nozzle air rate) and the outlet section of the stack (total air rate), to validate the continuity equation (the mass conservation).

Fig.4 shows the rate of air extracted respect to the areas ratio (inlet and outlet area). A peak is evident in correspondence of the 9 numerical value.

Tab.1 shows that the highest air rate extracted is obtained using the nozzle model 9/3. Considering that the stack has a flue, simulations are carried out varying the length of the flue from 0 to 7 m and taking into account the design without nozzle and with the nozzle 9/3.

Results in Tab.2 and in Fig.5 show that with the nozzle 9/3 and with the flue of 1.5 m of length, the performances of the system are enhanced. The wind speed is 3 m/s constant.

Further simulations have been carried out to study the system performances during air suction, varying the wind speed from 1 m/s till 7 m/s and using two different configuration of the stack: a) with nozzle 9/3 and b) without nozzle. Fig. 6 shows a linear trend for both the

configurations. The highest difference, considering the rate of air sucked, is found with a wind speed of 5 m/s.
Simulations were carried out by different size of length and diameters of the flue (250 and 400 mm) and different wind velocities (1,3,4,5,6 m/s). Results are summarized in Tab.3. Fig. 7 shows the simulation of the airflow rate (l/s) extracted at various external wind speed (m/s)., for four different types of system (wind jetter, wind catcher, cowl and wind turbine). Results show a linear relationship with increasing wind speed and extracted flow rate. The air flow rates extracted by cowl are comparable with other systems in providing adequate ventilation. However, irrespective of wind speed the air flow rates do change according to the wind direction and this may imply a lack of tolerances to turbulent wind conditions and also present unpredictability when calculating flow rates for sizing purposes.

4. Conclusions

The general result as expected is that the ventilation performance is primarily influenced by wind speed and direction .
In conclusion on these simulation results the cowl is appropriate for reducing cooling loads in summer and more than adequate for providing ventilation. Therefore, systems using natural and hybrid ventilation may be a real chance and not a pure theoretical hypothesis. These systems, in fact, may guarantee adequate changes of air with low energy consumption. The stack under study has been also realized, for wind driven ventilation, in a building (school) located in Northern Italy (Modena).
However these results are based on CFD simulation and the absence of much field data is an incentive for further research .

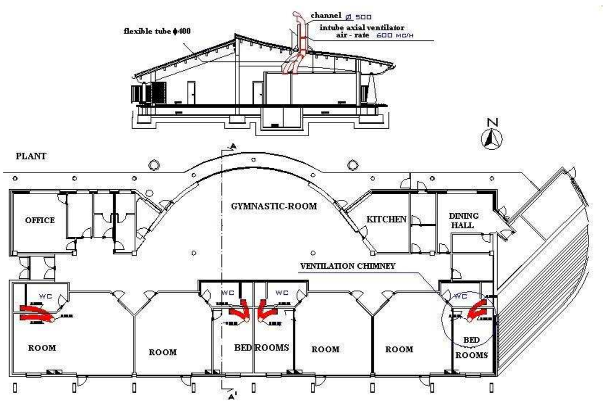

Fig. 1. Plant of the building.

Fig. 2. Vue of the cowls.

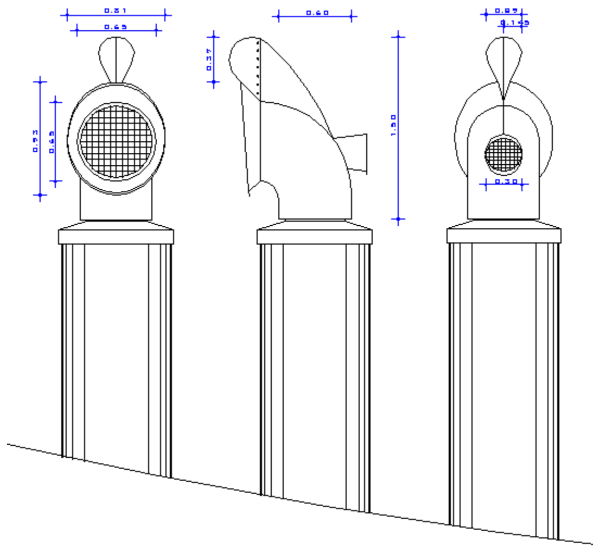

Fig. 3. Vue of the cowls.

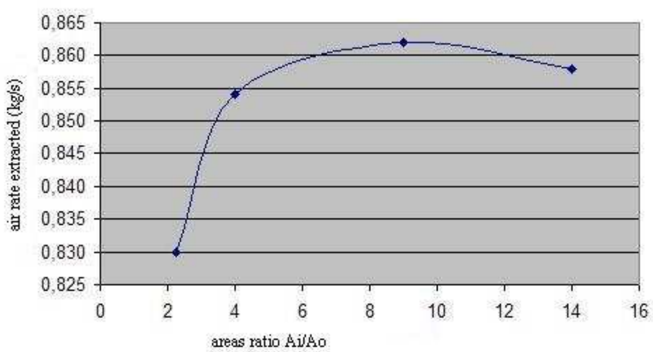

Fig.4. air extracted

nozzle	Areas ratio Ai/Ao	Wind speed (m/s)	Air rate Extracted (kg/s)	Nozzle (kg/s)
6/2	9	3	0,884	0,006
9/3	9	3	0,886	0,013
12/4	9	3	0,874	0,026
15/5	9	3	0,862	0,038
18/6	9	3	0,848	0,054

Tab.1

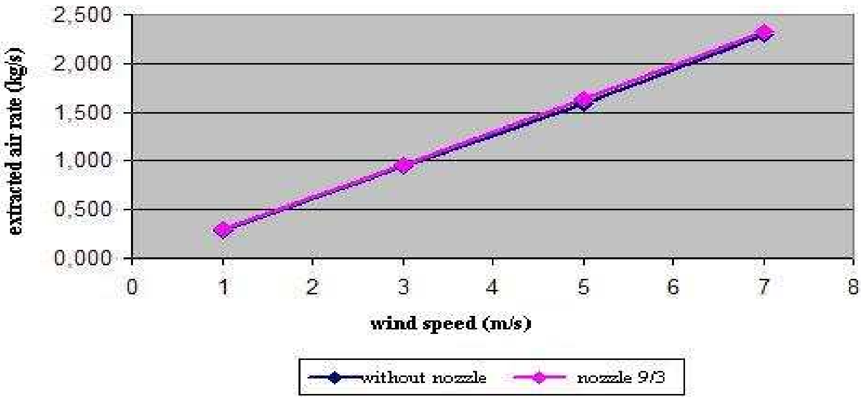

Fig.6

nozzle	areas ratio Ai/Ao	flue lenght (m)	wind speed (m/s)	air rate extracted (kg/s)	nozzle (kg/s)	total (kg/s)
-	-	1,5	1	0,289	-	0,289
-	-	1,5	3	0,938	-	0,938
-	-	1,5	5	1,594	-	1,594
-	-	1,5	7	2,303	-	2,303
9/3	9	1,5	1	0,306	0,006	0,312
9/3	9	1,5	3	0,954	0,013	0,967
9/3	9	1,5	5	1,634	0,020	1,654
9/3	9	1,5	7	2,324	0,028	2,352

Tab.2

nozzle	areas ratio Ai/Ao	flue lenght (m)	wind speed (m/s)	air rate extracted (m/s)	nozzle	total (kg/s)
-	-	0	3	0,888	-	0,888
-	-	1	3	0,943	-	0,943
-	-	1,5	3	0,938	-	0,938
-	-	3	3	0,916	-	0,916
-	-	5	3	0,888	-	0,888
-	-	7	3	0,860	-	0,860
9/3	9	0	3	0,886	0,013	0,899
9/3	9	0,5	3	0,932	0,013	0,945
9/3	9	1	3	0,948	0,013	0,961
9/3	9	1,5	3	0,954	0,013	0,967
9/3	9	2	3	0,946	0,013	0,959
9/3	9	3	3	0,924	0,013	0,937
9/3	9	5	3	0,902	0,013	0,915
9/3	9	7	3	0,868	0,013	0,881

Tab.3

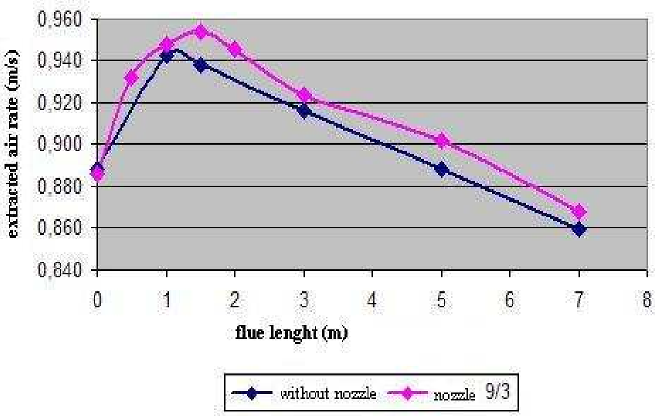

Fig.5

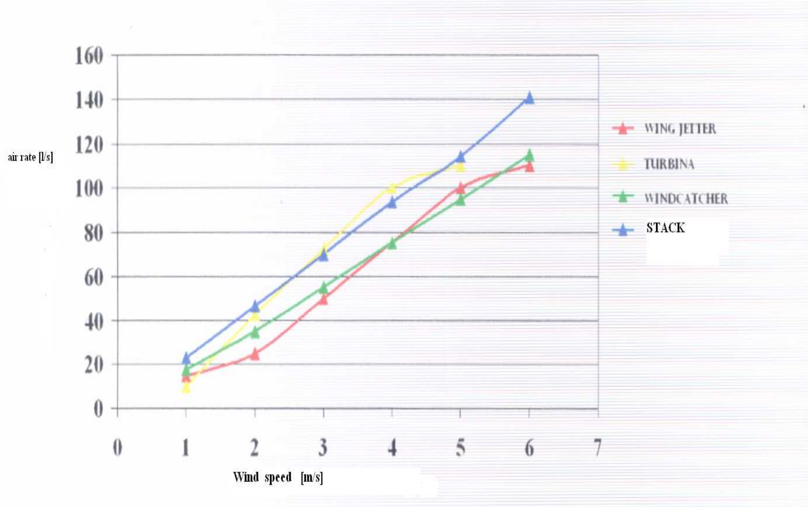

Fig.7

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