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An Experimental Investigation on the Air Permeability of Passive Ventilation Grilles

F.R. d'Ambrosio Alfano[a], G. Ficco[b], B.I. Palella[c], G. Riccio[c,*], A. Ranesi[a]

[a]*Dipartimento di Ingegneria Industriale (DIIn),Università degli Sudi di Salerno, Via Giovanni Paolo II 132, 84084 Fisciano, Italy*
[b]*Dipartimento di Ingegneria Civile e Meccanica (DICEM), University of Cassino, Via G. Di Biasio 43, 03043 Cassino, Italy*
[c]*Dipartimento di Ingegneria Industriale (DII), Università degli Studi di Napoli Federico II, Piazzale Vincenzo Tecchio 80, 80125 Napoli, Italy*

Abstract

The need of increasing both energy saving and acoustic insulation has leaded to the design of lowest air permeability frames resulting in the worsening of indoor air quality. Moreover, sometime in several civil-use existing buildings (i.e. schools or houses, historical buildings) mechanical ventilation systems cannot be installed due to non-removable constraints. In these cases, passive ventilation grilles are a cheap and effective solution for the ventilation. This work deals with an in-depth experimental analysis about the air permeability values measured over a set of passive ventilation grilles available on the market. Obtained results often showed performances very far to those declared. This is not due to multiplicity of involved parameters affecting their behaviour rather to a lack of standardized test methods.

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1. Introduction

In several civil existing buildings where the installation of a mechanical ventilation system is almost impossible or handy, the air change rate needed for satisfying IAQ requirements is based on the natural ventilation. This means that airflows are due to the pressure gap between the indoor and the outdoor environment produced by the wind and the difference of temperature [1]. Usually, the air permeability exhibited by historical and new buildings is not enough to assure suitable and effective ventilation levels in living spaces [2]. On the other hand, in order to increase building

* Corresponding author. Tel.: +39 0817682298; fax: +39 0812390364.
E-mail address: riccio@unina.it

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energy performances as required by International regulations [3, 4] and to improve acoustic comfort at the same time, more closely fitting window frames are ever more widely used, with a consequent reduction of IAQ levels. A clear symptom of this phenomenon is the increase in the number of rooms affected by moulds caused by humidity for condensation [5] and the increase of pathologies such as asthma and allergies [6, 7]. A cheap and simple solution is the application of ventilation grilles to the window frames on the blind cases, on the overhead bar or between the bar and the glass. Ventilation grilles, in fact, increase windows air permeability and natural ventilation with no risk of infiltration of insects, rain or draughts. These systems are named in various ways: window ventilators, grilles, trickled ventilators, window air inlet, air vent [8]. Ventilation grilles are classified into:

- ✓ Active grilles, provided with small electric fans producing, locally at least, a forced ventilation;
- ✓ Passive grilles, where the airflow is due to the pressure drop between the indoor and the outdoor environment in addition to the typical pressure drop of the grille itself. These devices are further classified into:
  - Simple, where the ventilation rate can be manually adjusted by varying the cross flow section;
  - Self-regulating, provided with a pressure drop sensor which controls the cross section of the grille to obtain a nearly uniform air flow;
  - Humidity-sensitive, provided with a humidity sensor, which controls the cross section by means of a special damper. In this way, the adjustment ability is related to a further indoor microclimatic parameter.

Despite these interesting features, such devices are widely diffused especially in Northern European countries (e.g. France, Netherlands, Germany and so on) whereas they are not so well known in Southern ones. In addition, although several Standards specify test methods for these devices [9-11], their effectiveness under real conditions was not investigated in the past and the few papers available in literature deal only with their soundproofing behaviour [12] or the optimization of the control system [13].

In this paper, which finalizes a research project started some years ago [14], the authors assessed the performances of a wide set of ventilation grilles, by designing and developing a specific experimental campaign. Obtained results will be useful to compare the real performances of some ventilation grilles presently available on the market and to start an in-depth discussion focussed on the need for verify the performances declared by manufacturers.

2. Experimental campaign

Ventilation grilles can be schematised as openings (or valves in case of self-regulating and humidity-sensitive grilles) placed in the wall separating two environments at different air pressure. The air flow rate is related to the pressure drop between the two environments and the local friction loss due to the grille. From a theoretical perspective, a systematic study on the grilles performances, would require an in-depth knowledge of the constructive peculiarities and the measurement of the air thermo-physical quantities (e.g., pressure and temperature). Anyway, for a first analysis aimed to assess the performances declared by the manufacturer is enough measuring the air flow rate as a function of the pressure drop applied. To this purpose a special apparatus consistent with the specification of EN 13141-1 and EN 12141-10 Standards [9, 11] has been designed and realized. The experimental campaign was focused on a set of 32 ventilation grilles (labelled from 1 to 32) produced by six International manufacturers (labelled from A to F) on sale in Italy including 19 simple, 10 self-regulating and 3 humidity-sensitive models, as summarized in the table 1.

Table 1. Summary of investigated grilles. S = Simple; SR = Self-Regulating; HS = Humidity-Sensitive.

No.	Manufacturer	Type	No.	Manufacturer	Type	No.	Manufacturer	Type	No.	Manufacturer	Type
1	A	SR	9	C	SR	17	B	S	25	E	S
2	A	SR	10	C	SR	18	B	S	26	E	S
3	A	SR	11	C	SR	19	C	HS	27	E	S
4	A	S	12	C	HS	20	C	HS	28	E	S
5	A	S	13	D	S	21	C	SR	29	E	S
6	B	S	14	A	S	22	C	SR	30	E	S
7	B	S	15	A	S	23	D	S	31	E	S
8	C	SR	16	A	SR	24	E	S	32	F	S

2.1 Experimental apparatus

The experimental apparatus has been designed for carrying out air flow rate measurements in the range from 10 to 300 m^3h^{-1} with pressure drops values between 1 and 50 Pa. Its core [14] is a cubic chamber 1 m^3 in volume (figure 1).

One side of the chamber is provided with a rectangular cross-section opening on which a grille holder is installed. On the opposite side, the aeraulic circuit connection allows a continuous air flow due to a special fan (F). This circuit is provided with two valves (V1 and V2) allowing the continuous air-flow adjustment and an anemometer (A) for air-flow rate measurements. The air flow rate was evaluated by measuring the mean air velocity inside the duct (d = 100 mm) by means of a fan anemometer with a relative expanded uncertainty of 2% at a probability level of about 95% in the range 0.25 ÷ 5.00 $m \cdot s^{-1}$ (Before the experimental campaign, all measuring devices have been calibrated at LAMI, the Industrial Measurements Laboratory of the University of Cassino and Lazio Meridionale, accredited by ACCREDIA, the Italian Accreditation Body). Inside the chamber the presence of a baffle (B) avoids the direct air flow between the frontal cross-section of the grille and the inlet of the aeraulic circuit. Finally, the measurement of the pressure drop through the grid is obtained by a digital differential micro-manometer (M) with a relative expanded uncertainty of 1 % at a probability level of about 95% in the range ± 200 Pa, and the air temperature inside the chamber by a calibrated platinum thermoresistance Pt 100 (T).

To verify humidity-sensitive grilles performances, the chamber is provided with a special device able to control the relative humidity level. It consists of a closed circuit in which a small flow of air reaches the moisture imposed and then is fed into the sensitive element of the grid. The set point value of the relative humidity has been kept by using the saline solutions method [15-17] for which the saturated vapour pressure of a saturated solution is less than that of the pure solvent. The attainment of steady state conditions in the humidity control loop has been verified by measuring continuously the temperature and relative humidity through a Thermal Comfort Data-logger, calibrated with an expanded uncertainty of 1.5% U.R. at a probability level of about 95% in the range 20-90% U.R. at 20 °C. Usually, the system takes less than a couple of hours to achieve the set point value of the relative humidity for all used saline solutions.

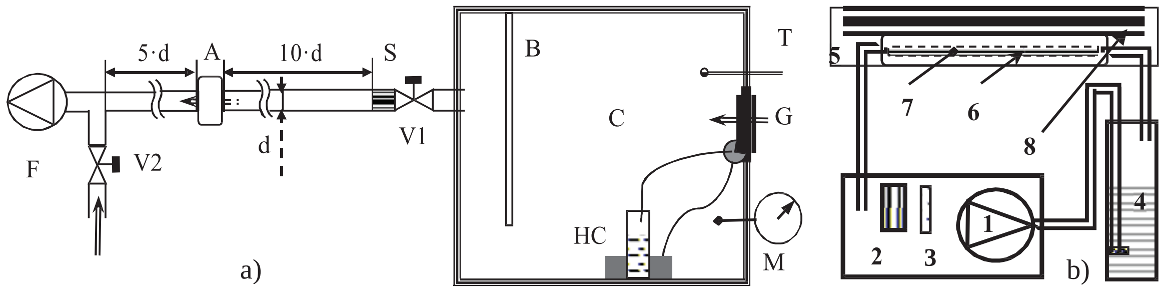

Fig. 1.a) Experimental apparatus. F: Fan; d: duct inside diameter; V1: flow control valve; S: flow straightener; A: anemometer; V2: bypass valve; C: cubic chamber; B: baffle; T: thermometer; G: grille; HC: humidity control apparatus; M: differential pressure gauge - b) HC. 1: fan; 2: thermometer; 3: hygrometer; 4: saline solution; 5: grille; 6: airtight screen; 7: grille element sensitive to moisture; 8: air outlet slot of the grille.

In order to verify the airtight of the whole apparatus, two leakage tests have been carried out: i) the first by simultaneously occluding the grille holder opening and depressurizing the whole system; ii) by simultaneously sealing each tested grille and depressurizing the chamber the latter. Any remarkable leakage has been detected up to pressure drops of 1000 Pa that is over typical operating values.

2.2 Experimental runs

To evaluate the air flow rate at each fixed Δp value, five measurements of the air velocity inside the duct were carried out as steady conditions were attained. The average velocity value has been calculated by averaging three measured values (maximum and minimum values were excluded). The final air flow rate has been then evaluated by multiplying the air velocity by the duct cross section area. Each grille has been investigated in the whole operating range from 5 to 50 Pa of pressure drops with a 5 Pa step. In case of manual grilles each measurement was repeated by changing its position (if allowed) whereas for humidity-sensitive by changing the relative humidity value. According to the need of a high reproducibility, each run was repeated three times (by alternatively increasing and decreasing Δp values). Thus, a set of over than 200 runs has been carried out.

3. Results and discussion

In figure 2, the behaviour of a typical manual grille provided with a three-position manual adjustment at the maximum opening value, is depicted. As clearly shown, an excellent reproducibility of measurements has been obtained with a very low deviation of the measured air flow rate (1 $m^3 \cdot h^{-1}$ on average and less than 3 $m^3 \cdot h^{-1}$ for the maximum and minimum imposed pressure drops).

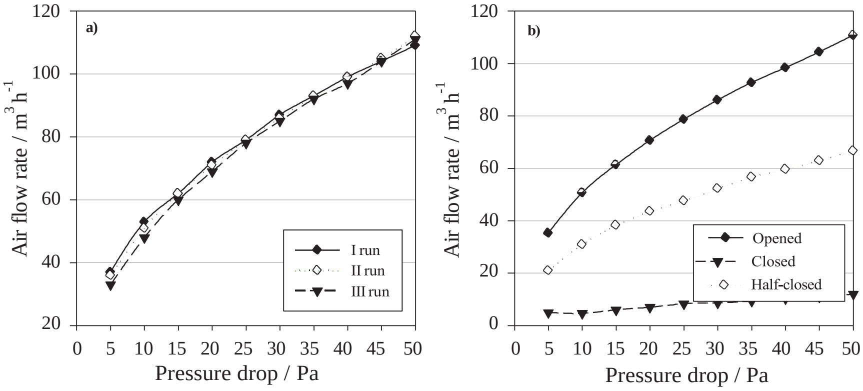

Fig. 2. (a) Reproducibility of the air flow measurements over the simple grille number 14 for an assigned cross section opening. (b) Effect of the grille opening level on the air permeability measured over the simple grille number 14. Each curve is obtained by averaging the measurements recorded in 3 different runs.

Figure 2 also reports the typical effect of the imposed pressure drop on the measured air flow rate over a simple grille by changing its opening cross section. According to these results, it is clear that the simple grille allows an even little air flow also when it is closed (5÷12 $m^3 \cdot h^{-1}$ depending on the pressure drop). Moreover, for both opening levels (half-opened, opened), the air flow rate grows up of about three times (from 21 to 67 $m^3 \cdot h^{-1}$and from 35 to 111 $m^3 \cdot h^{-1}$, respectively) by increasing 10 times the pressure drop. The measurements carried out on the devices labelled as “self-regulating ventilation grilles”, highlight two different behaviours (I and II, respectively) with respect to the pressure drop as shown in figure 3.

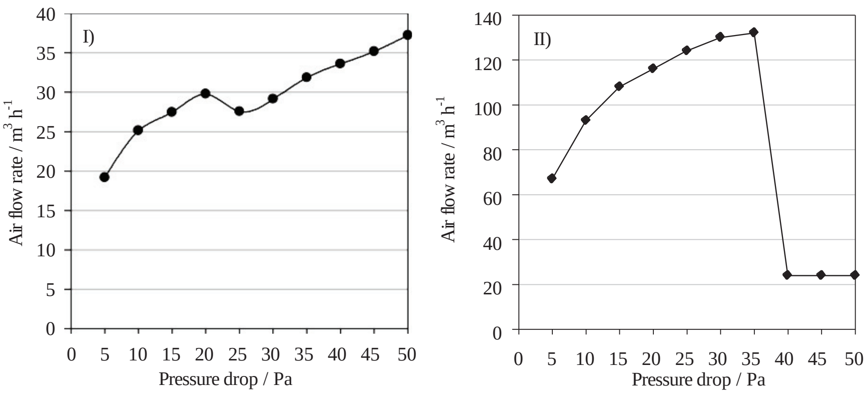

Fig.3. Mean air permeability values measured for the self-regulating grilles.

Type I grilles exhibit a continuous air flow adjustment with the increasing of the pressure drop (figure 3a), in fact the air flow only doubles (from 19 to 37 $m^3 \cdot h^{-1}$) by increasing 10 times the pressure drop. On the contrary, type II grilles (also labelled by the manufacturer as "self-regulating") are not able to implement a continuous air flow regulation within the entire range of pressure drop investigated values. In fact, this grille allows only a limitation of the maximum air flow rate (see figure 3b). Concerning humidity-sensitive grilles, the typical behaviour of these devices in figure 4 as a combined function of both imposed relative humidity (R.H.) and pressure drop is reported.

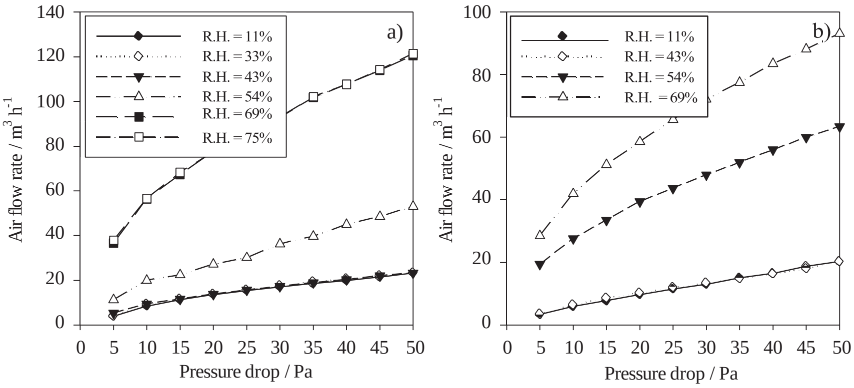

Fig.4. Combined effect of the relative humidity and the pressure drop on the air flow rate of the humidity-sensitive grille number 19 (a) and 20 (b). Each curve is obtained by averaging the measurements recorded during 3 different runs.

As clearly shown in the figure 4, all tested grilles exhibit a common range (from 43 to 69%) of humidity values for which the regulation is effective. Outside this range, the opening of grilles remains unchanged as clearly demonstrated by the overlapping of curves in the figures. Finally, the even little air flow rate increase observed at lowest relative humidity values, is probably due to the poor airtight of the grille damper.

In table 2 the deviation between measured and declared air permeability values has been expressed in terms of percentage deviation (when only a permeability value is declared) or averaged percentage deviation of the air flow rate (if data declared by the manufacturer are referred to a range of air flow rate and pressure drop values).

Table 2. Percentage difference between declared and measured air permeability. HS=Humidity-sensitive; S= Simple; SR=Self-regulating; MB=manual behavior.

No.	Type	Deviation	No.	Type	Deviation	No.	Type	Deviation	No.	Type	Deviation
1	SR	≤ 20 %	9	SR	≤ 20 %	17	S	(*)	25	S	(*)
2	SR	MB	10	SR	> 20 %	18	S	(*)	26	S	(*)
3	SR	MB	11	SR	> 20 %	19	HS	≤ 20 % for RH < 54 % > 20 % for RH > 54 %;	27	S	(*)
4	S	≤ 20 %	12	HS	> 20 %	20	HS	≤ 20 % for RH < 54 % > 20 % for RH > 54 %;	28	S	≤ 20 %
5	S	> 20 %	13	S	(*)	21	SR	≤ 20 %	29	S	≤ 20 %
6	S	≤ 20 %	14	S	≤ 20 %	22	SR	(*)	30	S	> 20 %
7	S	≤ 20 %	15	S	≤ 20 %	23	S	(*)	31	S	≤ 20 %
8	SR	≤ 20 %	16	SR	> 20 %	24	S	> 20 %	32	S	> 20 %

(*) Technical data from manufacturer not available

According to the above reported results, only 8 manual grilles on a base of 19 investigated show a deviation between the measured permeability and the one declared by the manufacturer below 20%, whereas 4 (No. 5, 24, 30 and 32) exceed 20%. For the remaining 7 investigated manual grilles technical data from manufacturer were not available. As far as self-regulating grilles is concerned, only 4 grilles (No. 1, 8, 9, 21) on a base of 10 exhibit a deviation lower than 20%. The others show deviations much higher than 20%. Moreover, two grilles classified by the manufactures as self-regulating (No. 2 and 3) exhibit a typical manual behaviour (MB). In fact, such grilles were equipped with a manual closing device operating at highest pressure drops. Humidity-sensitive grilles finally show a heterogeneous behaviour: two (No. 19 and 20) exhibit a bearable deviation only in the range of humidity where the regulating action was effective (33% <RH< 54%), whereas outside of this range they both show a deviation higher than 20%. On the contrary, the remaining grille (No. 12) shows a deviation much higher than 20% in the whole investigated U.R. range.

4. Conclusions

The installation of passive ventilation grilles in naturally ventilated buildings has been suggested by the need to reach an acceptable compromise between a good indoor air quality, plant ventilation costs and the energy saving. In order to reach this aim through a suitable design of the passive ventilation system, the knowledge of the whole of parameters affecting the ventilation grilles permeability seems to be a crucial matter.

The testing campaign here discussed, and carried out according to the existing standards, revealed a significant discrepancy between performances declared by the manufacturer and those measured. Additionally, in some cases the differences appear meaningful especially in case of self-regulating grilles, which are theoretically able to minimize the effect of outdoor climatic conditions on the air flow. It is noteworthy remind that some ventilation grilles labelled by the manufacturer as "self-regulating" show a behavior similar to that exhibited by manual grilles. In these cases the only difference revealed by our experimental runs was the presence of a limit pressure drop value giving rise the grille closing with the consequent air flow cut. The only grilles able to allow a continuous air flow adjusting, appear too much sensitive showing in any case an air flow increasing of 50% of the minimum value for a pressure difference less than 20 Pa. Therefore, for such device great efforts in terms of design are required, aiming to reduce as much as possible the permeability variation range. Moreover if we take into account that humidity-sensitive grilles can be used in all environments characterized by a higher humidity level (i.e. kitchens, toilets, bedrooms), it would be desirable a self-regulating behaviour so that the air permeability is only affected by the relative humidity.

Finally, our results highlight the need to suggest manufacturers to certify their own products according to the existing standards.

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