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Modeling large openings with COMIS

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Abstract

Conjunction of Multizone Infiltration Specialists (COMIS) is a model that can be used to simulate air flow and pollutant patterns in a multizone structure. Experimental data from air flow measurements in single sided naturally ventilated spaces, common in urban environments, and from cross-ventilated spaces, are compared against predictions from COMIS. The single sided ventilation experiments were performed in a full scale building and a test cell, which led to the definition of a correction factor for COMIS. Cross-ventilation experiments were performed in two zones of a full scale building. Results from both experimental and calculated data using COMIS were in good agreement. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: COMIS; Ventilation; Openings

1. Introduction

Natural ventilation is an effective technique for cooling in buildings, by extending the human thermal comfort zone as a result of higher indoor velocities [14,24]. Higher indoor air velocities, up to a certain limit, may be acceptable under summer conditions [19]. Natural ventilation through large openings is distinguished in single sided and cross-ventilation. For single sided ventilation, all space openings are located on the same wall or there is only one opening in the space. In this case, thermal buoyancy and wind induced pressures are the driving forces of ventilation. For cross-ventilation, openings are located on different wall sides of the space. In this case, the indoor air flow is strongly influenced by the wind characteristics, the location of the openings and it directly depends on the pressure differences at the various openings.

Experimental studies on single sided ventilation configurations carried out in wind tunnels, scale models and real buildings have shown, that the effects of turbulence are significant in single sided ventilation [2,10,17,23,32]. It has been shown [21], that the mechanisms of wind induced single-opening ventilation are pulsation and wind pressure eddy distributions. Cockroft and Robertson [7] and Warren [30] described this phenomenon as an adiabatic compression and expansion process of the indoor air. Cockroft and Robertson [7] have assumed an isotropic turbulence and a Gaussian probability distribution for wind velocity and flow rate. They have proposed a simple theoretical model, which, according to their data, gives a good agreement with experimental results. Narasaki et al. [23] reported that this model has little applicability when the incident angle is away from zero. Haghighat et al. [16], Rao et al. [25] have proposed models to calculate the pulsation flow in multizone buildings due to fluctuations of wind induced pressures. They use the concept of aerodynamic admittance functions to modify the wind pressure spectra in order to represent the average fluctuating pressures over the area of the opening.

El Telbany et al. [11,12] used computerised fluid dynamic, CFD, techniques to study the flow between a cavity and external air stream and have found good agreement with experimental studies. The same authors [22] have studied the transfer rates in single sided ventilation using CFD modelling and they have determined the magnitude of the variations associated with changes in parameters defining the configuration. However, for practical design assessment purposes, the use of CFD models is not appro-

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priate due to the complexity of the modelling procedure, the uncertainty of the limit conditions and the difficulty in describing real conditions.

For cross flow natural ventilation configurations, the difficulty in predicting the flow is mainly due to the uncertainty in the pressure coefficients of the openings, which is a major area of research [15]. Prediction of the ventilation rates, for design assessment purposes, is a complex problem. Simplified empirical models [5,10], offer general correlations to calculate the air flow. These expressions combining the air flow with the temperature difference, wind velocity and a fluctuating term, are deduced from specific experimental data, but can not be considered of general validity. Therefore, they should always be used within the limits of their applicability.

The Conjunction of Multizone Infiltration Specialists—COMIS [13], is a multizone air flow model created by specialists from various countries from around the world, including China, France, Greece, Italy, Japan the Netherlands, Spain, Sweden, Switzerland and the United States (Annex 23). It is a network prediction model, like AIRNET [29], BREEZE [4], ESP [6], NORMA [26] and PASSPORT-AIR [8], which are based on pressure boundary conditions. Network prediction models, combine the effect of wind and buoyancy to calculate pressure differences across nodes in the air flows between the building zones and the outside environment. However, these models consider a steady wind blowing towards the opening and neglect the turbulent effects and the corresponding fluctuating pressures. Therefore, though the indoor pressure increases as a function of wind velocity, the ventilation rate remains constant. COMIS accounts for cracks, duct system, fans, volumes, layers, vertical large openings, source and sink pollutant, and pressure coefficients of facades. COMIS handles turbulence effects by an equivalent pressure difference profile and effects of reduction of the effective area of the aperture represented by a single coefficient. It can also account for linear density stratification on both sides of a vertical opening [1], thus providing more accurate predictions for cases when the role of density stratification should not be neglected.

This paper presents the results of three extensive experimental studies on the performance of single sided and cross natural ventilation through large openings, and compares experimental data with the predictions from the COMIS model. This work was partly performed in the framework of the IEA-ECBCS Annex 23 program, for the validation of COMIS [18] against experimental data, mainly for infiltration, from 10 different buildings and 12 other simulation programs.

2. Single sided ventilation experiments

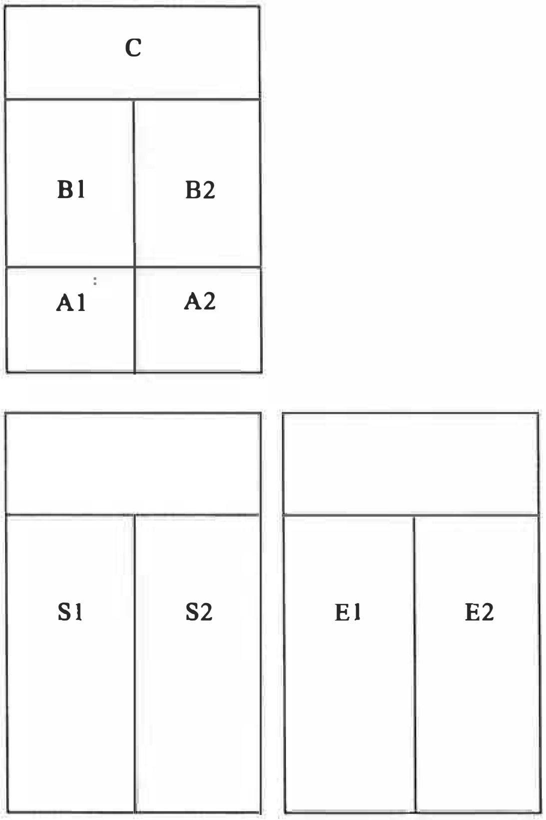
Single sided natural ventilation experiments were carried out in a full scale building and two Test Cells, one in Greece and one in Belgium. In Greece, a total of 49 single sided ventilation experiments were held at the building of the Institute of Meteorology and Physics of the Atmospheric Environment, at the National Observatory of Athens (NOA) site [9]. Additionally, four experiments were held in a PASSYS Test Cell outdoor facility [28]. The results are discussed in Section 2.1. The experiments carried out in Belgium were performed in an identical Test Cell facility. A total of 144 measurements were collected over a 4-day period. The results from this set of experiments are presented in Section 2.2.

2.1. Experiments in Greece

The first set of experiments were performed in the NOA building, which is a one-storey, naturally ventilated, office building, located in an open urban environment on top of a hill across from the Acropolis of Athens. Each floor is about 4.5 m high. The ventilation experiments were held in two independent offices, on the first floor of the building. The selected office rooms were isolated from the rest of the building and their thermal behaviour were constantly monitored. The first room, zone A, has a 13.59-m^2 floor area, with a 3-m length. The only external window (W1) is on the west external wall of the room and is divided in five independently operable parts, namely A1, A2, B1, B2 and C, as shown in Fig. 1. This unique design offers the possibility of varying the effective area of the window, by opening different parts. The total window area is 2.5 m^2. The area of each part of the window is identified in Fig. 1. One internal door connects the room where the experiments were performed, with an adjacent office room, which was kept closed and sealed during the experiments. The second room that was used for the experiments, zone B, has a 26.41 m^2 floor area. There are two external windows in zone B, one on the east wall (W2) and one on the south wall (W3), with the same area, 2.05 m^2, each. Fig. 1 illustrates the two windows in zone B. Only the two large sections for each window are operable, while the upper part of each window does not open.

The second test of single sided ventilation experiments were carried out in the PASSYS Test Cell, which is a fully equipped outdoor facility for thermal and solar monitoring [28]. The test cell is divided in two rooms, called the 'test room' and the 'service room', shown in Fig. 2. The service room, used for the experiments, has a floor area of 8.6 m^2, a length of 2.4 m and a height of 3.29 m. An external door, with an opening of 2.22 m^2 and a width equal to 1.01 m, connects the room with the outdoors. The service room is also connected with the test room through a 2.02 m^2 door opening, which is kept closed and sealed.

Thermal conditions in all spaces were constantly monitored, along with outdoor conditions from nearby meteorological stations. A detailed description of the experimental setup is available in Ref. [9]. The ventilation measurements were performed using a single tracer gas decay technique,



Section	Height (m)	Width (m)	Opening area (m^2)
A1	0.65	0.53	0.34
A2	0.65	0.53	0.34
B1	1.13	0.53	0.60
B2	1.13	0.53	0.60
C	0.62	1.06	0.66
W1			2.5

Section	Opening area (m^2)
S1	1.025
S2	1.025
S1+S2	2.05
Section	Opening area (m^2)
E1	1.025
E2	1.025
E1+E2	2.05

Fig. 1. Dimensions of the five independently operable parts window (W1), used during the single side experiments in Zones A (five-section window) and B (E on east facade and S on south facade) of the NOA building.

with N_2O as the tracer gas. Several injection and sampling points were carefully chosen and distributed at different heights inside the spaces, in order to supply the tracer gas homogeneously and also to monitor its spatial variation in the time period of the experiment. The sampling period was 30 s. Homogeneity was not difficult to achieve and under the most difficult conditions, mixing was satisfactory. Detailed description of the measurements and type of instrumentation used, is available in Ref. [9].

A total of 48 different single sided ventilation experiments were performed in both zones of the real scale building, opening different parts of the window in zone A and the different orientation windows in zone B, at different periods with different outdoor and indoor temperatures and wind speeds. The effective opening area, as well as the mean climatic conditions for each experiment are given in Table 1. A total of four experiments were performed at the test cell facility, following again the same general procedures. The measured mean climatic data during the experiments are listed in Table 2.

The measured air flow rates from the set of experiments performed in Zone A of the real scale building experiments were compared against the predictions from network models. A sensitivity analysis with regard to the predictions using network models for these single sided ventilation experiments focused on wind velocity, temperature difference between indoor and outdoor environment, surface and height of the opening and discharge coefficient (C_d). The wind speed was varied from 0 to 5 m/s, with a step of 1 m/s, the temperature difference varied from 0 to 5°C, with a step of 1°C, the surface of the opening varied from 0.5 to 2.5 m^2, with a step of 0.5 m^2, and the discharge coefficient varied from 0.4 to 1. All possible combinations were studied. The results of the sensitivity analysis and the impact of each parameter on the ventilation rate are summarised in the following discussion.

Air flow simulations have shown, that network model predictions for single sided ventilation configurations are not sensitive to wind speed variations [27]. This characteristic is actually a major source of inaccuracy for all

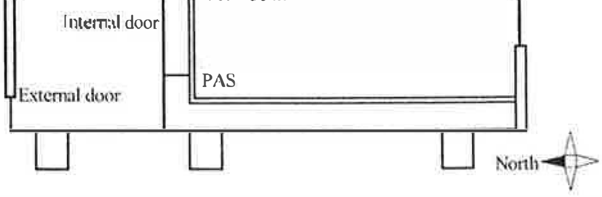


Fig. 2. Cross-section of the PASSYS test cell.

Table 1
Opening area and mean climatic conditions for single sided ventilation experiments in Zones A and B of the NOA building

Experiment no. (Zone no.)	Open window sections	Open window area (m^2)	Mean ambient temperature (°C)	Mean indoor temperature (°C)	Mean wind speed at 10 m height (m/s)
1 (A)	A1 + A2	0.68	31.3	31.4	6.8
2 (A)	B1 + B2	1.20	32.6	31.8	3.0
3 (A)	C	0.66	30.6	32.1	5.0
4 (A)	A2 + B2	0.94	32.5	31.8	6.7
5 (A)	A1 + A2 + B1 + B2	1.88	30.5	31.5	1.7
6 (A)	B1 + B2 + C	1.86	28.8	29.2	1.6
7 (A)	ALL	2.50	30.2	31.0	3.6
8 (A)	A1 + A2 + B1 + C	1.94	29.6	31.0	3.1
9 (A)	A1 + A2 + B2 + C	1.94	28.2	31.0	3.4
10 (A)	A2 + C	1.00	31.2	31.7	5.4
11 (A)	B2 + C	1.26	30.7	31.8	4.9
12 (A)	A1 + A2 + C	1.34	30.8	31.0	4.2
13 (A)	A1 + B1 + C	1.60	27.6	28.8	2.0
14 (A)	A2 + B2 + C	1.60	30.1	31.6	5.0
15 (A)	A2 + B1 + B2 + C	2.20	29.4	31.2	4.7
16 (A)	ALL	2.50	27	31.2	3.7
17 (A)	ALL	2.50	30.8	31.4	4.0
18 (A)	ALL	2.50	30.8	31.3	3.6
19 (B)	S1	1.025	32.2	33.1	3.4
20 (B)	S2	1.025	31.4	32.8	3.1
21 (B)	S1 + S2	2.05	30.6	32.8	3.1
22 (B)	E1	1.025	29.7	32.5	3.2
23 (B)	E2	1.025	28.7	32.1	2.9
24 (B)	E1 + E2	2.05	32.2	33.0	3.5
25 (B)	S1	1.025	31.1	33.1	3.7
26 (B)	S2	1.025	30.2	32.9	2.8
27 (B)	S1 + S2	2.05	34.9	34.1	3.2
28 (B)	E1	1.025	34.9	34.0	3.4
29 (B)	E2	1.025	33.4	33.6	3.2
30 (B)	E1 + E2	2.05	30.7	33.0	3.2
31 (B)	S1	1.025	29.0	32.7	3.2
32 (B)	S2	1.025	28.2	32.8	1.7
33 (B)	S1 + S2	2.05	32.3	34.0	3.8
34 (B)	E1	1.025	30.7	33.4	2.7
35 (B)	E2	1.025	30.4	33.2	1.6
36 (B)	E1 + E2	2.05	30.3	33.4	1.5
37 (A)	A1	0.34	34.3	33.0	3.6
38 (A)	A1 + A2	0.68	34.3	34.0	2.9
39 (A)	B1 + B2	1.2	34.1	33.9	3.4
40 (A)	A1 + A2 + B1 + B2	1.88	33.3	33.9	3.4
41 (A)	A1	0.34	35.1	33.4	4.5
42 (A)	A1 + A2	0.68	35.5	33.9	4.2
43 (A)	B1 + B2	1.2	35.6	34.1	4.1
44 (A)	A1 + A2 + B1 + B2	1.88	35.5	33.4	3.8
45 (A)	A1	0.34	33.7	33.1	4.0
46 (A)	A1 + A2	0.68	33.9	33.4	2.3
47 (A)	B1 + B2	1.2	34.0	33.4	2.2
48 (A)	A1 + A2 + B1 + B2	1.88	34.0	33.7	2.2

network models, since they neglect inertia forces. The air flow changes as a function of the square root of the absolute value of temperature difference between indoor and outdoor temperature. The air flow changes as a function of $H^{1.5}$, where H is the height of the opening. The width of the opening remained constant for the simulations. The predicted air flow is a linear function of the discharge coefficient.

The calculated air flow rates using network models, were obtained using a discharge coefficient set to unity. Compared to the corresponding measured data, the results were unacceptable with very large differences, especially for all the experiments with a large opening surface. When the calculated data were plotted against the measured volumetric flow rates, the correlation coefficient was 0.4. A closer investigation of possible correlation between the

Table 2
Prevailing climatic data during the single sided ventilation experiments at the test cell

Experiment no.	Mean ambient temperature (°C)	Mean indoor temperature (°C)	Mean wind speed at 10 m height (m/s)
1	24.1	23.4	3.35
2	24.7	24.3	2.51
3	25.7	26.2	3.82
4	25.6	26.6	3.56

observed differences between measured and calculated values as a function of the mean wind speed, wind direction and absolute indoor–outdoor air temperature difference during each experiment, revealed no clear dependence. However, for higher values of the wind speed, the measured values are much higher than the corresponding calculated values.

An analysis of the corresponding climatic parameters during the single sided experiments, has shown that the prevailing conditions are characterised by high wind speeds and small temperature differences between the indoor and the outdoor environment. These characteristics are actually very close to real conditions observed in naturally ventilated buildings in hot climates. Therefore, one should expect that the reported air flows would be dominated by inertia rather than by gravitational forces.

Following an analysis recommended by Warren [31], it was revealed that the available data is characterised by the dominance of wind rather than by stack effect [9]. To assess whether the observed differences between measured and calculated values can be correlated with indices describing the relative importance of the inertia and gravitational forces, led to the definition of a correction coefficient (CF) for each experiment, defined as:

$$\mathrm{CF} = \text{Mean measured air flow}/\text{Calculated air flow}$$

The CF coefficient can be calculated for single sided ventilation configurations using the following expression, which was empirically derived from the available experimental data [9]:

$$\mathrm{CF} = 0.08\left(\mathrm{Gr}/\mathrm{Re}_{\mathrm{D}}^{2}\right)^{-0.38}$$

where Gr is the Grashoff number ($= g\Delta \mathrm{TH}^3/T\nu^2$) and Re_{D} is the Reynolds number ($= \mathrm{VD}/\nu$). This expression predicts the correction factor with sufficient accuracy, especially when the conditions are not characterised by a significant wind speed and incidence angle fluctuations. The above expression for the CF model has been validated with data from various other localities, for wind speeds

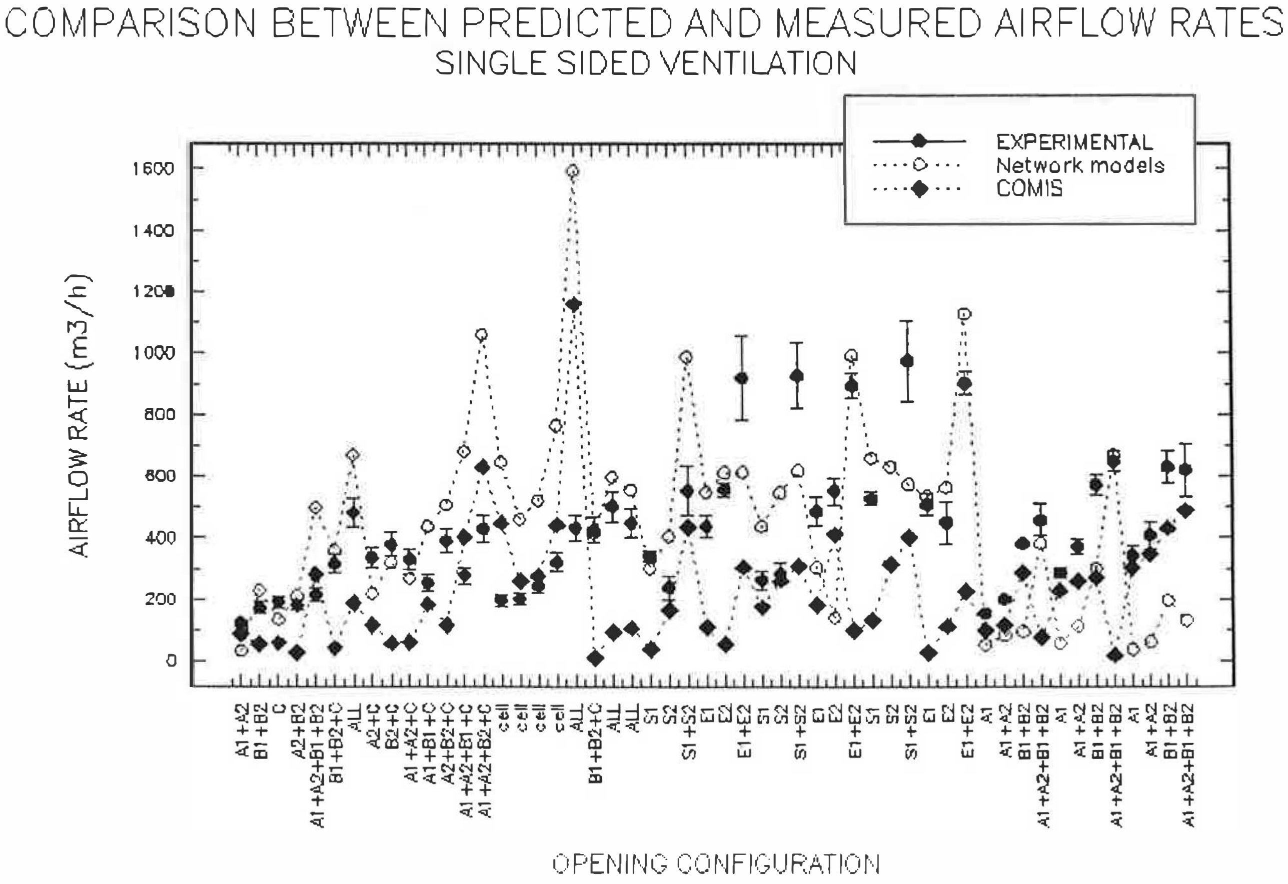


Fig. 3. Measured and calculated air flow rates using COMIS and a network model, for single sided ventilation experiments.

ranging from 2 to 10 m/s, prevailing wind directions from −60 to 60 degrees from the vertical to the opening, outdoor–indoor temperature differences from 0.5 to 8 C, and room depths from 3 to 7 m.

The calculated CF values for the single sided ventilation experiments in the real scale building, ranged between 0.31 and 8.8, while for the test cells, the CF values ranged between 0.76 and 3.66. Modifying the predicted values from COMIS with the CF factor, that is multiplying the predicted air flow rates with the corresponding CF values for each experiment, the results were improved considerably. The correction factor has already been integrated in COMIS. The results from COMIS, without the use of CF, are representative of results obtained from network type of models. Actually, all network models provide very similar results [9].

Fig. 3 illustrates the variation of the measured air flow rates for the experiments in the NOA building and the Test Cell, with the predictions from a network model (i.e., COMIS without the use of the correction factor) and from COMIS (using the CF correction factor). The correlation coefficient between the measured and calculated data from COMIS, is close to 0.7, while for a network model is close to 0.4. The difference between measured air flow rates and the predictions from a network model and COMIS, for all the single sided experiments in the real building and the test cell, are illustrated in Fig. 4.

The use of the correction factor has also been verified to improve the accuracy of predictions from other network air flow models [9]. The use of the CF coefficient for cases where inertia forces are more significant than gravitational forces, improves significantly the predictive capabilities of the various models. The CF coefficient, based on climatological and geometric characteristics of a given configuration can be easily integrated in existing (as it has already been done with COMIS) or future network models.

2.2. Experiments in Belgium

An identical PASSYS test cell, shown in Fig. 2, was also used for a series of experiments carried out in Belgium. The experiments were performed using both compartments of the test cell, for a total of 144 measurements over a four day period. A large vertical opening on the south facing reference wall (0.5 × 0.5 m) was used as a single opening in the two zone test cell. The internal door, between the two zones of the service and test room, was kept open.

The test cell is equipped with a mechanical heating and cooling system. In order to achieve large temperature

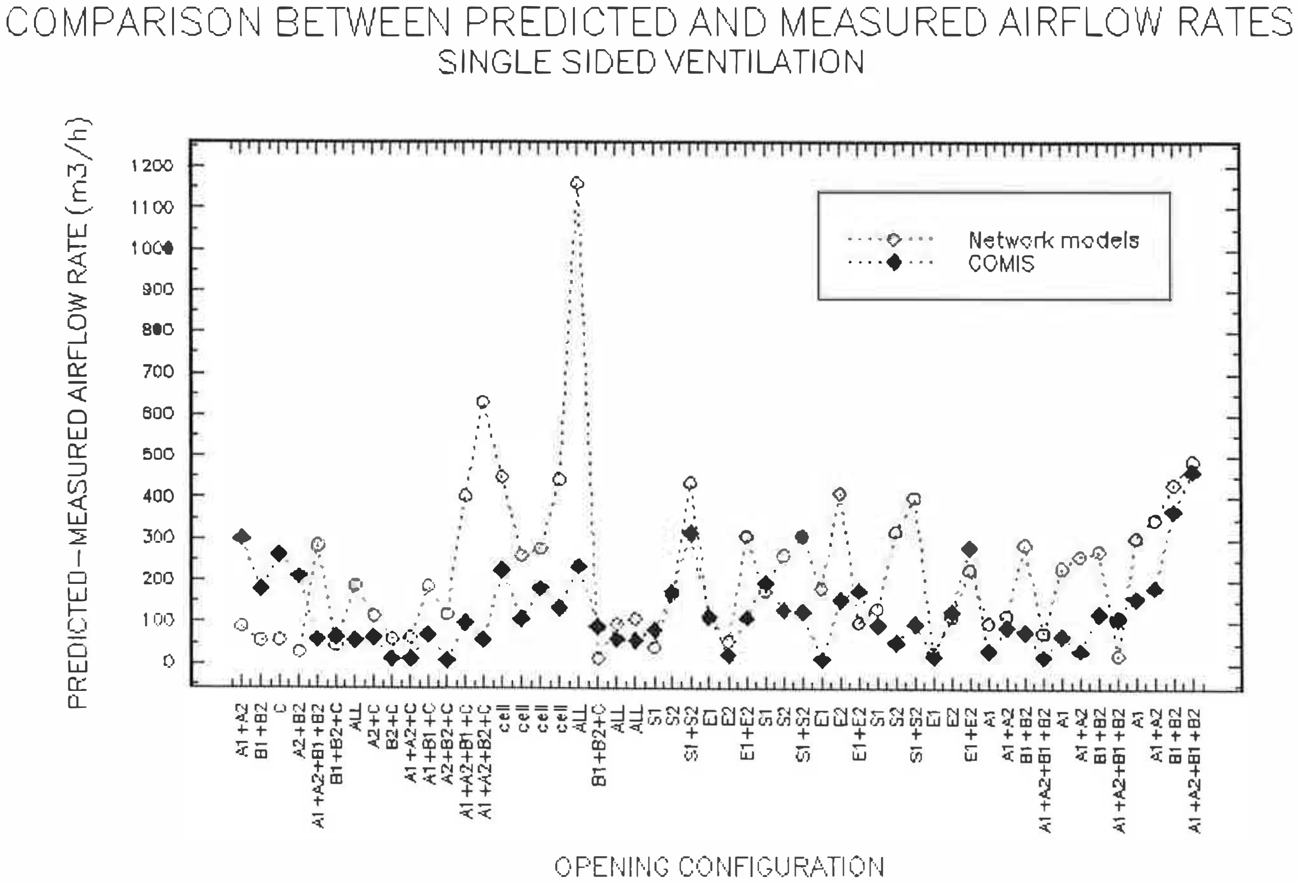


Fig. 4. Difference between measured air flow rates and calculated values using COMIS and a network model, for single sided ventilation experiments.

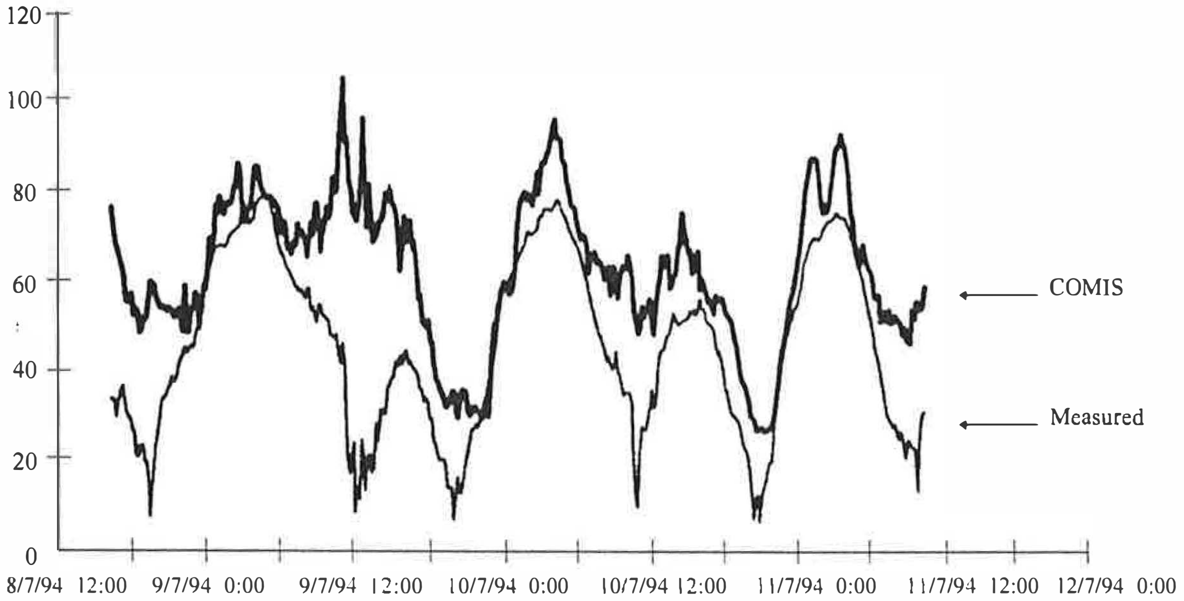


Fig. 5. Measured and calculated air flow rates using COMIS, through the external opening for single sided ventilation experiments in a 2-zone test cell.

differences through both openings, the mechanical system was used to heat the service room and cool the test room. Thermal conditions in both spaces were constantly monitored, along with outdoor conditions. A detailed description of the experimental setup is available in Bossaer et al. [3]. Two tracer gases were used for the ventilation measurements. R22 was continuously injected from eight different points in the service room, in order to secure good homogeneity, and SF6 in the test room through air distribution hoses. The time step between two measurements was 10 min. Detailed description of the measurements and type of instrumentation used, is available in Bossaer et al. [3].

The discharge coefficient was set at 0.6. The average values for the measured and simulated air flows through the external opening was measured at 64 m^3/h and estimated using COMIS at 47 m^3/h. The large differences are attributed to the fact that COMIS does not take into account the effect of the wind on the air flow rate through the opening. The predicted and measured data are in very good agreement when there is no wind. For the internal door, between the two zones, the results were in better agreement, since the measured values average 202 m^3/h and the COMIS predictions at 208 m^3/h. The complete results over the whole period are shown in Figs. 5 and 6, for the external and internal openings, respectively.

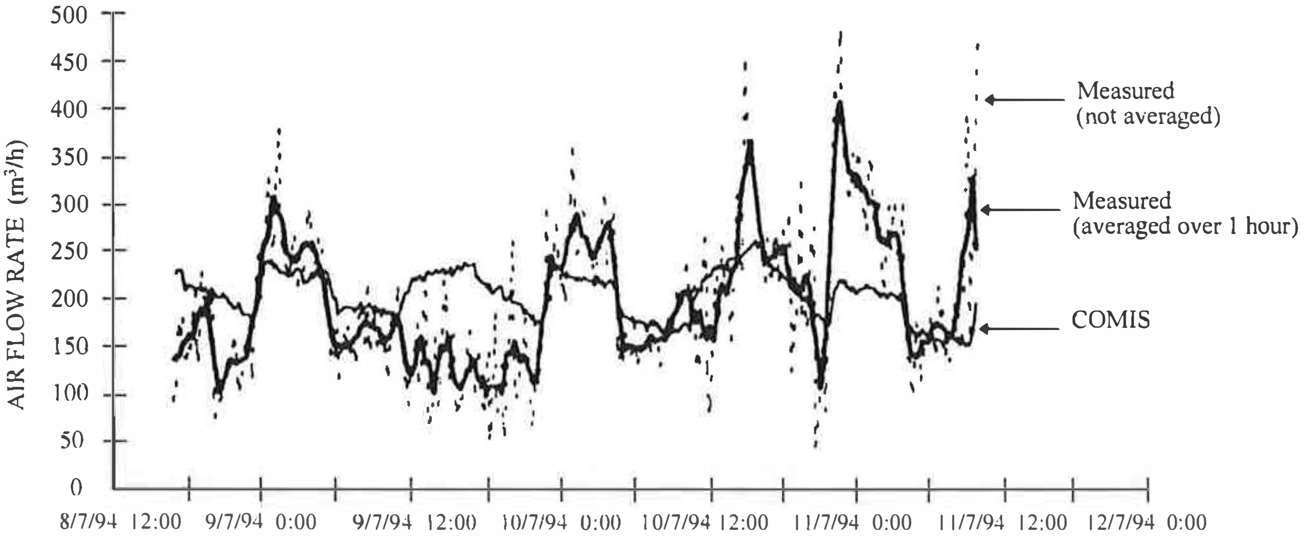


Fig. 6. Measured and calculated air flow rates using COMIS, through the internal opening for single sided ventilation experiments in a 2-zone test cell.

3. Cross-ventilation experiments

A total of six different experiments on cross-ventilation were carried out in two zones of a full scale building, located on the Ecole Nationale des Travaux Publics de l'Etat—ENTPE campus, in Lyon, France. This is a one-storey naturally ventilated building, housing the medical centre of the ENTPE-campus, located in a semi-urban environment. The building is approximately 20 m long and 9 m wide. Two zones in this building, shown in Fig. 7, were selected for the experiments. The air flow measurements were performed using a multiple-tracer gas decay technique, with R22 and SF6.

The two zones have the same volume (34.32 m^3) and the ceiling is at 2.6 m high. Each zone has one sliding window, 2.1 m wide and 1.1 m high. The lower edge of the windows are at 1.05 m from the floor. The maximum effective window area for ventilation purposes is 1.155 m^2. The windows are located on opposite sides, at two sheltered facades, as shown in Fig. 7. The two zones are connected through one door, with a 1.6-m^2 surface. The two zones are also connected to other adjacent zones by internal doors, which were kept closed and sealed throughout the experiments.

The indoor air temperature in each zone was monitored every minute, at the center of the zones at a height 1.3 m from the floor, using PT100 sensors. The outdoor conditions, including ambient temperature, relative humidity, wind speed and direction at a height of 7 m, were collected on a 5-min basis, from a nearby meteorological station, located approximately 100 m away from the test site. The gases were injected and sampled using the Bruel and Kjaer 1303 unit, analyzed using the Bruel and Kjaer 1302 unit and the results recorded by the B & K 7620 unit.

Two preliminary tests were performed, in order to determine the infiltration rates in the two zones and to determine whether gas homogeneity is achieved. The infiltration rate in each zone was measured, keeping all windows and doors closed and applying a classical gas decay technique. Accordingly, the infiltration rates were found to be negligible, averaging 0.3–0.4 air changes per hour (ACH). To test the gas homogeneity conditions, all windows and doors were kept closed and one tracer gas was injected in one of the two zones. The injection was then stopped and the gas concentration was measured at four different locations. The windows were then opened shortly and closed again, while monitoring the gas concentration. According to the results, homogeneity was achieved within 5–10 min.

Having performed these two preliminary tests, the ventilation experiments were then carried out. First, keeping all windows and doors closed, R22 was injected in zone 2, using the B & K 1303 unit. The SF6 was manually injected in zone 1. Small fans were used at the injection points in order to achieve good gas mixing. The concentrations of both gases in the two zones were monitored at two different locations, selected according to the preliminary tests, in each zone, as shown in Fig. 7. Once the internal gas concentration reached a certain limit (around 100 ppm), the gas injection was terminated. As soon as homogeneity was achieved, the internal door and both windows were opened for a short period (typically 1 min) and then closed again until a new homogeneity was achieved. This phase was repeated until the end of the decay.

Interzonal airflows were calculated for each opening sequence, solving the conservation of mass equations for each of the gases and for air. The gas concentrations measured just before the opening sequence were selected

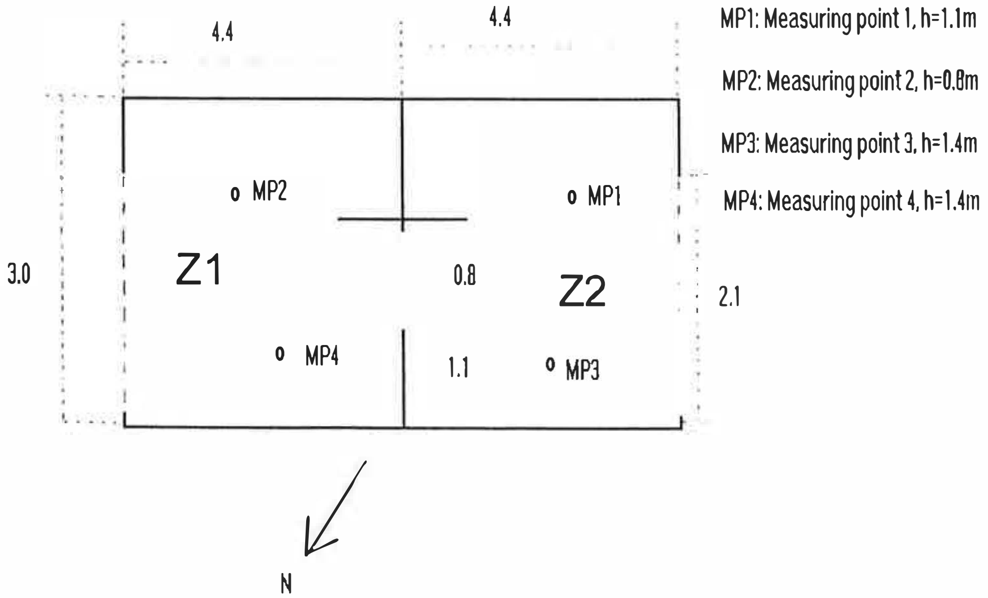


Fig. 7. Cross-section and location of the injection and measuring points of the tracer gas in the two zones, used for the cross flow ventilation experiments.

and used as the initial concentrations. The conditions for the final concentrations were the ones measured just before the next opening sequence. Having two measuring points in each zone, a total of four different data sets could be obtained (using points 1 and 2, 3 and 2, 1 and 4, and 3 and 4, respectively). The fifth data set was calculated as the average concentration values of the two measuring points in each zone.

This particular technique requires that air infiltration in each zone is negligible. This assumption was, however, not valid for the last opening sequence, when gas concentrations were typically lower than 15 ppm. This would have caused enormous errors or even negative values of experimentally calculated air flows. Therefore, only the first two to five opening sequences, depending on the opening area and wind speed, were analyzed.

A total of six different experiments were finally performed, as shown in Table 3. The experimental conditions were the same for all of them apart from the windows' opening areas. Three of them had exactly the same conditions, but were performed during three different days, with different outdoor conditions.

The meteorological data and measured indoor temperatures in the two zones, for each sequence and each experiment, are shown in Table 4. During the experiments, the outdoor wind speed was rather low, with a maximum value of about 3.0 m/s.

In order to compare experimental and calculated data using COMIS, the following assumptions were made. For the windows, the value of the discharge coefficient (C_d) was set at 0.85, while for the internal door the C_d value was set at 0.65. The corresponding pressure coefficients were calculated using a simplified model valid for low-rise buildings [20], corresponding to a long sheltered wall. The wind speed at the windows' level was calculated using the measured wind speed from the meteorological station, modified according to the Lawrence Berkeley Laboratory (LBL) air infiltration model wind profile [20]. The dependent parameters were evaluated for urban terrain, which results in a local wind speed reduction factor of 0.6804.

The measured and the corresponding calculated values using COMIS, of the total air flow from or out of each zone and the total outdoor air entering each zone, are shown in Fig. 8. The measured data correspond to the average value of the two measuring points in each zone. Part (a) illustrates the global measured and calculated flow rates for zone 1 and part (b) for zone 2, respectively. Part (c) illustrates the measured and calculated total incoming outdoor air. The prediction of the incoming outdoor air is the most accurate. The differences of the mass flow rates between zones 1 and 2 from the simulated global flows is usually below 180 m^3/h, although the measured differences are up to 700 m^3/h.

Table 3
Characteristics of cross-ventilation experiments

Experiment	Opening area zone 1 (m^2)	Opening area zone 2 (m^2)	Total number of analyzed opening sequences
1	1.155	1.155	3
2	1.155	1.155	5
3	0.506	0.583	3
4	0.891	0.891	2
5	0.275	0.275	1
6	1.155	1.155	4

Table 4
Measured meteorological and indoor temperatures during the experiments

Experiment, opening sequence	Wind		Temperature		
	Direction (deg)	Speed (m/s)	Outdoor (°C)	Zone 1 (°C)	Zone 2 (°C)
1,1	203	2.12	11.33	22.95	20.64
1,2	200	1.74	11.20	23.20	20.50
1,3	223	2.13	11.16	23.37	20.58
2,1	116	0.00	7.28	22.85	19.85
2,2	176	0.62	7.89	23.12	19.93
2,3	161	0.58	8.08	22.76	19.94
2,4	202	0.95	8.16	23.12	20.01
2,5	245	0.21	8.20	22.98	19.85
3,1	177	1.14	11.80	24.83	20.84
3,2	197	2.04	11.88	24.39	20.71
3,3	166	1.56	11.91	24.04	20.54
4,1	137	1.82	12.60	23.46	20.09
4,2	170	3.00	12.62	23.61	20.67
5,1	176	3.69	12.64	24.85	20.53
6,1	150	1.46	12.16	24.08	20.21
6,2	187	1.41	11.30	23.89	20.54
6,3	186	2.33	11.05	24.40	20.76
6,4	210	2.02	11.06	23.75	20.65

The comparison of measured and calculated global flows from or out of each zone results in reasonable correlations. Using the available data, a sensitivity analysis was also performed, resulting in some interesting conclusions, which are outlined in the following discussion. The analysis was performed using two different experiments, namely the second opening sequence from the fourth experiment, for which the measured wind speed is the highest from all experiments (the pressure coefficients on both facades are however almost equal: -0.25 and -0.178, respectively), and the fifth opening sequence from the second experiment, for which the measured wind speed was very low (but the pressure coefficient difference important: -0.304 and $+0.486$, respectively).

For the first case, with a high wind speed, the main fluctuations were due to the variations of the pressure coefficient values. Increasing the pressure coefficient difference by 0.2 (that is from 0.072 to 0.272) results in a 15% increase of both global flows (230 m^3/h). An increase of the pressure coefficient by 0.5 results to an increase of 60% or 950 m^3/h for both flows (905 m^3/h for zone 1 and 1024 m^3/h for zone 2, respectively). The dependency on wind speed was not found to be very

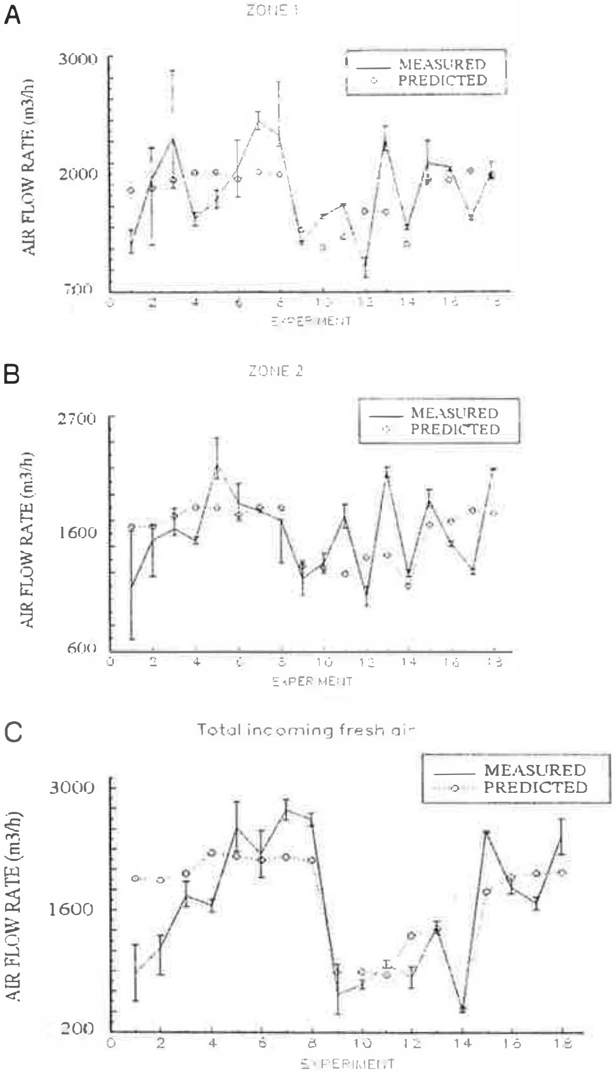


Fig. 8. Measured and calculated total mass air flow rates entering into (a) zone 1, (b) zone 2 and (c) to both zones.

important, as a result of the small difference between both pressure coefficients. Increasing the wind speed by 1 m/s results in an increase of both flows by only 5% or 80 m^3/h. The role of the outdoor temperature was also limited, as a result of the large difference with indoor temperatures. Increasing or decreasing the outdoor temperature by 1°C results in only a 2% change on both flows or ± 36 m^3/h. The impact of indoor temperature variations is much more important. Increasing (or decreasing) the temperature difference between both zones by 1°C results in an increase (or decrease) by 11% or 180 m^3/h in zone 1 and by 10% or 140 m^3/h in zone 2. Finally, the influence of the discharge coefficient is almost linear. Increasing by 0.1 the internal discharge coefficient results in an increase by 120 m^3/h of both global flows. Increasing by 0.1 one external discharge coefficient results in an increase by 95 m^3/h of the global flow from the corresponding zone.

For the second case, with a low wind speed, the pressure coefficients have almost no influence on the results. The wind speed on the other hand has a major impact. A 1 m/s increase results in an increase by 11% or 210 m^3/h of both flows and a 2 m/s increase results in unidirectional flows, with a global increase by 80% or 1670 m^3/h. The results with regard to temperature variations are almost the same as in the first case, although opening areas were slightly different. Again the outdoor temperature has a very small impact. Increasing or decreasing the outdoor temperature by 1°C results in a 2.5% or ± 50 m^3/h change of both flows. For the indoor temperature variations, the results were different. Increasing (or decreasing) the temperature difference between both zones by 1°C results in an increase of the flow coming in (or going out) by 9% or 180 m^3/h in zone 1 and by 7% or 130 m^3/h in zone 2. The influence of the discharge coefficient is similar to that of the first case.

4. Conclusions

Several single sided and cross-ventilation experiments through large openings, were performed in full scale buildings and test cells, to collect data and compare it against the corresponding calculated data from COMIS. The experiments for single sided ventilation were carried out in Greece and in Belgium, while the cross-ventilation experiments were carried out in France.

The single sided natural ventilation experiments in Greece, were performed with relatively high wind speeds and small temperature differences between the indoor and outdoor environment, the results from COMIS were in good agreement with measured data. COMIS, incorporating a correction factor, based on climatological and geometric characteristics of each configuration, can handle with good accuracy cases where inertia forces are more significant than gravitational forces. The single sided ventilation experiments in a 2-zone test cell, performed in France, have shown that COMIS provides good results at very low wind speeds. There are significant differences between measured and predicted air flow rates through a large opening when the prevailing conditions are high wind speeds. For internal large openings, this effect is quite small and there is a good agreement between measured and predicted values.

The cross flow experiments were performed with rather low prevailing outdoor wind speeds. Under this type of meteorological conditions, global flows were found to be reasonably well estimated by COMIS. Inaccuracies in pressure and discharge coefficients may cause significant errors in estimating the specific air flows at each opening between the zones and the outdoors.

5. Nomenclature

C_d	Discharge coefficient
CF	Correction factor

C_p	Pressure coefficient
D	Hydraulic diameter, room 'depth' (m)
ΔT	Temperature difference (°K)
F	Ventilation parameter
g	Acceleration of gravity (m s^{-2})
Gr	Grashof number
H	Vertical size of an opening (m)
υ	Air viscosity (m^2 s^{-1})
Re	Reynolds number
T	Absolute temperature (°K)
V	Wind velocity (m s^{-1})

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