Air Distribution in Rooms, (ROOMVENT 2000)
Editor: H.B. Awbi

13346

STUDY OF THE VENTILATION EFFICIENCY UNDER SOME TYPICAL AIR FLOW CONDITIONS IN A MECHANICALLY VENTILATED ROOM

S. CASTANET[1], C. BEGHEIN[2] and C. INARD[2]

[1]CETHIL, INSA, Bât 307, 20 av. Albert Einstein, 69621 Villeurbanne Cedex, France
[2]LEPTAB, Université de La Rochelle, av. Michel Crépeau, 17042 La Rochelle Cedex 1, France

ABSTRACT

The present study deals with indoor air quality and is mainly based on an experimental work.
The experimental set up is a full scale test cell with a ventilation system which comprises a fixed air supply and a mobile extract. A source of pollutant continuously supplies tracer gas at the centre of the cell. We carried out 12 tests under steady state and with various conditions. The test parameters were the exhaust location, the fresh air flow rate and the supply air temperature.
The analysis of the air temperature, air velocity and tracer gas concentration isovalues clearly show the effect of each parameter on the ventilation efficiency.

KEY WORDS

Ventilation efficiency, temperature efficiency, full-scale experiment, tracer gas, Archimedes number, Reynolds number, thermal length.

LIST OF SYMBOLS

A_0 supply jet area (m^2)
Ar_0 Archimedes initial jet number
Ce exhaust tracer gas concentration (mg/m^3)
Coc mean tracer gas concentration in the occupancy zone (mg/m^3)
g acceleration of gravity (m/s^2)
L_t thermal length of buoyant jet (m)
Re_0 Reynolds initial jet number
T_0 supply air temperature (°C)
Te exhaust air temperature (°C)
Toc mean air temperature in the occupancy zone (°C)
Top operative temperature (°C)
Tout outside air temperature (°C)
U_0 supply air velocity (m/s)
β thermal expansion coefficient (K^{-1})
ν kinematic viscosity (m^2/s)
ρ air density (kg/m^3)
ΔT_0 supply air temperature difference,
$\Delta T_0 = T_0$ - Toc (°C)

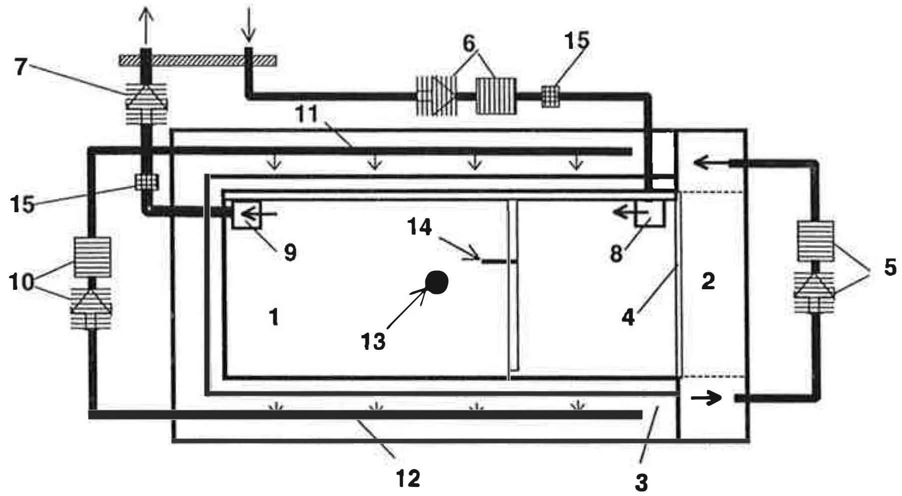
INTRODUCTION

The purpose of ventilation is to provide acceptable air quality indoors with an effective use of energy. Therefore, the ventilation rates in dwellings have been reduced for economical reasons and it is necessary to study whether this reduction has not been done to the detriment of indoor air quality.
This work, which is mainly experimental, makes part of a CNRS/ECODEV French Research Group "Ventilation and Air Quality in Dwellings". It deals with the ability of a ventilation system to settle a suitable indoor air quality for occupants according to different thermal and dynamic conditions.
We first present the experimental set-up, the conditions of the tests we carried out and then the experimental results obtained.

EXPERIMENTAL PROCEDURE

Experimental set-up

Experiments were carried out in a full scale test-cell of which a cross section is shown in figure 1.



1 : test cell, 2 : climatic housing, 3 : thermal guard, 4 : single glazing, 5 : climatic housing air handling unit, 6 : ventilation air handling unit, 7 : exhaust fan, 8 : air inlet, 9 : air outlet, 10 : thermal guard air handling unit, 11 : thermal guard air supply duct, 12 : thermal guard air exhaust duct, 13 : tracer gas (SF_6) source, 14 : velocity, temperature and SF_6 sensors, 15 : air flowmeter.

Figure 1 : Cross section of the test-cell used

This test-cell consists of a 24 m^3 (3.1x3.1x2.5 m^3) single volume of which the temperature is kept constant on five faces owing to another volume used as a thermal guard. The sixth face is in contact with a climatic housing which allows us to obtain air temperatures ranging from -5°C to +35°C with a good stability (±0.3°C).
The ventilation system has a fixed air supply and a mobile extract . Air supply temperature is controlled between +5°C and +35°C whereas supply and extract air flows could be set between 1 and 5 ach (air changes per hour).

2x9 K-type thermocouples distributed on the inner and on the outer surfaces of each of the six walls provide the thermal state of the envelope. At the centre of the cell, operative temperature is measured. Besides, air flow and air temperature are taken both at supply and extract. A source of pollutant continuously injects tracer gas (SF_6) at the centre of the cell.
A programmed system scans the vertical mid-plane of each zone so that temperature and velocity of the air (mean value over 3 minutes) and SF_6 concentration are automatically measured. Temperature is measured with a K-type thermocouple, velocity is measured with a TSI hot film omnidirectional anemometer and concentration is measured through photoacoustic effect (Brüel&Kjaer). The regular grid in the vertical mid-plane has an elementary mesh of 0.1x0.1 (m^2).
A more detailed description of the experimental set-up is available in Castanet (1998).

Experimental conditions

We carried out 12 tests whose parameters were :

- exhaust location (see figure 2)
- supplied air temperature ($\Delta T > 0$ and $\Delta T < 0$)
- supplied air flow rate (1 and 2 ach)

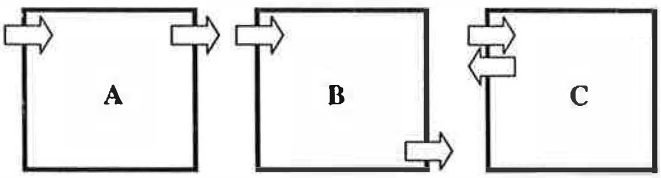


Figure 2 : Tested positions of exhaust

Table 1 gives the parameters of the 12 configurations tested. Initial Archimedes number Ar_0, Reynolds number Re_0 and thermal length (round jet) L_t are defined as follows :

$$Ar_0 = \frac{g\beta|T_0 - Toc|\sqrt{A_0}}{U_0^2}$$

$$Re_0 = \frac{U_0\sqrt{A_0}}{\nu}$$

$$L_t = \frac{\sqrt{A_0}}{\sqrt{Ar_0}}$$

The thermal length of buoyant jets is defined with the primary jet heat flow rate and momentum, Etheridge and Sandberg (1996), Malmström (1996), and can be compared to the room length which is sometimes more informative than the Archimedes number.

Furthermore, the inlet area being equal to 0.005 m^2, the supply velocity is ranging from 1.3 to 2.8 m/s depending on the ventilation air flow rate.
Experiments consist in setting a thermal configuration. When temperature and concentration steady state are obtained, 600 points of temperature, velocity and SF_6 concentration are measured in the vertical mid-plane of the cell. Each experiment is validated through both SF_6 mass balance and test cell thermal balance.
Lastly, in order to quantify indoor air quality, we calculated temperature and ventilation efficiencies, Etheridge and Sandberg (1996), Sandberg (1981). These efficiencies express the ability to respectively remove heat and pollutants.

TABLE 1
TESTED CONFIGURATIONS

	CONFIGURATION											
	A				B				C			
Test n°	1	2	3	4	1	2	3	4	1	2	3	4
a.r. (ach)	1.1	2.0	1.0	2.0	1.0	2.1	1.1	2.0	1.0	2.0	1.0	2.0
Tout (°C)	17.7	14.4	25.6	28.1	17.9	13.8	26.0	29.4	17.7	14.4	25.6	29.6
ΔT_0 (°C)	13.5	11.3	-10.6	-12.3	12.4	10.6	-10.7	-12.4	12.0	12.0	-11.2	-11.8
Ar_0 $x10^4$	151	35	144	41	155	32	134	42	149	37	142	39
Re_0	6983	13389	6919	14099	6594	13566	7205	13999	6632	13317	7186	14024
L_t (m)	0.58	1.20	0.59	1.10	0.57	1.25	0.61	1.09	0.58	1.16	0.59	1.13

The temperature efficiency is defined as :

$$\varepsilon_T = \frac{Te - T_0}{Toc - T_0}$$

Regarding pollutant removal, in this work, the pollutant source is located in the centre of the room, this thus implies that ventilation efficiency is expressed as follows :

$$\varepsilon_C = \frac{Ce}{Coc}$$

RESULTS AND DISCUSSION

Table 2 gives the experimental values of ε_T and ε_C for the 12 tests.
First, table 1 shows that the thermal length of the jet has always a value less than the mid-length of the room i.e. 1.55 m. Thus, beyond this distance, the jet behaves like a plume and in this case the buoyancy may have a great influence on the efficiency values depending on the ventilation configuration.

TABLE 2
EXPERIMENTAL VALUES OF ε_T and ε_C

	CONFIGURATION											
	A				B				C			
Test n°	1	2	3	4	1	2	3	4	1	2	3	4
ε_T	0.78	0.74	1.06	0.95	1.02	1.07	0.98	0.98	0.94	0.89	1.02	1.00
ε_C	0.60	0.54	0.95	0.84	0.98	0.94	1.04	0.98	0.93	0.74	0.95	0.94

For configuration B, the air is forced to pass through the occupied zone and therefore the temperature and ventilation efficiencies are close to unity (complete mixing value) under any experimental conditions whatever. For other configurations, one can see a thermal buoyancy effect for both temperature efficiency and for ventilation efficiency. Thus, with supply of warm air (tests A1 and C1), the jet does not penetrate the whole room and the flow exhibits a high short-circuiting (see figure 3). This phenomenon which is more pronounced for configuration A can be explained by the ventilation configuration (ceiling-ceiling) but also by the high density of the tracer gas which is equal to 6.3 kg/m^3.

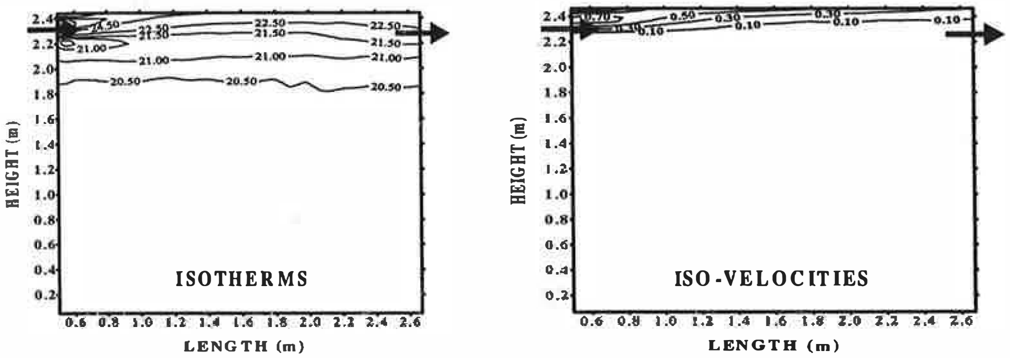


Figure 3 : Isotherms (°C) and iso-velocities (m/s) for test A1

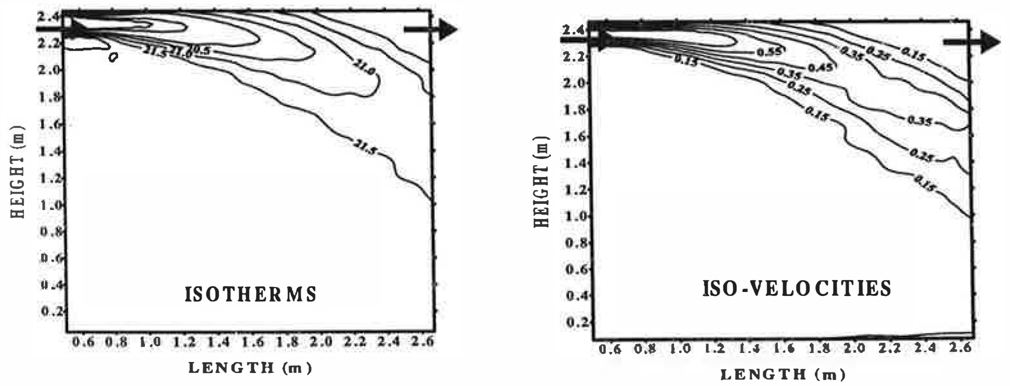


Figure 4 : Isotherms (°C) and iso-velocities (m/s) for test A3

With cooling and considering the low velocity of the air supplied, the jet separates from the ceiling and fall into the occupied zone (see figure 4) inducing a better mixing of the indoor air. The removal of heat and contaminant is therefore increased.
Furthermore, for these configurations only, one can see that increasing air flow rate results in decreasing ε_T and ε_C values. This is because of a greater short-circuit phenomenon induced by a higher momentum of the jet. The thermal length values give a clear explanation of this result since the ventilation efficiency values decrease when the thermal length values increase.
Lastly for A and B configurations, we can compare experimental values for the ventilation efficiency with typical ones given by Skaaret and Mathiesen (1982). For configuration A, the values given by the authors are ranging from 0.9 to 1.0 for cooling and from 0.4 to 0.7 for heating (ΔT_0 > 5°C). Concerning configuration B, the values are ranging from 0.9 to 1.0 whatever the air supply temperature.

CONCLUSION

In this study, we presented experimental results on temperature and ventilation efficiencies using various ventilation strategies. The main conclusion is that the ceiling-floor ventilation configuration always leads to efficiencies close to complete mixing configuration. On the opposite, the ceiling-ceiling ventilation configuration exhibits efficiencies very dependent on buoyant effect i.e. Archimedes and Reynolds initial jet numbers. In that way, we notice that increasing air flow rate does not increase ventilation efficiency.

ACKNOWLEDGEMENTS

This project has been possible thanks to French Department of Research and CNRS financial helps.

REFERENCES

Castanet S. (1998). Contribution à l'étude de la ventilation et de la qualité de l'air intérieur des locaux. *Thèse de Doctorat*, INSA Lyon, France

Etheridge D. and Sandberg M. (1996). *Building ventilation. Theory and measurement.* J. Wiley&Sons, Chistester, UK

Malmström T.G. (1996). Archimedes number and jet similarity. *Roomvent'96*, Tokyo, Japan, **1**, 415-422.

Sandberg M. (1981). What is ventilation efficiency? *Building and environment* **16:2**, 123-135.

Skaaret E. and Mathiesen H.M. (1982). Ventilation efficiency. *Environment Int.*, **8**, 473-481.