INTERNATIONAL ENERGY AGENCY
Energy conservation in buildings and
community systems programme

Development and evaluation of a new test method for portable air cleaners

A. Ginestet

Contributed Report 15

Air Infiltration and Ventilation Centre
Operating Agent and Management
INIVE EEIG
Lozenberg 7
B-1932 Sint-Stevens-Woluwe
Belgium

Contributed Report 15

Development and evaluation of a new test method for portable air cleaners

A. Ginestet

Acknowledgement
This report is republished with the authorisation of CETIAT (copyright)

CETIAT
Domaine Scientifique de la Doua
25, avenue des Arts - BP 52042
69603 Villeurbanne Cedex
FRANCE

www.cetiat.fr

Document AIVC-CR15
Year of publication: 2012

Table of contents

1. INTRODUCTION

Within the space of few years, indoor air quality has become of growing concern for many people. As a result, residential air cleaners have been proposed to a buoyant market and various air cleaners can now be found in the shops, either as stand-alone portable devices or as part of air-conditioning terminal units. Real technical advances have also been made. The first residential air cleaners to be sold were addressing specific indoor air quality (IAQ) problems such as odours or tobacco smoke. Now, most of the commercially-available devices are made up of various advanced filtering techniques (HEPA or electronic filters for particles, photocatalysis for VOCs and bio-contaminants, activated carbon or cold plasmas for gases, etc.), and thus can be considered as global solutions for IAQ improvement.

Apart from the issues of maintenance (frequency for the filters change for instance), energy consumption or noise, the main problem is that consumers don't have any information on the actual air cleaning efficiency of these systems in realistic configurations of building operation. Some standardised test methods exist (ANSI/AHAM AC-1-2006 in the United States **[1]**, JEM 1467 in Japan **[2]**) but the shortcoming is first that these methods overall focus on the problem of tobacco smoke, and secondly that they consider very high indoor pollution loads. Moreover, it has been shown that oxidising techniques and high-voltage electronic filters can contribute to yield secondary harmful products (aldehydes, ozone) in the indoor air. However, none of the existing test methods addresses this issue.

This study deals with a new test method to assess the air cleaning efficiency but also the harmlessness of residential air cleaners. It considers various kinds of contaminants (particles, gas, allergens and microorganisms) at concentrations that are representative of typical concentration levels found in indoor settings. The basis of this test method has been used to develop a new standard which has been published in France in 2011.

This report provides first information regarding the cleaning techniques used by portable air cleaners available on the market. Then a state of the art on the existing standardised test methods is provided.

A new experimental method to test air cleaners is proposed and described in detail. The report finally presents the results of tests for two commercially available portable air cleaners in order to validate that the proposed testing method is fully operational.

This study was sponsored by the French HVAC systems manufacturing companies which are members of CETIAT, together with the French Environment and Energy Management Agency (ADEME) and the French Ministry of Health (DGS).

The project has been operated by a French consortium composed of CETIAT (leader), EDF, LHVP, LEPTIAB, Hôpitaux Universitaires de Strasbourg and TERA Environment.

2. AIR CLEANING TECHNIQUES

2.1. Techniques in overall

Portable air cleaners use a wide range of different techniques (**[3]**, **[4]**). Amongst them are :

- mechanical filtration on fibrous medium,
- electrostatic precipitation,
- adsorption,
- photocatalysis,
- plasma.

These techniques can be used alone or, more generally, in series. They act against different air pollutants (**Table 1**) and rely on 3 different kinds of pollutant treatment :

- removal (mechanical filtration, electrostatic precipitation, adsorption),
- change through chemical reaction (adsorption),
- destruction (photocatalysis, plasma).

There are described in more details in the following paragraphs of this report.

Table 1. Air cleaning techniques and their action against different air pollutants.

	Inert particles	Gas	Allergens	Micro-organisms
Mechanical filtration	X		X	X
Electrostatic precipitation	X		X	X
Adsorption		X		
Photocatalysis		X		X
Plasma		X		X

2.2. Mechanical filtration on fibrous medium

Mechanical filtration on fibrous medium is probably the most widely used technique. The medium is made of a non woven assembly of different kind of fibers (glass, synthetic, cotton, cellulose). As the air passes trough the medium, particles are attached to the fibers by different effects: sieving, inertia, interception and diffusion.

The parameters used to characterize the medium by taking into account these combined effects and the change of the efficiency as function of particle size is the filtration efficiency at a point of the curve efficiency vs. particle size where efficiency is minimum for particle sizes between 0.1 and 0.2 µm (frequently named the most particle penetrating size (MPPS)).
As particles are collected by the filters, the pressure drop increases. The filtration efficiency is also changing and generally increases as the filters become loaded bay particles. In case of filters using electrostatically charged medium (electret medium), the filtration efficiency first begins to decrease as the electret effect disappears and then increases as the particles remain into the filters.
Performances of the filters depend on the characteristics of the medium, air velocity and particle size.
General ventilation filters are tested in Europe according to EN 779 **[5]** and in the US according to ASHRAE 52.2 **[6]** while EPA (Efficient Particulate Air), HEPA (High Efficiency Particulate Air) and ULPA (Ultra Low Penetration Air) filters are tested in Europe according to EN 1822 **[7]**.

2.3. Electrostatic precipitation

The electrostatic filters use 2 sections in series. In the first section air is ionised by high voltage (several kV) applied on tips or wires. This makes particulate electrified. Then particles enter a second section made of plates mounted in parallel on which high voltage is also applied in order to create an electric field between the plates, which makes particles attracted on one or an other plate.
This kind of filter exhibits generally low pressure drop which does not change as the plates become covered by particles.
The filtration efficiency of an electrostatic precipitator increases as particle size increases up to a size between 5 to 10 µm.
Air velocity is an important design parameter and the filtration efficiency of an electrostatic precipitator decreases as air velocity increases.

2.4. Adsorption

Adsorption is the most common technique used to capture gaseous molecules. An adsorbent is a substance, usually porous in nature and with a high surface area that can adsorb substances onto its surface by intermolecular forces and/or chemical reactions. Several distinct steps are involved in the overall removal mechanism of molecules from air. The removal of molecules

is based on a process where molecules are attached to the surface of the material used. Adsorption is exothermic. A material with high internal surface area, a suitable pore structure and appropriate surface chemistry is essential for effective operation. Activated carbon (adsorbent) is the most common product used for adsorption.
Before molecules can be adsorbed they flow through the pore structure of the adsorbent to the internal surface of the material. The first step is the diffusion of molecules from the air stream into the network of large pores that are opened on the external surface of the adsorbent.
Once molecules are inside the pore structure of the adsorbent, two adsorption mechanisms are possible: physical adsorption and chemical adsorption. Physical adsorption involves interactions between the carbon surface and the molecules. This process is reversible and desorption may occur especially if enhanced by heat. Chemical adsorption involves irreversible chemical reactions that occur if molecules react with water vapour and/or if adsorbent are impregnated with specific chemical compounds which the objective is to increase reactions against specific target compounds.
Adsorption phenomenon depends on a lot of parameter amongst them type of gas, gas concentration, temperature and relative humidity of air, residence time (air velocity), quantity of adsorbent, etc.

2.5. Photocatalysis

Photocatalysis is a technique which objective is to destroy gaseous molecules as well as microorganisms.
Photocatalysis involves the use of a catalyst irradiated by a UV source in presence of H_2O and CO_2. Once the catalyst is irradiated by UV, reactive radicals are formed on the surface of the catalyst which can react with the pollutants (molecules and microorganisms).
The most common catalyst is TiO_2 which is an inert, safe and relatively low price product. As it acts as a catalyst, its life time is in theory unlimited.
Photocatalysis is particularly suitable for VOCs (volatile organic compounds) removal and can be effective against NOx.
A problem of photocatalysis is that reaction byproducts are generated by the filter itself if the reaction is not fully completed, which is very often observed. Formaldehyde as well as acetaldehyde is often reported in the literature as byproducts of photocatalysis **[8]**.

2.6. Plasma

Plasma technique, also called cold plasma, needs high voltage current in order to highly ionise the air and then to create reactive radicals which can attack the pollutants to be destroyed.
Plasma is effective against molecules and gases. This technique does create ozone and NOx byproducts and then a catalyst has to be used in order to eliminate these compounds from the filtered air.

3. EXISTING PORTABLE AIR CLEANER TEST METHODS

3.1. ANSI/AHAM AC-1-2006 test method (USA)

The ANSI/AHAM AC-1-2006 standard establishes test methods for the measurement of the performances of portable household electric room air cleaners **[1]**.
The relative reduction of the particulate matter suspended in the air of a test chamber resulting of the use of an air cleaner is measured. Then the clean air delivery rate (CADR) of the air cleaner can be calculated.
Three different kinds of test particulate matters are used:

- cigarette smoke,
- fine test dust (Arizona road dust),
- pollen.

The k decay constant is calculated with equation (1) :

$$C_{ti} = C_{to} e^{-kti} \qquad (1)$$

where:

- C_{ti} is the concentration at time ti,
- C_{to} is the concentration at t = 0 (initial),
- k is the decay constant,
- ti is time at t = i.

Finally the clean air delivery rate (CADR), expressed in ft³/min (or cfm), is calculated with equation (2):

$$CADR = V(k_t - k_n) \qquad (2)$$

where:

- V is the test chamber volume,
- k_t is the test decay constant,
- k_n is the natural decay constant rate (no air cleaner within the test chamber).

Air cleaners can be compared each other on the basis of their clean air delivery rate (CADR).

3.2. JEM 1467 test method (Japan)

3.2.1. Introduction

JEM 1467 test method applies to air cleaners designed to be used at home, in offices, etc., and which are able to reduce odours and particulate levels indoors **[2]**.
First the air flow rate of the air cleaner has to be measured. The air cleaner under test is connected to ducts and test chamber and the air flow rate is measured according to a reference test method.

3.2.2. Determination of the real air cleaner capacity (expressed in number of cigarettes)

The ability of the air cleaner under test to remove gases is measured as follows. The air cleaner is installed within a small chamber (1 m^3) whose air is polluted by burning cigarettes. After the air cleaner has been turned on, the concentration of the three gaseous pollutants (measured on ammoniac, acetaldehyde and acetic acid) is measured after 30 minutes of use.

For each gas the removal efficiency is calculated by equation (3):

$$\eta = 100(1 - \frac{C}{C_0}) \qquad (3)$$

where :

- η is the removal efficiency,
- C is the gas concentration measured after 30 minutes of use,
- C_0 is the initial concentration.

Then the overall removal efficiency can be defined by equation (4):

$$\eta_t = (\eta_1 + 2\eta_2 + \eta_3)/4 \qquad (4)$$

where:

- η_t is the overall removal efficiency,

- η_1 is the removal efficiency on ammoniac,
- η_2 is the removal efficiency on acetaldehyde,
- η_3 is the removal efficiency on acetic acid.

The test described above has to be repeated until η1, η2 and η3 values are higher than 50 %. Once this level is achieved, the numbers of burned cigarettes are recorded (respectively K_1, K_2 and K_3) and the air cleaner capacity can be calculated by equation (5):

$$K_t = (K_1 + 2K_2 + K_3)/4 \tag{5}$$

where :

- K_t is the air cleaner capacity (in numbers of cigarettes).

And finally the real air cleaner capacity, M (expressed in number of cigarettes), is calculated by equation (6) :

$$M = 40K_t \tag{6}$$

where :

- M is the real air cleaner capacity.

3.2.3. Determination of the efficiency of the air cleaner

The air cleaner under test is installed within a test chamber (volume 20 to 30 m³) whose air is polluted by particles (1 to 5 mg/m³) produced by burning cigarettes. After the air cleaner has been turned on, the particle concentration (measured by optical method) is measured until its value is equal to one third of its initial value. Then the dust collection capacity can be calculated by equation (7):

$$P = -\frac{V}{t}(\ln C_2 / C_{02} - \ln C_1 / C_{01}) \tag{7}$$

Where :

- P is the dust collection capacity,
- V is the test chamber volume,
- t is the time,

- C_2 is the particle concentration measured at time t,
- C_{02} is the initial particle concentration,
- C_1 is the particle concentration measured at time t with no air cleaner within the test chamber (natural decay),
- C_{01} is the initial particle concentration during natural decay test.

Then the efficiency of the air cleaner can be calculated by equation (8):

$$\eta = 100 \frac{1}{Q} P \qquad (8)$$

where :

- η is the efficiency,
- Q is the air flow rate of the air cleaner,
- P is the dust collection capacity.

3.2.4. Final output of the test method

Tests described in **3.2.2.** and **3.2.3.** are alternately and successively repeated until the results obtained for two consecutive tests carried out according to **3.2.3.** are more or less equivalent. Then the number of cigarettes used is calculated and multiplied by 11. Finally, the life time of the air cleaner (expressed in days) is calculated taking into account the amount of cigarettes used and the amount of cigarettes supposed to be smoked per day.

3.3. Discussion

Two different standardised test methods exist and use the same principle: the parameter to characterize the air cleaner performance (clean air delivery rate (CADR) in the American standard, filtration efficiency in the Japanese standard) is calculated from the measurement as function of time of the pollutant concentration change produced by the air cleaner under test installed in an initially polluted experimental chamber. The US standard considers the initial performances of the air cleaners measured on particulate while the Japanese standard describes a method to measure the performances at the initial stage and after loading phases on gas and particulate pollutants.

In the US, AHAM (Association of Home Appliance Manufacturers) manages a voluntary certification programme for portable household electric room air cleaners (www.aham.org). This certification programme is based on the CADR values. This association is working on a standard for evaluating performance of air cleaners following accelerated loading (draft AHAM AC-3).
Also in the US, IAACM (International Association of Air Cleaners Manufacturers) manages a voluntary certification programme in which it is verified that air cleaners do not generate ozone (www.iaacm.org/program.html) with tests according to UL 867 recommendation (section 37).

Both methods described above need the use a test chamber and this induces several uncertainties because:

- Temperature and relative humidity of air are not controlled.
- Perfect mixing of the air within the chamber has to be ensured and this is not easy to perform.
- The choice of sampling points for concentration measurements may have an influence on the results in case of imperfect mixing of the pollutants into the chamber **[9]**.

In addition, the existing standardised methods focus too much on the tobacco smoke problem and they require the use of test pollutants which are not well adapted to the current filtration techniques used by the air cleaners available on the market (paragraph **2.**).
Finally, in case of a low efficiency air cleaner, testing time may be very long (more than 8 to 10 hours) to obtain a significant concentration change.

For these reasons, it has been decided in France to develop a new test method by following 2 different ways in parallel (paragraph **4.**):

- A standardisation work within AFNOR (French Association of Standardisation Association).
- A research study sponsored by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) and DGS (French Ministry of Health) which objective was to develop and to validate a new test method. Results of this study are used to provide information to the standardisation committee.

The method allows to test portable indoor air cleaners whatever the filtering technique they use (a "black box" can be tested), in a quick and repeatable way and for a wide range of common indoor pollutants at low concentration representative of inert particles, gases, microorganisms and allergens.

Air cleaners are tested at the initial stage, in a one pass test rig. Pollutant concentrations are measured upstream and downstream of the air cleaner under test and the efficiency is calculated. The air flow rate is also measured and as the output of the method the clean air delivery rate (CADR) is finally calculated. Reaction byproducts are also measured.

4. A NEW TEST METHOD DEVELOPED IN FRANCE

4.1. Standardisation process in France

The standardisation process began in France with the official creation by AFNOR in December 2007 of a working group "Air cleaner". Three different standardisation committees host this working group: AFNOR B44A (Photocatalysis), X43i (Indoor Air Quality) and X43c (Air Quality in Work Places). The experimental standard XP B44-200 has been published in May 2011 **[10]**.

4.2. Development of the test method

4.2.1. Introduction

In order to provide information to the group which aim is to develop a French standard (see paragraph ***4.1.***), a study sponsored by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie), the French Environment and Energy Management Agency, and DGS (French Ministry of Health), has been carried out by a group of several partners: CETIAT (project leader), EDF (Electricité De France), Hôpitaux Universitaires de Strasbourg, LEPTIAB (Laboratoire d'Etudes des Phénomènes de Transfert et de l'Instantanéité: Agro-industrie et Bâtiment) of the University of La Rochelle, LHVP (Laboratoire d'Hygiène de la Ville de Paris) and TERA Environnement.
The objectives of the study were:

- To review the air cleaners available on the market **[11]**.
- To review the existing standardised and non standardised test methods **[11]**.
- To propose a test method for the air cleaners efficiency determination (in laboratory) **[11]**.
- To validate the proposed test method and to initiate a standardisation work in France **[12]**.

Results of the study have been summed up in previous publications (**[13]**, **[14]**). The following paragraphs of this chapter present in more details the main points of the experimental standard **[10]**.

4.2.2. Test rig, method and calculation

4.2.2.1. Test rig

A test rig has been built in order to allow the measurement of the efficiency and the air flow rate of the devices under test (**Figure 1**). The test rig is mainly composed of a chamber (1.5 m x 1.5 m x 1.5 m) divided in two parts, with an upstream and a downstream duct respectively (**Figure 2**). The upstream duct is connected to a system which provides clean (free of contaminants) and controlled (temperature and relative humidity) air flow to the upstream (bottom) part of the chamber. The downstream duct allows air to leave out of the chamber (top) and is connected to a device for air flow rate measurement and an exhaust fan.

The two airtight parts of the chamber are separated by a wall. The air cleaner under test is installed in the chamber in such a way that the inlet of the cleaner is located in the upstream part of the chamber while the outlet is located in the downstream part (**Figure 3**). The exhaust fan is used to compensate the pressure difference due to the air cleaner and the test rig. It allows maintaining to zero the pressure difference between the two parts of the test chamber.

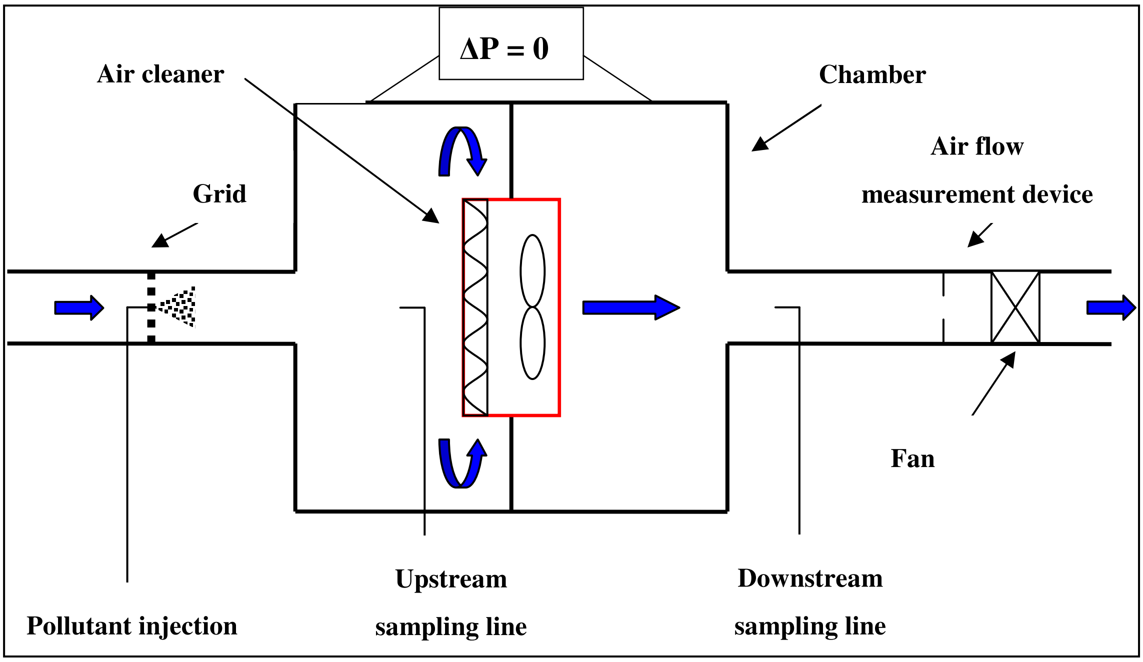

Figure 1. Schematic diagram of the test rig.

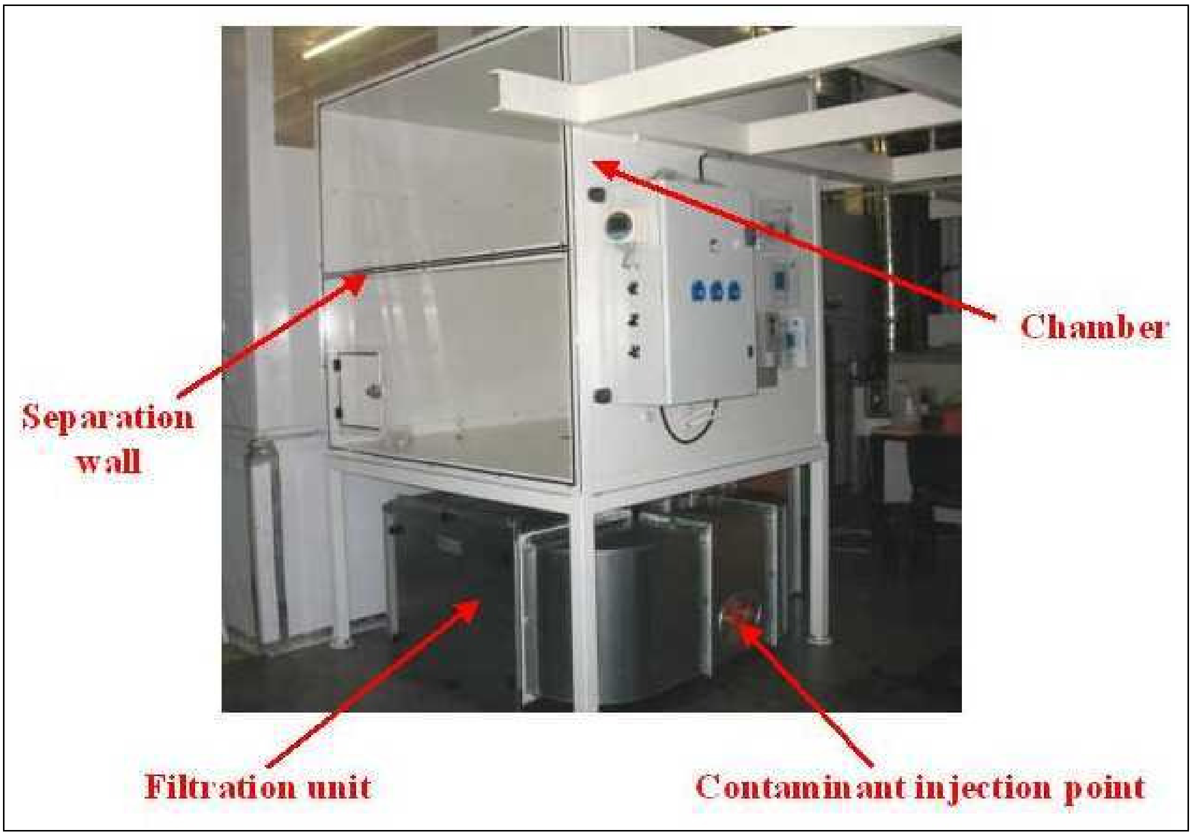

Figure 2. Photo of the chamber of the test rig.

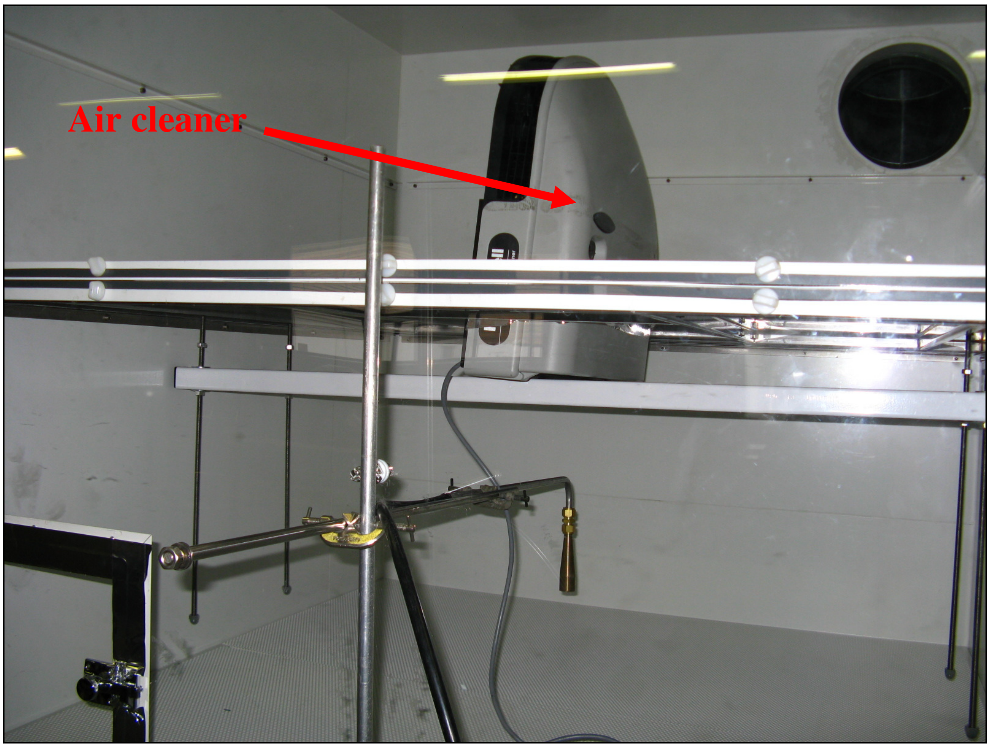

Figure 3. An air cleaner under test installed within the test chamber.

The air temperature is maintained at 22 °C ± 2 °C and the relative humidity is 50 % ± 5 %.

The behaviour of the materials of the test rig according to the contaminants, UV radiations, adsorption/desorption phenomena, etc. has to be well known and controlled.

According to XP B44-200, there is no requirement regarding the test rig airtightness. The possible loss of pollutants within the test rig as well as the possible leaks of the test rig are taken into account by the use of a correction factor calculated with the values of the pollutant concentrations measured upstream and downstream of the test chamber with no air cleaner within the test rig (§ 4.2.2.3.).

4.2.2.2. Measurements

The air flow rate (Q) of the air cleaner under test is measured by an appropriate method. For axample, NF EN ISO 5167-1 to 4:2003 **[15]** or NF EN ISO 5801:2099 **[16]** standards can be used.

The efficiency of the air cleaner under test is measured against different contaminants:
- Inert particles: DEHS (oil mist).
- Gas: a mixture of acetone, acetaldehyde, heptane and toluene.
- Allergens: cat allergens *Felis domesticus* 1.
- Microorganisms: *Staphyloccocus epidermidis* (bacteria) and *Aspergillus niger* (fungi). Measurements on microorganisms are described in an informative annex.

The contaminants are separately injected in the upstream duct in order to ensure that the concentration is maintained constant at the inlet of the air cleaner under test where the upstream concentration is measured. The downstream concentration is measured in the downstream duct at the outlet of the chamber.

For particles, the fractional efficiency (by particle size) of the air cleaner under test is measured on DEHS (between 0.3 and 5 µm). Particles are fed into the test rig with the use of a Laskin type particle generator fed by compressed air (pneumatic shearing of the oil by high velocity gas which produces a well defined aerosol output). Air sampled for upstream and downstream concentration measurements are analysed by an optical particle counter which allows counting particles as function of their size. Three samples upstream are catched and analysed, then three samples downstream and finally three samples upstream again. Mean concentrations are calculated for the upstream and downstream values.

Upstream concentration of particles has to be checked in order that the optical particle counter does not show coincidence error and that there is enough particles for each of the channels of the particle counter.

For the mixture of gases, the generation system may be based for example on the evaporation of the contaminants that are placed in liquid phase in a stainless steel container which temperature is regulated. The evaporation of the organic vapor is maintained by a regulated flux of clean air. The target concentration of each contaminant in the air stream is between 250 and 500 ppb. The effluent is then directed to the test via the injection point placed upstream of the chamber. The analysis is performed by online injection and cold trap focusing within a gas chromatograph for the separation of air constituents followed by Flame Ionization Detection (FID).
Gas concentrations are measured upstream and downstream simultaneously (three times) 15, 30 and 45 minutes after starting of the test, and mean concentrations are calculated for the upstream and downstream values.
A mixture of acetone, acetaldehyde, heptane and toluene has been chosen because these 4 compounds are representative of different VOC (volatile organic compound) groups present indoors.

Cat allergens are generated by a Collison type aerosol generator fed by compressed air. After air samples have been collected simultaneously upstream and downstream of the air cleaner, allergens concentrations are measured by Elisa technique (Enzyme-linked immunosorbent assay, a biochemical technique used mainly in immunology to detect the presence of an allergen in a sample).
Cat allergens concentrations upstream of the air cleaner are within the range from 10 to 20 ng/m^3.
These measurements are repeated three times and the 3 values of the efficiency are used for the calculation of the mean efficiency.

Microorganisms are generated by a Collison type aerosol generated fed by compressed air. After air samples have been collected simultaneously upstream and downstream of the air cleaner, allergens concentrations are measured by an appropriate technique which allows to measure the cultivable fraction of the microorganism which values are expressed in colony forming unit per cubic meter (CFU/m^3).
These measurements are repeated three times and the 3 values of the efficiency are used for the calculation of the mean efficiency.

Byproducts are continuously measured downstream of the air cleaner under test by appropriated means when testing against the mixture of gases is performed:

- Ozone (O_3).
- Formaldehyde (HCHO) and aldehydes.
- Ketones.
- Carbon monoxide (CO).
- Nitrogen oxide (NO).
- Nitrogen dioxide (NO_2).

4.2.2.3. Calculation

For a given contaminant, the efficiency of the air cleaner (E) is calculated by equation (9):

$$\boldsymbol{E} = 100\frac{(\boldsymbol{Cup} - \boldsymbol{Cdown})}{\boldsymbol{Cup}} \tag{9}$$

where:

- Cup is the concentration of the contaminant measured upstream of the air cleaner,
- Cdown is the concentration of the contaminant measured downstream.

The value of the efficiency E has to be corrected (Ecor) in case of the upstream and downstream concentrations are not equal when no air cleaner is installed within the test rig (equation (10)) :

$$\boldsymbol{Ecor} = 100(1 - \frac{\boldsymbol{Cdown}}{\boldsymbol{CCup}}) \tag{10}$$

Where:

- C is the ratio of downstream to upstream concentrations when no air cleaner is installed within the test rig.

For a given contaminant, the clean air delivery rate (CADR) is calculated by equation (11):

$$\text{CADR} = \text{QE} \tag{11}$$

Where:

- Q is the air flow rate of the air cleaner,
- E is the air cleaner efficiency.

4.2.3. Test rig validation

Upstream and downstream concentrations have to be measured without air cleaner within the test rig and the following efficiency values have to be obtained:

- 0 % ± 3 % for inert particles being lower or equal in size than 1 µm,
- 0 % ± 7 % for inert particles being higher in size than 1 µm,
- 0 % ± 5 % for each individual gas,
- 0 % ± 10 % for both microorganisms,
- 0 % ± 10 % for cat allergens.

If these conditions cannot be achieved, a correcting factor is calculated (ratio of downstream to upstream concentrations) and used to correct the efficiency values obtained from the efficiency calculations (see 4.2.2.3.).

4.2.4. Other measurements

The electrical power consumption of the air cleaner is measured with a wattmeter (references to different standardised methods).

The sound power level of the air cleaner is also measured and this measurement is described in an informative annex (references to different standardised methods).

4.2.5. Air cleaner test results

4.2.5.1. Air cleaners under tests

Two commercially available air cleaners have been used for the study. There are called respectively AC1 and AC2 further in the text. The air cleaner called AC1 uses a mechanical prefilter, a fine mechanical filter and a photocatalytic oxidation filter in series. The air cleaner AC2 uses a mechanical prefilter, an activated carbon filter and an electronic filter in series. The two devices have their own fan (4 different speeds for AC1 and 3 different speeds for AC2).
The objective was not to determine the performances of these air cleaners but to validate the use of the test method.

4.2.5.2. Test results

4.2.5.2.1. Air flow rate

The values are presented in **Table 2**.

Table 2. Air flow rate of the air cleaners under test (expressed in m³/h).

Speed	Air cleaner AC1	Air cleaner AC2
1	65	180
2	110	225
3	240	455
4	285	

4.2.5.2.2. Efficiency on inert particles

Test results are presented in **Figure 3** and **Figure 4**. The repeatability is good as the results are equivalent when tests have been repeated several times in the same way. The efficiency increases when the particle diameter increases. The shape of the curves indicates that the efficiency is almost constant over the studied particle diameter range, which may be due to air leakage around the filters. This hypothesis has been confirmed after the mechanical filter of AC1 air cleaner has been tested alone (results indicate that this filter is an HEPA filter).

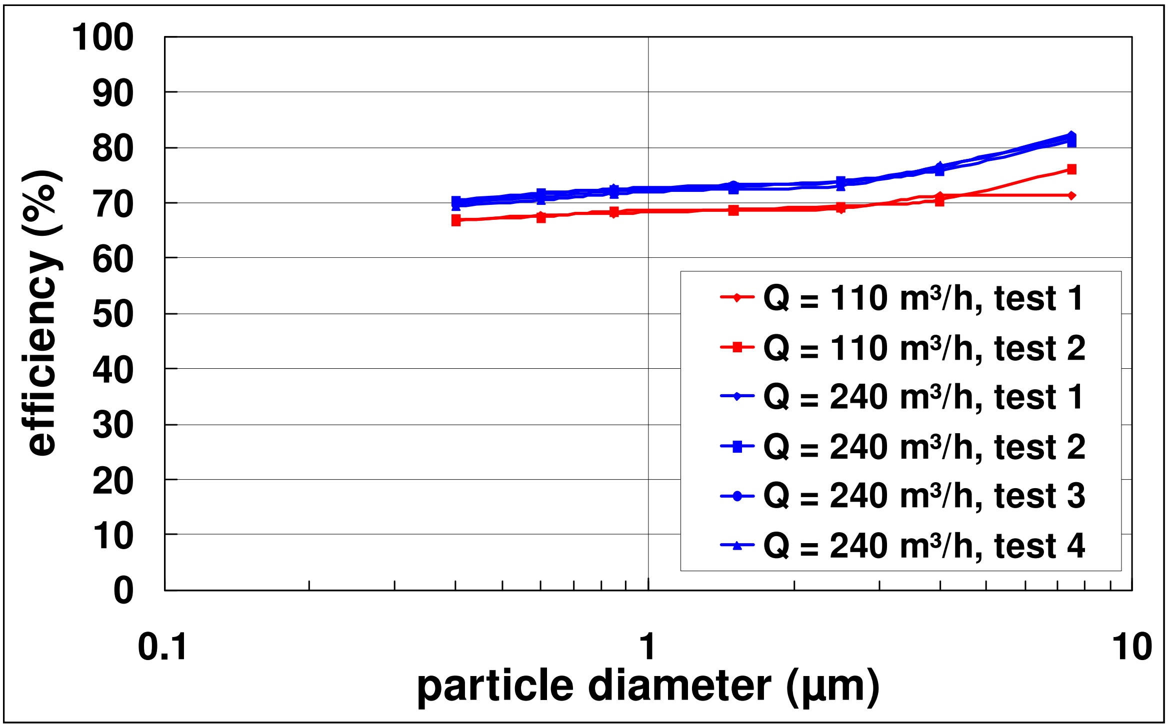

Figure 3. AC1 efficiency on inert particles.

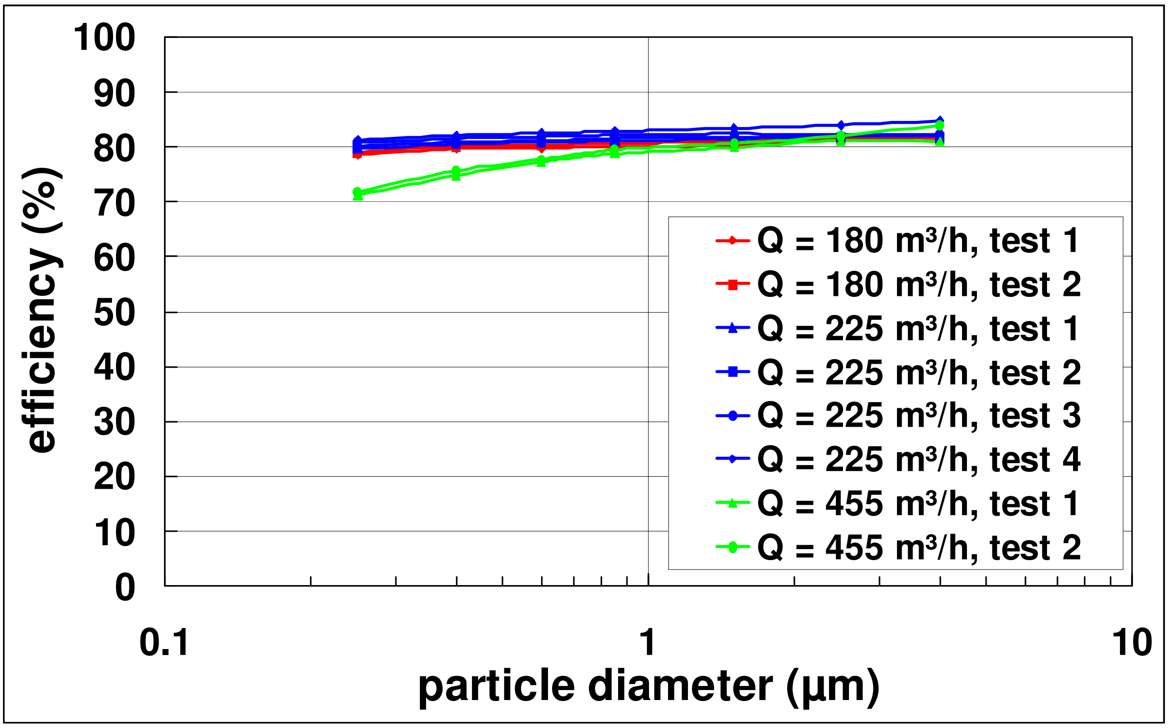

Figure 4. AC2 efficiency on inert particles.

4.2.5.2.3. Efficiency on gases

The efficiency which was measured on toluene only was very low and always lower than 5 % for both air cleaners.

4.2.5.2.4. Efficiency on allergens

Efficiency values with cat allergens are presented in **Table 3**. If we consider that the size of the allergens is around 5 µm, the values obtained with cat allergens are a little bit higher than the values for inert particles of the same size.

Table 3. Efficiency on allergens (expressed in %).

Speed	Air cleaner AC1	Air cleaner AC2
1	-	95.0
2	77.0	83.9
3	83.6	-

4.2.5.2.5. Efficiency on microroganisms

Efficiency values with cat allergens are presented in **Table 4a** for *Staphyloccocus epidermidis* and in **Table 4b** for *Aspergillus niger*.

Table 4a. Efficiency on *Staphyloccocus epidermidis* (expressed in %).

Speed	Air cleaner AC1	Air cleaner AC2
1	-	75
2	83	77
3	91	-

Table 4b. Efficiency on *Aspergillus niger* (expressed in %).

Speed	Air cleaner AC1	Air cleaner AC2
1	-	81
2	52	57
3	76	-

4.2.5.3. Clean air delivery rate (CADR)

Test results allow to calculate the clean air delivery rate of the air cleaners for the different contaminants (**Table 5**).

Table 5. Clean air delivery rate (expressed in m^3/h).

	Air cleaner AC1		**Air cleaner AC2**		
	Speed 2	**Speed 3**	**Speed 1**	**Speed 2**	**Speed 3**
Particles (0.3 – 0.5 µm)	**74**	**168**	**-**	**183**	**341**
Particles (1.0 – 2.0 µm)	**76**	**174**	**-**	**187**	**364**
Toluene	**2**	**10**	**-**	**12**	**15**
Cat allergens	**85**	**198**	**193**	**244**	**-**
Staphyloccocus epidermidis	**91**	**218**	**135**	**173**	**-**
Aspergillus niger	**57**	**182**	**146**	**128**	**-**

4.2.5.4. Byproducts

The amount of byproducts was very low and this is explained by the very low efficiency of both air cleaners on gases.

5. CONCLUSION

A test rig has been designed and built for the measurement of the initial intrinsic performances of portable indoor air cleaners. Contaminant concentrations (inert particles, gases, cat allergens and microorganisms) are measured upstream and downstream of the air cleaner under test in order to calculate its filtration efficiency. The air flow rate is also measured and finally the clean air delivery rate (CADR) can be calculated.

Tests of two different air cleaners have shown very good repeatability. The air flow rates were generally lower than those announced by the manufacturers and the filtration efficiency against gases (toluene) was very low (less than 5 %).

A new test method for the measurement of the intrinsic performances of portable air cleaners, whatever the filtration techniques they use, has been developed and validated. The experimental French standard AFNOR XP B44-200 has been published in May 2011. Once the tests have been carried out, the clean air delivery rate (CADR) can be announced and the intermediate byproducts, when they exist, are identified. The availability of this standard will allow to assess and to compare the air cleaners available on the market. Also, this new method solves the problems met with the use of the existing standardised test methods.

Finally, the experimental French standard XP B44-200 could be used as a basis for the development of an international standard.

6. BIBLIOGRAPHY

[1] Method for measuring performance of portable household electric room air cleaners, *ANSI/AHAM AC-1-2006*, Association of Home Appliance Manufacturers (AHAM), January 2006.

[2] Residential air cleaners, *JEM 1467*, Japan Electrical Manufacturers Association (JEMA), 1995.

[3] Residential air cleaners - A summary of available information, *EPA (United States Environmental Protection Agency) 402-F-09-002 Report*, August 2009.

[4] HASSEN-KHODJIA R. and DUSSAULT F.P., Les purificateurs d'air portables en milieu hospitalier - Etat de la question, *Montréal : Hôpital du Sacré-Cœur de Montréal - Unité d'évaluation des technologies et des modes d'intervention en santé,* August 2009 (in French).

[5] Particulate air filters for general ventilation - Determination of the filtration performance, *EN 779*, 2002.

[6] Method of testing general ventilation air-cleaning devices for removal efficiency by particle size, *ANSI/ASHRAE 52.2*, 2007.

[7] High efficiency air filters (HEPA and ULPA), *EN 1822- Part1 to 5*, 2010.

[8] GINESTET A., PUGNET D., ROWLEY J., BULL K. and YEOMANS H., Development of a new photocatalytic oxidation air filter for aircraft cabin, *Indoor Air*, Vol. 15, No. 5, p. 326-334, October 2005.

[9] PEI J., CHEN W., GAO Z. and ZHANG J., Simultaneous measurement of single-pass efficiency and clean air delivery rate for in-duct air cleaners - Test methods, results and implications, *Proceedings of the 11th International Conference on Indoor Air Quality and Climate - Indoor Air 2008*, Paper ID 154, 8 pages, Copenhagen, Denmark, 17 - 22 August 2008.

[10] Epurateurs d'air autonomes pour applications tertiaires et résidentielles - Méthode d'essais - Performances intrinsèques, *AFNOR XP B44-200*, May 2011 (in French).

[11] BLONDEAU P., GINESTET A., SQUINAZI F., DE BLAY F., OTT M., RIBOT B. and FROCHOT D., Mise en place de protocoles de qualification des appareils d'épuration d'air, *Rapport final convention ADEME n° 0404C0080*, 170 pages, May 2006 (in French).

[12] GINESTET A., PUGNET D., FROCHOT D., WALL-RIBOT B., OTT M., BLONDEAU P., POIROT A., SQUINAZI F., KALUZNY P. and PEPIN L., Développement d'une méthode d'essais des épurateurs d'air, *Rapport final convention ADEME n° 0604C0082*, 89 pages, January 2010 (in French).

[13] GINESTET A., BLONDEAU P., FROCHOT D., KALUZNY P., LEFEVRE M.C., OTT M., DE BLAY F., PEPIN L., PUGNET P., RIBOT B. and. SQUINAZI F., A new test method for indoor air cleaner efficiency determination and harmlessness assessment, *Proceedings of The 11th International Conference on Indoor Air Quality and Climate*, Copenhagen, Denmark, 17-22 August 2008.

[14] GINESTET A., BLONDEAU P., FROCHOT D., KALUZNY P., OTT M., PEPIN L., POIROT A., PUGNET D., SQUINAZI F., WALL-RIBOT B. and DE BLAY F., Development of a new standardized test method for portable indoor air cleaner, *Proceedings of The 9th International Conference and Exhibition Healthy Buildings 2009*, Syracuse, USA, 13-17 September 2009.

[15] Mesure de débit des fluides au moyen d'appareils déprimogènes insérés dans des conduites en charge de section circulaire, *NF EN ISO 5167-1 à 4*, 2003.

[16] Ventilateurs industriels - Essais aérauliques sur circuits normalisés, *NF EN ISO 5801*, 2009.

7. RÉSUMÉ

7.1.Résumé

L'objectif de cette étude était le développement d'une nouvelle méthode d'essais des épurateurs d'air portables.

Un banc d'essais a été conçu et construit pour la mesure des performances initiales intrinsèques des épurateurs d'air portables. Les concentrations en contaminants d'essais (particules inertes, gaz, allergènes de chat et microorganismes) sont mesurées en amont et en aval de l'épurateur en essais afin de calculer son efficacité. Le débit d'air est également mesuré et le débit d'air épuré est finalement calculé (produit de l'efficacité par le débit d'air).

Les essais de 2 épurateurs d'air différents ont montré une très bonne répétabilité. Les valeurs de débit d'air étaient généralement plus faibles que celles annoncées par les fabricants des appareils et l'efficacité de filtration sur le gaz (toluène) était très faible (inférieure à 5 %).

Une nouvelle méthode d'essais pour les épurateurs d'air portables, quelles que soient les techniques filtrantes qu'ils utilisent, a donc été développée et validée. La norme expérimentale française AFNOR XP B44-200 a été publiée en mai 2011. Une fois les essais effectués, le débit d'air des épurateurs d'air peut être annoncé et les produits intermédiaires de réaction, lorsqu'il y en a, sont identifiés. Grâce à cette méthode d'essais, les épurateurs d'air disponibles sur le marché vont pouvoir être évalués et comparés. Par ailleurs, les problèmes rencontrés avec les methodes d'essais normalisées existantes sont résolus.

Enfin, la norme expérimentale Française XP B44-200 pourrait être utilisée comme base pour le développement d'une norme internationale.

8. ABSTRACT

8.1. Title

Development and evaluation of a new test method for portable air cleaners - Proposal for an AIVC Technical Note writing

8.2. Abstract

The objective of this study was the development of a new test method for portable indoor air cleaners.

A test rig has been designed and built for the measurement of the initial intrinsic performances of portable indoor air cleaners. Test contaminant concentrations (inert particles, gases, cat allergens and microorganisms) are measured upstream and downstream of the air cleaner under test in order to calculate its filtration efficiency. The air flow rate is also measured and finally the clean air delivery rate (CADR) can be calculated (filtration efficiency multiplied by the air flow rate).

Tests of two different air cleaners have shown very good repeatability. The air flow rates were generally lower than those announced by the manufacturers and the filtration efficiency against gases (toluene) was very low (less than 5 %).

A new test method for the measurement of the intrinsic performances of portable air cleaners, whatever the filtration techniques they use, has been developed and validated. The experimental French standard AFNOR XP B44-200 has been published in May 2011. Once the tests have been carried out, the clean air delivery rate (CADR) can be announced and the intermediate byproducts, when they exist, are identified. The availability of this standard will allow to assess and to compare the air cleaners available on the market. Also, this new method solves the problems met with the use of the existing standardised test methods.

Finally, the experimental French standard XP B44-200 could be used as a basis for the development of an international standard.

The Air Infiltration and Ventilation Centre was inaugurated through the International Energy Agency and is funded by the following countries:

Belgium, Czech Republic, Denmark, France, Germany, Greece, Italy, Japan, Republic of Korea, Netherlands, New Zealand, Norway, Portugal, Sweden, and United States of America.

The Centre provides technical support in air infiltration and ventilation research and application. The aim is to provide an understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

Air Infiltration and Ventilation Centre
Operating Agent and Management
INIVE EEIG
Lozenberg 7
B-1932 Sint-Stevens-Woluwe
Belgium

www.aivc.org
Tel: +32 2 655 77 11
Fax: +32 2 653 07 29
inive@bbri.be
www.inive.org