CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 8

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

RELIABILITY of VENTILATION SYSTEM INSPECTION for DWELLINGS: COMPARISONS of MEASUREMENTS and CONTROLS PROTOCOLS TESTED DURING ON-SITE CAMPAIGN of the PROMEVENT PROJECT

Adeline Bailly[#1], Sylvain Berthault[2]

[#]*Cerema*
Direction Territoriale Centre-Est
46 rue Saint-Théobald
38081 l'Isle d'Abeau, FRANCE

[1]adeline.bailly@cerema.fr

[2]sylvain.berthault@cerema.fr

Abstract

The PROMEVENT project, conducted by 8 French organizations, tests and analyzes several protocols for controls and measurements of residential ventilation systems. It aims to make the practices more uniform and to improve ventilation systems inspection protocols, which include visual controls, airflow and pressure measurements at air terminal devices and ductwork airleakage measurement, for both single-family houses and multi-family dwellings.

In order to test the reliability of those protocols, various measurements have been performed on 2 multi-family dwellings with humidity demand controlled ventilation systems and 10 single-family houses with balanced ventilation with heat recovery systems. Those tests have been performed by different operators, with different types of measuring devices, on different types of air terminal devices.

The analysis of these different measurements points out the weaknesses of the protocols and/or the minimum specifications the instruments should achieve to assure reliable results, in particular for airflow measurement at terminal devices, for which, the type of material used may induce uncertainties due to the technology (not all technologies might be used with all types of terminal) and due to the material it-self (important impact of the correction with calibration data). For ductwork airleakage measurements, important differences of the results have been noticed with different obstructions of the ductwork at terminal devices. Results could also be different between a measurement performed in one time (one section) or in two times (the same section divided in two sections).

Therefore, all the tests performed during these campaigns confirm the need for a unique and more reliable protocol.

Keywords - ventilation; control; measurement; protocol; reliability

1. PROMEVENT project: context, objectives and campaigns organisation

a. French context for ventilaiton systems controls in dwellings

Currently, ventilation systems controls are generally performed on dwellings, in France, in four situations:

- During regulatory compulsory control (by the technical civil servants network of the Ministry in charge of the Construction's sector);
- For buildings applying for a certification, especially for the new Effinergie label (Effinergie +);
- When there are special requirements from the building owner to verify;
- When IAQ or noise issues have been set out for a building, such as moisture contamination.

In these cases, several diagnostic protocols are used: standards (such as the European standard EN12599), labels reference documents (Effinergie protocol) or good practice guide (DIAGVENT method). Because of these various different on-site practices, the analysis of these control could be difficult. Moreover, the reliability of these protocols differs a lot. Therefore there is a need for a unique protocol, which includes measurements with quantified uncertainties

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b. Partners, objective and calendar of the PROMEVENT project

In order to meet this need, 8 French organizations have proposed the PROMEVENT project to a call for proposals launched by ADEME[1] within the subject "toward responsible buildings in 2020" in 2014. The Consortium is constituted of 8 French partners, both from private and public sectors: a public institution (Cerema[2] - ex CETE de Lyon), a laboratory (CETIAT), 5 consultancies (ALLIE'AIR, ICEE, PLEIAQ, CETii, PBC) and an association (Effinergie). The project has financial supports from ADEME and the French Ministry in charge of the construction. The PROMEVENT project has begun in June 2014 and will be finished by December 2016.

PROMEVENT main objective is to improve the quality of ventilation system controls. More precisely, it aims to ensure the reliability of ventilation measurement protocols concerning pressure and airflow differences at air vents, and ductwork airleakage. This program will focus on residential buildings. According to current practices in new constructions, two "dwelling/ventilation systems" associations are being studied:

- Single-family houses equipped with balanced ventilation;

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[1] French Energy Agency

[2] Centre for expertise and engineering on risks, environment, mobility, urban and country planning

- Multi-family dwellings equipped with single humidity demand-controlled ventilation.

This project includes three work packages. The first one consists of a characterization of existing protocols in order to evaluate their reliability, through experimental campaigns. The second one is the elaboration of a new protocol which must ensure controls reliability. The last one will lead to a verification of the new protocol feasibility, reliability and relevancy, through on-site tests. This paper presents results from the on-site campaign of the first work package.

c. Protocols evaluation: on-site campaign

A complete protocol has been established from all existing protocols used in France. It includes:

- Visual checks;
- Airflow and pressure differences measurements at air terminal devices;
- Ductwork airtightness measurement.

Various controls according to this protocol have been performed on-site on 10 single-family and 2 multi-family dwellings. 4 operating-teams have contributed to this campaign, according to table 1.

Table 1: on-site campaign program

Buildings and measurements		Team 1	Team 2	Team 3	Team 4
2 multi-family dwellings	Building 1: *Visual checks, airflow and pressure difference measurements at air terminal devices, and ductwork airtightness measurement*	B1	B1		
	Building 2: *Visual checks, airflow and pressure difference measurements at air terminal devices*			B2	B2
10 single-family dwellings	House 1: *Visual checks, airflow and pressure difference measurements at air terminal devices*	H1	H1	H1	
	House 2: *Visual checks, airflow and pressure difference measurements at air terminal devices*			H2	H2

	House 3 to 10: *Visual checks, airflow and pressure difference measurements at air terminal devices, and ductwork airtightness measurement (only for House 5)*	H3 H4	H5 H6	H7 H8	H9 H10

Several applications of the protocol have been performed in each dwelling, in order to evaluate the repeatability of the protocol, and to identify its requirements which can have an important impact on the control result. The ventilation systems of 4 buildings (B1, B2, H1 and H2) have been controlled by 2 or 3 different teams in order to compare practices and measuring devices.

2. Analyse of visual checks requirements in current protocols

Various existing checklists have been studied are gathered in a unique checklist: the most exhaustive and the most relevant possible one. This checklist contains 6 major categories: ventilation unit, ductwork, internally mounted air transfer devices, externally mounted air transfer devices, exhaust air terminals devices and supply air terminals devices. It has been applied for all buildings of the campaign. In addition, for 2 houses (H1 and H2) and for the 2 multi-family dwellings (B1 and B2), it has been filled in by all operators present on-site.

The analysis of the filled checklists leads to the following conclusions:

- It will be relevant that the checklist is consistent with the movement of the operator during a control. Therefore, it will be more useful to have tables per site, rather than by type of control (for elements where measurements could be performed, all checks and measurements results have to be noted down in one unique table).
- Some checkpoints are very subjective.
- Some checkpoints are not relevant to each type of control (visual check, measurement at air terminal devices, ductwork airtightness measurement).
- The aim of some checkpoints is not obvious.
- Some checkpoints are not always controllable.

Therefore, for each checkpoint, an analysis has been conducted in order to establish:

- The type of ventilation system concerned and the type of building concerned.
- The objective of the control (impact on acoustic comfort, system cleanliness, respect and permanency of the airflows, feasibility of maintenance, system durability, fire safety, energy consumption).
- The sources of the requirement (respect of regulations or a standard, compliance with the rules of art, element for interpretation).

- The need for the system to comply with the checkpoint requirement in order to make scheduled measurements possible.
- The objectivity of the answer and the good understanding.
- The specific constraints (authorization, required insurance, specific knowledge, accessibility to areas or local, access to the specific technical documentation, knowledge of the specifics of a material).

3. Protocol for airflow measurement at air terminal devices

a. Requirements of the protocol

From the analysis of all identified protocols, the most relevant and complete protocol for airflow measurement at air terminal devices has been established as follows:

- The measurements are performed when windows are closed.
- The measuring device is placed around the terminal device checking that there is no leakage between the measuring device and the wall or the ceiling.
- The measuring is centered regarding the axis of the terminal device.
- The measurement is performed during stable conditions: when for 30 seconds, the flow rate does not vary by more than 10%. The result is the average of the airflows measured during that time.
- The measured airflow is corrected with on-site temperature and pressure conditions (according to the specifications of the measuring device).

b. Evaluation of the protocol repeatability

This protocol has been applied for all dwellings of the campaign. Additional measurements have been performed in order to evaluate the repeatability of this protocol. For some configurations, 3 measurements have been performed by one operator, with one measuring device, on one terminal device. This methodology has been applied by different operators, with different measuring devices, on different types of terminal device. Each time, the repeatability has been evaluated according to the following relation:

Repeatability = standard deviation (3 measurements result) / average (3 measurements result)

The figure 1 gives repeatability of the protocol for some on-site situations depending of the nature of the air terminal device.

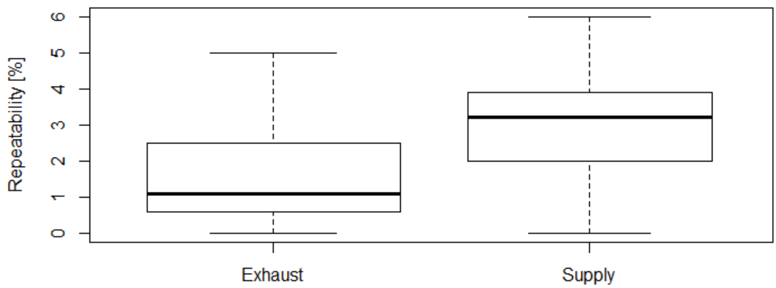

Fig. 1: Repeatability of the airflow measurement protocol for both exhaust and supply air temrinal devices

According to figure 1, the repeatability of the analyzed protocol for airflow measurement air terminal devices is satisfactory. Moreover, for all on-site situations considered for this analysis, the most important difference observed between two measurements performed on a terminal device on repeatable conditions is:

- 5 $m^3.h^{-1}$ for an exhaust air terminal device, with an average airflow of 206 $m^3.h^{-1}$; and
- 3 $m^3.h^{-1}$ for a supply air terminal device, with an average airflow of 40 $m^3.h^{-1}$.

c. Impact of the position of the measuring device

On-site, some requirements of the protocol are not always easy to meet. Indeed, depending on how and where the air terminal device is installed, it could be impossible to center the measuring device or to ensure there is no leakage between the measuring device and the wall or ceiling. Therefore, a sensibility of these requirements has been analysis. Firstly, measurements have been performed with intentionally leaving leakage between the measuring device and the wall or ceiling.

Table 2. Impact of intentional leakage between the material device and the wall or the ceiling during an airflow measurement at air terminal devices

Type of air terminal device	Median of the relative error	Maximum error
Kitchen (Exhaust)	13%	27 $m^3.h^{-1}$
Bathroom and toilets (Exhaust)	30%	10 $m^3.h^{-1}$
Rooms and living room (Supply)	17%	15 $m^3.h^{-1}$

According to results presented in table X, leakages around the measuring device could conduct to significant error on the measured airflow, up to 27 $m^3.h^{-1}$. Therefore, this specific requirement of the protocol has to be absolutely be respected.

Secondly, measurements have been performed with a measuring device off-center regarding the axis of the air terminal device. The analysis of the results of these measurements is presented in table 3. The off-centering of the material device could also lead to significant errors. As for the first point, this specific requirement has to be absolutely respected.

Table 3. Impact of off-centering of the material device during an airflow measurement at air terminal devices

Type of air terminal device	Median of the relative error	Maximum error / Measured airflow
Kitchen (Exhaust)	4%	8 $m^3.h^{-1}$ / 77 $m^3.h^{-1}$
Bathroom / toilets (Exhaust)	8%	4 $m^3.h^{-1}$ / 70 $m^3.h^{-1}$
Rooms / living room (Supply)	12%	9 $m^3.h^{-1}$ / 17 $m^3.h^{-1}$

Finally, a study has been conducted for one specific measuring device which includes a punctual thermal anemometer. Indeed, the position of the anemometer into the hood has to be very precise: at the center of the hood and with the thermal point into the axis of the airflow. Some measurements have been performed with different positions of this anemometer, as presented in figure 2.

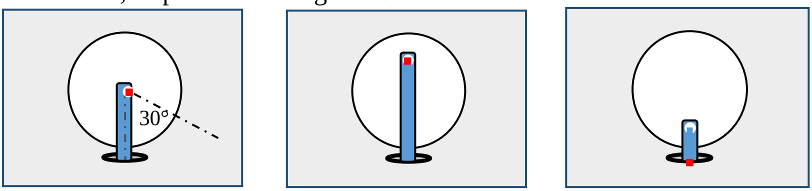

Fig. 2: 3 positions of the thermal anemometer which induce significant errors

With the anemometer into these 3 positions, errors from 0% to 12% have been observed on measured airflow on exhaust terminal devices, and from 2% to 33% on supply terminal devices. As for the two previous points, the position of this particular measuring device has to be exact.

d. Special control on single humidity demand-control ventilaiton systems

In France, new dwellings are very often equipped with a single humidity demand-controlled ventilation. The airflows at exhaust terminal devices vary depending on the relative humidity. For theses terminal devices, the airflow measurement is very complex. Therefore, a pressure difference measurement is performed to verify that the pressure which is available at the air terminal device matches with the producer documentation. The French standard Pr NF E51-777 provides guidance on the protocol for this measurement. Repeatability analyses have been conducted from pressure difference measurement performed during the PROMEVENT campaign. A maximum of 6 Pa has been observed for pressure differences measured from 42 to 96 Pa: the repeatability of this protocol is satisfactory.

4. Protocol for measurement of ductwork airtightness

a. Some specific requirements of the protocol

The French standard FD E51-767 provides guidance for ductwork airtightness measurement. Especially, it authorizes to perform the measurement on a ductwork airtightness sample for multi-family dwellings. It also authorizes to perform the measurement by sections of the sample. This measurement of ductwork airtightness requires a specific type of obstruction of the ductwork in place especially of the air terminal devices. For some buildings, the installed ductwork did not enable the operators to perform a ductwork airtightness measurement as it was scheduled.

b. Evaluation of the impact of the measuring device

Two teams have performed some ductwork airtightness measurement on a multi-family dwellings (B1) with two different measuring devices, and with two preparations of the ductwork at terminal devices. For the first preparation of the ductwork at terminal devices (obstruction with bladders), several measurements were made with different devices and different operators. The same measurements were then carried out with a different preparation (obstruction with adhesive on terminal devices). Table 9 shows the differences between the measurement results obtained by the two measuring devices for different columns with different preparations (and therefore different leakage rates). The two measuring devices have led to similar results, with a maximum difference of 6 $m^3.h^{-1}$for a leakage airflow measured of 121 $m^3.h^{-1}$. The ductwork airtightness class is always the same for the two measuring devices, regardless of the measured column and obstruction at the air terminal devices.

c. Impact of the preparation of the ductwork

The protocol requires that the obstruction of the ductwork at air terminal devices is realized in place of the terminal devices (they have to be removed). However, on-site, it is not always possible. Therefore, measurements have been performed according to this requirement, and then without remove the air terminal device and put adhesive on them.

For 2 of the 3 tests leading to a ductwork classification, the change of obstruction induces a change of class. Indeed, with the adhesive on the terminal devices, additional leaks (including voluntary) are included in the measurement. These leaks can represent up to 8 m3.h-1 by device. Then, the leakage airflow is overestimated.

d. Comparison of results of measurements performed in one and in two sections of a same sample

The protocol authorizes to perform the measurement by sections of the sample. On the multi-family dwellings B1, measurements have been performed in one unique section, and then in two sections (the unique one divided in two). The measurements performed in two sections overestimates the leakage airflow of the tested ductwork by 20% (5 to 6 $m^3.h^{-1}$). This is due, in particular, to the twice inclusion of the roof T-connections. Then, additional tests have been performed to evaluate leakage due to the roof T-connections with adhesive on this component. The results of these tests prove that the roof T-connections are responsible for large leaks (which confirms the preliminary study conducted by Sylvain Berthault, [1]).

5. Conclusions and prospect

The first on-site campaign leads to the following conclusions and prospect.

Firstly, the checklist has to be rewritten to optimize the realization of visual controls. It will be consistent with the movement of the operator during a control and organized by places. Furthermore, some checkpoints have been rewritten to ensure objectivity and good understanding. The guide will illustrate checkpoints when needed, with drawings, photos or videos.

Secondly, the position of the measuring device during an airflow measurement at air terminal device could cause significant errors. The protocol should therefore emphasize the importance to center the measuring device in an airtight position on the air terminal device. A specification for measuring devices which include a punctual thermal anemometer has to be included on the protocol. The guide will provide information on impact on the measurement result in case of no respect of the protocol. It will also give practical recommendations on the type of the measuring device depending on the type of air terminal device to limit the risk of error. In order to evaluate the repeatability and the reproducibility of the protocol for airflow measurement at air terminal devices, many measurements will be performed on repeatable and reproducible conditions in a laboratory. An evaluation of the measurement uncertainty will then be carried out taking into account the result of the first and the second campaigns.

Finally, the preparation of the ductwork for a ductwork airtightness measurement could dramatically impact the results of the measurement. The protocol has to be very precise to ensure all leaks from the part of the ductwork to be tested are taken into account, including that of the strain-side if it exists (especially in case of measurement performed by sections). The guide has to provide information and awareness for both operators and buildings owners about the ductwork preparation.

During the next steps of the PROMEVENT project, a protocol will be proposed including analyses conclusions of the first campaigns results. This protocol will then been tested on-site during another campaign. The final protocol will be proposed with a guide at the end of the project.

Acknowledgment

The “PROMEVENT” project receives funding from the French Environment and Energy Management Agency. The contribution of Cerema is funded by the French ministry for ecology, sustainable development, and energy (MEDDE). The sole responsibility for the content of this publication lies with the authors.

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