Development and test of quality management approach for ventilation and indoor air quality in single-family buildings

Sandrine Charrier*[1], Gaëlle Guyot[2], Romuald Jobert[2], François-Rémi Carrié [3], and Claire-Sophie Coeudevez[4]

1 DGAC/SNIA
82 rue des Pyrénées
75970 Paris Cedex 20, France
**Corresponding author:*
Sandrine-j.charrier@aviation-civile.gouv.fr

2 CEREMA
25 avenue François Mitterrand, CS 92803,
69674 BRON CEDEX, France

3 ICEE
93 rue Molière
69003 Lyon, France

4 MEDIECO Conseil & Formation
355 Allée Jacques Monod,
69800 Saint Priest, France

ABSTRACT

The "VIA-Qualité" project (2013-2016) aims at developing quality management (QM) approaches (ISO 9001) on ventilation and indoor air quality (IAQ), for low-energy, single-family buildings. The goal of these QM approaches is to improve both ventilation and IAQ actual in-situ performance. The main benefits of those approaches are to: 1-Improve ventilation system performance from design to implementation; 2-Limit indoor internal pollution sources, monitoring building materials selection and design regarding the outdoor pollution sources; 3-Improve final users understanding.

The first part of the paper is dedicated to the presentation of the schemes developed to help builders implement quality management approaches on ventilation and IAQ. The quality management approaches structuration led to the development of key tools. The first QM tool presents the main steps, processes and documents that should be implemented by a single-family house builder. The second QM tool is composed of technical drawings for the workers. The third QM tool, dedicated to the final user, aims at raising awareness on ventilation system maintenance and IAQ.

The second part of the paper presents the evaluation of the QM approach implementation by two French builders on 8 houses. We measured ventilation and IAQ performance at commissioning and measured results are disappointing. However lessons learnt are positive. The results focus on the implementation and the feedback on these approaches on the success factors or barriers to apply them, including training evaluations.

The paper concludes on lessons learnt by the development and the application of quality management approaches on ventilation system and IAQ and proposes some hints to implement such approaches.

KEYWORDS

Ventilation, indoor air quality, quality management approach, low energy single family houses

1 INTRODUCTION

The "VIA-Qualité" project (2013-2016) aims at developing quality management (QM) approaches on ventilation and indoor air quality (IAQ), for low-energy, single-family buildings. The goal of these QM approaches is to improve both ventilation and IAQ actual in-situ performance.

The first step of the "VIA-Qualité" project was to analyse current building performances, regarding ventilation systems and IAQ. The first step pointed out main ventilation systems actual dysfunctions and main steps that had failed and caused them. As a consequence, the second step of the "VIA-Qualité" project aims at proposing QM approaches on ventilation and IAQ. Indeed, the implementation of QM tools to better practices at every stage of the construction could avoid many dysfunctions.

The first part of the paper deals with the development of QM approaches on ventilation and IAQ. It presents the structuration of the QM approaches, and the 3 main tools implemented: the first one is dedicated to the single-family house builders, the second tool is composed of technical drawings, for the workers, and the third tool is dedicated to the final users.
The second part of the paper presents the evaluation of the QM approach implementation by two French builders on 8 low energy houses. First, the way the 2 builders were guided by the "VIA-Qualité" partners is presented. Then, results of the application of the QM approaches on 8 low-energy dwellings are presented.

2 DEVELOPMENT OF QUALITY MANAGEMENT APPROACHES ON VENTILATION AND INDOOR AIR QUALITY

The implementation of QM approaches on ventilation and IAQ needs feedbacks on currents results and dysfunctions analysis. (Jobert et Guyot, 2013) analysed results of regulatory compliance controls of 1287 dwellings ventilation system. This analysis enabled us to draw up categories of mechanical ventilation system elements, where dysfunctions are found. This analysis confirms that, even if industrials solutions are available, ventilation systems dysfunctions are very frequently observed in low-energy dwellings like in every dwelling, which entails the reliability of these installations. (Jobert et Guyot, 2013) highlighted too main steps that had failed and caused ventilation system dysfunctions and put forward lacks in professional organisation, training and current work. Moreover, the "VIA-Qualité" project conducted an original campaign on ventilation performance and IAQ in 21 low-energy dwellings representative for French buildings stock. The campaign results confirm the first analysis ones.

Then, a deep analysis of French building organisation of work enabled to identify the main rules of each work in dwellings conception and construction. This step enabled us to better understand the way French building workers were organised and the step when each dysfunction could be anticipated and treated.

Finally, the French experience on regulatory envelope QM approaches, related by (Charrier et al., 2013), helped structuring QM approaches on ventilation and IAQ. The "VIA-Qualité" project proposed two QM approaches: one dedicated to the ventilation, and the other one dedicated to ventilation and IAQ.

2.1 Structuration of quality management approaches

The 2012 French energy performance regulation (RT 2012), that enables QM approaches on buildings envelope, helped structuring QM approaches on ventilation and IAQ. A QM approach is applied at each stage of a building project. In a QM approach, we must know, at any stage, "who" "does what", "how", "when" and which document will trace each action.

Thanks to the above described analysis, we have been able to identify ventilation main actors, depending on the stage of the conception. Main protagonists ("who") acting in ventilation

systems conception and installation are: the client, the QM approach headmaster, the engineering department salesperson, the engineering department, the site supervisor and craftsmen. Moreover, for each dysfunction point observed, we analysed who should have acted to avoid it ("what").

Then, the main stages of a building conception and construction that have been noticed are the following ("when"): preliminary studies, engineering studies, beginning of the construction, dwelling construction, dwelling delivery and dwelling life and maintenance.

Thus, the first step of the QM approach structuration has been to create a QM board, detailing, at each stage of a building conception and construction, for each actor, the list of actions ("what"): processes to be applied and examples of documents that could trace their application. In addition, processes and documents descriptions have been implemented so that to help builders to implement their QM approaches. A synthesis of the processes and documents chronology is presented in figure 01.

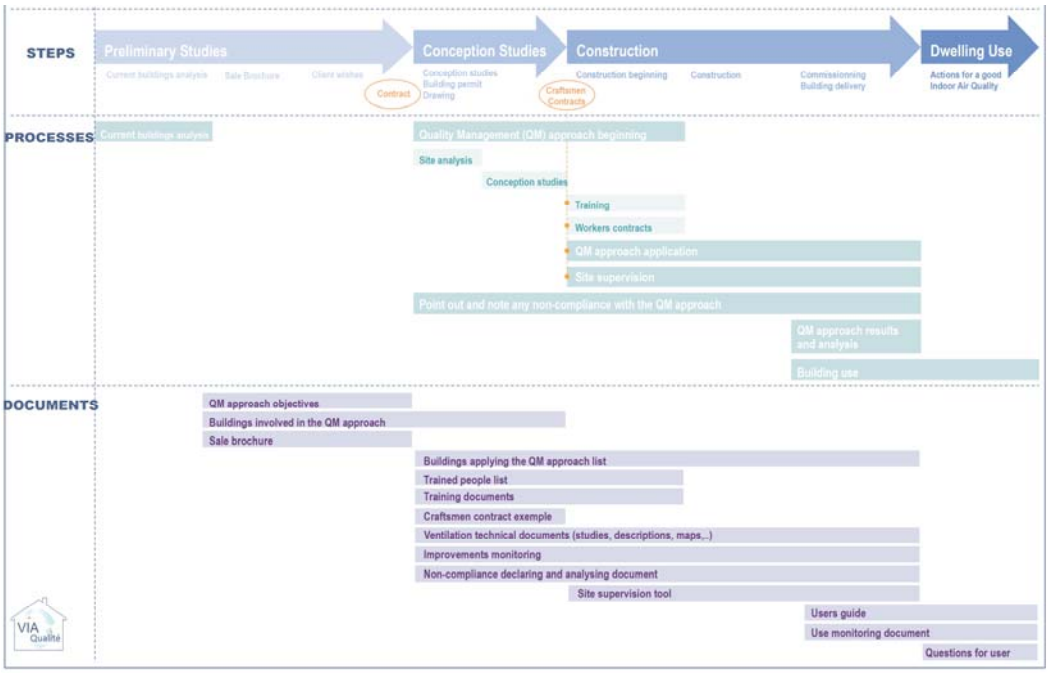

Figure 01: examples of processes and documents that could be implemented for a QM approach

This QM approach structuration led to the identification of 3 main tools: a single-family house builders guide, a craftsmen guide and a final users guide.

2.2 Tool 1: Guide for single-house family builder

This guide is dedicated to single-family house builders, in order to help them to implement a QM approach on ventilation and IAQ. The guide is the result of the "VIA-Qualité" project. Indeed, it synthesizes the proposed QM approaches and the feedbacks of their application by two builders. The guide is divided into 4 parts:

- The first part is dedicated to the reasons why a single-family builder should implement a ventilation or IAQ QM approach. Indeed, during the project, we realised that builders needed strong arguments to be convinced of the benefits of involving in a ventilation or IAQ approach. Therefore, this first part explains a QM approach

objectives and what is at stake. It gives also argues to help builders to be convinced of the health, economic, energetic and others benefits.

- The second part aims at helping the builder answering the questions “who-why-what-what for-where-when-how”. This part explains QM approaches on ventilation and IAQ contents.
- The third part details the main steps of a ventilation or IAQ QM approach. It describes, step by step, what is expected, the questions a builder will have to answer and the way the builder can get better. The main steps that have been identified are described in table 01.
- The last part details processes that could be implemented in a QM approach, giving examples of contents and tools.

Table 01: Main steps to implement a QM approach

1 Current dwellings evaluation	2 Organisationnal and technical improvements	3 « Who does what, when and how » description	4 QM approach implementation and application	5 QM approach improvements
• Ventilation and IAQ evaluation on a sample of the current production • Identify organisational and technical issues • Precise QM approach objectives and the type of dwellings that will be involved	• Identify ventilation and IAQ issues reasons • Find and class solutions	• Precise each conception and verification step in a dwelling conception and construction • Precise steps tracing documents	• Actors awareness and training • Apply QM approach during conception, construction and delivery steps • Scheduled evaluation (achieved performances and QM approach)	• Yearly evaluation of the achieved performances and the QM approach application
Actors involvement and training				

2.3 Tool 2: Guide for installers, technical drawings

The second guide, and not the least, is the craftsmen guide. It is composed of technical drawings. The tool aims at helping installers being aware of ventilation system components and rules and to know how to implement each one. It was also used to develop professionals training. In France, there is no craftsman which job is dedicated to the ventilation systems installation. In general, electricians or plumbers install the ventilation system. Moreover, there is few or no technical training for installers. The only existing professional trainings focus on ventilation systems conception and sizing, dedicated to engineering departments.

As a consequence, this guide answers the essential questions of ventilation systems understanding, its rules and its components. It is composed of technical drawings. It can be used at different steps of a QM approach: for professional training and during the construction, by craftsmen during the ventilation system installation and by the site supervisor for checking points.

The guide is divided into 6 parts.

- The first part explains the way ventilation systems work and the different ventilation systems that exist in France: simple exhaust (self-adjusting), simple exhaust humidity demand-controlled and balanced ventilation. This part has been added during the “VIA-Qualité” project because it appeared useful for builders and craftsmen to get this definition part.
- Then, the 5 following parts are dedicated to the 5 main ventilation system components: air inlet, air transfer, air exhaust, ventilation unit, ductwork, as shown in figure 02.

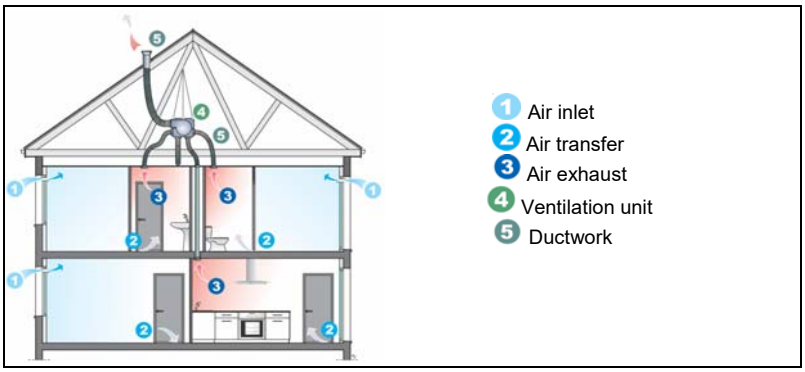

Figure 02: 5 main ventilation system components – simple exhaust ventilation

In each part, the introduction describes where the components have to be installed and regulations. Then, around ten technical drawings give a description of the ventilation system components, their characteristics, regulations and, when available, pictures of bad and good practices. Figure 03 is an example of technical drawing. The installers guide is composed of around 50 technical drawings.

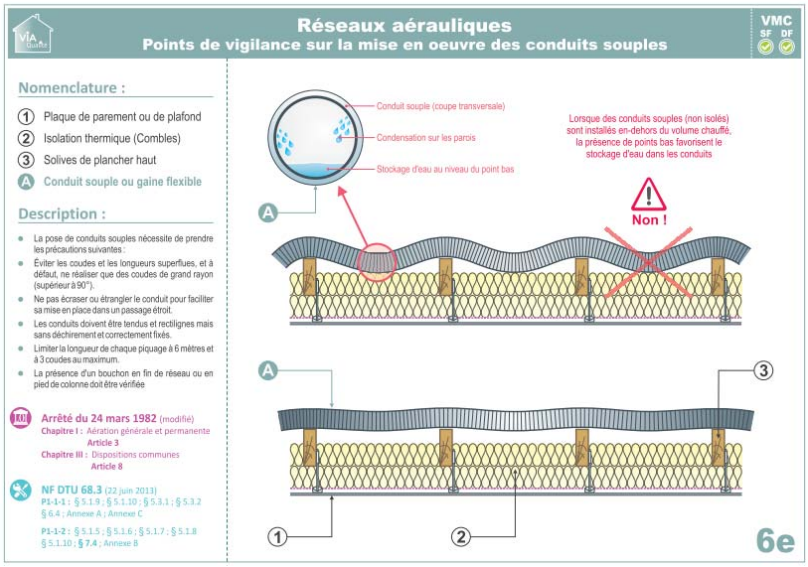

Figure 03: example of a technical drawing

2.4 Tool 3: Guide for final users

This tool is dedicated to final users and aims at raising awareness on ventilation system maintenance and IAQ. Indeed, in a building, final users will influence ventilation system quality and indoor air quality, by choosing final painting or surfacing, by using cleaning products, by being responsible for the ventilation system cleaning and maintenance, etc. As a consequence, the final users guide has been developed in order to inform users on how to choose products or to live in its dwelling with good ventilation and IAQ concerns.

The guide for final users is composed of 20 forms, organized into 3 main parts: “I embellish and convert my home”, “I live in my home” and “I change my indoor air”. Examples of forms that have been described: “I am painting”, “I am gardening”, “I am cooking”, “I am sleeping”, “I am washing”, “I am playing with children”, “I am aerating”,..

The users guide content has been defined by the « VIA-Qualité » project. Then, the Auvergne-Rhône-Alpes region decided to publish and distribute it. As a consequence, 1000 specimen have been published and distributed to inoccupants. The guide was named “Guide Grand Air” and was welcomed by every user who received it.

3 IMPLEMENTATION OF THE QUALITY MANAGEMENT APPROACHES ON 8 SINGLE-FAMILY DWELLINGS

Two single-family builders proposed to apply the main steps and tools of the proposed QM approaches on 8 single family dwellings. The “VIA-Qualité” partners guided builders on their implementation and application and, then, measured and analyzed ventilation systems and IAQ performances. The two volunteer builders were chosen as they had a certified QM approach on building airtightness. They were aware of QM approaches structuration and organization.

3.1 Sample selection and description

The two volunteer builders proposed 8 single family-dwellings. Each builder proposed 4 dwellings. 3 of them had simple exhaust humidity demand-controlled ventilation and the fourth one got a balanced ventilation. Moreover, each builder applied the ventilation QM approach on 3 dwellings and the IAQ QM approach was applied on one dwelling. For a builder, the IAQ QM approach was applied on a simple exhaust ventilation dwelling and for the other, it was applied on the balanced ventilation dwelling.

The main difficulty in the selection of the sample has been to find dwellings construction chronology fitting the “VIA-Qualité” project one.

3.2 The way builders implemented the QM approaches steps and tools

As it was not possible to make builders change their certified QM approach on building airtightness only for 4 buildings, we organised meetings in order to imply builders in ventilation and IAQ QM approaches. With one builder, those meetings enabled to choose the most appropriate dwellings and to analyse indoor air pollutants in its current sale brochure. With both builders, meetings enabled to define professionals training and to supervise construction. Moreover, for the dwelling applying the IAQ QM approach, a 6 months measuring system after the building delivery needed to be installed. As a consequence, we prepared an informing and engaging letter for the future user.

Then, the “VIA-Qualité” partners helped builders implementing and applying five main steps of the ventilation or IAQ QM approach. First, the project partners helped builders for the conception. To that goal, the project partners implemented two tools:

- A site analysis tool. This tools aims at identifying pollutants sources and conception solutions to avoid indoor air pollution.
- A simplified pressure drop calculation tool. Indeed, this tool had not been identified during the QM approaches implementation but it appeared necessary for builders and their internal engineering department. As a consequence, the tool helped builders to calculate pressure drop for the selected dwellings. This revealed that builders were not used to anticipate pressure drop before.

Then, training has been an important step in the partners support. The goal purchased was to raise awareness among engineering departments, site supervisors and installers, about ventilation and IAQ subjects and actors involvement to obtain good results. Training used the installers guide, presented in part 2.3. Two trainings have been organized:

- Engineering departments and site supervisors training. It aimed at presenting the QM tools, regulation and warning conception and supervision points.
- Installers training. It consisted in presenting regulation points, mains defaults in current practices and the installers guide. Then, practicing was proposed, with measures of good and bad practicing on ductwork and air inlets.

After that, the project partners helped builders in their supervision site. To help site supervisors verifying practices, the "VIA-Qualité" project partners implemented a site supervision board. It described the dwelling characteristics and proposed a list of points a site supervisor had to check during its weekly supervisions. These check-list was a summary of the installers guide drawing details. The tool proposed, for each point, to precise whether it suited with good practices or not. Moreover, photos could be integrated in the board.

The last step in the partners helping builders has been to raise awareness among future users, for dwellings applying IAQ QM approach. This consisted into a two hours meeting with final users, explaining indoor air quality and presenting the "Guide grand Air" (cf part 2.4).

To conclude, the builders' involvement was not the expected one. One of the two builders tried to apply as much as possible the QM approach steps and tools. The other one did not involve that much. Moreover, it is worth saying that it was very difficult to find dwellings chronology that suited with the project one. As a consequence, little of QM approaches has been actually implemented.

3.3 Measures campaign and results of QM approach implementation

After having applied ventilation and IAQ QM approaches steps and tools, the "VIA-Qualité" project aimed at measuring ventilation performance on the 8 dwellings and IAQ performances on the 2 dwellings applying the IAQ QM approach.

Regarding ventilation performances, following measures have been made: visual checks, airflow or pressure measures, ducts airtightness, envelope airtightness. Regarding IAQ performances, following measures have been made: passive measures, the same as those described by (Guyot et al, 2013), and dynamic measures. The results have been analysed thanks to the site supervision boards. Moreover, because of a conflict between the builder and one future user, only 7 houses have been involved in the experimentation.

Results of the measures are disappointing, but not surprising.

Regarding ventilation systems performances, 5/7 dwellings have non correct exhaust airflow or pressure measures. Concerning demand-controlled ventilations, 6/6 have non-correct fan pressure and concerning balanced ventilation, both have compliant fans pressures. Regarding ducts airtightness, the objective was to achieve class B. As regards demand-controlled ventilation, 4/5 ducts are class A, and one is out of class A. As regards balanced ventilation, ½ is class B, and the other one is out of class A. At least, the mean value of non-compliant points is 3.7, where we analyzed a mean value of 3.6 in the first campaign of the project. Table 02 summarizes the ventilation performance results and compares them to those of the first measuring campaign, detailed by (Guyot et al, 2013).

Table 02: Comparison of the 8 dwellings results with the 21 houses first campaign results

	7 dwellings with QM approach	**21 dwellings without QM approach**
Minimum exhaust airflow	No over-ventilated dwelling 2 regulatory airflows 5 under-ventilated dwellings	3 over-ventilated dwelling 4 regulatory airflows 14 under-ventilated dwellings
Mean value of non-compliant points	3.7	3.6
Defaults points	Fan : 35% Air exhaust : 23% Ducts : 19% System configuration : 12% Air transfer : 8% Air inlet : 4%	Fan : 24% Air exhaust : 31% Ducts : 15% System configuration : 15% Air transfer : 5% Air inlet : 11%
% duct airtightness class ≤ A	71%	47%

Those results have been analyzed with each site supervision board filled by the project partners. For each dwelling, we have been able to analyze positive and negative points in the dwelling conception and construction.

Regarding IAQ performances, the first dwelling results are positive. Internal comfort (temperature and indoor humidity) are good in every part of the house. Some volatile organic components (VOC) pics have been measured during meals. A mean value of VOC has been analysed, revealing the envelope impact on IAQ. At least, PM 2,5 are noticed at breakfast, linked to the toaster use. This first dwelling got a balanced ventilation, with good ducts airtightness class (class B). Regarding the second dwelling, which had worse ventilation performance results, it got bad IAQ performances too. Indoor temperatures vary a lot in the whole day. Humidity is quite stable. CO2 concentration is quite high in a bedroom, mainly in winter, not in summer, maybe due to a door opening during the summer nights. Moreover, VOC high levels have been measured, probably due to insufficient exhaust flow.
Finally, the first house has good results but is not representative of current practices as the ventilation system has been installed by the builder itself, in its future house.

3.4 Feedbacks

The project partners and the two builders agree to say that the application of the QM approaches on 8 single-family dwellings, only 4 for each builder, depending on different construction teams, is not enough to validate the QM approaches. Moreover, one of the two builders did not end the experimentation as he decided not to debrief after the delivery measures. And, last but not least, the project timing did not match easily with the buildings conception and construction one. However, the application of the QM approach tools and steps enabled to point out key steps to begin improving practices.

Regarding the two builders involvement in the project, a success factor has been their involvement in the teams' training, as they got implied so that the second training matched with the teams' interest. Moreover, one of the two builders actually involved in the project: he tested non usual ventilation ducts systems, proposed different solutions, checked for dysfunctions reasons, and after the project, evolved so as to better consider ventilation and IAQ interests, implementing self-commissioning controls for ventilation systems for instance. The main negative point has been, for the two builders, the lack of coordination between the engineering department and site supervisors and craftsmen.

Regarding the help for conception, a positive point has been the builders involvement, as it led to the implementation of two tools: a simplified pressure drop calculation tool and a construction site supervision tool. The use of the first tool made builders realize the importance of the calculation and the performance of the different existing systems. Concerning the conception step, it has been difficult to apply the QM approach proposals as the dwellings selection occurred after the conception step. Moreover, when client choices implied conception modifications, no new calculation or engineering department request was made. And, finally, builders and the project partners did not agree on how precise the map of ventilation systems should be. Nevertheless, the simplified pressure drop calculation tool implementation pointed out the pressure drop under-estimation of French technical rules and entailed their modification.

Regarding engineering departments and craftsmen training, it has been positively welcomed by everyone, thanks to the installers guide. Practical training, by installing ventilation ducts and then measuring their performance, has been welcomed. However, builders chose to focus on traditional systems, which entailed craftsmen difficulties to install non usual systems. Moreover, training occurred one year before the systems installation. The delay was too long between the training and the installation.

Regarding site supervision, some companies implied themselves in the correct installation of non-usual systems: they took care and proposed those systems to other dwellings. Moreover, a builder proposed to use the site supervision tool, for the future dwellings constructions. However, builders' involvement was not the expected one. Indeed, in most cases, site supervision board was not used by site supervisors. Only the project partners filled it.

Last but not least, one of the two builders, the most involved one, published in the project reports, its analysis of QM approaches on ventilation and IAQ. He highlighted the necessary conception step, as useful as the installation one. Moreover, as it has been useful for building airtightness, he points out the necessary craftsmen and engineering departments training and awareness. The global awareness on ventilation system and IAQ, can take time.

4 CONCLUSIONS

The "VIA-Qualité" project aimed at proposing the main steps of quality management approaches on ventilation and indoor air quality, and at testing them on 8 single-family dwellings. The validation of the approaches has not been possible, because of different time non-matching issues and others.

Nevertheless, the proposition and application of the QM approaches enabled to point out the main steps in the QM approaches implementation and application. Moreover, it enabled to highlight key rules that had not been identified at the beginning.
Thus, the main steps in a QM approach on ventilation and IAQ, are: conception, training, involvement and site supervision. The main tools that appeared useful for builders are:

- a guide for single-family builders, that explains how to implement a QM approach on ventilation and IAQ,
- a guide for installers composed by technical drawings,
- a guide for final user,
- and for builders: a simplified calculation drop tool and a site supervision document.

The “VIA-Qualité” project enabled to begin a global questioning of quality of ventilation systems and indoor air quality in French practicing. It enabled to define responsibilities, key rules and key steps. In addition, it implemented guides and tools that will help any professional to get better. French professionals are quite young on these subjects, but we can expect a future involvement as high as it occured for quality of building airtightness 10 years ago.

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