CRITICAL STEPS FOR WIDE SCALE IMPLEMENTATION OF BUILDING AND DUCTWORK AIRTIGHTNESS

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In this paper, we have identified 5 major steps for a successful wide-scale implementation of envelope and ductwork airtightness which is, or will be a growing concern in many EU Member States given the objective to generalise nearly zero-energy buildings by 2020:

- *Step 1 consists of defining relevant requirements – in particular with an appropriate knowledge of the leakage status – and implications of better airtightness in terms of energy, Indoor Air Quality (IAQ) and cost.*
- *Step 2 deals with the encouragement of professionals, including awareness raising strategies and training schemes for designers and workers.*
- *Step 3 addresses the control schemes, which must be realistic to be effective, and suggests several points of attention and ways to explore namely the robustness of testing schemes, as well as the development of intermediate testing and quality management approaches.*
- *Step 4 explains the importance of monitoring schemes, Research and Technology Developments (RTD) and the stimulation of front-runners to make a feed-back loop for policy revisions.*
- *Finally, in all steps, particular attention should be paid to fostering local, national and international networking (step 5, transverse to the other steps), which is essential to learn from each other and therefore to shorten the learning curve.*

Concrete examples, including lessons learnt from past or pioneering experience, illustrate the contents of those steps. This paper can be used as a basis for a roadmap for policy makers for national or regional initiatives on building and ductwork airtightness.

INTRODUCTION

Research bodies, industries, practitioners and policy makers have investigated building and ductwork airtightness with a very fluctuating degree of interest in time and space over the last 50 years. Interesting illustrations of this variability include: the regulatory envelope airtightness requirements gradually brought into force in the United Kingdom since 2002 [3]; the recent revived interest for building airtightness issues in Sweden, a pioneering country on this subject in the nineteen seventies [4]; the excellent ductwork airtightness achieved in Nordic countries in contrast with field observations in other countries [16][17]. Since the energy impact of envelope and ductwork leakage is becoming more and more significant compared to the other energy uses of low-energy buildings, airtightness issues have gained attention since several years. As an example to illustrate this, for a house in a moderately cold region (2,500 degree-days in K days), the energy impact is in the order of 10 kWh per m^2 of floor area per year for the heating needs and 0 to 5 kWh per m^2 of floor area per year for the ducts plus the additional fan energy use. Therefore, with the implementation of the Energy Performance of Buildings Directive (EPBD) and more recently with its recast [5], discussions take place on these subjects in many countries. In fact, the EPBD recast sets ambitious targets for the year 2020, including the obligation for EU countries to implement regulations to increase the number of nearly zero-energy buildings (NZEB) in the next few years, and to generalise nearly zero-energy targets in new buildings and major renovations. To reach this objective, envelope and ductwork airtightness are key players, although policy makers often do not perceive well the related energy savings potential, neither the possible ways to explore in order to improve the situation [14].

Therefore, the objective of this paper is to clarify these issues for policy makers and to underline the key challenges to overcome in order to adopt a wide-scale policy on building and ductwork airtightness implementation at country or regional level. Figure 1 shows the critical steps discussed in this paper.

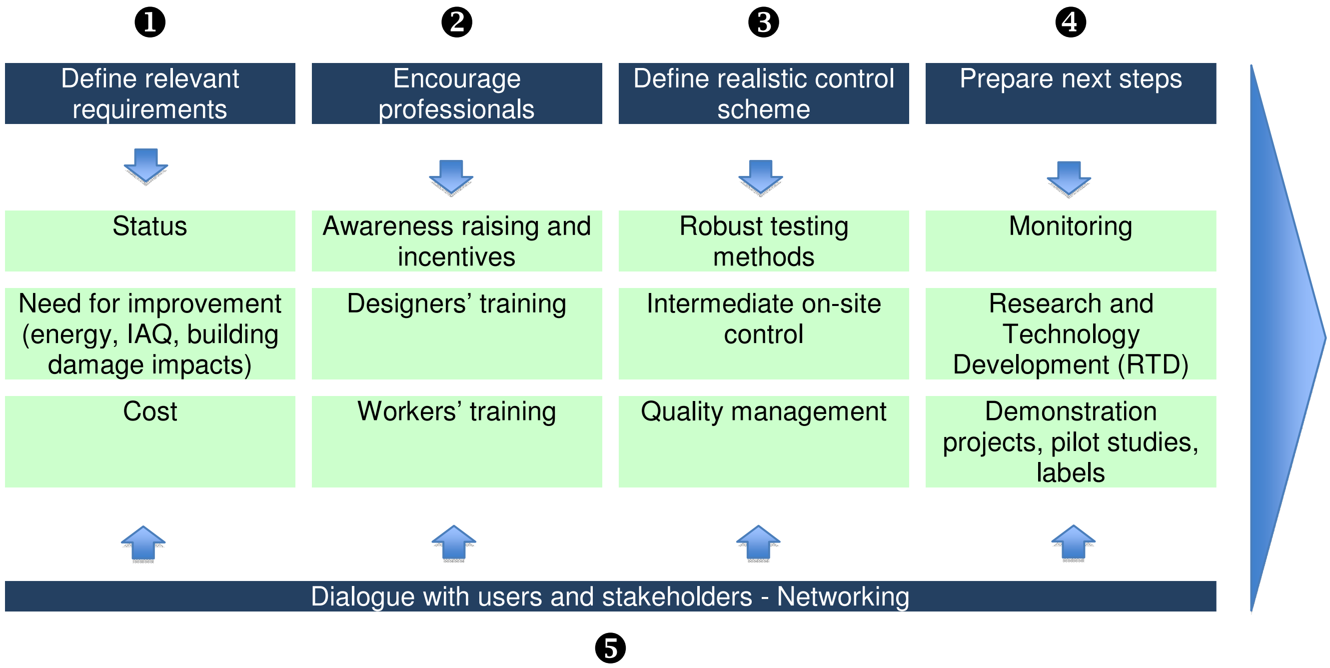

Figure 1: Critical steps for a wide-scale implementation on building and ductwork airtightness

1 DEFINE RELEVANT AIRTIGHTNESS REQUIREMENTS

Relevant requirements should be set based on energy, IAQ, building damage and cost implications of better envelope and ductwork airtightness. This implies some knowledge of the status of airtightness in new and existing buildings. Energy impacts can be estimated with calculation tools.

■ Status of building and ductwork airtightness

The wide-scale implementation of a policy implicitly assumes that the issue has been identified as a bottleneck. In our case, this preliminary step requires to know that envelope and/or ductwork leakage have a significant impact, e.g. on energy use, indoor air quality, or building damage. This means that the policy makers have some knowledge of the status of building and ductwork airtightness. However, in most countries, this status is poorly known and based on a limited number of measurements, especially when sub-divided into climate zones and building or system types. This requires a specific effort, which is underway in some countries.

To achieve progress, some countries have in parallel heavily encouraged, either directly or indirectly, good building and/or ductwork airtightness based on expert statements and at the same time taken steps to collect the measurement data induced by this encouragement. Note that in the longer term, this effort is also needed to monitor the progress made for future revisions of the policies (see below).

■ Proper estimates of energy impacts with appropriate EP calculation methods

Having appropriate tools to estimate energy impacts is key as it will form a major driver for the market. If the energy performance calculation method includes energy losses due to envelope and ductwork airtightness, designers can compare airtightness improvements with various options, e.g. increased insulation levels or solar collectors for domestic hot water. However, the comparison has to be fair; otherwise it distorts competition between the various options.

With an appropriate calculation tool[1], it is relatively easy to perform sensitivity analyses to find out the impact of envelope and ductwork leakage in various conditions. This should highlight if specific actions must be undertaken e.g., for a given building usage. In fact, one could think that the energy reward for good airtightness may be sufficient by itself to drive the market. However, for instance in the UK and more recently in France, or for labels such as PassivHaus or Effinergie®, it was preferred to set a minimum requirement to give a clear signal to the practitioners. Figure 2 shows fictitious examples of results of sensitivity analyses that are useful to take such decisions.

Note that heating and cooling energy impacts should be considered. This is

[1] Several studies have shown how energy losses due to envelope and ductwork leakage can be estimated. EN 15241 and 15242([11][12]) give several approaches that can be implemented in an energy performance calculation tool[16]. EN 15242 allows one to calculate the airflow rates including infiltration while EN 15241 gives the characteristics of the air passing through an air treatment plant as well as the power involved for its treatment. Today, several energy performance calculation methods include EN 15241/15242 with varying degrees of complexity.

obvious for ductwork airtightness if the duct system is used for cooling. For envelope leakage, the variability in additional cooling energy needs is large. In some cases (e.g., high internal loads in moderate climate), reaching extreme envelope airtightness levels can even be counter-productive energy-wise as it may increase cooling energy needs more than it reduces heating energy needs. In many other cases, improving airtightness reduces significantly the total energy use of air-conditioned buildings. Note that both for envelope and ductwork, in cooling conditions especially in hot and humid climates, the impact of air leakage on humidity conditions must be considered because it can affect significantly the latent load. In sum, this is a complex issue for which national or regional studies are most relevant to draw conclusions.

■ Analysing indoor air quality and building damage impacts

The impact of ductwork leakage on IAQ and building damage is fairly straightforward if the ventilation airflow rate is reduced either globally or in some building parts, or if pollutants enter the duct system through leaks. If the fan compensates for the leaks to provide sufficient air renewal, aside from energy use implications, we do not expect adverse effects on IAQ or building damage.

It is more subtle for envelope airtightness because:

- on the one hand, good airtightness helps ventilation systems (whether natural or mechanical) function better; namely, it allows for better control of the airflow rates in the different building zones. In many cases, it reduces condensation risks in the building structure as small amount of air flows out through building leaks;
- on the other hand, inadequate airtightness improvements or inappropriate tightening products may induce condensation damage. One trivial example lies in the positioning of the vapour barrier (often used as an air barrier as well) which, if inappropriate, can cause condensation. Another example consists in tightening the envelope without taking provisions for adequate ventilation, the worst case being a combustion appliance without outdoor air intake.

Solving the latter adverse side effects of inadequate tightening does not appear to be a major challenge in new European buildings. National regulations and standards usually cover these issues. For the existing building stock however, the task is considerably more complicated. Of course, there are a number of existing buildings for which the approach can be similar to new buildings. However, for instance, if water enters through a wall by capillarity, e.g., because of a construction defect or because it is a rubble construction without foundation, this problem obviously needs to be fixed before air tightening is performed.

In sum, while adverse side effects can be dealt with, they have to be carefully analysed to prevent improper initiatives, especially for the envelope airtightness improvement of existing buildings. If mandatory envelope airtightness improvements are envisioned for the existing stock, they must be included in a framework that addresses IAQ and building damage issues—e.g., to take provisions for adequate ventilation together with envelope tightening.

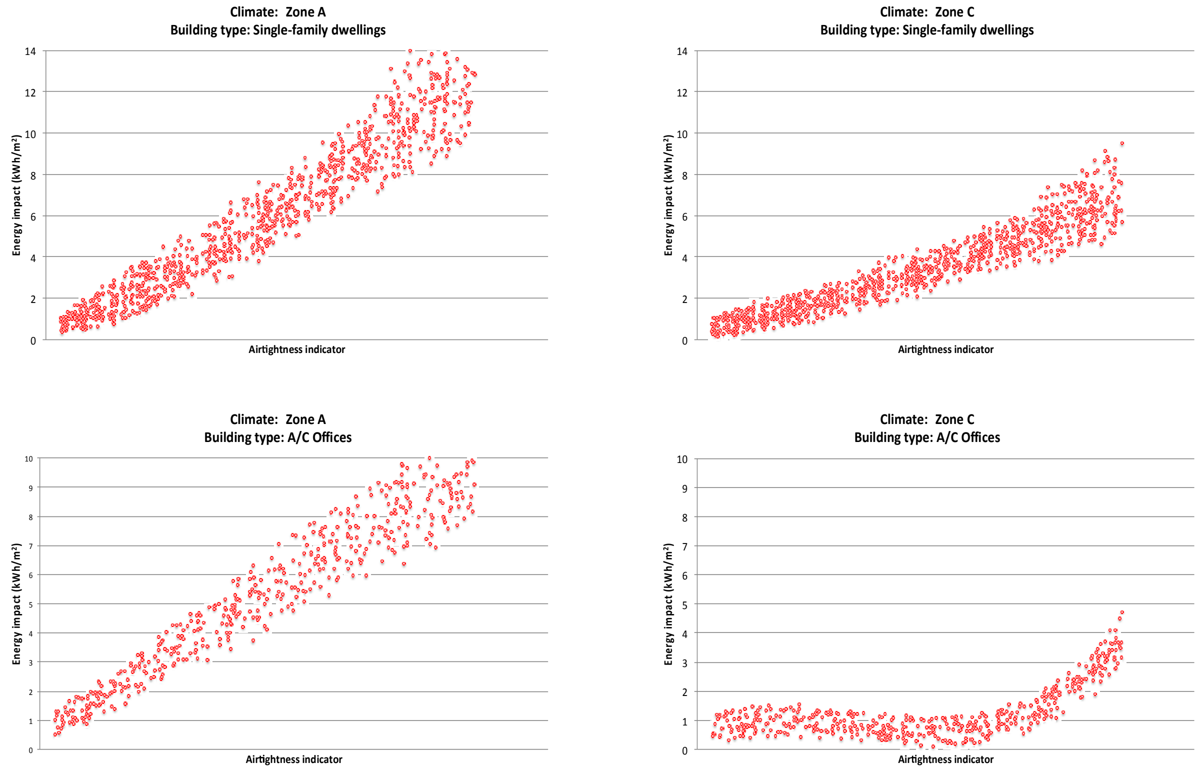

Figure 2: Fictitious examples of sensitivity analyses of the energy impact of building airtightness. Such analyses can help fine-tune the desired airtightness levels depending on e.g., building usage or climate.

■ Cost implications of better airtightness

The level to which airtightness has to be raised will be the result of a trade-off between the need (based on energy and IAQ implications) and the cost involved.

Proper cost analyses should take into account at least initial and operating costs. These costs vary from one country to another and especially from one time to another. Such analyses are available for ductwork systems in the SAVE-DUCT project report [1][13]. For envelope airtightness, Table 1 gives an example of the outcome of such an analysis conducted in France based on expert statements.

Cost estimates (in Euros exc. VAT)	
Cost for airtightness material and workmanship	500 to 1,000 €
Cost for airtightness testing	500 € (50 to 100 € with a quality management procedure)
Estimated energy savings	30 to 150 € per year
Savings on customer service with a QM procedure	1,500 €

Table 1: Cost estimates for reaching 0.6 $m^3/h/m^2$ (about n50 = 2.5 ach) in new individual dwellings in France. The savings on the customer service are based on feed-back from builders who have implemented such approaches [2].

2 ENCOURAGE PROFESSIONALS

Improving airtightness calls into question the traditions in design and workmanship. Appropriate awareness raising campaigns, incentives and training should be thought out to encourage professionals to integrate these challenges into their common practice.

■ Awareness raising and incentives

Although envelope and ductwork airtightness are in many cases very cost-effective measures to improve energy performance, practitioners are rarely aware of this potential. This is the reason why local or national bodies have set up information campaigns in several countries. The Holdtett campaign (http://www.holdtett.no) in Norway is one interesting illustration of such initiatives whose number remains unfortunately much too limited compared to the need.

Regarding incentives, at present, many countries have a range of financial stimuli to accelerate the implementation of energy efficient investments in buildings, e.g., subsidies, fiscal deduction, attractive loans, etc. Typically, a number of conditions have to be met in order to receive the benefits.

Quite often, the requirements are expressed in a descriptive way—e.g., installation of high efficiency glazing, of a condensing boiler, of a ventilation system with heat recovery, of good envelope airtightness. Although this approach is quite simple, attention is required to the fact that it fragments the design into partial objectives that are not necessarily integrated in a global strategy.

An alternative approach is to relate the benefit to the achieved energy performance as the quantitative basis. In such schemes, envelope and ductwork airtightness can compete fairly with other measures only if they are fairly rewarded in the calculation method (see paragraph about energy estimates above).

■ Designers and on-site workers training

It remains a common understanding that on-site workers are nearly the unique key to good airtightness. However, envelope and ductwork airtightness must be viewed as systems which are specified in the programme, designed, detailed in calls for tender, checked and corrected if necessary.

While designers should play a major role, it takes time and effort before they efficiently contribute to better airtightness. In fact, achieving better airtightness often questions their traditional design options and they do not necessarily have the resources to search for the sparse literature on envelope and ductwork airtightness design. This is where training programmes are useful, because they allow the designers to better understand the shortcomings of their standard methods and to take shortcuts to derive alternative solutions. Experience of successful designers training initiatives shows that practice-oriented approaches work well, e.g., with examples of construction details for various interfaces[2] in addition to the

[2] *See for instance one outcome of the PREBAT MININFIL project providing over 200 construction details for the French market. It took 3 years to develop the documents that can be downloaded from www.rt-batiment.fr or www.cete-lyon.developpement-durable.gouv.fr. Note that these construction details would need to be adapted to local regulations and customs if applied in a different country.*

general discourse on the overall approach to airtightness design.

Once the designers have properly detailed the provisions for airtightness, it becomes much easier for the project manager to explain what he expects from the workers. Detailed drawings are essential at this stage. Also, experience shows that hands-on training programmes for workers are extremely useful. Such programmes can be organised in a specific training centre (independent or part of an industry) or on a specific building site. The major challenge here is represented by the logistics involved in demonstrating good practice on real building or ductwork components.

In sum, it is clear that training designers and on-site workers is one essential ingredient to the success of the improvement of building and ductwork airtightness, because it implies new design and installation practice. Qualification processes attached to these trainings would bring added-value to the professionals, and therefore could attract more potential candidates. However, such trainings—including qualification or not—entail a tremendous effort because of the large number of potential trainees and the logistics implied. Therefore, they should be planned to achieve an impact with optimal use of financial and human resources. National or regional levels appear to be the relevant scale for such plans e.g., integrated within the national roadmaps that are to be defined in the context of the BUILD UP Skills initiative.

3 DEFINE REALISTIC CONTROL SCHEMES

Experience shows that control schemes represent one crucial aspect to foster improved building and ductwork airtightness among professionals. Voluntary controls or quality management approaches are very instructional. These issues should be addressed in a consistent framework that includes e.g., certification procedures for testers, encouragement for on-site testing, quality management approaches.

■ Robust testing methods and certification schemes for testers

Because of the weight of tradition in building design and construction, it is unlikely that a real market transformation will occur on such subjects without control procedures. This is also the reason why the EPBD recast in article 18 gives requirements for independent control. But this implies that the testing methods are homogeneous between inspectors.

Although various standards exist to perform envelope or ductwork pressurisation tests (European Standards 13829, 12237, 1507, 13403, 14239 [6][7][8][9][10]), experience shows that there remains room for interpretation which is difficult to narrow down at the international level, e.g., because of assumptions in the calculation method in which the test results are used. In particular, the following questions need to be addressed:

- How is the building prepared for an airtightness test to remain consistent with the inputs of the calculation method?
- How is the leakage-flow normalised and how does this affect the EP calculation input?
- How can airtightness tests results from parts of a building or duct systems, e.g.,

in a multi-family or a large building, be used to extract EP calculation inputs?
- How to measure ductwork falling under various standards (e.g., circular and rectangular ductwork)?
- Should there be a tolerance in meeting minimum requirements in order to account for measurement uncertainty?

Also, testers need to be trained. Finding out which openings should be sealed or closed during a pressurisation test, or how to interpret measurement data is not a trivial task. Performing such measurements requires some background on the EP regulations and HVAC systems, as well as experience with data analyses and field constraints. To our knowledge, such schemes are operational only for envelope measurements and only in the UK (www.bindt.org), in Germany (www.flib.eu/certifications.html) and in France (www.qualibat.fr, [2]). The certification procedure may imply an examination of several test reports produced by the candidate and examination in real testing conditions. It may be reduced to certain building or ventilation system types that require less experience and knowledge. All in all there is a trade-off between training cost, need for testers[3] and certification credibility and impact, that has to be considered in national or regional contexts.

[3] *The number of testers needed can be roughly evaluated on the basis of the number of tests performed per year on average. A high estimate of that number is 100.*

■ Intermediate voluntary site controls

Envelope and ductwork leakage are in general the only inputs for an EP calculation method that require testing at commissioning, if default values are not chosen for these items. However, it is very risky to wait until the end of the construction to find out if airtightness has been correctly dealt with. In fact, once finished, it is usually much more difficult to correct defects than during the construction phase: for instance, it is nearly impossible to seal ducts located in shafts once these are closed e.g., with a gypsum board, but relatively easy before. For this, it is advised to perform envelope and ductwork pressurisation tests during the construction to seal what can be sealed at this stage. This practice is fairly common for envelope airtightness for building professionals aiming at low-energy targets. Also, experience shows that such tests are very instructional for designers and workers as they better realise the weak points, as well as ways for improvement of their contribution. Such tests can be encouraged for instance through pilot projects supported at national or regional level.

■ Quality management approaches

To deepen this concept, the encouragement of quality management approaches appears one interesting path to be explored by policy makers. As of today, to our knowledge, this has been tried in the UK, Finland and France (in France, since 2006, and both for envelope and ductwork starting in 2011). In general, it introduces the possibility to claim for a better value than the default airtightness value in the EP-calculation, without systematically performing a test, provided that an approved quality management approach be applied [2][3].

The basic requirements for the quality management approach to be approved may be:
- to identify “who-does-what” and when;
- to trace each step of the approach;
- to prove that the approach is effective based on measurements on a sample;

- to propose a scheme to ensure that the approach will remain effective with time, based on measurements on a sample.

Of course, such a scheme needs to be carefully evaluated to make sure that it is sound and effective, but it presents two key advantages:
- first, it gives the signal to building professionals that envelope and ductwork airtightness must be viewed as an issue of concern for many actors, and certainly not only the carpenter, the plumber, or the electrician for instance. Airtightness has to be designed and properly dealt with generally by a number of professionals;
- second, it is a pragmatic approach to the cost induced by pressurisation tests and availability of qualified testers.

4 PREPARE NEXT STEPS

Action plans for better envelope and ductwork airtightness should be evaluated to prove whether they are effective or need to be revised. Monitoring is an important aspect for this. Policy revisions should also build on demonstration projects, pilot studies, labels and RTD developments.

■ Monitoring the progress in building and ductwork airtightness

Implementing a policy on building and ductwork airtightness implies that an evaluation scheme is set up; otherwise little can be learnt from this experience, for instance, for future revisions. This evaluation can be a one-shot effort, with the evaluation of a sample in a specific study. An alternative is to have a continuous monitoring scheme with a continuous data collection process. Both can be done with the help of a network of testers who provide their measurement data to the body in charge of the analyses. Note that one virtue of certification schemes for testers is that it can ease the collection of measurement results: as part of the certification, testers may be required to send their data to the certification body with the usual privacy precautions.

This work may look trivial, but it requires considerable human and financial resources to structure the database, to check the consistency of the data and to analyse the results. To our knowledge, this effort is underway in three countries only (France, Germany, USA) although it should be considered together with the implementation of an ambitious policy.

■ Demonstration projects, pilot studies, labels

Demonstration projects and pilot studies represent an interesting mechanism to entrain small groups of professionals to change their practice, hoping that their success stories will inspire their competitors. Several interesting initiatives include:
- organising project-specific training sessions;
- organising on-site information sessions for workers;
- financing intermediate and/or final airtightness tests;
- financing third-party evaluation of strength and weaknesses and ways to explore for improvement.

Specific requirements can also be introduced for evaluation of demonstration projects, for instance though labels (e.g., Passivhaus, Minergie®, Effinergie®) or based on expert statements. This has been successfully tried in various countries.

Overall, these schemes appear to be very effective for convincing professionals, especially when they are well inter-connected with dissemination actions. Evaluation of design and installation practices is also very useful to prepare policy revisions.

■ Research and technology developments

Although specific and efficient methods and products exist in order to achieve good building and ductwork airtightness, there remain areas where RTD would be useful to ease professionals' work.

One area concerns the renovation of buildings where, although the easiest and technically preferable approach is to conduct a one-step integral renovation, it is clear that the largest fraction of the building stock will be renovated step-by-step. This raises a specific problem for building and, to a lesser extent, ductwork airtightness that needs to be considered at all steps, e.g., to make sure that early measures do not prevent adequate treatment of leakage sites later on. The integration of airtightness and ventilation issues in a step-by-step or in an integral approach renovation is also a problem. There is little work on these subjects to support method and product developments.

Other areas that deserve deep investigation are: the durability of the buildings seals over the building's lifespan, the analysis of vapour transfer through leaks and through the building structure, the development and testing of new sealing methods and products, and the life-cycle cost of air tightening.

Research should also support the development and analysis of leakage databases for monitoring purposes, estimates of energy and IAQ implications, as well as pressurisation test protocols.

5 DIALOGUE WITH USERS AND STAKEHOLDERS - NETWORKING

Dialogue, although essential for a successful policy implementation, is challenging as few structured users and stakeholders networks exist on envelope and ductwork leakage. TightVent Europe can help fostering national and international networking on these issues, which would also be useful for other purposes, e.g., sharing experience on training programmes, control schemes, RTD, etc..

Dialogue with users and stakeholders is of course one key to the successful implementation of such policies. In most other energy performance related subjects, policy makers can rely on associations to have resource-efficient feedback on field practice and possible adverse or positive implications of policy orientations.

As for airtightness, some formal or informal structured networks have emerged mostly in the past few years. We have identified networks in 7 European countries. However, the vast majority focuses almost exclusively on building airtightness measurement techniques, which means there is a gap on the other issues mentioned in this paper.

There are some local initiatives on the issues raised herein, such as the development of air leakage databases or on workforce training schemes. Sharing practice and research experience and taking advantage of the lessons learnt from pioneering work would be mutually beneficial, and encourage other initiatives. However, to our knowledge, there is no structured communication between initiatives taken in various countries or towards other parties facing similar problems.

Fostering national and international networking is one main focus of the TightVent Europe platform (www.tightvent.eu) initiated by the International Network for Information on Ventilation and Energy Performance (INIVE EEIG), with at present the financial and technical support of the following partners: Buildings Performance Institute Europe (BPIE), European Climate Foundation (ECF), Eurima, Lindab, Soudal, Tremco illbruck, and Wienerberger. All partners are strongly interested in setting up a European wide collaboration and using the knowledge gathered through TightVent Europe for raising the awareness among all building professionals, for developing improved training courses, and for helping professionals in the development of quality management approaches. The partners also believe that TightVent Europe can play a major role both in terms of research development and dissemination in the RTD areas aforementioned. Also, TightVent Europe will make use of its network of well-known specialists around the world and will put forward synergies between national initiatives.

CONCLUSION

There are great challenges towards a wide-scale implementation of building and ductwork airtightness. The major pitfalls and cornerstones are identified in this paper. Together with the analysis of existing work and lessons learnt from previous experience, this can form a strong basis for a roadmap for national or regional initiatives on building and ductwork airtightness. One aspect which is not detailed in this paper is the time needed to implement such policies, but the UK, and more recently the French experience, show that market transformation on these issues takes time: 5 to 10 years seems a reasonable estimate. This is an important parameter to keep in mind given the 2020 objectives of the EPBD recast.

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