Brussels, Belgium

18-19 March 2014

International Workshop

Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings

Proceedings

This event is organized with the technical and/or financial support of the following organizations:

International workshop

Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings

Programme

Brussels, 18-19 March 2014

Day 1 – Tuesday 18 March 2014

09:30-10:20 Session 1. Welcome and introduction

10:20-11:15 Session 2. Impact of measurement uncertainties on energy performance calculations and IAQ

11:15-11:40 Coffee break

11:40-13:00 Session 3. Challenges for measurements of ventilation and air infiltration in low-energy buildings

13:00-13:45 Lunch (snacks and beverages)

13:45-14:45 Session 4. Measurement of air exchange rates with tracer gas

14:45-16:35 Session 5. Measurements of airflow rates in ducts and at air terminal devices

16:35-16:50 Coffee break

16:50-18:00 Session 6. Measurement solutions and integrated measurement devices

Questions and answers for the whole session

18:30 End of first day

Second day – Wednesday 19 March 2014

09:00-09:45 Session 7. Keynote lecture

09:45-10:45 Session 8. Schemes to address the quality of measurements

10:45-11:00 Coffee break

11:00-12:45 Session 9. Building and ductwork airtightness

Questions for short oral presentations

12:45-13:15 Session 10. Open discussion and perspectives

13:15 Lunch (snacks and beverages)

Newsletter
AIVC Air Infiltration and Ventilation Centre

Foreword

AIVC aims to play a central role in the ventilation and infiltration community with respect to the dissemination of information, either with its conferences or workshops, or with the material available on its website. The annual conferences continue to be greatly appreciated: 96 % of a sample of 76 conference attendees rated the 34th conference as excellent or satisfactory, 91% would recommend it to others. As you will see in this newsletter, we are working to uphold this quality for our future events.

We also hope the brand new AIVC website, including its advanced search capabilities on over 18000 publications, will experience similar success.

Please feel free to visit our website to find out more and mark your agenda for the following AIVC events:

- Workshop on Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings on March 18-19, 2014 in Brussels
- 35th AIVC conference on September 24-25, 2014 in Poznań, Poland

Peter Wouters, Operating Agent AIVC

no 5
January 2014

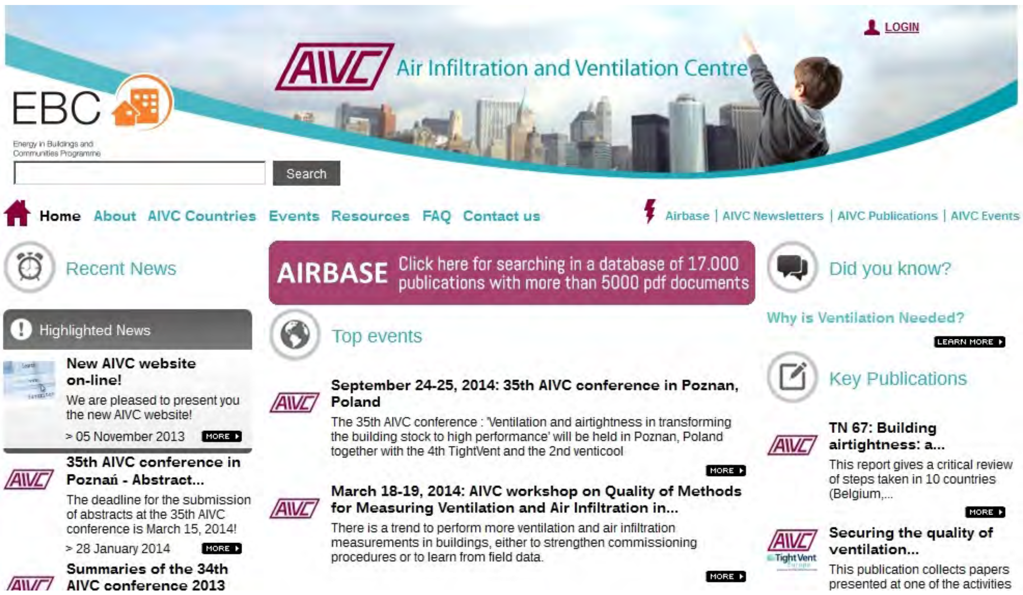
In this issue

New AIVC website

The new AIVC website was launched in November, 2013. Since 2001, the AIVC website had the same look and feel and we thought it was time for a fundamental change. In addition to the new look and feel, some of the major changes are:

- More interactive website with easier navigation
- More powerful search engine for AIRBASE
- Home page with highlights on news, events and publications

At present, AIRBASE contains abstracts of 18868 publications and more than 5000 related full documents. It is the intention to achieve in the coming months a substantial growth of full documents in AIRBASE.



34th AIVC Conference, 2013: Summaries of ventilative cooling and airtightness tracks

Over 160 persons attended the joint 34th AIVC, 3rd TightVent, 1st venticool and 2nd Cool Roofs' Conference held in Athens, Greece on 25-26 September, 2013. The conference focused on research, technologies, policies and market transformation to employ in an optimal way proper mitigation and adaptation techniques with the aim to reduce the energy consumption of buildings and improve the urban microclimate. Furthermore, focus was set on the energy impact of ventilation and air infiltration while ensuring good indoor air quality and thermal comfort, as well as converging work on smart materials to reduce the carbon footprint of the building sector.

Ventilative cooling was one of the major themes since the potential of this technique is more and more considered to reduce the cooling energy demand in summer or mid-season conditions, depending on outdoor climate, building design and internal loads. The ventilative cooling track of the conference consisted of 4 sessions with 27 presentations covering the following topics:

- Ventilation for summer comfort – energy impacts
- Experience with ventilative and passive cooling
- Ventilation and cooling strategies
- Ventilative cooling in standards and regulations–Challenges for Annex 62

Building and ductwork airtightness was another major theme of the conference. The airtightness track of the conference consisted of 4 sessions with 16 presentations covering the following topics:

- Collection and analysis of field data
- Quality of ventilation systems
- Methods for characterising airtightness – Durability
- Ventilation and airtightness nearly zero-energy buildings

The papers available at

venticool.eu/wp-content/uploads/2013/12/VC-summary_VF-2.pdf

and

tightvent.eu/wpcontent/uploads/2013/12/Airtightness-summary_V02.pdf

give a bird's eye view of trends and conclusions that appeared in the presentations and discussions in the ventilative cooling and airtightness tracks of the conference.

Opening & Closing session highlights at the 34th AIVC conference

During the opening session of the joint 34th AIVC conference in Athens, **Peter Wouters, Manager of INIVE EEIG**, presented a historic perspective of ventilation and air infiltration in buildings starting from 1973 and moving up to today with a time step of 10 years and looking ahead in the future. The presentation highlighted the first oil crisis in 1973 and its impacts on energy conservation policies and programs in that period (e.g. a lot of attention on airtightness – AIC – Air Infiltration Centre). It stressed the growing role of international collaboration in the 80's and the key role of e.g. AIVC to increase knowledge on air infiltration and ventilation, other key initiatives such as the Healthy Buildings or IBPSA conferences, augmented in the 90's by ISIAQ and EPIC conferences and a number of large international projects. Peter Wouters also acknowledged the political support with the creation of the IPCC in 1988, the Kyoto protocol in 1997, and (in Europe) the European Energy Performance of Buildings Directive in 2002 and its 2010 recast. This has led to major changes in the building design and solutions that must take into account indoor environmental quality together with economic constraints. There is still much work to be done to generalize NZEBs with almost no learning curve. Fortunately, international collaboration can surely help developing and disseminating guidance for training, legislation, etc…

Download the full summary of Peter Wouters' presentation here:

http://goo.gl/0hNQck

The closing session of the conference included a presentation by **Francis Allard, professor at the University of La Rochelle**, in France. The presentation focused on Energy Performance and Indoor Climate covering the main progress and perspectives in the last 20 years in the fields of: modelling tools, materials and components, the indoor environment quality concept, integration of environmental challenges, evolution of the regulation frame and accompanying initiatives. The presentation also highlighted the main characteristics of the Building Energy and Environmental System namely as multi-scale in space and time, multi-factorial, multi-performance objective (energy, IAQ …), multi-disciplinary and multi-purpose (application point of view). The speaker acknowledged the huge steps and efforts made during the last 20 years in research and development and the support by strong policies. The speaker stressed the need for the continuation of the development of models, new metrics, technology developments from components to systems and an occupant centered conceptual evolution.

Download the full summary of Francis Allard's presentation here:

http://goo.gl/B8MrUS

34th AIVC Conference, 2013: Best paper, best poster awards

Paper and poster awards were given during the closing session of the joint 34th AIVC, 3rd TightVent, 1st venticool and 2nd Cool Roofs' Conference held in Athens, Greece on 25-26 September, 2013.

1. Best paper award:

> **Title**: '*Toward Designing Strategies for Urban heat island Mitigation based on Multiscale Flow considerations*'

Authors: *Marina K.-A. Neophytou[1], Eleonora Tryphonos[1], Paris Fokaides[1],Mats Sandberg[2], Ekaterina Batchvarova[3], Harindra J.S. Fernando[4], Jos Lelieveld[5,6], Georgios Zittis[5]*

Affiliations: *[1] Environmental Fluid Mechanics Laboratory, Department of Civil and Environmental Engineering, University of Cyprus, [2] KTH Research School, University of Gavle, [3] National Hydrometeorological Institute, Bulgaria, [4] Department of Civil & Environmental Engineering and Earth Sciences, University of Notre Dame, USA, [5] Energy, Environment and Water Research Center, The Cyprus Institute, [6] Max Planck Institute for Chemistry, Mainz*

2. Best poster awards:

> **Title**: '*Effect of ageing processes and atmospheric agents on solar reflectivity of clay roofing tiles*'

Authors: *Chiara Ferrari[1,2], Ali Gholizadeh Touchaei[2], Mohamad Sleiman[3], Antonio Libbra[1], Alberto Muscio[1], Cristina Siligardi[1], Hashem Akbari[2]*

Affiliations: *[1] Dept. of Engineering "Enzo Ferrari" University of Modena and Reggio Emilia, [2] Heat Island Group, Building, Civil and Environmental Engineering Department Concordia University, [3] Heat Island Group, Lawrence Berkeley National Laboratory*

> **Title**: '*Preferred air velocity and local cooling effect of desk fans in warm environments*'

Authors: *Angela Simone[1] and Bjarne W. Olesen[1]*

Affiliation: *[1] International Center for Indoor Environment and Energy, Department of Civil Engineering at Technical University of Denmark*

> **Title**: '*Considering the Attica Example: Hotel location as a determinant factor of tourist carbon footprint*'

Authors: *Stella Panayiota Pieri[1], Panayiotis Kouyias[1], Vasiliki Milioni[1], Athanasios Stamos[1], Ioannis Tzouvadakis[1]*

Affiliations: *[1] National Technical University of Athens*

Download the pdf here: http://goo.gl/Kf9Bz1

New publications

On 18-19 March 2013, an international workshop was organized in Brussels to discuss existing approaches to secure the quality of residential ventilation systems in various countries. The edited proceedings of the workshop: 'Securing the quality of ventilation systems in residential buildings: existing approaches in various countries' are now available for download at: http://goo.gl/CN1Wl2

March 18-19, 2014: AIVC workshop on Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings

INIVE, on behalf of the AIVC, TightVent (Building and Ductwork Airtightness Platform); and venticool (the European platform for ventilative cooling, www.venticool.eu) organizes a 1, 5-day workshop on: Quality of methods for measuring ventilation and air infiltration in buildings. The workshop will primarily address field measurement of airflow rates, air exchange rates, air velocities, and pressures. Discussions and presentations may also include laboratory measurements as well as methods for measuring air temperature, air humidity, contaminants, energy use and power related to ventilation and infiltration in buildings. The methods will address natural, hybrid or mechanical ventilation, including ventilative cooling. Speakers will also give background information on readily-available measurement techniques.

More information on the programme and speakers will be soon available at our website: www.aivc.org

IEECB 2014 Conference, Frankfurt, Germany, 2-3 April 2014

The 8th International Conference on Improving Energy Efficiency in Commercial Buildings (IEECB'14) jointly organised by Messe Frankfurt and the European Commission DG JRC in conjunction with the Building Performance Congress will take place on 2 and 3 April 2014 in Frankfurt , Germany. The wide scope of topics covered include: smart building and low energy buildings, (Nearly) Net Zero Energy Buildings, equipment and systems (lighting, HVAC auxiliary equipment, ICT & office equipment, miscellaneous equipment, BEMS, electricity on-site production, renewable energies, etc.) and the latest advances in energy efficiency programmes, regulation & policies for public and private sector commercial buildings.

For more information visit the conference website at: iet.jrc.ec.europa.eu/energyefficiency/upcoming-events

Indoor Air 2014 Conference, Hong Kong, China, July 7-12, 2014

Indoor Air 2014 is the official conference of the International Society for Indoor Air Quality and Climate, ISIAQ. The triennial conference first began in 1978 to promote the science of IAQ and climate; it was held in Copenhagen, Denmark. The last Indoor Air 2011 conference was held in Austin, Texas.

Indoor Air 2014 is co-organised by The University of Hong Kong, Hong Kong University of Science and Technology, Hong Kong Polytechnic University and City University of Hong Kong. The event will be held on July 7-12, 2014 In Hong Kong, China and is co-sponsored by the AIVC.

For more information visit the conference website: www.indoorair2014.org

September 24-25, 2014: 35th AIVC conference, Poznań, Poland

The 35th AIVC conference: 'Ventilation and airtightness in transforming the building stock to high performance' will be held in the city of Poznań, Poland together with the 4th TightVent and the 2nd venticool conferences in September 24-25, 2014.

The conference is organised by:

- the International Network on Ventilation and Energy Performance (INIVE) on behalf of the Air Infiltration and Ventilation Centre (AIVC), TightVent Europe (the Building and Ductwork Airtightness Platform), venticool (the international platform for ventilative cooling); and
- the Poznań University of Technology.

Important dates:

- Receipt of abstracts: 15 March 2014
- Confirmation of acceptance: 1 May 2014
- Submission of papers: 30 June 2014

Visit the conference website www.aivc2014conference.org for programme and registration information.

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

October 2013

Newsletter No5

Foreword

The TightVent Airtightness Associations Committee now counts participants from 16 countries in Europe and North America. In parallel, TightVent Europe has been invited to a growing number of events either to give the status on European developments and perspectives on building and ductwork airtightness or to support new initiatives.

This trend demonstrates the major role of TightVent in disseminating information on building and ductwork airtightness and the help it provides to policy makers and professionals to deal with these issues, in particular in the context of the recast of the Energy Performance of Buildings Directive.

This newsletter will give you information on selected initiatives which we hope you will find useful. We would like to encourage you to join us for our future webinars (free of charge, see our event calendar), workshops and conferences for more information and fruitful exchanges.

Peter Wouters, *Manager INIVE EEIG*

Workshop on "Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings" in Brussels, Belgium, 18-19 March 2014

The objectives of this workshop are to review and to discuss:

- Recent and existing measurement methods for ventilation and air infiltration in buildings;
- Methods to estimate the uncertainty of those measurements;
- Conditions to obtain results whose quality is compatible with the purpose of the measurement;
- Conditions for large-scale implementation and pitfalls to avoid.

The workshop will address primarily field measurement of airflow rates, air exchange rates, air velocities, and pressures.

Interested parties are invited to submit an abstract by 15 November 2013 to info@aivc.org. Notification of abstract acceptance: 15 December 2013. Deadline for paper submission: 15 February 2014.

More information on: www.aivc.org

The workshop is organised by INIVE on behalf of the AIVC (Air Infiltration and Ventilation Centre); TightVent (Building and Ductwork Airtightness Platform); and venticool (the International platform for ventilative cooling, www.venticool.eu).

INIVE AIVC TightVent Europe venticool

In this issue

New publications

- ✓ d'Ambrosio Alfano, F., Dell'Isola, M., Ficco, G., & Tassini, F. (2012). *Experimental analysis of air tightness in Mediterranean buildings using the fan pressurization method.* Building and Environment, 53, 16-25.
- ✓ Sinnott, D., & Dyer, M. (2012). *Air-tightness field data for dwellings in Ireland*. Building and Environment, 51, 269–275.
- ✓ Van Den Bossche, N., Huyghe, W., Moens, J., Janssens, A., & De paepe, M. (2012). *Airtightness of the window–wall interface in cavity brick walls*. Energy and Buildings, 45, 32-42.
- ✓ Walker, I., Sherman, M., Joh , J., & Chan, W. (2013). *Applying Large Datasets to Developing a Better Understanding of Air Leakage Measurement in Homes*. International Journal of Ventilation, 11, 323-337.
- ✓ Wanyu R., C., Joh, J., & Sherman, M. (2013). *Analysis of Air Leakage Measurements of US Houses*. Energy and Buildings, 66, 616-625.

TightVent Airtightness Associations Committee continues to grow

The TightVent Airtightness Associations Committee (TightVent TAAC committee) was launched on September 26, 2012. Its primary goal is to promote reliable testing and reporting procedures. Since September 2012, the committee had a physical meeting in Hannover before the BUILDAIR symposium and has met five times (via internet).

At present, the committee has participants from 16 countries in Europe and North America: Czech Republic, Denmark, France, Germany, Sweden, UK, Belgium, Norway, Poland, Estonia, Ireland, Latvia, USA, Hungary, Croatia and Canada.

The scope includes various aspects:

- airtightness requirements in the countries involved
- competent tester schemes in the countries involved
- applicable standards and guidelines for testing
- collection of relevant guidance and training documents

Conditions for joining are described at www.tightvent.eu/partners/taac.

Recordings available

BUILD UP Webinar – Building and Ductwork Airtightness: Legislative Drivers, New Concerns and New Approaches

The recordings and slides for this webinar are now available here.

TightVent Belgium – A new local network of airtightness testers

BBRI and TightVent Europe have organised in Brussels on July 2 an information day on airtightness issues in the Belgium context. 52 persons exchanged points of views based on presentations that addressed in particular: the consultation process with stakeholders; the revision of ISO 9972; the development of technical guide; a review of quality schemes in Europe and the potential development of a quality framework in the Belgium context. Given the positive feedback of the participants on the relevance of such meetings, it is likely to lead to the inauguration of a Belgian network named "TightVent Belgium".

Flemish workshop on airtightness, Brussels, 4 September 2013

120 persons attended this workshop, which was organised by Flemish energy agency (VEA), the Flemish Royal association of engineers and BBRI. Presentations ranged from theoretical background to technical details via energy regulation context and issues as well as quality issues. TightVent Europe has been invited to give a presentation linked to the development of quality framework for airtightness measurements.

Lessons learnt from 3 field studies on airtightness durability

Maria Kapsalaki, INIVE

In 2002, the Fraunhofer Institute for Building Physics measured the airtightness of a series of 52 row houses compliant with the passive house standard in Stuttgart right after the construction phase. The measurements were repeated 2 years later. The initial air leakage test of all 52 row houses resulted in an average air change rate at 50 Pa (n_{50} value) of 0.37 h^{-1}, while the re-test of 31 of the houses measured 2 years later showed a slight increase of the n_{50} value by an average value of 0.09 h^{-1}. 5 out of the 31 buildings measured in 2002 no longer complied with the

original requirement of $n_{50} \leq 0.6\ h^{-1}$ but kept a relatively good airtightness level (maximum n_{50} value of $0.9\ h^{-1}$) compared to "standard" buildings.

A more recent study from B. Bossard and U.P. Menti presented during the 8th International BUILDAIR-Symposium held in Hannover in June 2013 showed no correlation between the durability of airtightness and the age of the building. The study involved air permeability tests on 25 buildings (single-multifamily homes, public buildings and schools, the majority certified as MINERGIE-P), in Switzerland, conducted from 1996 to 2012. For the great majority of the buildings measured, a difference of less than +/-20% between the first and the second measurement was observed.

Another recent report published in 2010 by the NHBC Foundation presented results from airtightness measurements of 23 mixed type dwellings (attached –detached, masonry and timber frame) performed within a time interval of one to three years. The research concluded that 65% of the dwellings became less airtight on average by 1.5 m^3 / ($h.m^2$) at 50 Pa while the remaining sample got tighter with an average increase of 0.63 m^3/ ($h.m^2$) at 50 Pa. A further comparison between the different types of dwellings, construction material, heating and ventilation systems and the changes in the air permeability, over time, appeared to influence the performance to a certain extent, bearing in mind the limited sample size of the measurements.

Securing desired airtightness levels in the long term is crucial. It is a very complex field of study because durability depends on many aspects, some of which being very difficult to objectively characterise. These range from the quality of the design and installation to the interaction of occupants. This may explain the differences between the partial conclusions of these studies. The papers of Erhorn et al. (2009) and Bossard and Menti (2013), focus on extremely airtight very low-energy buildings for which significant attention has probably been paid at design and execution for airtightness issues. Also, in these cases, the occupants are likely aware of the damage they can make to the airtightness layer, e.g. when drilling holes in walls. Therefore, it is not surprising that their results show less deviation between measurements performed on the same buildings than the third study with "standard" houses.

To make progress in this area, an important step consists in gathering data on larger samples of buildings

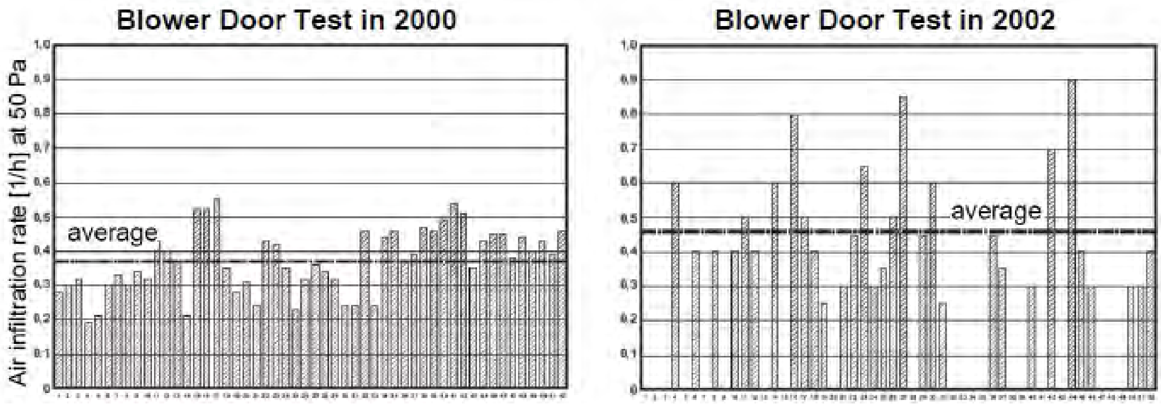


Figure 1: Results of airtightness measurements at 31 passive houses in Stuttgart, Germany measured right after the construction phase and 2 years later [1]

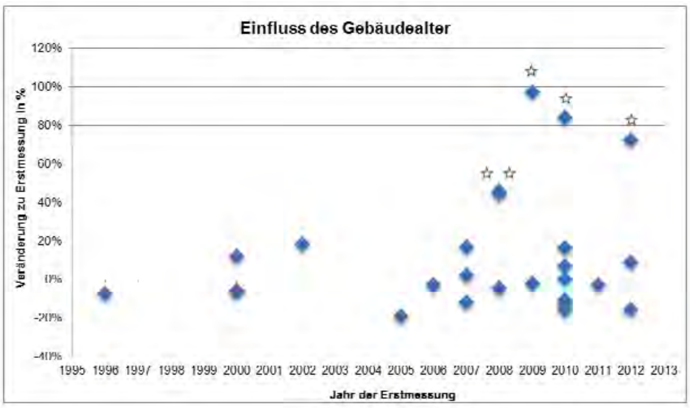


Figure 2: Air permeability tests of 25 buildings in Switzerland. Age modifications from the first measurements [2]

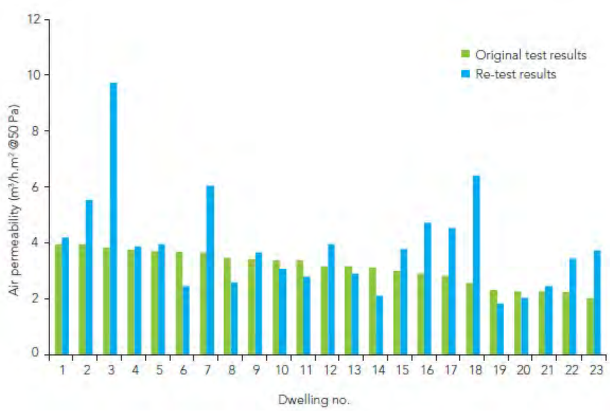


Figure 3: Air leakage test results at 23 dwellings in UK measured right after the construction phase and 1 to 3 years later [3].

TightVent Europe

BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

taking into account key parameters—yet to be identified and characterised—influencing airtightness durability like design options, product choice and assembly, building operations and maintenance, building environment and climate.

In the meantime, from a practical point of view, experience suggests that careful design and follow-up of installation, as well as awareness raising among occupants are effective short term actions to promote in order to improve airtightness durability.

Works Cited

[1] H. Erhorn-Kluttig, . H. Erhorn and H. Lahmid, "Airtightness requirements for high performance building envelopes," in ASIEPI Information Paper P157, 2009.

[2] B. Bossard and U.-P. Menti, "Luftdurchlässigkeitsmessung: Momentaufnahme oder langfristiges Qualitätsmerkmal?," in 8th International BUILDAIR-Symposium, Hannover, 2013.

[3] T. Phillips, P. Rogers and N. Smith, "Ageing and airtightness- How dwelling air permeability changes over time," NHBC Foundation, 2011.

AIVC conference in 2014 in Poznań, Poland, 24-25 September 2014 “Ventilation and airtightness in transforming the building stock to high performance”

The 35th AIVC conference will be held in Poland together with the 4th TightVent and 2nd venticool conference. The conference is organised by:

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AIVC — TightVent Europe (BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM) — venticool (the international platform for ventilative cooling)

Organisers: INIVE — Politechnika Poznańska / Poznan University of Technology

Events Calendar

NOVEMBER 14: TightVent webinar on ‘Airtightness testing: status and trends in competent tester schemes in the UK, Denmark and Belgium’. More information on: www.tightvent.eu

NOVEMBER 22: TightVent webinar on ‘Airtightness testing: status and trends in competent tester schemes in Germany, Czech Republic and France’. More information on: www.tightvent.eu

MARCH 18-19, 2014: AIVC-TightVent-venticool workshop in Brussels, Belgium on ‘Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings’. More information on: www.tightvent.eu

SEPTEMBER 24-25, 2014: AIVC conference in 2014 in Poznań, Poland on ‘Ventilation and airtightness in transforming the building stock to high performance’. More information on: www.tightvent.eu

No 3 ● DECEMBER 2013

Foreword

The venticool platform was inaugurated in September 2012 in response to the needs felt to increase awareness regarding ventilative cooling and to foster exchanges on this topic both for practitioners and researchers. 15 months later, its relevance is clearly confirmed:

- The IEA EBC Annex 62 project on "Ventilative cooling" has been approved for a 4-year working phase and will use venticool as key communication partner;
- The 2012 and 2013 AIVC conferences, together with the March 2013 workshop have been major discussion places on this topic and key elements to develop the annex work plan;
- The Intelligent Energy Europe project "QualiChEck" recently approved will address ventilative cooling issues related to compliance and quality of the works in collaboration with venticool.

This opens a period of 4 to 5 years at least with great developments expected on ventilative cooling. We hope you will have a good taste of it with this newsletter.

Peter Wouters, Manager of INIVE EEIG

2013 conference
Summary of the ventilative cooling track

By Maria Kapsalaki, INIVE and Per Heiselberg, University of Aalborg, Denmark.

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Ventilative cooling was one of the major themes since the potential of this technique is more and more considered to reduce the cooling energy demand in summer or mid-season conditions, depending on outdoor climate, building design and internal loads. The ventilative cooling track of the conference consisted of 4 sessions with 27 presentations covering the following topics:

- Ventilation for summer comfort – energy impacts
- Experience with ventilative and passive cooling
- Ventilation and cooling strategies
- Ventilative cooling in standards and regulations – Challenges for Annex 62

The paper available at venticool.eu/wp-content/uploads/2013/12/VC-summary_VF-2.pdf gives a bird's eye view of trends and conclusions that appeared in the presentations and discussions in the ventilative cooling track of the conference.

In this issue

IEA EBC Annex 62 Working phase approved!

By Per Heiselberg, University of Aalborg, Denmark.

The IEA EBC Annex 62 successfully completed its one year preparation phase and the EBC ExCo approved at their latest meeting in November 2013 in Dublin the proposed work plan and Annex Text. The four year working phase will run from 2014-2017 and representatives from about 20 research institutes and private industries from 15 different countries will join the research team.

Please consult the website for further information (venticool.eu/annex-62-home/).

The research in Annex 62 will focus on development of design methods and compliance tools related to predicting, evaluating and eliminating the cooling need and the risk of overheating in buildings and on development of new attractive energy efficient ventilative cooling solutions. Research achievements will be summarized in a number of publications addressing the need of different target groups (Table 1). All publications will be published on the venticool/annex 62 website.

It is expected that the first publication, giving an overview of the actual status of the ventilative cooling technology, will be published by the end of 2014.

At the 2nd Annex 62 preparation meeting 20 delegates from 13 countries completed the work plan and started work on the first Annex 62 publication. The meeting was held in Athens, Greece, September 23-24, 2013 and hosted by professor Mattheos Santamouris, NKUA.

ID	Official Deliverable	Target Group
D1	Overview and state- of- the art of Ventilative Cooling	Research community and associates. Policy makers
D2	Ventilative Cooling Source Book	Building component and ventilation system developers and manufacturers. Architects and design companies, engineering offices and consultants
D3	Ventilative cooling case studies	Architects, consulting engineers
D4	Guidelines for Ventilative Cooling Design and Operation	Architects and design companies, engineering offices and consultants
D5	Recommendations for legislation and standards	Policy makers and experts involved in building energy performance standards and regulation

Table 1: Annex 62 Deliverables & target groups

Figure 1: 2nd Annex 62 preparation meeting, Athens, Greece, September 23-24, 2013.

BUILD UP overview article

venticool prepared an overview article on ventilative cooling entitled as 'Ventilative Cooling Lowers Energy Consumption' which has been distributed in September through the BUILD UP News Alert channel. Articles going through this channel are distributed to more than 25.000 e-mail addresses in Europe. The article is now published and available at www.buildup.eu/news/35658

BUILD UP energy solutions for better buildings

OVERVIEW

Ventilative Cooling Lowers Energy Consumption

Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces. The use of outside air reduces the energy consumption of cooling systems while maintaining thermal comfort. The most common technique is the use of increased ventilation airflow rates and night ventilation, but other technologies may be considered as well. Ventilative cooling is applicable in a wide range of buildings and may be critical to realise low energy targets for renovated or new Nearly Zero-Energy Buildings (NZEBs).

Recent developments for ventilative cooling in standards and regulations – Perspectives with the EPBD recast

Several studies have demonstrated the energy saving potential of ventilative cooling. If well designed and executed, ventilative cooling can play a major role in reducing energy use in buildings as required by the recast of the Energy Performance of Buildings Directive.

To realise this potential and facilitate the use of ventilative cooling, it is important that this technology is correctly covered in future NZEB regulations. It must be supported by appropriate technical solutions which are compatible and accounted for in standards and regulations.

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Several countries - e.g. Austria, Denmark and France - have taken steps to integrate ventilative cooling into their building regulations, which is a positive development.

Within existing CEN standards, relevant to ventilative cooling and used in energy performance regulations (EN 15242, EN 15241, EN 15251 and EN 13779), there remain some critical limitations for these technologies. For example, how to properly reflect the effective cooling potential of outdoor air which varies within a single day, in seasonal or monthly methods. These limitations should be discussed within the context of implementing the recast of the Energy Performance of Buildings Directive (EPBD recast) for which the European Commission has issued Mandate M/480.

Case studies and demonstrated energy savings

There is a wide range of real world applications of ventilative cooling. Speakers at the International workshop on ventilative cooling, held in Brussels, March 2013, outlined solutions that have been implemented in schools, sport halls, offices etc. which have achieved considerable energy savings, particularly when ventilative cooling is operated overnight.

The examples of a dual sports hall and a medical centre in Switzerland show that with proper solar protection, thermal mass and reduction of internal loads, night ventilative cooling can completely eliminate the need for active cooling. Meanwhile, in Belgium, office buildings have been designed with night ventilative cooling. The new Nicosia Town-hall located in the hot Mediterranean climate of Cyprus, implemented a night cooling strategy that has recorded a 56 % reduction in the cooling demand.

www.buildup.eu the European portal for energy efficiency in buildings

Find resources Post your materials Share knowledge...

Figure 2: BUILD UP overview article on ventilative cooling

New venticool website – venticool and Annex 62 join forces

As the venticool platform will act as a key partner for dissemination of IEA EBC Annex 62 and in order to optimize the communication, it was decided to have one single website for both actions. Please visit the new and combined website of the venticool platform and of IEA EBC annex 62 'ventilative cooling' for more regular updates on the progress of the annex, events, publications, etc.

QualiChEck proposal accepted!

INIVE is pleased to announce that its 'QualiChEck' proposal submitted in the framework of the Intelligent Energy Europe Programme has been accepted and should start during the first semester of 2014. The project aims to develop a series of actions to increase attention and foster real actions:

- To improve the confidence in compliance of new and renovated buildings (with specific focus for residential buildings) to the claimed energy performance i.e. "Boundary conditions which force people to do what they declare";
- To achieve better quality of the works, i.e. "Boundary conditions which stimulate and allow the building sector to deliver good quality of the works".

The project in general is expected to raise awareness among stakeholders in several technology areas including ventilative cooling.

The QualiChEck consortium consists of a broad range of organisations in 10 countries spread over Europe. Its partners and otherwise related members cover a wide range of expertise and competences and have several strong links to many European initiatives.

Figure 3: The QualiChEck consortium organisations

The work programme consists of 3 types of activities:

> **Status on the ground**: what is the situation in practice? Critical situations? Interesting approaches? This is covered in work package (WP) 2.

> **Providing solutions**: a key activity of the project is to collect, document and structure possible solutions for achieving substantial improvements regarding on the one hand the reliability of data used in EPC calculations and on the other hand improved quality of the works. This is targeted in the following 3 WPs:

- "**Towards reliable and easily accessible EPC input data**" (WP3). The focus here is on the identification of interesting boundary conditions and, if needed, on the identification of relevant developments required to come to correct and transparent performance declarations in certificates. An important parameter is to guarantee a low level of effort required for the various actors involved in the EPC declarations.
- "**Towards improved quality of the works**" (WP4). Here the focus is on the identification of interesting technical & organisational frameworks for achieving better quality of the works
- "**Towards better compliance and effective penalties**" (WP5). Assuming that the procedures for collecting/declaring EPC data are clear (WP3) and/or that the frameworks for ensuring good quality of the works are available (WP4), this WP is focusing on effective procedures for achieving better compliance and/or effective sanctioning.

> **Outreach and engagement**: It is important that the outcomes of the project reach the market AND contribute to action. A series of activities are foreseen to achieve an effective outreach. More crucial addition is a series of activities foreseen with as aim to stimulate and accelerate engagement by various market players.

It is important to mention that QualiChEck is NOT focusing on the real measured energy consumption of buildings.

More information will be available on the venticool website.

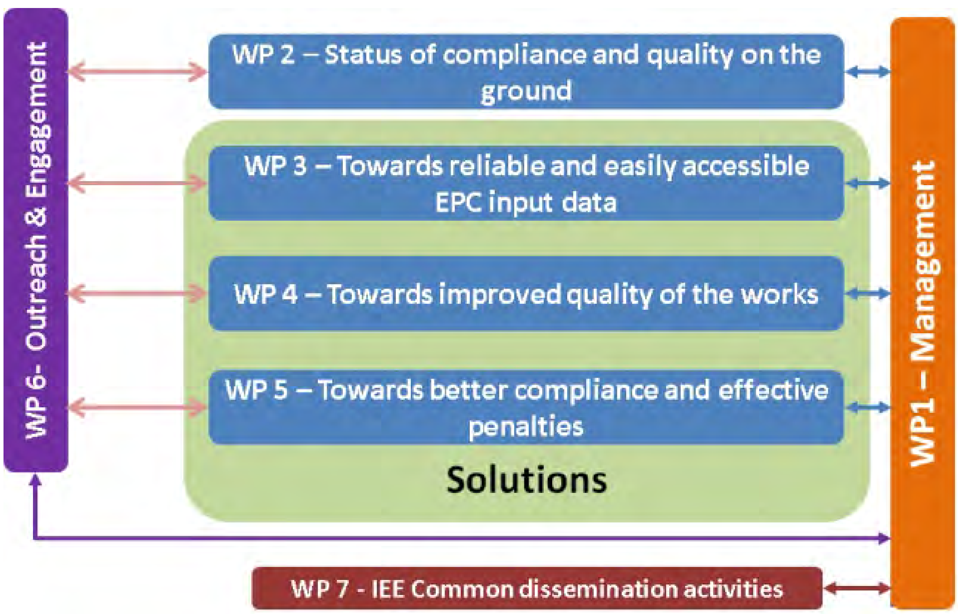


Figure 4: The QualiChEck work programme

Workshop on 'Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings' – 18-19 March 2014

The workshop will address primarily field measurement of airflow rates, air exchange rates, air velocities, and pressures. Several sessions will be particularly relevant to ventilative cooling which typically implies high air flow rates very difficult to measure.

For more information, visit: www.aivc.org/event/march-18-19-2014-aivc-workshop-quality-methods-measuring-ventilation-and-air-infiltration.

2014 AIVC conference – September 2014 in Poznań, Poland

The 35th AIVC conference will be held in Poznań, Poland in conjunction with the 2nd venticool conference and the 4th TightVent conference. It will be a major international event in 2014 with one track dedicated to ventilative cooling, focusing on the following topics: potential for ventilative cooling strategies, ventilative cooling in energy performance regulations, design approaches for ventilative cooling and case studies — Integrated design, thermal comfort and ventilation and active facades including topical sessions on building and ductwork airtightness.

Visit the conference website www.aivc2014conference.org for further information.

PARTNERS

- AGORIA-Naventa is the Belgian association of manufacturers of natural ventilation in residential and non-residential buildings. This group was founded within Agoria, the federation of the Belgian technological industry. As Naventa, we give special consideration to health-related issues when developing new natural ventilation, solar shading and night cooling systems. By supporting the venticool platform, Naventa wants to increase her knowhow and raise awareness that there is a huge need for CEN standards to calculate the influence of ventilative cooling on the energy performance of buildings.

- ES-SO, the European Solar-Shading Organisation, is the umbrella body representing the European solar shading and roller shutter industry. Its objectives are to provide a permanent point of contact between its members (mainly the national professional trade associations) and the European authorities, and to demonstrate that solar shading can make a substantial contribution to energy savings and indoor comfort. By joining the ventilative cooling platform ES-SO underlines the importance of different technologies and strategies to be used in a multidisciplinary and integrated conceptual way to reach the target of low energy buildings' thermal comfort criteria as well as maintaining a good indoor climate and visual comfort.

- Eurima is the European Insulation Manufacturers Association, representing the interest of the mineral wool insulation industry. Eurima actively support venticool to develop knowledge and application of ventilative cooling solutions for a successful implementation of the EPBD recast bearing in mind comfort issues. This requires appropriate levels of insulation and well-functioning ventilation making best use of building materials in order to guarantee energy efficiency, comfort and good indoor air quality.

- The VELUX Group offers a wide range of solutions for daylight and fresh air through the roof – regardless of roof pitch, size and purpose of the building.The VELUX Group considers ventilative cooling to be a sustainable technology. A technology which today is not at all used to its full potential. The mission of venticool is therefore crucial. It supports the effective and knowledge-based promotion of the use of ventilative cooling, it fills in the gaps in the value chain of ventilative cooling that exist in calculation methods, standards and regulations, and it promotes the communication and awareness of ventilative cooling that could act as a catalyst in the development of the right solutions for the market when they are most needed.

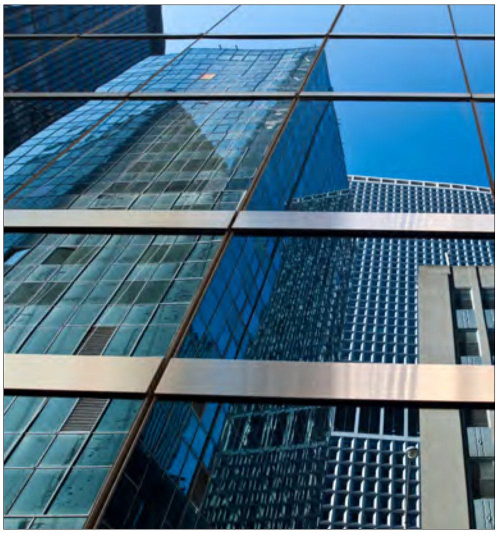
- WindowMaster A/S is founded on a vision to create better buildings that have plenty of fresh air and excellent and safe indoor climates. We supply sustainable indoor climate solutions for all types of buildings and our solutions are based on natural and hybrid ventilation. Also natural smoke ventilation is a part of our offerings. Our expertise is built on our knowledge of regulatory standards and project development, and our experience from thousands of completed projects across Europe.

PLATFORM FACILITATOR

- INIVE is a registered European Economic Interest Grouping (EEIG) that brings together the best available knowledge from its member organisations in the area of energy efficiency, indoor climate and ventilation.

DYNASTEE
NEWSLETTER ISSUE 2013/3

Foreword



Dear reader,

With pleasure we present you the 3rd DYNASTEE Newsletter. Dynastee is a platform of information exchange on dynamic analysis, simulation and testing of the energy performance of buildings. Dynastee is closely linked with the activities of the IEA ECB Annex 58 project; it is responsible for the subtask on dissemination and the Network of excellence. This is done through activities such as training of researchers on dynamic methods (see the Summer School 2013), bringing its expertise from earlier projects (PASSYS-PASLINK) into the Annex 58 project, organising workshops (see the High Performance Buildings event in Brussels, June 2013), and this newsletter. This issue is dealing largely with the intermediate results and the progress made in the Annex 58 project. Bit by bit the expertise is growing and we are quite confident that the research community involved will find the right answers how to bridge the gap between the real performances of a building and the calculated or designed ones. The building industry is welcome to forward its questions to this growing Network of Excellence.

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DYNASTEE Newsletter Editors

- Hans Bloem
- Luk Vandaele

Summary report of the workshop on

HIGH PERFORMANCE BUILDINGS

Design and Evaluation Methodologies

The EU Sustainable Energy Week (EUSEW) is an initiative of the European Commission coordinated by the Executive Agency for Competitiveness and Innovation, in close cooperation with the European Commission's Directorate-General for Energy. It showcases activities dedicated to energy performance, efficiency and renewable energy solutions. During that week, INIVE-DYNASTEE, EC-JRC-IET and ENEA organized a series of 4 half-day workshops on the theme "High Performance Buildings - Design and Evaluation Methodologies". The workshop was held in Brussels at the BBRI offices from 24 - 26 of June 2013. About 125 experts from all around the world registered for the workshop.

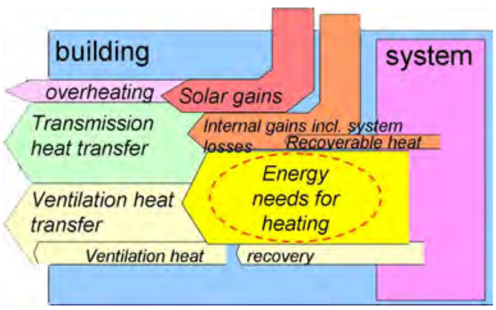
The aim of the event was to focus on the energy related part in the design process of new or renovated buildings. Four consecutive sessions dealt with dynamic aspects of performance assessment including cost analysis, monitoring, evaluation and modelling of high energy performance buildings, various aspects such as renewable energies and consumer behaviour, design case studies and EPBD related CEN energy standards. Experts from CEN TC371, working on the revision of the standards, were invited to participate as well as project leaders from IEA-EBC Annex 52 (nZEB), Annex 53 (Monitoring) and Annex 58 (Performance characterisation).

An overview of the IEA EBC-Annex 58 activities was given, focussing on characterization of thermal performance of building fabric based on full scale experiments to develop the necessary knowledge, tools and networks to characterise the actual energy performance and thermal response of building components and whole buildings based on full scale dynamic measurements.

This activity is highly relevant for achieving in-depth knowledge to the properties and features of different approaches to energy performance assessment.

Statistical methodologies were presented which are applicable for modelling building energy performance assessment based on measurements of heating in buildings, e.g. from smart metering. The range of methods spans from modelling based on simple daily readings of heat load, to detailed modelling based on high time-resolution data. Key performance indicators need to be coupled with knowledge of uncertainty provided by statistical techniques.

All papers and presentations from the workshop are available. Find the link on **www.dynastee.info**



IEA EBC Annex 58-project

"Reliable building energy performance characterization based on full scale dynamic measurements"

Since 2011, international experts from all over the world are working together for four years within the research project IEA EBC Annex 58 on the topic of 'Reliable building energy performance characterization based on full scale dynamic measurements'. This project takes place in the framework of the 'Energy in Buildings and Communities Programme' of the International Energy Agency. The addendum of one of the previous Dynastee-newsletter gave an overall overview of the project and its main objectives (see www.dynastee.info/download/DYNASTEE-NL-2012-A-Addendum.pdf).

At the latest expert meeting in Hong Kong October 2013, the project was halfway; time for an update on the status of the project. The aim and progress of subtasks 1 and 2 is described in more detail further on in this newsletter. In this article the general progress and ongoing research on dynamic data analysis and energy performance characterization is described.

Characterising the actual performance and dynamic behaviour of building components and buildings is an essential part to obtain – not only on paper, but in reality – high performance buildings. Furthermore, dynamic data analysis methods have shown to be a valuable tool to deduce simplified models of e.g. advanced components and systems to integrate them in a reliable way into Building Energy Simulation (BES) models or when optimizing smart grids for building communities. Investigating possibilities and limitations to characterise building (components) based on dynamic data is one of the key topics within Annex 58. This research is driven by case studies. As a first simplified case, an experiment on testing and data analysis is performed on a round robin test box. This test box can be seen as a scale model of a building, built by one of the participants, with unknown properties for the other participants. The test box is shipped to different partners (different climatic conditions) with the aim to perform a full scale measurement of the test box under real climatic conditions. The obtained dynamic data are distributed to different institutes who have to try to characterize the test box based on the provided data. The first result show how different techniques can be used to characterize the thermal performance of the test box, going from a simple stationary analysis to advanced data analysis methods starting from the measured dynamic data.

As a second case study, an experiment has been set up in the twin houses at IBP Fraunhofer in Holzkirchen, Germany. The data of this experiment will both be used as validation data for BES-models, as well as case study to characterize the thermal performance of the houses based on so-called grey box modeling. As up till now, BES-models are typically validated by intermodel comparison, there is a lot of interest in participating in the current real validation case, both from inside Annex 58 as from external partners. The blind run for the validation case should be finished by January 2014, afterwards the data is made available within the project for the thermal characterization of the dwelling. Results are expected spring 2014.

Further information about IEA EBC Annex 58 can be found at
www.ecbcs.org/annexes/annex58.htm

State of the art on full scale testing and dynamic data analysis

The IEA EBC Annex 58 is an international research collaboration on the topic 'Reliable building energy performance characterization based on full scale dynamic measurements'. The ultimate goal of the Annex is to develop the necessary knowledge, tools and networks to achieve reliable in situ dynamic testing and data analysis methods that can be used to characterize the actual energy performance of building components and whole buildings.

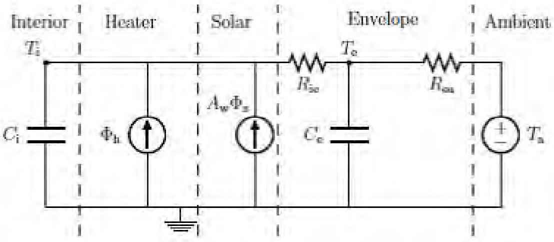
It is since September 2011 that the Annex has been active, which means that the project is halfway at the moment of writing (fall 2013). At the working meeting in Hong Kong in October 2013, one of the first outcomes of the project was presented: the state of the art report on full scale testing and dynamic data analysis, which was the result of the work of participants of subtask 1.

In subtask 1 an overview and evaluation was made of previous and ongoing in situ test activities based on a literature review and existing reports. An inventory was made of full scale test facilities available at different institutes all over the world. Common methods were described to analyze dynamic data, with their advantages and drawbacks. The overview of full scale testing and dynamic data analysis relates to energy performance characterization of either building components or whole buildings.

The data analysis methods discussed in the first section of the report range from averaging and regression methods to dynamic approaches. The methods are discussed in relation to their application in following in-situ measurements:

- measurement of thermal transmittance of building components based on heat flux meters;
- measurement of thermal and solar transmittance of building components tested in outdoor calorimetric test cells;
- measurement of heat loss coefficient and solar aperture of whole buildings based on co-heating tests;
- energy model characterization of whole buildings based on monitored dynamic energy and climatic data.

Left: Round Robin Test box at Almeria, Spain and right: one of the twin houses at IBP, Germany used as controlled test house for validation of BES-models.



Example of RC-network representing a two-state grey box model for energy characterization of a building

Calorimetric facility at IBP-Holzkirchen

The 25 test facilities described in the second section of the report are subdivided in three main groups, depending on the scope and scale of the testing:

- Test facilities for evaluation of (hygro)thermal building envelope performances
- Facilities for evaluation of building component energy performances
- Building integrated energy performance testing of components and systems

Within each group, facilities with a long tradition as well as recently developed or planned platforms are described. Compared to the previously published book on 'Full scale test facilities' (see Dynastee newsletter 2012/1), the subtask 1 report contains 10 new test facility descriptions.

More information:
www.ecbcs.org/annexes/annex58.htm

International Energy Agency: Annex 58: **Subtask 2**

The overall intention of Subtask 2 is to conceptualise the optimisation of full scale dynamic testing, based on the State of the art information gained from Subtask 1 and expert input obtained from annex members. When addressing the subject of building performance testing there are two key elements which must be appreciated in order to ensure reliable, accurate results are obtained:

1. Ensuring the test environment and experimental set up are correct and fit for purpose. This includes correct monitoring equipment, accurate sensor placement and robust control procedures.

2. Correct methods of data handling and analysis.

In order to present these concepts in a manageable, user-friendly way, Subtask 2 involves the production of a decision tree to aid researchers in their decision making when considering a full scale dynamic test. The decision tree acts as a guide to ensure the user has considered all possible aspects of their chosen environment, and by following the line of questioning within the decision tree they will ultimately arrive at documents which offer more information. These include published academic papers, ISO documents and test protocols. The researcher is questioned about a range of parameters, from broad considerations such as such as the test environment and conditions to the level of accuracy required from the results, allowing the most appropriate documents to be presented at the end.

During development, the decision tree is using the Xmind programme, a simple to use tool which allows wide ranging decision trees to be constructed and presented in a manageable way. Moving forward, the intention is to take the decision tree to an online platform, or possibly a living Wiki, with easy access for users.

The layout of the decision tree follows a question/response format, with a common route of questioning. For most topics this is:

1. What do we want to characterise?

2. The specific aspect.

3. Test Environment.

4. Test Conditions.

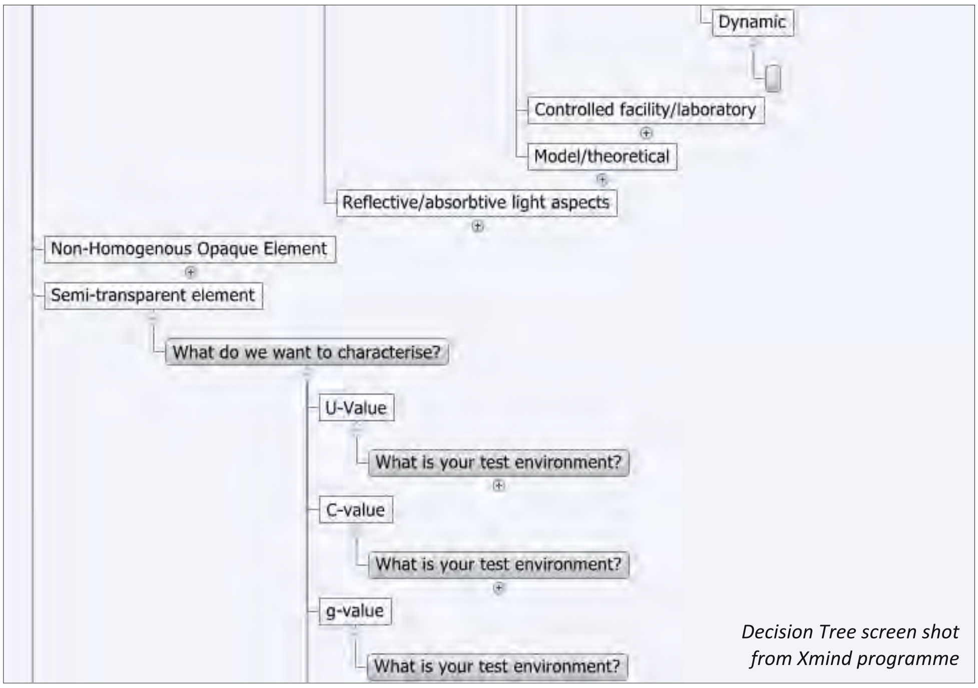
5. Degree of accuracy required.

Each question offers multiple responses for the user. Each path follows the same questioning logic. The number of **specific aspect** stages depends on the topic, for example within whole building envelope there are fewer sub topics than for specific building components. This is a weakness to the decision tree as it is a non-standard question with limitless answers. Components are often more defined and accompanied with test procedures. Going forward, the test environments with less content are those which Annex 58 will focus, capturing information that are necessary to realise a good reliable test environment.

It is the intention that all pathways terminate in a document offering further guidance. Guidance will be taken from the work of Subtask 1 (State of the Art) which covers current aspects of dynamic building testing. It is appreciated that not all pathways will be covered (particularly with regards to novel technologies) input from Annex members will be used to populate the decision tree as reliable guidance is developed.

The degree of accuracy, element of the decision tree is an area which is under constant investigation and develops with technology and better understanding of test procedure and data. Some forms of testing are not fully developed and confidence cannot be guaranteed. It is the case that later versions of the decision tree and guidance contained in the road map will offer information on accuracy when it is known.

Further information can be obtained from **Martin Fletcher, Sub Task 2 leaders: Professor Chris Gorse and Dr Aitor Erkoreka**



Decision Tree screen shot from Xmind programme

Group picture taken at mini-Hollywood (cowboy-city) near PSA-Tabernas.

Outcome of **Summer School 2013** that took place 9-13 September in Almeria, Spain

The second edition of the DYNASTEE Summer School on **Dynamic Calculation Methods for Building Energy Assessment** has been another very successful event with more than expected participants (36 students from 10 EU and 3 non-EU countries, China, India and Canada). The week-long Summer School was devoted to daily lectures by 5 lecturers on building physics and theory of time series analysis as well as plenty of time to guided exercises for improvement of skill of the students.

The ambience of Mediterranean climate, the high quality of the organisation and the sympathy of the student group made the outcome of the whole week, very positive and made the organisers conclude to organise a third Summer School in 2014 (follow us on www.dynastee.info). The requirement of a dedicated book on the lectured topics available at the next edition (probably before Summer 2014) was emphasised as well as the importance of the Open Source software tool environment **R** for future work on the application of dynamic mathematical techniques for energy performance assessment. One of the applied tools, **CTSM-R**, is partly an outcome of DYNASTEE and PASSYS initiatives.

The students were lectured on building physics as well as the applied mathematical and statistical techniques to basic building energy transfer problems. The problem, how to translate a physical energy system into mathematical equations and to assess the corresponding parameters was addressed and the dynamic methodologies were discussed. An in-situ wall exercise was provided and a simple building energy study also for a common approach while applying R-scripts for solving the mathematical equations to assess the thermal characteristics of the parameters in subject.

OPEN COMPETITION

Energy Design of High Performance Buildings

Organised by EC-JRC and ESRU for DYNASTEE

SUMMARY: The objective is to assess for a simplified high performance building (a cube), in a freely chosen climate and associated building energy regulations, the minimum primary energy consumption and GHG emissions for local boundary conditions by optimising thermal characteristics of the building envelop and the choice of building energy systems. The design freedom is in the building construction composition, the specific thermal parameters, the available energy resources and building system technologies. The energy design approach should follow three steps that deal with

1. building energy needs (envelope and its volume),

2. building system operational energy and

3. optimisation for available energy resources (feedback to step 1 and 2)

A High Performance Building (HPB) is a building that consumes as little as possible energy during a whole year for heating, cooling, ventilation, light, hot water and copes with the presence of people and domestic appliances. Such a building is expected to have a climate optimised insulation of the envelope, profits from environmental energy resources and uses thermal mass to balance thermal energy flows. The building energy systems are high efficient and innovative technologies that optimise the use of the available energy resources, delivered to the building or available in the environment of the building.

Each Member State has its national and sometimes regional building codes and regulation. They differ for particular parameters based on specific conditions such as climate, energy-mix and calculation methodology. As an example, Member States differ for the dimensions used for floor area, e.g internal, external or heart to heart dimensions. This will affect the reporting of energy performance expressed in kWh/m2. In the scope of this competition it has been decided to apply the external dimension which is limited to 10 by 10 meters. The minimum requirements set by the Member States in the building codes influence a lot the calculation methodology and results for reporting. The level of comfort that includes indoor temperature settings, temperature control regime, the air change rate etc. might differ even from one part of the country to another.

Beside the applied climate and building parameter settings, the results of primary energy consumption and GHG emission figures have to be reported.

The full description can be downloaded. For more detailed information please contact: **info@dynastee.info**

Target group: under-graduate, postdoc, PhD students and researchers level

ABOUT DYNASTEE

DYNASTEE is an informal grouping of organisations involved in research and application of tools and methodologies for DYNAmic Simulation, Testing and Analysis of Energy and Environmental performances of buildings. DYNASTEE provides a multidisciplinary environment for a cohesive approach to the research work related to the energy performance assessment of buildings in relation to the Energy Performance for Buildings Directive (EPBD).

DYNASTEE, being a network of competence in the field of outdoor testing, dynamic analysis and simulation, has over 25 years of experience through a series of EU research projects. DYNASTEE is an open platform for sharing knowledge with industry, decision makers and researchers.

DYNASTEE has the expertise needed to support the developments and design of Nearly-Zero Energy Buildings as required by the EPBD. Specific outdoor experimental work needs knowledge of the analysis process in order to optimise the dynamic information in the measurement data. Simulation requires results from analysis in order to be able to scale and replicate the results from analysis and testing to real buildings in different climates.

DYNASTEE functions under the auspices of the INIVE EEIG. For more information visit the DYNASTEE web-site at **www.dynastee.info**

The role of measurements in quality and compliance schemes

Peter Wouters, INIVE, Belgium

AIVC WORKSHOP – QUALITY OF METHODS FOR MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS

WHY IS IT IMPORTANT TO ADDRESS MEASUREMENT QUALITY ISSUES IN STANDARDS? HOW STANDARDS CAN CONTRIBUTE.

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SUMMARY

Product certification is a first essential step to assure the overall performance and energy performance of buildings. Designer and consultant pay a lot of attention to select, project and install HVAC&R products as part of heating, ventilating, air-conditioning and cooling systems in buildings.
They have to base their selection on the data presented by the producer or supplier of these products. The system designer or installer has to be sure that these data are reliable and applicable. The building system or sub-system will only perform according the expectation and connected contract obligations if the product data are correct and complete. The next step, the system design shall meet all design parameters on indoor environment, energy performance and other offered performances.
If at the end the building or building system doesn't perform according the agreed design specifications, who is to blame?

- The designer because of a poor design?
- The installer because of poor installation work?
- The supplier of the integrated products because of poor performance of these products?

Inspection and measurements of the realised ventilation and air systems are an essential factor to guaranty the performance of the system in relation to the building properties. Airtightness of the building and air systems, measuring flow rates of ATD's, measuring noise levels of ventilation devices, checking location of ATD's, checking the airway path in order to be able to report the performance of the ventilation and air systems.

To be able to rely on these inspection and measuring services we need to assure the quality of these processes. We have to describe the measurement procedures and the inspection protocols and additional the competence level of the qualified persons performing these assessments.

The EPB standards are restrictive, inspection standards like the standard EN15239 & EN15240 (currently under revision/development by CENTC156WG23) and expected to be published as: Energy performance of buildings –Ventilation for buildings – Module M4-11, M5- 11, M6-11, M7-11 - Guidelines for inspection of ventilation

and air conditioning systems. The scope of this standard excludes the qualification of the persons or organisation in charge of inspections.
The scope includes: air conditioning system(s) without mechanical ventilation; or air conditioning system(s) with mechanical ventilation; or natural and mechanical ventilation system(s).
The standard applies to: fixed systems; accessible parts that contribute to the cooling and mechanical ventilation services; ventilation-only systems. Applicable to all types of comfort cooling and air conditioning systems;
all types of ventilation systems like mechanical, natural, hybrid.

However this EPB inspection standard and related CEN standards do not specify the measurement accuracy. Flow rates in situ are to be measured by pressure compensated flow measuring devices. Their accuracy will not exceed $\pm 10\%$. This may lead to a safety margin chosen to prevent any negative assessment results, if installers have to guaranty full compliance this may lead to installations with a 10% higher performance as required.
It should be investigated if guidelines or standards are needed to give guidance or procedures for the required accuracy.

"DG Energy has launched a written consultation on the draft amendments of ecodesign implementing measures and energy labelling delegated acts related to the application of tolerances in verification procedures.
The purpose of this document is to clarify the use of Energy Efficiency measurement tolerances by the different stakeholders (market surveillance authorities, manufacturers, importers)."

This statement indicates a need for guidance for acceptable tolerances for in situ testing as well.

"The European Standardisation Organisations will be further encouraged to prepare the necessary measurement methods and to propose the measurement uncertainties of the measured parameters, to be taken into account by the Commission when setting tolerance values in future ecodesign and labelling measures. In this respect the Commission will continue to monitor the Organisations' activity to assure a timely preparation of the standards and of the relevant measurement uncertainties.
This approach would solve the problems identified by market surveillance authorities and would help to ensure that no misleading information is provided to consumers, that a level playing field is maintained for industry, and that the implementing measures and delegated acts achieve the expected savings contributing to the Europe 2020 targets. In principle the approach would have no negative effects and would not introduce a burden on any of the actors involved in the process, compared to the original intentions of the regulations concerned."

Although this statement is referring to product testing and meeting product requirements according ecodesign regulation, a similar statement could refer to in situ system testing.

INCLUDING UNCERTAINTY IN BUILDING ENERGY PERFORMANCE CALCULATION METHODS

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ABSTRACT

In building design, energy performances are commonly predicted based on deterministic stationary or dynamic calculations. However, many contributing parameters are inherently uncertain, resulting in potentially unreliable values for the performance indicators. To overcome this, a probabilistic design method is recommended to take uncertainties into account. Such uncertainty-based optimisation often requires many simulations, making it extremely time-consuming. To avoid this, meta-modelling can be of interest. A meta-model mimics the original numerical model with a simplified fast model. The current paper presents a global probabilistic design methodology to take different kinds of uncertainty into account in building energy performance calculation methods.

KEYWORDS

probabilistic analysis, robust design, energy performances, meta-modelling, optimisation

1 INTRODUCTION

The energy efficiency of dwellings is becoming increasingly important in view of climate change and fuel depletion challenges. At present, newly built dwellings should be low-energy, while passive and nearly zero energy buildings will become the standard in the near future. To calculate the energy demand and life-cycle cost of dwellings in multi-criterion decision making, deterministic simulations are commonly used. User behaviour and workmanship of building envelopes and services are however inherently stochastic and neglecting these uncertainties may lead to excessive deviations between design and reality. Such excessive deviations are undesirable, both from the point of view of the building occupant and of society in general: inhabitants require confidence in the return on their investments in energy efficiency, governments want guarantees that their subsidy programs have a correct impact. To minimise such deviations, the development and promotion of robust cost-efficient building envelopes and service solutions is an important step. Therefore, a reliable probabilistic robust design method is suggested in this paper.

2 PROBABILISTIC DESIGN METHODOLOGY

The probabilistic design methodology consists of four steps (see Figure 1): preprocessing, preliminary screening, updating and probabilistic design. These steps analogously select the input parameters and distributions (step 1), determine the most dominant input parameters and develop a meta-model to improve calculation efficiency (step 2), update the input distributions (step 3), and finally perform the actual probabilistic design (step 4).

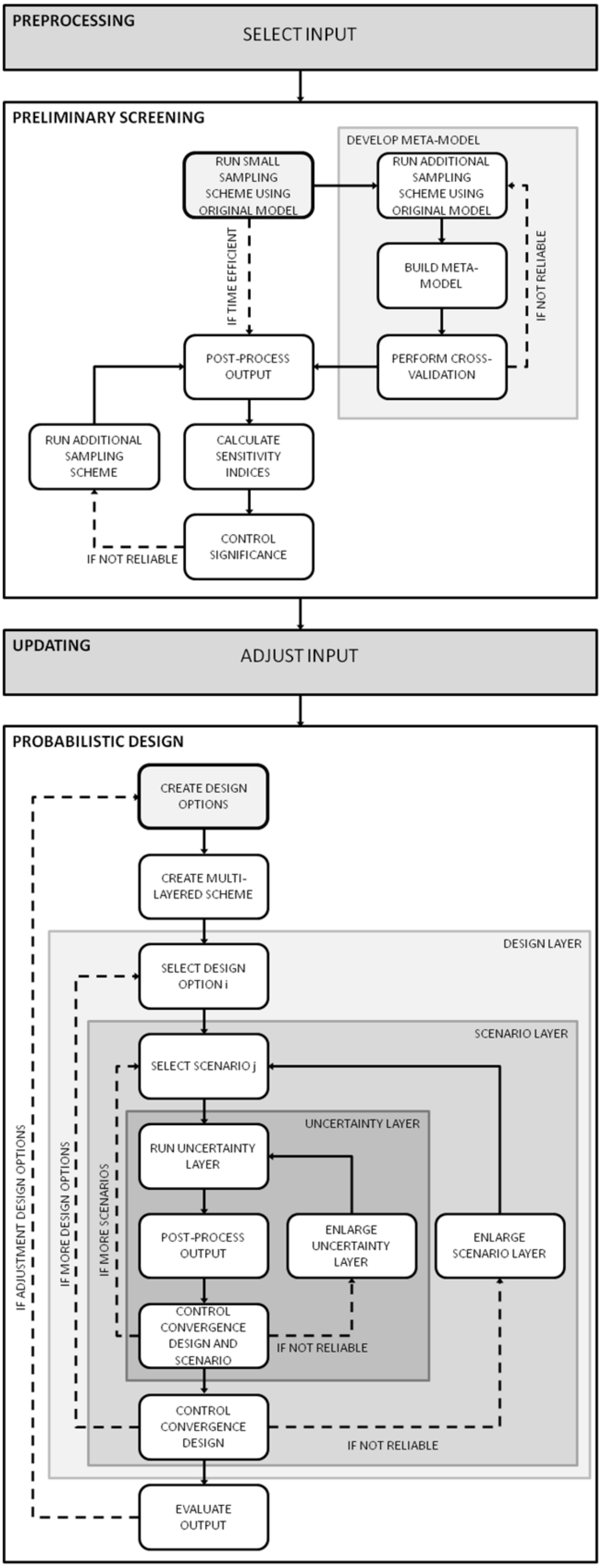

Figure 1: Methodology flowchart

Contributing input parameters of this probabilistic design can be divided into three categories. Design parameters, such as the preferred air tightness or thermal resistance, the type of ventilation system,… are fully controllable. They are the unknown parameters in the design process, but once a design option is selected, the parameter values are known. Inherently uncertain parameters, such as workmanship and user behaviour, are uncontrollable by the designer as their values are neither known in the design process nor after, but they can significantly influence the design performance. Finally, scenario parameters are inherently uncertain parameters dealing with potential future scenarios, such as economic or climatic evolutions, for which an explicit evaluation is wanted.

The probabilistic design (step 4) is therefore performed through a Monte Carlo loop with a multi-layered sampling scheme which enables sorting parameters by their conceptual meaning. By ascribing these parameter categories to a different layer in a multi-layered sampling scheme as shown in Figure 1, all design options are subjected to the same uncertainties and a direct comparison for several future scenarios is enabled. As a result, this probabilistic design can be used as an effective decision tool.
Prior to performing such a probabilistic design, the problem is first preprocessed (step 1) to select the output parameters needed for decision making and a suitable simulation model. Both stationary or dynamic, and simplified or complex models can be chosen. Contributing input parameters are determined and fixed values or (provisional) input distributions are ascribed for respectively deterministic and stochastic parameters.

Since the proposed multi-layered sampling scheme significantly increases the needed number of runs, time-inefficient models are preferably replaced by a meta-model in the preliminary screening (step 2). Therefore, training and validation sets are run in the original model to construct and validate the meta-model. Due to the extent of the multi-layered scheme, smaller sampling sets are used. These sets are also used to calculate sensitivity indices to rank the input parameters from most to least influencing the output distributions.
Based on this sensitivity ranking, the provisional distributions of most influencing parameters are updated (step 3), while the less influencing parameters can be omitted. Limiting the number of parameters eases collecting the required input distributions as this can be time-consuming. Moreover, this improves sampling efficiency and limits the number of considered design options in the multi-layered scheme. This stresses the importance of the preliminary screening in addition to the actual probabilistic design.
To enable numerical evaluation of these schemes, effectiveness and robustness indicators are proposed, inspired by robust design. Effectiveness is defined as the ability of the design option to optimise the performance, while robustness is defined as the ability to stabilise this performance for the entire range of input uncertainties. The proposed method appears to be very effective in comparing both effectiveness and robustness of multiple performance criteria for numerous design options with Pareto optimality or the weighed sum method.

3 ACKNOWLEDGEMENTS

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4 REFERENCES

Janssen, H., Roels, S. (2014) IEA EBC Annex 55, Report of Subtask 2.

Van Gelder, L., Janssen, H., Roels, S. (2013) Metamodelling in robust low-energy dwelling design, in: *Proceedings of 2nd Central European Symposium on Building Physics, September 9-11 2013, Vienna.*

Van Gelder, L., Janssen, H., Roels, S. (2014) Probabilistic design and analysis of building performances: methodology and application example. *Energy and Buildings (in review)*

Van Gelder, L., Janssen, H., Roels, S. (2014) Reliability of meta-modelling in robust low energy dwelling design, in: *Proceedings of the 10th Nordic Symposium on Building Physics, June 2014, Lund.*

DEFINITION AND ASSESSMENT OF INDOOR AIR QUALITY CLASSES: SOURCES OF UNCERTAINTIES AND RATING IMPLICATIONS

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ABSTRACT

This paper describes the method, in which human observers assess indoor air quality. This method is at present necessary to determine actual levels of air quality indoors in non-industrial buildings to fulfil comfort requirements specified by the standards. The paper attempts to identify the potential drawbacks of the method, its limitations and the factors influencing these measurements. Examples are given illustrating, how the measurement uncertainty influences the estimated level of indoor air quality. Implications are discussed for the indoor air quality levels and the categories of emissions from building recommended by the current standards. Suggestions for modifications are given and an alternate approach outlined, which both ensure that the intended indoor air quality levels can reduce health risks and can additionally be verifiable in practice.

KEYWORDS

Indoor Air Quality; Sensory Assessments; Measuring Errors; Building emissions; Non-Industrial Environments

1 INTRODUCTION

Humans are constantly exposed in residential and non-residential (public) buildings to varying number and concentrations of particulate, gaseous and biological contaminants, which have both an outdoor and indoor origin. For example, a typical mixture of gaseous contaminants measured indoors can contain several thousand compounds, few hundreds stemming from human bioeffluents, few hundreds from building materials and equipment and few thousand from tobacco smoke, if smoking is allowed. These contaminants affect the quality of air indoors.

The quality of air indoors may be expressed as the extent to which human requirements are met. There are, however, quite large differences between the requirements of individuals. Some people are rather sensitive to air quality and are difficult to satisfy, while others are less sensitive, and are easier to satisfy.

One way to characterize indoor air quality is by performing physical and chemical measurements. The results of these measurements can then be compared with the guideline values set by the cognizant authorities.

In case of industrial environments, occupational safety and health guidelines are used to regulate the quality of quality. They define maximum concentrations, to which people working in these environments can be exposed for a certain duration; usually the averaging times are 8 hours/day in a 40 hours week for a long duration (TLV-TWA, Threshold Limit Value-Time Weighted Average), and 15 min no more than 4 times a day for a short duration (TLV-STEL, Threshold Limit Value – Short-term Exposure Limit). They also define ceiling limits, i.e. exposures that cannot be surpassed ever (TLV-C). These limit values are usually defined by the concentrations, above which serious health risks will occur, e.g., irritation and/or other chronic diseases. They are defined for individual contaminants, since occupational exposure are predominantly governed by the exposure to a single or maximum few contaminants at elevated concentrations, all other contaminants being at background or negligible level. In case when there are few dominant contaminants, the sum of ratios of their concentration to their threshold limit cannot be higher than one.

With the exception of few compounds such as e.g., radon and formaldehyde, the approach used to reduce occupational hazards cannot be directly adopted to set limits in non-industrial environments. This is because in non-industrial environments people are exposed to hundreds and/or thousands of contaminants occurring in different combinations and at very low concentrations, frequently orders of magnitude lower than TLVs used to set occupational exposure limits; often these concentrations are even lower than their odour detection thresholds. For many of these contaminants, there is additionally very limited toxicological data in the present literature, which completely precludes using TLVs or any other guideline values. These contaminants under certain conditions can moreover interact with one another and can undergo chemical reactions with other contaminants changing thus their concentration in indoor air and creating new contaminants, which are not normally present taking into account typical sources of pollution. The exposures in non-industrial buildings are thus very dynamic, which sets an additional challenge not only for setting the exposure limits but also for monitoring and quantification of the potential risks for people exposed to them. Consequently, a complex compound-by-compound approach may not always be applicable and sufficient to define indoor air quality levels. It may not provide complete, adequate and credible information, as to what the true level of indoor air quality is. Regulating indoor air quality by defining guideline values for all compounds in non-industrial environments seems thus nearly unrealistic, considering additionally that every day many new contaminants are introduced into environment. The limits can still be effectively applied for those compounds that can be measured and quantified, and are known to be hazardous for humans; this approach should not be dismissed.

Because detailed chemical characterization provides incomplete evidence that is necessary to regulate and set classes of indoor air quality based on the negative effects on humans, it has become frequent practice to supplement it with the method that characterizes indoor air quality by asking people to judge whether the quality of indoor air is good or poor (certain harmful pollutants such as radon and carbon monoxide are not sensed by humans at all, so sensory evaluations of humans cannot be used to quantify their effects). Human senses are stimulated during breathing: the olfactory sense, situated in a small area of the nasal cavity, which is sensitive to around half a million odours, the general chemical sense, situated all over the mucous membrane of the nose, which is sensitive to more than one hundred thousand irritants, and the thermal sense located in the nasal cavity, which is sensitive to varying levels of air temperature and relative humidity, providing that the air temperature is different from the mucosal temperature which is ~30-32^{o}C. This stimulation can be used to determine whether air quality is good or poor.

Several measuring approaches can be used when people are asked to judge indoor air quality (ECA, 1999). The two have been used most prevalently, i.e. assessments of odour intensity and acceptability of air quality. The former method was first thoroughly documented and applied for setting the air quality criteria indoors in the classical studies of Yaglou et al. (1936). In the method it has to be arbitrarily decided which level of odour intensity is to be set as the air quality guideline. The latter method propagated by Fanger and his colleagues (e.g., Fanger et al., 1988) have an advantage that individual occupants of indoor spaces are the final arbiters of whether the indoor air quality is acceptable or not. The level of air quality can then be set by selecting the percentage of people finding the air quality acceptable, as used by ASHRAE Standard 62.1 (2013) or the maximum percentage of dissatisfied with air quality, as used by the European Standard EN15251 (2007). The method also assumes that the assessments of acceptability of air quality does not only take into account odour intensity but also integrates other sensory stimulations such as air pleasantness or freshness.

EN15251 (2007) defines four categories of indoor environmental quality, Category I representing high level of expectation, Category II providing normal level of expectation, Category III and acceptable moderate level of expectation and Category IV the environments, which does not meet the above categories; this category should be avoided or accepted only for a limited period of time during the year. For each of the categories, the range of conditions is defined securing that the requirements of the category can be satisfied. This applies to the thermal environment, acoustical environment and illuminance, as well as to the indoor air quality. For indoor air quality the four categories of indoor environment quality correspond to four levels defining the percentage dissatisfied persons with the air quality, namely 15%, 20%, 30%, and more than 30% dissatisfied. Thus, they need to be determined through the assessments made by the human observers. For each category of indoor air quality, the required level of ventilation rate is provided taking into account the person component, i.e. ventilation rate needed to dilute human bioeffluents, and the building component needed to dilute and remove contaminants emanating from other sources than humans; both components are eventually added to determine the total ventilation rate for a given space. The person component depends on carbon dioxide (CO_2) the well-established indicator of human bioeffluents being also the main product of human metabolism. In case of building component three classes of emissions are defined: non-low-polluting building, low-polluting building, and very low-polluting building; for each of the classes the ventilation rate is defined. EN 15251 gives examples on how the emission classes can be determined where among defining the acceptable emissions of certain gaseous contaminants such as ammonia and formaldehyde, the permissible levels of volatile organic compounds (VOCs) expressed as TVOC (total VOCs) and carcinogenic compounds are indicated, as well as permissible dissatisfaction with odour resulting from the emissions.

The purpose of the present paper is to identify and review the methods used to determine the levels of indoor air quality, to identify possible sources of errors and to discuss their impact on classification of indoor air quality based on comfort (perceived air quality), as proposed by EN15251. Effects on health, work performance and learning are outside the scope of the present paper.

2 INDOOR AIR QUALITY EVALUATIONS BY SENSORY PANELS

Different methods for sensory evaluations of indoor air quality exist with no consensus in the literature as to which method is best suited for practical applications (ECA, 1999). A method using sensory panels assessing odour intensity and/or acceptability of air quality used to estimate the % dissatisfies with air quality have been predominantly used for this purpose in the past and are described in the following.

2.1 Percentage dissatisfied with air quality: measurements, precision, influencing factors and implications

The percentage of persons dissatisfied with air quality cannot yet be measured directly with an instrument although there have been attempts to construct such instruments (e.g., Wenger et al., 1993; Müller at al., 2007). Human observers judging the air quality are the only feasible way at present. Air quality evaluations can be carried out using dichotomous yes/no scale (Fanger and Berg-Munch, 1983) or a continuous acceptability scale (Gunnarsen and Fanger, 1992; Clausen, 2000). The assessments of acceptability are then used to predict the percentage dissatisfied with air quality.

In case of dichotomous acceptability scale, the percentage dissatisfied with air quality is calculated as the ratio of the votes indicating the air quality to be "not acceptable" to all votes of made by all observers. In case of continuous acceptability scale, the percentage dissatisfied is usually estimated using the relation established by Gunnarsen and Fanger (1992). However, there are also other relations, which are different from this relation especially at the levels corresponding to high indoor air quality, i.e. low percentage dissatisfied (Figure 1). The reasons for the discrepancy between the different relationships have not been examined in detail, and neither it was established which of the three relationships provides the best estimate of the percentage of dissatisfied. The differences between the relationships may cause inaccurate prediction of the level of percentage dissatisfied with air quality. Assuming that the ratings of acceptability of air quality correspond to 20% dissatisfied (Category II in EN 15251 (2007)) then according to the relationship developed by Gunnarsen and Fanger (1992), the actual level of % dissatisfied can be up to 35% dissatisfied if the other two relationships are considered; this is actually outside the Category III described in EN 15251 (2007).

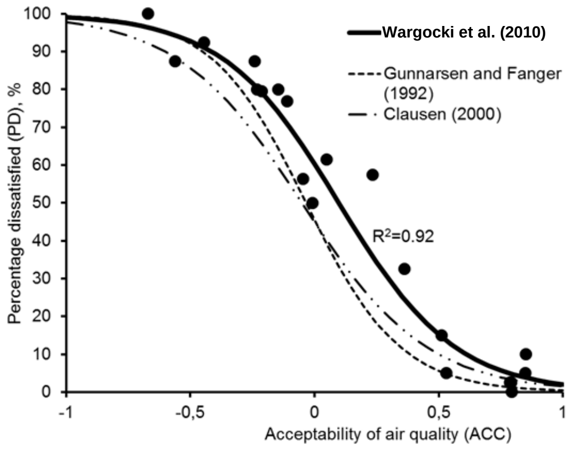

Figure 1: Percentage dissatisfied with air quality as a function of acceptability of air quality

The number of observers evaluating the air quality has significant influence on the accuracy of measurements. This is due to considerable variation in ratings of acceptability of air quality among individuals because of variation in chemosensory sensitivity in combination with variables such as personality, preference, mood and prior experience. In case of the dichotomous acceptability scale, the margin of error for assessments made by 20 observers is 20%, can be halved if 65 observers are used and to 1% for ca. 6,000 observers; 20 observers are recommended by ASHRAE Standard 62.1 (2013). The number of observers has to be thus considerably increased to improve considerably accuracy of measurements. This may not always be feasible and can cause logistic problems, as well as will increase the costs of performing the measurements. In case of the continuous acceptability scale, increasing number of observers above 30-50, which is a typical number of observers performing assessments, will actually have very little effect on accuracy (Figure 2). This is because of the quite large standard deviation of the acceptability ratings on a continuous scale, which is usually between 0.25 and 0.6 (12-30% full scale), and is on average 0.45 (22% full scale) (Gunnarsen and Bluyssen, 1994; Knudsen et al., 1998; Wargocki et al., 2010). The uncertainty of estimating whether the air quality meets Category II in EN 15251 (2007) corresponding to 20% dissatisfied will consequently be 5% to10% dissatisfied for a typical number of 40 observers and the average standard deviation, for which the standard error of acceptability rating will be 0.08 (Figure 2). This means that with the margin of error, the actual air quality level can range from 15% and 30% dissatisfied, which is actually the whole range defining different categories of air quality in the standard.

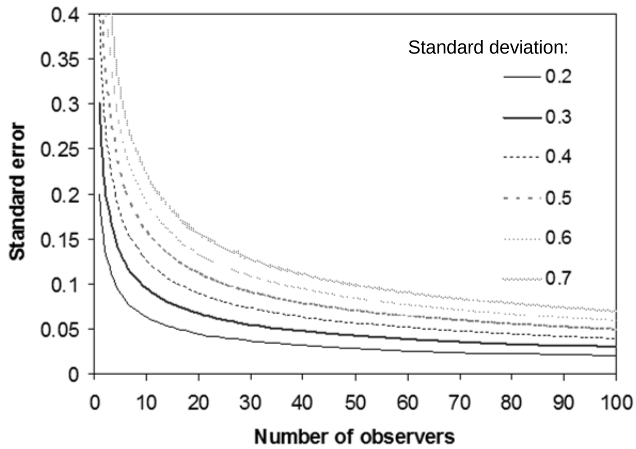

Figure 2: Standard error of the acceptability rating as a function of number of observers and standard deviation of the rating of acceptability

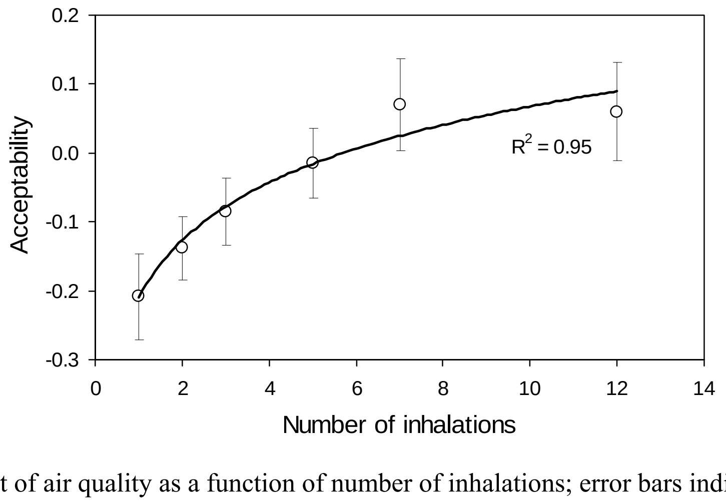

Figure 3: Assessment of air quality as a function of number of inhalations; error bars indicate standard errors

Human senses exhibit reduction in sensitivity with time of exposure, when the air is polluted by odours (adaptation). Gunnarsen and Fanger (1992) observed considerable adaptation when human bioeffluents were the pollution source, probably due to bioeffluents comprising mainly odours, moderate adaptation when tobacco smoke was the source and almost no adaptation when the air was polluted by building materials. They observed that adaptation occurred within the first 6 minutes of exposure, while in the other work the strong adaptation to indoor air polluted by typical building materials occurred already in the course of the first seven inhalations, corresponding to an exposure of about 24 seconds (Jørgensen and Vestergaard, 1998; Clausen, 2000) (Figure 3). In practical applications, it is expected that a judgment of indoor air quality be rendered immediately upon exposure and earlier than within the first 15 seconds in order to have unadapted vote; this is what is actually recommended by ASHRAE Standard 62.1 (2013). Figure 3 suggests, that there will be considerable adaptation during this time. It is thus impractical to assume in field evaluation that observers take only 1 inhalation when rendering the assessment of air quality and it should be acknowledged that some sensory adaptation will always be present: It may be thus difficult to distinguish in practical applications the unadapted assessments (of visitors to a space with very brief exposure) to the adapted assessments (of occupants staying in a space for an extended time).

The perception of air quality is also influenced by the humidity and temperature of the inhaled air even when the chemical composition of the air is constant, and the thermal sensation for the entire body is kept neutral (Berglund and Cain, 1989; Fang et al., 1998a,b; Toftum et al., 1998). Keeping the air dry and cool reduces the percentage dissatisfied with the air quality (Figure 4), and causes the air to be perceived as fresh and pleasant. Consequently, when the air quality is measured using sensory assessments of acceptability, the thermal conditions of the inhaled air should be well documented, and if necessary recalculated to reference conditions (set to 23°C and 50%RH) using models developed by Fang et al. (1998a,b). The strength of the thermal effect on the assessment of indoor air quality can be observed by examining Figure 4. For example, increasing the summer temperature from the lowest to the highest level recommended by EN 15251 (2007) for Category II can increase the % dissatisfied with air quality by as much as 15% (Figure 4).

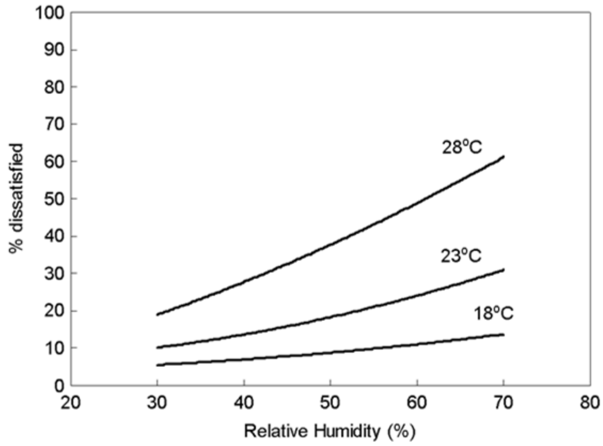

Figure 4: Percentage dissatisfied with air quality as a function of temperature and relative humidity of inhaled air

Selection of human observers evaluating the air quality can also affect the measurements of acceptability of air quality, but no systematic data exist to estimate the size of this effect on the predicted percentage dissatisfied persons. At best, the observers from the relevant population for which the measurements are addressed should be selected; this may however be difficult to achieve in practice. A rational compromise is to select at least observers of a similar age for the target population, as age has been shown to have a major impact on sensitivity, while gender and smoking status are of a slightly less importance. To minimize the errors that can result from the selection of observers, standardized methods quantifying their sensitivity should be used during recruitment and if possible observers performing similarly on these tests should be used. The screening tests comprising a ranking test used to evaluate the ability of observers to classify different odour intensities and the matching test used to assess their ability to identify several stimuli of odour (ISO 8587, 1988; ISO 8586-1, 1993) can be used for this purpose, as well as Chemical Sensitivity Scale (CSS), which examines experience with and exposure to odours and sensory irritants (Nordin et al., 2003; 2004).

2.2 Odour intensity

Measurements of odour intensity have also been used as a metric for defining the air quality levels, but to a much lesser extent than the assessments of acceptability of air quality. Measuring odour intensity requires the same experimental rigour as in case of performing assessments of acceptability of air quality, especially regarding the length of exposure and adaptation, because olfactory sense, which in this case is a main trigger of a response, exhibits very strong reduction in sensitivity with the time of exposure.

2.3 Acceptability, odour intensity and % dissatisfied

Although measurements of acceptability of air quality have been assumed to integrate different sensory attributes, it seems that they are primarily influenced by odour intensity (Wargocki et al., 2010): acceptability and odour intensity ratings of the same exposures exhibit strong correlation (Figure 5). Thus it can be stipulated that the measurements of acceptability can be substituted by the measurements of odour intensity, which are more straightforward and to a lesser extent influenced by the preferences and the experience.

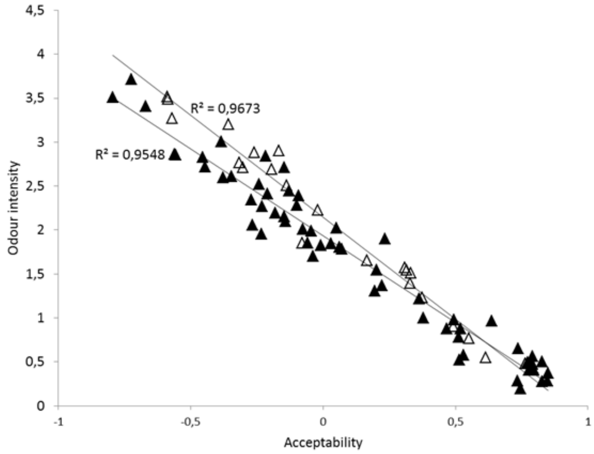

Figure 5: Correlation between ratings of acceptability of air quality and assessments of odour intensity

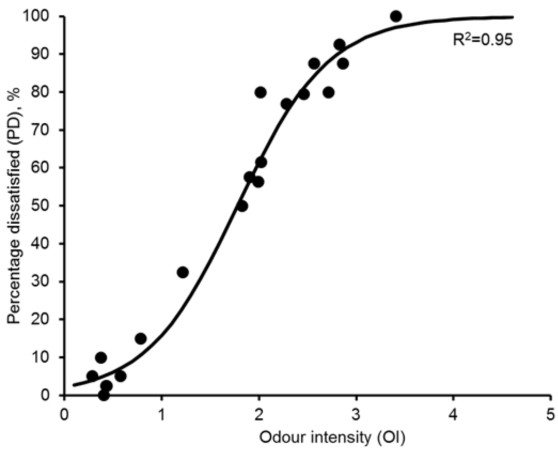

Figure 6: Percentage dissatisfied with air quality as a function of odour intensity

Assuming that odour intensity is strongly correlated with the ratings of acceptability (assuming that the exposures evoke unpleasant responses), the relationship between the percentage dissatisfied and odour intensity has been created (Figure 6). This relationship can be used to interpret and analyse the results from the experiments, in which only odour intensity has been measured. For example, Yaglou et al. (1936) in their classical studies assumed that moderate level of odour intensity should determine ventilation requirements for controlling body odour. With the relationship shown in Figure 6, the moderate odour intensity corresponding to 2 on a scale results in as many as 50% dissatisfied with the air quality; this is much higher than what is recommended by the present standards (ASHRAE, 2013; EN15251, 2007). To match the requirements of present standards, i.e. to bring the level of dissatisfaction down to e.g. 20%, the ventilation rate to control body odour should have been determined for the weak level of odour intensity (about 1 on the scale) and should correspond to about 15-20 L/s per person rather than about 7 L/s per person as proposed by Yaglou et al. (1936).

2.4 Carbon dioxide and percentage dissatisfied

The measurements of carbon dioxide are frequently used to control ventilation rates that need to be delivered to a space. Because there exists relationship between carbon dioxide concentration and the percentage dissatisfied with air quality (Fanger and Berg-Munch, 1983; ECA, 1992) (Figure 7), the concentration of carbon dioxide can be considered as the proxy for the level of indoor air quality. The limitation of this approach is that it can only be used when spaces are occupied by people (carbon dioxide is in this context a proxy for human bioeffluents as this is main human metabolite) and it may not take into account other contaminants that can potentially influence the actual level of air quality. Furthermore the levels of carbon dioxide indoor exhibit quite dynamic changes and not always reach and/or remain at the steady state level for the extended periods. The control would have to take into account these variations. Finally the sensors used to measure carbon dioxide may exhibit quite large inaccuracies. For example a study of Fisk (2007) examined 44 sensors used in nine Californian buildings and showed that their accuracy was quite low, the errors ranging from 378 to 1013 ppm. The reasons for this poor performance were not examined but certainly lack of frequent maintenance and calibration check as well as improper location of sensors are likely factors that cannot be disregarded in this context.

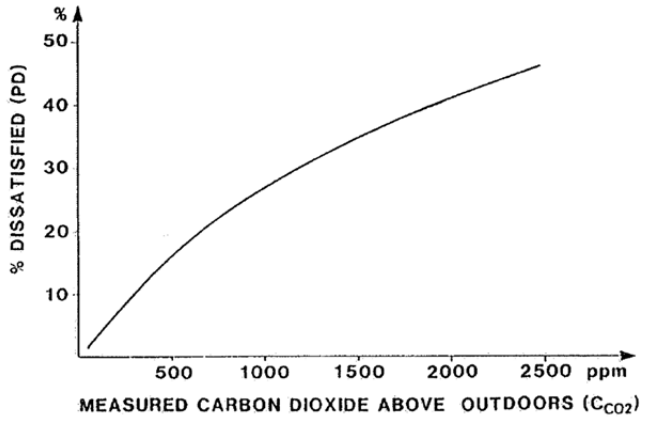

Figure 7: Percentage dissatisfied with air quality as a function of measured carbon dioxide level above outdoors

3 ODOUR INDEX

Sometimes odour index is used to examine, whether chemical compounds measured indoors would be causing odour nuisance. Odour index is defined as the ratio of the concentration of a compound to its odour threshold. Usually odour detection thresholds are used. The odour detection threshold is the lowest concentration of an individually occurring compound that can be detected by 50% of human observers (Cain, 1988; WHO, 1987). If odour index is ≥1 it is expected that the odour produced by the compound can be detected by majority of people. If an odour index is <1, the concentration is lower than the threshold and the odour produced by the compound will probably be not detected by people. Although the use of odour indices seems reasonable, the approach has several limitations. The most obvious is that chemical analysis unable to detect all compounds especially those causing sensory effects (e.g., Wolkoff et al., 1997). Another limitation is the reliability of odour detection thresholds, which can vary sometimes several orders of magnitudes for a single compound (Devos et al., 1990). The reason for this can among others be different methods of estimation of odour detection thresholds and insufficient scientific rigour when they are determined. Finally, perhaps even more important limitation of using odour indices is, that it is often observed that even when odour indices are <1, it is when it is expected that people cannot detect odour, the quality of air is still assessed as not acceptable (e.g., Wargocki et al., 1999).

4 EMISSION CATEGORIES

Standard EN 15251 (2007) defines three classes of emissions from building and for each class defines ventilation requirements. As shown in Table 1, the proposed classes represent well the variety and distribution of the potential emission rates of pollutants in non-industrial buildings related to building materials and furnishing, the HVAC system including the dust collected on the particle ventilation filters, and office equipment including personal computers (Wargocki 2004); the building components were defined based on ventilation rates required to handle emissions from building in order to reach certain level of air quality defined by the % of dissatisfied. The classes of emissions were estimated based on assessments made by human observers in different buildings (summarized by Wargocki et al., 2004). They can thus potentially be subject to inaccurate estimation considering the imprecisions related to assessments of air quality made by human observers and the factors influencing these assessments described in the preceding sections. Emission classes proposed by EN 15251 (2007) are useful when the ventilation requirements are roughly estimated. However, it can be quite challenging to predict beforehand, whether building and furnishing materials, which are going to be used in a building, meet specific postulated emission class. If material emissions are not known the designer may want to high ventilation rates according to the non-low polluting class to make sure that the air quality levels in the completed building will be met. Verification of the assumed class can be attempted, when the building is completed and put into use. Even then, the task is quite complicated. Remediation to bring the indoor air quality to the expected level, as specified during design, in case the class was improperly assumed, can be costly and demanding.

Table 1: Emission categories in EN 15251 (2007) compared to measured strength of pollution sources in buildings; the compnents provide ventilation requirements in Category II of indoor environment quality and air quality level corresponding to 20% dissatisfied

Building type	**Source strength (olf/m^2floor)**	**Estimated ventilation rate (L/sm^2floor)**	**Emission class (EN15251)**	**Source strength (olf/m^2floor)**	**Building component (L/sm^2floor)**
97 office buildings and assemby halls (where tobacco smoking occurred)	0.23±0.06	1.7±0.5	Non-low polluting	0.2	1.4
1 department store	0.15	1.1			
6 office buildings (no tobacco smoking)	0.11±0.09	0.8±0.6	Low-polluting	0.1	0.7
10 kindergartens	0.06±0.04	0.4±0.3			
6 schools	0.06±0.06	0.4±0.6			
3 office buildings (no tobacco smoking)	<0.05	<0.37	Very low-polluting	0.05	0.35

5 CONCLUSIONS AND IMPLICATIONS FOR FUTURE WORK

- Assessments of indoor air quality made by human observers can be largely influenced by the measuring errors and inaccuracies. These imprecisions can cause incorrect estimation of the indoor air quality expressed by the percentages dissatisfied with air quality. Consequently, using percentage dissatisfied to set the indoor air quality requirements can be regarded as somewhat challenging also because of the difficulties to ensure compliance. Improvements of current measuring methods using human observers are needed in order to continue application of this approach for setting indoor air quality levels.

- Other approaches for setting indoor air quality levels need to be explored. The approach proposed by the recently developed guidelines for health-based ventilation in Europe can be followed (Wargocki et al., 2013). The guidelines propose the strategy to control indoor air quality based on health end-points, in which source control is a primary method and the ventilation is used when all source control options are exploited. The World Health Organization (WHO) air quality guidelines are used to set the exposure limits (WHO, 1987; 2000; 2005; 2009; 2010). Ventilation rates are considered health-based when WHO air quality guidelines are met and the base rate is defined to control primarily human bioeffluents; the base rate must always be provided. Following WHO air quality guidelines and/or any other amenable exposure limits, e.g. EU-INDEX guidelines (Kotzias et al., 2005), for which general consensus has been reached as regards their applicability, validity and uncompromised scientific merit and completeness, may create more tangible and harmonized approach for setting indoor air quality levels. Inclusion of requirements on indoor air quality in the national regulations would be necessary to back-up and underpin this process.

- The harmonized regulation of product labelling and ventilation would be necessary to improve characterization of emissions and secure more accurate, manageable and verifiable use of emission classes. Two recently completed harmonization efforts can be used for this purpose, one for indoor products labelling (ECA, 2005; 2012) and one on health-based evaluation of indoor emissions from construction products (ECA, 2013). The first one proposes framework, which could assist in making informed choices about the new or existing products used in indoor environments. It also defines core and transitional criteria with an attempt to facilitate the convergence of existing mandatory and voluntary labelling schemes. The second one provides an approach for establishing harmonised lowest concentration of interest (LCI) values for 177 organic compounds detected in emission tests of construction materials and additionally a list of 82 compounds with interim LCI values. Integrating these frameworks with the ventilation rate design specification is likely to have a noticeable effect on improving the compliance and securing that the prospected indoor air quality levels are attained.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

ASHRAE (2013) ANSI/ASHRAE Standard 62.1-2007. Ventilation for Acceptable Indoor Air Quality, American Society of Heating and Air-Conditioning Engineers Inc., Atlanta

Berg Munch, B., Clausen, G. and Fanger, P.O. (1986) “Ventilation requirements for the control of body odour in spaces occupied by women, Environment International., 12, 195-199.

Berglund, L. and Cain, W.S. (1989) “Perceived air quality and the thermal environment”, In: Proceedings of IAQ’ 89: The Human Equation: Health and Comfort”, San Diego, pp. 93-99, Atlanta: American Society of Heating and Air-Conditioning Engineers Inc.

Cain, W.S. (1988) “Olfaction”, In: Atkinson et al. ed. “Steven’s Handbook of Experimental Psychology”, 2nd edition, John Wiley and Sons.

Clausen, G. (2000) ‘Sensory evaluation of emissions and indoor air quality’, in Proceedings of Healthy Buildings’2000, Espoo, Finland, vol 1, pp53-62

Devos, M., Patte, F., Rouault, J., Laffort, P. and van Gemert, L.J. (1990) Standardized Human Olfactory Thresholds, IRL Press, Oxford.

ECA (1992) Guidelines for ventilation requirements in buildings, Report no. 11, EUR 14449 EN, Luxembourg.

ECA (1999) Sensory evaluation of indoor air quality. Report No. 20. EUR 18676 EN. Luxembourg.

ECA (2005) Harmonisation of indoor material emissions labelling systems in the EU Inventory of existing schemes, Report No 24. EUR 21891 EN. Luxembourg.

ECA (2012) Harmonisationvframework for indoor products labelling schemes in the EU, Report No 27. EUR 25276 EN. Luxembourg.

ECA (2013) Harmonisation framework for health-based evaluation of indoor emissions from construction products in the European Union using the EU-LCI concept, Report No 29. EUR 26168 EN. Luxembourg.

EN 15251 (2007) Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

Fang, L., Clausen, G. and Fanger, P.O. (1998a) “Impact of temperature and humidity on the perception of indoor air quality”, Indoor Air, 8, 80-90.

Fang, L., Clausen, G. and Fanger, P. O. (1998b) ”Impact of temperature and humidity on perception of indoor air quality during immediate and longer whole-body exposures”, Indoor Air, 8, 276-284.

Fanger, P.O. and Berg-Munch, B. (1983) “Ventilation and body odour”, In: Proceedings of An Engineering Foundation Conference on Management of Atmospheres in Tightly Enclosed Spaces, ASHRAE, Atlanta, 45-50.

Fanger, P.O. (1988) “Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors”, Energy and Buildings, 12, 1-6.

Fisk, W. J. (2007) “A pilot study of the accuracy of CO_2 sensors in commercial buildings”, Proc. ASHRAE IAQ 2007, Baltimore, American Society of Heating and Air-Conditioning Engineers Inc., Atlanta.

Gunnarsen, L. and Bluyssen, P.M. (1994) “Sensory measurements using trained and untrained panel”, Proceedings of Healthy Buildings '94, Vol. 2, 533-538.

Gunnarsen, L. and Fanger, P. O. (1992) ‘Adaptation to indoor air pollution’, Energy and Buildings, vol 18, pp43-54

Jørgensen, M. and Vestergaard, L. (1998) ”Sensory characterization of emission from building materials. Selection of low-emitting materials and evaluation of the method” M.Sc. Thesis, Technical University of Denmark (in Danish with English summary).

Kotzias D, Koistinen K, Kephalopoulos S, Schlitt C, Carrer P, Maroni M, Jantunen M, Cochet

C, Kirchner S, Lindvall T, McLaughlin J, Mølhave L, Fernandes EdO and Seifert B (2005): The INDEX project. Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU. Final Report. EUR 21590 EN. European Commission, Directorate General, Joint Research Centre.
Müller, B., Müller, D., Knudsen, H. N., Wargocki, P., Berglund, B. and Ramalho, O. (2007) 'A European project SysPAQ', in Proceedings of CLIMA 2007, Finland, (on the CDROM)
Nordin S., Millqvist E., Lowhagen O., Bende M. (2003) "The Chemical Sensitivity Scale: Psychometric properties and comparison with the noise sensitivity scale", Journal of Environmental Psychology 23 359-367.
Nordin S., Bende M., Millqvist E. (2004) "Normative data for the chemical sensitivity scale". Journal of Environmental Psychology, 24, 399-403.
Toftum, J., Jørgensen, A.S. and Fanger, P.O. (1998) "Effect of humidity and temperature of inspired air on perceived comfort", Energy and Buildings, 28, 15-23.
Wargocki, P. (2004) "Sensory pollution sources in buildings," Indoor Air, 14 (Suppl 7), 82-91.
Wargocki, P., Fanger, P.O., Krupicz, P. and Szczecinski, A. (2004) "Sensory pollution loads in six office buildings and a department store", Energy and Buildings, (in press).
Wargocki, P., Knudsen, H.N. and Krzyzanowska, J. (2010) "Some Methodological Aspects of Sensory Testing of Indoor Air Quality", Proceedings of CLIMA 2010 (in press).
Wargocki, P., Carrer, P., de Oliveira Fernandes, E., Hänninen, O., Kephalopoulos, S., and HEALTHVENT Group (2013) Guidleines for health-based ventilation in Europe, Proc. AIVC Conference, Athens (on CD ROM).
Wenger J. D., Miller, R. C. and Quistgaard, D. (1993) 'A gas sensor array for measurement of indoor air pollution – preliminary results', in Proceedings of Indoor Air'93, Helsniki, Finland, vol 5, pp27-32
WHO, World Health Organization (1987) Air quality guidelines for Europe, WHO-Regional Publications, European Series no. 23, Copenhagen, Denmark.
WHO (2000). Air quality guidelines for Europe, 2nd ed. Copenhagen, WHO Regional Office for Europe, 2000 (WHO Regional Publications, European Series, No. 91).
WHO (2005). Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Copenhagen, WHO Regional Office for Europe.
WHO (2009). WHO guidelines for indoor air quality: dampness and mould. Copenhagen, WHO Regional Office for Europe.
WHO (2010). WHO Guidelines for Indoor Air Quality: Selected pollutants. Copenhagen, WHO Regional Office for Europe.
Wolkoff, P., Clausen, P.A., Jensen, B. Nielsen, G. D. and Wilkins, C.K. (1997) "Are we measuring the relevant indoor pollutants?", Indoor Air, 7, 92-106.
Yaglou, C.P., Riley, E.C. and Coggins, D.I. (1936) "Ventilation requirements", ASHVE Transactions, 42, 133-162.

FIELD MEASUREMENTS IN LOW-ENERGY HOUSES – QUALITY OF METHODS FOR MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS, 2014

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ABSTRACT

Low Energy dwellings in the Netherlands are build or renovated in most cases with very airt tight specifications and advanced ventilation systems. How easy is it to realize these air tight dwellings in practice and what is the performance in practice, also compared with other parameters? And most of all what is the effect on the energy performance? In the Netherlands there is an unique opportunity, because in the “Energy Leap” program almost 30 projects will be monitored not only on the performance when finished but also on energy performance, the building process and user experiences. This paper shows some first results.

Since 2010 the five year innovation/implementation program Energiesprong (Energy Leap) helps to create market conditions for an energy neutral built environment in the Netherlands. This program is operated by Platform31. The program focuses on new buildings and renovation, in residential and non-residential buildings and at district level. The program aims at the creation of market conditions required for a successful transition to an energy neutral built environment. This is done by promoting demand for energy neutral renovation, facilitating the development of high level renovation concepts by the market and suggesting improvements in legislation which bock the successful roll out of these concepts..

The quality of the ventilation and air infiltration in the very low energy renovated and newly build dwellings is measured through the “Bouwtransparant” (Build Transparently) method. This consist of an inspector who performances a blower door test including smoke tests, a near-infrared picture, a check which measures are taken, ventilation flows, and a inspection about the general quality of the work. This paper describes the experiences of these inspections, common building mistakes and the derivations of the specification on air tightness and ventilation. The effect of these derivations is shown on the energy demand.

Example of a renovated dwelling in Kerkrade, Energyleap programma P31 (picture: Frank Hanswijk, Platform31)

Because the energy use is measured of these dwellings in combination with the weather data and two indoor temperatures, first results are shown of the energy use both annual but also in relation to the outdoor and indoor temperature. Because there is a lot of variation in the energy demand in similar houses, possible explanation are given in these variations.

EXPERIENCE WITH MEASUREMENTS, VENTILATION AND INFILTRATION IN THE ACTIVE HOUSE CONCEPT. QUALITY ISSUES AND IMPLICATIONS FOR COMPLIANCE

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ABSTRACT

The present paper addresses experiences with infiltration and ventilation in the Active House concept, based on the Active House Specification and realized Active Houses. The Active House Specification is based on a holistic view on buildings including Comfort, Energy and Environment. It uses functional requirements to indoor air quality and thermal comfort, and does not have component requirements to airtightness or specific ventilation solutions. Experiences from realised Active House projects show that better airtightness than nationally required has been achieved. Indoor air quality is generally good, independently of the type of ventilation system installed (mechanical, natural and hybrid have been used). Good thermal comfort can be achieved in houses with generous daylight conditions. To succeed, natural ventilation and dynamic solar shading (ventilative cooling) must be applied and controlled to avoid overheating, which is possible under European climate conditions, where humidity is not a main issue during summer. The identified issues for quality and compliance have been that the current methods in standards and legislation that are used to determine the performance of ventilative cooling need to be further strengthened. And that affordable, intuitive and simple control systems for residential hybrid ventilation and dynamic solar shading are needed.

KEYWORDS

Active House, natural and hybrid ventilation, renovation, standards, controls systems

1 INTRODUCTION

The Active House Specification (Eriksen et al., 2013) has requirements in three categories, and has a main ambition that the three categories should have an equally high focus. The three categories are:

- Comfort (incl. indoor environment)
- Energy
- Environment

The Specification addresses residential ventilation as functional requirements to Indoor Air Quality (IAQ) and thermal comfort. All main rooms for occupancy must be evaluated separately. Four categories of IAQ are defined, based on the CO2-concentration, which must be achieved for minimum 95% of the occupied time:

1. 500 ppm above outdoor concentration
2. 750 ppm above outdoor concentration
3. 1000 ppm above outdoor concentration
4. 1200 ppm above outdoor concentration

It is a requirement that the air change rate can be manually influenced in all main living rooms, regardless whether mechanical, natural or hybrid ventilation is used. To reduce the risk of overheating, operable windows are recommended. Ventilation inlets, including natural ventilation openings, must be located so that draught risk is minimised.

There are no specific requirements to airtightness, or to performance of ventilation components, and no specific type of ventilation systems is required. The designer of the project can choose the most relevant system for the specific project, but to meet the ambitious requirements to energy performance, an energy efficient ventilation system and an airtight building envelope is needed (and therefore required indirectly).

Natural ventilation in combination with dynamic solar shading is a key instrument to avoid overheating with minimal use of energy. Four categories of maximum operative temperature are defined, setting requirements to air-conditioned and non air-conditioned buildings, using the definitions of EN 15251. For non-air conditioned buildings, the adaptive approach is used:

1. $T_{i,o} < 0.33 \times T_{rm} + 20.8°C$, for T_{rm} of 12°C or more
2. $T_{i,o} < 0.33 \times T_{rm} + 21.8°C$, for T_{rm} of 12°C or more
3. $T_{i,o} < 0.33 \times T_{rm} + 22.8°C$, for T_{rm} of 12°C or more
4. $T_{i,o} < 0.33 \times T_{rm} + 23.8°C$, for T_{rm} of 12°C or more

All other criteria are found in the Specification (Eriksen et al., 2013), which can be downloaded at no cost from the website of the Active House Alliance.

2 EXPERIENCES FROM COMPLETED ACTIVE HOUSES

2.1 Increasing number of Renovation Projects: Climate Renovation as new Paradigm

Two types of Active Houses have been completed: New buildings and Renovation projects. New buildings dominated in the first years after the launch of the Specification, but in recent years a shift towards more renovation projects have been seen. A common characteristic for the renovation projects is that they do not have improved energy performance as the only objective – improved indoor climate is often just as important. Climate Renovation has been adopted by some Active House Alliance members as the term to describe this new paradigm. Examples of recent renovation projects are:

- LichAktiv Haus: A typical 1950's post-war, one-family house in Hamburg, Germany. The renovation has transformed it to a modern, spacious house
- De Poorters van Montfoort: Ten row-houses in a social housing corporation were renovated to offer excellent energy performance, more space, better daylight conditions and improved indoor climate.

2.2 Ventilation System Configurations

Many of the realized Active House have been built with demand-controlled, hybrid ventilation systems for optimal IAQ and energy performance.

An example is from the project Sunlighthouse in Austria. Natural ventilation is used during warm periods and mechanical ventilation with heat recovery is used during cold periods. The switch between mechanical and natural ventilation is controlled based on the outdoor temperature. The set point is 12,5^{o}C with a 0,5^{o}C hysteresis. Below the set point the ventilation is in mechanical mode, above the set point the ventilation is in natural mode. In both natural and mechanical mode, the ventilation rate is demand-controlled. CO_2 is used as indicator for IAQ, and a set point of 850 ppm CO_2 is used.

LichtAktiv Haus in Germany is an example of a house where natural ventilation is used as the only ventilation system.

2.3 Measured airtightness

It is not required in the Active House Specification to measure airtightness. But in order to meet energy efficiency targets, airtightness has been measured with blower door tests in many cases. Table 1 presents examples of measured airtightness in realised Active Houses. This is in most cases well below the requirements in the national building codes.

Table 1: Measured airtightness in five Active Houses

	Home for Life DK, 2009	**Sunlighthouse AT, 2010**	**Maison Air et Lumiére F, 2011**	**Carbonlight Home GB, 2011**	**LichtAktiv Haus D, 2010**
n50 (h^{-1})	1,5	0,52	0,60	-	1,07
l/s/m^2 @ 50 Pa	-	-	-	1,33	-

The experience from the completed Active Houses and other houses built according to other standards for low energy buildings, is that the achieved airtightness is related to the competence level of the craftsmen building the house. It is also the experience that the competence level has increased in the relatively short period from 2009 to 2011 due to the increased awareness of the importance of airtightness for low energy buildings.

2.4 Measured IAQ and Thermal Comfort

Temperatures and CO_2-concentrations have been measured on hourly level in several projects, e.g. in LichtAktiv Haus (LAH), Germany. LAH is designed with a demand controlled IAQ, with the aim to achieve category 1 (500 ppm above outdoor levels) or 2 (750 ppm above outdoor levels) (Feifer et al., 2013). The measured CO_2-concentration in the living/dining room is presented in Figure 1.

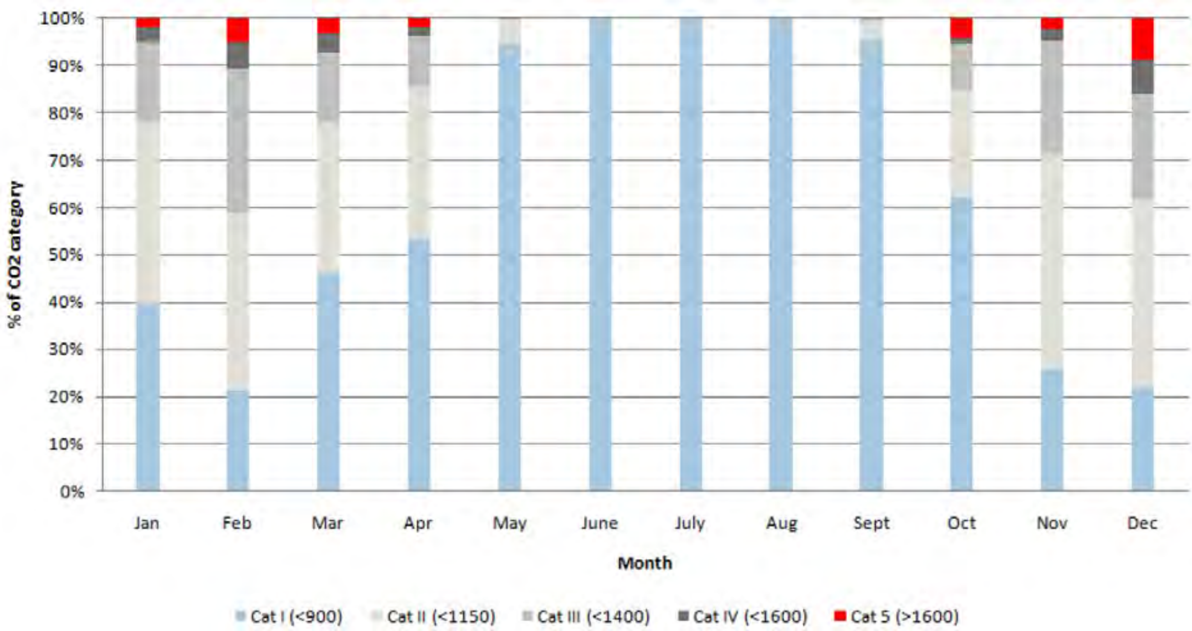

Figure 1: Measured CO_2 concentration in the kitchen/living room of LichtAktiv Haus, Germany. The data is categorized according to the Active House Specification

It is seem on Figure 1 that category 1 or 2 is achieved for 60% to 70% of the time during winter, and approx. 100% of the time during summer. The CO_2-concentration is lowest during the summer period as natural ventilation is also used to prevent overheating in this part of the year. Good summertime IAQ is thus a side-effect of applying ventilative cooling to prevent overheating. CO_2 concentration above category 2 during winter is caused by user override of automated controls. These results are similar to those seen in Active Houses with mechanical/hybrid ventilation.

It is the general experience that both natural, mechanical and hybrid ventilation systems are able to deliver the right ventilation rates and achieve the right IAQ. The key issue is that the systems must be designed, installed and maintained correctly, and most importantly, the controls must be transparent and intuitive for the occupants of the buildings.

Foldbjerg (Foldbjerg et al., 2013) reported on the thermal comfort in LAH and two other Active Houses. A typical characteristic of the realized Active Houses is that they have very generous daylight conditions. It is seen on Figure 2 that the living-dining room in LAH achieve category 1 in most months, with the exception of three summer months. Annually, the room achieves category 1. There are very few hours with temperatures below category 1. This means that there is no issues with overheating or low temperatures (undercooling).

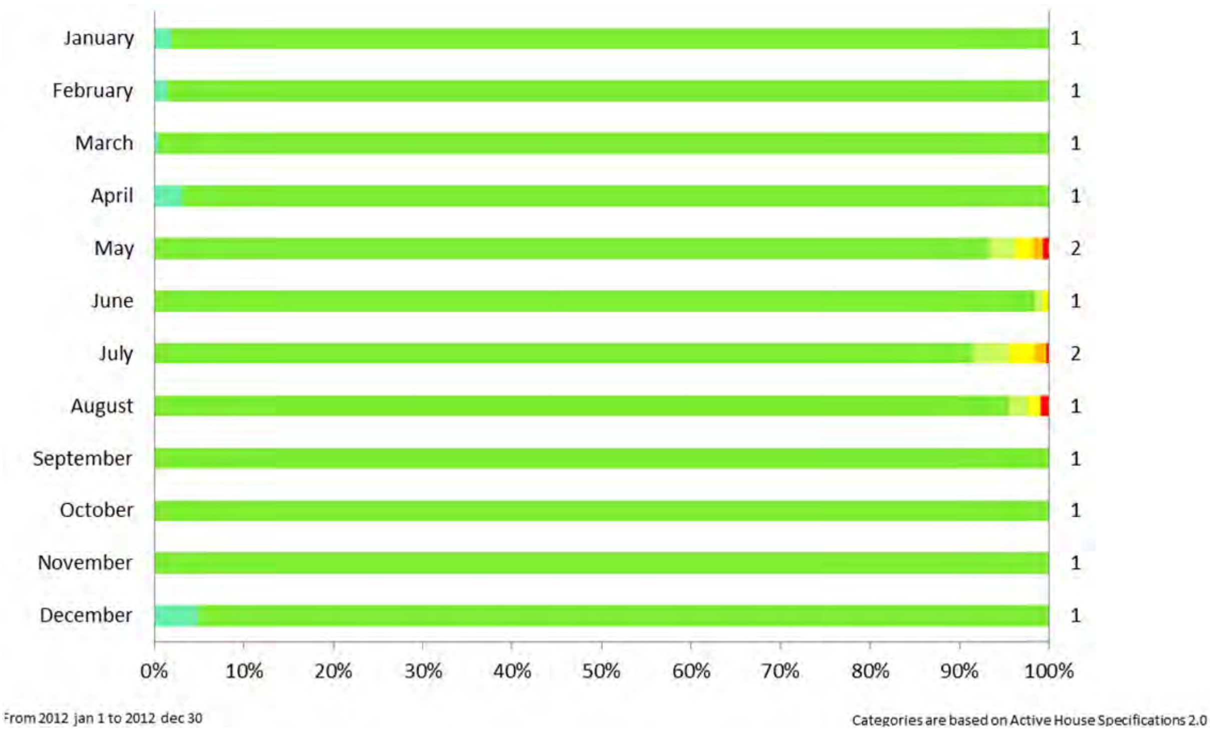

Figure 2: Measured indoor temperature in the kitchen/living room of LichtAktiv Haus, Germany. The data is categorized according to the Active House Specification. The number on the right side of the figure is the Active house category achieved for each month (max 5% of the time can exceed the category)

It is the general experience that good thermal conditions with only insignificant periods with high or low temperatures can be achieved. Prevention of overheating is a key issue, as low energy buildings can easily overheat, as reported by Larsen (Larsen, 2012) and others. The important elements to consider are natural ventilation and dynamic solar shading, as combined in ventilative cooling (venticool, 2014).

2.5 Ventilative Cooling in Standards and Legislation

Peuportier (Peuportier et al, 2013) measured the air change rates achieved with natural ventilation as the means of ventilative cooling in the Active House called Maison Air et lumière near Paris, France. Air change rates in the range of 10 to 22 ACH were achieved. These results were confirmed by simulations in CONTAM. However, later calculations with the methods presented in EN 15242 show much lower results despite similar geometry and boundary conditions. This is to some extent explained by the fact that EN 15242 only includes single-sided ventilation. BS 5925:1991 presents a method that allows for a two-sided window configuration, still with very conservative results. In the on-going revision of EN 15242 it is being discussed if a more accurate and generally applicable method can be included. The work in IEA Annex 62 will further support this goal.

To correctly account for the effect of ventilative cooling, more accurate methods are needed in standards, and in legislation. Regarding legislation, there is currently work on-going in Denmark and France to tighten the requirements to thermal comfort during summer – this process underlines that reasonably accurate methods are needed to predict the performance of the measures that can be used to prevent overheating.

2.6 Experience with Control Systems in Active Houses

Holzer (Holzer et al, 2014) is investigating the characteristics of Active Houses and particularly how the control systems should be designed to allow the houses to deliver the expected performance, and at the same time offer the occupants the experience they expect.

The preliminary conclusions are:

- Active Houses are react fast towards direct sunlight. Thus, an effective and fully automatically controlled system of dynamic shadings is obligatory for achieving good summer comfort.
- Hybrid ventilation systems stand the test, combining automated window operation, and mechanical ventilation systems as well as manual window operation. The learning is to consequently separate the operation periods of automated window and mechanical ventilation, depending from outside temperature.
- Beyond technical automation it's essential offering intuitively manually operable devices such as windows, doors, and awning blinds. Furthermore it's preferable having some devices literally manually operated than having them only manually telecommanded.
- Sun protection together with night ventilation is an effective combined strategy towards summer comfort, which turned out to be preferably automized. At least in central and northern Europe areas there turned out to be a somehow weak intuitive understanding of heat protective building operation.

There are few control systems currently available that deliver control of both mechanical and natural ventilation (as a hybrid solution), and which controls both ventilation, window openings and dynamic solar shading in a combined effort to maintain both good IAQ and good thermal comfort. Such systems should be cost-effective and are needed for the residential market.

3 CONCLUSIONS

There are several experiences with completed Active Houses regarding ventilation, quality and compliance.

A shift from focus on new buildings to also focus on renovation projects has been observed. The main driver is improved energy performance, but multiple benefits are actually expected, mainly related to good indoor climate. Some Active House members have used the term Climate Renovation to describe this new paradigm.

Airtightness is important to ensure the planned energy performance, and relies to a large extent on the competences of the craftsmen. There are indications that the competence level is increasing from year to year, and good results have been observed in the most recent houses. There seems to be a reduced need for focus on building airtightness now compared to the situation 5 to 15 years ago.

Good IAQ can be achieved with both natural, mechanical and hybrid ventilation systems. The important lesson is that they must be planned, installed and maintained right. This has been achieved in the investigated houses. By correct planning in the design process good IAQ can be reached with a minimum use of energy. Particular good IAQ during the summer period has been observed as a side-effect of applying ventilative cooling.

Whereas the above themes have been relatively unproblematic, some issues, mentioned below, have a greater need for increased focus regarding quality and compliance.

The realized houses are characterised by generous daylight conditions, which could potentially lead to overheating. This has not been the case. The houses show that good thermal comfort can be achieved in all seasons, regardless whether natural, hybrid or mechanical ventilation is used. But a strong relation between efficient natural ventilation in the summer (ventilative cooling) as well as dynamic solar shading has been a key element in achieving this, supported by windows being located towards more than one orientations in each room and not mainly towards the south as sometimes seen in low energy houses.

There is currently only weak support in standards and legislation to give a true and fair account of the performance of ventilative cooling and dynamic solar shading, and this needs to be improved.

There remains a need to identify and to discuss how ventilative cooling can become a standard solution in legislation and standards throughout Europe especially regarding renovation but also regarding Nearly Zero Energy Buildings.

Transparent and intuitive control systems scaled for residential buildings with regards to system architecture and price are needed. Such a control system should be able to control ventilation and dynamic solar shading to maintain both good IAQ as well as good thermal comfort.

4 REFERENCES

Eriksen, K.E. et al. (2013). *Active House – Specification*. Active House Alliance. 2013

Feifer, L. et al. (2013) *LichtAktiv Haus – a Model for Climate Renovation*. Proceedings of PLEA Conference 2013.

Foldbjerg, P. and Asmussen, T. (2013) *Ventilative Cooling of Residential Buildings: Strategies, Measurement Results and Lessons-learned from three Active Houses in Austria, Germany and Denmark*. Proceedings of AIVC conference 2013, Athens, Greece.

Holzer, P. et al. (2014). *Control of indoor climate systems in Active Houses*. Submitted to World Sustainable Buildings Conference 2014, Barcelona (currently in review).

Larsen, T.S. and Jensen, R.L (2012). *The Comfort Houses - Measurements and analysis of the indoor environment and energy consumption in 8 passive houses 2008-2011*. Aalborg University.

Peuportier, B. et al. (2013) *Evaluation of Ventilative Cooling in a Single Family House*. Proceedings of AIVC conference 2013, Athens, Greece.

Venticool (2014). http://venticool.eu/

VENTILATION AND INFILTRATION MEASUREMENTS IN THE EFFINERGIE LABEL

APPROACH TO QUALITY ISSUES AND IMPLICATIONS FOR COMPLIANCE

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KEYWORDS

Low-energy label, airtightness measurement, building, ductwork

1 INTRODUCTION

In 2006, France was little behind other European countries regarding low energy buildings. At that time, no definition of low-energy buildings existed in France, while Germany and Switzerland had been talking about Passiv'haus and Minergie Label for about 10 years. Thus, local initiatives began to emerge to go beyond energy performance regulation 2005 and promote low and very low-energy buildings.
Stake holders from various origins gathered around the necessity to develop energy efficiency in the building sector. Thereby, the Association Effinergie was created in March 2006 with a strong network of 70 members including almost all the French regions and also technical and research centers, banks, industrials, syndicates and professional federation, architects and engineering consultants and training centers.
The objective was to develop a dynamics for energy efficiency in new and refurbishment building sector in order to generalize positive energy buildings.
The aim of Effinergie is to

- Develop building references and tools
- Unite all the actors of the sector
- Ensure coordination between governmental authorities and regional initiatives
- Show the technical-economic feasibility of low energy buildings

Effinergie has then created references for low-energy buildings labels, and this, with a commission of experts in accordance with the French ministry for construction.

2 THE LABELS

Labels are consistent with the thermal regulations and thereby use the same calculation method, which is, in France, a very elaborate dynamic calculation tool. The energy is counted

in kWh of primary energy per square meter per year, it takes into account heating, domestic hot water, heating and ventilation auxiliaries, cooling and lighting.
The first label was “BBC-Effinergie” it has been operational from 2007 and till the end of 2012. In that time around 300 000 dwellings had been certified. At the end of 2012 it represented 60% of new dwellings.
January 1st, 2013 the new energy performance regulation (RT2012) came into force, imposing the BBC-Effinergie level as the mandatory one.
A new label “Effinergie+” has been created to fit with this new regulation. It imposes, among other things, to consume 20% less than the required level. In 2013, 9000 dwellings applied for the certification.

3 MEASUREMENTS IN LABELS

3.1 Requirements and reason behind

Label BBC-Effinergie has imposed, since 2007, a minimum requirement for building airtightness that has to be proved by testing. Reasons behind this requirement where:

- Hypothesis on the airtightness value was used in the energy performance calculation but never checked and not always respected.
- Low-energy labels was the perfect way to work on building airtightness as it is a voluntary approach, certified by a third part with a small amount of project (at the beginning).
- To prove by measuring and not only by calculation the building’s performance.

To make sure tests were performed correctly, Effinergie set, with the technical support of ministry for construction, a mandatory qualification process for testers.
Setting the qualification process was a difficult work but it eventually can be considered as a success because:

- It positively improved measurement quality,
- It gave credit to the approach,
- Perform a building airtighness test by a qualified tester is now required by the French regulation for all new residential buildings.

With this successful experience Effinergie decided to extend measurements in its new label “Effinergie +”. Indeed the label Effinergie + tends to

- Improve building airtightness by
    - Promoting measurement of whole multi-family buildings instead of sampling apartments (by setting the requirement at $1m^3/h/m^2$ if the measure is done on the whole building instead of 0.8 if it is done by sampling)
    - Requiring measurement on non-domestic buildings under 3000 m²
    - Requiring training of craftsman on single houses construction or an airtightness level of $0.4m^3/h/m^2$ (instead of 0,6 in the regulation)
- Improve the ventilation efficiency and air quality by
    - Requiring airtightness testing of the ventilation network and a level of at least Class A
    - Requiring a visual control of the ventilation system.

To be allowed to perform airtightness test in the context of Effinergie + label, testers have to be qualified. That is to say, they have to

- Validate an approved training program
- Justify a certain amount of test
- Apply for qualification from a certification body
- Fill a database

3.2 Difficulties

When testing is required it is necessary to ensure the reliability of tests. The qualification process ensures that testers are able to respect a protocol. Nevertheless a protocol first has to be clearly defined.

For building airtightness testing, Effinergie involved in the drafting of a new standard: GA-P 50-784, specific to French context that spell out EN 13829.

For ductwork airtightness various standards deal with measurements (EN 1507, EN 12237, EN 2599, EN 13403) especially a specific French one FD E 51-767 that is under revision to improve consistency with other standards and fit with Effinergie requirements.

Major difficulties came with the control of ventilation system. Indeed, at first “Effinergie +” was supposed to require measurement of ventilation flowrate to check the efficiency of the ventilation system. But it has been abandoned as standards dealing with ventilation flowrate measurement (NF 12 599, NF-X10-112, PR NF EN 16211):

- Are not consistent one to another
- Do not match with Effinergie needs: it is important to have non-destructive intervention of the tester (no drilling).
- Do not include measurement at air terminal devices.

This lead to major difficulty to establish a control protocol as:

- The reliability of flowrate measurement devices at air terminal were unknown
- The specific case of humidity sensitive ventilation was difficult to handle.

The requirement on measuring ventilation airflowrate was then abandoned, and only a visual control of the ventilation system is performed.

However in 2014 starts a research project aiming at testing the reliability of ventilation flowrate measurement at air terminal devices. The final purpose of this project is to test protocols and measurement devices and to transcript a reliable protocol in a standard.

4 CONCLUSIONS

Label BBC-Effinergie and then Effinergie + have required airtightness measurement to prove the energy performance of certified buildings not only by calculation but also by measuring. To ensure the reliability of measurement, specific protocols were developed and competent tester schemes were set.

This was possible for building and ductwork airtightness, however regarding control of ventilation flowrate measurement, requirements had to be abandoned because of the lack of applicable standards.

Ongoing research projects shall lead to the development of reliable and widely applicable protocols.

5 REFERENCES

Relevant websites:
www.effinergie.org
www.rt-batiment.fr
http://www.observatoirebbc.org/

PLANNING AND ORDERING MEASUREMENTS IN "PASSIVE HOUSE" BUILDINGS: LESSONS LEARNED FROM PRACTICAL EXPERIENCE AND APPROACH TO QUALITY CONCERNS

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1 INTRODUCTION

Bostoen is a building company that specialises in certified passive houses according to the innovative passive concept, nearly zero-energy and energy-efficient homes, as well as apartments. This within its own project builds as well as build to order, based on the client's own construction ground. In addition Bostoen also retails construction grounds in itself.

With years of expertise and market knowledge, Bostoen founded in 2013 a division of renovations for existing home owners. Under the brand name Bostoen, the company positions itself clearly as an all-round provider of housing solutions and dynamic market innovator. Bostoen evolved from a turn-key-project family business into a complete provider in the housing market with an integrated sustainable vision. It is a reference in the field of passive construction. In 2013 Bostoen also celebrated her 40th birthday with a total of 10.000 homes to this day.

2 WHAT ARE THE COMPLIANCE CONTROLS CARRIED OUT FOR PASSIVE HOUSE CERTIFICATION IN BELGIUM

2.1 Airtightness better than 0.6 h^{-1} at 50 Pa

The air leaks off the house should not cause more than 0.6 air changes per hour at 50 Pa in the house ($n50 \leq 0,6\ h^{-1}$). The test for this value should be performed in accordance with the NBN EN 13829 / measurement method A and this with overpressure and underpressure to get an average n50-value of both measurements.

This value is a direct certification criteria.

10. Synthesis of the additional specifications (requirements and recommendations)

The table below includes only the additional specifications addressed in the present document; the basic requirements for measuring the air leakage rate, $\dot{V}_{50}$, can be found in the NBN EN 13829:2001 standard.

	Requirements	Recommendations
Measured zone (§2.1)	EPR or EPN ≤ measured zone ≤ PV	Either measured zone = total PV or measured zone = individual EPR or EPN
Time of measurement (§2.2)	Envelope finished	All works completed
Choice of method (§3.1)	Method A	
Equipment (§3.2)	Measurement of pressure with an accuracy of 2 Pa	Regular calibration
Heating, ventilation and other apparatuses (§ 4.1)	Stop all apparatuses that take in air from or evacuate air to outside	
Intentional openings	If closing device available: close and keep closed Mechanical ventilation openings : seal Adjacent spaces: close the openings	
Installation of equipment (§5.1)	In the best sealed opening (safely accessible)	Seal the joint between the equipment and the building envelope
Measurement of leakage rate (§5.2)	2 series : pressurisation and depressurisation Highest pressure difference of at least 50 Pa (in absolute value)	Highest pressure difference of 100 Pa (in absolute value)
Calculation of result (§6.1)	$\dot{V}_{50}$ is the average of the leakage rate for pressurisation and depressurisation	

Figure 1: Excerpt from
http://www.epbd.be/media/pdf/etancheite_air/Airtightness_measurement_EPB_specifications_v3_130528.pdf

To come to this n50-value, we need to determine the net volume of the house. The net volume is calculated from the inner measurement between the finished surfaces of the building, inner walls and upper floors are included in this volume. This calculation is according to 'WTCB-Dossiers - Nr. 1/2007 - Katern nr. 6' hernomen in annex 4.

2.2 Ventilation

Our ventilation report will check two parameters, the ventilation airflow rates of every room/ventilation ducts and the energy consumption of the ventilation system at every airflow rate (1/2/3).
The ventilation unit has 3 fan speeds, each according to a specific use. The lowest speed and least airflow volume (1) is set for normal day use, the medium speed (2) is set to EPB standard and is recommended while cooking and/or taking a shower. The third fan speed is for extensive house use or high occupancy, for example when throwing a party.

The airflow rate is the maximum output of the system in which the legal demand for ventilation is required. In the case of supply of fresh air as well as the removal of polluted indoor air.

Depending on the region in which the ventilation system is installed there are rules to comply to (EPB, NBN D 50-001, ARAB, NBN EN13779, RGPT).

3 WHAT ARE THE ADVANTAGES/DISADVANTAGES TO WORK WITH AN INDEPENDENT COMPANY FOR THE AIRTIGHTNESS AND VENTILATION MEASUREMENTS ?

Pro’s

- \+ Third party confirmation – independent quality control for us and the costumer
- \+ Official compliance test /Blowerdoor is mandatory / ventilation will become mandatory in the future
- \+ Final check before completion and creates awareness for costumer

Con's

- Time management (Bostoen – independent company – costumer)
- Communication (what – why - where – when)
- Cost (this service is included in the tag price, but is seen as a blind increase.)

4 IS THERE A NEED FOR CERTIFICATION OF SUCH MEASUREMENT COMPANY IN THE CONTEXT OF COMPLIANCE (EPBD, PASSIVE HOUSE, ETC.) WHAT IS THE VIEWPOINT FROM THE CONSTRUCTION COMPANY ?

The blower door/airtightness certificate is in compliance with regulations, the company that produces these documents is not certified as a company. The ventilation certificate is done by the same company, the installation is up to code according to recommendations but there are no regulations to comply to.

In EPBD it is not mandatory to do either ventilation or a building pressurization test. There is a default value that can be used. Doing these tests overrules the default value, this 'wins' E points which results in a better scoring house and more government compensation. Certification is thereby a choice but has a certain advantage, especially from a consumer point of view.

In Passive house certification only a building airtightness test is mandatory; testing the ventilation system is nevertheless strongly recommended.

The ventilation certificate is another check we as a company choose to have. The Passive House Platform (PHP) looks at these reports but has no regulations about the matter. We have them done to make sure everything is up to code.

The airtightness test certificate is mandatory to prove the 0.6 h^{-1} airtightness. If this report is not according to certain rules, PHP requires a new test. We could be denied the passive house certificate as a result, which is promised to every passive house customer.

Doing both tests is in most case a choice by our company to keep our work up to code, this also gives us an advantage in credibility and marketing.

Overview of tracer gas measurement techniques

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Uncertainties in Air Exchange using Continuous-Injection, Long-Term Sampling Tracer-Gas Methods

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Environmental Energy Technologies Division

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Uncertainties in Air Exchange using Continuous-Injection, Long-Term Sampling Tracer-Gas Methods

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ABSTRACT

The PerFluorocarbon Tracer (PFT) method is a low-cost approach commonly used for measuring air exchange in buildings using tracer gases. It is a specific application of the more general *Continuous-Injection, Long-Term Sampling (CILTS)* method. The technique is widely used but there has been little work on understanding the uncertainties (both precision and bias) associated with its use, particularly given that it is typically deployed by untrained or lightly trained people to minimize experimental costs. In this article we will conduct a first-principles error analysis to estimate the uncertainties and then compare that analysis to CILTS measurements that were over-sampled, through the use of multiple tracers and emitter and sampler distribution patterns, in three houses. We find that the CILTS method can have an overall uncertainty of 10-15% in ideal circumstances, but that even in highly controlled field experiments done by trained experimenters expected uncertainties are about 20%. In addition, there are many field conditions (such as open windows) where CILTS is not likely to provide any quantitative data. Even avoiding the worst situations of assumption violations CILTS should be considered as having a something like a "factor of two" uncertainty for the broad field trials that it is typically used in. We provide guidance on how to deploy CILTS and design the experiment to minimize uncertainties.

Introduction

Building ventilation is the primary process used to insure acceptable indoor air quality by removing pollutants from indoor sources as well as conditioning the air for occupant comfort. In many buildings, ventilation occurs by the uncontrolled leakage of air through the building envelope termed infiltration. National efforts to improve building energy efficiency have focused on reducing infiltration by making homes more airtight. In the absence of mechanical ventilation, reduced infiltration can lead to elevated concentration of pollutants indoors. The use of mechanical ventilation, however, can result in increased energy use which can offset the reduced energy losses through improved airtightness. Thus, accurate measurement of the ventilation rate, or air exchange rate, is key to assess the energy and air quality impacts of infiltration (including exfiltration). Having a reliable estimate of building ventilation can also be necessary to characterize other indoor phenomena, such as the emission rate of contaminants indoors.

Ventilation is often expressed as an air exchange rate, where the air flow rate is normalized by the building volume. Air exchange rate varies as a function of HVAC operation, meteorological conditions, and changes in the configuration of the building envelope (e.g. windows open or closed). For buildings dominated by uncontrolled airflow through the building envelope, tracer gas techniques are the primary method used to measure air exchange rates. ASTM Standard E741 describes several methods for making tracer gas measurements. The two most common tracer gas methods are the decay rate and constant injection rate methods [Basset et al, 1981; Condon et al, 1981; Dietz et al, 1982; Grot, 1980; Harrje and Grot, 1977]. A third method uses a constant concentration approach in which the quantity of tracer emitted is varies to maintain a fixed target concentration. This allows the tracking of ventilation rate over short time scales but requires on-site tracer analysis in real time as well as computer controls for the tracer injection equipment – both of which require extra cost and complexity – hence it's limited application.

The decay rate method entails the injection of a tracer gas, mixing it to uniform concentration throughout the building and measuring the decay in real time over a few hours [Basset et al, 1981]. The method provides a robust measurement of the air exchange rate, but requires trained technicians to be onsite and only allows for the air exchange rate to be determined over short time-scales . This method assumes that the ventilation rate does not change during the experiment, so care must be taken to avoid variable weather conditions and changing building envelopes such as opening windows. Such techniques are well suited to research-grade investigations or very small sample sizes, but are often impractical for larger, more cost-constrained studies.

The constant injection method involves placing a number of emission sources, whose emission rate is well known and controlled – often using sophisticated mass flow controllers - of one or more tracer gases in a house together with samplers to measure the concentration of the gas over a period of time that can range from hours to days [Condon et al, 1980]. The time-averaged air exchange rate is determined from the volume of gas tracer emitted into the house and the concentration of that tracer measured by the sampler. Simpler methods utilize a passive technique to obtain relatively constant emission of tracer, such as the evaporation of a liquid through a controlling membrane initially developed by Brookhaven National Laboratory. This method is often called the "PFT" method because it used PerFluorocarbon Tracer gases. The defining characteristic of this technique is not the tracer gasses themselves but the fact that they use Constant Injection and Long-Term Sampling in the field. We shall refer to this technique with a more generic title of CILTS.

The CILTS method is widely used due to the small size and low cost of the(tracer gas) emission sources and samplers, the flexibility in measurement duration, and because it can be deployed using personnel with limited training. This is particularly important for applications such as field projects that require the measurement of the air exchange rate in large numbers of homes [e.g. Clayton et al., 1993; Ozkaynak et al., 1996; Weisel et al., 2005; Offermann, 2009]. There is general guidance regarding the number of (emission) sources that should be placed based on the total area of the space [ASTM E741 2000]; sources and samplers are largely placed in a specific locations within a home based on the convenience for occupants and engineering judgment.

Due to its widespread use, it is important to have a reasonably good idea of the uncertainties associated with the CILTS method, but limited analyses exist. The factors that affect measurement uncertainty include uncertainties in the tracer emission rate, the measured tracer concentration, the time rate of change in the tracer concentration, and the spatial variability of tracer concentration within the house. Previous studies investigated some of these uncertainties [Dietz and Cole, 1982; Leaderer et al, 1985], but do not explicitly discuss the implications for the resulting air exchange rate. D'Ottavio et al, 1988, showed how to analyze the data but contains no error analysis. The objective of this work is to estimate the sources and magnitude of errors for a typical single-zone application of CILTS. These uncertainties will be examined through analysis of field data using a theoretical uncertainty analysis method developed by Sherman (1988). Based on the analysis, recommendations for reducing the errors of using the CILTS method will be listed.

Uncertainties estimates for the CILTS method

All tracer gas methods use the continuity equation to calculate the air exchange rate from the measured tracer concentrations and other experimental parameters. The continuity equation for a single zone is as follows:

$$V \cdot \dot{C} + Q \cdot C = S \tag{1}$$

where V is the zone volume (m^3), Q is the ventilation rate of the zone (m^3/h), C is the tracer concentration (g/m^3) (assuming no outdoor concentration), $\dot{C}$ is the time rate of change of tracer concentration ($g/m^3/h$) and S is the tracer emission rate (g/h). The ventilation rate generally varies as a function of time, which is directly reflected in the term for the time rate of change of tracer concentration. However, the CILTS method results in a single measurement of tracer gas concentration averaged over the time period of the experiment. Therefore, the use of the continuity equation to calculate the air exchange rate measured using the CILTS method requires that sampling time period be sufficiently long enough that the transient changes in concentration can be neglected. When this is the case, an average air exchange rate, A (1/h) can be determined from the measured tracer emission rate and the measured concentration as follows

$$Q = S / C = A \cdot V \tag{2}$$

When the emitters are first placed in the building there is an additional transient period during which the tracer reaches equilibrium in the home. It is also important that the tracer sampling period either avoids this initial transient period or that the sampling period is long enough so that this transient period is inconsequential to use Eq. 2 to calculate the air exchange rate.

There are a number of errors to consider when calculating the air exchange rate using Eq. 2 with the CILTS method. The first types are instrumentation errors associated with the measurement of the tracer gas emission rate and concentration. The second types or errors are those arising from the simplified model of the continuity equation used to interpret the data or how actual flows violate the modelling assumptions. The subsequent discussion will discuss these different sources of error in detail.

Instrumentation Error

Instrumentation error encompasses all of the errors in the directly (or indirectly) measured quantities of average emission and concentration. The contribution to the uncertainty to the calculated air exchange rate follows from Eq. 2 and can be expressed as:

$$\left(\frac{\delta Q}{Q}\right)^2 = \left(\frac{\delta A}{A}\right)^2 = \left(\frac{\delta S}{S}\right)^2 + \left(\frac{\delta C}{C}\right)^2 \tag{3}$$

There can also be an error term for the uncertainty in the volume of the space, but for this effort, we shall assume that this is small. At steady-state the volume error only affects the volumetric air flow to air change rate calculation and is, therefore, not fundamental to the measurement technique, but volume errors can be significant issues whenever converting from mass/volume flows to air changes.

Estimating the uncertainty of the average tracer emission rate, S, is a straightforward exercise. The total mass emitted is often measured gravimetrically by weighing the emitter before and after the tracer gas sampling period, and the result can be highly accurate. Without gravimetric measurements, the emission rate can be found by laboratory calibration, which will generally be less accurate. The emission rate may not be constant, but if the changes in the emission rate are not correlated with variations in the air change rate, small variations in emission rate will not affect the results provided the sampling time is long enough. We will, therefore, consider the tracer emission rate to be constant, but that assumption should be evaluated when atypical protocols are being considered. Equivalently we could consider the non-stationery emission rate to be part of the error in the emission rate measurement.

The error in the measured tracer gas concentration is due to errors in both sample collection and analysis. The analytical technique used to measure the amount of tracer gas in the sample can have precision errors due to variability in instrument response and bias errors due to imperfect calibration. The errors in sample collection are primarily due to uncertainly in the value of sampling rate and a sampling rate that may not be constant. Both of these errors are of particular importance with concentrating samplers (e.g. sorbent tubes) due to effects of changing temperature and potential sample saturation. Non-concentrating sampling techniques such as bag sampling do not experience the same issues with respect to temperature and saturation effects. There is a modelling error (discussed later) associated with assuming the concentration is spatially homogeneous at the spatial average, but there is also a measurement error associated with determining the average concentration, which is the more common problem of sampling variations. The uncertainty associated with measurement errors can be reduced by using multiple samplers in the usual manner, but the modelling error cannot, because it is a bias error.

Most experiments using the CILTS technique do not analyse the concentration data in the field, and transporting the sample to the laboratory for analysis is an opportunity for sample degradation. A thorough discussion of best practices is beyond this report, but some example issues might be beneficial: For instance, some of the sample may be lost in transit or storage due to leakage. This is particularly important for concentrating samplers where the concentration measurement is a function of the total collected mass. For non-concentrating samplers, such as units that directly sample room air into a bag, the loss of part of the sample is less important because analysis results directly in a concentration. For concentrated samples any loss will create a negative bias. For all kinds of samples, contamination of the sample in transportation can result in error in either direction. Contamination can come from samplers and emitters being proximate or from other chemicals which might mimic or interact with a tracer.

Combining these factors results in the following expression on uncertainty due to instrumentation error,

$$\left(\frac{\delta Q}{Q}\right)^2_{instrument} = \left(\frac{\delta A}{A}\right)^2_{instrument} = \left(\frac{\delta S}{S}\right)^2_{emit} + \left(\frac{\delta C}{C}\right)^2_{collect} + \left(\frac{\delta C}{C}\right)^2_{transport} + \left(\frac{\delta C}{C}\right)^2_{analyze} \quad (4)$$

where the uncertainty in the measured tracer gas concentration, C, is expanded to include those errors arising from collection, transport, and analysis as discussed above. With the right equipment and good experimental technique, it is possible to reduce these instrumentation errors to acceptably low levels.

Model Errors

To analyse the data in the CILTS approach the following assumptions are made:
1. it is assumed that the system is in steady-state such that the concentration has had sufficient time to reach equilibrium that transient effects are unimportant
2. the parameters are stationary. (i.e., that the air exchange is truly a constant over the measurement period, and
3. the space is a single-zone and the tracer concentration is homogenous throughout the space). (Any inhomogeneity is due to an interaction between emitter placement and the actual air flow patterns. It is not necessary to know how it occurred.)

Each of these assumptions has an intrinsic error that is dependent o)n the system being measured rather than the instruments measuring that system. We will examine each of these errors individually (i.e. assuming no instrumentation or other model errors contribute) and then combine them assuming they are independent.

Steady-State Assumption Errors

The time dependent continuity equation, Eq. 1, includes the time rate of change of the tracer concentration, thus a complete solution will have include a term that accounts for the initial concentration. The CILTS method assumes that transient changes in concentration can be neglected, and so represents a source of error that depends on the difference between the initial and final concentrations.

$$\left(\frac{\delta Q}{Q}\right)_{steady-state} = \left(\frac{\delta A}{A}\right)_{steady-state} = -\frac{V}{S}\frac{\Delta C}{\Delta t} = -\frac{1}{A\Delta t}\frac{\Delta C}{C} \quad (5)$$

The bias from this error could be corrected if we knew the initial and final concentration. Since CILTS only measures the average concentration over the sampling period, we cannot correct the result without some prior knowledge of the system. For instance, if we know that the initial concentration was zero, Eq. 5 can be used recursively to correct the CILTS result. However, as previously discussed, successful implementation of the CILTS method requires sufficiently long sampling times that these transient changes in concentration, which should make this error quite small. (We can't actually calculate that time a priori as it requires knowing the answer first, but likely a good experimenter will have an estimate that can be used to bound it.) We shall assume this is the approach taken and that any calculable biases have been taking into account.

Constant Air Exchange Assumption Errors

The air exchange rate will most likely vary over the sampling period, so the tracer gas concentration will be varying over time. The CILTS method measures the average concentration, but the air exchange rate is inversely related to the concentration. Thus, the CILTS analysis will underestimate air exchange rather than providing in a true average air exchange rate. If the variation is small, the bias can be corrected for (See Sherman (1989a) for details), however, the bias can be intractably large if the variation in air exchange is large - as might be the case for an experiment where windows are opened and closed during the testing or the weather changes significantly. This magnitude is important when the measured *average* air exchange rate is used for energy calculations. However, the effective air change rate from CILTS is the correct air change to use for investigating the dilution of indoor contaminants.

Homogeneity Assumption Errors

The CILTS analysis assumes that the space can be treated as a single zone and that the concentration is the same everywhere in this zone. Incomplete mixing, however, can result in substantial variability in tracer concentration within the zone, resulting in a measured concentration that may not be representative of the space as a whole. In addition, the average concentration measured in the zone may not be the representative concentration needed in the CILTS analysis because the continuity equation requires that the representative concentration must be the flow-weighted average concentration of the air flowing from the space to outside.

To investigate the errors due to inhomogeneity, we have broken down the putative single zone into a set of N interacting multizone spaces. Details of the analysis are reported in the appendix. The results show that, even if the spatial average concentration could be measured with minimum uncertainty, there would be an error in the calculated average air exchange rate induced from the spatial inhomogeneity as follows:

$$\left(\frac{\delta Q}{Q}\right)^2_{spatial} = \left(\frac{\delta A}{A}\right)^2_{spatial} = N\left(\frac{\delta\, C_{rms}}{C^2}\right)^2 + N\left(\frac{\delta\, S}{S}\right)^2 \tag{6}$$

Combining these errors results in the following expression for the uncertainty in a CILTS measurement:

$$\left(\frac{\delta Q}{Q}\right)^2_{effective} = \left(\frac{\delta A}{A}\right)^2_{effective} = \left(\frac{\delta C}{C}\right)^2_{collect} + \left(\frac{\delta C}{C}\right)^2_{transport} + \left(\frac{\delta C}{C}\right)^2_{analyze} + \left(\frac{1}{A\Delta t}\frac{\Delta C}{C}\right)^2 + N\left(\frac{\delta\ C_{rms}}{C^2}\right)^2 + N\left(\frac{\delta\ S}{S}\right)^2 \quad (7)$$

The last terms, from Eq. 6, are proportional to the number of actual zones. Note that the single-zone "emission" error has been replaced by the multizone one.

Error Analysis of CILTS data

An intensive investigation of the CILTS method was recently performed in three test homes (Lunden et al, 2012)). The tests used multiple simultaneous PFTs sampling at high spatial density in multiple configurations to evaluate the precision of the technique and to provide guidance on the best way to deploy emitters and samplers. This data set, hereafter referred to as the "Lunden data", is used to examine the errors that result from the CILTS method in the error analysis presented above. Each test house used four different PFTs with different sample densities and two different sampling methods, resulting in four separate experimental measurements of the same air exchange rate. The differences between the experiments serve to identify which factors are most important with regards to experimental uncertainty. In addition, the high spatial density of sampling locations in the experiments will help to quantify the spatial variability in tracer concentration.

The experiments were designed to investigate a range of ventilation conditions. These experimental ventilation conditions included no forced air system operation, normal operation of an air conditioner, constant operation of the forced air system fan, and other variations. The specific experimental ventilation conditions used for each of the three homes are listed in Table 1.

Estimates of precision and bias errors that are the same for each experiment are as follows:

- Emission source: The PFTs sources were the same type of emitter device for all experiments. They consisted of liquid in a glass vial with a septum through which the gas diffused. The vials were placed in dry block heaters to keep the emitters at a constant temperature. This eliminates a source of error due to changing emission rates with temperature. Given how simple and easy it is to use these block heaters are, they are highly recommended for use in CILTS experiments. The emission rate for each vial was measured gravimetrically on site using a high precision scale. The accuracy of these scales is assumed to be on the order of 1%.

- Collection and Transport: We shall assume that any precision errors due to sample collection will be reflected in any inhomogeneity of the measured concentrations, and will thus only consider bias errors. For the purposes of this analysis, we shall assume an empirically-based bias error of 3% and no transportation error.

- Analysis: The tracer gas analyser had a precision error of 5%. This uncertainty is reduced as multiple samplers are used to estimate the mean concentration. During the analysis of the tracer gas samples, a significant bias was discovered and corrected, with no residual bias reported; Lunden (2012) has more details on this issue.

Error estimates for more conventional CILTS experiments may differ from those in Lunden data. Errors associated with emission sources can sometimes include transport and handling that will affect the precision of the measured emission rate, i.e. sources are shipped to and from experimental locations by mail can cause losses in the tracer that will result in an emission rate that may be biased high. The effect of temperature will be important for emission rates that are not determined gravimetrically. Lunden et al. (2012) found that emission rates for the LBNL vials varied by approximately 4% for every 1 °F change in temperature. The temperature dependence of other emitter types may differ, and should be characterized, but this value can provide an estimate of the importance of this error if important. Collection and transport errors that affect the tracer gas samples may occur in high-volume, mail-in, or occupant-performed experiments can be much more common, and should be carefully considered. Analysis errors are present in any experiment, and must always be methodically estimated.

Using the values listed above for the Lunden study, the errors are as follows:

$$\left(\frac{\delta Q}{Q}\right)^2 = \left(\frac{\delta A}{A}\right)^2 = \left(\frac{1}{A\Delta t}\frac{\Delta C}{C}\right)^2 + N\left(.05\right)^2_{emit} + \left(.03\right)^2_{collect} + \left(.02\right)^2_{analyser} + N\frac{\delta^2 C_{rms}}{C^2} \quad (8)$$

One of the samplers used in the experiment collected time resolved gas samples, resulting in 15 measurements of the tracer gas concentration every 24 hours. The time resolved results provide a way to estimate the magnitude of the time varying concentration. We estimate the magnitude of this variation (ΔC) as the difference in the concentrations calculated at the 95% confidence limits. Using a Δt of 24 hours and the measured average air exchange rate and concentration, the magnitude of the time resolved term in Equation 8 ranged 3% to 16% depending on the experiment. The largest values tended to occur when there was no central air handling fan operating. The use of the economizer in House 2 resulted in the largest tracer gas concentration variability with time due to the large changes in air change rate induced by this system. The average value of the time varying term for all conditions with (continuous) central forced air fan operation was 4%.

Thus the error for the Lunden study becomes approximately the following:

$$\left(\frac{\delta Q}{Q}\right)^2 = \left(\frac{\delta A}{A}\right)^2 = 0.0034 + N\left(0.0001 + \frac{\delta^2 C_{rms}}{C^2}\right) \quad (9)$$

If we disregard the time varying term and assume that the space is truly a homogeneous single zone, the air exchange rate resulting from the CILTS method as deployed by Lunden et al (2012) would have an uncertainty of 6%. Assuming a value of 4% for the time varying term increases the uncertainty to 7%. This uncertainty estimate represents the minimum uncertainty in the measured air exchange rate. It is highly unlikely that the tracer gas concentration in a home would ever be homogeneous. The extent to which spatial homogeneity contributes to the uncertainty can be assessed for the Lunden data due to the relatively high spatial density of samplers deployed in their experiments.

Spatial Homogeneity Errors in the Lunden Data

House 1

House 1 in the experiments conducted by Lunden et al (2012) is a 93 m^2 (1000 ft^2) single story house with a simple, compact floor plan. Four different PFTs were deployed, each with a different spatial distribution of emitters, and in some cases, samplers. The tracer gases were over-sampled (i.e., using more locations) compared to a typical CILTS measurement to allow a better estimate of the spatial variation. The number of emitters for each PFT is specified in Table 2. Table 2 also lists the average air exchange rate for the house calculated using each PFT as well as the spatial coefficient of variance. In their report, Lunden et al. (2012) divided the space into nine zones. Some of the zones are small enough to ignore or sufficiently well coupled to be considered a single zone. As a result, we shall assume four zones in our error calculations, recognizing that this may be an under estimate. The air handler in house 1 turns over the air seven times per hour.

In the test in which the central air handler was not run the average air exchange rate from the four tracers was 0.5 ACH with a standard deviation from the different tracer approaches of 13%. The four tracer gasses all showed a spatial variation of 16%-22% with an average of 20%. Using Equation 10 to estimate the error we expect an uncertainty of 40%. This value is much larger than the 6 to 7% uncertainty due to all other sources of error and bias, showing that the heterogeneity in the measured tracer concentration dominates the overall uncertainty of the measured air exchange rate. The air change rate measured with this data has an unknown bias, but the standard deviation of 13% between the four tracer gases is well within the 40% estimate of the overall uncertainty. Thus if only that standard deviation were considered as a measurement of the error, the total uncertainty would be under-estimated.

The average air exchange rate for the experiment with constant central forced air fan operation was 0.87ACH with a standard deviation of 29%. This value is higher than with the air handler off, and may be due to the contribution of duct leakage. There is also a larger standard deviation between the four tracers. The average spatial variation, 12%, was smaller for this condition, but had a larger range of values. The larger range of spatial variation is largely due to the results from tracer 3, which had only two emitters in the house. Discounting this value, the total uncertainty we would expect in this test is 18% but because of the outlier we see almost 25%.

Lunden attributes the outlier to the fact that the concentrations analyzed were low and close to the detection threshold for the analyzer. This type of error can happen because of the difficulties of knowing the air exchange rate and therefore the required emission rate as well as the appropriate number and location of emitters and samplers before starting the experiments. This problem is particular to these passive measurements that lack the instant feedback from real time measurements.

House 2

House 2 was a 325 m^2 (3480 ft^2) ranch style home with a long narrow floor plan. This house had two central forced air systems and with them both operating the air was circulated 4.3 times per hour. The number of emitters for each PFT is specified in Table 3. The house was divided into nine zones. Unlike the more compact configuration of house 1, these zones do not combine as easily and nine may be an under-estimate. In the error calculations, we shall use nine as the physical number of zones. The average air exchange rate for the house calculated using each PFT as well as the spatial coefficient of variance is listed in Table 3.

During economizer operation, one of the central systems supplied air from outside at the airflow rate used by the central system in normal recirculation mode – in this case about 3 ACH. This is a much higher flow than natural infiltration or most mechanical ventilation. For the three experimental conditions, it appears that the results from tracer 3, which has only one emitter, has a higher spatial variability than that observed for the other three tracers. (One emitter for a house this size would not be good practice, but we wished to explore its effect.) This is similar to the results for house 1, where there was a significantly higher spatial variability for one of the experimental conditions for the tracer with only two emitters.

In Normal Operation, the average measured ACH from the 4 tracer gasses is 0.27 ACH with a standard deviation of 10%. The coefficient of variation was the same (15%) for three tracers , and almost double this at 28% for tracer 3, that only has one emitter. Using the average coefficient of variation (CV) of 18% and nine zones results in an ACH total uncertainty of 55%. Continuous fan operation reduced the CVs for tracers 1-3 but not for tracer 4, and had twice the effect for tracer 3 that had the biggest CV. This indicates that the fan operation can help a lot to reduce mixing errors, but not in all cases. The concentration variation for the home with continuous fan operation is between 12% and 22%, with an average of 15%, leading to an overall estimated uncertainty of 45%, while the measured air change is 0.42 ACH with a standard deviation of 9%. In economizer mode, the economizer operates at times when outdoor air will cool the home. This leads to times of very high air change rate when the economizer is operating and much lower air change rate at other times. The resulting concentration variation is between 10% and 25% with an average of 20%, leading to an estimated uncertainty of 60%. The measured air change rate is 0.29 ACH with a standard deviation of 7%. This apparent reduction in variability in ACH in economizer mode when we know the time varying ventilation is large is an indicator that other factors, such as weather changes and opening of windows, can have as big an influence on variability and errors as well known and characterized ventilation changes. In addition, the reduction in air change rate observed here, when we know the economizer significantly increases ventilation rates, is another indicator of the uncertainties in the PFT method – particularly the underprediction of average air change rates when air change rates are not constant.

We note again that the standard deviations of our measured values are significantly smaller than our estimated uncertainty. If all one cared about were repeatability this would indicate that our error estimate was too large, but our error estimate includes errors caused by model violations—in particular the fact that the average concentration may not be the same as the exfiltration weighted concentration - and all the tracers have these errors. An example of this from the House 2 experiments was that a couple of rooms on the windward side had slightly open windows. This resulted in a net flow of air across the house leaving the windward rooms at lower concentrations. These rooms likely had less exfiltration and the samples from these rooms should have been weighted less. Thus we might expect a positive bias in the results, i.e., the experiment overestimated the air change rate.

The increased mixing due to central forced air heating and cooling system air handler operation reduces the variability in concentrations from zone to zone. It also shows increased air exchange - probably due to leaky ducts. The improvement in homogeneity is most noticeable for the experiments that had the fewest number of emitters.

House 3

House 3 experiments were designed to evaluate the effects of different distributions of emitters. House 3 was a 237 m^2 (2540 ft^2), 3 story, open-plan house. Unlike houses 1 and 2, the tracer gas emitters were placed differently in house 3. Each floor had a unique tracer associated with it in order to better identify distribution patterns. A fourth tracer was evenly distributed. The number of emitters for each PFT and the floor location are specified in Table 4. Operation of the air handler fan introduced 3.4 ACH of internal mixing. House 3 was divided into 12 zones within the space spread over 3 floors. Because of the large stack effect in this home, there are generally much larger differences in tracer gas concentration from floor to floor than between most rooms within a single floor. Since the spatial variability is driven by vertical stratification in the house and each floor is open-plan, we shall use the three floors as the number of zones.

If we look at the case where the tracer was emitted everywhere the air exchange was 0.26 with an estimated error of 40% when the air handler was not running and 0.3 with an estimated error of 29% when the air handler was running. (Based on CVs of 23% and 17% respectively.) Since the natural ventilation air change rate was stack dominated for this house we would expect that the single tracer emitted only on the lower floor would give results similar to the tracer emitted everywhere. The air exchange for this single tracer was 0.26±47% with the air handler off and 0.32±9% with the air handler on, which confirms that this is indeed the case. By contrast if we use the data from the tracer injected only on the upper floor the result is quite different: 1.3±211% with the air handler off and 0.98±124% with the air handler on. The very large positive bias is the result of there being very little third floor tracer on the lower two floors due to the internal stack driven airflow from the lower to upper floors. These results indicate that if sampler locations are poorly chosen the errors are so large that the results are not useable. Again, we have the problem for passive methods that we do not know a priori (or even during the experiment) that these errors are occurring. The best we can do to minimize this problem it to emit and sample tracers on all floors of buildings and in more than one location per floor.

Additional experiments were performed in house 3 with interior doors closed and a kitchen exhaust on the second floor operating. With no air handler fan, this mode of operation showed the biggest special variation for each tracer with a range of CV from 68% to 196% and a mean of 114%. The estimated error increased to 118% for the tracer emitted everywhere and for the third floor tracer the error increased to over 300%. With the air handler fan operating these errors decreased only marginally to 107% and 253% respectively. This result shows that even with the air handler operating it could not overcome the compartmentalization due to closed doors combined with highly non-uniform exfiltration.

Mixing and Emitter Density

We can use the complete dataset to get some idea of whether mixing and/or density of emitters can have a significant impact on the CILTS errors. We know these errors are dominated by spatial concentration inhomogeneities and so anything that reduces those will reduce the error.

Figure 1 plots the spatial CV as a function of source emitter density. Different symbols indicate whether the air handler was on or off or ran intermittently. The size of the emitters and air handlers varied from experiment to experiment so quantitative estimates of the impacts are problematic but we can see some general trends. The clearest signal is that running an air handler reduces inhomogeneity and thus improves the accuracy of the measurement significantly. Using a central air handler may not always be possible, however, due to absence of a central unit or because operating the unit would change the desired experiment.

If one cannot mix with an air handler (or similar device) then there is a trend toward reduced inhomogeneity with increased emitter density. As discussed earlier it may be desirable to have higher emission rates in some zones than another, but for a given emission rate more physically separate emitters is generally preferred.

Applications to other experiments

In the Lunden data there were many redundant measurements, allowing for the uncertainty to be determined with a higher degree of confidence. More typical execution of the CILTS method will result in sparser data. For instance, there may be only a few emitters and perhaps only a single sampler. These experiments will require estimates of quantities like the spatial inhomogeneity, making it difficult to calculate a credible estimate for the uncertainty of the resulting air exchange rate. The uncertainty will depend strongly on the number of zones and assumed heterogeneity. For instance, using the same instrumentation and experimental error estimates as in Lunden et al. (2012), Equation 10, a 4 zone structure with a 20% homogeneity in tracer concentration results in a 40% uncertainty in the calculated air exchange rate. A home with 7 zones with an assumed 30% inhomogeneity will result in an 80% uncertainty.

The issue of whether a factor of 2 is good enough or 10% is not good enough depends on how the number is to be used. When the air exchange is used as an input to a calculation of, for example, energy or contaminant emission rate any error in the air exchange will propagate through and limit the certainty of the final answer. If the value is to be used as part of a large statistical sample, a lot more error can be tolerated than if it is being used to answer a question specific to that particular building. This would be particularly true if were an issue of compliance with some code, standard, or program.

Recommendations for CILTS Applications

CILTS can be an accurate and precise method for determining air exchange when the system being measured matches the model assumptions—in particular that the air exchange and source emission are constant and that the system is in fact a single, isolated, well-mixed zone. Such a situation may occur in the laboratory or field studies with low air exchange rates and high internal mixing (e.g., due to operating a central forced air heating or cooling system air handler).

However, CILTS is most used in homes where we know the assumptions are violated to at least some non-trivial degree. The uncertainties associated with these violations can be minimized by careful experimental design and deployment. The recommendations below will reduce the uncertainty of the CILTS result:

- *Emission Rate*: The emitters typically used by CILTS are passive emitters whose rate changes slowly over time, but more importantly is a function of temperature. The emitters should be placed in a temperature controlled environment to keep their emission rate constant during the experiment. The emitters should be calibrated for each experiment or they should be gravimetrically weighed before and after each experiment such that the total amount of emission is determined.
- *Emitter Deployment*: Emitters should be deployed in proportion to the local infiltration to improve homogeneity. Of course the infiltration is not actually known; so this becomes a judgment by the experimenter. In many instances the best strategy is to deploy them evenly around the perimeter on all floors of the building. In instances where we know the air flow patterns, such as in the winter in a stack-dominated building, we know that the infiltration will predominantly happen in the lower parts of the building; so our emitter deployment should be predominantly in the lower parts.
- *Sampler Deployment*: As with the emitters, if we have no a priori knowledge, the samplers should be deployed evenly throughout the building. However if we can predict some of the air flow patterns in advance the emitters should be placed near areas of exfiltration. For example, if there is a prevailing wind direction, the samplers should preferentially be placed away from the windward side.
- *Sampler Number*: We recommend using a sampler for every 250-300 sq.ft. (25-30 sq. m) of floor area. An advantage of using multiple samples in addition to improving special averaging is that we can use the results to improve uncertainty estimates based on the standard deviation of the sampler results
- *Mechanical Mixing*: When additional mixing (e.g. by use of air handler) can be applied it will improve homogeneity and reduce uncertainty. Care must be taken, however, to assure that the mixing does not change the system being measured. If the duct system connected to the air handler is leaky, for example, use of the air hander to provide additional mixing may increase the air exchange.
- *Experiment Duration*: To avoid issues from initial equilibrium transient effects a good practice is to deploy emitters for 24 hours before sampling begins. If this cannot be done, the integration time for CILTS must be at least 24 hours and preferably longer. The integration time, however, should not be so long that the fundamental flow paths have changed—for example going from a stack dominated to wind dominated pattern. In such a case there will be a bias to the results and the estimate of the uncertainty from the spatial concentration variance will be under estimated.

Conclusions

We have analysed the results from oversampled field experiments with multiple gases and sampler/emitter locations and combined them with an error analysis to show that the CILTS method can have an uncertainty of 6-15% under ideal conditions. Ideal conditions include quality calibration of experimental equipment, correct placement of samplers and emitters relative to air flow patterns in the building, and a constant ventilation rate. All these things are generally impossible to achieve in a typical field experiment and real laboratory analyses; thus we should not expect to get close to ideal results.

Deviations from ideal conditions include several issues related to effective sampling. Overall the most important factor about the system is the degree of mixing (i.e. how closely it is a single, well-mixed zone). It is not sufficient to measure the average concentration correctly as spatial inhomogeneities themselves introduce additional uncertainties. The experimental data suggests that even with optimum emitter and sampler placement, CILTS uncertainties of 20-25% should be expected when no special provisions are made for mixing. The amount of (intermittent or continuous) mixing needed depends on the air exchange and also the air flow patterns, but most household central heating and cooling systems operating to provide roughly 5 ACH of internal mixing should be adequate for most experiments. Of course adding mixing can create its own biases, by changing the system being measured.

When the infiltrating and exfiltrating flows are not evenly distributed around the parts of the building errors increase. The induced errors can, in principle, be mitigated by careful placement of the samplers (near exfiltrating areas) and the emitters (near infiltrating areas). This requires that those patterns persist through the experiment and that the experimenter knows what the pattern is.

Variations in the air exchange during the experiment will result in a negative bias on the inferred average air change rate independent of the issues of mixing and the need to change the optimal deployment. CILTS measures the effective air exchange not the average air exchange. The effective air exchange is the value relevant for dilution and most IAQ purposes, but not for energy purposes.

In general CILTS is not a very good method for estimating air exchange when there are large intermittent air exchanges going on (e.g., through open windows). In most circumstances it will be practically impossible to deploy samplers and emitters to accommodate this situation and it is unlikely that sufficient mechanical mixing can be supplied to minimize its impact. CILTS is best deployed over a period of time where the weather conditions are stable such that the air exchange is reasonably constant.

The typical use of CILTS is in high-volume or low cost situations where it is deployed by technicians (or even occupants) who are not highly trained in its application. Very often no prior estimate of the air exchange (rate or pattern) has been made. Under these more typical (and less certain) conditions, one might consider CILTS to provide results in the range of a “factor of 2” of the right answer.

References

ASTM, E741-00 (2000) Standard test method for determining air change in a single zone by means of a tracer gas dilution, American Society for Testing Materials, West Conshocken, PA.

Bassett, M.R., Shaw. C-Y, and Evans. R.G. (1981) An appraisal of the sulfur hexafluoride decay techniques for measuring air infiltration rates in buildings, ASHRAE Trans. 87, 361-373.

Clayton, C. A., Perritt, R. L., Pellizzari, E. D., Thomas, K. W., Whitmore, R. W., Wallace, L. A., Ozkaynak, H., and Spengler, J. D. (1993) Particle Total Exposure Assessment Methodology (PTEAM) study: distributions of aerosol and elemental concentrations in personal, indoor, and outdoor air samples in a southern California community. J. Exposure Analysis Environ. Epidemiol., 3, 227-250.

Condon, P.E., Grimsrud, D.T., Sherman, M.H., and Kamerud, R.C. (1981) An automated controlled-flow air infiltration measurement system, in Building air Change Rate and Infiltrations Measurements, C.M Hunt, J.C. King, and H.R. Treschel, eds., pp. 60-72. ASTM STP 710, American Society for Testing Materials, Philadelphia, PA.

Dietz, R.N. and Cote, E.A. (1982) Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique. Environment International, 8, 419-433.

D'Ottavio, T.W., Senum, G.I., and Dietz, R.N. (1988). Error analysis techniques for perfluorocarbon tracer derived multizone ventilation rates. Building and Environment, 23(3), 187-194.

Fisk, W.J., Faulkner, D., and Hodgson, A.T. (1993) "The Pollutant Control Index: A New Method of Characterizing Ventilation in Commercial Buildings." *Proceedings of Indoor Air'93: The 6th International Conference on Indoor Air Quality and Climate*, vol. 5, pp. 9-14, July 4 - 8, 1993, Helsinki, Finland. Published by Indoor Air'93, Helsinki. LBL-33685.

Grot, R.A. (1980) A low-cost method for measuring air infiltration rate in a large sampler of dwellings, in Building Air Change Rate and Infiltration Measurements, C.M. Hunt, J.C. King and H.R. Treschel, eds., pp. 50-59, ASTP STP 719, American Society for Testing and Materials, Philadelphia, PA.

Harrje, D. and Grot, R. (1977). Automated air filtration measurement and implications for energy conservation, in *Proceedings of the International Conference on Energy Use Management*, Vol. 1, R.A. Fazzalare and C.B. Smith, eds., pp. 457-464, Pergamon Press, New York.

Klepeis, N.E., Nelson, W.C. et al, (2001) J. Exposure Anal. Environ. Epidemil. 11, 231-252.

Leaderer, B.P., Schaap, L., and Dietz, R.N. (1985) Evaluation of the perfluorocarbon tracer technique for determining infiltration rates in residences. Environ. Sci. Tech., 19, 1225-1232.

Lunden, M., Faulkner, D., Heredia, E., Cohn, S., Dickerhoff, D.J., Noris, F., Logue, J., Toshifumi, H. Singer, B. and Sherman, M. 2012. *Experiments to Evaluate and Implement Passive Tracer Gas Methods to Measure ventilation Rates in Homes.*

Offermann, F. J. (2009) *Ventilation and Indoor Air Quality in New Homes*. California Air Resources Board and California Energy Commission, PIER Energy-Related Environmental Research Program. Collaborative Report. CEC-500-2009-085.

Ozkaynak, H., Xue, J., Spengler, J., Wallace, L., Pellizzari, E., and Jenkins, P. (1996) Personal Exposure to Airborne Particles and Metals: Results from the Particle Team Study in Riverside, California. Journal of Exposure Analysis and Environmental Epidemiology, 6 (1), pp. 57-77.

Sherman, M.H., "Analysis of Errors Associated with Passive Ventilation Measurement Techniques," Building and Environment 24 (No. 2): 131-139, 1989a. LBL-23088.

Sherman, M.H. , "Uncertainty in Air Flow Calculations Using Tracer Gas Measurements", Building and Environment, 24(4), pp. 347-354, 1989b. LBL-25415

Sherman, M.H., "On Estimation of Multizone Ventilation Rates from Tracer Gas Measurements," Building and Environment 24 355-362, 1989c. LBL-25772.

Sherman, M.H., "Tracer Gas Techniques for Measuring Ventilation in a Single Zone," Building and Environment 25 (No. 4): 365-374, 1990. LBL-29328.

Weisel, C.P., Zhang, J., Turpin, B.J., Morandi, M.T., Colome, S., Stock, S.H., Specktor, D.M and others. (2005) Relationships of Indoor, Outdoor, and Personal Air (RIOPA): Part 1. Collection Methods and Descriptive Analyses. HEI Research Report 130, NUATRC Research Report 7, Health Effects Institute, Boston, MA.

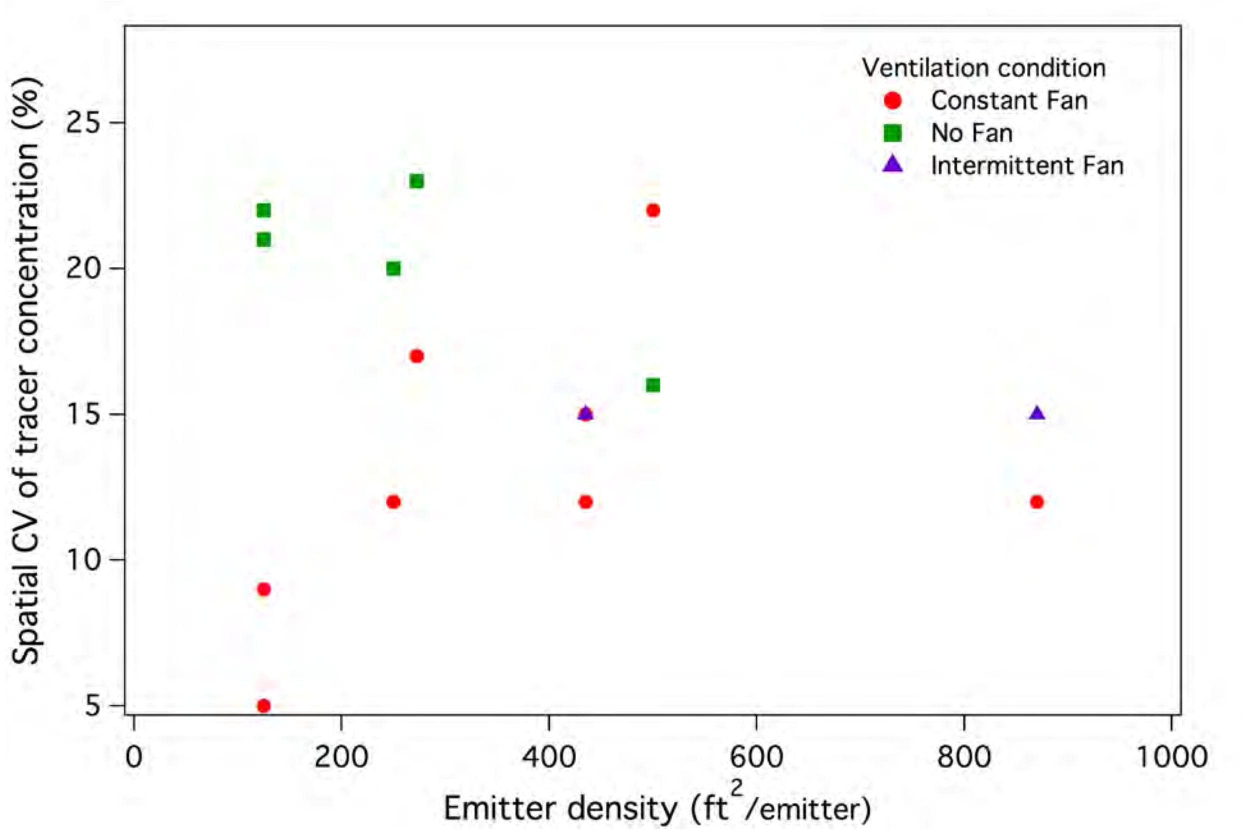

Figure 1: The variability of tracer concentration (CV, %) as a function of emitter density for the three houses. The markers indicate different ventilation conditions: constant fan use (circles), no fan use (squares), and intermittent fan use (triangles).

Table 1: Experimental Ventilation conditions performed at the three houses.

	Experiment	Ventilation Condition
House 1	1	No forced air system operation
	2	Constant forced air system fan
House 2	1	Normal operation of air conditioner
	2	Air conditioner use with constant fan operation
	3	Normal operation of air conditioner with economizer
House 3	1	No forced air system operation
	2	No forced air system operation but with constant kitchen exhaust fan. Internal doors closed.
	3	Constant forced air system fan and kitchen exhaust fan use. Internal doors closed.
	4	Constant forced air system fan

Table 2: Results from House 1, including the number of emitters for each tracer and the air exchange rate, spatial coefficient of variation in the PFT concentration, and the error in the ACH calculation due to this spatial concentration.

		No Fan			Continuous Fan		
	# of emitters	ACH (hr-1)	Spatial CV (%)	Error (%)	ACH (hr-1)	Spatial CV (%)	Error (%)
Tracer 1	4	0.48	20	41	0.81	12	25
Tracer 2	8	0.47	21	42	0.76	5	12
Tracer 3	2	0.60	16	33	1.23	22	44
Tracer 4	8	0.43	22	44	0.62	9	19
Average		0.5 ± 13%	20 ± 2	40	0.87 ± 29%	12 ± 6	25

Table 3: Results from House 2, including the number of emitters for each tracer and the air exchange rate, spatial coefficient of variation in the PFT concentration, and the error in the ACH calculation due to this spatial concentration.

		Normal Operation			Continuous Fan			With Economizer		
	# emit	ACH (hr-1)	CV (%)	Error (%)	ACH (hr-1)	CV (%)	Error (%)	ACH (hr-1)	CV (%)	Error (%)
Tracer 1	8	0.29	15	46	0.46	12	37	0.301	21	63
Tracer 2	4	0.27	15	46	0.39	12	37	0.282	10	31
Tracer 3	1	0.31	28	84	0.45	22	66	0.305	24	72
Tracer 4	8	0.24	15	46	0.37	15	45	0.253	25	75
Ave		0.27± 10%	18± 5	55	0.42± 9%	15± 4	46	0.29± 7%	20± 6	60

Table 4: Results from House 3, including the number of emitters for each tracer and the air exchange rate, spatial coefficient of variation in the PFT concentration, and the error in the ACH calculation due to this spatial concentration.

			No Fan			No Fan w Exhaust			Cont Fan w Exhaust			Continuous Fan		
	# emit	Floor	ACH (hr-1)	CV (%)	Error (%)	ACH (hr-1)	CV (%)	Error (%)	ACH (hr-1)	CV (%)	Error (%)	ACH (hr-1)	CV (%)	Error (%)
Tracer 1	3	1	0.41	54	93	1.01	81	142	0.59	19	33	0.32	10	17
Tracer 2	3	2	0.26	27	47	0.63	111	192	0.47	29	50	0.32	5	9
Tracer 3	3	3	1.30	122	211	0.54	196	339	0.62	146	253	0.98	72	125
Tracer 4	9	All	0.26	23	41	0.26	68	118	0.35	62	107	0.30	17	29
Ave			0.56± 78%	57± 40	98	0.52± 59%	114± 50	197	0.51± 21%	64± 50	111	0.48± 60%	26± 26	45

APPENDIX:

Multizone Bias in Single Tracer

In the main body of this paper (e.g. eqs. 1-3) we develop the equations for determining the air exchange from steady-state tracer gas measurements assuming a single, well-mixed zone. We know from field measurements (e.g. Lunden 2012) that a real building is virtually never a single, well-mixed zone.   Using those equations would then cause a systematic error (i.e. bias or modeling error) that may not be apparent from a simple error analysis. This appendix derives the bias due to this assumption.

Although we know the whole building is not really a single, well-mixed zone, we can assume that it can be broken down into a set of N well-mixed zones that communicate with each (and outside). Sherman(1989c and 1989b) develops the general case and we use that nomenclature unless otherwise specified.

With N independent tracer gases, it is possible to simultaneously determine the N^2 independent flows and their uncertainties, but the CILTS case is more limited. We are considering only a single tracer gas and we only wish to find to total air exchange with the outside. Without a priori knowledge of zonal flows this can only be done in steady state using a constant-concentration technique (i.e. where the concentration in each zone is made to be the same by adjusting the emission rate of tracer gas in each zone accordingly). In such a case we can find the desired air exchange as follows:

$$Q_o = S_o / C_o \qquad \text{(A.1)}$$

where C_o is the concentration everywhere and the other "o" subscripts represent single-zone totals. In equation A.2 S_i is the injection rate in zone i necessary to produce that concentration and S_o is the total injection rate:

$$S_o = \sum_i S_i \qquad \text{(A.2)}$$

Equation A.1 is just a restatement of the single zone equation (Eq. 1), but the assumptions that it is derived under will allow us to better estimate biases. (Note that the subscript "o" is used here to designate whole-building values, but is dropped in the main body of the paper.) The constant concentration assumption would in fact allow us to determine the *in*filtration of outside air into each zone

$$I_i = S_i / C_o \qquad \text{(A.3)}$$

where I_i is the infiltration rate in each zone necessary to produce that concentration the sum of these infiltration flows is the total value we seek. The sum of the infiltration (or exfiltration) rate in all zones is the total:

$$Q_o = \sum_i I_i = \sum_i E_i \tag{A.4}$$

where E_i is the exfiltration of air to outside from zone i

In the actual CILTS experiment though, this is not particularly useful because we are not controlling the injection rate in every zone to rigorously maintain a constant concentration. These expressions are, however, useful because the provide guidance on how best to deploy the emitters to get close to constant concentration. That is, one should deploy the CILTS emitters proportional to any a-priori knowledge one has about the infiltration rate into that zone.

Because we are not rigorously controlling the concentration at a single level, we need to know how to measure "the" concentration (i.e. is the representative concentration, C_o, the physical averaged concentration) used in our analysis. The multizone continuity equation provides the answer (again from Sherman 1989c) that the right concentration to use in the simple equation is the exfiltration-weighted average concentration:

$$C_o = \sum_i (E_i / Q_o) C_i \tag{A.5}$$

Conceptually, again, this is a useful expression because it indicates we should deploy samplers proportion to the local *ex*filtration, but since we don't know that values quantitatively, we cannot use this expression directly. If we posit as a practical matter that the exfiltration is proportional to the volume of the space represented by the concentration we can use a common operational definition of "the" concentration by using volume weighting:

$$C_o \approx \sum_i (V_i / V_o) C_i \tag{A.6}$$

Regardless of how reasonable a choice is made there will be bias in our definition of C_o, since we don't know the exfiltration a priori. This bias comes from the nature of the experiment itself and not the measurement errors from sources such as instrumentation discussed in the main body. It is, therefore, present in every zonal measurement and the best we can do is include it in our uncertainty estimate.

To see what effect these multizone considerations will have on the determination of air exchange we care about, we can use Equation 21 from Sherman (1989c) to estimate the uncertainty for a multizone, constant-concentration measurement:

$$\delta^2 Q_{multizone} = \left(\frac{N}{C_o}\right)^2 \sum_i \left(\delta^2 S_i + V_i^2 \delta^2 \dot{C}_i + E_i^2 \delta^2 C_i\right) \tag{A.7}$$

The first of the three terms in parenthesis reflects uncertainties in the measured source emission in each zone. In a true, constant-concentration experiment these might be quite complicated, but for CILTS we assume this is a fixed value and we can express the error term in terms of the error of the total emission rate:

$$\sum_i \left(\delta^2 S_i \right) = \frac{\delta^2 S_o}{N} \tag{A.8}$$

This is a reasonable assumption, but is surely never correct. The error could be either higher or lower, but we can use this expression to make a reasonable estimate.

In a true constant-concentration experiment, the last two of the three terms should be insignificant because the concentration in every zone should be being held constant. In a CILTS experiment the middle term should still be insignificant because the period of the experiment is long enough to minimize it. We shall ignore it moving forward, but care should be taken not to make a CILTS experiment so short (e.g. less than a day in most typical houses) that that term becomes significant.

We must investigate the last term because the concentration in any one zone is neither constant nor necessarily centered on C_o. We do not know the exfiltration distribution, but if we assume it is not correlated to the concentration variations we can bound the size of the last term by looking at the cases where the exfiltration is concentrated:

$$0 < \sum_i \left(E_i^2 \delta^2 C_i \right) < Q_o^2 \delta^2 C_{i,\max} \tag{A.9}$$

A reasonable intermediate to choose is when the exfiltration is evenly distributed (by volume) in all zones using the same weighting as we did for the concentration:

$$\sum_i \left(E_i^2 \delta^2 C_i \right) \approx Q_o^2 \frac{\sum_i \left(V_i^2 \delta^2 C_i \right)}{V_o^2 N^2} = \frac{Q_o^2 \delta^2 C_{rms}}{N} \tag{A.10}$$

Where δC_{rms} is the volume-weighted, root-mean square deviation of the measured concentrations around C_o.

Putting this all together we can get an estimate for the uncertainty of our result due to the fact that the experimental configuration is truly multizone.

$$\frac{\delta^2 Q_{multizone}}{Q_o^2} = N \frac{\delta^2 S_o}{S_o^2} + N \frac{\delta^2 C_{rms}}{C_o^2} \tag{A.11}$$

This uncertainty increases roughly with the square root of the number of zones in the building. This is the number of actual well-mixed zones in the building; it may or may not be related to the number of samplers or emitters used and thus needs to be estimated independently.

The root-mean-squared concentration deviation also refers to the actual number of zones, but in this case multiple samplers deployed around the building may give a reasonable estimate of its value. Operationally, these definitions are the ones we use in the body of the paper.

PREN16211 DRAFT STANDARD – MEASUREMENT OF AIR FLOW RATES ON SITE, 2014

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ABSTRACT

The preliminary Standard prEN16211 deals with methods, including method uncertainties for measuring air flow rates on site. It has its background in the Nordic countries, where these guidelines have been used for decades. PrEN16211 include an alternative method for flow measurement in a duct compared to EN 12599. An average flow can be obtained from just a few measurement points when a straight duct is used and some simple flow conditions are met.

KEYWORDS

Air flow measurement method, k-factor, ventilation

1 INTRODUCTION

In the Nordic countries, Denmark, Finland, Norway and Sweden there has been a long tradition and need to install, balance and test ventilation systems in buildings. Due to climate, energy tight houses has been built and there has developed a tradition of controlled air exchange. A Nordic guide of how to measure was developed by today retired professor Anders Svensson. This work is widely used in revised editions of guidelines ”Methods of measuring air flow in ventilation installations”, in swedish ”Metoder för mätning av luftflöden i ventilationsinstallationer” His work has is now transferred into a proposed European standard. PrEN16211.

2 MEASURING METHODS IN PREN 16211 AND EN12599:2012

PrEN 16211 “Measuring of air flows on site – methods”, including 41 pages, covers air flow rates measuring methods and their uncertainties.
EN 12599 “Test procedures and measurement methods to hand over air conditioning and ventilation systems.” including 85 pages covers what to check, the extent of check and measurements, what to measure, (Electric current, air flow, air temperature, filter pressure drop, ductwork leakage, humidity, sound, air velocity) and special agreed measurements, uncertainty and test reports.
Below follows the different measuring methods in the two standards.

2.1 Method: Air flow in duct cross section

Figure 1

prEN 16211 requires 4 to 8 measurement points are selected according to a table. It requires also that the velocity in any point is less than 1,4 times the velocity in the center, that no back flow occure and that the cross-section is in a straight duct at least 5...6D_h downstream from a disturbance, such as a bend. The unceratainty of this measurement is : 10% (instrument=5%, method 8%) with 95% confidens level. The method stipulates that the flow is multiplied with 0,89 for diameters lower and equal to 160mm. The calculated air flow is density compensated.

EN 12999 divides the the cross-section equal area annular rings. An uncertainty calculations is made depending of number of measurement points and distance from disturbance. For circular ducts a multiple of four points is choosen. For a measurement uncertainty of 10%, nine points (but will be 12 points – since a multiple of four points is used) are required for a disturbance minimum 6D_h upstream. In section 2.4.2 there are rules regarding minimum air velocity in relation to the diameter of the Pitot static tubes. There is also a formula for reducing the flow depending of the area of the probe in the air stream. For a 9mm probe in a duct with diameter 100 mm the reduction factor is 94%.

The difference between prEN 16211 and EN12599 could lead to difference result and could be investigated by using other measurement methods, such as pressure drop over orifice plates in laboratory conditions. For circular ducts, the reduction factors for prEN 16211 has been recommended by "Slutrapport, Nordtest Prosj. 1463-99 from Norges Byggforskningsinstitut Rev 2001.05.23."

2.2 Other Methods in booth EN 12599 and prEN16211

Pressure drop method. The air flow is calculated from a pressure drop over a valve or throttle device. The k-factor is supplied by the supplier of the valve and is multiplied by the square root of the measured differential pressure. Instead of square root another exponent could be used.

Figure 2

The bag method uses a bag with a calibrated volume. The flow is the Volume of the bag diveded by the time it takes to fill it. Two persons are normally needed. The picture does not

show the stop watch and a differential pressure meter.

Figure 3

Flow funnel methods. Large uncertainties can occur due to pressure drop and leakage. There are compensations methods for the pressure drop. Two point measurement with calculation of the unrestricted flow and the zero-pressure drop measurement with an built-in fan in the flow funnel. By measuring the pressure drop over the funnel there is a formula in prEN 16211 to use for compensation.

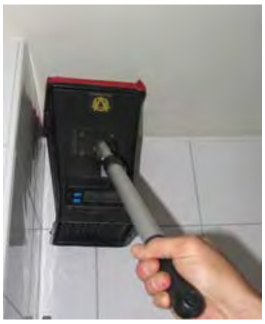

Figure 4

The tracer gas method inserts tracer gas in the air flow and calculates the flow. Important is that a good mixing take place.

Figure 5

The effective area method is only in EN 12599. The air velocity is measured at the air terminal, which works like a nozzle. The air velocity is multiplied with an effective area given by the manufacturor of the air terminal.

2.3 Uncertainty of measurement

Booth standards stipulates the measurement uncertainty to be stated with a probability coverage of approximately 95%. prEN 16211 calls this the expanded measurement uncertainty, being twice the standard measurement uncertainty. prEN 16211 divides the standrad measurement uncertainty into standard instrument uncertainty, standard method uncertainty and standard reading uncertainty.

2.4 Density compensation

PrEN 16211 stipulates that real or standard air flow rate should can be choosen. A formula how to convert between them is presented. EN 12599 stipulates that for fan measurements air flow should be presented with an air density of 1,2 kg/m3.

3 CONCLUSIONS

Air flow measurement on site are widely used according to prEN 16211 and EN 12599.
prEN 16211 methods and uncertainty calculations are used in the Nordic countries including the duct flow measurement. prEN16211 is only dealing with measurements of air flow rates on site, which makes it easy to follow and use and also to edit if future needs arise. By approving prEN 16211 as an European standard, the daily work of measurement technicians will be standardised.

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5 REFERENCES

EN 12599:2012 Ventilation for buildings – Test procedures and measurement methods to hand over air conditioning and ventilation systems

prEN 16211 Ventilation for buildings – Measurement of air flows on site - methods

Johansson, Svensson (2007). *Report T9:2007, Metoder för mätning av luftflöden I ventilationsinstallationer (Methods for measuring air flow in ventilation installations), ISBN 978-91-540-6001-6, earlier report T22:1998, ISBN 91-540-5827-9 and T32:1982.* Stockholm: the Nordic Ventilation Group, published by the Building Research Council

Hestad, Trygve (2001). *Slutrapport, Nordtest Prosj. 1463-99. Rev 2001.05.23* Oslo: Norges Byggforskningsinstitut.

MEASUREMENT OF AIR FLOW RATES IN DUCTS BY VELOCITY MEASUREMENTS: AN OVERVIEW

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ABSTRACT

To measure a flow in a closed duct, one of the available methods is to explore the velocity field. The duct is divided in elementary sections in which the velocity is measured. Using these elementary results, a mean velocity is calculated. Knowing the exact section of the duct, the mean flow rate can then be deduced. With this method, the quality of the flow measurement is there very dependent on the number of individual velocity measurements and on the scheme of distribution of these measurements in the duct section.
Recommendation about velocity schemes are proposed in international standards (ISO 3966, ISO 7145, EN 12599, …) for circular and/or rectangular ducts. These recommendations assume that turbulent flow profile is established. This requires a flow profiler and/or long straight lengths upstream and downstream the measurement section. On site, these recommendations are difficult to apply strictly because conditions of straight lengths are often not available. Moreover, the velocity measurement schemes proposed in standards are time consuming and users prefer sometimes to simplify them. In this case, the estimation of the measurement error is not known.
The different investigation methods are presented in this overview. Additionally, based on the study performed by Caré *et al*, Bonthoux *et al*, the measurement error due to simplified velocity schemes and/or reduces straight lengths is presented.

KEYWORDS

air flow rate, duct, air speed, measurement error

REFERENCES

ISO 3966: (2008). *Measurement of fluid flow in closed conduits. velocity area method for regular flows using Pitot static tubes*

NF X 10-113: (1982). *Détermination du débit des fluides dans les conduites fermées de section circulaire - Méthode par mesure de la vitesse en un seul point*

NF EN 12599: (2000). *Ventilation des bâtiments. Procédures d'essai et méthodes de mesure pour la réception des installations de ventilation et de climatisation installées*

Pr EN 16211, (to be published). *Ventilation for buildings - Measurement of air flows on site – methods*

F. Bonthoux, J.R. Fontaine, (2012). *Mesure des débits d'air en conduit – incertitude liée au nombre et à la position des points de mesure,* Hygiène et Sécurité au travail – 2e trimestre 2012 – 227, 53-57. France.

I. Caré F. Bonthoux, J.-R. Fontaine, (2013). *Measurement of air flow in duct by velocity measurements*, Congrès international de Métrologie, Paris, October 2013

COMPARATIVE ANALYSIS OF METHODS FOR MEASURING THE AIR VELOCITY AND FLOW IN MECHANICAL VENTILATION SYSTEMS – QUALITY OF METHODS FOR MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS, 2014

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ABSTRACT

The purpose of ventilation system is to provide and remove the airflow from room in accordance with its design. Unfortunately, in practice, this basic task is very often not fulfilled, which is frequently caused by negative handling by the users of the building. The most common reason for improper operation of the mechanical ventilation system is its insufficient output in particular sections of the system. There may be a number of reasons for that: wrong calculation at the stage of designing, disregarding or bad choice of working parameters of devices used in the system or significant changes at the stage of execution works.

In case when the network is already malfunctioning or only being activated, the need to carry out measurements of output appears at a certain point. A significant parameter that should be assessed is the velocity and the amount of the air flow. Generally, such parameters are measured directly in ducts or near the air supply terminals (ATDs) or air exhaust grills. The aim of this paper is to compare available methods for measuring the size of the airflow supply in regard to the accuracy of the measurement and the analysis of the measurement results.

For the purpose of conducting the necessary measurement in the Laboratory of Air Conditioning and Ventilation of the Faculty of Environmental Engineering at the Lublin University of Technology a specially designed measurement stand was created. It is equipped with air handling unit, the network of ducts distributing the air to the ATDs as well as the measurement elements assembled directly on the ventilation ducts.

The measurements were conducted by the four air supply grills. Traditional instrumentations such as, thermo-anemometers, pitot-tubes were compare with blades, IRIS damper, and ?? air flow cones. On the basis of the results, the most appropriate measurement methods for different types of air inlet vents or different size of airflow supply were defined.

KEYWORDS

HVAC system, measurement methods for ventilation,

1 INTRODUCTION

A ventilation system is essential for the thermal comfort and good health of occupants in a living space. Without proper airflow the system and operation are compromised resulting in unsatisfactory equipment operation, customer dissatisfaction and utility waste. The airflow must first be set according to the equipment design not to the air delivered at the registers. While the design of the duct system is imperative for proper air distribution to the conditioned space, air measurements are only to be measured at the appliance for the equipment commissioning procedure.

According to Standard EN 12599 (2012), the air flow rate can be evaluated by different methods. It is usually calculated according to the air velocity and the corresponding cross section. The air velocity can be measured with the use of by means of an appropriate anemometer, Pitot Static Tube (Prandtl tube) or a pressure drop across a throttling devices. The measurement can be carried out:

- in the duct cross-section or,
- with calibrated throttle devices or,
- in the cross-section of a chamber, fan-casing or device or,
- at the air terminal devices.

If an appropriate measuring section is available, then the measurements shall be performed within the duct. If not, then cross-sections within the central unit or appliance can be used in order to determine the mean air velocity. This measurement may be used when a uniform flow and a clearly corresponding cross-section are given. Direct measurements at air terminal devices are only possible in the case of quite simple constructions (e.g. a nozzle with a known cross section). An additional measuring device is usually necessary.

The Standard EN 12599 (2012) does not define tolerances for design values itself. The results is accepted when the designed value is within the range of the uncertainty of the measurement. The permissible uncertainties of the measured values are given in Table 1.

Table 1: Permissible uncertainty of the measurement (EN 12599:2012)

Parameter	Uncertainty
Air flow rate, each individual room	± 15 %
Air flow rate, each system	± 10%
Supply air temperature	± 2 ^{o}C
Relative humidity [RH]	± 15 % RH
Air velocity in occupied zone	± 0.05 m/s
Air temperature in occupied zone	± 1.5 ^{o}C
A-weighted sound pressure level in the room	± 3 dB(A)

This paper presents a comparison of available methods for measuring the size of the airflow supply in regard to the accuracy of the measurement and the analysis of the measurement results.

2 METHODS

2.1 Experimental setup

The experiments were performed in the Laboratory of Air Conditioning and Ventilation of the Faculty of Environmental Engineering at the Lublin University of Technology. Figure 1 shows the layout of specially designed measurement stand which is equipped with air handling unit, the network od ducts, air terminal devices as well as the air flow meters. Table 2 presents the bills of materials used in the experiment setup.

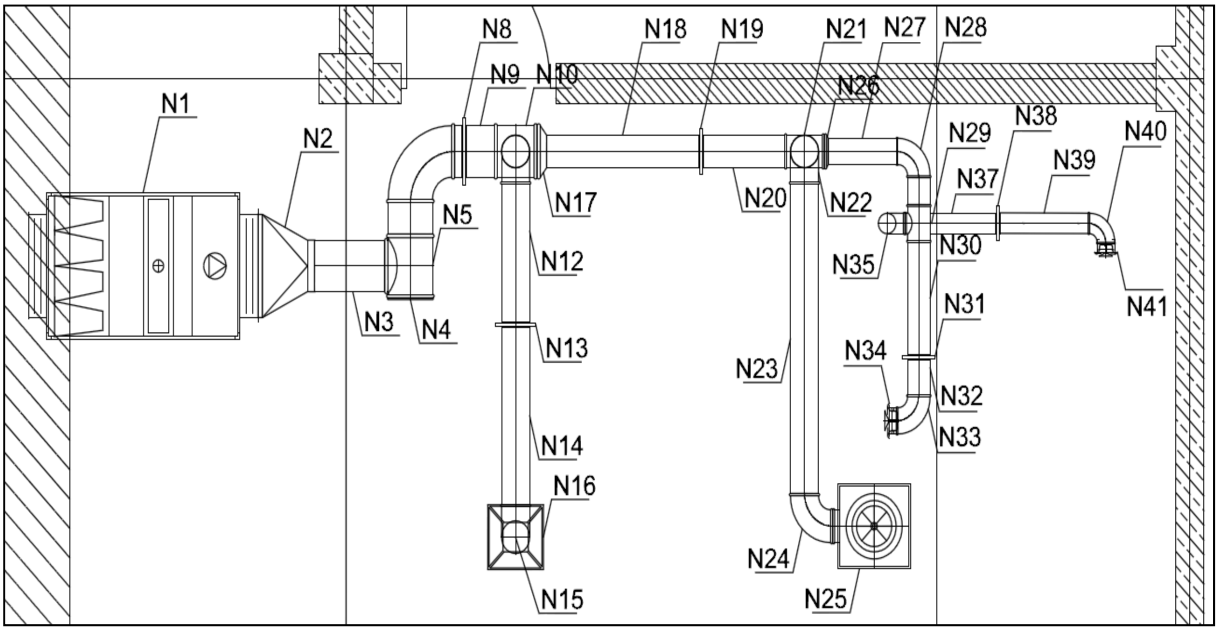


Figure 1. Scheme of experimental setup

Table 2. Bill of materials

No	Label	Description	No	Label	Description
1	N1	Air handling unit – only supply DEIMOS 0/N-5A/1-1/P made by DOSPEL	22	N22	Elbow 90^o DN200
2	N2	Transition rectangular/round 630x315/DN315	23	N23	Spiro duct DN200, L=1890 mm
3	N3	Spiro duct Ø315, L=500 mm	24	N24	Elbow 90^o DN200
4	N4	Tee DN315/DN315/DN315	25	N25	Air terminal device Konika-A-250 with plenum box PER-200-250
5	N5	End cap DN315	26	N26	Reduction DN200/DN160
6	N6	Spiro duct DN315, L=190 mm	27	N27	Spiro duct DN160, L=480 mm
7	N7	Elbow 90^o DN315	28	N28	Elbow 90^o DN160
8	N8	IRIS damper DN315	29	N29	Tee DN160/DN125/DN160
9	N9	Spiro duct DN315, L=200 mm	30	N30	Spiro duct DN160, L=700 mm
10	N10	Tee DN315/DN200/DN315	31	N31	IRIS duct DN160
11	N11	Elbow 90^o DN200	32	N32	Spiro duct DN160, L=300 mm
12	N12	Spiro duct DN200, L=850 mm	33	N33	Elbow 90^o DN160
13	N13	Air flow meter FMU 200-160	34	N34	Supply air valve KN-160
14	N14	Spiro duct DN200, L=1080 mm	35	N35	Elbow 90^o DN125
15	N15	Elbow 90^o DN200	36	N36	Elbow 90^o DN125
16	N16	Perforated diffuser TSO-200	37	N37	Spiro duct DN125, L=660 mm
17	N17	Reduction DN315/DN200	38	N38	IRIS damper DN125
18	N18	Spiro duct DN200, L=1080 mm	39	N39	Spiro DN125, L=630 mm
19	N19	IRIS damper DN200	40	N40	Elbow 90^o Ø125
20	N20	Spiro DN200, L=580 mm	41	N41	Exhaust air valve KN-125
21	N21	Tee DN200/DN200/DN200			

2.2 Measurements methods

Several measurement methods were investigated. These can be broadly divided into three groups of direct air measurement, direct air measurement with an attachment on the air intake and indirect air measurement.

Direct air measurement methods

Method 1

Pitot static tube (Prandtl Tube) or anemometer traverse in the supply duct. The number and location of the test points are specified in Standard EN 12599:2012 Annex D. The distance between the measuring section and an upstream disturbance of the duct at the measurement plane were established on the basis of 6 points as a number of measuring points for the 15% uncertainties , including an error of 5% of the measuring devices (see Figure 2). The distance was equal 0.625 m for diameter DN 125 (N41 – see Figure 1), 0.8 m for diameter DN 160 (N34 – see Figure 1) and 1.0 m for diameter DN 200 (N25 and N15 – see Figure 1). The measurement points are presented in Table 3.

Table 3. The distance from walls for different diameter

Diameter	**Number of points i**					
	1	**2**	**3**	**4**	**5**	**6**
	Distance from the duct wall y_i (mm)					
DN 125	5.5	18.3	37.0	88.0	106.7	119.5
DN 160	7.0	23.4	47.3	112.7	136.6	153.0
DN 200	8.7	29.3	59.2	140.8	170.7	191.3

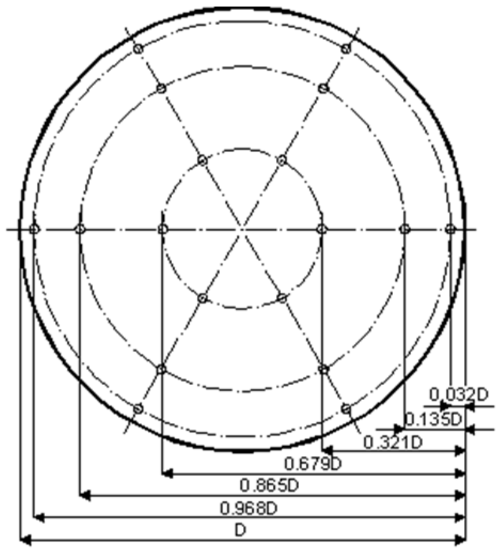


Figure 2. Position of measurement points for the circular duct cross-section

The speed for air temperature 20 °C was calculated according to the following equation:

$$V = A \cdot 1.291 \cdot \sqrt{(p_d)},\ \text{m/s} \quad (1)$$

where:

p_d – value of the dynamic pressure, Pa,
A – cross section area, m^2.

Method 2

Measurement using the effective area A_k was based on Standard EN 12238 (2001). The flow rate was calculated according to face velocity and louvre free area or a factor. Area factor or equivalent area A_k vane anemometer with a large head is recommended to integrate a large area including both louvre structure and open areas. The air flow rate q_v for a given ATD can be calculated on the basis of equation 2.

$$q_v = v_k \cdot A_k \quad (2)$$

where:
A_k – effective area of air terminal devices (see table 4), (m^2);
v_k – average air velocity (m/s).

The air velocity is measured in n values v_{ki} (i from 1 to n) in accordance with the methodology given by the manufacture. Mean value of air velocity in set number of points can be calculated on the basis of equation 3.

$$V_k = (\Sigma\, v_{ki}) / n \quad (3)$$

The uncertainty for the parameter A_k should be less than ± 5 % and for the parameter v_{ki} should be less than ± 10%.

Table 4. Effective area of air terminal devices

Air terminal devices	**N41**	**N34**	**N25**	**N15**
Effective area of ATD A_k (m^2)	0.00628	0.008038	0.055223	0.066248

Method 3

Measurement at the air terminal devices is presented in Figure 3. As measuring element used plenum box PER-250-200 equipped with special measurement points. The difference in pressure was measured by a pressure calibrator KAL 84. Supply air flow amount calculated according to the formula (1). The coefficient k for the plenum for supply is 27.7. This method was only used in N25 air terminal device.

Figure 3. Plenum box PER-250-200 with air flow measurement pipes
(www.systemair.com, 10.02.2014)

Method 4

Pressure measurement was performed with the pressure calibrator KAL 84. The measurement was performed on a special measuring element FMU 200-160 (N13). Supply air volume was calculated according to the formula (1). The value of the correction factor k for FMU 200-160 orifice is equal to 29.4.

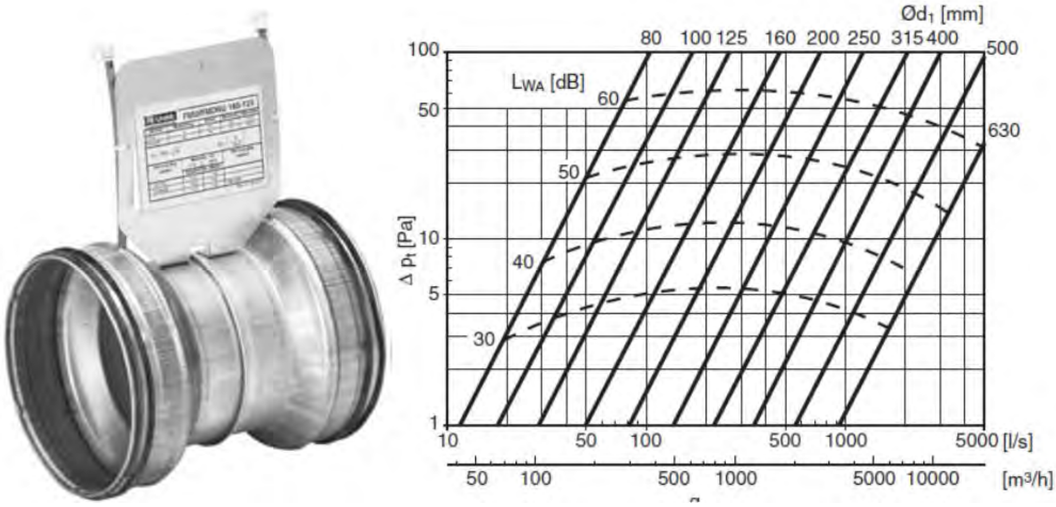
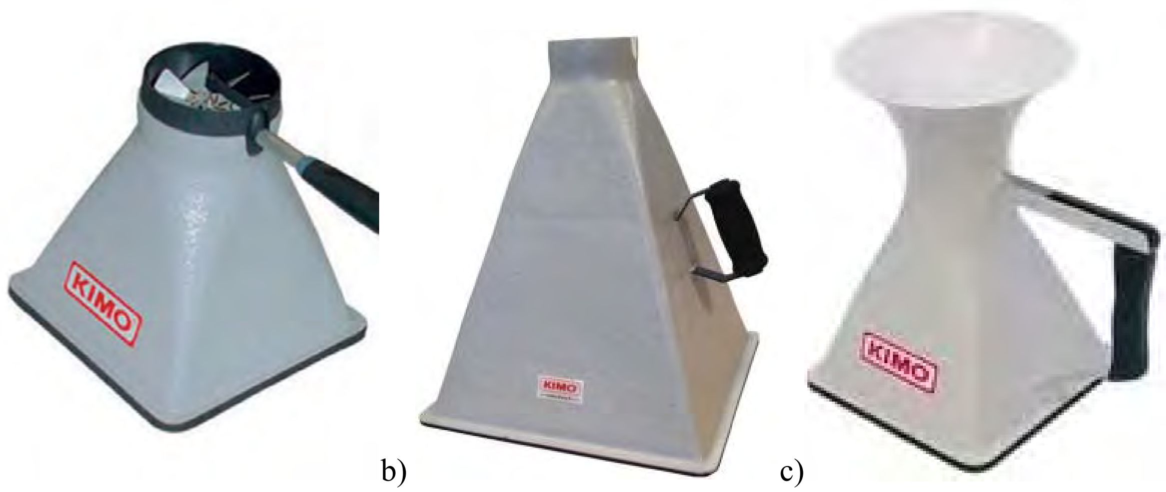


Figure 4.. Flow meter FMU (www.lindab.com, 15.02.2014)

Direct air measurement methods using an attachment on the intake

Method 5

Airflow hood fitted to the intake louvre. This technique could be applied to the air intakes of the small AHUs and the hood must be calibrated for supply or exhaust air flow measurement. This method is based on the measurement of the ventilation air velocity using a vane anemometer with probe diameter Ø100 or thermoanemometer. Measurement of the air flow takes place directly on the ventilation grilles. The probe is placed in the cones with different dimensions of measurement i.e.: model K25 (Figure 5a) is for measuring air flow from grilles surface up to 200x200 mm, model K80 (Figure 5b) up to 350x350 mm and model K120 (Figure 5c) up to 450x450 mm. First two cones are made of fiberglass and designed for the ventilation airflow ranged from 10 to 400 $m^3 h^{-1}$; and the last one is from 50 to 1200 $m^3 h^{-1}$.



a) b) c)

Figure 5. Airflow cone type a) K25 b) K80 c) K120

$$V = k \cdot w \quad (3)$$

where:
k - coefficient factor, (-);

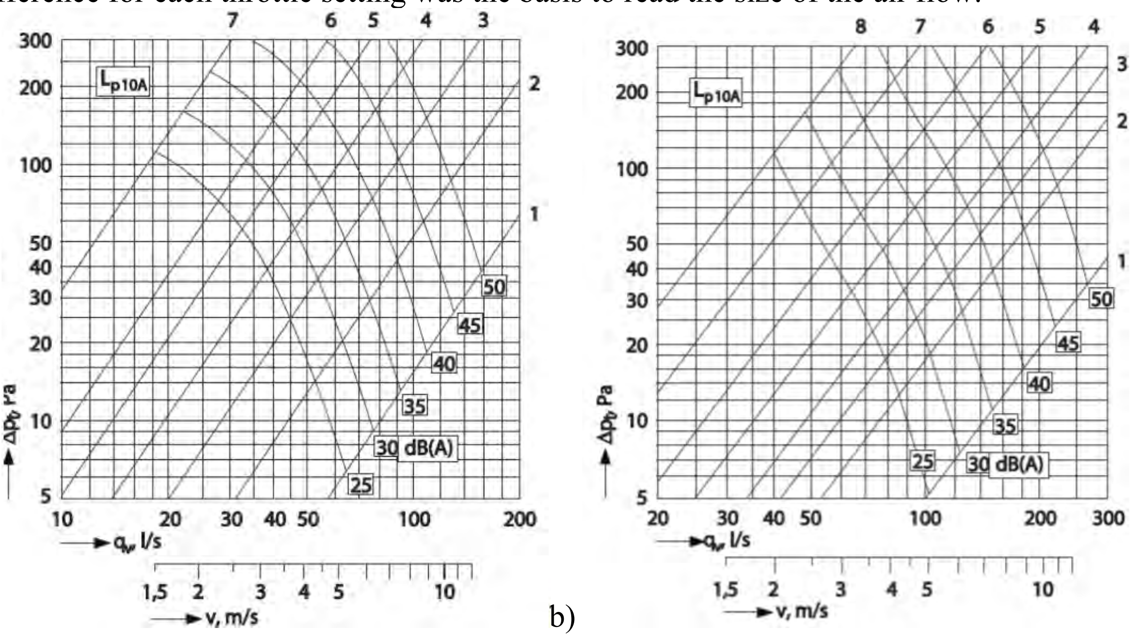
w - air velocity, (m/s).

According to KIMO company (www.kimo.fr, 05.02.2014), the value of the correction factor k for cones K25 and K80 has to be taken depending on the range of the air velocity. For the air velocity below 1.45 m s^{-1}, k is equal to 28.33; for air velocity in the range from 1.45 to 3.8 m s^{-1}, k is equal to 21.26; and when the air velocity is above 3.8 m s^{-1}, k factor is equal to 20.35. For cone model K120 the k factor is constant for different air velocity and is equal to 135.

Indirect air measurement methods

Method 6

Assessment damper characteristic and traverse of the total supply duct by pitot static tube (Prandtl tube). The air rate is determined on the basis of the intake damper position and the damper characteristic which are provided by the damper manufacture. Differential pressure measurement was made using the pressure calibrator KAL 84 for measuring element in the form of throttle lens IRIS-125 (see Figure 6a) and IRIS-160 (see Figure 6b). The pressure difference for each throttle setting was the basis to read the size of the air flow.



a) b)

Figure 6. Air velocity and flow vs measured differential pressure on iris damper with flow meter
a) duct diameter 125 b) duct diameter 160

Table 5 consists of the list of the accuracy of instruments used in the measurement. Table 4 shows the list of air terminal devices and applied measurement technique for each model.

Table 4. Summary of measurement methods for specific ATDs

ATDs	N41	N34	N25	N15
Method 1	x	x	x	x
Method 2	x	x	x	x
Method 3	-	-	x	-
Method 4	-	-	-	x
Method 5	x	x	x	x
Method 6	x	x	-	-

Table 5. Accuracy of instruments used in airflow measurement technique

Type	Min vel.	Max vel.	Min Temp	Max Temp	Select test largest			
					Accuracy	Accuracy	Accuracy	Accuracy
	m/s or (m^3/h)	m/s or (m^3/h)	(^oC)	(^oC)	(% of reading)	(± m/s)	(% of full scale)	(± digit)
Vane 100 mm	0.20	3	-	-	2	0.06	-	-
	3.1	35	-	-	2	0.2	-	-
Hot wire	0	3	-	-	3	0.03	-	-
	3.1	30	-	-	3	0.1	-	-
Airflow hood	-	-	-	-	-	-	5	-
Prandtl tube	2	20	-	-	-	-	5	-
Manometer	0	200	-	-	1	-	-	-

3 RESULTS AND DISCUSSION

In Table 6 the results for six measurement technique for air terminal devices N41 and N34 are compared (supply air valve).

Table 6. Results for air terminal devices N41 and N34

Air terminal devices			N41			N34		
Position of damper			5	3	1	9	5	1
Method 1	Prandtl tube	dp [Pa]	*11.57*	*33.8*	*54.5*	*3.48*	*10.78*	*14.23*
		V [m^3/h]	**194.0**	**331.6**	**421.5**	**174.3**	**306.81**	**352.5**
Method 2	Free area	w [m/s]	*7.9*	*9.4*	*11.5*	*5.5*	*7.3*	*8.2*
		V [m^3/h]	**178.6**	**212.5**	**259.9**	**159.2**	**211.3**	**237.3**
Method 3	Plenum box	dp [Pa]	-			-		
		V [m^3/h]						
Method 4	Air flow meter	dp [Pa]	-			-		
		V [m^3/h]						
Method 5	K25	w [m/s]	*9.32*	*11.38*	*12.06*	*6.62*	*8.95*	*9.88*
		V [m^3/h]	**189.7**	**231.6**	**245.5**	**134.7**	**182.2**	**201**
	K80	w [m/s]	*9.84*	*12.05*	*12.96*	*6.95*	*9.53*	*10.66*
		V [m^3/h]	**200.2**	**245.2**	**263.73**	**141.4**	**193.9**	**216.9**
	K120	w [m/s]	*1.65*	*2.85*	*4.41*	*1.21*	*2.29*	*2.7*
		V [m^3/h]	**222.7**	**384.8**	**595.4**	**163.4**	**309.2**	**364.5**
Method 6	IRIS 125	dp [Pa]	*198.6*	*102.7*	*18.8*	-		
		V [m^3/h]	**218.1**	**315.8**	**390.2**			
	IRIS 160	dp [Pa]	-			*120.59*	*49.49*	*8.8*
		V [m^3/h]				**162.1**	**226.1**	**266.6**

For the supply air valve, the direct method of measurement is the most proper method for checking the air flow. The most problematic to interpret is cone air flow measurement based on vane anemometer (model K25 and K80). The measured values of velocity are much higher than 10 m/s, therefore, the calibration coefficient K for, which the proper value is estimated, is calculated according to for air velocity above 3.8 m/s. Much better results are received by cone combined with thermoanemometer. In Table 7 are shown results for two diffusers N25 and N16.

Table 7. Results for air terminal devices N25 and N16

Air terminal devices			**N25**			**N16**		
Position of damper			10%	50%	100%	30%	60%	100%
Method 1	Prandtl tube	dp [Pa]	*4.78*	*16.45*	*22.95*	*4.31*	*17.9*	*23*
		V [m^3/h]	**319.2**	**592.4**	**699.4**	**303.1**	**617.9**	**701.3**
Method 2	Free area	w [m/s]	*1.5*	*3.1*	*3.6*	*1.4*	*2.5*	*2.8*
		V [m^3/h]	**298.2**	**616.3**	**715.7**	**333.9**	**596.2**	**667.8**
Method 3	Plenum box	dp [Pa]	*16.84*	*32.78*	*51.9*	-		
		V [m^3/h]	**409.2**	**570.9**	**718.4**			
Method 4	Air flow meter	dp [Pa]	-			*12.53*	*28.5*	*30.7*
		V [m^3/h]				**374.6**	**565**	**586.3**
Method 5	K25	w [m/s]	-			-		
		V [m^3/h]						
	K80	w [m/s]	*9.24*	*13.86*	*14.48*	*11.76*	*13.38*	*13.58*
		V [m^3/h]	**188.1**	**282.1**	**294.7**	**239.3**	**272.3**	**275.9**
	K120	w [m/s]	*1.68*	*4.71*	*5.27*	*2.82*	*4.74*	*5.42*
		V [m^3/h]	**226.8**	**635.4**	**711.9**	**380.2**	**639.7**	**731.6**
Method 6	IRIS 125	dp [Pa]	-			-		
		V [m^3/h]						
	IRIS 160	dp [Pa]	-			-		
		V [m^3/h]						

The results confirm that method 1, 2, 3, and 5 (cone k120) present the similar results. The data obtained for cone K25 and K80 should not be taken into account because they are on measurement border. Only first result for this technique can be taken into consideration but their values are very low compared to another results.

4 CONCLUSIONS

As a result of measurement, it was found that:

- the results of measurements using different methods are significantly different,
- it must necessarily follow the manufacturer's recommendation contained in the technical data sheet for the devices,
- proper selection of the method of measuring the specific model of each air terminal devices is essential.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Awbi H.B. (2003) *Ventilation of buildings*. 2nd edn. Spoon Press.

EN 12599 (2012) *Ventilation for buildings. Test procedures and measurement methods to hand over air conditioning and ventilation systems.* International Organization for Standardization.

EN ISO 5167-1 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full General principles and requirements.* International Organization for Standardization.

EN ISO 5167-2 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Orifice plates*. International Organization for Standardization.

EN ISO 5167-3 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Nozzles and Venturi nozzles.* International Organization for Standardization.

EN ISO 5167-4 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Venturi tubes.* International Organization for Standardization.

ISO 7194 (2008) *Measurement of fluid flow in closed conduits. Velocity-area methods of flow measurement in swirling or asymmetric flow conditions in circular ducts by means of current-meters or Pitot statics tubes.* International Organization for Standardization.

PD ISO/TR 12767 (2007) *Measurement of fluid flow by means of pressure differential devices. Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167.* International Organization for Standardization.

Standard EN 12238 (2001) *Ventilation for buildings. Air terminal devices. Aerodynamic testing and rating for mixed flow application*. International Organization for Standardization**.**

MEASUREMENT OF AIR FLOW RATES AT AIR TERMINAL DEVICES: AN OVERVIEW

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ABSTRACT

The measurement of the ventilation air flow rates is necessary for the adjustment of the flow rates in the different rooms, as part of the commissioning. Flow rate measurement is also of primary importance in the context of compliance with the regulation or other requirements. For small and residential applications, the measurement of air flow rates at air terminal devices is a very common measurement method.

The different methods for air flow rate measurement at air terminal devices are presented in this overview, such as van anemometer with a cone, small velocity probe (thermal probe or small vane anemometer), compensation method, etc. Several measurement methods are available on the market at highly variable cost. However some of these methods are suspected to lack reliability.
Some of these measurements methods are not really appropriate for the measurement of flow rates at air terminal devices, with errors up to more than 50% in some cases!
The compensation method with sufficient stabilisation of the flow gives reliable measurements at the air terminal device in all the tested conditions (less than 10% error). This method uses a flow hood and combines a grid for the stabilisation of the flow and an auxiliary fan for the compensation of the pressure drop of the device, mainly due the stabilization grid (zero pressure differential). It has also been shown that the principle of pressure compensation as such is not enough to assure reliable results. The stabilisation grid plays probably also an important role given that another instrument with pressure compensation but without stabilisation grid gives bad results in certain measurement conditions.
For vane anemometer combined with a flow hood, the following conditions can have a dramatic effect on the measurement error: air terminal device with asymmetric flow rate, air terminal device adjusted in nearly closed position, measurement instrument not perfectly centred on the air terminal device, etc. Some new development shows that a stabilisation of the flow is also possible with vane anemometers.
Finally, another problem is the influence of the pressure drop created by the measurement instrument itself. Again, the compensation method presents also the advantage of neutralizing this additional pressure drop.

As a conclusion one can say that more attention should be paid from the commissioner over the choice of the measurement instrument in terms of reliability. As there are only very few reliable instrument on the market, there is a real need for the development of such instruments for the measurement of flow rates at the air terminal device.

KEYWORDS

air flow rate, vane anemometer, compensation method, measurement cone, measurement hood, measurement error

REFERENCES

NBN EN 12599:2012. *Ventilation for buildings - Test procedures and measurement*

methods to hand over air conditioning and ventilation systems

Pr EN 16211 (to be published). *Ventilation for buildings - Measurement of air flows on site – methods*

G. Hawkins (2013). *Domestic ventilation systems – A guide to measure airflow rates.* A BSRIA Guide, BG 46/2013. www.bsria.co.uk

A. Gilbert, Ch. Knights (2013). *Quality of ventilation systems in resiedential buildings : statut and perspectives in the UK*, AIVC International Workshop, Brussels, Belgium, 18-19 March 2013

I.S. Walker, C.P. Wray, D.J. Dickerhoff, M.H. Sherman (2001). *Evaluation of flow hood measurements for residential register flows.* Lawrence Berkeley National Laboratory

C.P. Wray, I.S. Walker, M.H. Sherman (2002). *Accuracy of flow hoods in residential applications.* Lawrence Berkeley National Laboratory

I. Carré, P. Chaffois, P. Henry (2013). *Guide des bonnes pratiques des mesures de débit d'air sur site pour les installations de ventilation.* Cetiat, France.

I. Caré (2013). *Measurement of flow rate at air terminal device*, Congrès international de Métrologie, Paris, October 2013

PROMEVENT: IMPROVEMENT OF PROTOCOLS MEASUREMENTS USED TO CHARACTERIZE VENTILATION SYSTEMS PERFORMANCE

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ABSTRACT

For the coming energy-efficient buildings, the guarantee of energy performance becomes a major challenge. It is therefore crucial to implement accurate and reliable measurements, in order to ensure this performance. The in-force French EP-regulation RT2012 already imposes compulsory justification of envelope airtightness. Moreover, the Effinergie+ label requires ventilation systems control and ductwork airleakage performance. This requirements, ventilation control for IAQ concerns and buildings regulatory compulsory controls need reliable diagnostic protocols.

In January 2014, several French partners, led by the CEREMA[1], proposed a new project, PROMEVENT, to improve ventilation systems measurements protocols, through experimental campaign. Several points should be tested through repeatability and reproducibility evaluations. By the end of the PROMEVENT project, recommendations and a first version of a protocol for the measurement of residential buildings ventilation systems should be proposed. Moreover, one of the main objective is to produce a more reliable and optimised protocol which should be written as a proposed draft standard.

This paper presents the context in which the PROMEVENT project has been defined, and expounds its main objectives.

KEYWORDS

Ventilation – Measurements – Airtightness – Airflow - Improvement

[1] A new public scientific organism born from the merging of 11 scientific institutes (including the CETE de Lyon) of the French ministry for ecology, sustainable development and energy (MEDDE).

1 CONTEXT AND OBJECTIVES

The recent French energy performance regulations and labels have resulted in a new buildings generation. Since 2000, airtightness requirements have been gradually implemented in French regulations, leading to a reinforcement of air renewal systems and a need to ensure their reliability. First labels and mostly Effinergie-BBC label have imposed a requirement on building envelope airtightness for residential building. Since January, 2013, the in-force EP-regulation RT2012 imposes airtightness requirements for all new residential buildings.

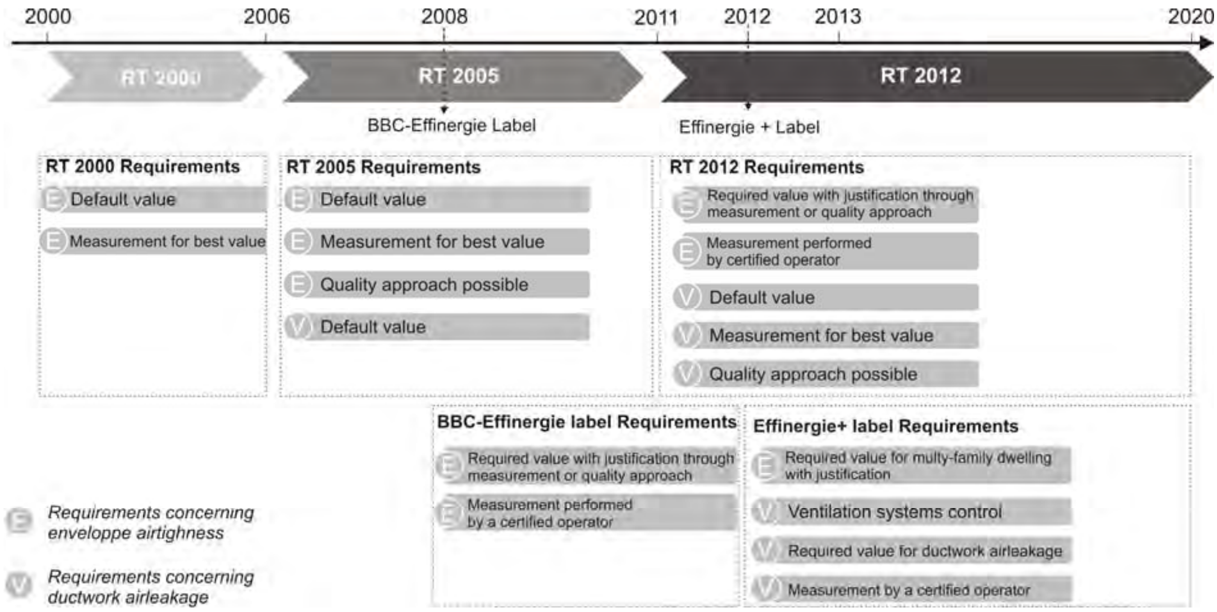

Figure 1: Evolution of French Thermal Regulations

Those highly airtight buildings create an issue for both comfort and indoor air quality. Indeed, in this dwellings, air change rate are provided by ventilation system, which have to be efficient to ensure good indoor air quality, while limiting heat losses due to air change. Several recent studies illustrate this concern. The OQAI (French indoor air quality observatory) performed a national IAQ campaign from 2003 to 2005 (Kirchner, 2008). 567 dwellings (chosen in order to represent the national housing stock) have been investigated through ventilation systems diagnostics and indoor air quality measurements. This national study has concluded that the air change rate and the duration windows are opened are the most important factors of the indoor air quality. Moreover, calculations analysis which have been performed during the project QUAD-BBC have shown some typical evolution of pollutants in highly airtight low consumption buildings (Boulanger, 2012).

The ventilation regulation in force requires a general and permanent ventilation for residential buildings. It also imposes minimal airflow of exhaust air. So as to meet those two seemingly divergent objectives, technically advanced mechanical ventilation systems have been developed. Nevertheless, high quality and technical skills are required during design phase, implementation and maintenance, which are often neglected. Ventilation systems have an influence on the sanitary aspects of the supplied and indoor air, through moisture development for example (Van Herreweghe, 2013). Moreover, inhabitants may have not understood the functioning of new mechanical systems, especially for balanced ventilation, and might decide to take it down. The OQAI has recently carried out a field survey in seven new built energy-efficient houses in France (Derbez, 2014). All inhabitants have experienced some difficulties with their Mechanical Ventilation with Heat-Recovery systems, because they are difficult to use, the user's manual is complex, high noise levels can be produced or they cause a lack of comfort. But if MVHR systems are turned out or voluntary degraded (airvents closed for example), indoor air quality can become poor and present a risk to human health.

Therefore, in many countries, several studies have been launched to realize a state of the art of ventilation systems in dwellings. In France, a survey (Jobert, 2013) has been carried out through control reports performed between 2008 and 2011 concerning 1287 dwellings (88% are multi-family dwellings). Almost all buildings are equipped by simple exhaust ventilation systems.

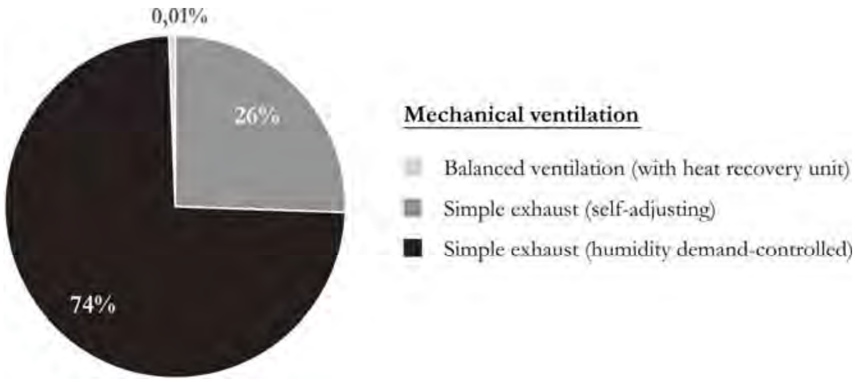

Figure 1: Ventilation system repartition in the analysed sample (Jobert, 2013)

47% of the sample do not comply with the airing regulation, which means that they present at least one non-compliance remark (68% for single-family dwellings, and 44% for multi-family dwellings). Those non-compliances are generally related to design errors, poor implementation and lack of maintenance. Same issues have been observed in many European and American countries (Van Den Bossche, 2013). Two practices could improve the quality of ventilation systems. On one hand, a quality approach could be set up. In France, such approaches have been successfully adopted for building envelope airtightness (Charrier, 2013). Moreover, the VIA-Qualité project is testing the feasibility of such approach for ventilation systems and IAQ (Jobert, 2013). In a second hand, as the French thermal regulation imposed the airtightness level justification, the ventilation system performance could also be controlled, what is already compulsory with a recent label, "Effinergie +". Those controls are in accordance with new approaches, which impose that standards and regulations compliance is ensured by on-site verifications. Those approaches might lead to financial or organizational consequences. Currently, ventilation systems controls are generally performed in France in three cases:

- For buildings applying for new Effinergie label (Effinergie +)
- During regulatory compulsory control (by the technical civil servants network of the Ministry in charge of the Construction's sector)
- When IAQ issues have been set out for a building.

Therefore, control protocols have to be unquestionable. In these cases, several diagnostic protocols are used: either labels reference documents or good practice guide, such as the Effinergie protocol, the DIAGVENT method and the European standard EN12599. The reliability of those protocol may be not sufficient. The next paragraph presents a project, proposed to ADEME, which main objective is to study and improve the reliability of those protocols.

2 PROMEVENT PROJECT

The PROMEVENT project has been proposed to a call for proposals launched by ADEME within the subject "toward responsible buildings in 2020". The Consortium is constituted of 8 French partners, both private and public sectors: a public institution (CEREMA[2]), a technical center (CETIAT), 5 consultancies (ALLIE'AIR, ICEE, PLEIAQ, CETii, PBC) and an association (Effinergie).
The PROMEVENT project objective is to define a new protocol for controls of ventilation systems performance, based on many existing protocols currently used. Indeed, several protocols are currently used in France and abroad to control ventilation systems performance, including visual diagnostic, proper functioning at air vents control and ductwork airtightness measurement. There are described in label reference documents, campaign protocols, standards or good practice guides. EN12599, DIAGVENT method, Effinergie protocol or OQAI protocol are some of them. The PROMEVENT project proposes to test repeatability, reproducibility and feasibility of those protocols in order to define a more reliable protocol for ventilation system controls. This project may have to deal with such issues as: how can it be representative of all different situations? How can it characterize the equipment use impact? How will it overcome airflow measurement difficulties?
PROMEVENT proposes to carry out several laboratory and in-situ campaigns in order to test repeatability, reproducibility and feasibility of those protocols, including the equipment choice impact. It is expected that conclusions of this project will lead to a new standard which could be imposed in new buildings regulation, in order to impose compulsory check of ventilation systems performance. Discussions on new protocols should focus on several points, such as:

- Ensure sufficient reliability
- Ensure technical and financial feasibility
- Define self-checking equipment conditions
- Define needs and organisation of operators training, qualification and control.

At the end of this project, training and recommendations should be provided to operators through a practical guide, which may be useful for measurements performed for label.

3 ACKNOWLEDGEMENTS

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. It does not necessarily reflect the opinion of the ministry.

[2] Centre for expertise and engineering on risks, environment, mobility, urban and country planning - A new public scientific organism born from the merging of 11 scientific institutes (including the CETE de Lyon) of the French ministry for ecology, sustainable development and energy (MEDDE).

4 REFERENCES

S. Kirchner, M. Derbez, C. Duboudin, P. Elias, A. Gregoire, J-P. Lucas, N. Pasquier, O. Ramalho, N. Weiss. *Indoor air quality in French dwellings*. Indoor Air 2008. Copenhagen, Denmark - Paper ID: 574. 2008

X. Boulanger, L. Mouradian, C. Pele, Y-M. Pamart, A-M. Bernard. *Lessons learned on ventilation systems from the IAQ calculations on tight energy performant buildings*. 33rd AIVC Conference. Copenhagen, Denmark. 2012.

J. Van Herreweghe, S. Caillou, M. Roger, K. Dinne. *Sanitary aspects of domestic ventilation systems: an in situ study*. 34th AIVC Conference. Athens, Greece. 2013.

Jobert, R., Guyot, G. *Detailed analysis of regulatory compliance controls of 1287 dwellings ventilation systems.* 34th AIVC Conference. Athens, Greece. 2013.

M. Derbez, B. Berthineau, V. Cochet, M. Lethrosne, C. Pignon, J. Riberon, S. Kirchner. *Indoor air quality and comfort in seven newly built, energy-efficient houses in France.* Building and Environment. N°72, p. 173-187. 2014.

P. Van Den Bossche, A. Janssens, D. Saelens. *Securing the quality of ventilation systems in residential buildings: existing approaches in various countries.* 34th AIVC Conference. Athens, Greece. 2013.

S. Charrier, J. Ponthieux, A. Huet. *Airtightness quality management scheme in France: assessment after 5 years operation*. 34th AIVC Conference. Athens, Greece. 2013.

CETIAT (2005). *Diagnostic des installations de ventilation dans les bâtiments résidentiels et tertiaires – Guide pratique DIAGVENT*. France. Available at: http://www.cetiat.fr/fr/publicationsveille/servezvous/guidesgratuits/index.cfm. 40p.

Effinergie (2013). *Protocole de contrôle des systèmes de ventilation des bâtiments demandant le label Effinergie*. France. Available at: http://www.effinergie.org/index.php/permeabilite-a-lair/les-reseaux-de-ventilation. 12p.

EN 12599:2000. Ventilation for buildings - Tests procedures and measuring methods for handing over installed ventilation and air conditioning systems.

GENERAL APPROACH TO THE EVALUATION OF MEASUREMENT UNCERTAINTIES

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ABSTRACT

Since 1995 with the first edition of the GUM by Joint Committee Guide for Metrology, (JCGM) expression of uncertainty in measurement takes a large part in measurement activities. To be able to give a measurement result with a sound uncertainty expectation, different approaches exist that were covered in several linked documents depending of the available measurement model. In this presentation, we will give an overview of the main methods based on physical model and show that each available method addresses a corresponding model situation.

KEYWORDS

Uncertainty measurement, measurement model, measurement result

1 INTRODUCTION

The Joint Committee for Guides in Metrology (JCGM) provides us with invaluable material such as the GUM (JCGM 100:2008) and other related documents. A very short description of uncertainty in measurement could be seen as: measurement model definition, uncertainty components and propagation. Starting from measurand definition, we will through key questions discuss the available uncertainty assessment methods.

2 GENERAL APPROACH

The definition of a measurand is fully detailed in International Vocabulary in Metrology (JCGM 200:2012). The main difficulty is : does a good corresponding measurement model exist ?

2.1 What is a measurement model ?

A measurement model could be seen as the right depiction of the measurement process corresponding to a targeted uncertainty. International Vocabulary in Metrology (JCGM 200:2012)defines it as a : "mathematical relation among all quantities known to be involved in a measurement..." (§2.48)

Three cases are identified:

- a physical measurement model is unavailable or too complex
- a physical measurement model is available
- a complex physical measurement model is available

2.2 Physical measurement model unavailable or too complex

This case could be addressed through the use of global model (statistical approach).
A good example is interlaboratory comparison, for which a statistical model is described in ISO 5725. This presentation will not cover this type of model.

2.3 Physical measurement model available

From a simple measurement model describing a direct measurement with influence quantities (like direct pressure measurement or direct temperature measurement) to a more complex measurement model using a mathematical relation combining several simple measurements (like for example the measurement of gas flow through an orifice plate), GUM (JCGM 100:2008) is the reference document and its application could be done relatively easily.

An example will be provided during the presentation.

2.4 Complex Physical measurement model available

When model is too complex or non linear, JCGM 101:2008 addresses the issue through propagation of distributions using Monte Carlo method. This numerical approach is interesting for three reasons :

1. no more need to calculate partial derivatives,
2. this approach addresses non linear models which are difficult to treat using GUM (JCGM 100:2008),
3. this method could be used to validate GUM approach choice in showing that there are no significant differences between both approaches.

An example will be provided during the presentation.

3 CONCLUSIONS

The main conclusion of this presentation is that every method of uncertainty assessment is corresponding to a particular state of availability of the measurement model. Each method is completing others and should be seen as a tool responding to the available information.

4 REFERENCES

JCGM 100:2008. Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM)

JCGM 101:2008. Evaluation of measurement data - Supplement 1 to the Guide to the expression of uncertainty in measurement - Propagation of distributions using a Monte Carlo method

JCGM 104:2009. Evaluation of measurement data An introduction to the Guide to the expression of uncertainty in measurement and related documents

JCGM 200:2012. International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (also known as "VIM 3")

MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS - SWEDEN

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ABSTRACT

"When you can measure what you are talking about and express it in numbers you know something about it"
Lord Kelvin (1824-1907)

Measuring air flows and tightness of ventilation ductwork is compulsory in Sweden but not measuring air infiltration or building tightness which normally is done only in some research projects. Instead building tightness is regarded to be covered by compulsory construction guidelines. Tightness of a buildings envelope (external walls, roof and floor) is required for two reasons: to reduce dampness problems and to reduce the use of heating energy of the building. This aim and direction of the Swedish building authorities today is different from earlier codes as shown below.

During the 1980's several studies reported health problems from emissions in badly ventilated dwellings. This resulted in in a new Swedish law requiring compulsory inspection of ventilation systems – the **OVK** commissioning system that is described shortly in the paper.

The quality of ventilation systems in Sweden is also governed by another unique scheme **– AMA** - General Material and Workmanship Specifications. It has been in use since 1950 and is a tool for the customer to specify his demands on a new building and its installations. AMA contains e.g. requirements for tightness tests of ventilation ductwork, methods for measuring and adjusting airflows shortly described in the paper.

KEYWORDS

AMA, OVK, SBN, BBR, Ductwork tightness, Infiltration

SWEDISH REQUIREMENTS FOR AIR FLOWS AND INFILTRATION

Measuring air flows and tightness of ventilation ductwork is compulsory in Sweden but not measuring air infiltration or building tightness which normally is done only in some research projects. Instead building tightness is regarded to be covered by compulsory construction guidelines. Tightness of a buildings envelope (external walls, roof and floor) is required for two reasons: to reduce dampness problems and to reduce the use of heating energy of the building. This aim and direction of the Swedish building authorities today is different from earlier codes as shown below.

The quality of ventilation systems in Sweden is also governed by another unique scheme **– AMA** - General Material and Workmanship Specifications. It has been in use since 1950 and is a tool for the customer to specify his demands on a new building and its installations. AMA contains e.g. requirements for tightness tests of ventilation ductwork, methods for measuring and adjusting airflows shortly described in the paper.

Defective and badly maintained ventilation systems and insufficient airflows were found in studies during the 1980's to be main reasons for sick buildings. This resulted in a new Swedish law 1991 requiring compulsory inspection of ventilation systems – the **OVK** commissioning system – with aim to control and improve the function of ventilation installations. The ordinance requires that the ventilation in most types of buildings has to be controlled before the installations are taken into operation and then regularly at recurrent inspections.

The first global oil crises 1972-73 with rapidly increasing energy prices often led to a change of systems from oil-based to electric heating and from natural ventilation to mechanical extract in a vast majority of residential buildings in Sweden. As a follow-up the Swedish authorities raised the demands on thermal insulation and tightness for new buildings in order to reduce the oil import.

Swedish building codes for ventilation changed from detailed to functional demands

The Swedish building codes have changed from detailed requirements of e.g. building tightness and airflows for different types of buildings and premises to functional demands.

This change came gradually from 1988 when the (detailed) regulations, recommendations and directions in the Swedish Building Code, **SBN**, published by the earlier authority, Statens planverk (The National Board of Physical Planning and Building) was replaced by the mandatory provisions and general recommendations in Building Regulations (**BBR**) from the new authority Boverket (The Swedish National Board of Housing, Building and Planning) where the provisions are in the form of functional requirements, referring to standards when applicable.

In Sweden residential buildings are required to provide an acceptable air quality. The Swedish national environmental legislation states that: “In the year 2020 all buildings shall be healthy and have a good indoor environment”.
One of the intermediate goals within the frame of good indoor climate is that: “All buildings where people stay often or during a longer time shall 2015 at the latest have been proven to have a functioning ventilation system”.

MEASURING VENTILATION AS REQUIRED IN SWEDISH BUILDING CODES

The airflows to be measured have changed during the years

The reason for requiring correct airflows in ventilation systems has varied during the past years. During the 1930’s up till the oil crisis 1973/74 the main demand was to supply enough air to dilute the pollutants produced by the people in the premises – the dimensioning rules were based on the work done by Yaglou during the 1930’s and formed the basis for authority demands for general ventilation in new buildings. Energy was cheap and there was no special reason to economize with air.

The oil crisis changed this – drastically increasing prices and shortage of oil lead to reduced airflows. The old Swedish building code was replaced by SBN with special and detailed demands for maximum supply and exhaust airflows for different buildings, premises and production facilities.

With the new code, **BBR**, these demands were changed from detailed into functional demands.

Airflows – functional requirements in BBR

6:21 General

Buildings and their installations shall be designed to ensure they can provide the conditions for good air quality in rooms where people are present other than occasionally. The requirements for indoor air quality shall be determined on the basis of the room's intended use. The air must not contain pollutants in a concentration resulting in negative health effects or unpleasant odours.

6:25 Ventilation

Ventilation systems shall be designed to ensure the required outdoor air flow can be supplied to the building. They shall also be able to carry off hazardous substances, moisture, annoying odours and emissions from people and emissions from building materials, as well as pollutants from activities in the building.

General recommendation

When designing ventilation flows in buildings, the environmental impact aspects of occupants, activities, added moisture, and emissions from materials, ground and water should be considered.
The installations should be designed in such a way that calibration, testing, inspection, supervision, servicing and exchange can be easily effected and adequate efficiency maintained.

6:251 Ventilation flow

Ventilation systems shall be designed for a minimum outdoor air flow corresponding to 0.35 l/s per m^2 floor area. When in use, rooms shall be able to have a continuous air exchange.
In residential buildings where the ventilation can be controlled separately for each dwelling, the ventilation system is allowed to be designed with presence and demand control systems. However, the flow of outdoor air

must not be lower than 0.10 l/s per m^2 of floor area when the dwelling is unoccupied and 0.35 l/s per m^2 of floor area when the dwelling is occupied.
General recommendation
The requirements for ventilation flow should be verified by calculation and measurement.
When designing outdoor air flow, account should be taken of the fact that the flow could be reduced due to dirt in ventilation ducts, changes in differential pressure over filters, etc.
For buildings other than residential buildings, the ventilation system may be designed so that a reduction of supply airflow, in multiple stages, continuously, or by intermittent operation, is possible when the building is unoccupied.
General recommendation
After a period of reduced air flow, normal air flow should be provided at least for a period of such length as is required to achieve a complete exchange of the volume of air in the room before it is reused.
The reduction of the ventilation air flow is not allowed to cause adverse health effects. Nor shall the reduction be allowed to bring about damage to the building or its installations due to moisture etc.

6:254 Installations
Ventilation installations shall be situated and designed in such a way that they are accessible for maintenance and cleaning purposes. Main and connect ducts shall have stationary measure outlets for flow measuring.
General recommendation
For the appropriate design of duct systems and cleaning hatches, see SS-EN 12097.

6:255 Airtightness
Pressure conditions between supply air and extract air installations shall be adapted to the airtightness of the installation, to ensure that transfer of extract air to the supply air does not occur.
General recommendation
To prevent pollutants from returning through heat exchangers where air can shift from the extract air side to the supply air side, the pressure level should be higher on the supply air side than on the extract air side.
The building envelope should have adequate airtightness in relation to the selected ventilation system to ensure good functionality and for adjusting airflow in individual rooms. The airtightness of the building envelope should also be ensured with regard to the risk of damage due to moisture. Rules on airtightness of a building's envelope are contained in Section 6:531.
Measurements of leakage in sheet metal ducts can be made in accordance with SS-EN 12237. Additional information on airtightness testing of ventilation ducts are contained in Formas publication Metoder för mätning av luftflöden i ventilationsinstallationer (Methods for measuring air flow in ventilation installations) (T9:2007) and instructions in **AMA** VVS & Kyl 09 and SS-EN 15727.

Summary of Swedish ventilation requirements: Functional requirements providing conditions for good air quality should be verified by calculation and measurement. The installations should be designed in such a way that calibration, testing, inspection, supervision, servicing and exchange can be easily effected and adequate efficiency maintained. Airflow and ductwork tightness measurement, and accepted methods, as stated in **AMA.**

AIR INFILTRATION IN BUILDINGS

Air Infiltration – detailed requirements in SBN

In the last edition, **SBN** 1980 edition 2, maximum air infiltration in buildings were stated as maximum accepted air leakage (in m^3/m^2,h) for different building types: “For premises intended (designed) to be heated above +10°C a maximum air leakage as stated in column 33:3 (see below) is accepted”.

Table 1 (SBN 33:3) - Maximum accepted air leakage (in m^3/m^2,h)

Building part	Pressure difference Pa	Building with height in floors		
		1 - 2	3 – 8	>8
Exterior wall	50	0.4	0.2	0.2
Exterior window and door (referring to the tightness of the chink between the frame and the window sash and door leaf respectively	50	0.4	0.2	0.2
	50	1.7	1.7	1.7
	300	5.6	5.6	5.6
Roof and floor towards the outside or towards a ventilated space	50	0-2	0.1	0.1

During the late 1970’s a majority of the existing buildings were tightened to reduce the need for heating energy (the easiest way to do this was to tighten leaking window frames). This however often led to critically reduced air flows in buildings with natural supply and exhaust (S-system). In buildings with natural supply and mechanical exhaust (F-system) the increased under pressure in the rooms often resulted in noise problems.

Building tightness, when measured, is controlled with blower door but only for smaller buildings, type one-family houses and not for e.g. office buildings. The author has been involved in tightness tests of two large buildings where the supply air fans were used for pressurizing the buildings : (1): the R2 Reactor Hall at Studsvik where the large reactor hall for safety reasons was pressure and tightness tested at 1000 Pa!; and (2): the Fries office building at Växiö which was constructed to obtain a high degree of tightness, the windows were e.g. mounted in projecting frames being part of the concrete exterior walls (covered on the outside with mineral wool and grouted brick).

Air Infiltration – functional requirements in BBR

In **BBR** maximum air infiltration in buildings have been replaced by functional requirements, referring to reducing the risk for damage due to damp in the building structure (6:95) or to reduce the maximum use of energy for buildings (9:21 – dwellings; 9:31 – premises):

<u>6:255 Airtightness</u>
Pressure conditions between supply air and extract air installations shall be adapted to the airtightness of the installation, to ensure that transfer of extract air to the supply air does not occur.
General recommendation
To prevent pollutants from returning through heat exchangers where air can shift from the extract air side to the supply air side, the pressure level should be higher on the supply air side than on the extract air side.
The building envelope should have adequate airtightness in relation to the selected ventilation system to ensure good functionality and for adjusting airflow in individual rooms. The airtightness of the building envelope should also be ensured with regard to the risk of damage due to moisture. Rules on airtightness of a building's envelope are contained in Section 6:531.
Measurements of leakage in sheet metal ducts can be made in accordance with SS-EN 12237. Additional information on airtightness testing of ventilation ducts are contained in Formas publication T9:2007, see above, and instructions in AMA VVS & Kyl 09 and SS-EN 15727.

<u>6:531 Airtightness</u>
General recommendation
To prevent damage due to convection of moisture, the parts of the building that separate spaces with different climatic conditions should have as high airtightness as possible. In most buildings, the risk of convection of moisture is greatest in the building's upper parts, i.e. where internal excess pressure may be prevalent.
Particular care should be taken to ensure airtightness where the environmental impact of moisture is great such as in public baths or where temperature differences are particularly great.
Airtightness can affect the moisture level, thermal comfort, ventilation and a building's heat loss.
A method for determining air leakage is contained in SS-EN 13829. When determining air leakage, it should also be investigated whether the air leakage is concentrated to a particular structural element. If this is the case, there is a risk of moisture damage.

<u>6:95 Damp</u>
Buildings should be designed so that moisture does not cause damages, bad smell or hygienic nuisances or microbial growth that can affect the health of people.

The air tightness of a building shall be such that convection of moist air does not lead to that the highest accepted moisture pickup of the material is exceeded.

<u>9:21 and 9:31 Building envelope tightness with reference to energy use</u>
The building envelope shall be so air tight that the requirements on specific energy use of the building and installed electric power for heating purposes are fulfilled.

9:4 Alternative requirements on the energy use of the building
As an alternative to the requirements for buildings given in Clauses 9:2 and 9:3,
where
- the floor area A_{temp} does not exceed 100 m^2,
- the window and door area A_f does not exceed 0.20 A_{temp} and
- there is no requirement for cooling,

the following requirements relating to the thermal insulation of the building, the airtightness of the building envelope and heat recovery may be applied.
…

The building envelope shall be of sufficient tightness to ensure that the average air leakage rate at a pressure difference of ± 50 Pa does not exceed 0.61 l/s m2. In relation to this, the area A_{om} shall be applied. *(BFS 2006:12)*
General recommendation
A method for determining air leakage rate is given in SS-EN 13 829. *(BFS 2006:12)*

A common question put to Boverket: "Why are there no quantified demand values stated for the building envelope tightness in chapters 9:21 and 9:31?" was answered as follows:
"There is an all-embracing functional demand on the energy use of the building. This demand can be fulfilled in many ways, e.g. with more or less heat insulation, different technical installations and a more or less airtight building envelope.

The building envelope needs to be so tight that the building can fulfil the energy use requirements for the whole building. Other relevant all-embracing demands to be fulfilled are installed electric power, ventilation, thermal comfort, moisture safety and noise. How tight the building envelope has to be is therefore something that has to be decided from case to case by the building proprietor/designer depending on the choice of ventilation systems, energy management solutions etc."

Summary of Swedish air infiltration requirements: Today there are no Swedish quantified building airtightness requirements except for small buildings (<100 m^2 A_{temp}).

MEASURING VENTILATION AS REQUIRED IN AMA

Practically all buildings and their installations in Sweden are performed according to the quality requirements in **AMA** specification guidelines (General Material and Workmanship Specifications). The AMA requirements are made valid when they are referred to in the contract between the owner and the contractor.

Starting more than 60 years back in time we have been using this probably quite unique quality assurance system in Sweden covering all aspects of building and installation technologies.

But requirements and demands can be worthless unless they are controlled. The AMA requirements thus also include demands for tightness testing of the ductwork and adjusting airflows in the building. The results of prescribed measurements have to be reported to the proprietor on standard protocol forms signed by the testing contractor.

AMA is a voluntary complementary to statutory rules, regulations and specified building standards laid down by the authorities. The statutory rules, e.g. in BBR, are normally mostly focussed on reducing the risk of injuries while AMA (not having to deal with that) is focussed on reducing damages and LCC-costs. Common interest areas for both are sustainability and low energy use.

Two of the AMA rules are relevant for measuring airflow and ductwork tightness: "Express your requirements in measurable terms and control that you have got it!" and the other: "The costs and risks for the contractor to fulfil the requirements in the contract should be possible to calculate".

YTC.157 – Control of air handling systems
Functions specified in the contract documents shall be controlled.
Before the control is made the control responsible shall make sure that the parts of other contracts that can have influence on the control are performed.

Measurement uncertainty
Extended measurement uncertainty is calculated as:

$$U = \sqrt{U_1^2 + U_2^2 + U_3^2 + \ldots}$$

Where
U_1 = the extended measurement uncertainty of the measuring instrument, percent
U_2 = the extended measurement uncertainty of the measuring method, percent
U_3 = probable extended uncertainty when reading off the instrument, percent
In literature occurring term ***m***, probable measurement error is here the same thing as standard measurement uncertainty.

Values for these uncertainties are given in the report T9:2007 presented above and referred to in both BBR and AMA. Values are given for normally used measurement methods and instruments such as:
(Extract)
Methods for measuring in duct
Prandtlrör in duct with circular and rectangular cross section (Methods A11 and A12)
Fixed flow measurement (Methods A21 – A29)
Measuring airflow with tracer gas (Method A3)
Methods for measuring extract registers and air intake grilles
Hot-wire anemometer on rectangular grilles with the 4-point method (Method B1)
Pressure drop measurement with probe (Method B21)
Pressure drop measurement with fixed measuring connection (Method B22)

Tightness control of duct systems
Leak airflow shall primarily be measured at 400 Pa test pressure but can be measured at another pressure if found suitable due to control device and controlled surface area. The pressure shall not be lower than 200 Pa and not higher than 1 kPa. Duct with a larger circumference than 6.4 m shall however be controlled at 200 Pa.

The sum of measured leak airflow and measurement error shall not exceed the value for prescribed tightness class.

Leak airflow shall be measured with recommended method in Formas report T9:2007(see above), Metoder för mätning av luftflöden i ventilationsinstallationer (Method for measuring airflows in ventilation installations). Tightness control shall be made as spot test, each with approx. 25 m^2 duct exterior perimeter area. Controlled duct area shall for each test be at least 10 m^2 . Tightness control shall be made with either over- or under-pressure depending on the operation pressure.

Tightness control of type approved duct systems for prescribed tightness class shall be controlled in following manner: circular spiral wounded ducts shall be controlled to 10 percent of the total duct exterior perimeter area; other ducts to 20 percent.

If the prescribed tightness requirement is not fulfilled the control shall be extended to another duct part with the same percentage. If the requirement neither is fulfilled at this control, the control shall be extended to comprise all the ducts.
Tightness control of other types of ductwork shall comprise 100 percent of the total duct exterior perimeter area. The proprietor shall in each case give instructions on which ducts and units that shall be controlled. Tightness control shall be documented on AMA form YTC/5.

YTC.257 – Airflow measuring of adjustment in ventilation systems
(Extract)
Measuring of system total airflow shall be made at a filter pressure drop corresponding to the final filter pressure drop in system with pressure controlled fans. Other systems shall be flow adjusted with clean filters with correction for a flow increase of 3 percent.
Adjusting systems with more than one operation case shall be made at one of the operation cases and measured at both max and min airflow
Airflow measurement shall be made with recommended method in Formas report T9:2007(see above)
Measurement shall be made and reported in such a way that a new measurement is possible and should give the same result if the conditions are the same, e.g. at recurrent OVK inspections.

System types F (exhaust), FT (supply and exhaust) and FTX (supply and exhaust with heat recovery) shall be adjusted with closed doors and windows.

Adjustment of airflows
Adjustment of airflows shall be made to achieve the values given in the building documents.

Alternative 1. Proportionality method
The adjustment shall be made with a systematic step-by-step-method with successive measurements and adjustments of throttling device (dampers) in accordance with the working procedure described in Building Research Council’s report Injustering av luftflöden i ventilationsinstallationer, T12:1981 (Adjustment of airflows in ventilation installations).
If the contract documents do not indicate reference register and index register they shall be decided at the adjustment.

Alternative 2. Pre-set value method
The adjustment shall be made by adjusting registers and dampers according to the pressure drop calculation. Airflow measurements shall be made for control. Consideration shall be taken to thermal influence power (stack effect).

Records
Records over adjustment and airflow control shall be presented after adjustment and following control has been made. Instructions for accounting are given under YTC.157.

MEASUREMENT COSTS

Measurements and control of the ventilation systems before the building is taken into operation and then regularly at recurrent inspections in the future are necessary to guarantee that the building and its installations are working properly.
Compared to the initial cost for the building and its installations the costs for control and maintenance are negligible. REHVA Guidebook No. 06, Indoor Climate and Productivity in Offices, shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available. The quantitative relationships presented in the guidebook can be used to calculate the costs and benefits of running and operating the building.
The cost for obtaining and controlling ventilation system tightness for the specified tightness class (A – D) in the HVAC specification (referring to the requirements in the Swedish HVAC AMA) is included in tender price given by the contractor.
There are no values available for the specific cost for obtaining and controlling building tightness.
For ventilation ductwork it is necessary to require high quality ductwork, units and components that have a known tightness are adapted to each other to form a system with the required tightness. During commissioning the actual tightness should be measured by skilled personnel (if not totally, in parts of the total installation chosen by the building proprietor) and reported in prescribed forms.
Building tightness should primarily be obtained by choosing suitable window/wall construction, using plastic foil with long-time durability and checking that it is not perforated by e.g. electric installations.

OVK – COMPULSORY INSPECTION OF VENTILATION SYSTEMS

Many Swedish and Nordic studies during the 1980's showed that defective and badly maintained ventilation systems and insufficient airflows was a main reason for sick buildings.

This resulted in a new Swedish law 1991 requiring compulsory inspection of ventilation systems – the OVK commissioning system – with aim to control and improve the function of ventilation installations. The ordinance requires that the ventilation in most types of buildings has to be controlled before the installations are taken into operation and then regularly at recurrent inspections.

Table 2 - OVK inspection intervals for different buildings and ventilation systems

Type of building and ventilation system	Inspection intervals
Day nurseries, schools and hospitals	3 years
Block of flats and offices with FT-ventilation	3 years
Block of flats and offices with F-ventilation	6 years
Block of flats and offices with S-ventilation	6 years
One and two dwelling-houses with FT-ventilation	only first inspection (new buildings)

Boverket is responsible for this control system and for nation-wide authorization of the inspectors while local authorities control the observance of the law locally and report the result to Boverket.
The inspector records the inspection. The result of the OVK inspection, the certificate, is given to the owner with a copy sent to the local authority. A copy of the certificate shall be posted in full view in the building by the owner, e.g. at the building entrance or staircase.

CONCLUSIONS

Back to the citation on the first page: “When you can measure what you are talking about and express it in numbers you know something about it”.

You have to know what you are aiming at and express it in measurable units, be willing to pay the cost to arrive there and control that you have got what you have paid for. For this you need to use measurement methods with low measurement uncertainties.

REFERENCES

[1] Andersson, J. 2013. Swedish experience with airtight ductwork, *The REHVA European HVAC Journal*, 50 (1): 28-32.

[2] AIVC-TightVent workshop in Brussels, 28-29 March 2012

[3] AIVC-TightVent workshop in Copenhagen, 10-11 October 2012

[4] AIVC-TightVent workshop in Brussels, 18-19 March 2013

[5] Carriè FR, Andersson J, Wouters P. 1999. Improving ductwork. A time for tighter air distribution systems. AIVC. Air Infiltration and Ventilation Centre.

[6] Malmstrom T, Andersson J, Carriè FR, Wouters P, Delmotte CH. 2002. AIRWAYS Source book on efficient air duct systems in Europe. Belgian Building Research Institute.

[7] AMA VVS & Kyl 12. Allmän material- och arbetsbeskrivning för VVS- och Kyltekniska arbeten (General Material and Workmanship Specifications of HVAC installations). AB Svensk Byggtjänst, Stockholm 2012. (in Swedish).

[8] AMA VVS & Kyl 09. Allmän material- och arbetsbeskrivning för VVS- och Kyltekniska arbeten (General Material and Workmanship Specifications of HVAC installations). AB Svensk Byggtjänst, Stockholm 2010. (in Swedish).

[9] Swedish Building Code, SBN 1980, Chapter 36 Air Quality. National Swedish Board of Physical Planning and Building, Stockholm 1982.

[10] Swedish Building Code, BBR 2012, Chapter 36 Air Quality. The Swedish National Board of Housing, Building and Planning, Karlskrona 2012.

[11] Andersson, J. et al, 2002. The Swedish Key Action The Healthy Building, Stage 1 - Research Results Achieved during the First Three-Years Period 1998-2000, Indoor air 2002 and Formas, Stockholm, The Healthy Building Research Seminar Series No. 5-E, December 2001.

[12] Andersson J. et al, REHVA Handbook No. 6, Indoor Climate and Productivity in Offices. REHVA, Brussels 2010.

[13] Report T9:2007, Metoder för mätning av luftflöden i ventilationsinstallationer (Method for measuring airflows in ventilation installations). Formas, Stockholm 2007

REASONS BEHIND AND LESSONS LEARNT WITH THE DEVELOPMENT OF AIRTIGHTNESS TESTERS SCHEMES IN 11 EUROPEAN COUNTRIES

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ABSTRACT

Mandatory building airtightness testing has come gradually into force in the UK, France, Ireland and Denmark. It is considered in many other European countries because of the increasing weight of the building leakage energy impact on the overall energy performance of low-energy buildings. Therefore, because of related legal and financial issues, the building airtightness testing protocol and reporting have become crucial issues to have confidence in the test results as well as the consistency between the measurement results and values used in the energy performance calculation method. The reference testing protocol in Europe is described in EN 13829. In addition, many countries have developed specific guidelines to detail or adapt EN 13829 requirements. However, performing and reporting correctly an airtightness test requires knowledge and know-how as well as pre-requisite on the tools used by the tester.

This study compares the steps taken in 11 European countries to improve the competence of the testers and thereby the reliability of the airtightness measurement. Information has been collected through a questionnaire sent to TAAC (TightVent Airtightness Associations Committee) members. We found out that 8 out of the 11 countries surveyed have developed or were developing a competent tester scheme for airtightness testers. Those schemes go together with technical documents beyond the measurement standard and include most of the time training, examination of testers and the proof of use of appropriate equipment. The feedback from France from the training institutes and experts analysing the reports of applicants as well as the failure rate at the examinations confirm that performing and reporting correctly an airtightness test is not straightforward. Those schemes are reinforced with databases that allow better follow-up of the approved testers and tracking of suspicious results.

KEYWORDS

Airtightness measurement, competent tester schemes, European comparison

1 INTRODUCTION

Building airtightness is a key issue to reach low- and very low-energy targets. Therefore an increasing number of tests are performed in European countries for various reasons: compliance to the energy performance regulation; compliance to a specific energy programme; or will of the building owner. For instance, to our knowledge, measuring the airtightness of all new buildings or at least part of them is required by the energy performance regulation in UK, France, Ireland and Denmark. Besides, specific energy programs (such as Passivhaus or Minergie) that require or encourage building airtightness testing are

increasingly popular in many other countries. Likely, within a few years, over a million tests will be performed every year in Europe.
Airtightness measurements are useful to check that the building envelope complies with a given requirement. The measurement protocol is described in the European standard EN 13829 adapted from ISO 9972 which is now under revision.

There are four key sources of uncertainty in airtightness testing:

- Measurement devices (accuracy and precision);
- Calculation assumptions (e.g. reference pressure, weighted versus unweighted linear regression);
- External conditions (wind and stack effect impact); and
- Tester's behaviour.

The uncertainty associated to tester's behaviour has to be separated into three parts:

- His knowledge and interpretation of the measurement protocol;
- His know-how to use the equipment, analysis and reporting tools; and
- His honesty and will to perform a test correctly.

This document describes how some European countries attempt to decrease uncertainty due to tester's behaviour by setting competent testers schemes.

2 APPROACH

This work has been done in the context of the TightVent Airtightness Associations Committee (TAAC). TAAC is a European working group, set up and hosted within TightVent. The scope of this working group includes various aspects such as:

- Airtightness requirements in the countries involved;
- Competent tester schemes in the countries involved;
- Applicable standards and guidelines for testing;
- Collection of relevant guidance and training documents.

At present, the participants are from Belgium, Czech Republic, Denmark, Estonia, France, Germany, Latvia, Ireland, Poland, Sweden, UK and contacts have been established with other European countries.

A questionnaire has been developed within the committee to compare competent tester schemes in a broad manner, ranging from administrative to technical issues. A representative from each country has kindly accepted to answer the questionnaire. This document summarizes their answers focusing on aspects relevant to this paper.

3 RESULTS OF THE STUDY

3.1 Countries with a competent tester scheme

An increasing number of countries have minimum building airtightness requirements either for energy performance regulation or specific energy savings program subsidized at national or regional level. Most of the time, those minimum building airtightness requirements must be justified with a pressurization test. In Denmark, Ireland, France and United Kingdom who have implemented minimum building airtightness requirements, competent testers schemes have been developed and, except for Denmark those schemes are state-approved and the qualification is required by the regulation to perform test to prove compliance with the energy performance regulation.

Germany also has a competent tester scheme that is required by some specific energy performance programs. Belgium and Sweden are developing their own that should be operational in 2014. The Czech Republic has no tester scheme but there exists an association of testers with an ethical code.

3.2 Comparison of competent testers' schemes

Key components of competent tester scheme are:

- To set a minimum standard for the knowledge of the tester (in particular on the regulatory or the programme context, the fundamentals of ventilation and infiltration, and the fundamentals of airtightness measurement);
- To set pre-requisites on the tools used (equipment, analysis and reporting tools);
- To set a minimum standard for the know-how of the tester.

These components are supported by technical documents, training programs and evaluation procedures.

Technical documents beyond measurement standards

Each country that has set a competent tester scheme has developed technical documents to spell out EN 13829 and adapt measurement to its national context. These documents always specify the building preparation procedure. In countries where testing is required by regulation, technical documents also described the input values that are used for derived quantities and give sampling rules for multi-family buildings and housing developments. In addition, to limit the uncertainty due to measurement devices, calibrated equipment is required in 6 out of the 7 schemes studied and 3 countries have set specific requirements for equipment beyond standards.

Training programs

Training is included in 5 out of the 7 qualification schemes (DE, DK, FR, IE and UK for domestic buildings) there are specificities for the UK non-domestic buildings scheme (which requires UKAS accreditation). The training lasts from 1 to 5 days and costs from 0 to 2100€. The validation of the training always includes an examination of test reports. It includes also a theoretical examination and an onsite evaluation of the tester's skills in France, Germany, Ireland and UK (not in Denmark). Training for testers also exists in Estonia but there is no validation process.

The training in the six countries (DE, DK, EE, FR, IE and UK-domestic buildings) includes following items:

- The rules(including building preparation, calculation of derived quantity, calibrations);
- The purpose and steps of the test;
- How to use the equipment on site;
- How to write/file a report.

Qualification requirements

The qualification process always includes an evaluation of test report(s). Most of the time (5 out of 7), the validation of a specific training is required, but no educational background is required, except for Germany where Engineer, Master or Technician level is required. Most of the time (4 out of 6), there are also some administrative requirements, e.g., specific insurance for airtightness testing in France and the UK.

3.3 Qualified testers

Figure 1 represents the number of qualified tester in each of the 6 countries with operational schemes in January 2014. Some of those schemes are recent, in which case the number of testers evolves rapidly. In the UK, testers are qualified for domestic buildings and companies are for non-domestic ones.

The typical background for testers is:

- Building service, building physics consultants;
- Housing inspector;
- Craftsman; and
- Industry services.

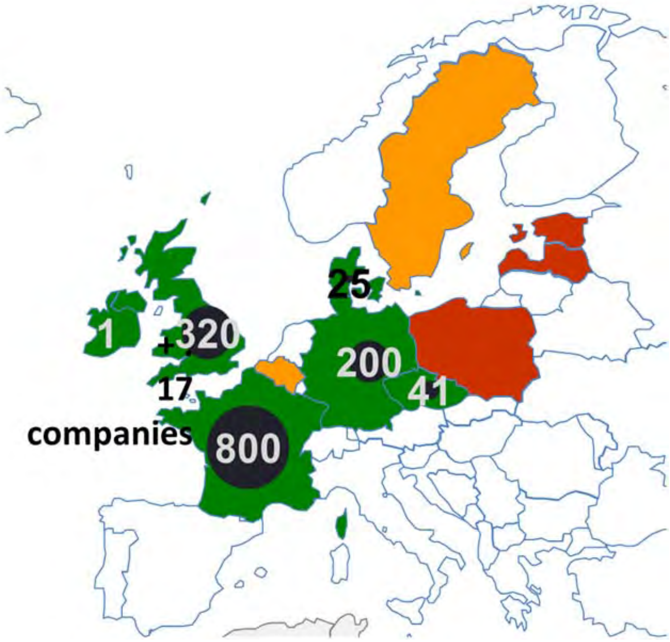

Figure 1: Number of qualified testers in 6 European countries in January 2014

3.4 Success rates for applicants in France

This paragraph is not based on the results of the questionnaires but on feedback from the French competent scheme holder “Qualibat”. During its annual meeting in December 2013, Qualibat presented the success rates for applicants. Only a little over a quarter of the applicants are successful with the first review of their first application. One fifth need a third or even a fourth review. This confirms the relevance to check the competence of the testers before they are allowed to perform and report airtightness tests to justify compliance with a given requirement. It also confirms experts’ unstructured feedback on their reviews.

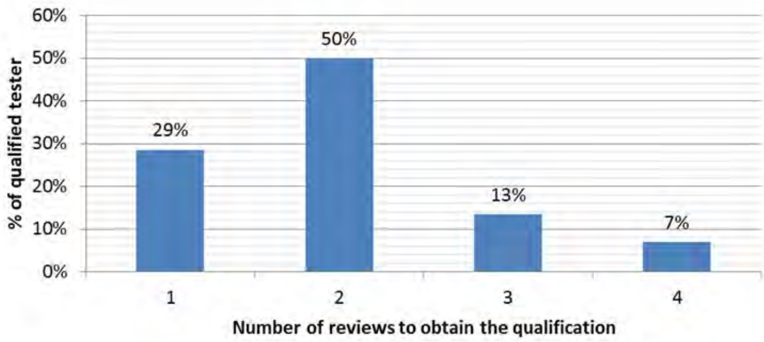

Figure 2: Success rate for applicant: number of reviews needed to obtain the qualification

3.5 Development of databases

Four schemes (DK, DE, CZ, FR) require specific reporting in a database. This has two key advantages, provided that the database is well-structure:

- It becomes easy to analyse large samples and extract meaningful trends, e.g. per building type or construction methods. The French database expects to grow by over 100 000 tests per year;
- It is possible to track suspicious results. To our knowledge, this is not operational in any scheme now but simple checks (and maybe cross-checks with energy performance certificates) could be performed to check the consistency of the results. It can be one step to check the testers' honesty (e.g. by cross-checking the number of tests performed in a single day and the distance travelled).

4 CONCLUSIONS

Several competent tester schemes are now operational. Because they require specific knowledge and know-how as well as pre-requisites for the tools used, they can only improve the quality of measurements although it is difficult to quantify this improvement.

Note that sources of uncertainties mentioned but not covered in this paper include external conditions, analysis methods and calibration methods which may be significant.

5 ACKNOWLEDGEMENTS

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CHALLENGES AND SOLUTIONS FOR AIR SPEED AND AIR FLOW RATE CALIBRATION

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ABSTRACT

One of the first and necessary steps in the increase of confidence in the result of a measurement is the calibration of the used instrument. Moreover, the principle of a reliable calibration is reinforced through the concept of traceability.
The terms "calibration" and 'traceability", which apply equally across metrology and whose definition is given by the VIM (International Vocabulary of Metrology), are examined and put in the context of the challenges for air flow and air speed calibrations.
From the definition of the standards to the way to evaluate the repeatability, the reproducibility, all the concepts are discussed with a special focus on the importance of calibration fluid and conditions.
The presentation outlines also the basic principles of the air speed and air flow calibration methods, both the more accurate and the less ones. Some calibration examples are given to enhance the understanding of the presented concepts.

KEYWORDS

calibration, air flow rate, air speed, measurement error, traceability, uncertainty

REFERENCES

VIM (2008). *International vocabulary of metrology – Basic and general concepts and associated terms*, www.bipm.org

CEN DUCTWORK STANDARDS. TC 156 WG 3 VENTILATION FOR BUILDINGS DUCTWORK

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ABSTRACT

This paper gives an overview of the work undertaken within CEN TC 156 WG 3 dealing with ductwork for ventilation in buildings.

KEYWORDS

Airtightness, Ductwork, European Standards, Working Group 3,

1 INTRODUCTION

CEN TC156 "Ventilation for buildings" deals with all aspects of ventilation for buildings. The scope covers the standardization of terminology, testing and rating methods, dimensioning and fitness for purpose of natural and mechanical ventilation systems and components for buildings subject to human occupancy; it includes both dwellings and non residential buildings.

Working Group 3 of CEN TC 156 deals with the following properties for ducts:

1. Airtightness at pressure level
2. Strength at pressure level
3. Resistance to external pressure
4. Surface area
5. Dimensions
6. Mechanical strength criteria
7. Pressure loss
8. Service temperature
9. Thermal resistance
10. Reaction to fire
11. Release of substances /Emission

2 ACTIVITIES AND TOPICS

The working group has been active in the past 25 years since 1989 with 2,2 meetings a year and the next meeting will be the 55th meeting in Paris. The group consists of ca 20 people and the participation varies between 8-15 persons from different countries, companies and branches like manufactures, test institutes, sales organizations and other comities.

The following extracts from WG 3´s first meeting on 27th of April 1989 give the original intentions of the working group:

- To establish and define the various ductwork components used in ventilation of buildings and develop standards for aerodynamic and physical characteristics.

- To Establish standards for characteristics related to ductwork according to:
  1. Dimensions and tolerances.
  2. Definition of air tightness classes.
  3. Determination and presentation of air leakage.
  4. Establishing strength requirements for ductwork components.
  5. Determination, testing and presentation of strength of ductwork components.
  6. Determination and presentation of energy loss.
  7. Determination and definition of classes of corrosion protection.
  8. Identification of ductwork components.

- To establish a relevant, common terminology and illustrations for ductwork components.

- To take the hygienic aspect into consideration according to: "Provision of ductwork components for hygienic treatment of ventilation systems".

- Basic documents should be chosen in the following order, depending on availability:
  1. ISO Standards.
  2. Eurovent documents.
  3. National standards.

- Basic documents should be chosen in the following order, depending on availability:
  1. Dimensions and tolerances: ISO 7807, Eurovent 2/3, Eurovent 2/4.
  2. Definition of air tightness classes: Eurovent 2/2.
  3. Determination and presentation of air leakage: Eurovent 2/2, Eurovent document in preparation, based on Nordic standards, HVCA DW 143.
  4. Establishing of strength requirements: Eurovent document in preparation, based on Nordic standards, HVCA DW 143.
  5. Determination, testing and presentation of strength: Eurovent document in preparation, based on Nordic standards.
  6. Determination and presentation of energy loss: Test method in preparation by Cetiat.
  7. Determination and definition of classes of corrosion protection: Swedish document.
  8. Identification of ductwork components: HVCA document.

Most of these topics have been dealt with for the following duct systems:
1. Circular ducts made of sheet steel.
2. Rectangular ducts made of Sheet steel
3. Flexible duct
4. Ducts made of insulated duct board
5. Nonmetallic ducts.

The Working Group has produced a number of standards listed in the reference section below.

3 CONCLUSIONS

The world is getting more and more complicated and standards make it a little bit easier. The standards of CEN TC 156 Working Group 3 may not be very important for our life but they make it easier for the manufacturers to compete on equal conditions. They make perfect platform for more important standards for example the ones made to fulfil the Energy Performance for Building Directive and they are a small part of the European and National building legislation.

4 REFERENCES

EN 1505:1997	Ventilation for buildings - Sheet metal air ducts and fittings with rectangular cross section - Dimensions
EN 14239:2004	Ventilation for buildings - Ductwork - Measurements of ductwork surface area
EN 12236:2002	Ventilation for buildings - Ductwork hangers and supports - Requirements for strength
EN 12220:1998	Ventilation for buildings - Ductwork - Dimensions of circular flanges for general ventilation
EN 13180:2001	Ventilation for buildings - Ductwork - Dimensions and mechanical requirements for flexible ducts
EN 12237:2003	Ventilation for buildings - Ductwork - Strength and leakage of circular sheet metal ducts
CR 14378:2002	Ventilation for buildings - Experimental determination of mechanical energy loss coefficients of air handling components
EN 13403:2003	Ventilation for buildings - Non-metallic ducts - Ductwork made from insulation duct boards
EN 12097:2006	Ventilation for buildings - Ductwork - Requirements for ductwork components to facilitate maintenance of ductwork systems
EN 1507:2006	Ventilation for buildings - Sheet metal air ducts with rectangular section - Requirements for strength and leakage
EN 1506:2007	Ventilation for buildings - Sheet metal air ducts and fittings with circular section - Dimensions
EN 15727:2010	Ventilation for buildings - Ducts and ductwork components, leakage classification and testing
EN 15780:2011	Ventilation for buildings - Ductwork - Cleanliness of ventilation systems

DURABILITY AND MEASUREMENT UNCERTAINTY OF AIRTIGHTNESS IN EXTREMELY AIRTIGHT DWELLINGS

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ABSTRACT

In this paper we present a series of leakage tests on extremely airtight dwellings (ACH_{50} < 0.6 upon completion) in which the durability of the airtightness and the measurement uncertainty involved are assessed. In literature, repeatability and reproducibility issues have been discussed by several authors, along with influences of weather. It remains unclear, however, to what extent the available uncertainty intervals are relative or absolute. With the current tendency towards extremely low leakage levels and the introduction of airtightness requirements in building codes, the further exploration of this issue has become crucial.
In this paper, 4 aspects are studied consecutively: the repeatability and reproducibility of the fan pressurization method in extremely airtight houses, the impact of weather conditions on the measurements, the impact of the age of the construction and the reproducibility of the airtightness level in repeated construction of virtually identical houses. The latter is limited to short term effects since all dwellings (n = 15) were completed after 2010.
The results show similar relative repeatability and reproducibility intervals to those found in literature. The rather large effects of weather conditions reported in previous studies could not be reproduced. Normal wear and tear due to occupation of the dwelling proved to introduce substantial relative deterioration of the airtightness of the building shell (20-100% increase in leakage), although in absolute values, the additional leaks were modest and the buildings remained very airtight. In general, we conclude that pressurization tests render robust results in extremely tight construction, but with respect to ambitious leakage limits, test conditions and small preparation details such as the locking of window hardware can easily determine whether the dwelling will pass or fail.

KEYWORDS

Blowerdoor, reproducibility, durability, uncertainty

1 INTRODUCTION

Given Europe's ambitions to cut down CO_2 emissions, all new-built houses will need to be constructed as nearly zero energy buildings by the end of 2020. While the public and building industry is well aware of the need for well-insulated buildings, there is still much room for improvement in terms of airtightness. In Belgium, for example, the median leakage level of standard construction in 2010 was just under 6 ACH at 50 Pa pressure difference (Laverge et al., 2010), about 10 times as much as the limit imposed by the Passive Haus Institut to obtain the passive house certificate (ACH_{50} < 0.6).
Since new standards are emerging and maximum air leakage limits are imposed in energy performance codes, the need for a reliable test method and reliable results is growing. Although the European standard EN 13829 (CEN, 2001) describes the preparation of the

building and explains in detail how the measurements should be performed, there still is room for interpretation. In Belgium, some of this ambiguity has been addressed in a separate guideline for tests within the framework of the official Energy Performance of Buildings (EPB) calculation (2013), but a number of issues are very case dependent and decisions on how to deal with them have to be taken by the tester on site.
The growing (financial) consequences of the result of a blowerdoor measurement put increasing stress on the reliability of these tests, especially in extremely airtight construction. In these cases, a modest absolute difference in leakage can make a large difference relative to the very low leakage limit imposed. Having well-trained test operators, reliable equipment, clear standard regulations and calculation methods are evident prerequisites for reliable results. Even if all the above conditions are met, measurement uncertainties will occur due to the effects of wind and temperature or the specifics of the installation of the equipment. It’s important to be able to estimate and evaluate these uncertainties in order to compare test results and to define maximum wind speeds during the test.
It’s also important to study the long-term variation of air leakage. Do blowerdoor test results remain stable during the changing seasons? If not, how big is the variation that occurs? Is this variation uniform for all building methods? What’s the relation to the prevailing climate? Should airtightness parameters be corrected for these seasonal effects to obtain an objective result? And for the project-owner: when is the best time to test?
Besides seasonal effects, air barriers, like all building components, may be subject to degradation due to wear and tear, resulting in a rise in the air leakage after some years. It’s essential to evaluate which materials or elements are responsible for this rise in order to build future houses with a more durable airtightness barrier, as well as to estimate infiltration losses over the course of the buildings lifespan.
In addition to the reliability and reproducibility of test results, the increasing stress, with the attached financial liabilities, on tight construction also intensifies the need for data on the reproducibility of the leakage level of a construction itself. How robust is the leakage level achieved by a specific construction method?
This paper addresses these issues with respect to houses at passive house leakage levels, since these represent the lowest 10% of the tested leakage rates included in the official EPB database in Belgium (De Baets and Jonckheere, 2013) and can therefore be considered to be representative for future airtight construction. In the next section, reproducibility issues of the pressurization test are discussed. The third section addresses the impact of weather conditions, while the fourth looks at the evolution of the leakage level over time. The reproducibility of the construction method is dealt with in the last section, followed by a conclusion section that sums up all results. For all tests a Minneapolis blower door type 4.1 was used.

2 TEST REPRODUCIBILITY

2.1 Literature

A number of studies available in literature give an idea of the expected variation when performing airtightness measurements.
A study by Delmotte and Laverge reported a standard deviation of 1.4% and maximum variation of 4.0% for 10 pressurization tests under repeatability circumstances (same operator, same test equipment) (Delmotte and Laverge, 2011). These numbers increased to 2.7% and 7.9% under reproducibility circumstances (different operators, different test equipment).
Persily performed 28 pressurization tests on a house during a three-month period and found a 5.5% standard deviation and 19.4% maximum variation (Persily, 1982). When only retaining the results from relatively calm weather days (< 2.5 m/s wind speed) these statistics decreased to 1.7% and 4.8%, showing the high impact of wind speed on the repeatability of

pressurization test results. High wind speeds seem to be correlated with higher leakage results.
Kim and Shaw studied the air leakage from a house during a one-week period. They noticed similar results as the previous researches: a standard deviation of 1.7% and maximal variation of 4.2% (Kim and Shaw, 1986). The highest air leakages were measured during low wind speeds, in contrary to Persily's findings.

2.2 Measurement results

The repeatability of the pressurization test was studied on 2 passive houses in Belgium. Passive houses are currently the only buildings subjected to maximum airtightness levels (ACH_{50} < 0.6) and can be regarded as 'a look in the future' of the housing market.
House 1 is a semi-detached house, built in a traditional way using masonry walls. 58 pressurization tests with identical setup were performed on 10 different days in a 15-month period between December 2012 and February 2014. On average, the measurements showed a standard deviation of 1.4% and a maximum variation of 3.5% within the same day (Table 1). The mean leakage measured in all tests was 234 m^3/h at 50 Pa pressure difference, corresponding to 0.55 ACH_{50}.

Figure 1. Picture of the façade of house 1 (left) and house 2 (right)

House 2 is a detached house with a wood-frame structure. It was tested 53 times in total, on 9 test days within the same period as for House 1. Here, the variation within the same day was higher with an average standard deviation of 2.3% and an average maximum variation of 6.0%. These uncertainties are well in line with those reported in literature. When absolute values are considered, the average standard deviation within a test day is 3.31 and 3.33 m^3/h, for house 1 and 2 resp., suggesting that the error due to repeatability might be more absolute in nature than relative, although Murphy suggests that, in contrast, the error is relative to the square of the leakage (Murphy et al., 1991) and Delmotte did not find a clear correlation (Delmotte and Laverge, 2011).
No relation between wind speed and air leakage could be discovered, but the results on windy days show generally more variation. Wind speeds were derived from online weather observations, which are not always reliable. A mobile weather station would be a much better option to monitor wind speed and direction.
A few additional tests were performed, to evaluate the effect of decisions in building preparation or test procedure – without neglecting EN 13829.

Table 1: Overview of air leakage measured in house 1

test day	date	V_{50} (m^3/h)	ACH_{50} (-)	stdev (%)	max var (%)
day 1	17/12/2012	221.7	0.52	1.39	4.06
day 2	7/01/2013	219.8	0.51	1.18	4.32
day 3	29/01/2013	229.3	0.54	1.13	3.49
day 4	19/02/2013	223.2	0.52	1.05	2.69
day 5	11/03/2013	241.4	0.57	1.03	4.35
day 6	9/04/2013	246.2	0.58	0.92	1.83
day 7	29/04/2013	248.7	0.58	0.49	1.41
day 8	22/11/2013	236.2	0.55	2.52	3.87
day 9	20/12/2013	234.5	0.55	0.60	1.28
day 10	13/02/2014	237.5	0.56	3.86	7.16

As different pressure differences over the building envelope exist due to wind and temperature effects, the place of the external pressure point might influence the measurement results. Pressurization tests were performed on both passive houses, while changing the external pressure tap around the building. Although t-tests showed no significant difference between different positions of the pressure tube in most cases, we can’t conclude that this effect is negligible. Probably the effect is masked by the usual variation in airtightness measurements.

Despite well-trained test operators, reliable equipment, clear standard regulations and calculation methods, pressurization tests will always show some uncertainty due to changing natural pressure differences around the building. As wind fluctuates constantly in speed and direction, natural pressure differences across the building envelope also change. External reference taps and baseline pressure corrections are intended to cancel out these fluctuations and thereby obtain reliable test results. For this to work, however, the external reference tap should be in the ‘open field’. In actual measurements, this is often impossible to achieve because of the presence of all kinds of objects around the dwelling that create wind-induced turbulences.

The results of consecutively executed natural pressure difference measurements within a total time span of 5 minutes reported in Table 2, show that even 30-second averages can change substantially in a short period of time, with a difference of more than 8 Pa over 5 minutes for the south facade. Baseline pressures, measured before and after a pressurization test, which typically takes 20-30 minutes, are therefore not per se representative for the natural pressure difference during the test and can lead to false corrections.

Testing at high pressure differences reduces the impact of these changing boundary conditions and, renders more robust results, as was clearly demonstrated by Delmotte (Delmotte and Laverge, 2011).

Generally, the fan should be installed in the most airtight opening of the building envelope. As this is difficult to evaluate without performing multiple tests, the test operator will use the front door in most of the cases. But when the front door is leaky, this leakage is of course not included in the measurements. In house 2, measurements were performed on both doors, showing a decrease by 22.3 m^3/h (or 15.5%) when the fan was installed in the back door.

Standards give no clear indication whether doors should be locked during the pressurization test, or just closed, without turning the key. As leaks around doors can be almost eliminated by locking the door in case a multi-fix hardware is available, this decision can have a substantial impact on leakage results. In house 2, not locking the front or back door during a test led to an increase in leakage by 40.2 m^3/h and 41.2 m^3/h. As the overall leakage in these dwellings is very low, this resulted in a relative increase of the total leakage of 33.4% and 28.9% respectively.

Table 2: Consecutively measured 30-second averaged natural pressure differences at north, east and south facades for house 1.

measurement	North	East	South
measurement 1	-0.1	0.8	-2.2
measurement 2	-0.5	0.5	-3
measurement 3	-0.5	0.9	-2.3
measurement 4	-0.4	0.4	-2.2
measurement 5	0.2	1.3	-5.6
measurement 6	-0.6	0.6	-6.9
measurement 7	-1	-0.5	-3.7
measurement 8	-0.6	-0.7	1.3
measurement 9	-0.8	-0.8	-0.8
measurement 10	-1.1	-1.2	-2.6
average	-0.54	0.13	-2.8
minimum	-1.1	-1.2	-6.9
maximum	0.2	1.3	1.3

Passive houses are equipped with mechanical supply and exhaust ventilation. These systems should be sealed off during the pressurization test, since the supply and exhaust openings represent huge leaks that are not relevant for infiltration in the building envelope.
It’s up to the test operator to decide where the ventilation system will be disconnected. This can be anywhere between the external air supply/exhaust and the local air vents in the rooms. Obviously, the test result includes leakage through the ducts from the air supply/exhaust up to the point where the seals for the test are applied. Tests on House 1 show that leaks between ventilation ductwork, heat exchanger, ventilation system and silencer are responsible for an additional 43.3 m^3/h, or 17.6% of the total leakage when the ventilation system is not sealed off directly after the external air intake and discharge points.
These examples show how apparently small decisions can have an impact on the overall air leakage. This is especially true for passive houses, which have a very small air leakage and thus, although the change in absolute value of the leakage is modest, will show a huge relative difference when something in the building preparation or test procedure is changed. This makes comparing test results difficult when looking for seasonal variation or durability effects, especially when pressurization tests are not performed by the same operator.

3 SEASONAL VARIATION

3.1 Literature

Studies reporting seasonal variation are available in literature, but building methods and prevailing climate should be taken in mind when drawing conclusions. Persily performed multiple tests during one year on a house in Princeton (Persily, 1982). He noticed up to 30% higher air leakage in the winter compared to the lowest measurement results in summer. Air humidity on the contrary, showed peaks in the hot, humid summers and very low values in de the dry, cold winters. Persily claims the moisture in the hot summer air results in a swelling of the wood. When the wood swells, small cracks and gaps in the construction disappear resulting in a lower air leakage.
Kim and Shaw measured a seasonal variation up to 20% when performing a similar study on two houses in Canada, with the highest values appearing after the dry winter period (Kim and Shaw, 1986). One of these houses had an air leakage very similar to the air leakage in passive houses.

Dickinson and Feustel performed a study on 10 houses in three different climates (Dickinson and Feustel, 1986). Three houses were located in Truckee and showed a clear seasonal variation due to the extreme climate, with up to 45% higher leakage in summer, compared to the winter measurements. This variation is very similar for all three houses, although the highest variation occurs in the house with the highest air leakage and vice versa. The fact that winter measurements show lower values is mainly attributed to the presence of large quantities of snow on and around the building envelope.

3.2 Measurement results

During the period December 2012 – April 2013, multiple pressurization tests were performed on both passive houses every three weeks. The results show an increase in average air leakage over each single test day by 13% over the course of the first 7 test days in house 1. Seven months later, the seasonal variation measurements were continued on a regular basis and showed a 5% decrease. These results are shown in Figure 2.

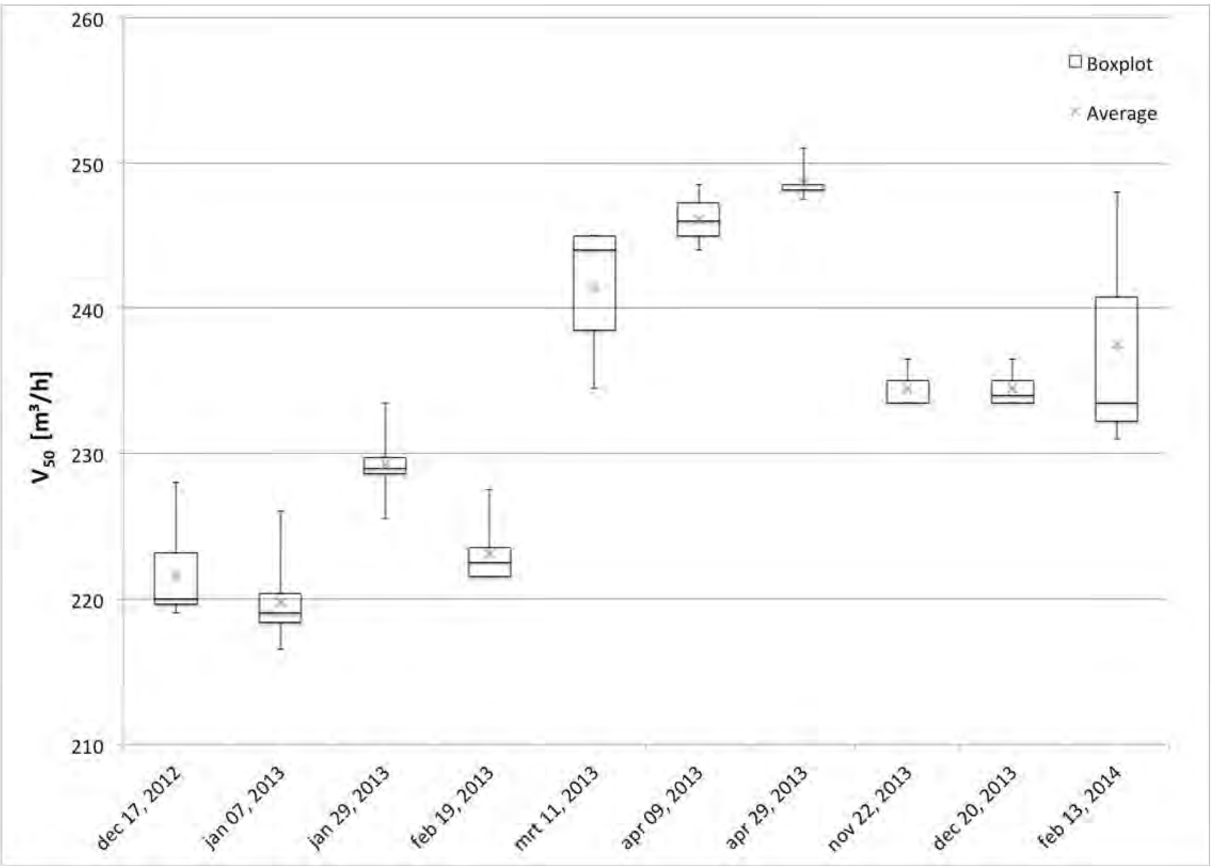

Figure 2. Boxplot and average of the leakage measured on 7 test days between December 2012 and February 2014 in house 1.

Although small in relative magnitude, the variation seems to follow a yearly pattern with lower leakage in winter period and higher leakage in summer. These findings are the opposite of what Kim and Shaw (Kim and Shaw, 1986) or Dickinson and Feustel (Dickinson and Feustel, 1986) concluded. No substantial snowing occurred during the measurement period. The increase in leakage therefore has to be attributed to other factors. One potential mechanism is the differential thermal dilation of the masonry/concrete structure and the plaster that assures most of the airtightness. This would create fine cracks in the plaster, especially at edges and joints, leading to increased leakage. Another, more straightforward

explanation might be a change in the air tightness of the ventilation ductwork, as this was dismantled after the 4th and 7th test day to evaluate the influence of the sealing place (e.g. before/after heat exchanger), as discussed earlier.
During the first 7 test days, the air leakage results of house 2 show no clear rising or declining trend. The results fluctuate around the average value, with a slight increase of 6% between the first and the 7th test day (Figure 3). When the seasonal variation tests were continued half a year later, the air leakage has decreased by 25%.
Although house 2 has a wood construction with wooden windows and doors and the Belgian climate creates a similar evolution in moisture content, it does not display the decreasing leakage in summer reported by Persily (Persily, 1982). In contrast to traditional wood frame construction, in passive houses such as this, all joints between wood panels and around envelope details such as windows etc. are sealed with tape. As these joints already are airtight, the swelling of wooden elements can't make them more airtight.
It's unclear what has caused the 25% air leakage decrease in the last three test days. As these measurements were conducted during the winter period, just like the measurements from the first three test days, a seasonal variation seems unlikely. Possibly the firm owning the show house has made some interventions due to the reported leakage paths from the first measurements.

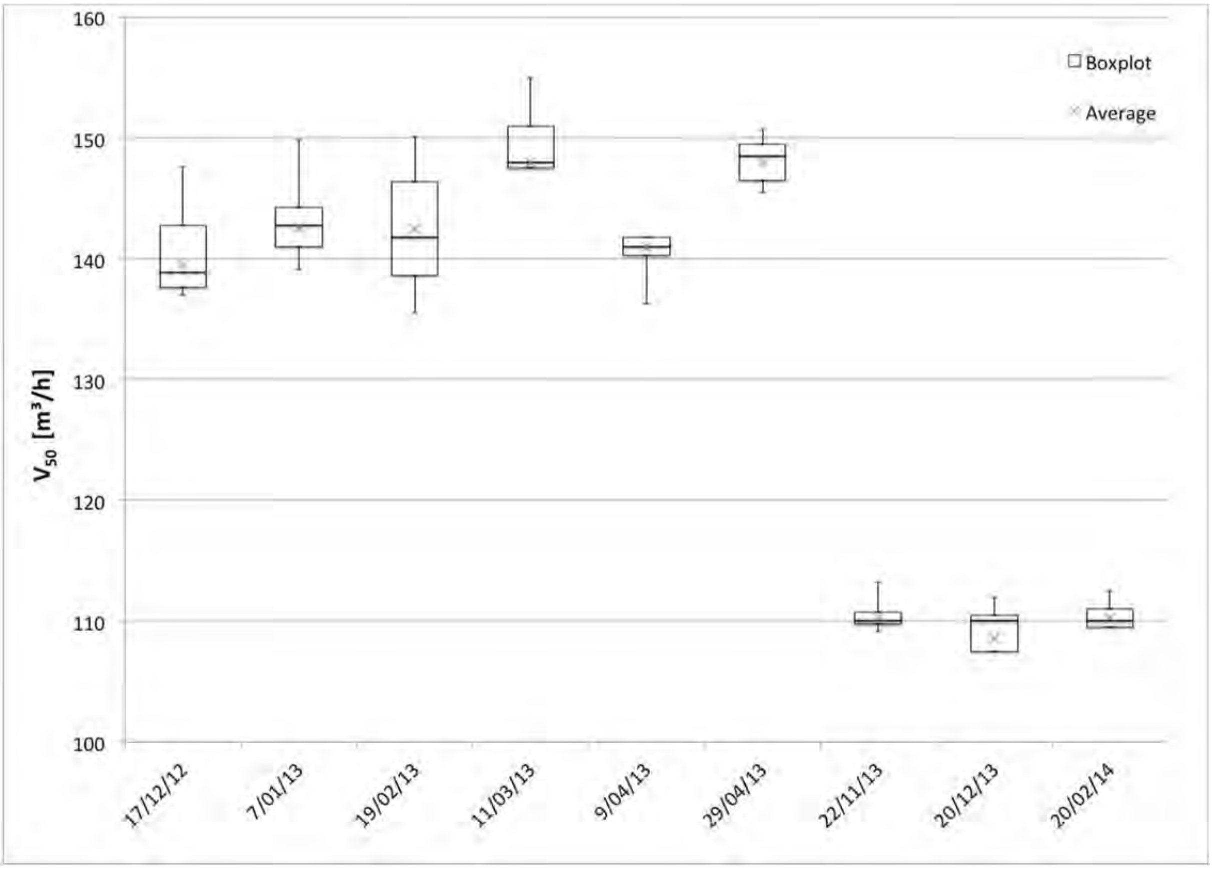

Figure 3. Boxplot and average of the leakage measured on 6 test days between December 2012 and February 2014 in house 2.

4 LEAKAGE DURABILITY

4.1 Literature

Some studies cover groups of buildings, which have been tested and retested after some years to evaluate the durability of airtightness. Due to the variation of building techniques and

materials, conclusions are hard to draw. It’s essential to make sure no interventions that may affect the airtightness were executed on the buildings between successive pressurization tests.
Lux tested a group of 30 relatively airtight (ACH_{50} < 3.0) houses six years after the original tests were carried out (Lux, 1987).
Only five houses were withheld, in which no interventions were performed. The evolution of the air leakage varies greatly, the maximum increase measured was 32% but one of the houses became 9% more airtight.
Proskiw and Eng performed tests on a group of 24 houses over a period of three years (Proskiw and Eng, 1997). The houses were on average five years old at the start of the test. Although the biggest evolution in airtightness is expected the first years after construction, Proskiw and Eng measured a maximum increase in air tightness of 37% and a 30% decrease over this period. The leakage of a group of houses with a PE airtightness barrier increased by 3% on average, while a group with a drywall airtightness barrier increased by 7%.
Reiß and Erhorn compared the air leakage of 52 passive houses after construction and after a two-year period (Reiß and Erhorn, 2003). They reported an average 30% increase, which seems dramatic but corresponds to an increase of the ACH_{50} by 0.09. Increases in leakage rate as high as 216 % were seen, but a few houses also showed a decrease up to 39%.

4.2 Measurement results

Pressurization tests were performed on two estates of similar passive houses in Temse and Bredene, Belgium. The results of these tests were compared to the original test reports, generated from pressurization tests performed on completion of the dwellings one or two years earlier. No specific interventions on the dwellings occurred, making the results representative for normal wear and tear of the construction.
Eight houses were tested in Temse, as reported in Table 3, showing an average increase in air leakage by 29%. Seven tests were performed in Bredene (Table 4), showing an average increase of 45% in air leakage. A few extreme values are responsible for this high increase. The median of 25% might be a more representative value for the increase in air leakage. Some tests were probably not performed using the same building preparation as the original tests. It’s not clear whether all doors were locked during the original tests and the sealing of the ventilation system might not have been executed in exactly the same way as during the original pressurization tests. As discussed in Paragraph 2, these ‘small’ differences can have a serious relative impact on air leakage. This makes qualifying the individual evolutions in air tightness very difficult. Despite these uncertainties, it seems clear that there is an increase in air leakage over the years, of an order in line with findings reported in literature. Similar leaks around the doors and service penetrations in the roofs were detected in Bredene as in Temse. These leaks seem to be responsible for a good part of the measured increase.

Table 3. Measured evolution in leakage rates in Temse

House	ACH_{50} (-) 1	ACH_{50} (-) 2	Timespan (months)	$\Delta_{depress.}$ (%)	$\Delta_{press.}$ (%)	$\Delta_{average}$ (%)
house 1	0.43	0.56	19	30	35	32
house 2	0.55	0.81	21	38	55	47
house 3	0.56	0.54	13	2	-9	-3
house 4	0.33	0.43	13	26	34	30
house 5	0.50	0.68	13	33	36	34
house 6	0.59	0.82	19	38	42	40
house 7	0.44	0.56	13	23	27	25
house 8	0.46	0.64	18	30	30	30
mean	0.48	0.63	16	28	31	29
median	0.48	0.60	-	30	35	31
stdev (%)	18	22	-	-	-	-
max var (%)	54	62	-	-	-	-

Table 4. Measured evolution in leakage rates in Bredene

House	ACH_{50} (-) 1	ACH_{50} (-) 2	Timespan (months)	$\Delta_{depress.}$ (%)	$\Delta_{press.}$ (%)	$\Delta_{average}$ (%)
house 1	0.41	0.51	5	43	10	25
house 2	0.58	0.68	3	14	24	19
house 3	0.59	0.69	14	23	10	17
house 4	0.41	0.75	9	115	56	86
house 5	0.5	0.64	15	21	32	27
house 6	0.34	0.75	19	127	114	120
house 7	0.6	0.73	27	21	21	21
mean	0.49	0.68	13	52	38	45
median	0.50	0.69	-	23	24	25
stdev (%)	21	12	-	-	-	-
max var (%)	53	35	-	-	-	-

The super isolating doors might suffer from high temperature differences, which cause the door to warp. These slightly warped doors create leaks at the upper and lower parts of the doors. Reinforced doors might tackle this problem. The leaks surrounding roof penetrations can be avoided by using custom airtight sockets or top hat sleeves. Note that, although considerable relative deteriorations are found, in absolute terms, the buildings remain extremely airtight.

5 WORKMANSHIP REPRODUCIBILITY

Since the dwellings in Bredene and Temse are virtually identical, the results reported above also allow to assess the reproducibility of the leakage level achieved by the used construction method and workmanship. All houses in both case studies have masonry and concrete building envelopes, with PVC window frames and a wood frame roof construction. The air barrier of the building envelope is plaster, while for the roof a polyethylene membrane is used.

The results from these measurements are compared to those of a similar case study in Kortrijk in Figure 4 (Laverge et al., 2010). The Kortrijk case study consists of 29 identical houses built according to standard Belgian construction methods, which is very similar to the construction of the passive houses, but without specific attention to air tightness. The variance coefficients go down from 28% in the Kortrijk case to 12% in Bredene. Since only passive houses are included in the measurements in Temse and Bredene and this requires a maximum leakage level of 0.6 ACH_{50}, outliers will not appear in these samples. Nevertheless, the progress in reproducibility is remarkable. Note that, although vastly improved, the reproducibility of the workmanship is still far below that of the leakage test itself, the variance coefficient of which is around 0.025 (Delmotte and Laverge, 2011).

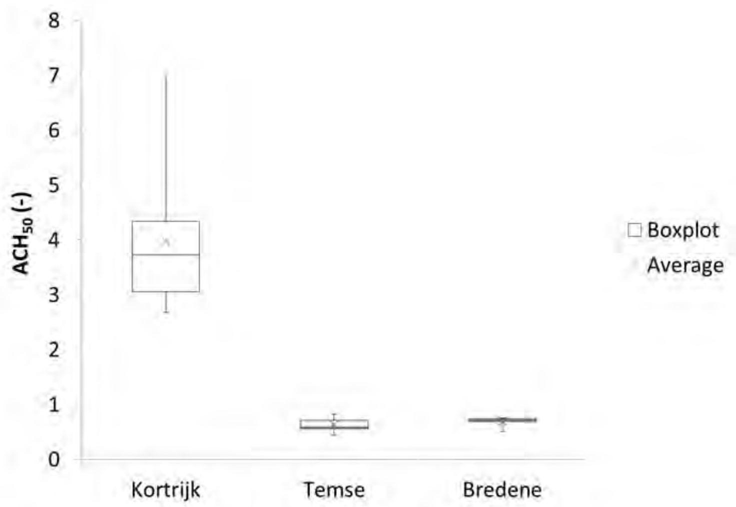

Figure 4. Boxplot of the leakage level (ACH_{50}) for the cases from 3 different case studies of quasi identical houses (N = 29, 8 and 7 respectively)

6 CONCLUSIONS

In this paper, 4 aspects of building leakage in extremely airtight houses are studied: the repeatability and reproducibility of the fan pressurization method, the impact of climate conditions on the measurements, the impact of the age of the construction and the reproducibility of the airtightness level in repeated construction of virtually identical houses. The leakage levels of the houses included in the tests are in the 10^{th} percentile of those included in the official Belgian energy performance database.

The results show similar relative repeatability and reproducibility intervals to those found in literature. The rather large effects of climate conditions reported in previous studies could not be reproduced. Normal wear and tear due to occupation of the dwelling proved to introduce substantial relative deterioration of the airtightness of the building shell (20-100% increase in leakage), although in absolute values, the additional leaks were modest and the buildings remained very airtight. The reproducibility of the workmanship in extremely airtight construction proved better than that found in standard construction.

In general, we conclude that pressurization tests render robust results in extremely tight construction, but with respect to ambitious leakage limits, test conditions and small details such as the locking of window hardware can easily determine whether the dwelling will pass or fail.

7 REFERENCES

2013. Bijkomende specificaties voor de meting van de luchtdichtheid van gebouwen in het kader van de EPB-regelgeving (in Dutch), In: Overheid, V. (ed), Brussels, 16.

Cen. 2001. Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified), CEN.

De Baets K. and Jonckheere T. 2013. Cijferraport energieprestatieregelgeving: Procedures, resultaten en energetische karakteristieken van het Vlaamse gebouwenbestand - periode 2006 - 2012 (in Dutch), Brussel, VEA, 51.

Delmotte C. and Laverge J. 2011. Interlaboratory tests for the determination of repeatability and reproducibility of buildings airtightness measuremetnts, *32nd AIVC conference and 1st TightVent Conference: Towards Optimal Airtightness Performance*, Brussels, 9.

Dickinson J.B. and Feustel H.E. 1986. Seasonal variations in effective leakage area, *Thermal performance of the exterior envelopes of buildings III*, Atlanta, ASHRAE, 144-160.

Kim A.K. and Shaw C.Y. 1986. Seasonal variation in airtightness of two detached houses., *Measured Air Leakage of Buildings.*, National Research Council Canada (NRC).

Laverge J. et al. 2010. Airtightness assessment of newly build single family houses in Belgium. In: Proceedings of Buildair 2010, pp. 8.

Lux M.E. 1987. time dependent changes in air leakage of low energy houses having sealed vapour retarders, National Research Council Canada, 25.

Murphy W. et al. 1991. A round robin test of Fan Pressurization Devices, Vol. RP-594, ASHRAE.

Persily A. 1982. Repeatability and Accuracy of Pressurization Testing, *ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelope of Buildings*.

Proskiw G. and Eng P. 1997. Variations in Airtightness of Houses Constructed with Polyethylene and ADA Air Barrier Systems Over a Three-Year Period, *Journal of Building Physics*, 20, 278-296.

Reiß J. and Erhorn H. 2003. Messtechnische Validierung des Energiekonzeptes einer großtechnischen umgesetzten Passivhausentwicklung in Stuttgart-Feuerbach, Fraunhofer Institute for Building Physics, 132.

Airtightness Tests at different wind conditions in a high building

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ABSTRACT

Because of temperature-based uplift within the building and the impact of wind on the building, airtightness measurements of high buildings are especially challenging. Temperature differentials between the building interior and the exterior with particularly high buildings can lead to excessively high baseline pressure differentials on the building envelope while the impact of wind can cause their extreme fluctuation, both of which may have a negative effect on the measurement.
This paper will present two airtightness measurements with a special test set-up in the same high-rise building at different times, i.e. under windy conditions and in calm weather. The first measurement was conducted at a wind force of 4 Beaufort. Two weeks later, a second airtightness measurement was conducted in calm conditions. This is highly interesting for the measuring practice of large buildings, because the testing date is usually set based on constructional and organizational aspects and only rarely takes into account optimal weather conditions. This presentation compares the test results of both airtightness measurements and in addition to sharing the experience from these measurements is also meant to prompt a discussion of the error of measurement with regard to the measuring standard EN 13829.

Fig. 1: Building view during the measurement in calm conditions (no wind). The measurements were conducted with a Minneapolis BlowerDoor Measuring System.

KEYWORDS

building airtightness, high building, airflow V_{50}, air change rate n_{50}

INTRODUCTION

The challenges when conducting airtightness measurements of tall buildings are as follows:
- How should we deal with the 5-Pascal limit for the baseline pressure differential according to German and European Industrial Standard DIN EN 13289?

- During the depressurization test it must be ensured that the entire building is depressurized.
- During the pressurization test it must be ensured that the entire building is pressurized.
- The pressure drop within the building must be controlled.

The first depressurization and pressurization measurement was conducted under relatively strong windy conditions (4 Beaufort). The testing team consequently asked itself how accurate the measurement was. Fortunately, the measurement could be repeated two weeks later under calm conditions and the measurement results could be compared.

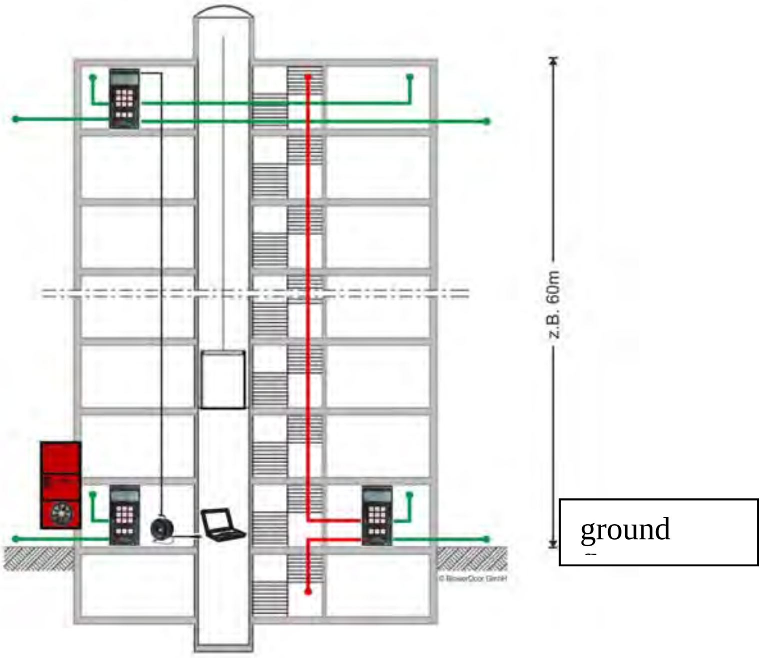

Fig. 2: Set-up of the measuring devices. The measuring data was recorded using the TECLOG software. Since the air flow rate to be measured was below 7,200 m³/h, one Minneapolis BlowerDoor Standard Measuring System (Model 4) sufficed to measure the 23,000 m³ tall building with an envelope area of 10,000 m².

The green lines in the diagram represent the tubes for determining the building pressure differential. On the ground floor, two measuring points have been marked. In reality, there were three. On the top floor, you have two measuring points, one on the upwind and one on the downwind side in order to cover the extremes. The red line represents the tube for determining the pressure differential within the building.
To prepare the building all interior doors were opened (approx. 250 doors), the flaps of the ventilation system and the stairwell smoke extraction were closed. The stairwell served as the re-flow path.

Summary of the results
The mean value V_{50} of the measurement under windy conditions is 4,893 m³/h. Under calm conditions (no wind), the mean value V_{50} was measured at 4,846 m³/h. This means more than 99 percent conformity of the results.

Airtightness measurement under windy conditions
The following graph shows the pressure curves of the first airtightness measurement under windy conditions. The wind force is estimated at 4 Beaufort. The inside temperature was 19°C, the outside temperature 10°C.

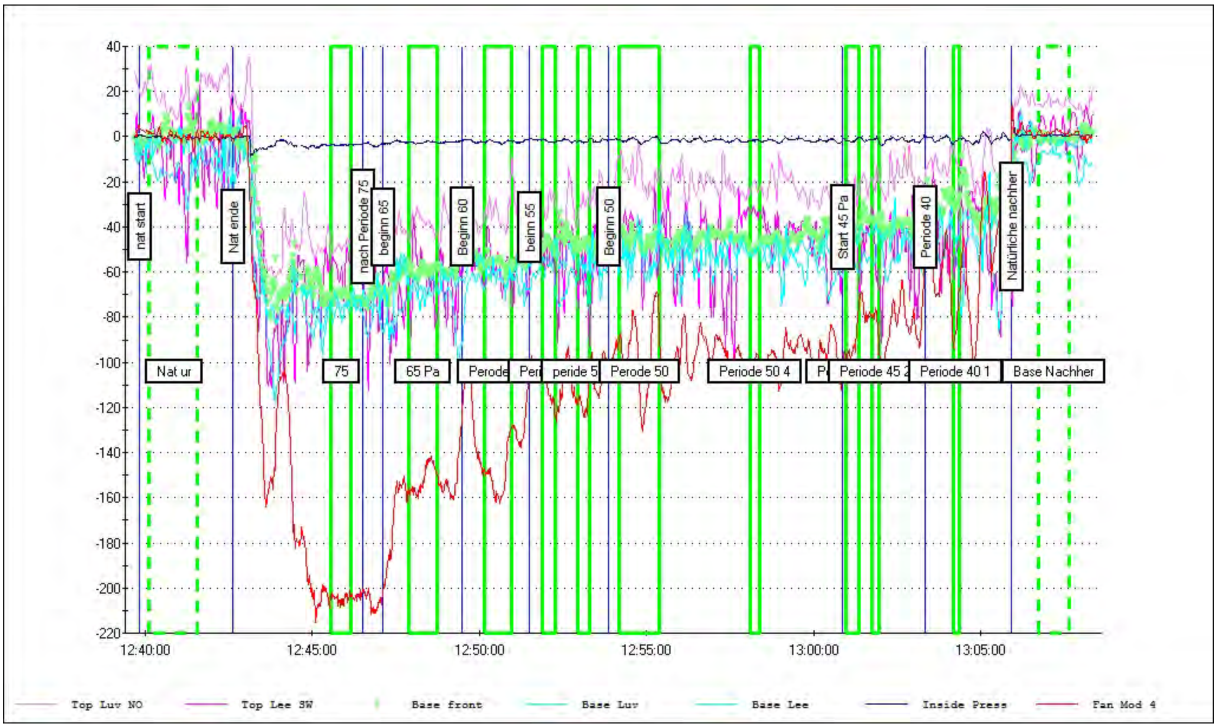

Fig. 3: Recording of the depressurization measurement under windy conditions on 5 February, 2011.

Explanations of the graph:
The curves "Top Luv No" [Top Upwind North] and "Top Lee SW" [Top Downwind Southwest] show the building pressure differentials measured on the top floor. "Base front", "Base Luv" [Base Upwind], and "Base Lee" [Base Downwind] show the building pressure differentials measured on the ground floor. "Inside Pressure" is the pressure differential in the building. "Fan Model 4" shows the pressure at the Minneapolis BlowerDoor fan for determining the air-flow rate.
The pressure differential in the building (Inside Pressure) clearly was below 5 Pascal.

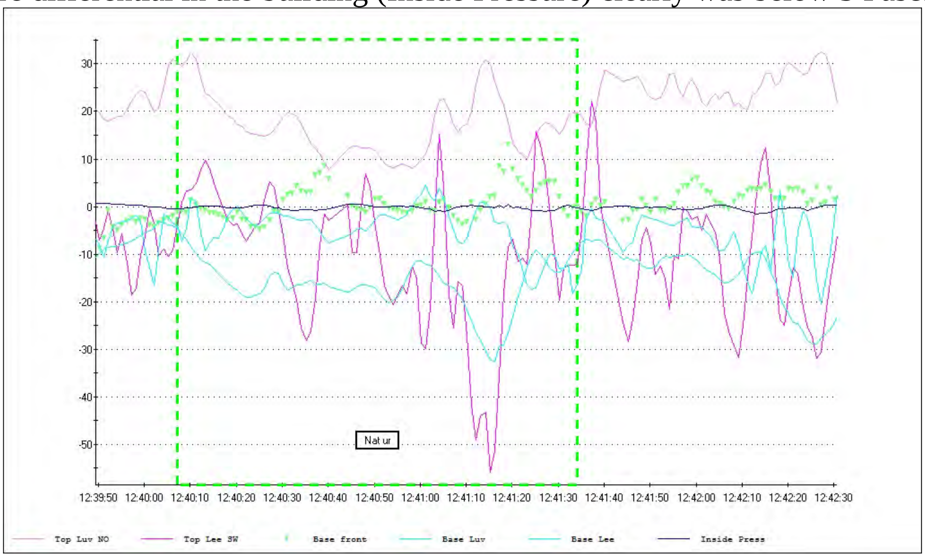

Fig. 4: Recording of the baseline pressure differentials before the measurement under windy conditions on 5 February, 2011.

The mean baseline pressure at the three measuring points on the ground floor before the measurement was -6.8 Pascal (measured over a period of 90 seconds). It ranges from -30 Pascal to +15 Pascal. On the top floor it is 30 Pascal on the upwind side and -55 Pascal on the downwind side. The baseline pressure differential after the measurement is -3.9 Pascal.

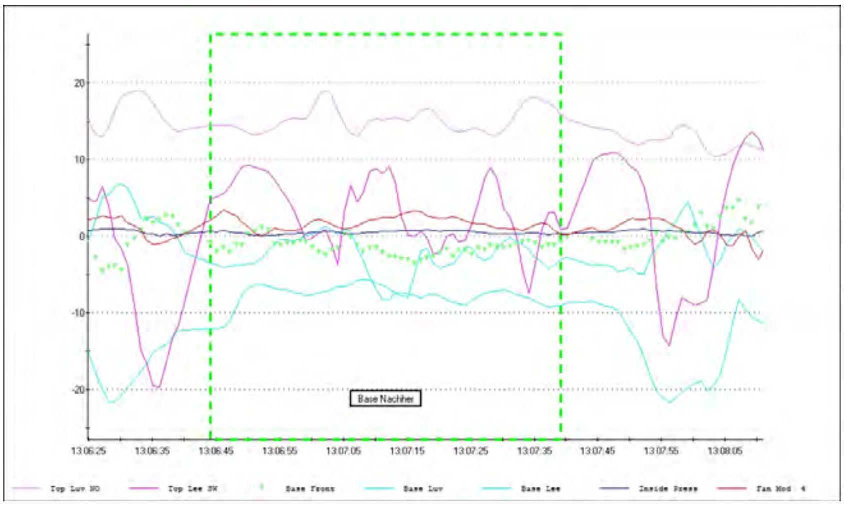

Fig. 5: Recording of the baseline pressure differential after the pressurization measurement under windy conditions on 5 February, 2011.

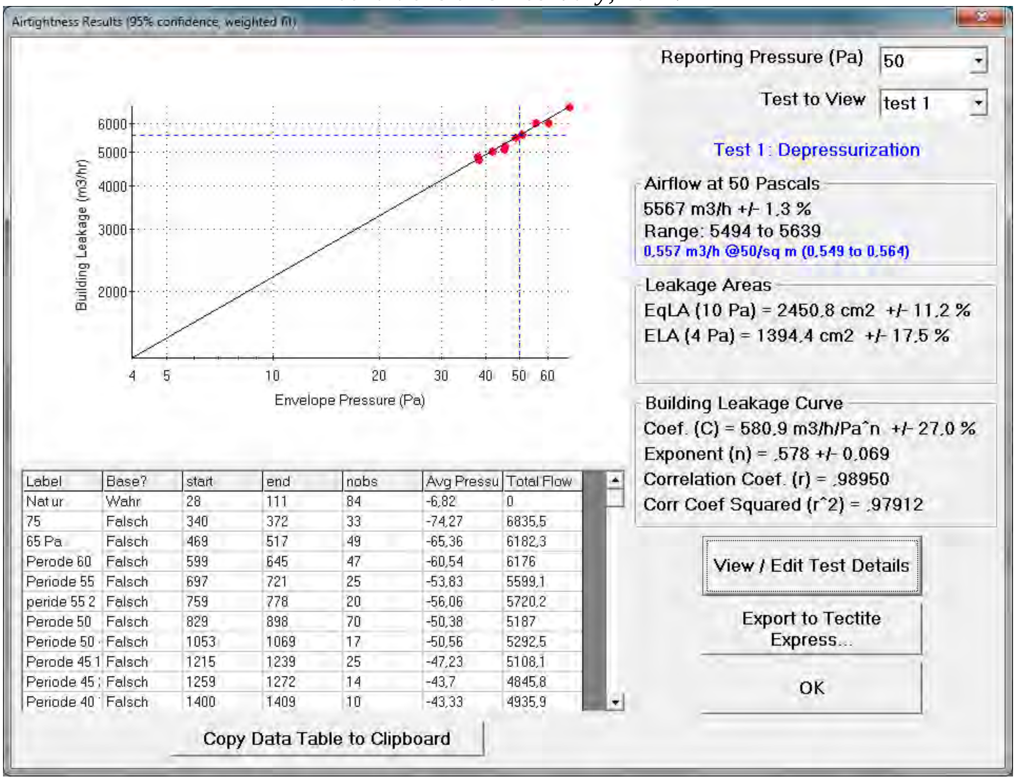

Fig. 6: Measuring result of the depressurization measurement under windy conditions (program window of the TECTITE Express 3.0 software).

The measuring curve in Fig. 3 shows that building pressure differentials from -75 Pascal to -40 Pascal were selected for the evaluation. These periods are marked by the fields edged in green. In total, 10 measuring periods were selected.

The recording of the measurement for the pressurization test can be seen in the following graph:

Fig. 7: Measuring curve for pressurization under windy conditions on 5 February, 2011.

The result of the depressurization test is V_{50} = 5,567 m³/h and of the pressurization test V_{50} = 4,219 m³/h. The mean value is V_{50} = 4,893 m³/h.

Measurement under calm conditions (no wind)

The measurement under calm conditions was conducted on 20 February, 2011 at a wind force of 1 to 2 Beaufort. The inside temperature was 17°C, the outside temperature 3°C.

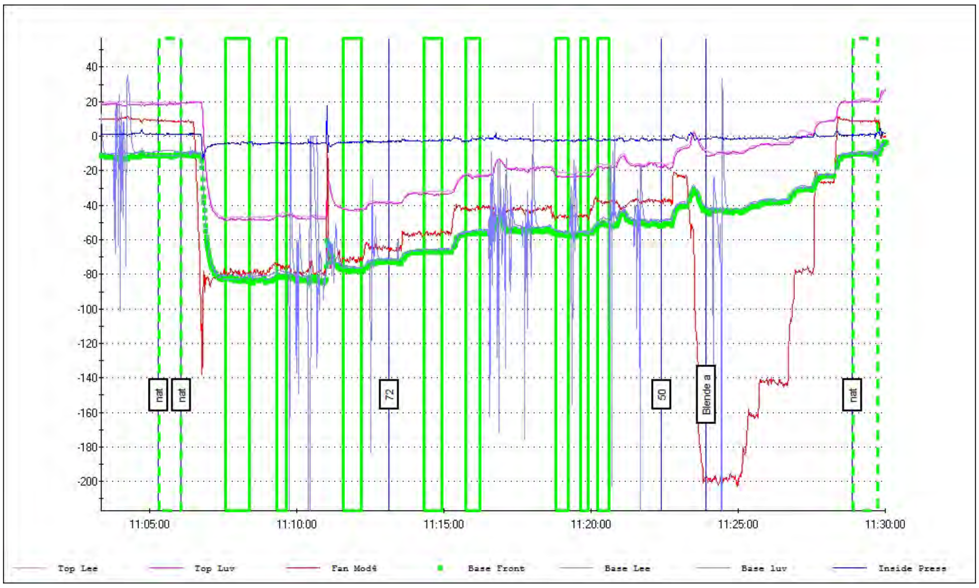

Fig. 8: Recording of the depressurization measurement under calm conditions (no wind) on 20 February, 2011.

Explanations of the graph:

The curves “Top Luv No” [Top Upwind North] and “Top Lee SW” [Top Downwind Southwest] show the building pressure differentials measured on the top floor. “Base front”, “Base Luv” [Base Upwind], and “Base Lee” [Base Downwind] show the building pressure differentials measured on the ground floor. “Inside Pressure” is the pressure differential in the building. “Fan Model 4” shows the pressure at the Minneapolis BlowerDoor fan for determining the air-flow rate.

The measuring curve in Fig. 3 shows that building pressure differentials from -75 Pascal to -40 Pascal were selected for the evaluation. These periods are marked by the fields edged in green. In total, 10 measuring periods were selected. This measurement also resulted in a building pressure differential inside the building (“Inside Pressure”) clearly below 5 Pascal.

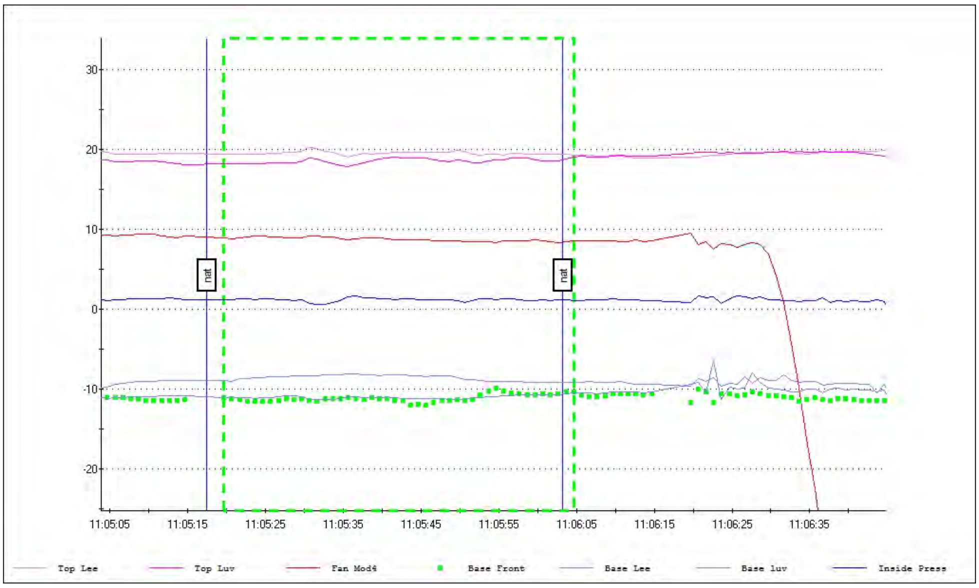

Fig. 9: Recording of the baseline pressure differentials before the measurement (under calm conditions) on 20 February, 2011.

In the recording of the baseline pressure differential before the measurement (Fig. 9) the difference of 30 Pascal between the ground floor and the top floor stands out. In the following graph (Fig. 10), the baseline pressure differential after the measurement is very similar to the previous one. The high pressure differentials stem from the high temperature difference between the inside and the outside.

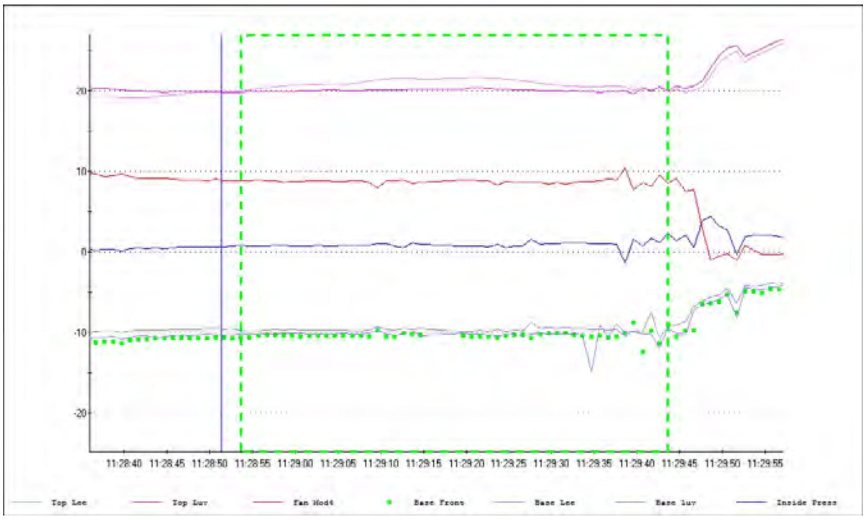

Fig. 10: Recording of the baseline pressure differential after the measurement (under calm conditions) on 20 February, 2011.

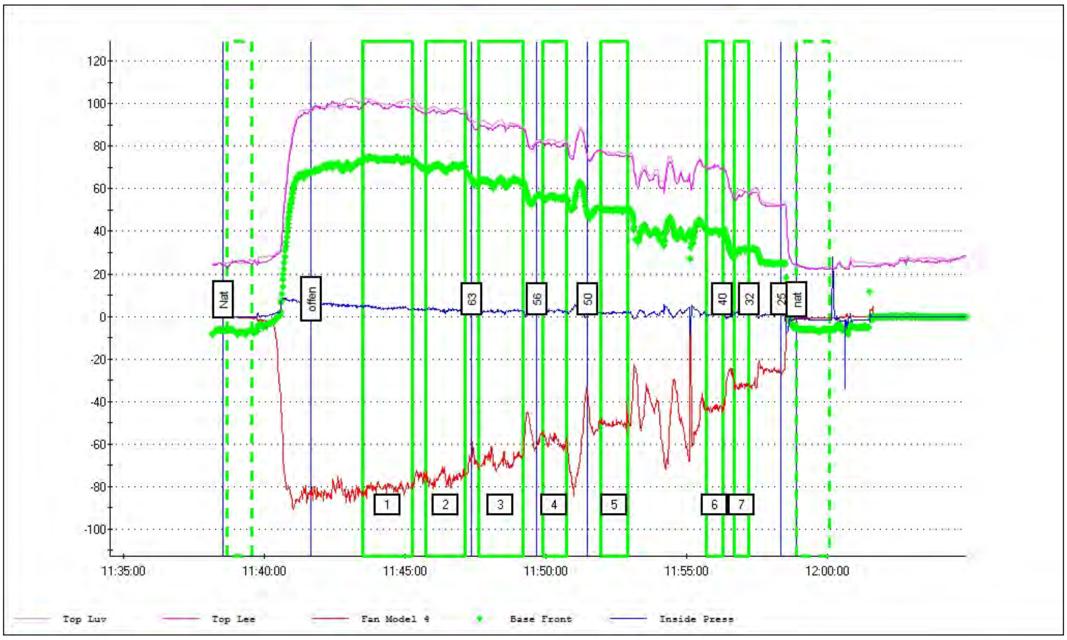

Fig. 11: Pressurization measurement under calm conditions (measurement on 20 February, 2011).

During the final pressurization measurement, the natural baseline differential on the ground floor could only be recorded at the fan (“Base Front”), because some floorers were working in the area of the tubes at the reference points Upside and Downside and frequently stepped on the tubes.

The pressurization on the top floor at all seven measuring stages (fields edged in green) was 25 Pascal higher than on the ground floor.

Overview of the measuring results:

1: Measurement under windy conditions					2: Measurement under calm conditions			
depressurization	5567	m^3/h			depressurization	4833	m^3/h	
pressurization	4219	m^3/h			pressurization	4859	m^3/h	
mean value	**4893**	**m^3/h**	**(under windy conditions)**		**mean value**	**4846**	**m^3/h**	**(under calm conditions**

The mean values of the measurement under windy conditions and under calm conditions in absolute terms differ by 47 m^3/h, i.e. by less than one percent.

Conclusion

With measurements at high and sometimes strongly fluctuating pressure conditions, a pressurization and depressurization test must be conducted. The measuring result is generated from the mean. By contrast, with a measurement according to German and European Industrial Standard DIN EN 13289 either a depressurization or a pressurization test is enough to get a measuring result.

When testing tall buildings, the extremes of the pressure conditions must be monitored in order to ensure, for example, that depressurization is achieved at all points of the building envelope when conducting a depressurization test.

Conclusion: This measurement is practical proof that the measuring method described above also allows for conducting sufficiently accurate measurements in conditions not according to standard. In order to confirm this, further theoretical considerations and practical experience must be taken into account. It must, for example, be analyzed to which extent the leakage distribution influences the measuring result.

Hypothesis: When conducting a depressurization and pressurization test as well as monitoring extreme pressures, the requirements of DIN EN 13289 with regard to the limits of the baseline pressure differential (±5Pascal) must not be observed.

ON THE USE OF INFRARED THERMOGRAPHY TO ASSESS AIR INFILTRATION IN BUILDING ENVELOPES

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ABSTRACT

Infrared thermography is an interesting technique that is often used for qualitative assessment of the building envelope. The method allows to detect construction deficiencies e.g. thermal bridges, moisture problems, incomplete blown-in retrofit insulation of cavity walls, wind washing in insulation layers etc. in a very fast way. Another application is the use of infrared thermography in combination with pressurization tests in order to detect air leakages through the building envelope. As the airtightness plays a major role in reducing heat losses in well-insulated buildings, this is an interesting method as it allows for a quick qualitative evaluation of possible air infiltration/exfiltration locations. This paper offers a first attempt to analyse the important parameters (e.g. pressure difference, temperature difference between inside and outside) for a thermographic airtightness survey by means of simulations and in situ measurements. Furthermore an overview of the currently existing literature on thermographic surveys of the building envelope is given. Simulations show that the pressure difference does not play a significant role for the execution of a thermographic survey, while the indoor-outdoor temperature difference changes the outcome of the survey significantly. Without taking into account the environmental conditions, the survey can be either executed from the inside or along the outside. Solar radiation, wind and rain can although have a negative influence on the measurement results taken from the outside.

KEYWORDS

Quantitative/qualitative infrared thermography, Air infiltration, Pressurization test

1 INTRODUCTION

Europe has high ambitions concerning energy efficiency and the reduction of greenhouse gas emissions. By 2050, one of the goals is to reduce the CO_2-emissions by more than 80 % (BPIE, 2011). Therefore one of the key factors to satisfy the need for energy efficiency is a high performing building envelope. This can be achieved by a high insulation level and en excellent airtightness. For this application, thermography offers an alternative solution on top of the traditional techniques e.g. smoke detection, pressurization test, tracer gas measurements . It can not only be used for the detection of insulation defects but also for the detection of air leakages.

In combination with a pressurization fan, air leakage spots can easily and instantaneously be visualised by using a thermographic camera. On top of that, ongoing research reveals the possibilities of thermography to quantify and asses the severity of an individual air leakage spot. Together with the fact that thermography is fast and non-destructive, makes it a promising tool for building energy audits.

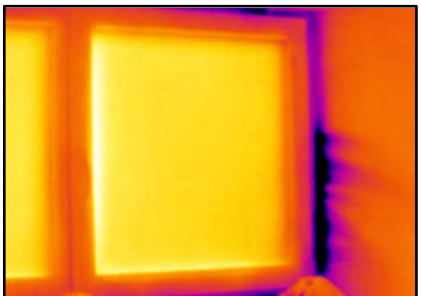

Figure 1: Example of an airtightness survey using a thermographic camera (blue spots are coldest and white spots are warmest)

Figure 1 illustrates the use of thermography in combination with a pressurization fan (imposing a pressure difference of 50Pa) to detect air infiltration spots. In this case, cold outside air was infiltrating through the window-wall interface. In general air leakage spots can be easily recognized by the temperature pattern as shown on the right hand side of Figure 1.

In the following section an overview of the currently existing literature concerning thermography for air leakage detection and the influential parameters are discussed. In section 3 an overview of the basic concepts of thermographic airtightness surveys is given. In section 4 a simulation model of a window-wall interface is developed to investigate the possibility of quantitative research. Sections 5 and 6 offer an overview of the first results, the conclusion and possibilities for further research.

2 LITERATURE OVERVIEW

The existing standards concerning infrared thermography in buildings give a set of recommendations and guidelines for thermographic surveys. These stay rather superficial and impractical, while it is in profit for every thermographer to obtain delineated guidelines in order to make the measurements reproducible. For air leakage surveys for example, it can be expected that the inside-outside temperature difference and the pressure difference imposed by the pressurization fan will play an important role. However, rarely a distinction between air leakage measurements or insulation defect measurements is made.

2.1 Normative literature

In general, guidelines concerning the required skills of the thermographer and the minimum requirements of a thermographic report are found. As in the NBN EN 13187 (CEN, 1999), these regulations mainly concern the formal aspect of a thermographic measurement. Almost no attention is paid to the influential parameters during a thermographic survey. While, environmental factors for example, are perhaps the most important aspect of a thermographic measurement, they are rarely mentioned in the normative literature. And when they are listed however, the different standards contain different values (CEN, 1999), (RESNET, 2012), (TheCH, 2010), (ASTM, 2011). For the wind velocity for example, a maximum wind velocity of 6,7m/s is recommended by ASTM (ASTM,2011) while 3,6m/s is proposed by RESNET (RESNET, 2012). An overview of the different influential environmental factors and their limit value given in normative literature is shown in Table 1.

Table 1: Review of the influencing environmental parameters and their limitations given in standards

	Construction type	Light	Medium	Heavy
Influential parameters	Solar radiation	Not allowed during 3h prior to IR (ASTM, 2011)	Not allowed during 8h prior to IR (ASTM, 2011)	/
		Not allowed 12h prior to IR (CEN, 1999)		
	Wind velocity	Maximum 6,7 m/s for evaluation of insulation defects (ASTM, 2011) Maximum 3,6 m/s (RESNET, 2012)		
	Precipitation	No influence if IR from small distance (TheCH, 2010) Measurement on wet surface or with snow covered surface not allowed (TheCH, 2010)		
	Temperature difference	Δ_{Ti-e} > 10°C during 4h prior to IR for evaluation of insulation defects (RESNET, 2012) ΔT_{i-e} > 1.7°C during 4h prior to IR for evaluation of airtightness (RESNET, 2012) ΔT_{i-e} > 5°C during 24h prior to IR (CEN, 1999)		
	Temperature gradient	ΔT_e < 10°C 24h prior to IR, < 5°C during IR (CEN, 1999) ΔT_i < 2°C during IR (CEN, 1999)		
	Night sky radiation	Ideally IR when fully overcast sky (TheCH, 2010)		

For the specific case of infrared thermography in combination with a pressurization fan little normative information can be found. Among the few, RESNET provides separate guidelines for the execution, the report and the influential parameters during an airtightness survey, for instance a minimum temperature difference between inside and outside of 1,7°C is recommended (RESNET, 2012).

2.2 Scientific literature

Yet there are some authors describing the potential of thermography in combination with a pressurization fan. For example, in (Kalamees, 2007) measurements of the airtightness of a number of Estonian houses are presented and analysed. First the airtightness of each building was measured using a standardized pressurization fan. Then the typical air leakage spots were determined using a thermographic camera in combination with a pressurization fan, providing a negative pressure difference of 50 Pa. It appeared that the typical air leakage places were ceiling/floor-wall interfaces, the window-wall interfaces and the junctions of separating walls with the external walls or roof. In Figure 2 an air leakage spot at the wall-ceiling interface can be clearly spotted. As mentioned before the specific shape of the temperature pattern reveals the presence of an air leakage. A thermal bridge would be much more delineated and geometrical in shape. The penetrations of ventilation ducts and electrical sockets through the air barrier were also typical leakage spots.

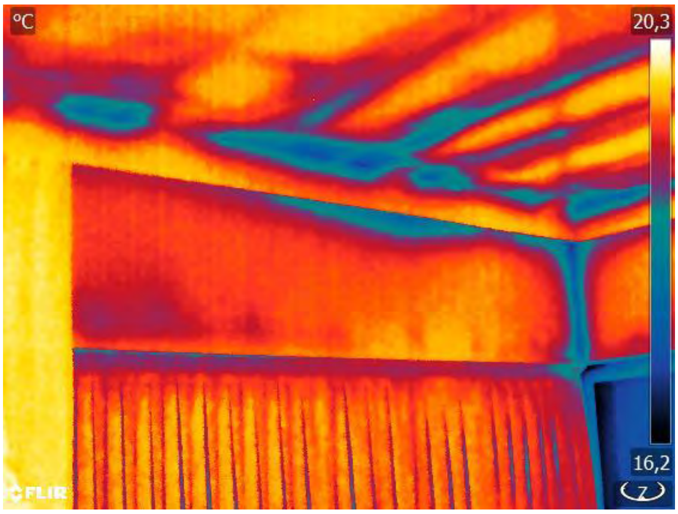

Figure 2: Air leakage spot at wall – ceiling intersection

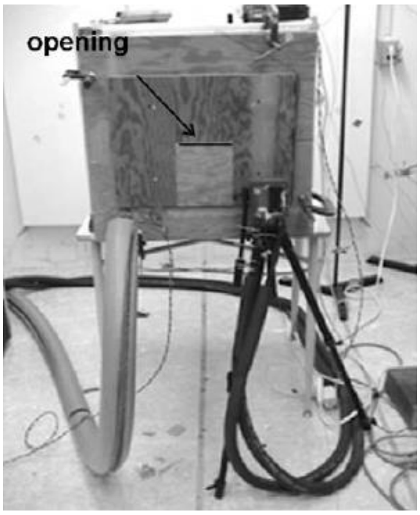

Figure 3: Experimental set-up to determine shape and dimensions of cracks (Bérubé Dufour, 2009)

In a second study a first step towards quantitative airtightness measurements using thermography is taken (Bérubé Dufour, 2009). Here, two image-processing methodologies to determine the dimensions of air leakage spots (cracks) are developed based on laboratory measurements. The experimental set up is depicted in Figure 3 and consists of a pressurized box holding the specimen panel with a crack of known dimensions in the middle of it and an air handling system. Using the thermographic pictures the authors try to make a reconstruction of the geometry of the crack. Though it can be argued that this sort of experiment is representative for the air leakage spots that are commonly found in building envelopes. In reality, air leakage spots will often be found at junctions or penetrations of the building envelope (Kalamees, 2007).

3 THERMOGRAPHIC AIRTIGHTNESS SURVEY

A thermographic airtightness survey can be performed with or without the use of a pressurization fan. When the outside wind pressure is rather high and a sufficient temperature difference between inside and outside (table 1) is reached, the most important air leakage spots can be visualised with a thermographic camera without the use of a pressurization fan. In most cases this will be sufficient to perform a qualitative thermographic research. When one is interested to visualise also the smaller air leakage spots or to use the thermographic information for quantitative purposes, a pressurization fan is recommended nonetheless a pressurization fan can also be used for qualitative measurements. Up till now in situ thermographic surveys are rarely executed for quantitative purposes. During a qualitative thermographic survey variations in the wall surface temperature are being observed without the need of an exact knowledge of that temperature. If it is the intention to obtain quantitative measurements a statement concerning the severity of the deficiency has to be made and therefore wall surface temperatures needs to be known as accurate as possible. Therefore a couple of parameters have to be determined using one of the standardized methods (ASTM, 2002 & 2005). When looking at the general formulation for infrared radiation at opaque material surfaces three terms can be distinguished (Barreira, 2013), (Dall'O', 2013) :

$$_{ot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau\, W_{amb} + (1-\tau)W_{a\ m} \qquad (1)$$

Where W_{tot} is the total radiation captured by the thermographic camera [W/m²], W_{obj} the object radiation (with object temperature) [W/m²], W_{amb} the ambient radiation (with temperature of environment) [W/m²], W_{atm} the atmospheric radiation (with atmospheric temperature) [W/m²], τ the transmission trough the atmosphere [-] and ε the emissivity of the material [-]. The methods to determine these parameters (e.g. emissivity, reflectivity, transmission of the atmosphere, transmissivity) are included in standards and scientific literature (ASTM, 2005), (Albatici, 2013), (Marinetti, 2012), (Ciocia, 2012), (ASTM, 2002).Once these parameters are determined, the thermographer is ready to perform a thermographic quantitative survey. Due to the dynamic behaviour of the environment (e.g. solar radiation, wind, precipitation, orientation,…), the thermographer is obliged to determine these parameters for each room and each material.

In the Figures below thermographic images of an air leakage spot at the same window-wall interface with the use of a pressurization fan after 5 (Figure 4) and 10 (Figure 5) minutes are depicted.
Figure 4 shows a thermographic image of a window-wall interface at a pressure difference of 50 Pa after 5 minutes. The air leakage spots can already clearly be seen in the picture with their typical shape. Both pictures were taken in the morning of a sunny day, with direct solar radiation on the window examined. That is why the window seems warmer than the walls (50cm Cellular concrete block – 4cm Air cavity – 9cm bricks). With an outdoor temperature of 4,4°C and an indoor temperature of 20.5°C, the temperature difference between the inside and outside was greater than 15°C. In Figure 5, that is taken after 10 minutes, the cold outside air has clearly cooled down the window frame and the wall niche. In the graphs the temperature profile along the line L0, starting at the window frame, is given. An obvious change in temperature can be noticed, and the complete width of the window frame has cooled down. At the location of the air leakage spot (crack) the temperature reaches its minimum.

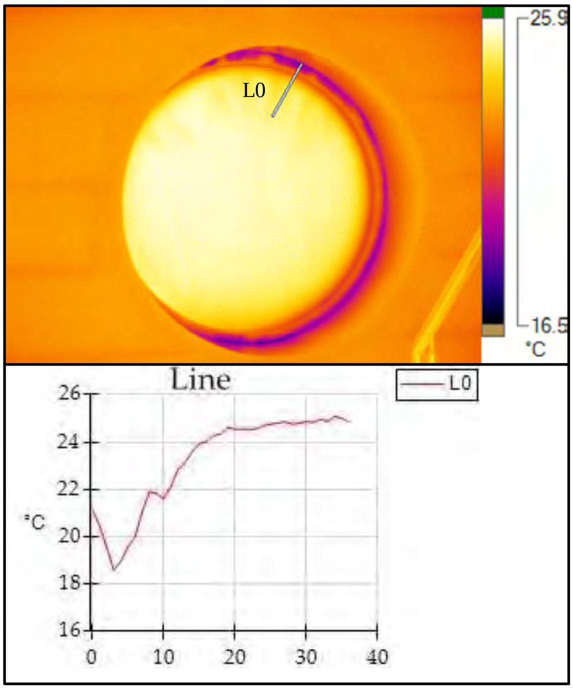

Figure 4: Window-wall interface at a pressure difference of 50 Pa after 5 minutes

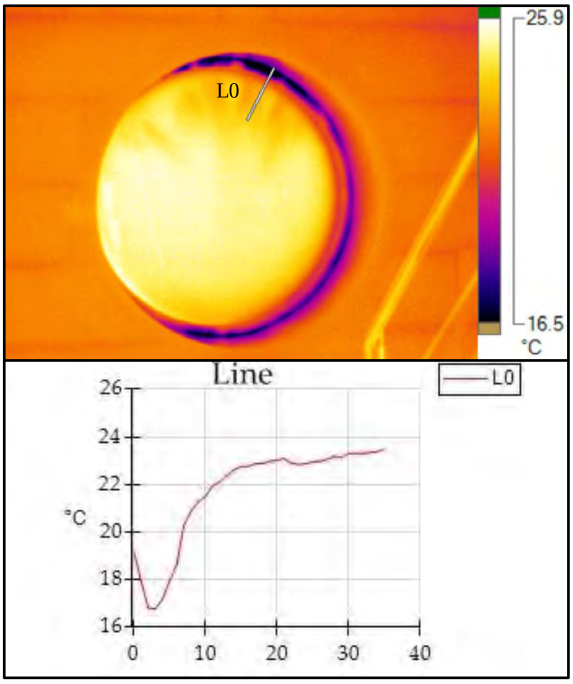

Figure 5: Window-wall interface at a pressure difference of 50 Pa after 10 minutes

While a standardized pressurization test has to be performed with a varying pressure difference between 0 and 100Pa (minimum top value is 60Pa), a constant pressure difference is recommended while executing a thermographic survey in combination with a pressurization fan. (CEN, 2001) A possible examination method consists in bringing the building to a constant over- or underpressure (infiltration of cold outside air/exfiltration of warm inside air), and then monitoring the temperature profile of the wall surface temperature after 5, 10, 15, 20, 25 and 30 minutes. As shown in Figures 4 and 5 a change of the shape of the temperature pattern caused by an air leakage will be seen. This way it can be identified whether a temperature variation is an air leakage spot or a thermal bridge, because the temperature pattern on the wall surface will not change when the deficiency that causes it is a thermal bridge. It is therefore best to start with a general thermographic examination of the whole building before using a pressurization fan to distinguish air leakages from thermal bridges (where necessary).

4 PRELIMINARY DYNAMIC SIMULATIONS

In this section the influence of the pressure difference imposed by the pressurization fan and the temperature difference between outside and inside on the course of the temperature profile is being analysed using a simulation model in Voltra. Voltra allows to study 3D dynamic heat transfer using a finite element method. Also air flows through predefined paths can be included in the model (Physibel, 2008). Both possible methods - overpressure and underpressure- are being examined with changing pressure differences from 20Pa up to 100Pa and changing temperature differences from 10°C up to 30°C. The simulation results will be compared with in situ measurements to evaluate whether similar trends are being observed.

4.1 Assumptions and simulation model preparation

A simplified simulation model of a window-wall intersection of 1m height is modelled (Figure 6). An air leakage ("crack") with dimensions 1000mm x 10mm was modelled. Several assumptions were made:

- Environmental factors like the sun, wind or rain are neglected
- The indoor temperature is kept constant at 20°C
- The outside temperature during one simulation is also kept constant -> stationary simulations!
- The window glazing (e) is replaced by an opaque material with an equivalent U-value (1 W/m²K)
- The wall structure is composed of (from inside to outside) 15mm gypsum (a) - 190mm reinforced concrete (b) - 100mm insulation (with λ=0.025 W/mK) (c) - 90mm (light) masonry wall (d).
- For the calculation of the convective heat transfer coefficient prior to the simulation the temperature inside the crack was taken as the mean value of the inside and outside temperature. Furthermore the convective heat transfer coefficient was constant over the length of the crack and did not change during the simulations.
- The specific heat and the air density were also derived from the mean indoor-outdoor air temperature.
- It was assumed that the radiative heat transfer over the length of the crack can be neglected compared to the convective heat transfer because the internal crack surfaces have a similar temperature

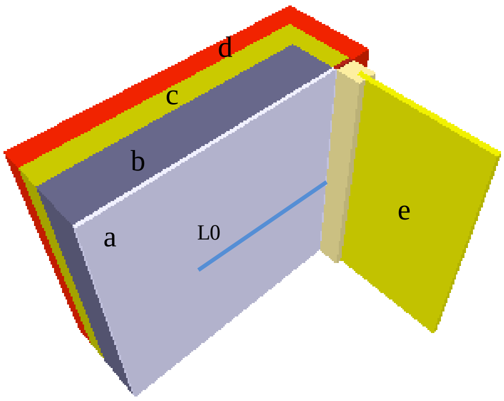

Figure 6: Simulation model used for the analysis

For an estimation of the air flow rate entering the building through the crack, the power law formulation was used (Van Den Bossche, 2005), (Hall, 2004), (AIVC, 1994):

$$V = C\,\Delta P^n \qquad [\text{m}^3/\text{h}] \qquad (2)$$

Where V is the air flow rate [m³/h], C the air flow coefficient [m³/(h Pa^n)], ΔP the pressure difference [Pa] and n the air flow exponent [-]. The values of the air flow coefficient and the air flow exponent are derived for specific air leakage places using in situ and laboratory measurements (Van Den Bossche, 2005), (AIVC, 1994). For the flow exponent a standard value between 0,6 and 0,7 is suggested (Van Den Bossche, 2005), (AIVC, 1994), (Jokisalo, 2009). In the current simulations a value of 0,66 is chosen for the flow exponent. For the flow coefficient values are proposed in (AIVC, 1994) depending on the type of connection. In (Van Den Bossche, 2012) the airtightness levels of 13 different typical North Western European installation methods of a wall-window interface are investigated. This study shows that the airtightness level of the investigated installation methods covers a wide range from 0m³/hm up to 31m³/hm at 50Pa. Considering a regular average Flemish building, with a mean length of window-wall interface of 105m and an average volume of 516,1m³ (Van Den Engel, 2001) this study recommends the air loss of the window-wall interface to be limited below 10% of the overall building leakage. For a newly built detached residential building in Flanders the average building airtightness n50 is 6h^{-1}. Thus the maximal acceptable air loss at the window-wall interface is equal to 3.3m³/hm at 50Pa (Van Den Bossche, 2012). This value was used for the calculation of the air flow coefficient adjusting Eq. (2):

$$C = \frac{V_{50}}{\Delta P^n} * x \qquad [\text{m}^3/\text{h. Pa}^n] \qquad (3)$$

Where V_{50} is the air flow rate per meter window-wall interface length at 50 Pa[m³/h m] and x the length of the window-wall interface. For a simulation model with a window-wall interface length of 1m, this gives a C-value equal to 0,25m³/hPa^n. Using these values for the air flow coefficient and exponent an expected air flow rate can be calculated for different pressure differences using Eq. (2). From the resulting air flow rate and the dimensions of the crack the air velocity inside the crack and the convective heat transfer coefficient can be calculated using the formulas for noncircular ducts (Lienhard, 2003), (Shah, 1975).

4.2 Simulations

12 Different situations are examined using the simulations, each returning a temperature profile along the line L0 starting at the window-wall interface (Table 2, Figure 6). During each simulation the indoor and outdoor temperature remain constant. The only dynamic parameter is the pressure difference that rises from 1Pa (starting situation) to the desired pressure difference (Table 2). The time step used for the simulations is 5 minutes with a start-up duration of 1 day.

Table 2: Different simulation situations

No.	**ΔP (Pa)** T_i = 20°C T_e = 0°C	No.	**T_e (°C)** T_i = 20°C ΔP
1	20	6	-10
2	40	7	-5
3	60	8	0
4	80	9	5
5	100	10	10
		11	15

5 FIRST RESULTS

Some of the preliminary simulation results are shown below. In Figure 7 a comparison is made between the temperature profiles obtained by in situ measurements and by simulation. The temperature profiles obtained from in situ measurements are the same of Figure 4, on the left after 5 minutes and on the right after 10 minutes of depressurization. For the simulation model a similar indoor-outdoor temperature difference and pressure difference is chosen than those during the in situ measurements (e.g. pressure difference of 50Pa and temperature difference of 15°C). It have to be noticed that the trends of the temperature profiles are similar of those obtained from in situ measurements.

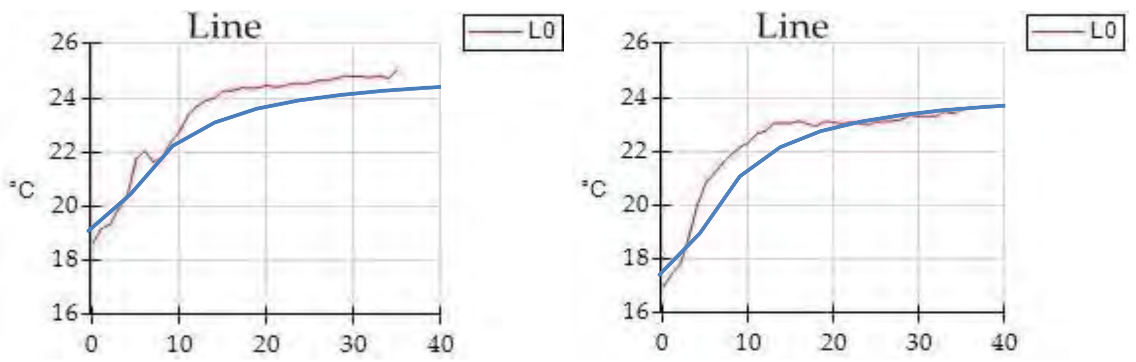

Figure 7: Comparison between the trend of the temperature profiles obtained by simulation (blue line) and in situ measurement (red line)

In Figure 8 a comparison is made between the temperature profiles obtained by depressurizing (left) and pressurizing (right) the building with a pressure difference of +/- 50Pa, an indoor temperature of 20°C and an outdoor temperature of 0°C (temperature difference of 20°C). These curves were obtained by inversing the direction of the ventilation flow inside the crack. A similar (but inverse) trend can be noticed, but taking into account the additional external environmental factors (wind, solar radiation, rain) an indoor measurement with depressurization will be recommended in most cases. In the case of an air cavity wall one may expect that an outdoor survey will be nearly impossible. Further research on that subject needs to be done.

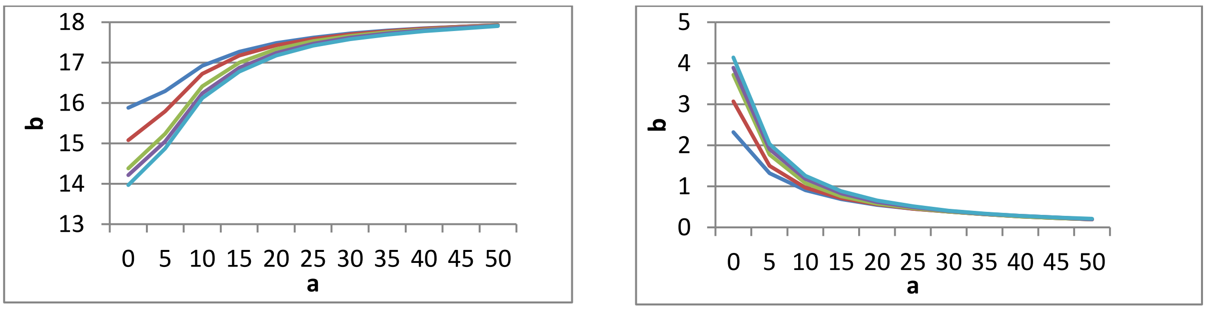

Figure 8: Comparison between the trend of the temperature profiles obtained by depressurization (left) and pressurization (right): a) Distance from leakage spot (mm) ; b) Wall surface temperature (°C)

In Figure 9 the influence of the pressure difference on the course of the temperature profile is depicted. The pressure difference varies from 20 up to 100Pa with a constant indoor air temperature of 20°C and outdoor air temperature of 0°C (ΔP = 20°C). It can be noticed that the pressure difference does not play a significant role, although the temperature difference per time step is slightly increasing with rising pressure difference. For all the examined pressure differences the cooling down of the wall surfaces is insignificant after 30 minutes of pressurization/depressurization, therefore only six time steps are considered.

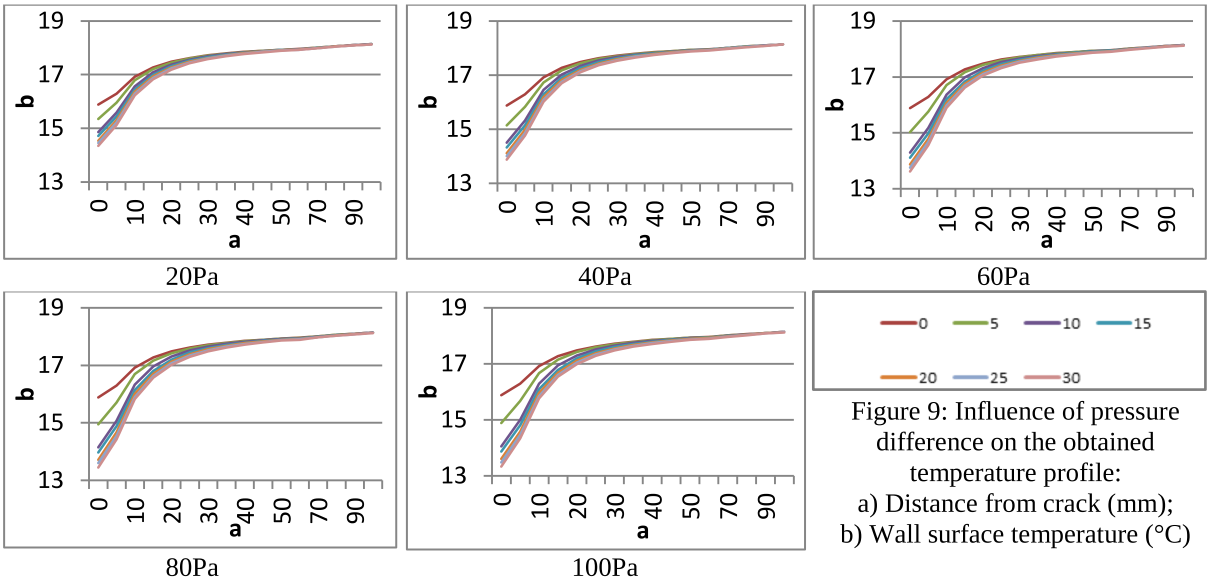

Figure 9: Influence of pressure difference on the obtained temperature profile:
a) Distance from crack (mm);
b) Wall surface temperature (°C)

Finally Figure 10 depicts the influence of the indoor-outdoor temperature difference on the obtained temperature profile. The indoor temperature and the pressure difference is kept constant at respectively 20°C and 50Pa, while the outdoor temperature varies from -10°C up to 15°C (Figure 10) (5°C < ΔT < 30°C) with a step of 5°C. This has a much greater influence than the imposed pressure difference, since the maximum temperature difference of the temperature profiles at start and after 25 minutes ranges from 0,5°C (ΔT = 5°C) to 3°C (ΔT = 30°C). A duration of 25 minutes was chosen following the results derived from Figure 9. When proposing a minimum temperature variation between the 2 time steps of 1°C a thermographic survey can be executed starting from an indoor-outdoor temperature difference of 10°C.

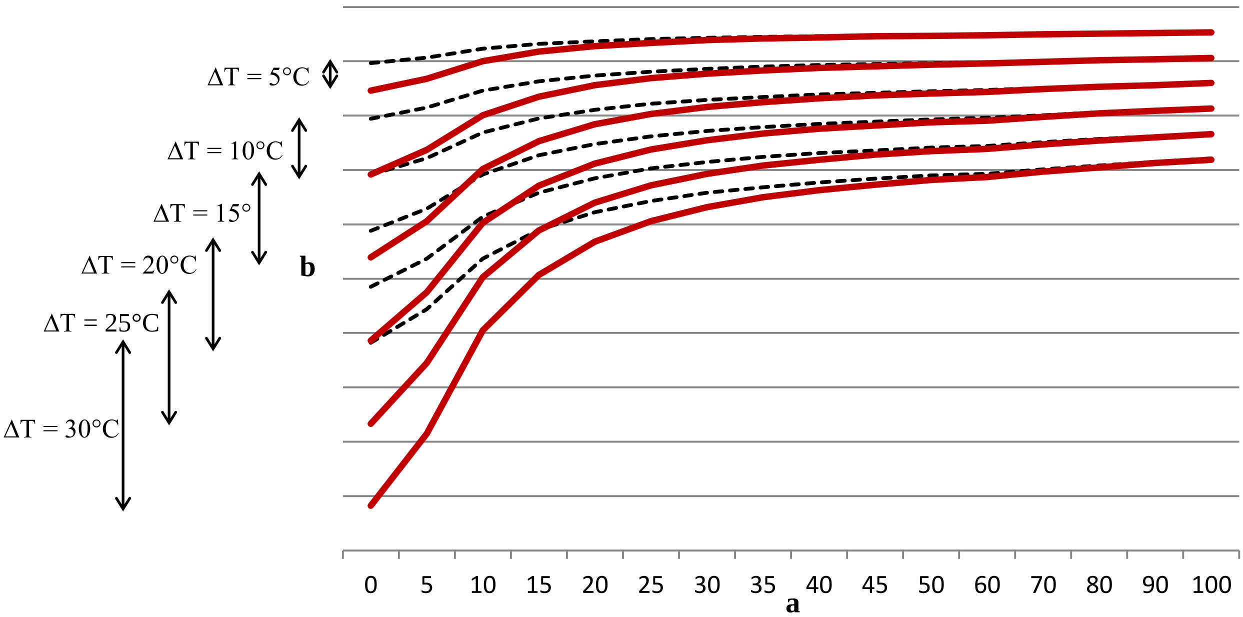

Figure 10: Influence of indoor-outdoor temperature difference on the obtained temperature profile at start (black dotted line) and after 25 minutes (red line): a) Distance from crack (mm); b) Wall surface temperature (°C)

6 CONCLUSIONS & FUTURE WORK

The airtightness of the building envelope plays a major role in the overall energy efficiency of buildings. A thermographic survey in combination with a pressurization fan seems a recommended method to identify the exact place of the air leakage spot. Currently, this method is mainly used to determine where renovation of the building envelope is needed most. Although this method has the potential for quantitative analysis of the buildings airtightness, it is rarely used for this purpose nowadays. These simulations constitute a first step towards a method for quantitative determination of air leakage cracks. Future research has to determine if it is possible to say something about the size/magnitude of the crack using the temperature profiles obtained by thermographic measurements. However, the implemented simulation model has to be finetuned and validated by laboratory tests. Another possibility is extending the current simulation model with other models representing other types of leakage spots.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

AIVC (1994). *Technical Note 44 – An Analysis and Data Summary of the AIVC's Numerical Database.* Air Infiltration and Ventilation Centre.

ALBATICI R., PASSERINI F., TONELLI A. M., GIALANELLA S. (2013). *Assessment of the thermal emissivity value of building materials using an infrared thermovision technique emissometer.* Energy and Buildings 66, pp. 33-40.

ASTM (2002). *ASTM International E 1862 – 97: Standard test methods for measuring and compensating for reflected temperature using infrared imaging radiometers.* American society for testing and materials.

ASTM (2002). *ASTM International E 1897 – 97: Standard test methods for measuring and compensating for transmittance of an attenuating medium using infrared imaging radiometers. American society for testing and materials.*

ASTM (2005). *ASTM International E 1933 – 99a: Standard test methods for measuring and compensating for emissivity using infrared imaging radiometers.* American society for testing and materials.

ASTM (2011). *ASTM International C1060 – 11a: Standard practice for thermographic inspection of insulation installations in envelope cavities of frame buildings.* American society for testing and materials.

BARREIRA E., DE FREITAS S., DE FREITAS V. P., DELGADO J. M. P. Q. (2013). *Infrared thermography application in building diagnosis.* Advanced Structured Materials 36.

BERUBE DUFOUR M., DEROME D., ZMEUREANU R. (2009). *Analysis of thermograms for the estimation of dimensions of cracks in building envelope.* Infrared Physics & Technology 52, pp. 70-78.

BPIE (2011). *Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings.* Buildings performance institute Europe (BPIE), Brussels

CEN (1999). *NBN EN 13187: Thermal Performance of Buildings – Qualitative detection of thermal irregularities in building envelopes – Infrared method.* European Committee for Standardization, Brussels

CEN (2001). *NBN EN 13829: Thermal Performance of Buildings – Determination of Air Permeability of Buildings – Fan Pressurization Method.* European Committee for Standardization, Brussels

CIOCIA C., MARINETTI S. (2012). In situ e*missivity measurement of construction materials.* 11th QIRT Conference.

DALL'O G. (2013). *Infrared Audit.* Green energy audit of buildings, pp. 111 – 125.

HALL M. (2004). *Quantifizierung von Luftdichtheits-Leckagen,* bauen mit holz, nummer 8

JOKISALO J., KURNITSKI J., KORPI M., KALAMEES T., VINHA J. (2009). *Building leakage, infiltration, and energy performance analyses for Finnish detached houses.* Building and Environment 44, pp. 377 - 387

KALAMEES T. (2007). *Air tightness and air leakages of new lightweight single-family detached houses in Estonia.* Building and Environment 42, pp. 2369-2377.

LIENHARD J. H. IV, LIENHARD J. H. V (2003). *A heat transfer textbook: third edition.*

MARINETTI S., CESARATTO P. G. (2012). *Emissivity estimation for accurate quantitative thermography.* NDT&E International 51, pp. 127 – 134

PHYSIBEL, VOLTRA (2008). *3-dimensional dynamic simulation tool using the finite element method.* Version 7.0, Physibel Software, Maldegem, Belgium.

RESNET (2012). *Interim guidelines for thermographic inspections of buildings.* Residential energy services network.

SHAH R. K. (1975). *Laminar flow friction and forced convection heat transfer in ducts of arbitrary geometry.* Int. J. Heat Mass Transfer Vol. 18, pp. 849-862.

TheCH (2010). *Standard de qualité bâtiment.* Association Suisse de thermographie (theCH), Switzerland.

VAN DEN BOSSCHE N. (2005). *Luchtdichtheid: Experimenteel onderzoek naar schattingsmethodes bij woningen.* Thesis.

VAN DEN BOSSCHE N., HUYGHE W., MOENS J., JANSSENS A., DEPAEPE M. (2012). *Airtightness of the window-wall interface in cavity brick walls.* Energy and Buildings 45, pp. 32-42.

VAN DEN ENGEL J. J., OP'T VELD P.J.M. (2001). *Luchtdicht Bouwen – Ontwerpaanbevelingen.* Stichting BouwResearch, Rotterdam, The Netherlands.

FIELD MEASUREMENT TESTING OF AIR TIGHTNESS – EXAMPLE FROM A HOSPITAL PROJECT IN SWEDEN

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ABSTRACT

Over the recent years more effort has been given to air tightness of public buildings such as hospitals. The demand for well insulated buildings increases the importance for low infiltration air rates and thus the air tightness becomes more important. Besides, air infiltration is a quantitative way to put into requirements for the tenders to fulfill.

In this work we describe field measurement of air-tightness on site in early stage of production, as well as field measurement of a whole floor in a hospital building. Hospital buildings are large enclosures that sometimes are difficult to test. We describe some outcomes from evaluating the testing method and how qualitative results as well as quantitative results can be used to improve the building process. Early measurements are important to give input to the builders how to build correct and to give an understanding about the importance of the air-tightness of a building. The different techniques to measure air tightness and to find leaks in the building envelope has been part of a learning process, both for the builders as well as the design team.

The results show, after that the air-tight measurements was started, that the building process has improved. However, another finding from the project is that information should be given continuously and to all builders, as various work teams, has their own way of working with air-tightness.

Measuring building parts should be the first test to evaluate different constructions and how the construction has been sealed. In the work described in this paper the building was divided by a temporary construction made by plastic film, adhesive tape everywhere where the plastic film meets another material and where the plastic film is overlapping. Butyl-based adhesive strip was used under the floor joist, at the corners and under the ceiling joist. The measurements showed that there was an air-leakage between ceiling and outer walls. This air-leakage was evaluated by a small box for only that part. By this test a suitable method involving air-tight foam was used and the results from measurements after the action shows air-leakage close to zero.

The result from the whole floor measurement shows higher air-infiltration than the requirement. The contractor will take action to improve the air-permeability. From the

experience of the measurements one last conclusion is that a design that emphasise air-tightness is the first step to achieve an air-thigh building.

KEYWORDS

Air-tightness, Hospital buildings, early stage, field measurement testing.

1 INTRODUCTION

Health care environments are essential for a sustainable development of society, especially from a social point of view. Health care buildings, e.g. hospitals, are buildings that are built to stand for several years. They could therefore serve as good examples of sustainable architecture, and low-energy demand.

Due to increased need for health care and the fact that the main part of Swedish hospital buildings were built in the 60's and the 70's and need to be refurbished and there are several construction projects regarding new hospital buildings in Sweden. Most of them endeavour for high energy efficient standard. In new constructions there is often ambitious goal on air-tightness, as in a well-insulated construction infiltration rates is relatively more important. One part to achieve an air-tight construction is to measure the air- tightness continuously during the building process. Measuring the air- tightness is both a way to examine the construction and a way to learn for the project the air- tightness for different constructions. This paper describes the work with measuring air-tightness in one of the most energy efficient hospital buildings in Sweden. The measurements have been used for both qualitative and quantitative examination of the project.

This article describes field measurement of air-tightness on site in early stage of production of a new hospital building. Different kinds of measurements have been used and in this article we present 1) Spot-checks of parts of the building envelope, for example a floor divided into parts by temporary stud walls with plastic film. 2) Measurement of building parts. 3) Measurement of a whole floor and techniques to identify leakage sources with smoke machine and infrared camera.

2 SUSTAINABLE HEALTH CARE ENVIRONMENTS

Sustainable health care environments includes healthy indoor climate. Design of health care buildings is connected to regulations and standards but also, as in every project, there is a need for an integrated design between different professions. The scope of the energy profession is wide and connected to most other professions, such as architectural, construction, heating, ventilation and air conditioning (HVAC)-design.

Energy efficient measures will in most cases improve indoor climate. Especially measures of thermal insulation, air-tightness, heat recovery in ventilation systems, accurate control system and energy efficient lighting. Improved thermal insulation will decrease demand for heating power and improve indoor temperatures mainly during wintertime. In cold climates low ventilation rates or efficient heat recovery are essential to not exceed energy targets but still provide for fresh air supply. Accurate control system will improve temperature control in rooms, which will lead to temperatures that are closer to peoples comfort temperature. Energy efficient lighting system will decrease surplus heat that will cause over-heating problems during summertime.

2.1 Energy demand in hospital buildings

According to a survey study of energy demand in Swedish health care buildings (SEA, 2008) these buildings use about 2.8 TWh of heat, 63 GWh of district cooling and 1.7 TWh of electricity in 2008. Thus, the health care sector stands for about 3 % of the total energy demand for buildings in Sweden.

A survey of energy demand for hospitals in several OECD countries, made in the mid 90's, shows the energy demand per square meter and beds, respectively (Jakelius, 1996). The study shows that there is a great difference if floor area or amount of beds is used as unit. In Sweden floor area is usually larger than in other countries.

A comparison between a hospital in the UK and Sweden shows that the specific energy for space heating is similar, but if space heating is divided by patients the Swedish hospital uses almost eight times more energy. The two buildings are similar regarding thermal insulation.

3 PROJECT DESCRIPTION

The expansion of the University hospital in Linköping is a project with ambitious environmental goals. The building is of about 65 000 m^2. The project has a goal of total annual energy demand (including operational energy) below 100 kWh/m^2, which is one of the most energy efficient hospital projects in Sweden right now. The building fabric is well insulated with U-values for walls about 0.12 W/m^2, K. Ventilation heat recovery is using mainly recovery wheel, which gives a heat recovery rate of about 83 %.

In addition, this building also has a good floor area/volume ratio, about 0.6. District heating and cooling is supplied from a district heating network with a combined heat and power (CHP) plant. Cooling is produced by absorption chillers heated by district heating.

The requirement of air infiltration for the new buildings is set as a value of the air permeability at 50 Pa. The mean air leakage rate at 50 Pa should not exceed 0,2 l/s, m^2 envelope area. The envelope area is the surface for walls, floor and roof that border to outside air or rooms that's not intended to be heated above 10 °C. If this number converts into air changes per hour (n_{50}) it is equal to 0,116 h^{-1}. The total volume of the buildings is 245 849 m^3, total envelope area is 39 678 m^2 and the maximum allowed air flow infiltration is 28 568 m^3/h.

4 MEASURMENTS

The measurements done in early stage was indented to identify leakage sources, not to measure the air permeability. Some of the leaks that were identified in early stage were then later tested on site to find out a value of the specific air flow per identified leak. This was done as a basis for deciding whether to take actions or not with the systematic leaks that were found. Although the requirement for air infiltration is ambitious some leaks can be acceptable and this was very important for the contractors to know.

The air-moving equipment used was a Retrotech 3100 series Blower Door. For leakage seeking during depressurising an infrared camera, NEC Thermo Tracer TH 7800, was used together with Regin smoke bottles. When pressurising tests were performed a smoke machine, Martin Magnum 850 with training smoke fluid, was used to fill the enclosed area with thick white smoke and then examine the building for leaks from outside.

Measurements of individual building components and connections were made by pressurising and depressurising a small box that was mounted (pressed) very carefully and tight around the part being tested. The measuring equipment was a system consisting of a variable speed fan, a measuring tube (VEAB Elmicro) for small air flows (0.5-15 l/s) and a pressure-measuring device (TESTO 435).

4.1 Measurements of parts of the building, parts of a floor

In early stages it is not suitable to measure the air-tightness of a whole floor, instead the floor was divided into parts, for example a corner. The purpose of testing a part of the building in early stage is not measure the air permeability but to search for leaks.

Booth representative and critical parts of the building was picked out for testing. The areas suitable for testing were found by studying drawings and by visits on site. The areas were then chosen depending on if they were representative for different kind of constructions and/or if the construction was difficult to build with high air permeability.

As shown in Figure 1 below the constructor built temporary walls to divide the floor. The box was then depressurised to 50 Pa with the Blower Door equipment and search for leaks with infrared camera and Regin Smoke bottle (RFA 10) was performed.

Figure 1. Different temporary boxes made with a stud frame and plastic film for early stage testing

It is very important that the box is made as air-tight as possible. During the first test it was a lot of leaks in the box. Important things to get the box as air-tight as possible are to use a flexible multi-purpose adhesive tape everywhere where the plastic film meets another material and where the plastic film is overlapping. It is also important that there is a butyl-based adhesive strip under the floor joist, at the corners and under the ceiling joist.
It is also important that the building workers know the purpose of the temporary box and the purpose of the tests.

4.2 Smoke machine

When pressurising the temporary boxes it has been very effective to fill the box with smoke and to search for leaks from outside the building envelope. To have booth the building workers and the design team present during these tests has been very pedagogical for everyone. Figure 2 shows a temporary box that is filled up with smoke. In Figure 3 the smoke is finding its way out through the wall, indicating air leakage.

Figure 2. Temporary box filled with smoke for early stage testing and to identify leakage sources from outside of the building

Figure 3. Smoke coming thru the outer wall and connection to existing parts of the hospital during pressurising test at +50 Pa.

4.3 Measurement of individual building parts

One result of the early measurements was that there was an air leakage in the connection between ceiling and outer walls (Figure 5 below). As this was a common part of the building a program for measuring the air-tightness for this part was developed. The measurements equipment was including a box that was mounted to the ceiling. The box was connected to a duct with a fan (Figure 4 below). The air-flow pressure was measured and the air-flow was changed by the fan.

Figure 4. Equipment used for measuring air-leakages in ceiling along the outer walls

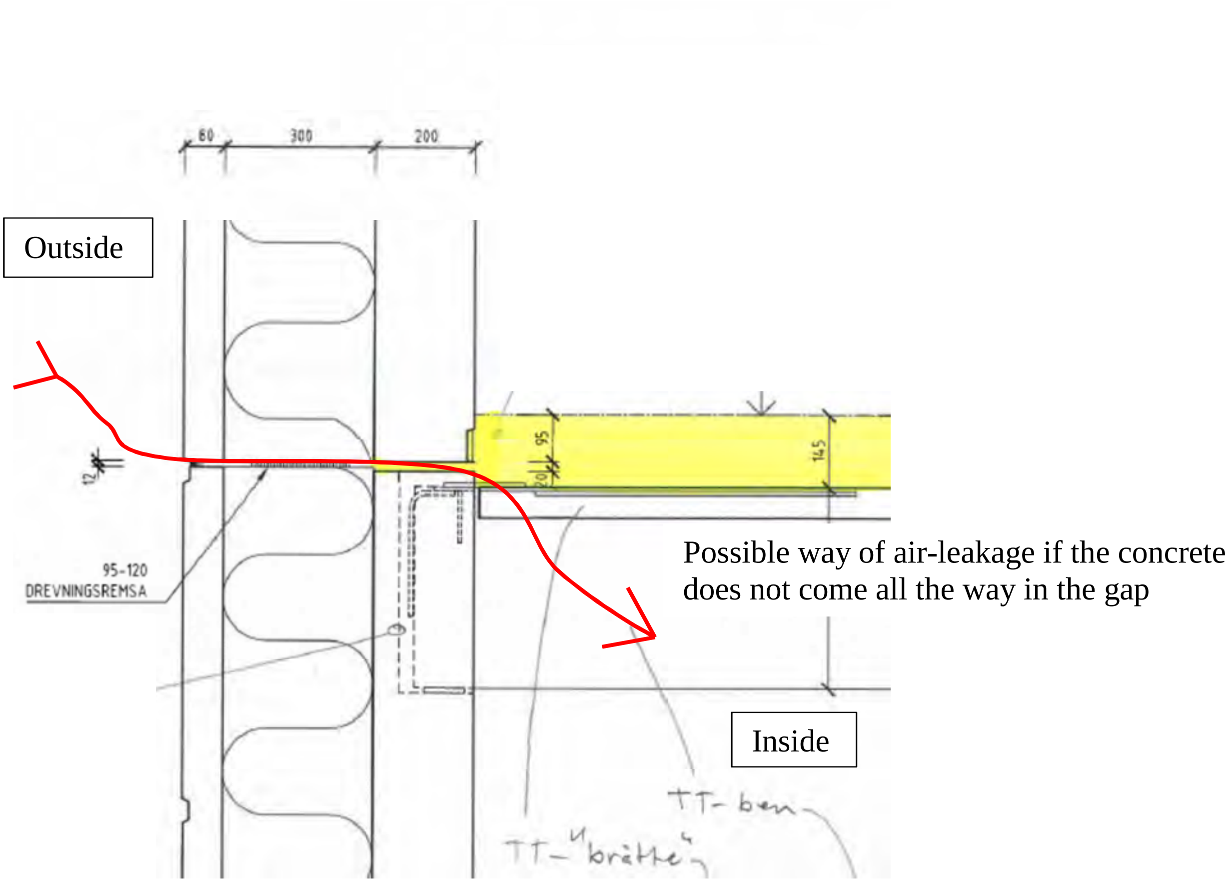

Figure 5. Outer wall construction drawing with possible air leaks in the gap between concrete elements

The first measurements of this building part show high air-flow rates in some places. Table 1 below shows the results from a couple of measurements.

Table 1 Results from tests of connections between outer wall and ceiling

Test nr	Building nr	Floor nr	Pressure in test box (Pa)	ΔP measuring tube (Pa)	Leakage flow (l/s)
1	443	12	-50	175	6,5
2	443	12	-50	25	2,5
3	439	15	-50	0-1	0
4	439	15	-50	2-3	<0,5

After that the construction was sealed with air-tight foam (see Figure 6 below) two new tests were performed, resulting in a very low air-infiltration rate (see Table 2 below).

Figure 6. Ceiling along outer walls after sealing with air-tight foam

Table 2. Results from tests of connections between outer wall and ceiling after sealing with air-tight foam

Test nr	Building nr	Floor nr	Pressure in test box (Pa)	ΔP measuring tube (Pa)	Leakage flow (l/s)
5	443	12	-50	0-1	0
6	443	12	-50	0-1	0

5 FIELD MEASUREMENT OF A WHOLE FLOOR

The measurements of whole floors were indented to measure the air permeability of a whole part of the building to check compliance with the airtightness specification. One floor is about 1500 m^2. As the test was adjusted to the building process inner walls was not finished and there were still some outer constructions that was not air-tight during the measurement. Thus, several temporary seals with foam and tape were used. For example, ducts, floor drains and shafts were sealed (Figure 7).

Figure 7. Temporary seals between different floors (ducts and floor drains)

The top floor of the building is a construction with light steel frame walls. The walls are built with 3 layer of insulation, a total of 310 mm of Rockwool. The plastic film is placed between two layers of insulation, 70 mm from the inside gypsum board. This is to create a space for installations and to minimise the risk of penetrating the plastic film.

The measurement of the whole floor was made during a weekend when the building site was closed (results are presented in Table 3 below). The gypsum boards where not put up and thus there still would be a chance of correcting errors found. Below are some pictures of the most commonly spotted errors (Figure 8, 9, and 10).

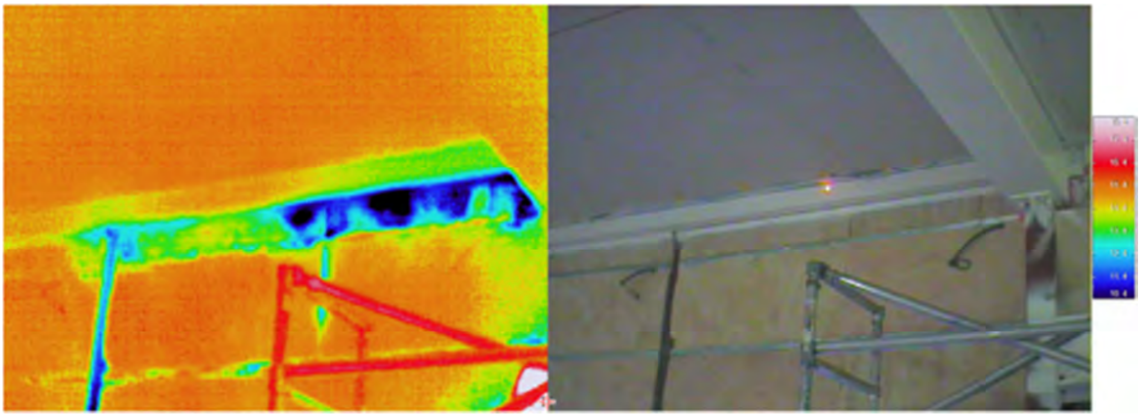

Figure 8. Air leakage in the ceiling angle

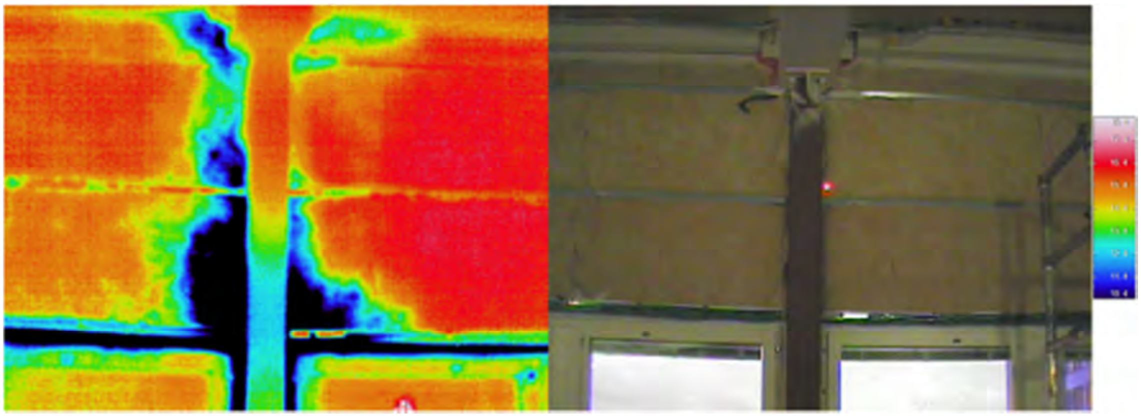

Figure 9. Air leakage where steel column connects to the light steel frame walls

Figure 10. Air leakage in a corner

Table 3. Test results from measurement of a whole floor

Date	Floor nr	Envelope area	Pressure in test (Pa)	Leakage flow (l/s)	Air permeability at 50 Pa (l/s, m^2)
2014-02-09	15	2267	-50	930	0,41

Because the test was performed before the finishing gypsum boards were up the leaks could be fixed. Most of the leaks could have been avoided from the beginning if the design team had had focus on air-tightness and if work preparation descriptions had been better. The work preparation should include figures and photos that show how different constructions should be sealed and what should be done if the plastic is broken.

6 CONCLUSIONS

Outcomes from evaluating the work that has been described in this article are that qualitative results as well as quantitative results can be used to improve the building process. Qualitative results give an understanding for builders, designers, and project leaders were there is air leakage. Smoke visualisation in combination with thermal imaging gives a good understanding for most people were the leakage is and if it is large or small. However, smoke can be hard to see if the air leak is large and thus the air velocity is low. Qualitative results does not relate to the goal for air-tightness that the project aim to achieve. Quantitative results are easier to communicate and can be related to the goal for the project but are sometimes difficult to calculate appropriate at early stages. In the project described in this article quantitative results have only been reported for whole floor measurements and measurements for building parts, e.g. the connection between the ceiling and outer walls.

The builders understanding of the air-flow through air-leakage is important. Both thermal imaging and smoke have been used to visualise the air-flow and have been found to be a very good way to achieve understanding for the builder.

Measurement if air-tightness of a whole floor is connected to some major difficulties as the potential leakage area is large and possible air-leakage to other floors through shafts etc. are many. The results from the measurement can be improved if it possible to perform back pressure on the adjacent floors. The Blower Doors that are used in such a test should be connected and it should be possible to control and read the results for all equipment simultaneously.

The results show, after that the air-tight measurements was started, that the building process has improved. However, another finding from the project is that information should be given continuously and to all builders, as various work teams, has their own way of working with air-tightness. A clear work preparation description can be a way to achieve a better standardization of the work. The work preparation should include figures and photos that show how different constructions should be sealed and what should be done if the plastic is broken. If the builders go through the work preparation together with the foreman while actually doing the sealing of a real construction, and not only read it through, it will probably improve the air-tightness of the building.

Another problem to achieve an air-tight building is that nevertheless the building is air-tight after the construction work, there is still a problem with other entrepreneurs that provide electrics or ventilation that might broke the air-sealing.

The result from the whole floor measurement shows higher air-infiltration than the requirement. The contractor will take action to improve the air-permeability.

Last, a design that emphasise air-tightness is the first step to achieve an air-thigh building.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

SEA (2008). *Energianvändning i vårdlokaler (Energy demand in heath care buildings)*- Förbättrad statistik för lokaler, STIL 2. Eskilstuna: Swedish Energy Agency, 2008, Eskilstuna. ISSN 1403-1892. In Swedish.

Javelins, S. (1996) *Learning from experiences with Energy Savings in Hospitals*, CADDET Energy Efficiency Analysis Series No. 20, 1996.

Air change rate test results in the Croatian and Hungarian border region.

Joint research project of Pécs (HU) and Osijek (CR) Universities supported by EU IPA scheme

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I. Introduction

The aim of this paper is to present a summarized results of natural air change rate (ACH) tests of residential houses and rooms carried out under the management of Building Engineering Department of Pollack Mihály University of Pécs, HU in cooperation with Architecture Faculty of Josip Juraj Strossmayer University, Osijek, CR in 2013.

II. Blower door tests performed

Types of Blower-Door tests:

A. *Air Change Rate (ACH) test*

"Type A test": for testing the building ACH as is during normal use.

B. *Air Tightness test*

"Type B test": testing the air tightness of the building envelope. All purposely made openings of the envelope (e.g. vents, chimneys) had to be closed or tightened.

III. Presenting the houses tested

The use of the buildings is mostly residential, detached houses and apartments apart from a few offices and classrooms in Hungary. In most of the cases the whole homes were tested plus in some cases a selected room too.

The structure of the buildings varies. The detached houses made of traditional brickwork construction while the apartments are in traditional as well as in prefabricated reinforced concrete blocks.

The year of the construction ranging from early 1900 to very recent years. The majority of the old ones are refurbished.

A. *Locations of the Croatian buildings*

In Croatia there were ACH tests at total of 58 sites. This includes 47 sites at Osijek and 11 in the outskirts of the city.

B. *Locations of the Hungarian buildings*

In Hungary, there were field test both ACH (Type A), and air tightness tests (Type B) at 33 locations of that 19 are in Pécs and 14 in smaller settlements in the Hungarian-Croatian border.

IV. Test results at a glance

When evaluating the data it is apparent that there is a significant dispersion of data in both countries. There are very high and very low ACH data too.

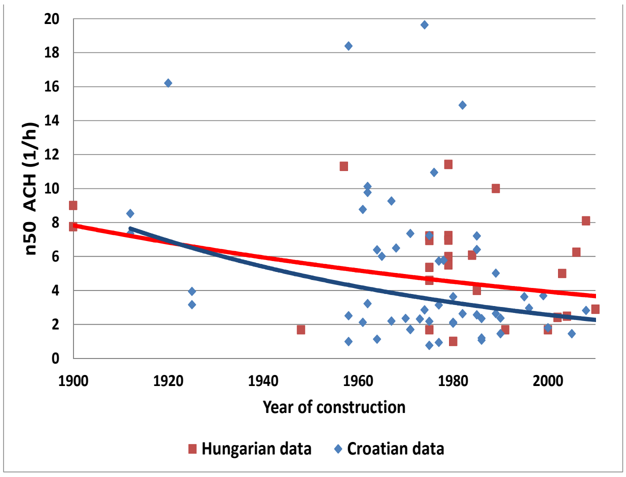

Fig. 1. n50 Blower Door "A-type" ACH test results in Croatia and in Hungary

As a result of the more and stricter energy requirements and introducing better and better windows the ACH number of buildings decreases as a function of construction year. As a consequence there are cases when the natural

ACH is even too low and it is not possible to meet the consistency protection, comfort and health care requirements without intentional ventilation.

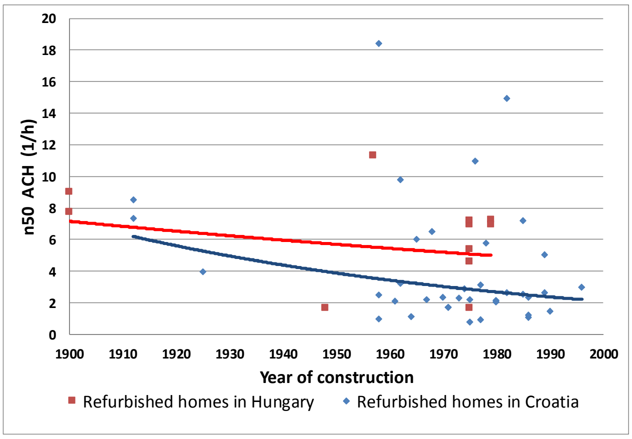

Fig. 2. n50 ACH test results of refurbished houses in Croatia and in Hungary

In Croatia not only the old, but several newer houses are refurbished as a consequence of the Balkan war in early nineties.

V. COMPARING THE TEST RESULTS FOR N50 ACH OF THE TWO COUNTRIES

The initial assumption was that air tightness and ACH values are similar in old buildings when construction technologies and cultural tradition are similar due to common history. That proved to be right.

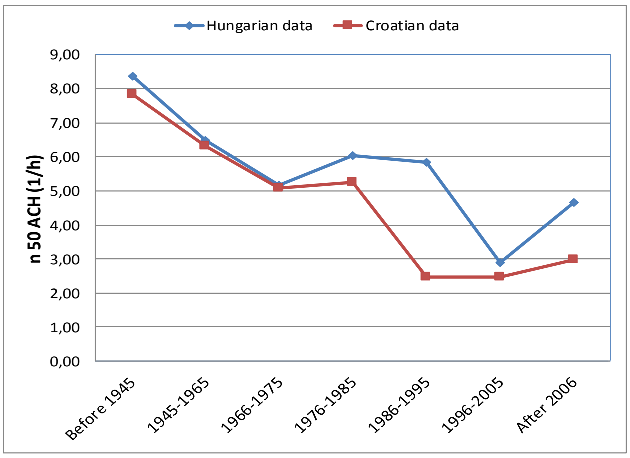

Fig. 3. Comparison of n50 Blower Door "A-type" ACH test result average values in Croatia and in Hungary

In the second part if the 20th Century the air tightness and ACH is different. It is less in the Croatian tested houses.

The time periods for averages were set according to significant changes in standards or usual construction technologies.

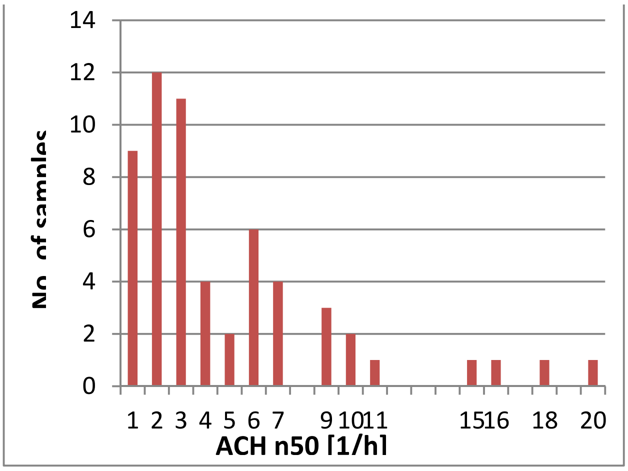

Fig. 4. Distribution of n50 ACH values in Croatia

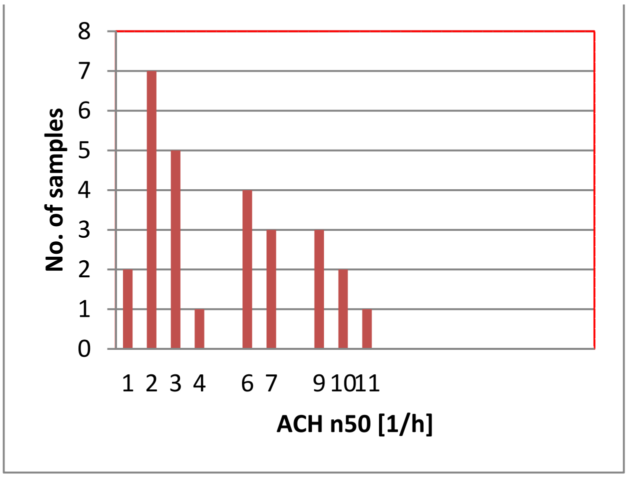

Fig. 5. Distribution of n50 ACH values in Hungary

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