ISSN 1307-3729

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

The REHVA European HVAC Journal

www.rehva.eu

Special issue for ACREX India 2018 exhibition

Spotlight on the EN ISO 52000 family of EPB standards

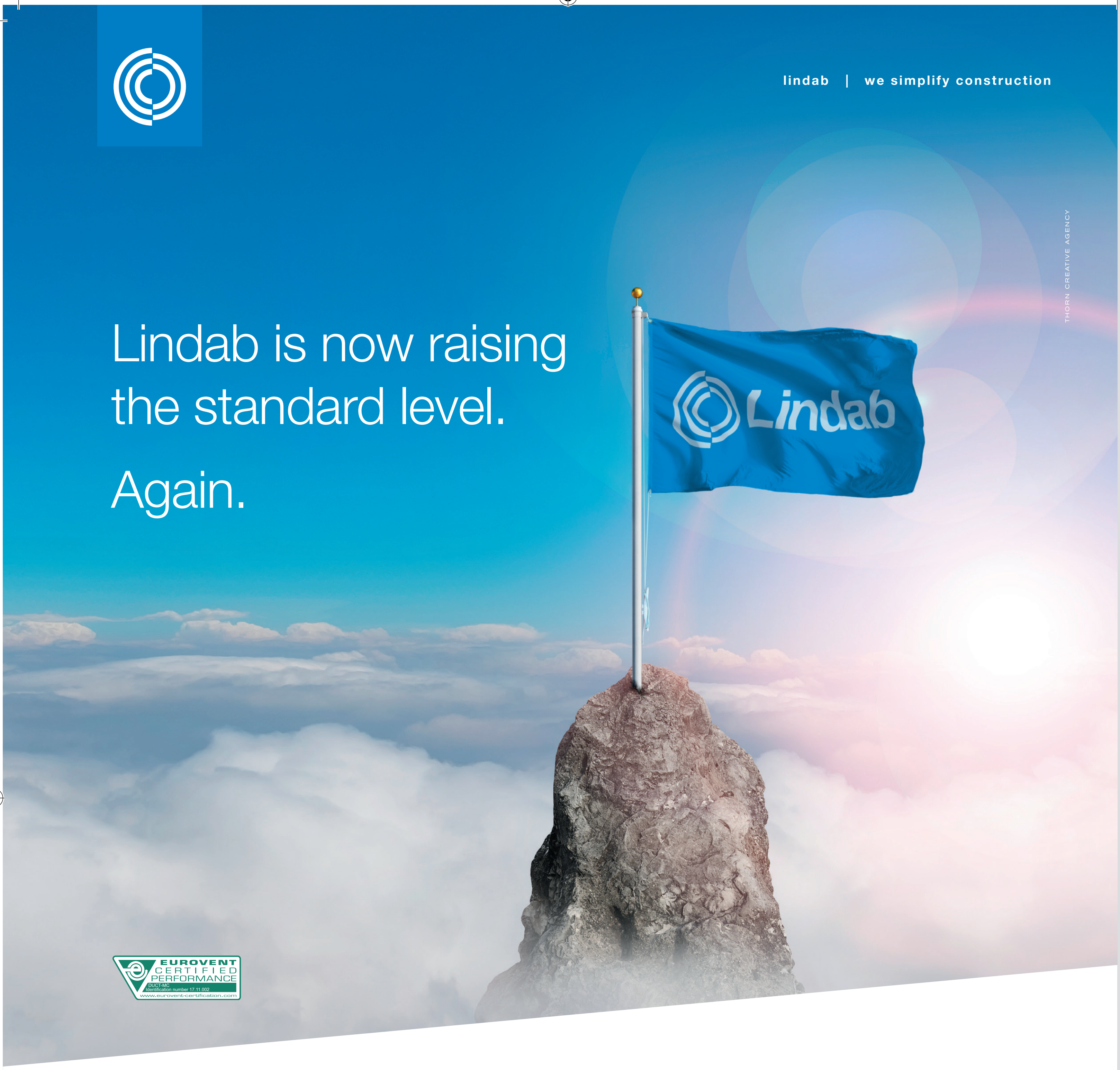
Indoor Air Quality Monitoring 2.0

PUE indicator for datacentres efficiency

REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

Indian Society of Heating Refrigerating & Air Conditioning Engineers · ISHRAE

Eurovent Certita Certification



It has now been officially proven that Lindab Safe and Lindab Safe Click systems come with the best possible tightness and thus quality.

Our ventilation ducts with Lindab Safe and Lindab Safe Click, are first in the world to have Eurovent certification. Certification means that the product must meet certain standards throughout the entire production process.

Eurovent certification guarantees that the product has been submitted for an independent check and has been honestly and correctly graded.

This means you can feel safe with the product you buy, and you can be completely sure that it maintains high quality and tightness class D.

Lindab is constantly striving to raise its standard when it comes both to product development and new energy efficient innovations.

Check ongoing validity of certificate:
www.eurovent-certification.com

www.lindab.com

Lindab®

The REHVA European HVAC Journal

www.rehva.eu

Special issue for ACREX India 2018 exhibition

ADVERTISEMENTS
Ms Chiara Girardi, cg@rehva.eu

SUBSCRIPTIONS and CHANGES OF ADDRESSES
REHVA OFFICE:
Washington Street 40
1050 Brussels, Belgium
Tel: 32-2-5141171, Fax: 32-2-5129062
info@rehva.eu, www.rehva.eu

PUBLISHER
TEKNİK SEKTÖR YAYINCILIĞI A.Ş.
Barbaros Mahallesi, Uğur Sk. No: 2/2
Üsküdar/İstanbul, Turkey

Cover image source: Breather on Unsplash

Contents

Download the articles from **www.rehva.eu** -> REHVA Journal

Advertisers

REHVA Journal

REHVA Journal is a technical, practical journal for the HVAC industry professionals. It is read by Designers, Consultants, Manufacturers, Investors, Mechanical Contractors, Sales and Representative Companies, Architects Energy sector's professionals, governmental institutions authorities, etc.

REHVA President Stefano Paolo Corgnati (left) and ISHRAE President Vishal Kapur display the ISHRAE-REHVA Commissioning Guidelines.

Facing Global Challenges by International Cooperation

We are living in a dynamic and challenging context for the HVAC sector, where innovation and technological transfer is based on multidisciplinary skills and expertise, needed to face problems becoming more and more complex.

Under this scenario, international cooperation enables to open up to a wider perspective and deeper insight on the continuously evolving building users' needs. That's why these cross-border collaborations are key to drive the strategic choices of the HVAC sector towards new products and services. And that's indeed why REHVA and ISHRAE, the leading HVAC associations in Europe and India, are making their collaboration closer and closer. The joint efforts focus on the selection of common areas of interest, to be studied through joint Task Forces. This cross-fertilization, carried out through the exchange of both theoretical knowledge and professional practice, has already yield valuable results, such as the publication of joint Guidebooks.

Furthermore, the penetration of new technological expertise in the HVAC sector has nowadays opened a lively exchange of ideas. Think about ICT and IoT and how they could serve the cause of energy efficiency in buildings. Or consider the role of Big Data and data mining in supporting energy management and control strategies in buildings.

The chances that REHVA and ISHRAE have had to discuss and collaborate on these topics is already paying off, creating joint opportunities and add value for both associations.

STEFANO PAOLO CORGNATI
REHVA President

The set of Energy Performance of Buildings (EPB) standards: spotlight on the (EN) ISO 52000 family

The set of Energy Performance of Buildings (EPB) standards has been published in summer of 2017. About 30 documents as European standards (CEN) and about 17 as international standards at global level (ISO), in collaboration with CEN (EN ISO standards). All new EN ISO EPB standards are part of the new (EN) ISO 52000 family of EPB standards. These include the backbone of the whole set of EPB standards. The series will help architects, engineers and regulators assess the energy performance of new and existing buildings in a holistic way. Technical support and more information is found at the website of the EPB Center.

Keywords: energy performance of buildings, EPB, EPB regulations, energy performance rating, ISO 52000, EPB Center

DICK VAN DIJK
MSc Applied Physics
EPB-research –The Netherlands
EPB-research@dickvandijk.nl

A comprehensive series of European (CEN) and international (CEN & ISO) standards has been prepared, aiming at international harmonization of the methodology for the assessment of the overall energy performance of buildings. This set of EPB standards has been introduced in earlier issues of the REHVA Journal (e.g. [1], [2], [3], [4], [6]).

This article focusses specifically on the subset formed by the (EN) ISO 52000 family [5] and the option of a step-by-step implementation at national level.

Complete overview now available at EPB Center

More information on the set of EPB standards, with extensive background information and explanation, is provided at the website of the EPB Center [7].

One of the recently added features of the website is a complete overview of all EPB standards and their accompanying technical reports (http://epb.center/support), with information about how the documents can be obtained. For each document a link is provided to the page in the ISO catalogue or CEN database where a summary and other information about the document can be found.

Holistic approach

From energy using product to energy efficient building systems

In the past, energy performance requirements were set at component level: minimum thermal insulation levels and minimum efficiencies of products. However, a product or component with a high performance under standardized conditions may perform significantly less good when installed in a building, due to fluctuating weather conditions, varying occupants' demands and a possible negative influence of or interference from other components. And vice versa: several new technologies are designed to make the best out of varying operating conditions. Thus, energy performance requirements that are restricted to the performance of individual components create a barrier to the necessary technology transitions.

The holistic approach to assess the overall energy performance of buildings and the built environment, provided by the set of EPB standards (inclusive the EN ISO 52000 family of standards), is a key tool to overcome these barriers.

The EN ISO 52000 family of standards will enable to assess the overall energy performance of a building. This means that any combination of technologies can be used to reach the intended energy performance level, at the lowest cost. Due to this 'competition' between different technologies, the holistic approach is a key driver for technological innovation and change.

CEN and ISO

In CEN, the set of EPB standards has been prepared to support the EU Directive 2010/31/EC on the energy performance of buildings (EPBD).

This implies that the EPB standards need to be fit to be used in the context of building regulations and codes. Therefore, all EPB standards follow specific rules to ensure overall consistency, unambiguity and transparency.

At the same time, all EPB standards provide certain flexibility with regard to the methods, the required input data and references to other EPB standards. This enables national or regional authorities to tailor the energy performance assessment to a specific (national or regional) situation. For each option, a clear template is provided in Annex A of each EPB standard, supplemented by an Annex B with informative default choices, as mentioned above.

Global relevance of the set of EPB standards

This approach also facilitates the applicability of the EPB standards at global (ISO) level. A good example is the overarching EPB standard, ISO 52000-1 (EN ISO 52000-1) that offers choices to tailor the assessment to any national situation, worldwide. The choices range from policy factors (e.g. primary energy factor values, choice of perimeter of the assessed object, appreciation of renewable energy surplus exported to the grid, …), building and space categorization, specification of standard indoor conditions for each building or space category, choice of the metric for the building size, etc.

One of the frequently asked questions concerning the preparation of EN ISO standards (collaboration between CEN and ISO) is the following:

Each International (ISO) Standard is relevant at global level, so also in Europe. So why are these standards published as combined European and global international (EN ISO) standard, instead of simply just ISO standards?

The short answer to this very relevant question: ISO standards are voluntary. European (CEN) standards may be mandatory in the context of European regulations. Take for example the CEN standards needed for or to support the declaration of performance of products as defined in the Construction Products Regulation (CPR) and to affix the CE marking. As mentioned above, the set of EPB standards supports the implementation of the EPBD.

New: the (EN) ISO 52000 family of EPB standards

Already 17 of the about 50 EPB standards are EN ISO standards, the result of collaboration between CEN and ISO. The other EPB standards are up until now only available at European (CEN) level.

Except for already existing standards that underwent only (minor) revisions, these EN ISO standards received an ISO 52xxx number, the series of numbers which have been reserved for the EPB standards. Only standards that meet the specific requirements for all EPB standards will be awarded such number.

This first series in the (EN) ISO 52000 family comprises the overarching EPB standard (EN ISO 52000-1), complemented by a set of standards dealing with the calculation methods for heating and cooling needs and indoor temperature, performance of building elements, as well as aspects regarding energy performance indicators, ratings and certificates.

The (EN) ISO 52000 family was prepared in a unique collaboration between

- ISO technical committees ISO/TC 163, *Thermal performance and energy use in the built environment*,
- ISO/TC 163/SC 2, *Calculation methods*,
- ISO/TC 205, *Building environment design*, and
- the CEN (European) technical committees CEN/TC 371, *Energy Performance of Buildings project group*, and CEN/TC 89, *Thermal performance of buildings and building components*.

ISO 52000 family of standards: road ahead

Additional ingredients to expand the holistic approach are expected to be added to the EN ISO 52000 family in the near future, in cooperation with other technical committees in ISO and CEN. First new work item proposals have already been launched, dealing with specific parts of heating and cooling systems and building automation and control.

The intention is to come (eventually) to a complete and consistent set of EN ISO standards on the Energy Performance of Buildings (EPB).

Clear and consistent policy targets play an important role in driving innovation in the building sector. International Standards will be needed to harmonize the terms, definitions, assessment procedures and indicators in order to develop new concepts and technologies as well as monitor and evaluate progress.

Common quality criteria

For all EPB standards, including the (EN) ISO 52000 family

One of the main purposes of the EPB standards is to enable their use in laws and regulations to, in some cases, make them compulsory. This calls for a systematic, clear, comprehensive and unambiguous set of energy performance procedures.

The holistic approach to assess the overall energy performance of a building requires that many of the EPB standards are applied in an interactive way. Standards that do not properly fit in the set (with respect to input-output relations, methods, common features and overall quality) may compromise the quality of the whole set.

Consequently, each EPB standard (both in CEN and in ISO) needs to respect specific requirements (http://epb.center/epb/common-rules-all-epb-standards) to ensure overall integrity, consistency and quality of the whole set, as well as usability in the context of building regulations.

Thanks to these profound specific quality criteria, the ISO 52000 family is expected to become a strong brand mark.

Modular approach and national choices

In CEN, the set of EPB standards has been prepared to support the EU Directive 2010/31/EC on the energy performance of buildings (EPBD).

The aim is a systematic, clear, comprehensive and unambiguous set of energy performance procedures. At the same time, differences in national and regional climate, culture and building tradition, as well as policy and legal frameworks have to be taken into account.

In each EPB standard, different options are given, thus enabling specific choices in:

- Calculation procedures (e.g. monthly or hourly calculation; specific simplified or detailed calculation method).
- Input data and boundary conditions (e.g. national default values, climatic data, policy related data)
- References to other EPB standards; see further on (Modular structure and step-by-step implementation)

For the correct use of the EPB standards, each EPB standard typically contains a normative template in Annex A to specify these choices. And informative default choices are provided in Annex B.

Example of a table from Annex A and Annex B is given in **Figure 1a** and **Figure 1b**.

Table A.2 — Choice between hourly or monthly calculation method (see 5.2)

Type of object and/or application	….. [b]	…. [b]
Description	Choice [a]	Choice [a]
Only hourly method allowed	Yes/No	Yes/No
Only monthly method allowed	Yes/No	Yes/No
Both methods are allowed	Yes/No	Yes/No

[a] Only one Yes per column possible.

[b] Add more columns if needed to differentiate between type of object, type of building or space, type of application or type of assessment. Use the list of identifiers from ISO 52000-1:2017, Tables A.2 to A.7 (normative template, with informative default choices in Tables B.2 to B.7).

Figure 1a. Example of the normative template for national choices (EN ISO 52016-1, Table A.2).

Table B.2 — Choice between hourly or monthly calculation method (see 5.2)

Type of object and/or application	**All applications [b]**	
Description	Choice [a]	
Only hourly method allowed	Yes	
Only monthly method allowed	No	
Both methods are allowed	No	

[a] Only one Yes per column possible.

[b] Add more columns if needed to differentiate between type of object, type of building or space, type of application or type of assessment. Use the list of identifiers from ISO 52000-1:2017, Tables A.2 to A.7 (normative template, with informative default choices in Tables B.2 to B.7).

Figure 1b. Example of the informative default option for national choices (EN ISO 52016-1, Table B.2).

Note that in each EPB standard there may be many tables with a wide variety of choices, ranging from choices between calculation options to choices of specific coefficients or correction factors.

National annex or national data sheet

The main target groups for this document are architects, engineers and regulators.

In case an EPB standard is used in the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications. These choices (either the informative default choices from Annex B or choices adapted to national / regional needs, but in any case following the template of this Annex A) can be made available as national annex or as separate (e.g. legal) document (national data sheet).

Note that in this case:

- the regulators will **specify the choices**;
- the individual user will apply the standard to assess the energy performance of a building, and thereby **use the choices** made by the regulators

Topics addressed in a standard can be subject to public regulation. Public regulation on the same topics can override the (informative) default values in Annex B of the EPB standard.

Legal requirements and choices are in general not published in standards, but in legal documents. In order to avoid double publications and difficult updating of double documents, a **national annex** may refer to the legal texts where national choices have been made by public authorities.

Different national annexes or national data sheets are possible, for different applications.

If the default values, choices and references to other EPB standards in Annex B are not followed due to national regulations, policy or traditions, it is expected that:

- national or regional authorities prepare data sheets containing the choices and national or regional values, according to the model in Annex A. In this case the national annex (e.g. NA) refers to this text;
- or, by default, the national standards body will consider the possibility to add or include a national annex in agreement with the template of Annex A, in accordance to the legal documents that give national or regional values and choices.

Template for national annex or national datasheet at the EPB Center

The EPB Center has developed a template for national annex or national data sheet to EPB standards. This template consists of a model national annex or national data sheet with extensive guidelines and useful tips. It is intended as a tool for the implementation of the EPB standards at national or regional level.

This template for national annex or national data sheet to EPB standards can be downloaded from the support section of the website (http://epb.center/support/support).

Modular structure and step-by-step implementation of the set of EPB standards

Modular structure

For the set of EPB standards, an overarching modular structure is used:

- to identify all required parts of the assessment procedure and to provide an overview;
- to identify the modules covered by the EPB standards;
- to identify the input-output connections between the EPB standards (e.g.: calculation, expression of the energy performance).

The over-arching modular structure has the following four main areas:

- M1 Overarching standards
- M2 Building (as such)
- M3 - M11 Technical Building Systems under EPB
- M12 - M13 Other systems or appliances (non-EPB)

More details can be found at the EPB Center website (http://epb.center/implementation).

Step by step implementation at national level

The modular EPB structure and the "Annex A/Annex B" approach, in particular with the option to (preferably for a limited transition period) reference to a specific national standard instead of a specific EPB standard, strongly facilitates a step by step implementation of the set of EPB standards by individual countries or regions.

In order to make this possible, in the EPB standard the other EPB standards are not referenced by the standard number, but by the module number.

Example (from EN ISO 52016-1):

- Instead of referring to the other EPB standard directly:

$q_{V,k;t}$ is the airflow rate of air flow element, *k*, as provided by EN 16798-7, in m³/s.

- The reference is to the module number:

$q_{V,k;t}$ is the airflow rate of air flow element, *k*, as provided by the relevant standard(s) under EPB module M5-5, in m³/s.

This is further illustrated in **Figures 2a, 2b and 2c.** The left columns in the tables presented in these figures contain the referenced module numbers, the other columns are: empty (template, **Figure 2a**), completed with informative default choices (**Figure 2b**) and completed with (an example of possible) national choices (national annex or national data sheet, **Figure 2c**).

The references, identified by the EPB module code number, are given in Table A.1.

Table A.1 — References

Reference	Reference document [a]	
	Number	Title
M1-4		
....		
M1-13		
....		
....		
M5-5		
....		
....		
M10-1		

[a] If a reference comprises more than one document, the references can be differentiated.

Figure 2a. Example of the normative template for national choices in references to other EPB standards (extract from EN ISO 52016-1, Table A.1).

The references, identified by the EPB module code number, are given in Table B.1.

Table B.1 — References

Reference	Reference document [a]	
	Number	Title
M1-4	ISO 52003-1	*Energy performance of buildings – Indicators, requirements, ratings and certificates – Part 1: General aspects and application to the overall energy performance*
....		
M1-13	ISO 52010-1	*Energy performance of buildings - External climatic conditions - Part 1: Conversion of climatic data for energy calculations*
....		
....		
M5-5	EN 16798-7	*Energy performance of buildings — Ventilation for buildings — Part 7: Calculation methods for the determination of air flow rates in buildings including infiltration (Module M5-5)*
....		
....		
M10-1	EN 15232-1	*Energy performance of buildings – Part 1: Impact of Building Automation, Controls and Building Management - Modules M10-4,5,6,7,8,9,10*

[a] If a reference comprises more than one document, the references can be differentiated.

Figure 2b. Example of the informative default choices in references to other EPB standards (extract from EN ISO 52016-1, Table B.1).

The references, identified by the EPB module code number, are given in Table NA.1.

Table NA.1 — References

Reference	Reference document [a]	
	Number	**Title**
M1-4	ISO 52003-1	*Energy performance of buildings – Indicators, requirements, ratings and certificates – Part 1: General aspects and application to the overall energy performance*
....		
M1-13	ISO 52010-1	*Energy performance of buildings - External climatic conditions - Part 1: Conversion of climatic data for energy calculations*
....		
....		
M5-5	National standard number xxx	*Title of the national standard with calculation method for the determination of air flow rates in buildings including infiltration*
....		
....		
M10-1	EN 15232-1	*Energy performance of buildings – Part 1: Impact of Building Automation, Controls and Building Management - Modules M10-4,5,6,7,8,9,10*

[a] If a reference comprises more than one document, the references can be differentiated.

Figure 2c. Example of national choices in references to other EPB standards (extract from a possible Table NA.1 in a national annex or national data sheet for EN ISO 52016-1).

The EPB Center

Having these standards available is a first step. Implementing them needs dissemination actions at the level of building regulators as well in our professional community.

The EPB-Center, where REHVA is a stakeholder and where the current expertise is concentrated, is expected to support this process.

The EPB Center activities are to plan, coordinate and guide the process of promoting implementation, use maintenance and further development of the set of EPB standards and safeguard the coherence of their technical content.

It is also important to support regulators and national standardization bodies in the implementation of the standards by providing guidance on the completion of the national annexes or national data sheets.

More information, including an overview of all EPB standards, extensive background information and explanation, is already provided at the website of the EPB Center [7]. ■

References

[1] The REHVA European HVAC Journal, issue: "*Focus on EPB standards*", Vol. 52, Issue 1, January 2015 (various articles).

[2] The REHVA European HVAC Journal, issue: "*EPB standards*", Volume 53, Issue 3, May 2016 (various articles).

[3] The REHVA European HVAC Journal, issue: *EPB standards published for formal vote*, Volume 53, Issue 6, Dec. 2016.

[4] The REHVA European HVAC Journal, editorial, *The implementation of the new EPB-standards will boost product and HVAC system innovation and create new market opportunities for the HVAC industry*, Jaap Hogeling, Volume 54, Issue 1, February 2017.

[5] ISO News, ISO 52000 leads the way on clean energy building solutions, Elizabeth Gasiorowski-Denis, June 28, 2017.

[6] The REHVA European HVAC Journal, *Boosting energy efficiency of buildings through ISO's holistic approach*, Jaap Hogeling, Volume 54, Issue 4, August 2017.

[7] The EPB Center: see website: www.epb.center.

Green Air Conditioning

– Using indoor living wall systems as a climate control method

This article seeks to present an optional cooling tool based on the integration of a Living Wall System (LWS), a fan and a dehumidification process (desiccant) to reduce the use of an HVAC system. This study showed that it is possible to use the evapotranspiration of plants for air-cooling and humidity control.

Keywords: Indoor Environment, Climate control, Living Wall System, Evaporative cooler, Biofiltration.

TATIANA ARMIJOS MOYA
Delft University of Technology, Faculty of Architecture and The Built Environment Delft, The Netherlands
T.E.ArmijosMoya@tudelft.nl

©TUDelft, photo by J. Jansweijer

ANDY VAN DEN DOBBELSTEEN
Delft University of Technology, Faculty of Architecture and The Built Environment Delft, The Netherlands
A.A.J.F.vandenDobbelsteen@tudelft.nl

MARC OTTELÉ
Delft University of Technology, Faculty of Civil Engineering and Geosciences, The Netherlands
M.Ottele@tudelft.nl

PHILOMENA M. BLUYSSEN
Delft University of Technology, Faculty of Architecture and The Built Environment Delft, The Netherlands
P.M.Bluyssen@tudelft.nl

In the current world, people spend on average 80%-90% of their time indoors; consequently, the risks to health may be greater due to indoor air pollution than to outdoor air pollution. Doctors around the world face lots of complains about the fact that people feel sick because of the misuse of air conditioning system within their offices and they pay very expensive bills every year, so they can work in a "comfortable place". In many cities across the world, the air-conditioning system has become an essential instrument to achieve indoor comfort within most of the buildings. Thus, it is important that engineers, designers, manufactures and all the professionals involved in keeping a good the indoor environment explore new alternatives to improve the current systems since there is an increasing energy requirement for cooling and air-conditioning of buildings in cities, rising indirectly, the urban heat island (UHI) and climate change. Nowadays, Living Wall Systems (LWS) are an emerging technology that utilize the potentials of plants in living environments, regarding the fact that there is an instinctive bond between human beings and other living systems within nature (**Figure 1**). Using plants as design elements in working environments brings nature inside to create warm and inviting spaces that reduces stress, oxygenate the air, and increases your overall well-being, resulting in healthier work and living areas that decrease absenteeism, increase productivity and overall satisfaction and happiness in people's lives.

Figure 1. Living Wall System, Quito, Ecuador.

Some studies have shown that common indoor plants may provide a valuable strategy to avoid rising levels of indoor air pollution and cleaning the air inside buildings through biofiltration and phytoremediation (Wolverton, 1989); and it provides a natural way of helping combat Sick Building Syndrome (SBS) (Fjeld, 2000). Besides, it has been shown that it is possible to use the evapotranspiration of plants for air-cooling and humidity control around the plant environment (Davis & Hirmer, 2015). The use of vegetation as tools to improve the overall indoor environment is a field that needs more research to prove the real impact of the different green systems in the indoor environment; therefore, this project aims to conduct a multidisciplinary research to explore, validate and evaluate the efficacy in terms of indoor comfort within office environments of LWS climate control systems.

I am Tatiana Armijos Moya, I come from Quito, Ecuador where I got my degree as an Architect at the Pontifical Catholic University of Ecuador. I worked at the University for two years as a researcher in sustainable design. In 2015, I got my diploma as a Master of Science Specialized in the field of Building Technology in the Faculty of Architecture and the Built Environment, TUDelft. Currently, I am PhD candidate within the Green Building Innovation Research Group also at TUDelft with the guidance of my supervisors; Prof.dr.ir. Andy van den Dobbelsteen, Prof. dr. ir. Philomena Bluyssen, and Dr.ir. Marc Ottele.

Evaporative coolers

Plants absorb water and nutrients from the environment and carry them from one zone (leaves) to another (roots) where their roots represent a hanging system. For instance, epiphytes, tropical plants such as English Ivy, Peace Lily, Reed Palm, Boston ferns and Tillandsia, are plants that get their water from the air instead of through their roots. They are common houseplants that filter the moist out of the air thus reducing excessive humidity levels. Regarding temperature control, the evapotranspiration from plants contributes to the lowering of temperatures around the environment. In this study, some strategies where reviewed and a prototype was built to evaluate its performance within a hot humid environment.

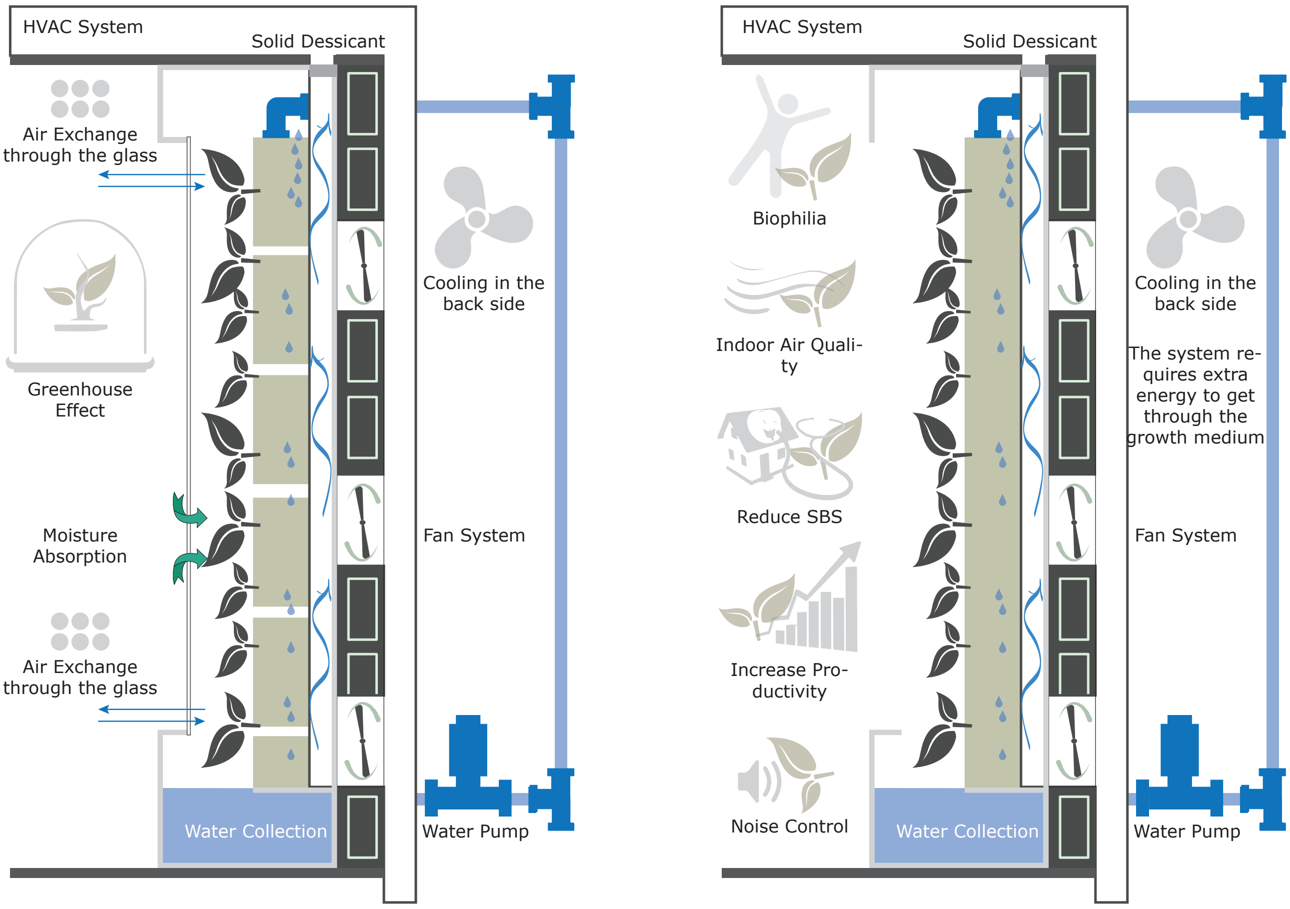
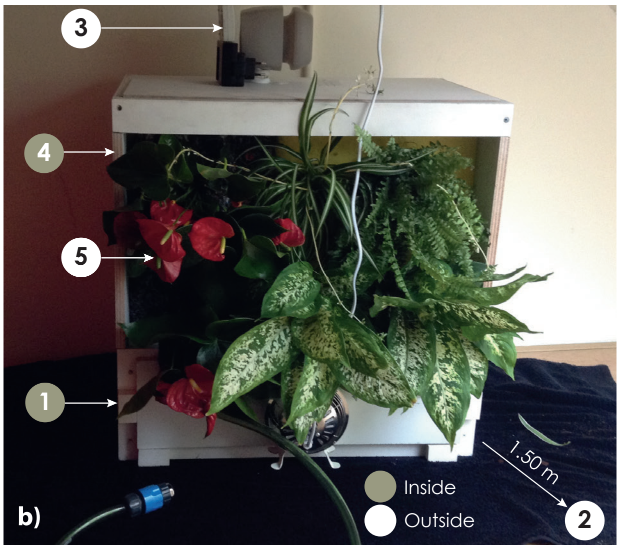


Figure 2. Diagrams of the alternatives for LWS. (Armijos Moya, 2016)

It was considered that a highly humid climate reduces the effect of the living wall system substantially, acting as an evaporative cooler; therefore, it was necessary to integrate a dehumidification process within the system. Several dehumidification processes and strategies were analysed where desiccant dehumidifiers appeared to be more suitable to apply in this system because it can be regenerated, and it be used again. In fact, for future applications, it may use waste heat to regenerate. Desiccant dehumidifiers have several benefits, such as providing humidity control, removing bacteria and other micro-organisms and they can use waste heat to regenerate, as mentioned before. Regarding these factors, it is proposed to use calcium chloride ($CaCl_2$) as a desiccant dehumidifier because of its properties in control of relative humidity, its flexibility, and size particles, residual water produced (Lewis, 2002).

As mentioned before, a prototype was built (**Figure 3b**) to examine the construction system and climate behaviour of the system. The prototype was assembled as a plug-in system constituted by a wooden box (0.60 m x 0.60 m) with mineral wool and cotton as growth media that provides a structural system for the plants to grow in and it must have the perfect balance between porosity, aeration and water absorption capacity. Furthermore, a fan (15 W, 230 V, 50 Hz) was integrated in the bottom part of the system. This allows cooling down the air before it enters the air gap behind the substrate, because the air passes over the water



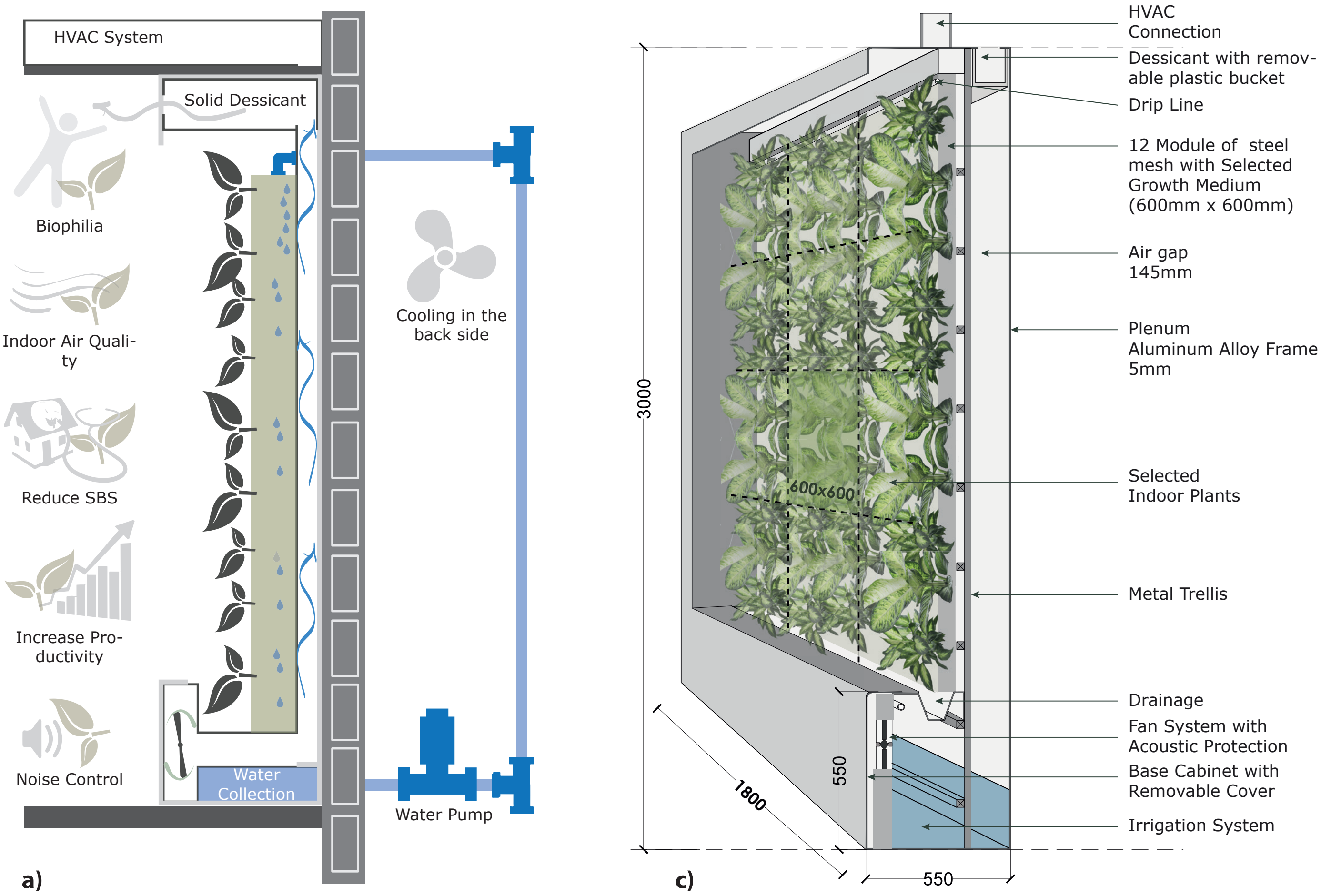


Figure 3. Prototype. **a)** Diagram of the LWS Design, **b)** LWS scaled Prototype and Data logger location, **c)** Section. (Armijos Moya, 2016)

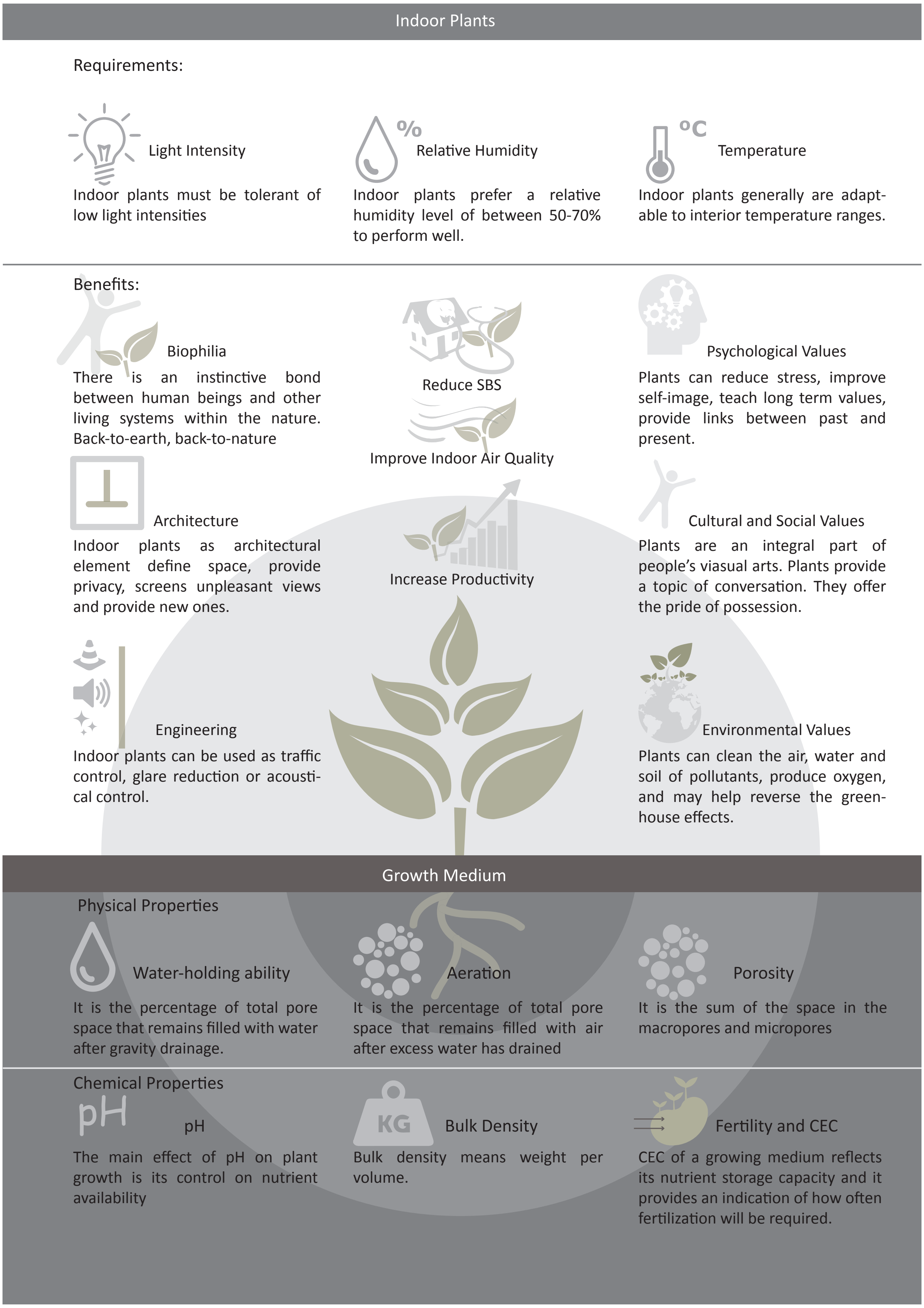


Figure 4. Indoor Plants: Benefits and Requirements.

storage of the system. This location of water allows a better cooling effect within the system and it allows an easier maintenance. The selected desiccant ($CaCl_2$) was placed in the top of the air cavity to dehumidify the air before it leaves the system to the outside (**Figure 3).**

The evapotranspiration from this living wall, the fan and the desiccant working together contributed to the lowering of temperatures around the planting environment.

To build an optimum system, some requirements were taking in account to select the type of plants to be used, such as light conditions, climate conditions and growth medium. Consequently, non-pollinating and, medium- and low-light-tolerant plants, and an inorganic growth medium were used (**Figure 4**).

Regarding all these aspects, spider plants and anthuriums were tested during this evaluation because they are epiphytes, which are plants that absorb moisture from the environment to get their nutrients. The plants were pre-grown and re-pot within the LWS to allow them to adapt to the new growth medium. Irrigation is provided at different levels along the prototype, using a drip irrigation method using gravity to let water flow through the growing media.

Conclusions and recommendations for further research

After the evaluation, the system presents several positive results such as reducing the temperatures around the system with a green climate control method (LWS) which generate pleasant and healthier environment. Some challenges were faced during the study. First, the rise of relative air humidity (RH) in the areas with plants is one of the major issues. In fact, a highly humid climate reduces the effect of the LWS acting as an evaporative cooler; thus, it was necessary to integrate a dehumidification method within the system, in this case a desiccant material, to control the moisture level in the environment. Subsequently, it seems that this green climate control system will reduce the load on the HVAC system more significantly in a dry hot climate due to the natural evapotranspiration of the system; thus, not needing a dehumidification process at all.

On the other hand, the air conditioning system is like the lungs of any building. It draws in outside air, filters it, controls and maintains the temperature, humidity, air movement, air cleanliness, sound level, and pressure differential, circulates air around the building, then expels a portion of it to the outside environment. However, it is in constant competition between the air cooled and air circulated. Air must be circulated to ensure a good air quality, but the air conditioning unit relies on a closed cycle, where if new air is brought in it needs a greater amount of cooling. Therefore, it is expected that this method will have important effects on the amount of energy used by a standard HVAC system regarding that recirculating the air through the LWS will omit the process of cooling outdoor air because the indoor air will already be at the required temperature and humidity level. It is recommended that for further applications the building where the system in going to be integrated should incorporate a solar thermal collector or a gas heater to help regenerating the desiccant. What is more, the desiccant-based air conditioning systems, in general, also use a humidifier as part of the process because the air inside sometimes is too dry. Therefore, this system will most likely help to decrease the loads for humidifiers as well.

There is still a lack of solid and significant figures available to understand all the possible benefits of an active LWS as a climate control system such as the true pollutant-removal mechanisms, and even more the effect of these systems within the energy performance of the building. For forthcoming studies, this system is going to evaluate the possibility of reducing the levels of indoor pollution through phytoremediation and biofiltration. ■

Phytoremediation

Use of plants to remove pollutants from the air, water and soil. Plants have been shown to uptake air pollutants via their stomata during normal gas exchange.

Biofiltration: the process of drawing air in through organic material (such as moss, soil and plants), resulting in the removal of organic gases (volatile organic compounds) and contaminants with a mechanical system involved.

References

Davis, M., & Hirmer, S. (2015). The Potential for Vertical Gardens as Evaporative Coolers: An adaptatioon of the 'Penman Monteith Equa on'. Elsevier, Building and Environment, 135–141.

Fjeld, T. (2000). The Effect of Interior Planting on Health and Discomfort among Workers and School Children. HorTechnology , 46–52.

Lewis, G. &. (2002). The Dehumidification Handbook. Amesbury: Munters Corporation: Dehumidification Divition.

Wolverton, B. (1989). Interior Landscape Plants for indoor Air Pollutioon Abatement. NASA.

Indoor Air Quality Monitoring 2.0 – Seeing the invisible

In China, the new battle is for clean air and to keep the ubiquitous pollution at bay. Therefore, China is plenty of opportunity for professionals in the IAQ industry having the world's highest levels of public awareness of indoor air quality combined with incredible growth in built environments. As the market has matured, one of the fastest trends has been the continuous monitoring to track and validate indoor environmental quality. Yet, for all the interest, there are still many questions about how to select and use monitors.

Keywords: Monitoring, IAQ, Sensors, QLEAR, China, RESET™, Standards "air quality".

LOUIE CHENG
President PureLiving China
Shanghai China
louie@purelivingchina.com

Practitioner's perspective

The perspective of a consulting and engineering firm is providing IAQ consulting, ventilation system design, implementation of systems and their monitoring. This article is aimed at the practitioner and operator.

Four years ago, a client requested the ability to continuously monitor their air quality after we had installed an office-wide filtration system. After a market search failed to yield suitable systems that could measure PM2.5 levels and report over the internet, we had no choice but to create our own monitor, one of the first of its type for non-industrial use in China. Less than a month after we installed the monitors, Shanghai experienced some of the highest levels of pollution ever recorded locally (over 1800% higher than the WHO 24-hour health standard). The monitoring system showed that despite the high outdoor levels, the filtration system achieved 93% average reduction with a healthy level inside. Instead of having to respond to employees' panic and absenteeism, our client won staff trust and scored a PR coup for employees' care and wellness. Since then, we have sought to integrate monitoring into schools, offices, and buildings, and currently oversee more than 3000 monitors streaming live data over a cloud monitoring network.

Why monitor?

China is an ideal proving ground to acid test sensors and monitors. The frequent high levels of pollution outdoors paired with a cultural preference for natural ventilation provide challenging requirements. We often find that sensors created in North America or Europe fail quickly in China, and perhaps, not unsurprisingly, most of our preferred technology is domestically produced. Against this backdrop, we have seen very fast growth in the adoption of monitors for a number of reasons.

1. **Monitors are critical for developing recognition of an indoor air quality (IAQ) problem, which then drives improvement.** Traditionally, facility managers or building owners had to commission long and in-depth audits with handheld particle counters to determine whether there was a problem. However, today, continuous monitors make it possible to quickly, inexpensively, and meaningfully depict the health performance of a space.
2. **Moore's Law – sensors have come way down in price while increasing in performance**. There are superior monitors today at, approximately, one third of the cost compared to those provided only two years ago.
3. **There is growing recognition that monitoring is critical to validate performance**. In China, the phrase "PM2.5" was the fourth most searched term on the internet (per Baidu.com) in 2015. Visitors entering elevators in the popular SOHO

office complexes have a full colour display showing outdoor versus indoor air quality readings. With the easy availability of inexpensive consumer grade monitors (as low as ~USD40), it is easy and natural for employees and tenants to test out their homes and offices. If they discover problems, they will usually share the information on social media or else challenge their managers, facilities managers, or operations teams. This can either be a PR nightmare or, as in the case of our first monitoring client, a marketing, selling or recruiting point.

4. **Monitoring data enables self-auditing and green building certification performance validation.** Most sophisticated clients want to show the Return of Investments (ROI) on projects to justify their investment. They may also want to keep their building or office space performing at a high level over time. The addition of furnishings, increase of headcount density, maintenance, outdoor air infiltration and occupant activity all are factors that impact air quality after commissioning. An unnoticed side effect of air quality monitoring is a mind shift in involving the facilities managers and operations team in the "care and feeding" of their indoor environment, because they have a feedback loop now which allows them – and other stakeholders – to view cause and effect.
5. **Monitoring enables automation**. In the past, we used to design and implement solutions for clients. We, then, would train teams on how and when to operate the systems. Typically, a unit is only considered successfully commissioned if it achieves over 95% single pass reduction from the outlet vs. inlet readings and either below PM 2.5 of 35 µg/m³ over a 24 hours' average, or greater than 90% ambient room reduction during the same period. However, we found that in reality, once we left, results would often degrade due to:

a. Improper system operations – speed, on/off, filter maintenance
b. Failure to control infiltration of outdoor air, or;
c. Negative pressurization bringing in unfiltered outdoor makeup air

Training helps, but it is very difficult to overcome ingrained habits such as opening the windows for "fresh air" during cleaning or out of habit. Operations staff also frequently turn over, resulting in a new crop of untrained personnel. Experience has shown that the best answer is to take the operator out of the equation, using automation software powered with live readings to govern filtration and ventilation system operation "on-demand" only when needed. Automation systems should generally also have a scheduling system to differentiate between working and non-working (or non-occupied) hours. Not only does this ensure consistent performance, but, such systems can also reduce energy usage up to 90% (compared to continuous operation).

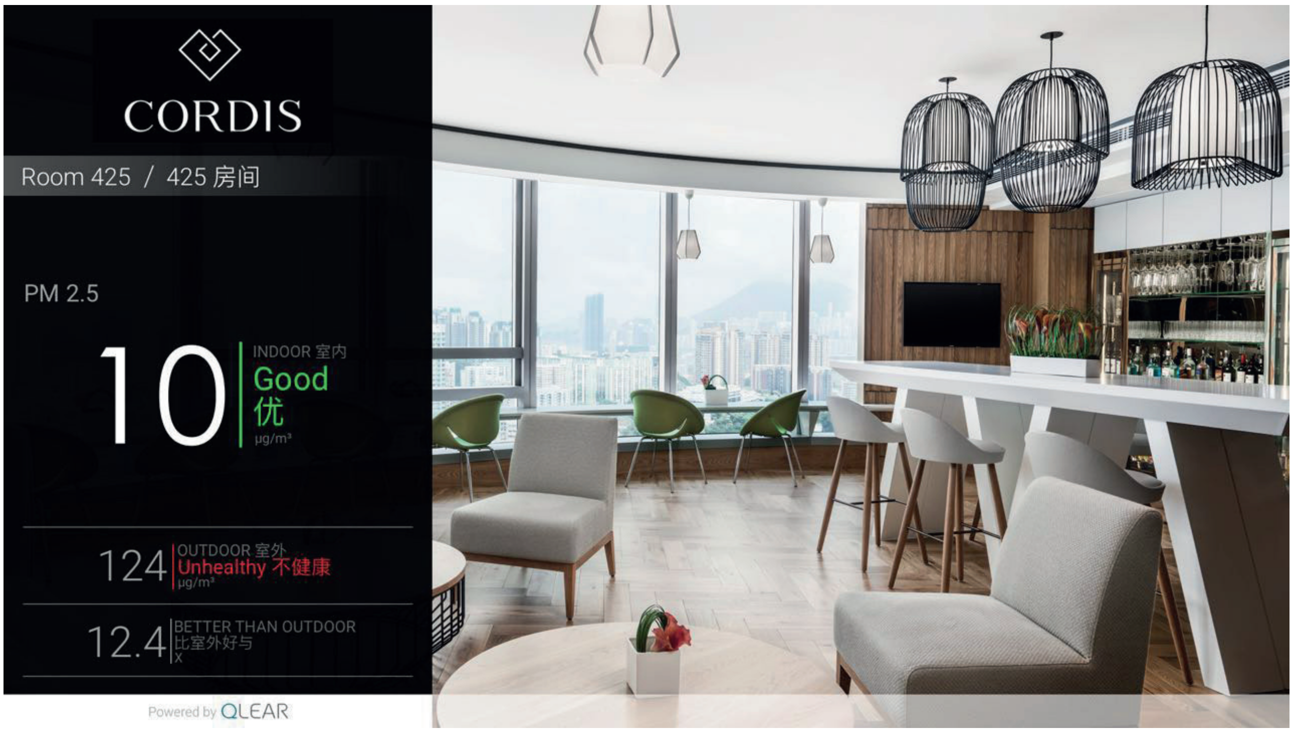


Figure 1. Indoor air quality monitoring data screenshots as displayed in a hotel public spaces.

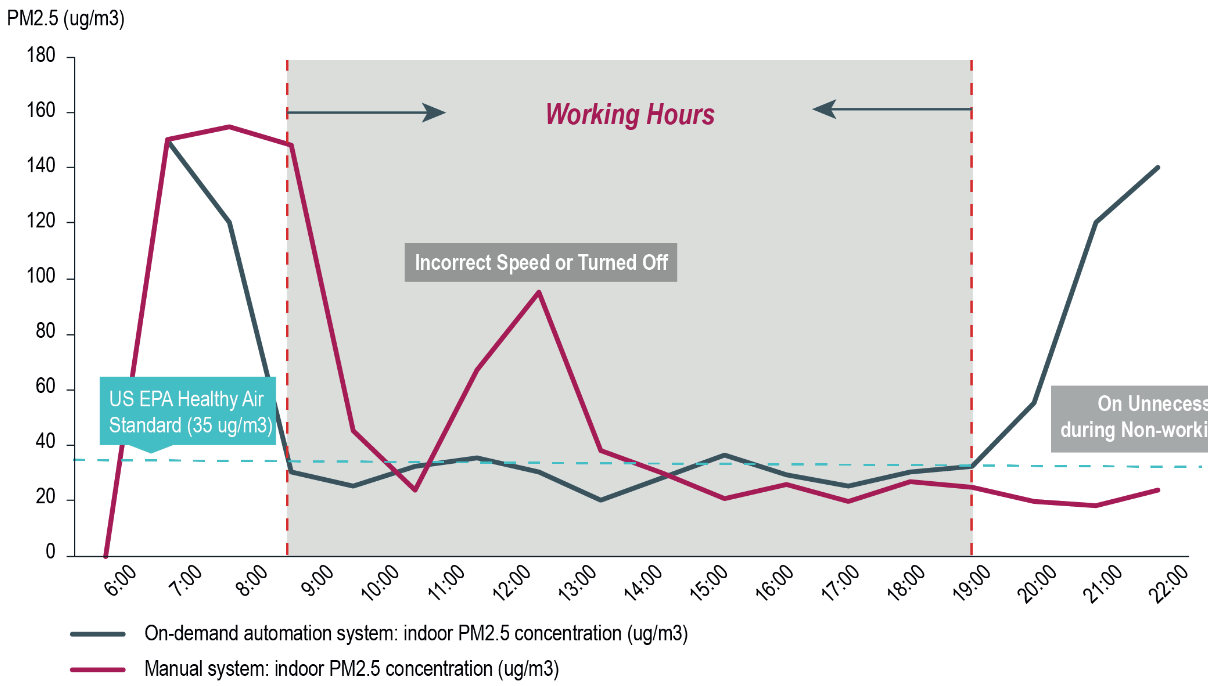


Figure 2. On-demand Automation vs. Manual Operation (µg/m^3 equals µg/m^3). [Source: "Every breath we take–transforming the health of China's office space," JLL & PureLiving Research Report, December 2015.]

All sensors are not created equal

One of the most frequent questions we are asked is "How do I select a monitor?" After all, monitors today may cost between $35 to more than $5000.

Figure 3. Various types of continuous monitoring equipment.

Typically, we guide monitor selection with a few considerations:

1. Pick a monitor based on the sensors needed, the criticality of performance, and how challenging the environment is. The parameters presented in **Table 1** are the most important in IAQ monitoring.
2. "Paper specs" are not a good indicator of performance. Often, sensor capabilities listed in technical or marketing data sheets are used to compare and select sensors, even by inexperienced monitor manufacturers. However, sensors are impacted by design (i.e. sensor proximity on a Printed Circuit Board may lead to elevated temperature readings and premature failure.) Sensors often also vary widely in terms of long-term stability. Therefore, monitors must be either performance tested by the end user's representative over time or by a reputable multi-brand dealer.
3. Realistic expectations of accuracy. Instead of looking for accuracy that is close to the reference source, evaluators should test by batches of at least 4 units and look for repeatability of readings and fit to the reference monitor's response curve. This indicates manufacturing and sensor quality. Accuracy also needs to be evaluated over a wide range, not just a single reading. Cheaper sensors may match a reference method within a common range, but not at low or high ranges.
4. RESET™ monitoring standards are key to identifying the difference between good and poor sensors. Created in China in 2011 and adopted by companies across the world, RESET™ is a healthy building standard for indoor air quality built around continuous monitoring data. In addition to whole building and interiors certifications, RESET™ also certifies monitoring hardware with a set of requirements that categorize monitor quality into three groups: A for calibration-grade, B for commercial-grade, and C for consumer-grade. RESET™ includes requirements that one would not normally consider such as a data buffer so that in case communications fails, data will still be stored.

Table 1. The most important parameters in IAQ monitoring.

IAQ parameter	Common sensor technologies	Recommended measurement range (Grade B)	Selection notes
Particulate Matter (PM)	Optical particle counter (OPC)	0–300 µg/m³	Sensors should be able to provide particle count, not just mass concentration. Critical considerations: humidity compensation, stability, repeatability, accuracy over the ranges likely to be encountered.
Carbon Dioxide (CO_2)	NDIR	0–2000 ppm	CO_2 indicates the "quality" of ventilation and is possibly the most important IAQ parameter. Select sensors that have auto-zeroing features and that can be field-replaceable.
Total Volatile Organic Compounds (TVOC)	Metal Oxide Sensors (MOS) Photoionization Detector (PID)	0.15–2.00 mg/m³	Both MOS and PID sensors are indicative only and used mainly to show relative change. They will not usually match lab testing. High chemical levels will also require recalibration.
Temperature	Thermocouples; Resistive Temperature Devices (RTDs); Silicon diodes	0–50°C	Many inexperienced manufacturers or first generation monitors suffer from inaccuracy due to heat generated from nearby components on same PCB.
Relative Humidity	Capacitive	20–90%	Generally, field-replaceable, important to measure due to impact of humidity on measurements of other parameters.
Formaldehyde	Colormetric, electrochemical; chemical	0.03–0.3 mg/m³	Currently, there are no real-time technologies known to the author that reliably match laboratory HPLC analysis. Avoid.

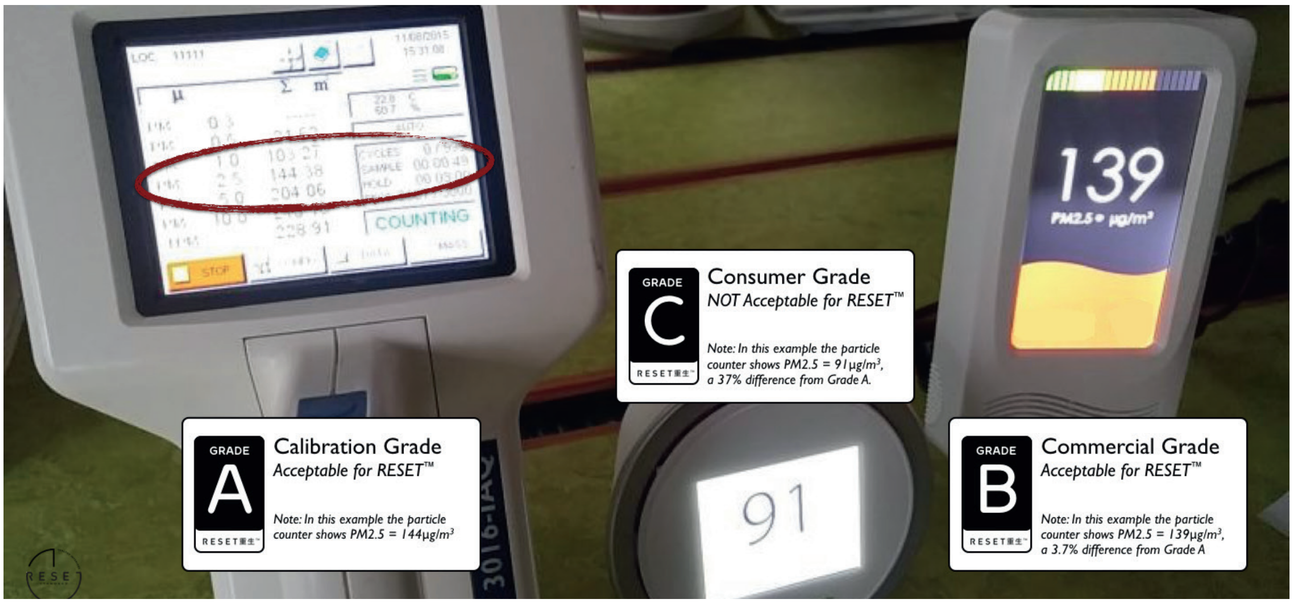


Figure 4. Varying accuracy of three monitors show the difference between monitor quality grades. General rule: if you can't calibrate it, don't buy it. Only Grade A and Grade B monitors are accepted for RESET™. Latest RESET™ standards are here: http://reset.build/resources/RESET_Accredited_Air_Monitor_Requirements

5. Costs

- Initial. Monitors meeting RESET™ standards typically cost about $100–300 for Grade C (Consumer-grade) monitors, about $600–1400 for Grade B (Commercial-grade) monitors, and upwards of $3000 for Grade A (Calibration-grade). Costs vary depending on number of sensors, convenience features, and brand.
- Maintenance. Annual or semi-annual calibration is critical for maintaining accuracy, particularly in polluted environments and is generally mandatory for recertification. Generally, annual calibration and maintenance costs are typically 10-20% of initial cost.
- Software. Most professional software is on a subscription basis and can be paired with different hardware. Annual costs may be free for limited basic versions or $100–300 per monitor per year depending on total number of monitors and the sophistication of the software.
- Hosting and connectivity. If privacy is a concern, local hosts and networking may be required, but in most cases, monitors simply need to connect to the internet. Initial installation can be done by third parties or DIY.
- Leasing options. Increasingly, service providers are offering "pay-as-you-go" monitoring packages that include hardware, calibration, cloud-ware, and support on an annual basis. This way, hassle is minimized and technology is future-proofed.

Deployment Tips:

Deployment location, choice of communications protocols, power supplies, should be carefully planned to ensure representative data – or data at all – is received for analysis.

1. **Connectivity**. The ability for the monitor to transmit data is a major source of problems if not carefully considered when monitors are selected and deployed. IT departments must be involved early on or can pose challenges later (see **Table 2**).
2. **How many monitors are needed?** Monitors read only the nearby air quality. Therefore, the appropriate number of monitors depends on how many representative environments are in a space. A small 500 m² office with staff area, conference rooms, canteen, and lab, for instance, may need four monitors, while a 2000 m² factory floor with the same equipment and ventilation system may only need two. In a mixed-use office environment, **the general rule of thumb is about one per 500 m².** Building standards and certification programs such as RESET™ may have their own requirements. Also, sensitive populations may expect monitoring around them. Generally, focus on staff areas.
3. **Location and placement**
   - Height. Generally, in the breathing zone – 1–2 m high above the floor is ideal. However, if there are children (i.e. school) or theft/interference is an issue, mounting monitors above head height or in lockable boxes are options.
   - What to avoid. Monitors should not be located near windows or areas of outdoor air intrusion, near HVAC supply ducts (unless the supply air is being monitored), or any sources of unusual IAQ pollutants. If possible, a site survey taking handheld readings to check the representativeness of planned monitoring locations should be done ahead of time.
   - Tables vs wall mounted. If possible, wall mounted is preferable, as occupants are major sources of IAQ pollution and can particularly impact CO_2 and VOC readings. Wall mounts do require some installation (see photos) but also are less likely to be disrupted, unplugged, or moved. For new construction, be aware that newly painted walls can impact TVOC readings.
   - Ducts. Generally, we are most interested in measuring the actual ambient air that occupants are breathing and place the monitors in the breathing zone. However, if our purpose is to measure the building's own ventilation system or filtration systems before the occupants' behaviour or indoor sources filter or contaminate this air, we want to measure the air being supplied by the ducts. The use of a duct box that penetrates the duct as well as secures the monitor, can achieve this. Tip: monitoring outdoor air supply ducts is a convenient way to measure outdoor air quality without needing an outdoor "hardened" monitor to be exposed to the elements.
   - Documentation. It is very important to create – and maintain – the location of monitors on a floorplan or BIM (building information management) system plan. Monitors have a way of moving and accountability can be a problem over time, especially with staff turnover.
4. **Power options.** Corded power packs, while convenient, are likely to be unplugged, so DC from within the walls is preferred. If power cords must be used, select outlets that are less utilized, and mark the power plugs with signs saying, "Do not unplug", etc. Some monitors have a battery option, which can be convenient for validation or calibration against fresh air.
5. **Validation.** Monitors must be checked against reference machines, preferably before deployment and then once again on-site. Documentation should be kept in case of challenge. Outdoor air may be used as a field expedient check for CO_2 and TVOC. Be careful about comparing spot PM readings against published PM readings, which are typically hourly averages and, also, not co-located. If many monitors are being deployed (typically more than 10), it is often advisable to also deploy a high quality handheld reference machine or an "alpha class" monitor that can be used as a comparison.
6. **Signage.** As previously mentioned, occupants may often impact monitoring, either by moving the monitors, unplugging them, breathing on them, doing construction work near them, or even stealing them. If the monitors cannot be deployed in a secure manner or out of reach, clear dual language signage that says, "Ongoing monitoring, please do not touch or unplug" is necessary.
7. **Renovation or other indoor sources.** If possible, monitors should not be installed until just before occupation. Since monitors can be a useful tool in gauging the readiness of indoor air for move-in, they can be set up before, but never should be exposed to construction activity such as painting, which can damage or destroy sensitive sensors. If they must be installed during construction, they should be bagged up in airtight bags and secured to avoid loss.

Table 2. The pros and cons of different communications types.

Communications type	Pros	Cons
Bluetooth	Useful for portable hand-carried or wearable monitors, but not fixed ones; useful if application requires frequent communications with mobile phones	Very limited range; pairing problems; Bluetooth is still not a universal standard
Wifi	Ubiquitous in most places; if not many monitors, easy to set up a dedicated "hotspot" style Wi-Fi router. Mainly useful in residential or small business and non-critical sites	Can be unstable; routers settings or passwords often changed due to business process; some monitor chipsets cannot handle 5.0 GHz bands; most monitors cannot handle username login systems that businesses often use
GPRS (mobile SIM card)	Can be used anywhere there is mobile signal; can be used to augment gaps; separate GPRS modem may be more acceptable to some security requirements than piggybacking on inter/intranet	Cell coverage can be spotty and change over time; must remember to keep subscription paid; cost of GPRS modem; must check compatibility of network with monitor's SIM card module
Zigbee	Longer distance than Wi-Fi, penetrates walls and solid materials better	Requires "hub and spoke" setup; ZigBee router is cost prohibitive if just several monitors; not very popular with monitor suppliers
LAN (RJ-45)	Very stable; fewest chances of connectivity problems	Some IT departments and business rules don't allow third party devices to get on network; physical cabling needed
Coax/analog	Similar to LAN; very stable; good for hotels or buildings; inexpensive	Generally, only available during construction (or requires opening up walls); less common

Cloud-ware and analysis

Sensor data is of little value, especially to non-experts. Data needs to be aggregated, made visually meaningful, and interpreted to drive action. In the old days, software was like cleanroom software – unattractive, purpose-built, not flexible, and local to the building. Today, the software is built on the cloud to provide remote access, be interoperable, create easier interoperability, allow benchmarking and trend analysis, and enable automation. However, privacy issues may impact this decision. Although the focus is currently on air, software platforms are enabling us to increasingly include other environmental parameters, such as light and sound. Due to space constraints, software, visualization, and data analysis will be the subject of a follow-on article.

Conclusions & takeaways

Continuous air quality monitoring is a critical component of effective IAQ systems, from assessing the baseline condition to optimizing settings to maintenance. The monitoring hardware industry is growing rapidly, but "soft knowledge" – selecting the right hardware, deploying monitors correctly, and getting maximum value out of the data with a cloud analysis platform and automation software – will need attention in order to actually achieve results. ■

Articles

Metrics of Health Risks from Indoor Air

BENJAMIN JONES
Dr, University Of Nottingham

In a recent review of 31 green building certification schemes used around the world, IAQ was found to contribute to only 7.5% of the final score on average (Wei et al., 2015). As policy makers strive to reduce the energy demands of buildings by sealing or reducing outdoor air ventilation rates, an unintended consequence could be the reduction in the quality of indoor air with corresponding negative health effects at a population scale. This article summarizes the discussions of an Air Infiltration and Ventilation Centre workshop on IAQ metrics held in March 2017 (AIVC, 2017). It first identifies the types of contaminants found in many buildings today, the mechanisms of exposure to them, and methods of mitigating their effects. It then explores metrics that could be used to quantify the quality of indoor air.

Keywords: Indoor air quality, metric, health, contaminant, pollutant.

Problems

Building materials and systems, and the activities carried out in them, can be a source of contaminants that are harmful to human health. For example, there is evidence that some of the materials used to construct and furnish buildings emit harmful gases and harbour biological organisms. Unvented combustion processes for space and food heating emit gaseous and particulate contaminants and can be a source of moisture that is a primary driver of biological growth. Human activities, such as cooking and vacuum cleaning, also emit particulates, cleaning and deodorizing products emit gaseous contaminants and particulates, and smoking emits over 7000 different compounds of which many are harmful (CfDC, 2010). Pets harbour and transport biological contaminants, and can themselves be allergens. People and pets also emit gaseous bio-effluents that are disagreeable to smell, and harbour pathogens that produce disease. These examples show the many potential hazards and contaminant sources in buildings, for which there are multiple exposure pathways, and not all of them are airborne.

The measurement of airborne contaminant concentrations is generally a task carried out by experts, and reported in academic journals and technical reports. The presence and concentrations of contaminants is often measured without careful consideration of their relevance, and those measured may not be the most prolific or the most harmful. Some contaminants are inappropriately grouped together; for example, there are over 1 million volatile organic compounds (VOCs) and their toxicities are generally unknown, yet they are sometimes reported as single values and referred to as *total VOCs* (TVOC). Carbon dioxide (CO_2) is often used as an indicator of poor IAQ, although it does not negatively affect the health of occupants in the concentrations usually found in buildings, it is a marker of human bio-effluents. Its presence is a function of occupancy, occupant activity, gender, age and physiology, combustion, and transport from elsewhere. Without an understanding of these variables, indoor CO_2 cannot be used to assess indoor air quality or ventilation. And, it can never be used to indicate the presence of other important indoor contaminants, such as formaldehyde emitted from building materials, whose emission is unrelated to CO_2 concentration.

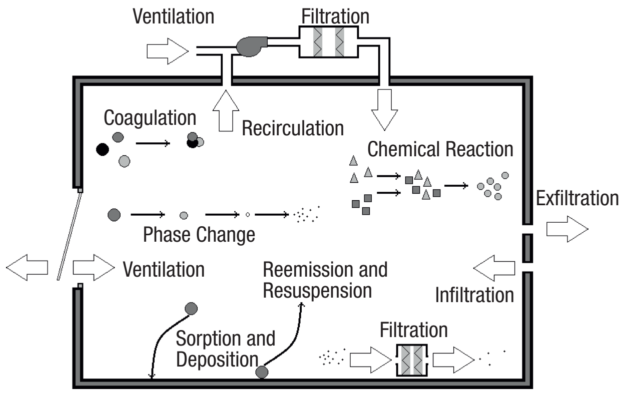
However, existing measurements of contaminants, whose type and toxicity are known, still give cause for concern (Logue *et al.*, 2011). They could negatively affect the health of occupants of any building they were found in and, when extrapolated to larger building stocks, could adversely affect healthcare systems and economies.

What do we think we know about IAQ?

Ventilation is the primary method of contaminant dilution and removal in buildings. Ventilation standards generally agree that indoor air should be perceived as fresh and pleasant by a significant majority of occupants and so they set a baseline ventilation requirement of around 8 l/s per person to dilute bio-effluent odours to an *acceptable* level for anyone who enters an occupied room from relatively clean air (Persily, 2015). They then attempt to account for other contaminants, such as building materials and furnishings, by increasing the baseline rate to around 10 l/s per person, although the increase is not based on specific contaminants (Persily, 2006). Ventilation rates in national standards around the world differ by up to 4 times, and their origins aren't always known or documented (Borsboom, 2017). Comparisons of measured ventilation rates against those prescribed by national standards suggest that there is also a widespread inability to implement them effectively in many building types (Persily, 2016), such as houses (Dimitroulopoulou, 2009) and schools (Chatzidiakou *et al.*, 2012). This suggests that they are smelly, but they could be unhealthy too.

There are limits to the ability of ventilation to mitigate these contaminant exposures. Occupants are exposed to contaminants via three mechanisms: inhalation, dermal absorption (through the skin), and ingestion. For example, infections are carried by fomites, such as skin cells, hair, clothes, bedding, utensils, and furniture, and are spread by all three mechanisms. The pumping action of doors, the movement of bedding, and the action of sitting on soft furniture can all re-suspend fine particles that can be inhaled into the lower respiratory tract. Large droplets produced by breathing, talking, sneezing, and coughing contain mucus, saliva, cells, and infectious agents that are transmitted over distances of less than 1 m.

Such particles can be inhaled into the upper respiratory tract (Atkinson *et al.*, 2009). Semi-volatile organic compounds (SVOCs), such as those emitted by dry cleaned clothing or flame retardants, are absorbed through the skin from clothing and can be sorbed by food and ingested (Weschler & Nazaroff, 2008). Organic

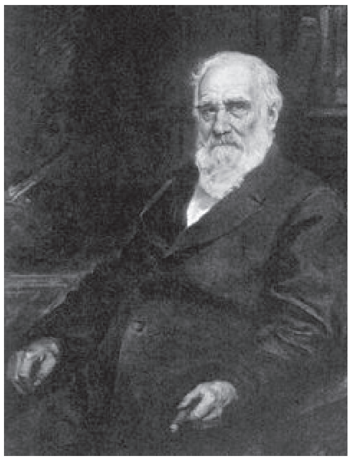


Ventilation Mechanisms and Pollutant Behaviours Indoors.

allergens, such as those produced by dust mites, are contained in bedding, carpets, and soft furnishings and are inhaled (Biddulph *et al.*, 2007). The complexity of such exposures shows that ventilation is an insufficient remediation measure on its own and inherently doesn't deliver acceptable IAQ, especially when contaminant sources are not reduced or eliminated.

Practical solutions

By the mid-1800s, a pioneer of modern hygiene and environmental science, Max Joseph von Pettenkofer, had identified *source control* as the most effective first step towards acceptable IAQ.



"If there is a pile of manure in a space, do not try to remove the odour by ventilation. Remove the pile of manure."

Attributed to
Max Von Pettenkofer

Source Control (Fanger, 2006).

When source control is impossible, then local exhaust ventilation, such as a kitchen cooker hood, is effective in removing contaminants before they are able to mix in a space.

These devices are imperfect, and so it is still necessary to dilute well mixed contaminants using ventilation, or to remove contaminants using an air cleaner. These devices can be a useful alternative to ventilation, but they have energy and financial penalties, as well as performance limitations. There is also evidence that they can reemit collected particulates, and serve as sites for microbiological growth or chemical reactions that create secondary contaminants, such as ozone, formaldehyde, and other VOCs (Siegel, 2016). There is a pressing need for standardization and performance data for these devices.

Capture efficiency of a range hood commonly found in the U.S.A (Image courtesy of Iain Walker at the Lawrence Berkeley National Laboratory).

Some contaminants, such as carbon monoxide, are harmful when the exposure is acute and so sensors and alarms can be useful for monitoring indoor levels. However, many others require exposures to be chronic before negative health effects occur. Traditionally, CO_2 has been used as a marker for IAQ although its limitations have already been highlighted. Therefore, devices that are capable of indicating the presence of specific contaminants should be used, but given the plethora of possible contaminants it is not always clear which should be measured first, and what thresholds the measurements should be compared against. To do this, a system of measurement is required.

IAQ metrics

An air quality metric should identify when the quality of indoor air is unacceptable and should be based on its effects on human health and comfort, acknowledging that they may not be immediate.

One method of analysis is to ask occupants to personally assess IAQ. The human nose is as sensitive to some gaseous contaminants as chemical analyses and using it indicates occupant preference and ensures that people are the focus of an assessment. Perceived air quality (PAQ) is the basis of most ventilation standards and is used to assess indoor odours (ISO, 2014) and air quality in buildings (Wargocki *et al.*, 2004). However, its very subjectivity, the inability of the nose to smell all harmful contaminants (CO is odourless, for example), its high dependence on temperature and relative humidity (Fang *et al.*, 1998), and the propensity of people to adapt to malodours after only a few minutes (Berg-Munch *et al.*, 1986), are acknowledged by some as fundamental concerns.

A second method might be to identify properties of a building that are known to affect IAQ directly, for example using a tick-box approach. Each feature could be weighted according to their hazard and aggregated to produce a single metric. This method could be used to develop a third-party rating system, similar to many existing energy rating schemes, and should be helpful to someone who is particularly sensitive to specific contaminants in choosing a house to live in.

To obtain a comprehensive picture of the IAQ in a building it would be necessary to measure a range of contaminants, but their individual concentrations may be incomparable because of different health impacts and time scales, and units; for example, radon (Bq.m^{-3}) and particulate matter (μg.m^{-3}). One approach is to convert the individual contaminant concentrations into sub-indices, which may be a function of their health risks, before they are aggregated into a single index. However, the summing of sub-indices can lead to situations where they are all under individual health thresholds, but the final index shows exceedance. Conversely, the averaging of sub-indices can lead to a final index that indicates acceptable IAQ when one or more sub-indices are greater than their individual thresholds. One solution is to use the maximum of all sub-indices as the final index (Sharma and Bhattacharya, 2012), but this does not indicate overall IAQ. Other methods weight the sub-indices before aggregation (Abadie *et al.*, 2016).

Exposure limit values (ELV) are used in occupational environments to prevent or reduce risks to health from hazards, such as vibrations (HSE, 2008), by setting a maximum quantity experienced per person per day. This principle could be applied when measuring the concentrations of a range of contaminants in a building. Here, the ratios of their maximum concentrations to their respective ELV concentrations give a quick indication of risk, where a ratio 1 might be acceptable but one approaching or exceeding unity may be problematic.

A problem with IAQ indices and ELVs is that it isn't clear how a change to either metric, say by 10%, would affect occupant health and comfort. Here, an indication of the relationship between exposure and health consequences is required.

The disability adjusted life year (DALY) is a measure of time where a value of unity is one year of *healthy* life lost to some disease or injury. DALYs are calculated as the sum of years of life lost to premature mortality and morbidity in a population for some negative health effect. Disability is weighted by its effect on person's life in general, and so can account for mental illness. In the case of IAQ, the burden of disease is a measurement of the difference between the current health status of a population of building occupants and an ideal situation where they all live into old age, free of disease and disability (WHO, 2009). The DALY has been used by the AIVC (2016) to prioritize indoor contaminants found in houses for mitigation.

Next steps

For a metric to be useful and accepted as *best practice*, it must be robust and trusted. Unreliable evidence can be disputed and could lead to litigation. A metric must have robust technical specifications, prescribing

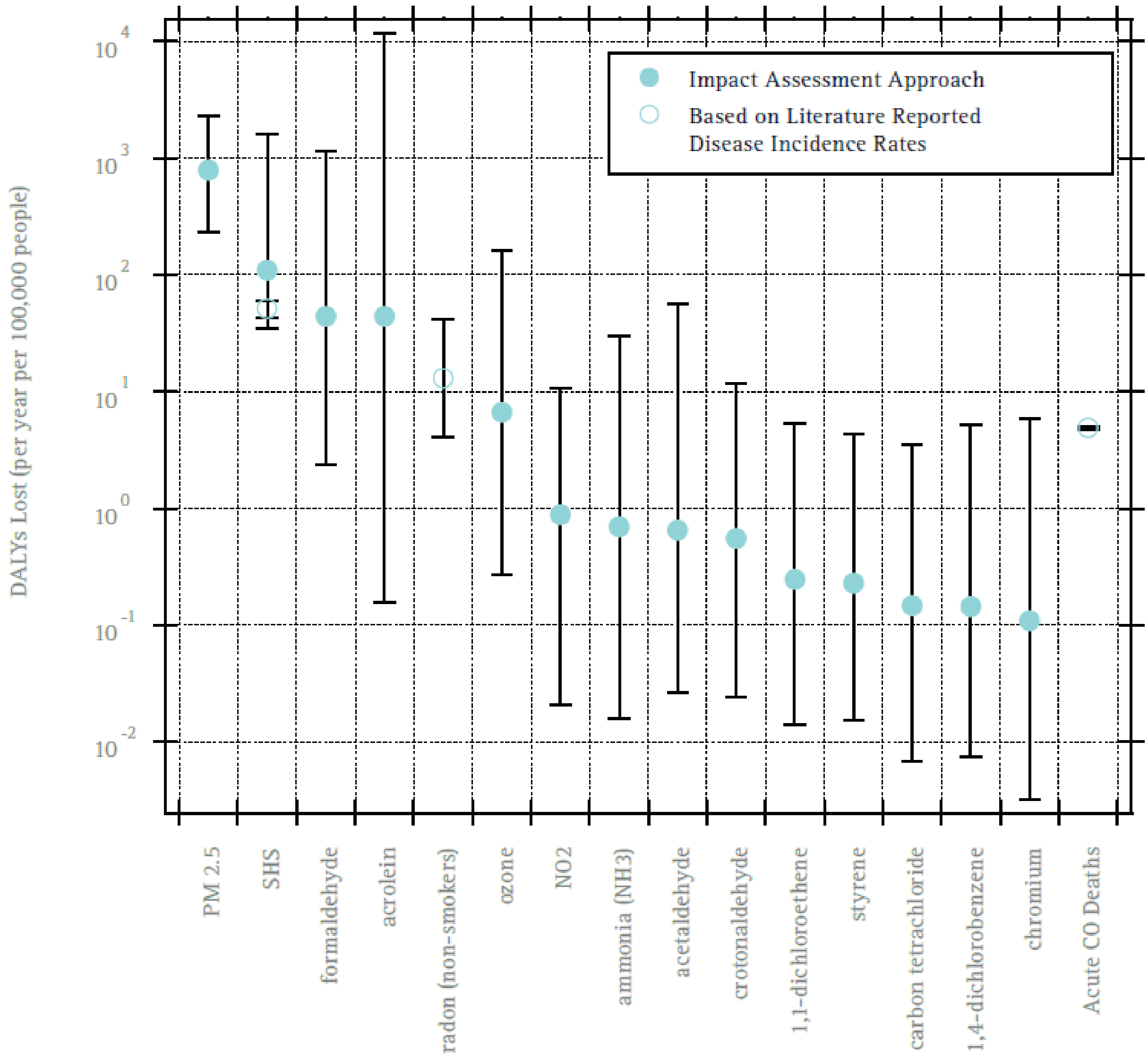


Figure 4. Estimated population averaged annual cost, in DALYs, of chronic air contaminant inhalation in U.S. residences (AIVC, 2016).

the methods of measurement and calculation. It must clearly identify measurement locations, device types, tolerances, calibration intervals, and measurer and analyst competences. This will aid consistency, and increase the likelihood that two different assessors surveying the same building arrive at the same metric score.

Metrics should not be a barrier to innovation, and so it is important that methods of pollution control are not prescribed. This follows the principles of *performance-based building design*, which focus on the end result and not on the means of achieving it. Any remediation measure should consider the need to simultaneously provide acceptable IAQ and energy use reduction, and so they should only be used when they are effective in achieving both ends. This requires good sensing and control devices whose performance is understood.

When non-compliance is identified, then pre-defined sanctions must be imposed. It is also important to define who is liable and the actions in cases of non-compliance. To develop and apply metrics, there is a clear need for resources, such as technical, legal, and administrative staff, and for equipment. Towards this end, it is fundamentally important to actively involve stakeholders so that they ensure they meet any IAQ metric required in their building and support the enforcement of infringements.

There are many hurdles to overcome, but the AIVC has begun to discuss key issues and challenge preliminary ideas. It will continue to research IAQ metrics and to give guidance on their development. The consideration of IAQ and its effects on occupant health and comfort will lead to a new paradigm in building standards and guidelines, moving them beyond the control of odour towards the provision of indoor environ-

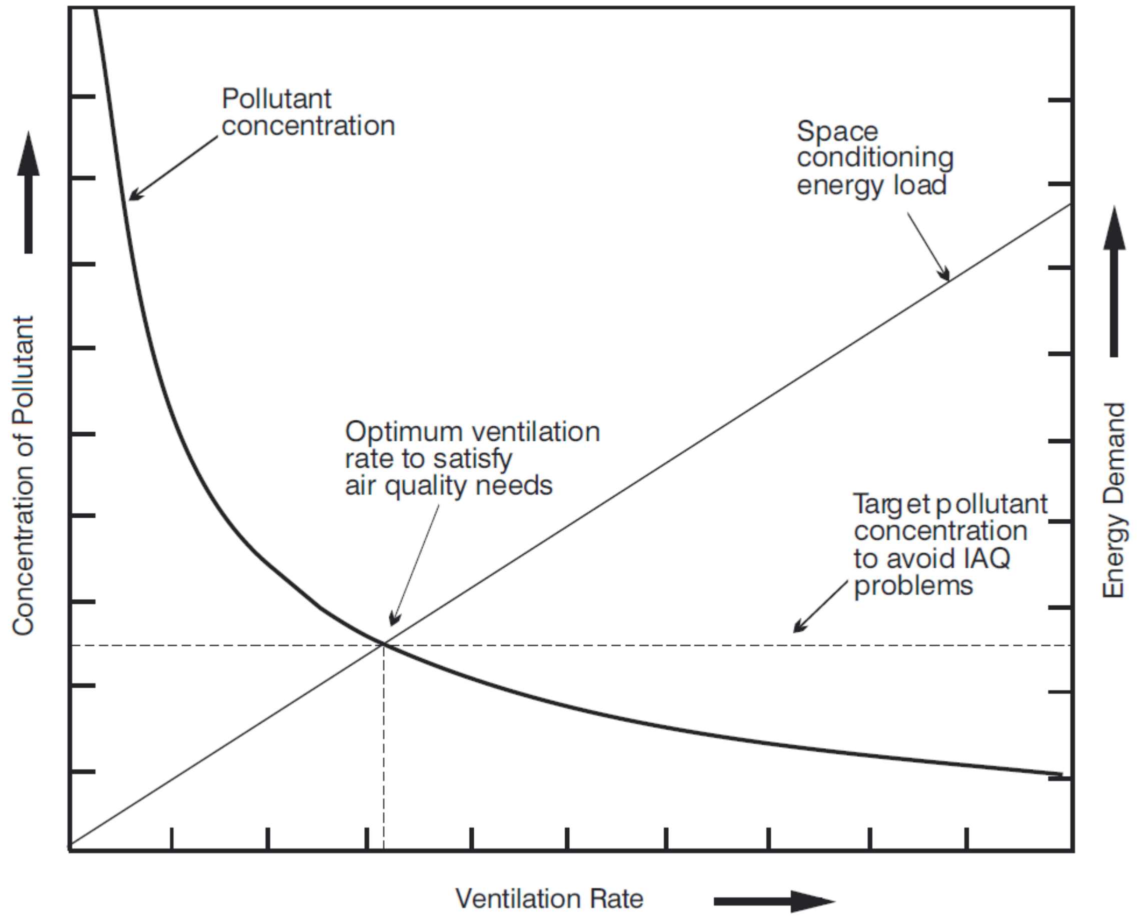


Figure 5. Controlling the Dominant Pollutant (AIVC, 1996).

ments that consider occupant health. ASHRAE 62.2 (ASHRAE, 2016) has begun this transition, and as other standards join, they will begin to have a tangible effect on people, healthcare systems, and economies. ■

Acknowledgements

The author is grateful to Max Sherman, Andrew Persily, Iain Walker, and Rémi Carrié for their comments on this article.

Literature

Abadie M, Wargocki P, Rode C. IEA EBC Annex 68 - Indoor Air Quality Design and Control in Low Energy Residential Buildings – Setting the Metrics. The 14th international conference of Indoor Air Quality and Climate. Ghent, Belgium. July 3–8, 2016.

AIVC. Is ventilation the answer to indoor air quality control in buildings? Do we need performance-based approaches? AIVC Workshop held in Brussels, Belgium. 14th–15th March, 2017.

AIVC. TN 68: Residential Ventilation and Health. Air Infiltration and Ventilation Centre, Brussels, Belgium; 2016.

AIVC. GU03: A Guide to Energy Efficient Ventilation. Brussels, Belgium: Air Infiltration and Ventilation Centre; 1996.

ASHRAE. ANSI/ASHRAE Standard 62.2 - Ventilation and Acceptable Indoor Air Quality in Residential Buildings. 2016.

Atkinson J, Chartier Y, Pessoa-Silva CL, Jensen P, Li Y, Seto W-H. Natural Ventilation for Infection Control in Health-Care Settings. World Health Organization; 2009.

Berg-Munch B, Clausen G, Fanger PO. Ventilation requirements for the control of body odor in spaces occupied by women. Environment International. 1986; 12:195-9.

Biddulph, P *et al.* Predicting the population dynamics of the house dust mite Dermatophagoides pteronyssinus (Acari: Pyroglyphidae) in response to a constant hygrothermal environment using a model of the mite life cycle. Experimental and Applied Acarology. 2007; 41:61-86.

Borsboom, W. Rational Behind Current Ventilation Airflow Rates. *Presentation to* AIVC Workshop: Is ventilation the answer to indoor air quality control in buildings? Do we need performance-based approaches? Brussels, Belgium. 14th March, 2017.

CfDC. How Tobacco Smoke Causes Disease. The Biology and Behavioral Basis for Smoking-Attributable Disease. Centers for Disease Control. Atlanta, Georgia, U.S.A.: U.S. Public Health Service; 2010.

Chatzidiakou L, Mumovic D, Summerfield AJ. What do we know about indoor air quality in school classrooms? A critical review of the literature. Intelligent Buildings International. 2012; 4:228-59.

Dimitroulopoulou C. Ventilation in European dwellings: A review. Building and Environment. 2012; 47:109-25.

Fang L, Clausen G, Fanger PO. Impact of Temperature and Humidity on the Perception of Indoor Air Quality. Indoor Air. 1998; 8:80-90.

Fanger PO. What is IAQ? Indoor Air. 2006; 16:328-34.

HSE. Hand-arm vibration. - The Control of Vibration at Work Regulations 2005. Health and Safety Executive. ISBN 0-7176-6125-3. Richmond, UK. 2008.

ISO. 16000-30 Indoor air: Sensory testing of indoor air. International Standards Organization. 2014.

Logue JM, McKone TE, Sherman MH, Singer BC. Hazard assessment of chemical air contaminants measured in residences. Indoor Air. 2011; 21:92-109.

Persily A. Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62. Building and Environment. 2015; 91:61-69.

Persily A. Field measurement of ventilation rates. Indoor Air. 2016; 26:97-111.

Persily A. What We Think We Know about Ventilation. International Journal of Ventilation. 2006; 5:275-90.

Siegel JA. Primary and secondary consequences of indoor air cleaners. Indoor Air. 2016; 26:88-96.

Sharma M, Bhattacharya A. National Air Quality Index. Central Pollution Control Board. Ministry of Environment, Forests, & Climate Change; 2012.

Wargocki P, Fanger PO, Krupicz P, Szczecinski A. Sensory pollution loads in six office buildings and a department store. Energy and Buildings. 2004; 36:995-1001.

Wei W, Ramalho O, Mandin C. Indoor air quality requirements in green building certifications. Building and Environment. 2015; 92:10-9.

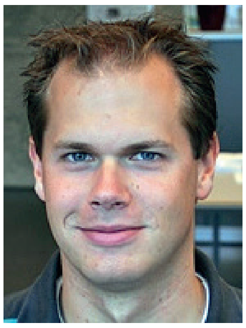
Weschler CJ, Nazaroff WW. Semivolatile organic compounds in indoor environments. Atmospheric Environment. 2008; 42:9018-40.

Articles

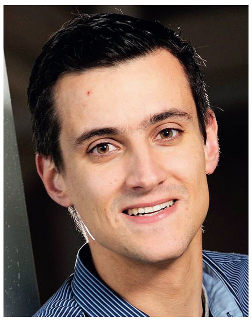
Particulate matter reduction in Eindhoven

R. VERVOORT
ir.
r.p.m.vervoort@tue.nl [a]

B. BLOCKEN
prof. dr. ir.
b.j.e.blocken@tue.nl [a, b]



T. VAN HOOFF
dr. ir.
t.a.j.v.hooff@tue.nl [b, a]



R. GIJSBERS
dr. ir.
r.gijsbers@enstechnology.nl [c]

[a] Building Physics and Services, Department of the Built Environment, Eindhoven University of Technology, P.O. box 513, 5600 MB Eindhoven, The Netherlands

[b] Building Physics Section, Department of Civil Engineering, KU Leuven, Kasteelpark Arenberg 40, bus 2447, 3001 Leuven, Belgium

[c] ENS Technology, Grotestraat 41, 5431 DH Cuijk, The Netherlands.

High traffic intensities in cities are a cause of high particulate matter (PM) concentrations due to tailpipe emissions and tire and brake wear. The objective of this study, is to assess whether PM removal in parking garages by implementation of electrostatic precipitation, can reduce PM concentrations in the wider urban surrounding.

Keywords: Air quality; Air pollution; Fine dust; Particulate matter; Computational fluid dynamics (CFD); Electrostatic precipitation; Positive ionization; Urban physics.

The effects of particulate matter exposure

The collection of all solid and liquid particles suspended in the atmosphere, known as particulate matter (PM), is currently one of the most dangerous forms of air pollution. According to the World Health Organization (WHO), daily and long-term exposure to PM is strongly related to human morbidity and mortality [1]. Health effects are closely related to the size of the inhaled particles [1]; large particles can be filtered by the nose and throat, however, particles smaller than 10 µm (PM_{10}) can enter the bronchi and lungs. Particles smaller than

0.1 µm ($PM_{0.1}$) can directly be transported into the bloodstream [1]. Many studies have linked PM exposure to lung cancer, respiratory, cardiovascular and cardio-pulmonary diseases (e.g. [2-3]) (an extensive overview of references is given in the paper by Blocken et al. [3]). Furthermore, links with Alzheimer, Parkinson, dementia, multiple sclerosis and stroke incidences are found (e.g. [2-4]). Groups with pre-existing lung or heart diseases, elderly people and children are especially vulnerable [2]. PM exposure affects lung development of children; i.e. lung functioning is impaired and lung growth rate is chronically reduced [5]. According to the Organization for Economic Cooperation and Development (OECD), air pollution will become the world's top environmental cause of premature mortality by 2050 when no measures are taken [6]. According to the European Environment Agency (EEA), the world-wide number of premature deaths due to PM exposure, as presented in **Figure 1**, will climb from approximately 1.5 million today, to 3.5 million in 2050 [7]. Given that good health and a long life are highly valued in society, analysis shows that economic costs of air pollution are significant [8].

Air pollution in the city

The WHO provides limits for the annual mean PM concentrations. i.e. for PM_{10} the annual mean is set at 20 µg/m³ and the 24 hour mean is set at 50 µg/m³ [9]. For $PM_{2.5}$ these values are set at 10 and 25 µg/m³ respectively [9]. Worldwide, more than 80% of the people that live in urban areas are exposed to air quality levels that exceed the WHO limits [10]. While in Asia all the global cities fail to meet the 10 µg/m³ $PM_{2.5}$ limit, in Europe few are able to pass (e.g. Helsinki, Edinburgh and Stockholm) [10]. In a global context, ambient $PM_{2.5}$ concentrations in European cities seem relatively low. For example, when considering $PM_{2.5}$ concentrations, annual mean concentrations in Paris are exceeded by a factor 1.8 while in Delhi this is a factor 12.2 [10]. Although the WHO limits are defined strictly, it is important to keep in mind that epidemiological studies were unable to define a specific threshold for which PM concentrations have no effect on human health [2]. It is expected that there is a very wide range in susceptibility; some individuals might be at risk when exposed to very low concentrations [2].

High ambient concentrations of PM are found in regions with high traffic intensity, including urban areas, due to tailpipe emissions and tire and brake wear [11]. Other studies showed that PM is accumulated in parking garages [12–13]. In the surroundings of parking garages the ambient PM concentrations are highly dependent on parameters such as traffic intensity, meteorological conditions and urban geometry.

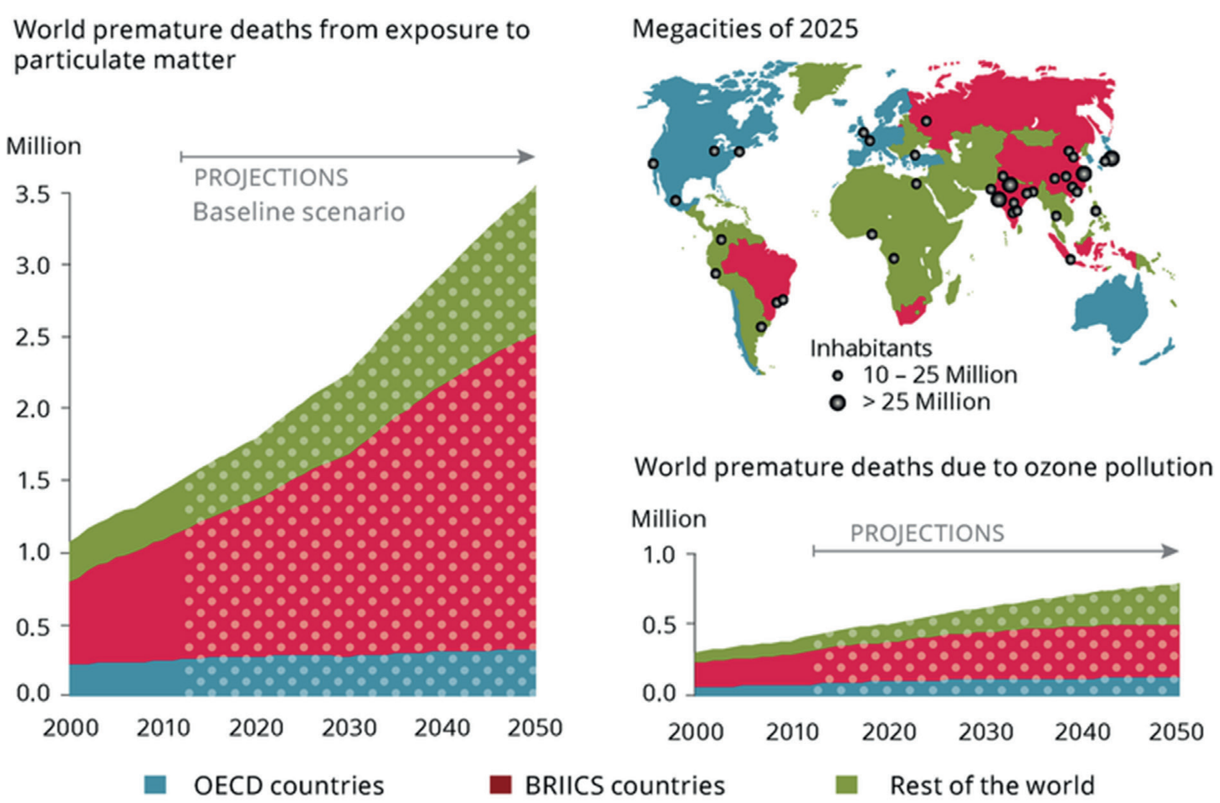


Figure 1. Projected premature deaths due to PM and ground-level ozone [7].

Exposure to high ambient PM concentrations does not only occur outside, in streets where the traffic intensity is high, but also in buildings due to ventilation. Since people roughly spend 85–90% of their time indoors [14], PM exposure is certainly a very serious problem, putting health at risk.

Air purification in garages

Various solutions are available to limit ambient PM concentrations, such as porous media filters, cyclonic separators, wet scrubbers and electrostatic precipitators (ESP). ENS Technology [15], a manufacturer of ESPs based on a positive ionization technology, applied two of their ESP units in a parking garage in Cuijk (the Netherlands). The technology captures fine particles and ultrafine particles without the use of traditional filtering techniques. In the ESP, particles are bound together, forming coarse dust that cannot be inhaled (since it is not airborne). One of the advantages of this system is that most of the energy penalty, associated with the pressure drop across media filters (traditional technique), is eliminated. Furthermore, it is found that the applied systems do not add to the normal background ozone level, unlike several other ESP-based technologies. In Cuijk it is found that PM_{10} concentrations are strongly reduced in the parking garage, but also in the shopping mall connected to the garage [16]. This leads to the idea of large-scale application of ESP units in parking garages, which would thus function as 'lungs of the city'.

CFD model Eindhoven city center

A computational fluid dynamics (CFD) case study is conducted for the city center of Eindhoven (the Netherlands), including ESP units in 16 parking garages. Eindhoven is located in the south of the Netherlands and it is the fifth largest city of the Netherlands with 225,020 inhabitants [17]. The city center of Eindhoven is characterized by a mixture of low-rise and a few high-rise buildings, both commercial and residential, with open areas such as roads, parks and squares. The generated computational grid consisting out of 65.7 million cells, as presented in **Figure 2**, covers an area of about 5.1 km².

To determine sources of PM_{10} in the model, traffic intensity, traffic emission data, parking garage use and background PM_{10} concentrations are considered. Terrain roughness is taken into account by assigning the correct aerodynamic roughness height (y_0), equivalent sand-grain roughness height (k_S) and roughness constant (C_S) to the wall surfaces. Simulations are performed for a reference wind speed (U_{ref}) of 1 m/s at 10 m height and a south-east wind direction. The southeast wind direction is chosen because ambient concentrations in Eindhoven are generally higher for this wind direction [18]. Thermal effects are not taken into account.

ESP units are implemented in the garages by means of a PM_{10} sink term. The units run at a volume flow rate of 9,000 m³/h and a PM_{10} removal efficiency of 70%

Figure 2. Overview of the computational grid of the city center of Eindhoven (65.7 million cells) [3].

[16]. Three different cases are modeled: a reference case without ESP units, a case including 99 units (one unit per 65 parking spots) and a case including 594 units (six units per 65 parking spots) spread over the 16 parking garages. Garage ventilation is imposed based on the Dutch building regulations (10.8 m³/m²h).

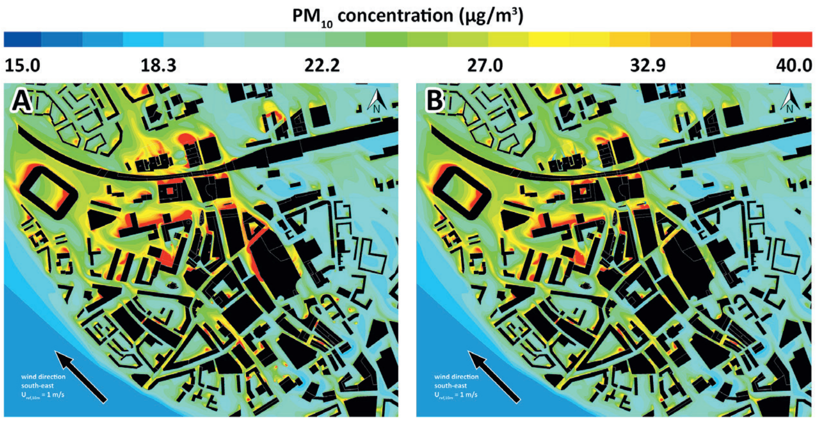


Figure 3. Contours of PM_{10} concentrations (µg/m³) in a horizontal plane at 1.75 m height without units (a) and including 594 units (b) installed over 16 parking garages in the city center of Eindhoven. Wind direction South-East $U_{ref,10m}$ = 1 m/s.

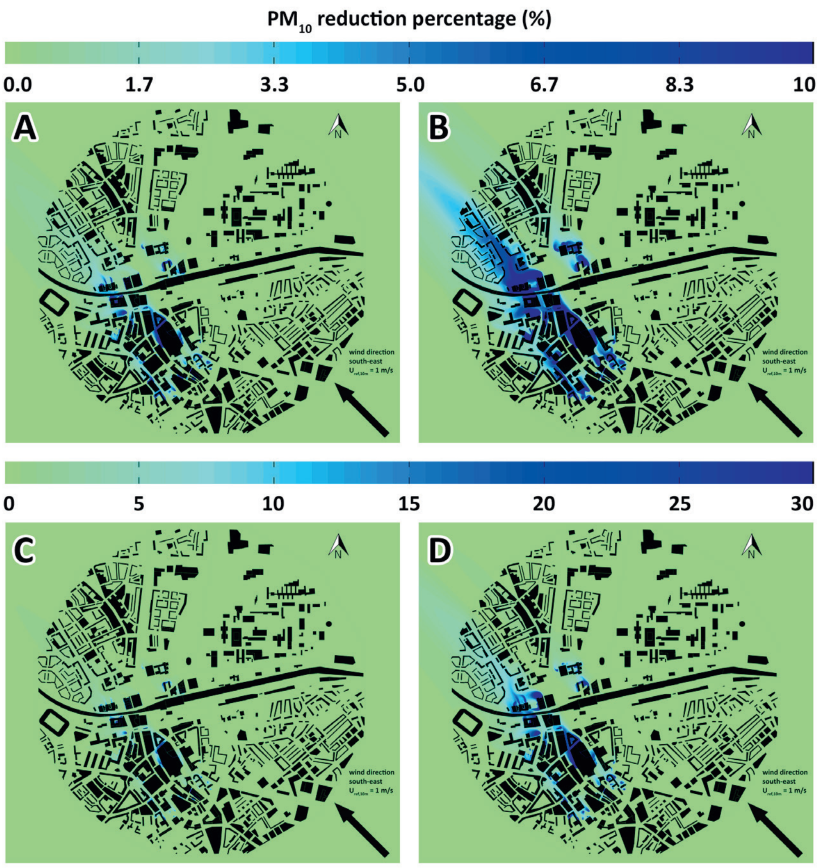


Figure 4. Contours of PM_{10} concentration reduction percentage at a height of 1.75 m for the case with 99 units (a, c) and 594 units (b, d) relative to the reference case without units. Wind direction South-East $U_{ref,10m}$ = 1 m/s. [3]

In this study, the steady Reynolds-averaged Navier-Stokes (RANS) approach is used in combination with the realizable k-ε turbulence model [19] for turbulence closure. A sub-configuration validation study is conducted using wind tunnel measurements of gas dispersion in regular arrays of rectangular building blocks by Garbero et al. [20]. The reader is referred to Blocken et al. [3] for more information on this validation study.

Case study results

Figure 3 presents the PM_{10} concentration contours at a height of 1.75 m (pedestrian level) for the reference case without ESP units (**Figure 3a**) and for the case including 594 ESP units (**Figure 3b**). Results are presented for the region where most of the parking garages are located and where the urban density is relatively high. The concentrations exceed 60 µg/m³ but in this case the maximum concentration shown is limited to 40 µg/m³ for visualization purposes.

Figure 3 shows that relatively high PM_{10} concentrations are found near the exhaust openings of the parking garages (> 40 µg/m³). High PM_{10} concentrations are found in the area with a high concentration of parking garages. Furthermore, in this area the urban density is relatively high compared to the rest of the city, resulting in relatively low wind velocities. **Figure 3** shows that PM_{10} concentrations are significantly reduced near the garages and in the exhaust flow from the garage. This is also shown in **Figure 4** where the PM_{10} concentration is compared with the reference case. **Figure 4a, c** presents the PM_{10} reduction percentage for the case including 99 ESP units and **Figure 4b, d** presents the PM_{10} reduction for the case including 594 ESP units. For the case with 99 ESP units, reductions of up to 10% are found near the garage. However, further away from the garages the reductions are insignificant. For the case with 594 ESP units, reductions of up to 30% are found near the garages (locally even up to 50%). Further away from the garages reductions of up to 10% are found.

Discussion and conclusion

Although the study has some limitations, it can be concluded that local removal of PM in parking garages can be an effective strategy towards higher outdoor air quality. As previously mentioned, studies have shown that PM exposure is strongly related to human morbidity and mortality. For this reason the presented work could be very interesting for cities in which problems related to PM exposure are severe (e.g. where the urban density is high). Further research will focus on the limitations of the current study. First of all, the maximum PM_{10} concentrations in the current simulations are rather limited (< 80 μg/m³). This is due to the fact that all the emissions are uniformly distributed over the subdomains (instead of assigning them to the exact locations of streets) and the emissions are averaged over a period of 10 hours. It can be expected that during rush hours local concentrations are higher. For this reason unequal spreading, both in time and space, of traffic and thus of PM emissions will be taken into account. In addition, thermal effects can be included in future studies. In this way, the dispersion of emissions can be taken into account in a more accurate way and different meteorological situations can be analyzed. While the current research work and suggestions will certainly not solve the PM city problem completely, at least it can be a significant step in the right direction. ■

Acknowledgements

Twan van Hooff is currently a postdoctoral fellow of the Research Foundation – Flanders (FWO) and is grateful for its financial support (project FWO 12R9715N). The authors also gratefully acknowledge the partnership with ANSYS CFD.

References

[1] WHO 2014. Ambient (outdoor) air quality and health. Fact sheet N°313, updated March 2014. http://www.who.int/mediacentre/factsheets/fs313/en/

[2] WHO 2013. Health effects of particulate matter – policy implications for countries in eastern Europe, Caucasus and central Asia, ISBN 978 92 890 0001 7.

[3] Blocken B., Vervoort R., van Hooff T. (2016). Reduction of outdoor particulate matter concentrations by local removal in semi-enclosed parking garages: a preliminary case study for Eindhoven city center, J. Wind Eng. Ind. Aerodyn. 159, pp. 80-98.

[4] Chen H., Kwong J.C., Copes R., Tu K., Villeneuve P.J., van Donkelaar A., Hystad P., Martin R.V., Murray B.J., Jessiman B., Wilton A.S., Kopp A., Burnett R.T. (2017). Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study, Lancet 389, 718-726.

[5] Rijksinstituut voor Volksgezondheid en Milieu (RIVM). Luchtkwaliteit.

[6] OECD 2012. OECD Environmental Outlook to 2050: the Consequences of Inaction. 350 p. 9789264122246 (PDF).

[7] EEA 2015. World premature deaths due to urban pollution from particulate matter and ground-level ozone. http://www.eea.europa.eu/data-and-maps/figures/world-premature-deaths-due-to. European Environment Agency.

[8] WHO 2015. Economic costs of health impact of air pollution in Europe: clean air, health and wealth. http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf?ua=1

[9] WHO, 2005. Air quality guidelines, global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. ISBN 92 890 2192 6.

[10] WHO 2016. WHO Global Urban Ambient Air Pollution Database. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

[11] Rogge WF, Hildemann LM, Mazurek MA, Cass GR, Simoneit BRT. 1993. Sources of fine organic aerosol. 3. Road dust, tire debris, and organometallic brake lining dust — roads as sources and sinks. Environm. Sci. & Techn. 27(9): 1892–1904.

[12] Kim SR, Dominici F, Buckley TJ. 2007. Concentrations of vehicle-related air pollutants in an urban parking garage. Environ. Res. 105(3): 291–299.

[13] Zhang GS, Li TT, Luo M, Liu JF, Liu ZR, Bai YH. 2008. Air pollution in the microenvironment of parked new cars. Build. Environ. 43(3): 315–319.

[14] Valavanidis A, Fiotakis K, Vlacogianni T. 2008. Airborne particulate matter and human health: toxicological assessment and importance of the size and composition of particles for oxidative damage and carcinogenic mechanisms. J. Environ. Sci. Health Pt. C – Environ. Carcinog. Ecotoxicol. Rev. 26(4): 339-362.

[15] ENS. 2008. Environmental Nano Solutions. www.enstechnology.nl/en.

[16] ENS. 2016. Environmental Nano Solutions. Personal communication B. Blocken and ENS. 30 August 2016.

[17] Eindhoven Municipality, 2015. http://www.eindhoven.nl/home.htm.

[18] AiREAS. Meetdata Eindhoven, www.aireas.com.

[19] Shih, T.H., Liou, W.W., Shabbir, A., Yang, Z., Zhu, J., 1995. A new k-ε eddy viscosity model for high Reynolds number turbulent flows. Comput. Fluids 24, 227–238.

[20] Garbero V, Salizzoni P, Soulhac L. 2010. Experimental study of pollutant dispersion within a network of streets. Bound.-Layer Meteor. 136: 45.

Analysis of performance metrics for data center efficiency

– should the Power Utilization Effectiveness PUE still be used as the main indicator? (Part 1)




TOM VAN DE VOORT
Eindhoven University of Technology
Department of Architecture, Building, and Planning
the Netherlands
t.v.d.voort@student.tue.nl

VOJTECH ZAVREL
Eindhoven University of Technology
Department of Architecture, Building, and Planning
the Netherlands
v.zavrel@tue.nl

IGNACIO TORRENS GALDIZ
Eindhoven University of Technology
Department of Architecture, Building, and Planning
the Netherlands
j.i.torrens@tue.nl

JAN HENSEN
Eindhoven University of Technology
Department of Architecture, Building, and Planning
the Netherlands
j.l.m.hensen@tue.nl

To halt the ever-increasing energy consumption by data centers it is important to use performance indicators which accurately represent this performance. The strengths and limitations of PUE as the key performance indicator are analyzed and suggestions are made to complement any limitations.

Data centers were responsible for 1.5% of global energy consumption in 2010 and this figure is only expected to double soon. Data centers are becoming more energy efficient, a trend lead by the introduction of PUE (Power Utilization Effectiveness) as a performance metric. PUE's simplicity and focus on infrastructure efficiency was quickly adopted by the industry, but now the question is raised if PUE is still able to lead the quest for improved energy efficiency. PUE does not show performance regarding IT efficiency, water usage, heat recovery, on-site energy generation or carbon impact. This can lead to misuse of PUE by focusing on just improving PUE values instead of real energy use. Improving data center performance assessment is proposed in this paper by broadening the scope beyond PUE.

Key Words: PUE, Performance metrics, Data Center, Energy Efficiency, Indicators

A data center is a building which houses IT hardware, like computational units, network infrastructure and data storage, next to supporting equipment, like cooling and power supply. What all these different types of equipment have in common is that they are all high-energy density systems. This results in great amounts of energy being used, but also major energy savings potential by improving these systems.

Context

The data center industry is growing rapidly and the overall industry is expected to have an annual growth rate of over 10% until 2019 (Technavio, 2015). This is caused by the increase in number of chip driven appliances from 3 billion devices in 2010 to 15 billion devices in 2015 and it is expected to increase to up to 50 billion devices by 2020 (Modoff *et al.,* 2014).

Because of the growth of the data center industry, its energy consumption is rapidly increasing as well. Data center energy consumption accounted for between 1.1% and 1.5% of global energy consumption and up to 2.2% of US energy consumption in 2010 (Koomey, 2011). This meant a 56% increase over the period between 2005 and 2010 after doubling between 2000 and 2005 (*idem,* 2011). The slowing of this trend has partially been caused by increasing energy prices leading to increased operational cost. Giving more incentive to adopt energy efficiency strategies. Another important reason is the economic crisis in 2008. Despite this, energy consumption by data centers is still predicted to double between 2010 and 2020 (Whitney *et al.,* 2014), thus requiring more focus on energy efficiency measures to halt this trend.

Research and Markets (2015) proposes a 30% annual growth rate for green data centers compared to 10% for the whole industry. This predicted demand for energy efficient data centers shows a way forward, but the question is how to accomplish and monitor such progress.

Performance metrics

Over the last years, different performance metrics have been introduced to measure and compare performance and efficiency of data centers. These metrics can be used to assess individual pillars (cooling, IT, power supply) of the data center or the data center as a whole. This can relate to total energy use, water use or carbon emissions, as well as subsystem efficiency like temperature distribution (Wang *et al.,* 2011).

PUE: Power Utilization Effectiveness

The most widely used performance metric is PUE, which shows the ratio between total facility power use and IT equipment power use (Averal *et al.,* 2012):

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}; 1 \leq PUE$$

Therefore, the optimal value for PUE is 1.0, the maximum value is infinity. PUE has been developed to give data collection standards 'to determine the effectiveness of any changes made within a given data center' (*idem,* 2012). Beyond its intended use, PUE has been adopted by the industry to make comparisons between data centers. The limited scope PUE offers can make it unreliable for comparison as some strategies can improve PUE values without reducing energy consumption. There is also a lack of strict measurement and reporting guidelines, only recommendations exist. This leads to publishing PUE values based on designed nominal values instead of part-load values measured during operation. (Donnely, 2015). A survey by Uptime Institute (2014) found that 'a large majority (75%) of participants said the data center industry needs a new energy efficiency metric'. Which is part of the aim of this study.

The analysis presented in this paper will start by discussing the merits and shortcomings of PUE and continue by presenting other metrics to complement these shortcomings and try to find improved ways for accurately assessing data center energy performance.

Research methodology

To find a solution to the problem described above, the following research question has been formulated:

'Does the broadly accepted PUE metric reflect the real energy performance of a data center?'

This question is answered by performing a literature review on PUE and other available performance indicators.

The first part of this literature review focuses on both the merits of the PUE metric and its limitations. The misuse of the metric resulting from these limitations is also discussed as this helps to illustrate the reason behind the need of complementary performance metrics.

To solve the issues raised in the first part of the literature review, the second part consists of a review of existing metrics which can be used to complement PUE, or in some cases could even replace PUE. An overview of relevant metrics and their intended purpose is provided.

PUE analysis

PUE merits

The total efficiency of a data center comes down to how much useful work is produced per unit of energy. But as different data centers perform different tasks and are often relying on external input, useful work is difficult to determine. Therefore, PUE gained popularity as it shows the efficiency not by quantifying useful work, but by showing the ratio of energy available for useful work and the part that is lost to overhead, also referred to as the infrastructure. This lead to an industry wide adoption of PUE as the main performance metric after PUE's introduction. As in the data center industry energy consumption is one of the major expenses, what all data centers have in common, despite their different specializations, is the requirement to reduce their infrastructure energy consumption to increase efficiency.

When PUE was introduced in 2007 it provided new guidelines for measuring and reporting the internal energy flows in data centers. Industry average PUE values found after PUE's introduction lay between 2.5 and 3.0 in various studies (Foster, 2013). By using the framework provided by PUE average values have decreased to around 1.7 in the last major industry survey by uptime industries (Stansberry, 2015). In this way, PUE has lead the first major industry shift towards energy efficient data centers.

For state-of-the-art large-scale internet data centers the PUE value has always been significantly lower and is close to values of 1.1 now (Google, 2016). Which means further improvement within the boundaries PUE provides is difficult. This underlines the need for other metrics to broaden the scope of energy efficiency assessment beyond PUE to further lower data center energy consumption.

PUE limits and misuse

As said, PUE has been used for comparison since its introduction. As the green grid (2012) states 'the metric is best applied for looking at trends in an individual facility over time and measuring the effects of different design and operational decisions within a specific facility'. Despite the recommendation of applying PUE for internal use it's understandable that it started to be used for comparison. If a facility reports very low PUE values other facilities will be interested in the ways to achieve this efficiency. This also lead to infrastructure designers 'rating' their system with achievable PUE values, but as no strict guidelines apply to the origins of these values it often remains unclear for which conditions they were calculated and if they can be achieved in real life. PUE is supposed to be a tool to decrease the energy consumption of data centers, but decreasing the PUE value has become the goal itself. This leads to strategies where PUE doesn't necessarily reflect real energy performance.

As it can be taken as a fact that PUE will be used for comparison, its reporting parameters should be better regulated. At this moment, there is a lot of flexibility in choosing the measurement point for a data center's energy use (appendix A). As PUE was introduced for internal use it can be decided within a data center which level of monitoring is chosen. For comparison and marketing purposes it is obvious that you would like to choose the best-case scenario. Regulating this reporting parameters can greatly increase the reliability of the PUE metric.

Guidance as to which measurement points and intervals are required and recommended for each PUE measurement level.

Where do I measure? How often do I measure?		Level 1 (L1) Basic	Level 2 (L2) Intermediate	Level 3 (L3) Advanced
IT Equipment Energy	Required	UPS outputs	PDU outputs	IT equipment input
Total Facility Energy	Required	Utility inputs	Utility inputs	Utility inputs
	Additional recommended measurements*		**UPS inputs/outputs** **Mechanical inputs**	**PDU outputs** **UPS inputs/outputs** **Mechanical inputs**
Measurement Intervals	Required	Monthly	Daily	15 minutes
	Additional recommended measurements*	**Weekly**	**Hourly**	**15 minutes or less**

* Recommended measurements are in addition to the required measurements. The additional measurement points are recommended to provide further insight into the energy efficiency of the infrastructure.

The scope of PUE is limited to energy consumption and as stated by The Green Grid (2012) 'PUE awards no credits or percentage points for on-site energy generation, waste heat recovery, etcetera. While important, these are not the focus of the PUE metric'. Also, the energy source being used isn't monitored by PUE. Electricity generated by PV-panels is treated the same as electricity from a coal plant. By including the ecological impact of the energy source the total energy impact can be better assessed.

Other forms of resource consumption fall beyond the scope of PUE, like water consumption by evaporative cooling. Especially when treated water is used for this purpose a significant energy impact exists. Broadening the scope of performance assessment to include these effects will increase the complexity, but will help to promote the circular use of resources and the use of low impact energy sources.

Maybe the most important issue with using PUE as the guiding performance metric is its disregard for IT equipment efficiency. As the computational power per watt increases per Moore's law (Moore, 1965) the useful work produced per watt can double every two years, therefore renewing IT equipment might be one of the best energy efficiency strategies. 'A typical data center's PUE is likely to vary with the levels of its IT load' (Green Grid, 2012). And as illustrated in **Figure 1**, PUE values are better during periods of high relative IT load. **Figure 2** illustrates how the average IT load can drop when more efficient IT equipment is installed, causing a degradation in PUE values. This is obviously not a desirable effect for accuracy of performance evaluation using PUE. When the cooling temperature set, point is increased the PUE value doesn't accurately reflect real performance. This leads to a decrease of energy consumption by the cooling system, but an increase of IT equipment energy use as the server fans speed up. Also, the electric resistance of the IT equipment increases together with IT energy consumption. It is obvious that the PUE value improves, but total energy consumption might be unchanged or could even increase (Hartfield, 2011). This effect is illustrated in **Figure 3**.

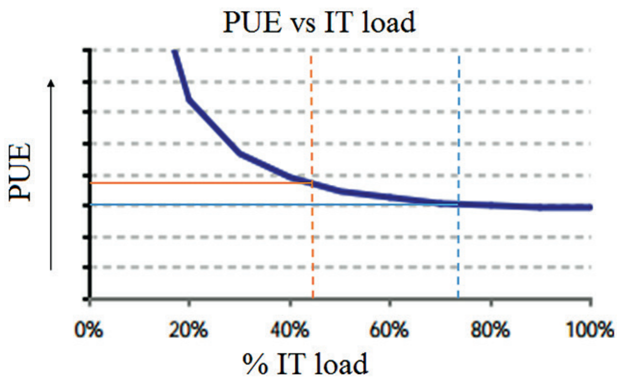


Figure 1. Relationship between PUE and IT Load with example from Figure 2 (adapted from Bisci 2009).

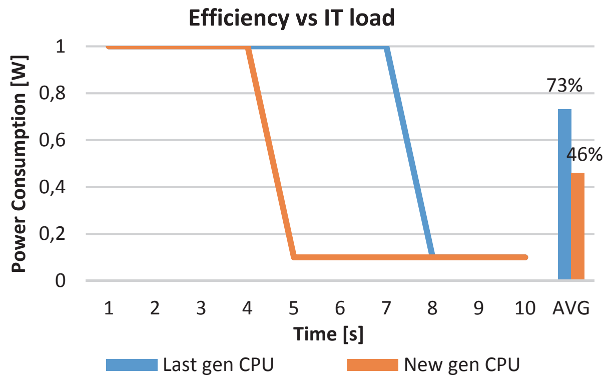


Figure 2. Relationship between efficiency and IT Load (adapted from Wasson 2015).

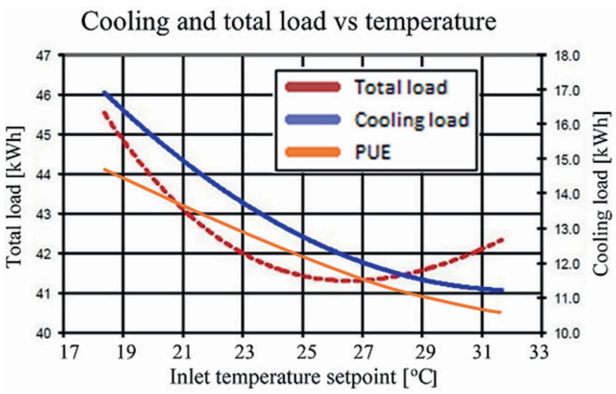


Figure 3. Typical relationship between temperature set point, cooling load, total load and PUE (adapted from Hartfield 2011).

Performance metrics complementing PUE

As made clear in the previous section, to provide a complete assessment of energy efficiency for the data center industry through performance metrics, the scope should be widened from PUE alone. On the other hand, it is important to track the efficiency of separate parts of the data center as well. PUE performs very well if its limits are respected. Therefore, it is proposed to use complementing metrics to PUE addressing the previously presented issues.

Energy source impact: CUE

To give insight into the primary energy impact of a data center and related carbon emissions the Carbon Usage Effectiveness (CUE) metric has been selected to evaluate this aspect (Belady, 2010). From the same developers of PUE, CUE multiplies the total facility energy with its Carbon Emission Factor (CEF), being the carbon emitted per unit of energy. It is defined as:

$$CUE = \frac{CEF * Total\ energy}{IT\ energy} \left[\frac{kgCO_2}{kWh}\right]$$

$$0 \leq CUE$$

This adds information about the data center's ecological footprint. If the data center has multiple energy sources, like a combination of grid-sourced electricity and on-site renewable sources, the partial contribution of both should be considered. Adopting the CUE metric will incite the industry to choose low impact energy sources, like on-site renewables.

On-site renewables: OEF & OEM

The CUE metric already reflects the positive impact on-site renewables can have on the total energy impact of a data center, but doesn't provide enough insight on the effectiveness of these on-site renewables. To evaluate the energy (mis)matching the On-site Energy Fraction (OEF) and On-site Energy Matching metrics have been chosen. They are defined as:

$$OEF = \frac{\int_{t_1}^{t_2} Min[R(t); L(t)]dt}{\int_{t_1}^{t_2} L(t)dt}; 0 \leq OEF \leq 1$$

$$OEM = \frac{\int_{t_1}^{t_2} Min[R(t); L(t)]dt}{\int_{t_1}^{t_2} R(t)dt}; 0 \leq OEM \leq 1$$

where R(t) is the on-site generated renewable power and L(t) is the load power at time 't'. And 'dt' is the time-step of the calculation (Cao, Hasan and Sirén 2013).

Ideally, the on-site renewable generation is equal to the facility power, this is where the lines in **Figure 4** intersect. Area I is the amount of useable renewable energy, Area II is the surplus generation distributed back to the grid (when OEM < 1) and area III is the energy required from the grid (when OEF < 1).

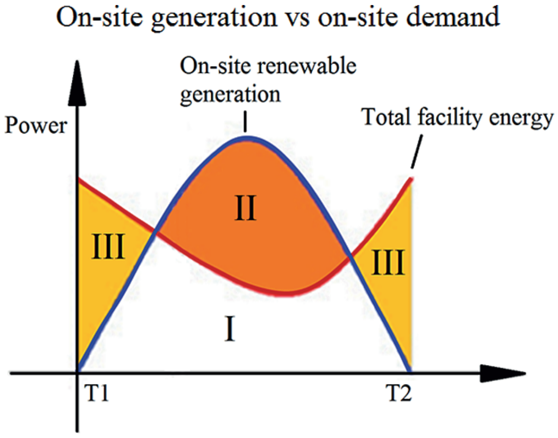


Figure 4. On-site generation vs. demand (adapted from Cao et al. 2013).

Information obtained from the OEF and OEM metrics can be used to track and improve the energy matching. This can be done by adapting generation to the expected demand or adapting demand to supply, i.e. by saving some of the non-essential workload for periods with high on-site energy availability. But also by applying energy storage to conserve surplus generation.

Energy reuse: ERF

Data centers always have a heat surplus resulting from the conversion of electrical energy into heat within the IT equipment. This heat surplus can be reused in different ways depending on local circumstances, like heat demand near the data center. Though it might be difficult to quantify the amount of energy that is efficiently being reused, it does provide opportunities for improving energy efficiency. The metric to track the amount of energy reuse is the Energy Reuse Factor (ERF), defined as (Patterson, 2010):

$$ERF = \frac{Reuse\ energy}{Total\ energy}; 0 \leq ERF \leq 1$$

Some data centers have already taken measures to efficiently reuse waste heat by providing it to greenhouses or residential and commercial buildings. The best results have been achieved when this is done through an aquifer thermal storage system which helps to mitigate the effect of seasonal demand.

Water usage: WUE

Though PUE doesn't include water use in the total energy consumption, it is estimated that '4% of U.S. electricity demand is for the movement and treatment of water' (EPRI, 2002). To keep track of the impact this has on the ecology the Water Usage Effectiveness (WUE) is available (Green Grid, 2011). It is defined as:

$$WUE = \frac{Water\ usage}{IT\ energy}\left[\frac{L}{kWh}\right];\ 0 \leq WUE$$

Alternatively, if information concerning the embodied energy of the water source is available it's also conceivable to add this embodied energy from the total water usage to the total facility energy use.

IT efficiency: ITEE & ITEU

The IT efficiency is a very important factor contributing to the total data center facility energy use, but it's also a very complicated contribution. Different data centers have different purposes like storage, calculation and networking, or a combination. This makes a comparison of efficiency difficult. For every type of function the efficiency of all the installed equipment can be compared to a standardized alternative. The average value that is found results in the IT Equipment Efficiency (ITEE) metric (Green IT council, 2012), defined as:

$$ITEE = \frac{W_{DC,rated}[units\ of\ useful\ work]}{P_{DC,rated}[W]}$$

$$0 \leq ITEE \leq 1$$

With $W_{DC,rated}$ being the capacity of the IT equipment multiplied by the standardized capacity per watt and $P_{DC,rated}$ is the rated power of the IT equipment. The capacity is subdivided in three categories: servers [GTOPS], storage [Gbyte] and networking [Gbps].

Also, important to monitor is the average IT load, as total energy efficiency is better for high IT utilization. This can be done using the IT Equipment Utilization (ITEU) metric (Green IT council, 2012), defined as:

$$ITEU = \frac{E_{IT}}{E_{IT,rated}};\ 0 \leq ITEU \leq 1$$

Some data centers only provide the infrastructure and rent out floor space to customers, meaning the owners have no influence over the efficiency of the IT equipment installed, in this case ITEE and ITEU shouldn't be used to assess the data center's efficiency.

Discussion, conclusion & further research

The literature review has provided sufficient information to answer the research question:

'Does the broadly accepted PUE metric reflect the real energy performance of a data center?'

The merits of PUE for improving data center energy efficiency are clear, but the industry has come to a point where further improvements can only be found by assessing energy performance in a broader sense. It is concluded that the scope of the PUE metric is insufficient to reflect the real energy performance of a data center. Subjects that PUE doesn't touch upon, but should be included in energy performance assessment, are water usage, on-site renewable energy generation, energy recovery, IT equipment efficiency and carbon footprint. For these topics, respectively the WUE, OEF/OEM, ERF, ITEE & ITEU and CUE metrics can be used.

The literature review showed a large energy savings potential by using up-to-date IT equipment, as the IT equipment efficiency doubles each 2 years on average. A very important conclusion is that, at least in some cases, PUE values can be positively influenced by increasing the energy use of IT equipment as it does not track the actual meaningful work that's being done by the data center. This can also be achieved by shifting cooling loads from the HVAC system to the server fans. These practices can be prevented by using complementary metrics as proposed in this paper.

Also, the importance of tracking water usage was shown as, for example, 4% of the U.S. national energy consumption is connected to water treatment and transport. This becomes increasingly important because of the increased use of evaporative cooling systems.

Further research should show to what extent the issues raised in this paper influence the discrepancy between PUE values and real energy performance. This can aid data center designers in their decision-making process on energy efficiency measures and help the data center industry to take another step in reducing its, still increasing, energy impact. ■

Literature

Avelar, V., Azevedo, D., French, A., (2012), PUE™: *A Comprehensive Examination of the Metric*, The Green Grid.

Avram, M.G., (2014), Advantages and Challenges of Adopting Cloud Computing from an Enterprise Perspective, Procedia Technology, Volume 12, pp. 529-534.

Bouley, D. (2009), Understanding PUE, Data Center Science Center APC by Schneider Electric, accessed on April 1st 2016 https://www.bicsi.org/uploadedFiles/BICSI_Website/Global_Community/Presentations/Caribbean/APC%20Understanding%20PUE%20Denis.pdf.

Cao, S., Hasan, A., Siréna, K., (2013) "Onsite energy matching indices for buildings with energy conversion, storage and hybrid grid connections." Energy and Buildings 64, pp. 423–438.

Donnely, C., (2015), found on October 15th 2015: http://www.computerweekly.com/feature/Datacentre-PUE-Whos-keeping-score.

EPRI, (2002), electricity consumption for water supply & treatment - the next half century, Water & Sustainability (Volume 4): U.S.; No. 1006787; Electric Power Research Institute: Palo Alto, California.

Foster, P., (2013), European data centers are less energy efficient than you might think, last accessed on February 19th 2016, http://www.thegreenitreview.com /2013/05/european-data-centres-are-less-energy.html.

Green IT promotion council, (2012), New Data Center Energy Efficiency Evaluation Index DPPE (Datacenter Performance per Energy) Measurement Guidelines, p. 37.

Google, (2016), Efficiency: How we do it, last accessed on February 16th 2016, https://www.google.com/about/datacenters/efficiency/internal/.

Belady, C., (2010), Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric, The green grid.

Guo, C. *et al.*, (2009), BCube: a high performance, server-centric network architecture for modular data centers, Proceedings of the ACM SIGCOMM 2009 conference on Data communication, pp. 63-74.

Hartfield, L., (2011), Server room temperature myth busting – energy savings, disk failure and temperature, Accessed on February 28th 2016, http://www.carbondescent.org.uk/blog/?p=164.

Koomey, J.G., (2011), Growth in data center electricity use 2005 to 2010, Analytical Press, August 1, 2011.

Leopold, G., (2014), Data center spending up, energy efforts hitting wall, last accessed on October 12th 2015: http://www.enterprisetech.com/2014/06/04/datacenter-spending-energy-efforts-hitting-wall/.

Modoff, B., Bhagavath, V., Clifton, K., (2014), Not quite the Jetsons yet, but places to look *Internet of Things (IOT) is a big idea but promise and reality are a distance apart*, F.I.T.T. for investors, Deutsche Bank Securities, 6 May 2014.

Moore, G. E., (1965), Cramming more components onto integrated circuits, Electronics.

Patterson, M., (2010), ERE: A metric for measuring the benefit of reuse energy from a data center, p 9.

Research and Markets, (2015), Green Data Center Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2014 – 2022, http://www.researchandmarkets.com/research/594p54/green_data_center.

Stansberry, M., (2015), 2014 data center industry survey, [accessed on 16-02-2016], https://journal.uptimeinstitute.com/2014-data-center-industry-survey/.

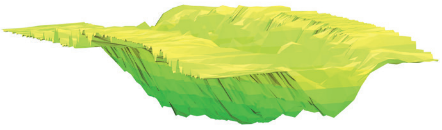
Uptime Institute (2014), found on October 15th 2015: https://journal.uptimeinstitute.com/2014-data-center-industry-survey/

Technavio, (2015), Global Data Center Market 2015-2019, accessed on October 15th 2015 http://www.technavio.com/report/data-center-market.

Wang, L., Khan, S.U., (2011), Review of performance metrics for green data centers: *a taxonomy study*, J Supercomput, Volume 63, pp. 639-656.

Wasson, S., (2015), Intel's Core i7-6700K 'Skylake' processor reviewed, last accessed on April 1st 2016, http://techreport.com/review/28751/intel-core-i7-6700k-skylake-processor-reviewed/5.

Whitney, J., Delforge, P., (2014), America's Data Centers Are Wasting Huge Amounts of Energy, *Critical Action Needed to Save Billions of Dollars and Kilowatts*, NRDC, August 2014. APPENDIX A - Measurement guidelines PUE.



Analysis of performance metrics for data center efficiency

– should the Power Utilization Effectiveness PUE still be used as the main indicator? (Part 2)

TOM VAN DE VOORT
Eindhoven University of Technology
Department of Architecture, Building, and Planning
the Netherlands
t.v.d.voort@student.tue.nl

VOJTECH ZAVREL
Eindhoven University of Technology
Department of the Built Environmentg
the Netherlands
v.zavrel@tue.nl

IGNACIO TORRENS GALDIZ
Eindhoven University of Technology
Department of the Built Environment
the Netherlands
j.i.torrens@tue.nl

JAN HENSEN
Eindhoven University of Technology
Department of the Built Environment
the Netherlands
j.l.m.hensen@tue.nl

Previous research posed that PUE (Power Usage Effectiveness) does not always reflect the real energy performance of data centers. This is because PUE does not show performance regarding IT efficiency, water usage, heat recovery, on-site energy generation or carbon impact. Broadening the scope of performance assessment beyond PUE has therefore been proposed by including these subjects. Using a simulation study, this paper shows the potential of finding energy efficiency measures beyond the scope of PUE by using complementary metrics. In this way, a heat reuse potential of 11-15% of the total energy use is found for a 1MW data center in Killarney. It also shows a 4% energy impact reduction for a roof sized PV-system in Sevilla as well as the potential and challenges accompanying the implementation of larger PV-systems. To better evaluate the efficiency of on-site generation the GUE (Grid Usage Effectiveness) metric is introduced. By broadening the scope of data center energy performance assessment, the next step energy efficiency improvement can be taken and the industry can take environmental responsibility by reducing its energy footprint.

Keywords: PUE, Performance metrics, Data Center, Energy Efficiency, Indicators, Simulation, GUE

The data center industry was responsible for between 1.1% and 1.5% of global energy consumption in 2010 (Koomey, 2011) and this value is expected to double by 2020 (Whitney *et al.*, 2014) as the growth of the data center industry is expected to continue following the increasing number of connected devices requiring this infrastructure (Modoff *et al.*, 2014).

Awareness of this trend has led to an effort to improve the sustainability of the data center industry by improving its energy efficiency. Currently, the energy flows within a data center are monitored at different levels to be able to assess both overall and subsystem energy efficiency. Performance metrics are calculated and used as indicators for the efficiency of the systems (Wang *et al.,* 2011).

The main indicator that is being used to assess overall data center energy efficiency is PUE, which shows the ratio between total facility power use and IT equipment power use (Avelar *et al.,* 2012):

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}; 1 \leq PUE$$

Therefore, the optimal value for PUE is 1.0, the maximum value is infinity. PUE was developed give data collection standards 'to determine the effectiveness of any changes made within a given data center' (*idem,* 2012), but is widely being used to compare energy efficiency between data centers. The scope of PUE however is insufficient to accurately reflect the overall energy performance of a data center as it does not cover, among others, IT equipment efficiency, water usage, energy recovery or on-site renewable energy generation (Van de Voort *et al.*, 2017). This paper aims to show the added benefit of using metrics complementary to PUE in data center performance assessment to further decrease the data center industry energy impact.

Research methodology

To find a solution to the problem described above, the following research question has been formulated:

'How can performance metrics complementary to PUE help to better reflect the real energy performance of a data center?'

High resolution data of the energy flows in a data center is required to evaluate to which extent these additional metrics improve the assessment of the actual energy performance of data centers. Because this information obtained from measurements in data centers is very confidential, a virtual environment has been created. Another benefit is the ability to define different boundary conditions making it possible to simulate various scenarios under controlled conditions. This building energy simulation model is used to analyze in detail the benefit of using complementary metrics beside PUE for data center energy performance assessment. The simulation provides hourly values of the energy flows within the data center for one year. The different energy flows calculated by the simulation can be found in **Table 1**. From this high-resolution data, all required values for the relevant performance metrics can be calculated.

Table 1. Simulation output parameters.

Output	Unit
IT Power	[kWh]
PS Loss	[kWh]
Auxiliry Power	[kWh]
Cooling Power	[kWh]
Total Power	[kWh]
PV Power	[kWh]
Heat Recovery Potential	[kWh]

The analysis of the simulation results is focused on three scenarios which implement different energy efficiency measures. Namely, on-site sustainable energy generation; energy recovery; and geothermal energy harvesting. The calculated values for PUE and other relevant metrics: ERF (Energy Reuse Fraction, Patterson, 2010):, OEM (Onsite Energy Matching, Cao *et al.,* 2013), OEF (Onsite Energy Fraction, Cao *et al.,* 2013) and GUE (Grid Usage Effectiveness, Van de Voort *et al.,* 2017) will be used to assess the benefit of using metrics complementary to PUE.

Simulation setup

For these simulations, an adaptation of the data center simulation model by Van Schie et al. (2015) has been used to represent a 1 MW data center. TRNSYS was used as a modeling tool to create a white-box model which represents this data center. An overview of the model can be found in **Appendix A***.

The model has been used to simulate the effect of the different variables described in **Table 2** on the energy flows in the data center. The locations were chosen to represent three different climate conditions in Europe. Four different HVAC systems have been modelled, representing a wide spectrum of cooling system efficiency. Two different IT workload profiles are used as input to evaluate the influence of IT load on energy flows. Also, two inlet temperature set points have been used as control strategies. Lastly, three differently sized PV-systems are introduced to evaluate the benefit of on-site renewable generation.

ACREX2018.indd 41 29.1.2018 22:25:29

The first PV system is sized to the dimensions of the roof area of a typical 1MW data center (2 000 m² PV). This simulation shows to what extent PV systems can reduce the energy impact of a data center within this realistic boundary. There are no issues with energy matching as the OEM value remains 1 all year. For the second scenario, the PV system size is increased to maximize generation while keeping the average OEM close to 1 (11 100 m² PV). This case shows which part of the total energy demand can be met by a PV-system without causing matching issues. The third PV system is sized to generate the same amount of energy yearly as the total energy consumption of the data center (51 750 m² PV). At this point matching issues occur because peaks in generation greatly exceed demand.

Simulation results

Out of the results found by this simulation a selection of three cases has been made for further analysis, these cases are shown in **Table 3**. They have been chosen as they represent three important strategies to reduce the energy impact of data centers. These are on-site generation, energy reuse and the use of geothermal energy.

Results of the PUE values for the chosen simulation cases are given in **Figure 1**. The PUE values are largely dependent on the type of cooling system, this became clear after analysis of the complete simulation results. The figure shows the previously described relationship between PUE and IT load, showing better PUE

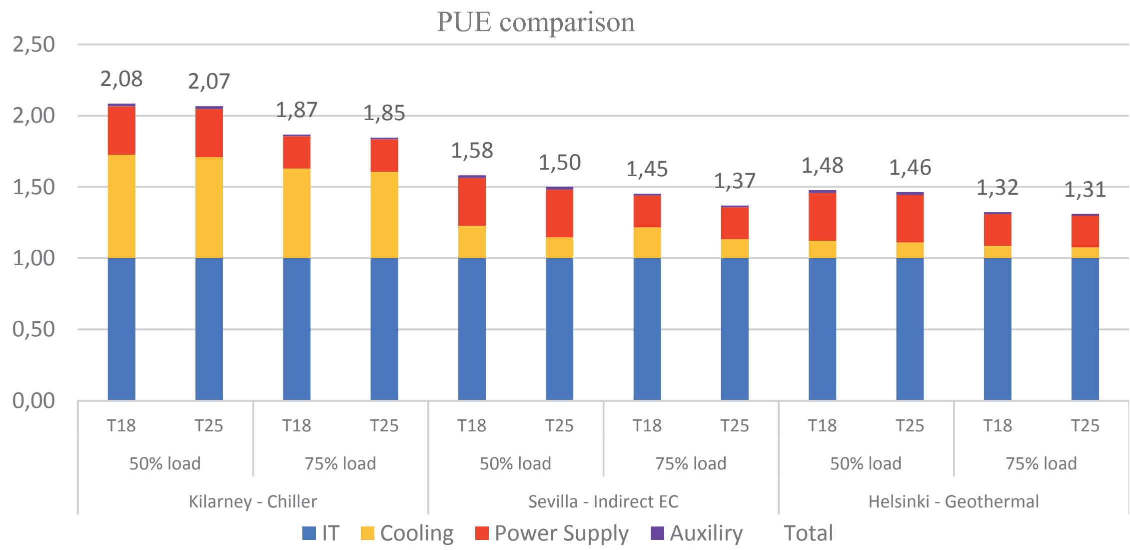


Figure 1. PUE results for the twelve different simulations for the three chosen configurations.

Table 2. Input variables for simulation exercise.

Location	**Sevilla**	**Killarney**	**Helsinki**	
Workload	50%	75%		
Inlet Temperature	18°C	25°C		
HVAC System	Chiller	Chiller/Free Cooling	Indirect Economizer	Seawater Cooling
PV size	Realistic (Roof) 2000 m²	Peak matching 11100 m²	Load Matching 51750 m²	

Table 3. Three cases chosen for detailed analysis.

Location	**Sevilla**	**Killarney**	**Helsinki**
HVAC System	Indirect Economizer	Chiller	Seawater Cooling
Renewable Strategy	PV-panels	Energy Reuse	Geothermal
Workload	50%/75%	50%/75%	50%/75%
Inlet Temperature	18°C/25°C	18°C/25°C	18°C/25°C
Performance Metrics	PUE, OEF, OEM	PUE, ERF	PUE

values for higher IT loads. It also shows the relationship between PUE and IT load, showing better PUE values for higher IT loads. It also shows the relationship between PUE and cooling temperature set point, with a higher cooling set point leading to lower PUE values.

The most interesting results regarding the scope of PUE were found for the Sevilla case where a PV-system has been applied. In the following section this energy efficiency strategy is further analyzed to see whether the metrics put forward provide a better framework for reflecting the real performance of a data center than PUE alone. First the main characteristics of the other two cases are described.

Killarney – Energy reuse

Usable waste energy was defined as exhaust air with temperatures over 30°C. The ERF potential resulting from this is displayed in **Figure 2**. The potential found lies between 11–15% of total energy consumption for the different scenarios.

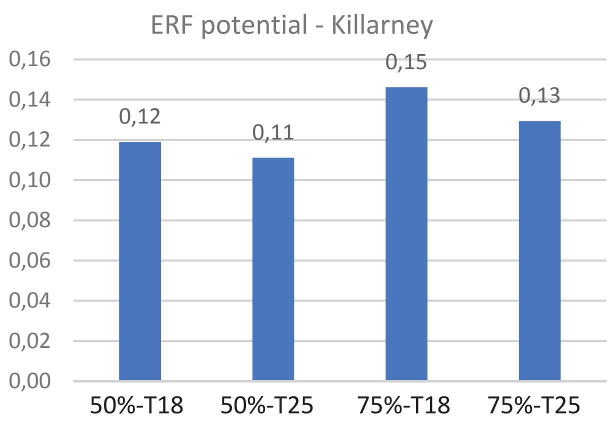


Figure 2. Energy recovery potential for the data center in Killarney.

In cases where this waste energy can only be reused when there is simultaneous demand the actual reuse value can greatly decrease. Losses will also occur during the energy transport. Because of these reasons, it is impossible to translate the ERF potential in an actual value for ERF as the influence of these factors is unknown. To make the best use of the ERF potential the mentioned issues need to be addressed when designers implement energy reuse strategies. An interesting strategy is coupling energy recovery to an aquifer thermal storage system to avoid the necessity for simultaneous demand.

Helsinki – Geothermal

For this case PUE reflects the real energy impact very well. As seen in **Figure 1**, the partial contribution of energy use for cooling to the PUE value has become very small, making this a very efficient design. Because PUE only assesses the use of electric energy, the thermal energy used for cooling the data center in this case does not increase the value for the total facility power, keeping the PUE value low.

Sevilla – PV

As previously stated, PUE doesn't give insight into the positive contribution to the energy impact of on-site renewable energy generation. The OEF and OEM metrics can be used for assessing the amount and efficiency of on-site renewable generation. Results discussed in this section are for the Sevilla case with 75% average workload and 18°C inlet temperature. **Figure 1** shows results from the other simulation setups follow a similar trend for the energy flows making the results discussed in this section also relevant for those cases.

Even though the data center industry is characterized by its high-energy density, **Figure 3a** shows on-site renewables can have an impact on its energy footprint. If we look at the roof sized PV system 4% of the total energy demand could be met, even for a high average utilization of 75% IT load. This impact will only increase as PV efficiency increases and therefore this benefit should be considered during performance assessment. When looking at the PV system sized for matching peak loads, the energy impact reduction further increases to 20% of the total energy demand. A larger site would be necessary or extra areas near the data center should be outfitted with PV panels. Nearby building or site owners might allow placement of PV panels for this purpose.

When the PV area is further increased problems will arise with energy matching. This is clear when annual energy generation by the PV system is equal to the annual energy demand of the data center. **Figure 3a** shows that for the simulated workload profile only 41% of the supply is matched by simultaneous demand meaning 59% cannot be used by the data center. Also, the electricity grid must balance this influx of energy, which is causing more and more problems as the adoption of renewable generation increases.

Figure 3b shows the average OEM value is still relatively high, because the value for OEM is 1 when there is no supply, this skews the average figure. Hourly values for OEM should be considered when interpreting results. One-year graphs containing hourly values for OEF and OEM can be found in **Appendix B***. There are ways to improve energy matching for on-site renewable generation. This can be done by matching generation to expected demand, save non-critical workload for periods of high on-site availability or by energy storage. To indicate with a single performance metric the benefit of using on-site renewables and to promote energy matching by showing to which extent the data center operates grid independent, it is proposed to introduce the Grid Usage Effectiveness (GUE) metric.

GUE

The GUE shows the grid dependence of the data center in relation to the IT load, it is defined as:

$$GUE = \frac{(\frac{1}{OEM} - OEF) * Total\ Power}{IT\ Equipment\ Power}$$

$$GUE \geq 0, lower\ is\ better$$

Figure 4 shows how the GUE is dependent of the OEF and OEM metrics. At first, the GUE value improves as the on-site generation and OEF increase, it is optimal when the OEF and OEM are both 1. At this point the data center operates independent of the grid as its demand is exactly matched by on-site generation. When the on-site generation starts to exceed the facility demand the GUE value increases again as the grid is being burdened with the excess electricity.

This accurately reflects to which extent the grid is being used, be it for supply or demand, and will promote energy balancing. GUE combines information concerning on-site (renewable) generation and energy matching with PUE. Though it is adding complexity, it's giving a more complete picture of a data center's energy impact without losing the clarity of the single metric. The average, minimum and maximum PUE

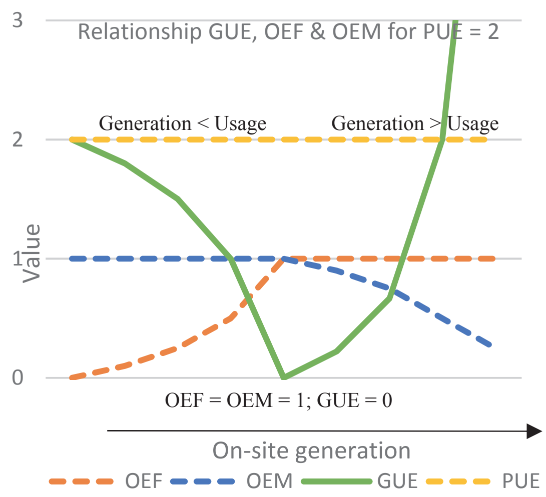
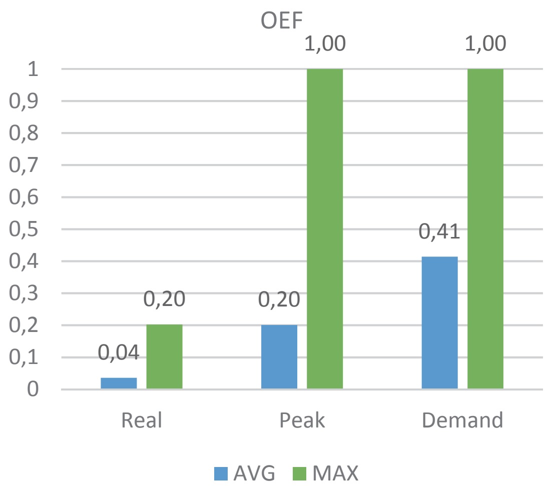


Figure 4. Relationship between GUE, OEF & OEM.



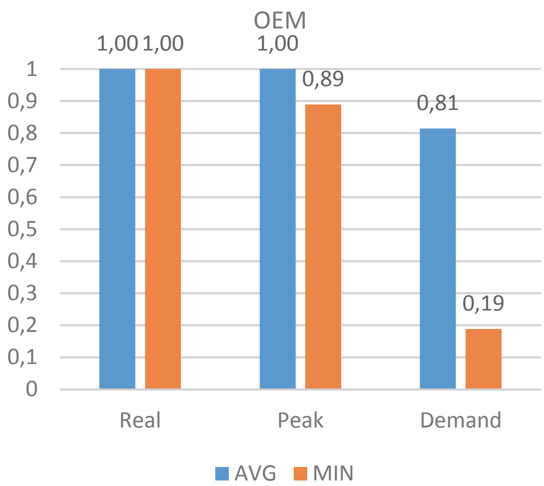


Figure 3. a) OEF values for the three PV-systems. b) OEM values for the three PV-systems.

and GUE values for the case from the previous section is shown in **Figure 5**.

When smart grids are introduced it is conceivable that weighing factors dependent on the momentary grid balance are introduced to the metric. In that case, data centers can help balance the grid by using energy from the grid when supply is abundant and they can supply energy to the grid when demand is high, without penalties to their GUE. This will add a further incentive to implement demand response strategies.

Figure 6 shows a simplified representation of the hourly PUE values and the GUE values for the three PV-system sizes. The full graphs can be found in **appendix C***. The impact of the roof sized PV-system is subtle, whereas the positive impact of the peak size PV-system is very clear. The matching issues related to the demand size PV-system is also clearly illustrated, with the highest peak around noon during summer. This makes it immediately clear where the focus should lie for improvement.

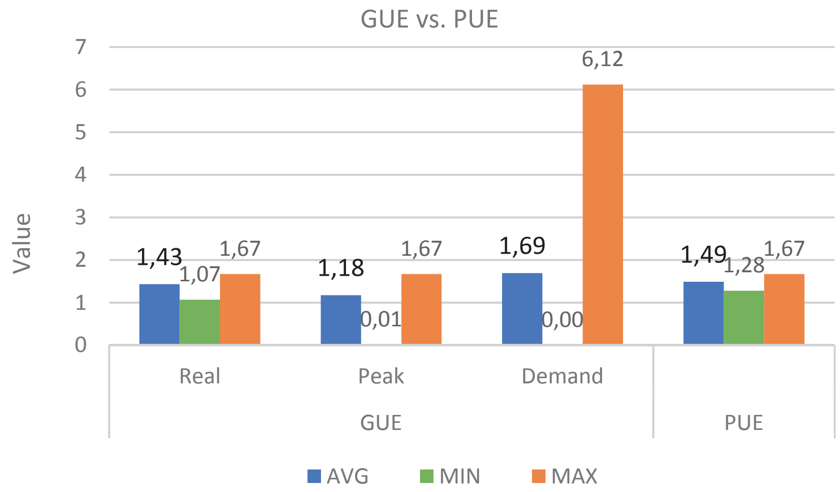


Figure 5. GUE vs. PUE for Sevilla case.

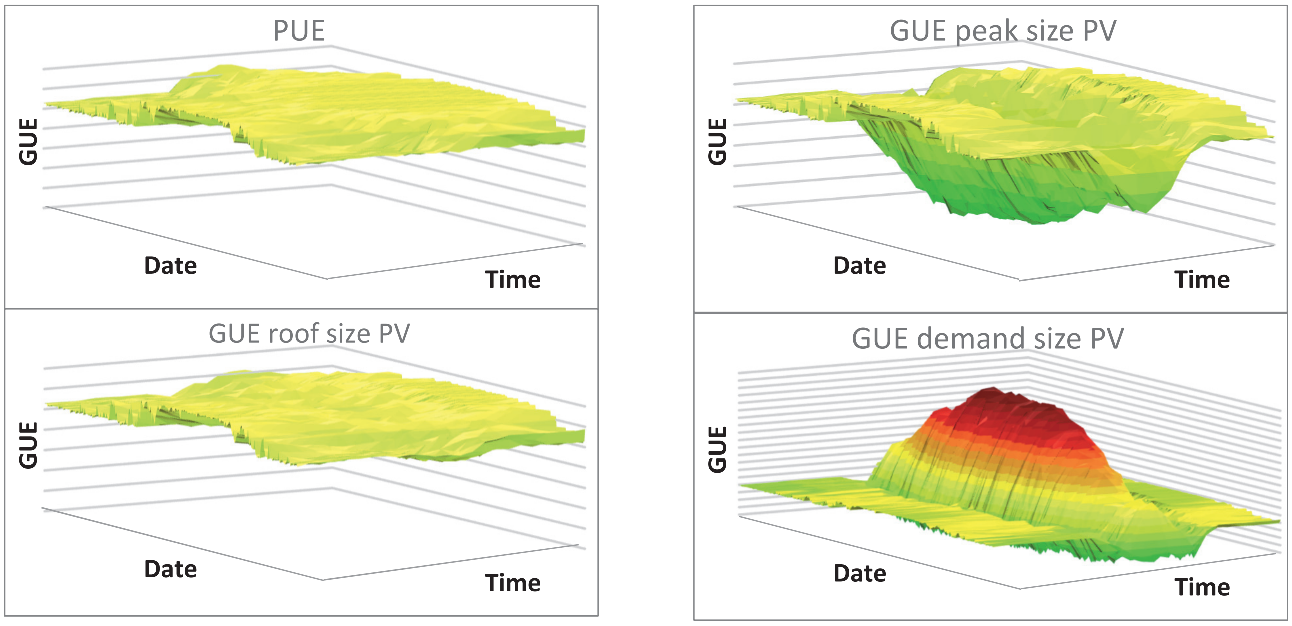


Figure 6. Visualization of the hourly values for the PUE and different GUE values for one year.

Future data center designers will be able to use the GUE metric to design data centers which efficiently use on-site generation to reduce the impact they have on the electricity grid and the environment. As we are preparing for a future solely reliant on renewable energy this will be hugely important. The efficiency of demand management, supply matching and energy storage strategies can be assessed using this metric.

Discussion & conclusion

Though more situations are conceivable where the scope of PUE is too narrow to thoroughly assess the complete energy performance of a data center, the simulation exercise has provided information to answer the research question by reviewing case studies with energy reuse, geothermal energy use and on-site energy generations with PV panels.

'How can complementary performance metrics to PUE help to better reflect the real energy performance of a data center?'

For the simulation case using geothermal energy PUE proved to accurately reflect the cooling systems energy impact. With help of the ERF metric, the simulation scenario for Killarney demonstrated a potential benefit for energy reuse of up to 15% of the total energy consumption. This scenario used a chiller as cooling system and the minimum exhaust air temperature for reusable waste heat was set to 30°C.

Using the OEM and OEF metrics, the simulation case for Sevilla showed a reduction of the total energy impact of 4% for a roof sized PV-system in Sevilla, increasing to 20% for a PV-system sized to maximize generation without causing matching issues. When further increasing the PV size energy matching issues arise that need to be mitigated.

To quickly assess the effectiveness of onsite energy generation, the GUE metric can be used. It shows the positive impact on-site renewable generation can have on the energy footprint and can also help to understand the challenges involved in energy matching. Evaluation of resulting GUE values can help find better strategies to tackle energy matching challenges. Suggested strategies for energy matching can involve demand management, supply matching and energy storage. Further research can provide information on effective use of these strategies to further reduce the energy impact of the data center industry.

In short, it's necessary to broaden the scope of data center performance assessment beyond PUE to meet future challenges the upcoming energy transition will present. The metrics used in this paper, among others, are part of the tools required to meet these challenges. The next step will be to use this expanded framework of energy performance metrics for the creation and evaluation of a new generation of state-of-the-art energy efficient data centers. ■

* Find appendixes A, B and C on the REHVA Website: http://www.rehva.eu/publications-and-resources/rehva-journal.html

Literature

Avelar, V., Azevedo, D., French, A., (2012), PUE™: *A Comprehensive Examination of the Metric*, The Green Grid.

Koomey, J.G., (2011), Growth in data center electricity use 2005 to 2010, Analytical Press, August 1, 2011.

Modoff, B., Bhagavath, V., Clifton, K., (2014), Not quite the Jetsons yet, but places to look *Internet of Things (IOT) is a big idea but promise and reality are a distance apart*, F.I.T.T. for investors, Deutsche Bank Securities.

Van de Voort, T., Zavrel, V., Torrens, J.I., Hensen, J.L.M, (2017), Analysis of performance metrics for data center efficiency: should PUE still be used as the main indicator, TBP, accepted by: The REHVA European HVAC Journal.

Van Schie, F.T., Zavřel, V., Torrens, J.I., Hundertmark, T.F.W., Hensen, J.L.M., (2015), Optimizing the total energy consumption and CO2 emissions by distributing computational workload, among worldwide dispersed data centers, in Proc. Building Simulation '15. Hyderabad: IBPSA.

Wang, L., Khan, S.U., (2011), Review of performance metrics for green data centers: *a taxonomy study*, J Supercomput, Volume 63, pp. 639-656.

Whitney, J., Delforge, P., (2014), America's Data Centers Are Wasting Huge Amounts of Energy, *Critical Action Needed to Save Billions of Dollars and Kilowatts*, NRDC, August 2014.

Natural ventilation uncertainties in building energy simulations

With the increase of building envelope's performances, wind effects on natural ventilation represent an increasing share in energy consumption. In classical building energy simulations, those effects are extremely simplified in comparison to reality; however numerical simulations can significantly improve the quality of predictions.

Keywords: natural ventilation, pressure coefficient, building energy simulation.

MATEUSZ BOGDAN
PhD. MSc.
CFD, Air Quality and
Civil Engineering Advisor,
AREP, France
mateusz.bogdan@arep.fr

EDOUARD WALTHER
PhD. MSc.
Building Physics Advisor,
AREP, France
edouard.walther@arep.fr

Calculation of wind driven natural ventilation in building energy simulations

To illustrate the issue, let us consider the trivial case of a building with wind driven cross-ventilation. The standard Building Energy Simulation (BES) tools compute the transversal cross-ventilation between to openings *a* and *b* at a same height *z* using the Bernoulli equation:

$$Q_v = S_{eq}\times v(z)\times\sqrt{C_p^a - C_p^b}\ .$$

With $v(z)$ is the wind velocity at height z, and C_p is the pressure coefficient on each opposite façades. The effective opening area S_{eq} is a weighted average of each individual opening area as well as their respective discharge coefficient, as in the following equation:

$$\frac{1}{S_{eq}{}^2} = \frac{1}{(C_d^a S_a)^2} + \frac{1}{(C_d^b S_b)^2}.$$

S_a and S_b represent the actual surface area of both openings. To overcome Bernoulli hypothesis of non-viscous fluids, their respective discharge coefficients C_d^a and C_d^b are added. They stand for two distinct phenomena reducing the theoretical flow. On one hand, the flow vein is contracting after the opening due to jets inertial effects. The cross-ventilation is thus reduced by a coefficient C_c, equal to the surface ratio between the jet area after the opening and the actual opening area (an illustration presented in **Figure 1**, for two simplified openings). On the other hand, the viscous friction also tends to reduce the airflow. It is usually taken into account through a coefficient C_f, usually taken between 0.95 and 0.99.

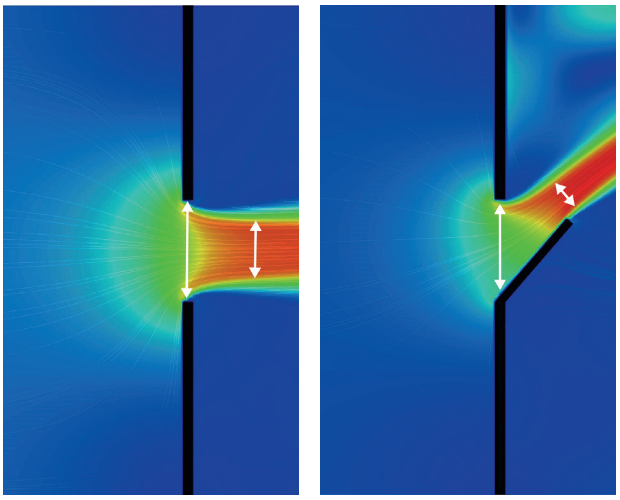


Figure 1. Contraction illustration for two simplified openings.

The discharge coefficient is thus defined by $C_c = C_c \times C_f$. The typical value given in the (ASHRAE 1997) standard and several natural ventilation simulation tools (CONTAM, IES-VE MacroFlo, EnergyPlus) ranges from 0.60 to 0.65.

Since neither the stagnation pressure at the opening height, nor at the actual pressure gap across the two openings a and b are known in classical BES, a pressure coefficient C_p is introduced for each façade. It represents a fraction of the undisturbed flow's dynamic pressure, and can be either positive or negative, in case of overpressure or depression.

$$C_p = \frac{p_{façade}}{\left(\frac{\rho v_{ref}^2}{2}\right)}$$

$p_{façade}$ represents the stagnation pressure, ρ the air density, and v_{ref} the wind speed at reference height. According to the software accuracy, the C_p coefficient is approximated according the empirical relations, valid only for rectangular buildings, with a shape factor close to one. Sometimes the inflow angle is also taken into account by a corrective factor, as well as the building height influence (Swami et Chandra 1988), (Akins, Peterka et Cermak 1979).

The undisturbed flow velocity v_{ref} is taken equal to closest weather station data. To ascertain the wind speed at the opening height z, a logarithmic law describing the atmospheric boundary layer is used:

$$v(z) = v_{ref} \times k_0 \times \ln\left(\frac{z}{z_0}\right)$$

To model the surroundings of the studied building, the profile of the atmospheric boundary layer can be adjusted by the terrain constant, the coefficients k_o and z_o. They represent respectively the apparent terrain's roughness and the roughness' height. k_o usually ranges from 0.14 to 0.25, and z_o from 0.5 mm to 2 m according to the terrain (sea, lake, snow field, desert, or at the opposite a tropical forest or a dense city center).

Modeling critical review

Reality is often very different from the theory presented above due to buildings complex shapes, exact location within an urban context or the actual shapes of openings. In the following paragraphs, we will demonstrate the possible biases on each modelling parameter.

Discharge coefficient: The C_d coefficient is usually misdocumented by the manufacturers since it relies on many variables. (Salliou 2011) and (Regard 2000) noted that it may vary according to the opening ratio, the temperature difference between the inside and outside or the wind speed. In addition, those authors calculated that this variation ranges from $C_d = 0.1$ to $C_d = 2$, in other word from 10% to 200% influence on the flow across the opening. However, it is difficult to lift this uncertainty without a wind tunnel experiment or a numerical simulation. According to the building of interest, the hypothesis on the C_d should be conservative at best, and the results should be properly interpreted.

Pressure coefficient: Those coefficients vary strongly per the wind direction, its magnitude close to façades, building shapes and urban surroundings. Even for simple building geometries, the pressure coefficients are not homogeneous throughout façades. **Figure 2** displays a simulation result in terms of C_p, where the values can be contrasted on a unique façade, ranging from slightly negative to positive values in certain areas of a same wall.

Reference air velocity: This parameter is taken from the closest weather station, for which the exact measurement height is usually unknown, nor the precise location. It is hence often difficult to ascertain precisely the actual wind speed near the location of interest. The velocity around buildings also depends on the topography, the close and distant urban settings with their respective roughness's. **Figures 3 & 4** depicts the flows complexity such areas, in plane and sectional view.

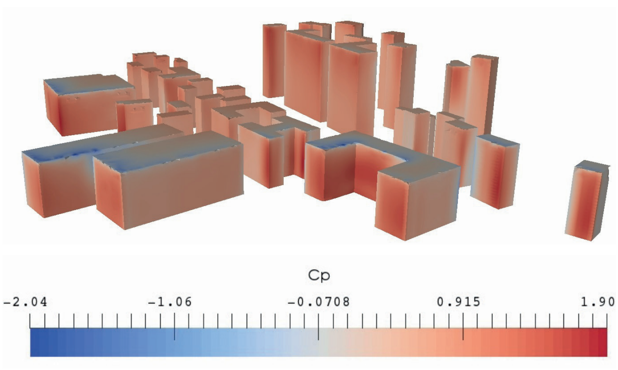


Figure 2. Façade pressure coefficient unevenness – Chambéry train station urban environment.

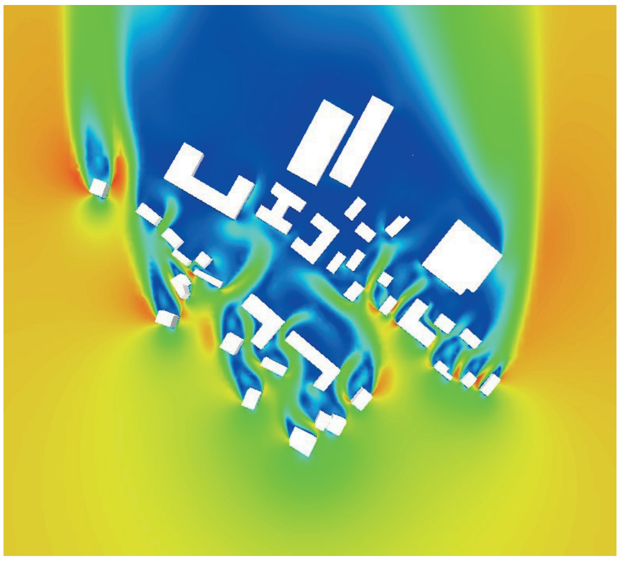


Figure 3. Velocity field fluctuation in urban environments - plane view.

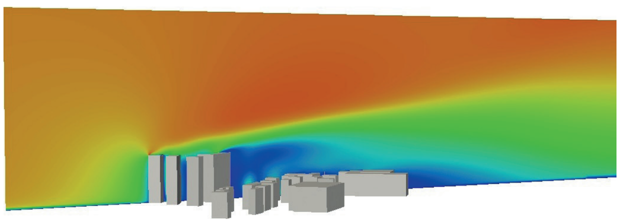


Figure 4. Velocity field fluctuation in urban areas – sectional view.

The uncertain parameters reduction should thus be undertaken using computational fluid dynamics (CFD) simulations. The use of an open-source or purchase-available software that solve the Reynolds-averaged Navier-Stokes equations coupled to a mass-balance model (RANS) is then necessary, using for instance a $k - \varepsilon$ turbulence modelling.

This approach allows the explicit determination the C_p on each façade of interest, according to the annual wind data and urban environment. It reduces the near-building velocities and pressure coefficient uncertainties. Those results are then taken as inputs for the annual hourly BES. It should nevertheless be reminded that this approach only considers wind effects: the buoyancy driven ventilation can be evaluated through a Froude's numbers condition. ■

References

Akins, R.E., J.A. Peterka, and J.E. Cermak. "Averaged Pressure Coefficients for Rectangular Buildings." Proceedings of the Fifth International Wind Engineering Conference. Fort Collins, 1979. 369-380.

ASHRAE. "Ventilation and Infiltration." In HVAC Fundamentals Handbook, 492-519. Atlanta: ASHRAE Handbook Editor, 1997.

Havenith, G., I. Holmér, E.A. Den Hartog, and K.C. Parsons. "Clothing Evaporative Heat Resistance - Proposal for Improved Representation in Standards and Models." Ann. Occ. Hyg., 1999: (43-5):339-346.

Holmér, I., H. Nilsson, G. Havenith, and K. Parsons. "Clothing Convective Heat Exchange -Proposal for Improved Prediction in Standards and Models." Annals of Occupational Hygiene, 1999: (43)5-329-337.

Regard, Muriel. Contribution à l'étude des mouvements d'air dans le bâtiment à l'aide d'un code de champ. Thèse de doctorat, Lyon: INSA, 2000.

Salliou, Jean-Rémy. Analyse de l'influence de paramètres géométriques et physiques sur le coefficient de décharge appliqué à la ventilation dans le bâtiment. Thèse de Master Recherche, Nantes: Ecole Supérieure d'Architecture de Nantes, 2011.

Swami, M.V., and S. Chandra. "Correlations for pressure distribution on buildings and calculation of natural-ventilation airflow." ASHRAE Transactions, 1988: 243-266.

Supervised Commissioning Solutions

Cost and performance problems plague almost all building projects. Commissioning offers perhaps the best solution and a rapid return on investment. REHVA has partnered with COPILOT Building Commissioning Solutions to provide online solutions to supervise and certify the commissioning process. These solutions are delivered by local commissioning engineers.

CORMAC RYAN
COPILOT Building Commissioning Solutions, Paris, France,
www.copilot-building.com
c.ryan@copilot-building.com

Keywords: commissioning, commissioning engineer, technical monitoring, HVAC performance, HVAC comfort

Buildings underperform

Quality costs = **10%**

Construction quality problems cost about 10% of sector turnover according to *Agence Qualité Construction* [1]. In France alone, this represents an annual cost of over €11 Billion.

While building remains a "bricks and mortar" industry, construction process & performance requirements are becoming increasingly sophisticated (**Figure 1**).

Listing a random sample of elements in the ecosystem, **Figure 1** illustrates the complexity of the environment in which we operate. Accelerating demands have not, so far, been matched by step improvements in building and construction technology and quality. Construction suffers from a mismatch between expectations and results (**Figure 2**).

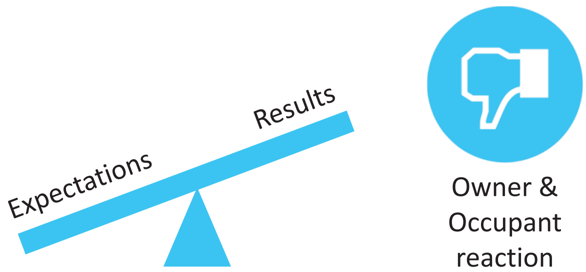


Figure 2. Construction suffers from a mismatch between expectations and results.

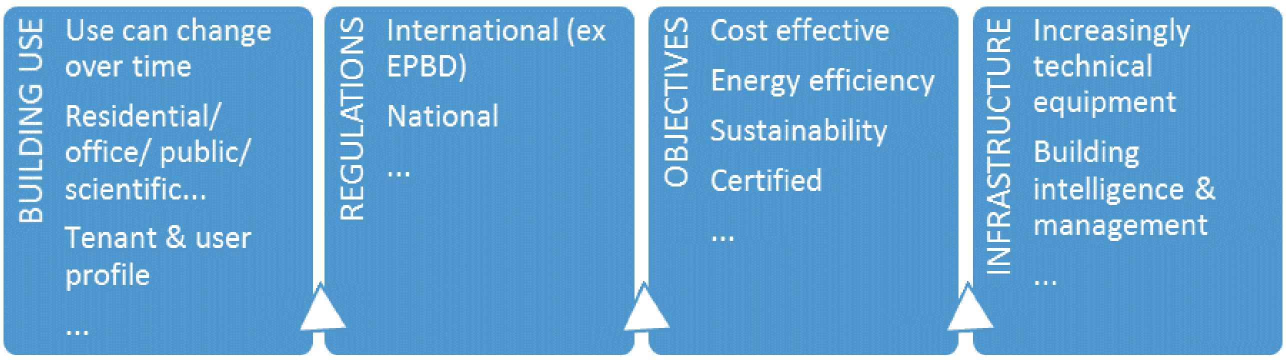


Figure 1. The complexity of the environment in which we operate.

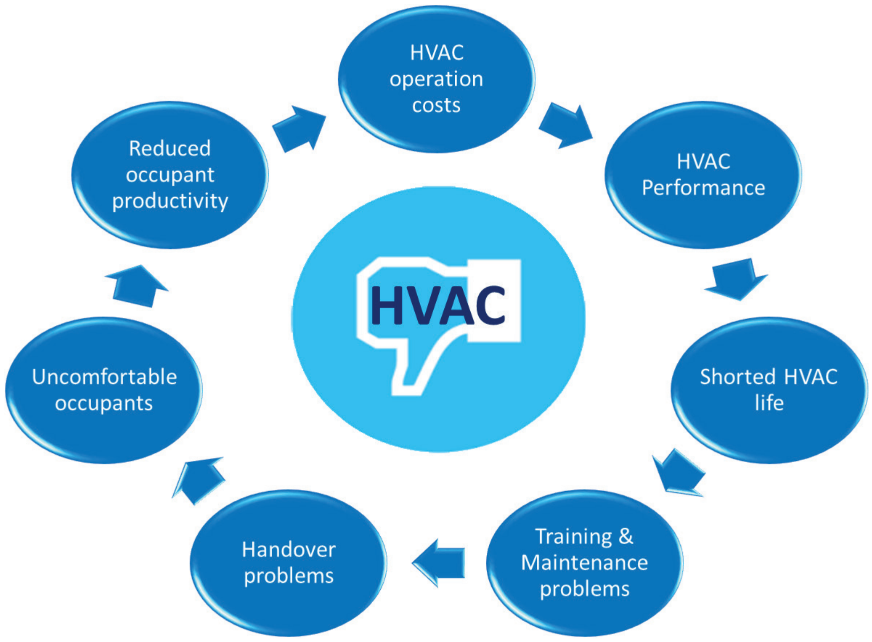


Figure 3. HVAC is among the biggest causes of owner and user dissatisfaction.

This mismatch can clearly be observed in owner and occupant dissatisfaction. Rather than theorise, think of where you work or live. Does the building satisfy your expectations?

- Is it functional / fit-for-purpose?
- Are you and your colleagues happy with the temperature all year around?
- Does it get stuffy or draughty?

Many buildings fail to satisfy these simple questions. And I have not listed critical issues like return on investment, operational costs, energy performance etc.

Two of the questions I listed pertain to Heating, Ventilation and Air Conditioning (HVAC). This is no accident, as HVAC is among the biggest causes of owner and user dissatisfaction (**Figure 3**).

Improve building performance via "Commissioning"

If we simplify the construction ecosystem as shown in **Figure 4**, we observe that successful execution of a building project depends on a number of actors.

The problem of coordination of multiple actors is complicated by the fact that certain actors may have diametrically opposed interests. Owners, for example, may want to ensure minimal investment costs and rapid delivery. Facility Managers privilege easy maintenance while Occupants tends to prioritise functionality and comfort.

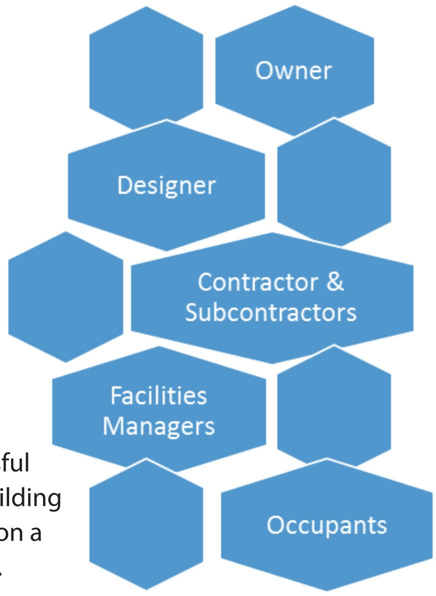


Figure 4. Successful execution of a building project depends on a number of actors.

Similarly, Designer and Contractor interests are not always aligned. The complexity of this bricks and mortar ecosystem is one of the prime reasons for quality problems.

There is a solution to manage problems arising from multiple actors, conflicting interests, unsatisfactory quality control and coordination: Commissioning. This is a quality-focused process for enhancing the delivery of a project. The process focuses upon **verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements (OPR)**.

Commissioning is undertaken by qualified engineers who have extensive practical experience. Their role could be compared to a referee who verifies the work flow to ensure it complies to the rules of the game (i.e. the owner's project requirements).

The reference [2] return on investment research undertaken on commissioning proves its cost effectiveness. On a pure financial basis, median return on investment is a single year for retro-commissioning of existing buildings and four years for commissioning of new buildings.

1 year payback for existing buildings

4 years payback for new building

If one takes comfort and associated occupant productivity improvements into account, it seems likely that we are looking at payback in a matter of months

The interest of commissioning is evident; all the more if you subscribe to the theory that "a stitch in time saves nine". Investment in commissioning, which is estimated to add only about 0.5% to a building project, has a knock-on impact throughout the building's life cycle. The importance of this becomes particularly clear when one considers about three-quarters of life cycle costs occur after construction is completed!

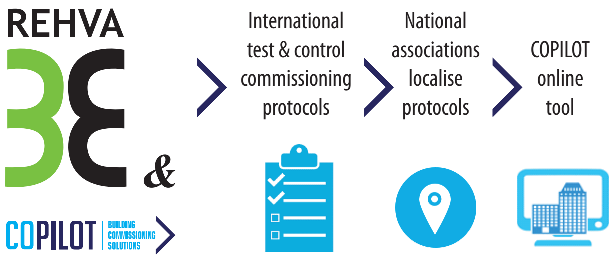
Reassure your clients with world class commissioning

Supervision and certification of the commissioning process offer additional reassurance. That is why **COPILOT Building Commissioning Solutions** entered into partnership with **REHVA** to develop solutions to satisfy this gap in the market.

COPILOT has developed a cradle-to-grave solution to avoid typical HVAC problems and deliver quality buildings. **We deliver online supervision to commissioning engineers and certify their work. COPILOT commissioning solutions can be used on new or existing buildings**.

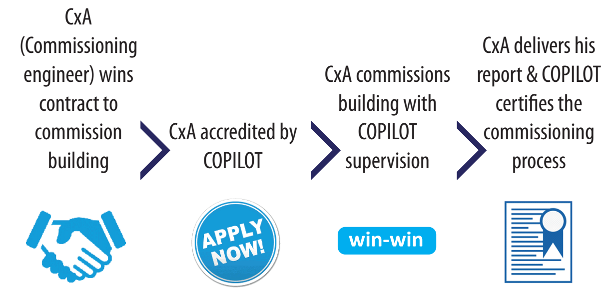
COPILOT's solution is based on test and control commissioning protocols developed by international REHVA experts. These standardized protocols will be adapted to local regulatory and language requirements of different markets in collaboration with national HVAC engineer associations.

Professionalise HVAC Commissioning



COPILOT accredits qualified and experienced commissioning engineers to deliver its online solutions. In this manner, COPILOT proposes a unique and independent commissioning supervision service. On successful completion of a project, COPILOT certifies the commissioning process.

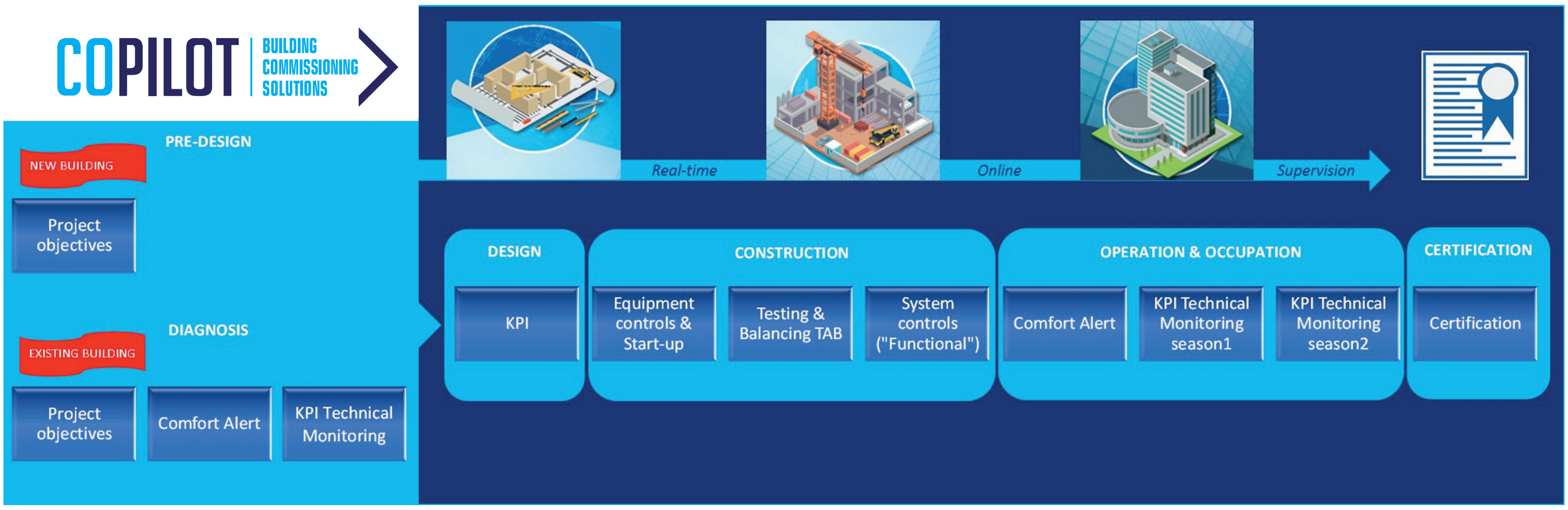
Key role of Commissioning Engineer (CxA)



Avail of COPILOT supervision and certification of the commissioning process

Ideally COPILOT joins the project during the Pre-design phase when the owner formalizes his objectives. Follow-up during the Design phase will include reviewing designer plans, their conformity to owner requirements and the definition of measurable key performance indicators (KPIs).

Sometimes COPILOT becomes involved during the Construction phase. In this case, we ensure that Pre-design and Design requirements are available and documented before supervising equipment and system balancing and testing. We seek confirmation that equipment works correctly on its own and as part of



Zoom: Technical Monitoring

COPILOT offers a stand-alone technical monitoring or trouble-shooting solution. In this case, the Construction phase may not exist. We will work with partners to identify objectives (equivalent to Pre-design phase) and KPIs (equivalent to Design phase). We will then monitor performance, analyse it against KPI requirements and prepare graphic report for easy interpretation.

We will certify successful projects that follow the COPILOT process.

the HVAC and building management systems, that all issues are resolved and documented as appropriate and that sufficient training is undertaken.

Once construction has been completed and the building is occupied and operational, COPILOT provides a Comfort Alert to generate qualitative occupant feedback on comfort performance. In parallel, COPILOT undertakes technical monitoring of HVAC performance compared to KPIs.

On successful completion, COPILOT certifies the commissioning process. COPILOT certification can also feed into credits for LEED and other building certifications.

Conclusion

Commissioning engineers have a key role to play in improving building quality, notably HVAC quality. COPILOT Building Commissioning Solutions has allied with REHVA to develop online cradle-to-grave commissioning supervision solutions. We work with local commissioning engineers and certify the commissioning process on successful completion of new or existing buildings. ■

References

[1] Agence Qualité Construction, http://www.qualiteconstruction.com/uploads/tx_commerceaddons/tbs10_01.pdf.

[2] Mills, E. «Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-Gas Emissions», Lawrence Berkeley National Laboratory (LBNL), 2009.

A Wire-to-Air approach for AHU Fans Certification

As key component in a HVAC-R device, the fan is of prime interest for Air Handling Units (AHU) manufacturers. In order to improve the fan performance data reliability, Eurovent Certita Certification launched in July 2017 a new certification programme for AHU fans with a "wire-to-air" approach as main asset.

Keywords: fans, certification, performance ratings, wire-to-air

MARIE-CLÉMENCE BRIFFAUD
Eurovent Certita Certification, Paris, France
mc.briffaud@eurovent-certification.com

Certifying the fans for Air Handling Units

The Eurovent certification programme for Air Handling Units (AHU) has been running for many years now and it unfortunately appeared that some test failures resulted from fan related performances inaccuracies.

The fan is indeed a key component in an AHU. The fan is responsible for proper air circulation, providing the airflow rate and pressure required to compensate the pressure drop occurring in the AHU and related ductwork. If the fan does not perform as expected the AHU functioning is jeopardized and the power consumption can be drastically affected.

In order to improve the reliability of the fan performance data, and thereby provide peace of mind to AHU manufacturers when they declare their own fan-related performance ratings, ECC decided to establish a certification scheme for fans intended to be used as Air Handling Units components. Thus, after one year of work comprising meetings with AHU manufacturers and laboratories, a new Eurovent Certified Performance (ECP) certification programme dedicated to fans was published in July 2017.

Laying the foundation for the ECP-AHU fans certification scheme

Third-party certification for a fair and objective comparison of the ratings

The FANS certification was developed under a Eurovent Certified Performance (ECP) mark, which is the most renowned certification mark in the HVAC&R fields in Europe and beyond. It is estimated that 66% of HVAC&R products sold on the European market are ECP certified[a].

The same procedures and rules (product selection, testing, auditing, etc.) are applied to all manufacturers participating to the programme, guaranteeing that the products are evaluated the same way. Indeed, the FANS certification process is described in the certification programme documents [2][3] and these documents are public[b]. Any manufacturer can therefore check that each of the certification process steps is conducted in accordance with the related procedure, which guarantees a fair treatment of the manufacturers.

The final objective of the third-party certifier is to make available reliable, comparable and transparent data. To this extent, the certification programmes are developed in such a way that published certified data can be objectively compared.

To achieve the appropriate level of reliability, the FANS certification scheme comprises product performance testing but also production sites auditing and operating software checking. This way the consistency between tested data and advertised data is ensured.

To enhance the comparability, the certified data are quantifiable values expressed in specific units which are stipulated in the certification programme documents [2][3]. Moreover, the certified data is available on-line 24/7, to anyone, without any registration or password.

Accreditation and approval from the CPPC as further guarantees

As third-party certifier, ECC has to fulfill impartiality, independency and integrity requirements. The ISO 17065 accreditation by national body COFRAC[c] guarantees that these requirements are met and provides as a solid international recognition thanks to the EA[d]/IAF[e] agreements.

The certification documents [2][3] were approved by the Certification Programmes and Policy Commission (CPPC) before publication. The CPPC is an independent body composed of four (4) colleges: end user representatives, manufacturers, technical and scientific experts and finally national authorities.

A strong certification scheme towards reliable and transparent data

A wire-to-air approach

AHU fans can be supplied as separate components to be assembled. However, to evaluate and compare fan technologies fairly and effectively, all the components involved in the air stream generation that affect the fan performance should be accounted for, whether they are supplied separately, pre-assembled or fully-assembled. The principle of assessing the fan performance including all the fan components, from the electric wire to the air discharge, is known as the "wire-to-air" approach. This "wire-to-air" approach was used as guiding principle for the FANS certification scheme.

To fulfill the "wire-to-air" principle, all the components that appear in the applicant/participant product catalogue have to be included in the tested fan assembly. Whenever a given component is not included in the catalogue, a recommended complementary component is to be specified and its influence on the certified performance values is to be assessed in the operating software according to specific rules specified in the FANS documents [2][3].

Indeed, corrective coefficients and default values were established to account for the specified recommended complementary components whenever necessary. Thus, the certified data for not fully assembled fans can also be displayed in "wire-to-air" mode and is guaranteed to be conservative.

Two sub-programmes were implemented in order to distinguish basic assemblies (impeller + housing + ancillaries, see **Figure 1**), from complete assemblies (impeller + motor + drive + controller + support structure + ancillaries, see **Figure 2**). Ancillaries cover inlet/outlet finger guards and inlet connection (cone, ring, nozzle, etc.).

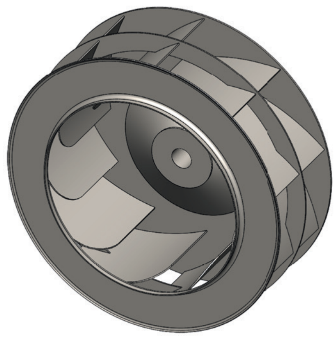


Figure 1. Illustration of a basic assembly. [4]

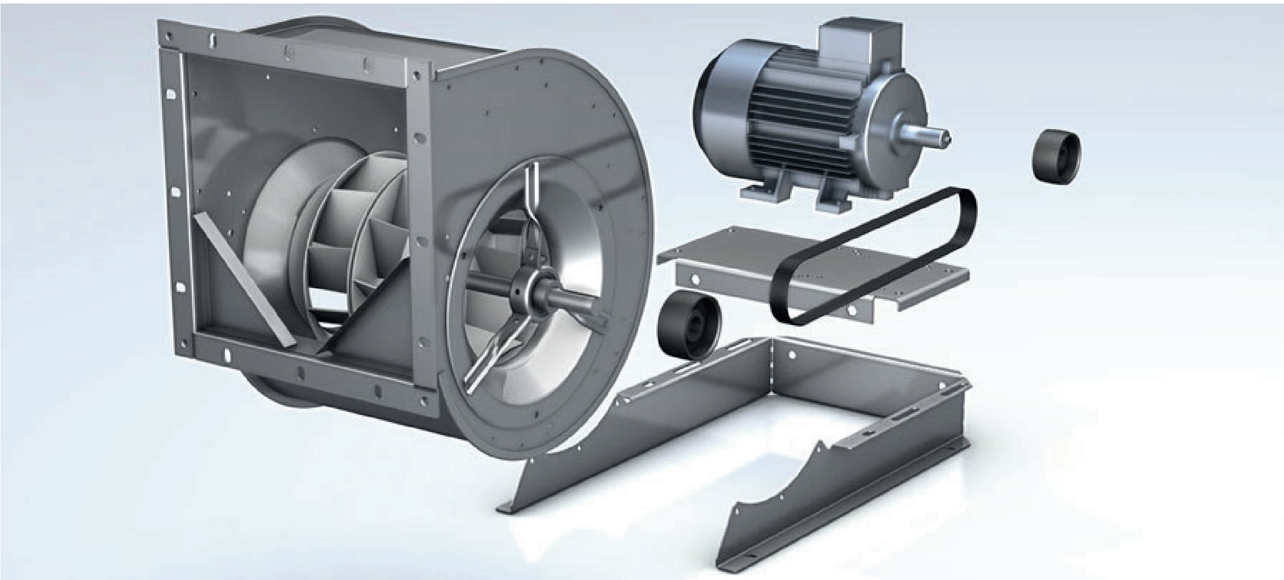


Figure 2. Illustration of complete assembly components. [5]

For clarity and transparency purposes, the sub-programme name (FAN-I for basic assembly and FAN-C for complete assembly) will appear on the certification diploma so that the end-user can know at a glance if the certified value corresponds to a fully-assembled fan or not.

Product performance testing

Product performance testing is to be conducted annually in order to continuously check that compliance to the certification requirements is maintained.

In order to ensure the comparability, consistency and impartiality of the fan performance testing, at least two fans per range have to be tested in the independent laboratory selected and approved by Eurovent Certita Certification. Among other requirements, the independent laboratory must be ISO 17025 [6] accredited.

A total of six units per range (two copies of three different models, see Table 1) will be sampled from regular production during the audit (production line or stock) and authenticated (marked and sealed) by the auditor. Once the test session is complete the manufacturer can get the units back upon request.

All fan types will be tested using installation category A (free inlet, free outlet with partition [7]) in order to facilitate the ratings comparison and avoid any potential misunderstanding when reading the performance values.

The aerodynamic test, conducted in accordance with ISO 5801:2007 [8], enables to verify the performance ratings (see **Table 2**) for 10 measuring points chosen by ECC within the fan operating area [3].

The acoustic test, conducted for complete assemblies (FAN-C sub-programme) in accordance with ISO 13347-2:2004 [9] enables to assess the acoustic behavior (see Table 3) of the fan when it operates at nominal rotational speed [3].

Capitalizing on existing efforts

On top of the tests in independent laboratory, the manufacturer shall provide to Eurovent Certita Certification the appropriate number of aerodynamic test reports (see **Figure 3**).

As fans manufacturers may have already initiated efforts to improve the accuracy of their products performances (qualification of the factory test bench by an accredited body, performance tests conducted by a laboratory

Table 1. Purpose of the units sampled and sealed by the auditor.

Unit	Purpose
Model A, copy 1	**Sent to laboratory for regular test**
Model A, copy 2	Sent to laboratory in case of component failure (regular test) or unit failure (second test) if any.
Model B, copy 1	**Sent to laboratory for regular test**
Model B, copy 2	Sent to laboratory in case of component failure (regular test) or unit failure (second test) if any.
Model C, copy 1	Sent to laboratory in case of unit failure (penalty test) if any.
Model C, copy 2	Sent to laboratory in case of component failure (penalty test) if any.

Table 2. Certified data according to the sub-programme – Aerodynamic test. [3]

Aerodynamic test	FAN-C	FAN-I
Overall pressure difference (static) [Pa]	✓	✓
Shaft power P_a, including bearings [W]	–	✓
Impeller efficiency η_r [%]	–	✓
Maximum fan speed N_{max} [rpm]	–	✓
Motor (electrical) input power P_e [W]	✓	–
Drive/control electrical input power P_{ed} [W]	✓	–
Overall efficiency η_e or η_{ed} (static; with or without VSD) [%]	✓	–

Table 3. Certified data according to the sub-programme – Acoustic test. (source [3])

Acoustic test	FAN-C	FAN-I
Inlet and outlet sound power level by octave bands between 125 Hz and 8000 Hz [dB]	✓	–

Number of aerodynamic tests reports to be provided for qualification

For FAN-I (basic assembly) the applicant has to provide $N_{FAN\text{-}I}$ test reports and

$$N_{FAN\text{-}I}=N_{impeller}$$

For FAN-C (complete assembly) the applicant has to provide $N_{FAN\text{-}C}$ test reports and

$$N_{FAN\text{-}C}=Max(N_{impeller};N_{motor};N_{drive})$$

where

$N_{impeller}$: number of impeller tip diameters available in the range
N_{motor} : number of motor sizes available in the range
N_{drive} : number of drive types available in the range

Example: The range to be certified concerns centrifugal fans fitted with either a variable-speed drive or a multi-speed drive. There are nine (9) impeller tip diameters and six (6) motor sizes possible so

$$N_{FAN\text{-}C}=Max(9;6;2)=9$$

Nine (9) models of fans will be selected in such a way that each impeller tip diameter, each motor size and each drive type is represented at least once.

Number of aerodynamic tests reports to be provided for surveillance

For the surveillance procedure the manufacturer has to provide one (1) test report per production site.

If only part of the production sites is equipped with a validated test rig, the participant can either deliver the units to be tested to these particular sites or order the tests to Eurovent Certita Certification. In both cases the tested units will have to be traceable so that it can be evidenced that each of them comes from a different production site.

Example: If the participant has five (5) production sites that manufacture the certified ranges then a total of five (5) test reports shall be provided annually.

Figure 3. Number of aerodynamic tests reports to be provided. (source [2])

organized according to ISO 17025:2005 [10], etc.), the FANS certification scheme includes specific criteria [2] for the evaluation of existing aerodynamic test reports acceptability.

Among these criteria, the aerodynamic test reports shall be recent enough (less than three years for qualification and since last audit for surveillance) and a third-party shall be involved either in the test conduction itself or in the frame of the manufacturer's test bench qualification. To be acceptable the test reports shall also comprise essential information regarding measurement uncertainties and sensors calibration.

If the criteria are not met, the appropriate number of aerodynamic tests is ordered to the independent laboratory.

Production sites auditing

Audits enable to verify that the products declared to certification are indeed the ones manufactured. The manufacturing process is also assessed to ensure that the tested object is representative of the whole production.

Indeed, the three interdependent principles verified during an ECP audit are:

- What is declared is what is produced by regular production
- What is offered and sold is what is declared
- What is produced is what is tested during the certification test

The auditor conducts an on-site checking of the software/DLL consistency, proceeds to the units sampling/sealing and verifies that applicable requirements are fulfilled.

The requirements comprise notably the proper use of the ECP mark when displayed on the production units or on documentation, the consistency between products declared for certification and observed in the sales record and/or production line and/or stock, the compliance of the quality management system to key criteria detailed in the certification documents, etc.

Audits are conducted annually to verify that the requirements are met at all times.

Software checking

As it is not possible to test each and every fan configuration (combinations of impeller size, motor type, drive type, etc.) at a reasonable cost, the number of tests is limited. To reach the appropriate level of confidence in the ratings for the whole range the tests are supplemented by audits and software checking.

Specific requirements are foreseen in the FANS certification documents [2][3] for stand-alone softwares on the one hand and Dynamic Link Libraries[f] (DLL), on the other hand.

The initial check, conducted remotely, enables to verify compliance to general requirements applicable to all ECP programmes [10] but also that the software/DLL ratings are consistent with the operating values (test conditions and measured performances) observed in the tests reports provided by the manufacturer.

The software/DLL is also verified during the audit to check that the version sent to the certifier is the one indeed used for the orders treatment. To conduct this consistency check the auditor selects two (2) orders at random from the manufacturer's sales records and runs the software/DLL. The design resulting from the computation must correspond to that provided to the customer.

Finally Eurovent Certita Certification recalculates the ratings with the software (or DLL interface) according to the test operating conditions displayed in the test report ("test-check") so that the test results are compared to the appropriate ratings.

If all the checks prove the software/DLL consistency, the software version is certified, appears on the certificate and is published online[g] together with the certified range references.

Conclusion

A new approach was used in order to certify the performances of fans integrated in AHUs: the "wire-to-air" approach. This principle consists in taking into account all the components from the electric wire to the air discharge that influence the performances of AHU fans. The implementation of such a "wire-to-air" principle in the FANS certification programme ensures that AHU fans are evaluated under the same conditions and that performance ratings are indeed comparable and transparent.

With the FANS certification programme, Eurovent Certita Certification expects to improve the level of confidence in the AHU fans performance ratings and thus provide to AHU manufacturers more reliable performance data, but also peace of mind since fans are considered as the most important component within AHUs in terms of energy efficiency. ■

Bibliography

[1] Commission regulation (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW, 2011

[2] Eurovent Certita Certification - OM-22 - Operational Manual for the certification of fans, 2017

[3] Eurovent Certita Certification - RS/1/C/001 – Rating Standard for the certification of fans, 2017

[4] AirPro Fan & Blower Company - Backward curved fans [online]. <https://airprofan.com/centrifugal-fans-blowers/backward-curved-fan>, consulted on 14/11/2017

[5] Nicotra-Gebhardt - Fans solutions for all applications (brochure), issue 1.2 EN, 2012

[6] ISO/IEC 17025 - General requirements for the competence of testing and calibration laboratories, 2005

[7] ISO 13349 - Fans-Vocabulary and Definitions of categories, 2010

[8] ISO 5801 - Industrial fans - Performance testing using standardized airways, 2007

[9] ISO 13347-2 - Industrial fans – Determination of fans sound power levels under standardized laboratory conditions - Part 2 : Reverberant room method, 2004

[10] Eurovent Certita Certification - Certification Manual of the Eurovent Certified Performance mark, 13th edition, 2016

References

a 2014 data valid for Chillers, Heat Pumps, Fan Coil Units, Heat Exchangers and Filters within the certified scope

b OM-22 [2] and RS/1/C/001 [3] available on-line at http://www.eurovent-certification.com

c COFRAC certificate n°5-0517. Accreditation scope available at https://www.cofrac.fr

d European accreditation http://www.european-accreditation.org

e International Accreditation Forum http://www.iaf.nu

f I.e. a library of functions made available to the user for integration in his own software.

g http://www.eurovent-certification.com

Seasonal Efficiencies for Rooftop units

After almost 20 years, Eurovent Certita Certification is well recognized on the European market for heating, ventilation and air-conditioning products. Currently 66% of the HVAC sold on the EU market are certified by Eurovent Certita Certification with the Mark "Eurovent Certified Performance" (ECP).

ARNAUD LACOURT
Head of Thermodynamics Department
Eurovent Certita Certification
a.lacourt@eurovent-certification.com

Launched in 2007, the rooftops certification programme was the thirteenth programme of Eurovent Certita Certification. The current certified products and their performances are available 24h/24 on the ECP website.

Since the beginning of the programme, performances of rooftops used to be compared at fixed conditions, also named "Standard Rating Conditions" or "Nominal Conditions"

However, these conditions do not represent the usual operating conditions of the equipment over a season, which becomes especially important for the calculation of the energy efficiency.

From January 2013, the European Commission implemented step by step seasonal efficiencies for several types of heating and cooling devices:

- Residential Air Conditioners below 12 kW since 1st of January 2013;
- Air-to-water & water-to-water Heat pumps below 400 kW since 15th of September 2015.

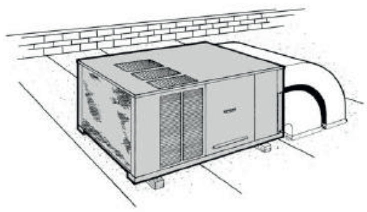
From 1st of January 2018, the European Commission will require that seasonal efficiencies be applied also to:

- Air-conditioners above 12 kW
- Variable Refrigerant Fluid systems
- Chillers
- **Rooftops units**.

Consequently, Eurovent Certita Certification has updated its rooftops programme in accordance with this new Regulation.

Scope of the programme

This certification programme concerns air-to-air and water-to-air rooftops below 200 kW (nominal capacity in cooling mode). It also applies to units intended for both cooling and heating by reversing the cycle.



Rooftop units are defined by the following features:

- Single packaged unit assembled in factory
- Common single frame
- Direct expansion system
- For Air-to-air unit, the outdoor side heat exchanger (condenser / evaporator) allows heat transfer with 100% outdoor (ambient) air.
- Designed to operate permanently outdoor
- The rooftop is designed to permanently handle 100% recycled air with the possibility of mixing partly the fresh air. Nevertheless, the rooftops are excluded from the ventilation unit regulation N° 1253/2014 (according to EVIA/Eurovent Guidance Document on Ecodesign requirements for ventilation units)
- The outdoor fan from an air-to-air rooftop could be ducted but for the certification tests, the unit must be not ducted.
- Rooftops could be equipped with 2, 3 or 4 dampers depending on heat recovery system included or not, even if the heat recovery mode is currently outside the certification programme.

Nevertheless, the following features are not certified:

- gas burners,
- pre-heaters,
- heaters,
- additional internal coil,
- heat recovery (plate, wheels, thermodynamic systems),
- exhaust fans.

Process of Certification:

The programme is split into three sub-programmes:

- One mandatory sub-programme: Air-to-air units up to 100 kW
- Two optional sub-programmes:
  - Air-to-air units from 100 kW to 200 kW
  - Water-to-air units up to 200 kW

The purpose of all Eurovent Certification Programmes is to encourage honest competition and to assure customers that equipment is correctly rated on the market. The purpose is achieved by verifying the accuracy of ratings claimed by manufacturers by continuing testing of production models, randomly selected, in independent laboratories.

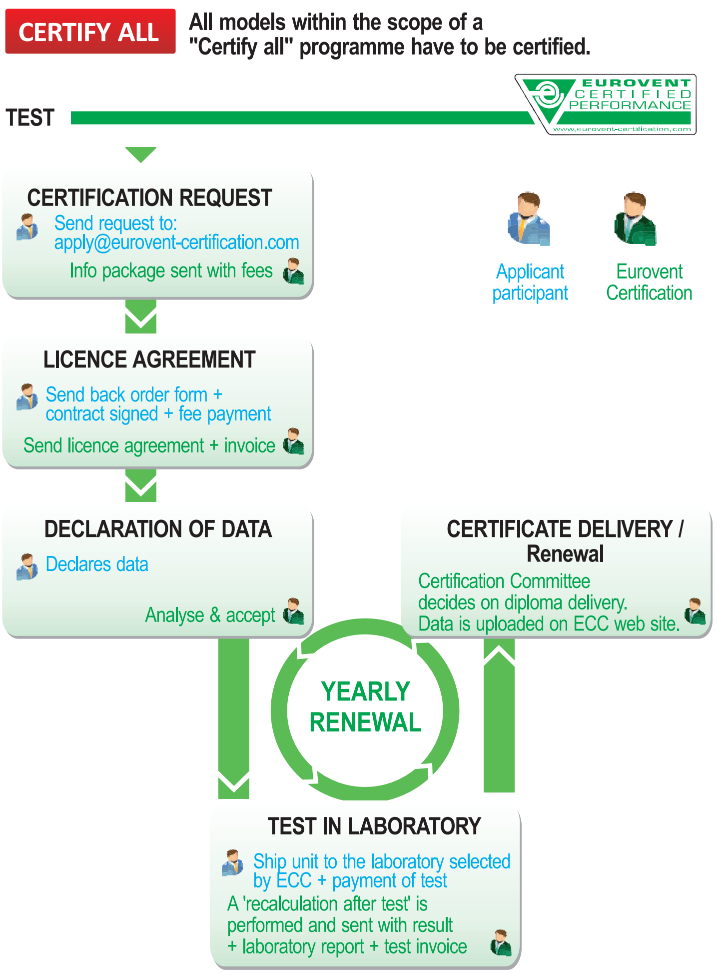


Figure 1. Steps in the certification process of the product performance.

One particularity of rooftop programme is to apply the "Certify-all" principle.

All standard products of the relevant certification programme manufactured or sold by a Participant inside the defined scope must be certified. "All products inside the defined scope presented, at least, on the European market".

"Certify-all" brings clarity and transparency and therefore increases the value of the whole system.

From standard rating conditions to Seasonal efficiencies

Performances of rooftops used to be compared at a fixed condition, also named "Standard Rating Condition" according the standard EN 14511.

Table 1. Operating conditions for standard rating (EN 14511:2013).

	INDOOR SIDE		OUTDOOR SIDE			
	Air entering °C		Air entering °C		Water °C	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	In	Out
Cooling	27	19	35	24	30	35
Heating	20	15 max	7	6	20*	
SOUND**	27	19 (±2)	20–35	–	30	35

* For units designated for cooling mode, the water flow rate obtained during the test at standard rating conditions in cooling is used.

** Same airflow and same available pressure as for the thermal test shall be used.

Commission Regulation (EU) No 2016/2281 of 30 November 2016 implementing Directive 2009/125/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for rooftops introduced on the European market after the 1^{st} January 2018.

The Directive defines minimum energy efficiency for air-to-air rooftops as shown in **Table 2**.

Table 2. Requirements for minimum energy efficiency.

	Tier 1 *from 1^{st} of January 2018*	**Tier 2** *from 1^{st} of January 2021*
Heating ηsh	115%	125%
Cooling ηsc	117%	138%

The seasonal efficiency is expressed by:

- ηsh for the heating mode [%],
- ηsc for the cooling mode [%].

These new performances come from SCOP & SEER mentioned in the EN14825 standard and given by the following formula:

$$\eta sh = 100 \text{ x } \frac{SCOP}{2.5} - 3\%$$

$$\eta sc = 100 \text{ x } \frac{SEER}{2.5} - 3\%$$

where:

- SCOP: Seasonal Coefficient of Performance for heating mode
- SEER: Seasonal Energy Efficiency Ratio for cooling mode
- 2.5 is the coefficient for power generation efficiency
- –3% is the correction that accounts for a negative contribution to the seasonal energy efficiency ratio due to adjusted contributions of temperature controls (for water-cooled units, an addition correction is required: –5%)

New Energy Efficiency Ratio and Standard for Rooftops

The ηsh and ηsc, mentioned in the Directive, represent the usual operating conditions of the equipment over a season. This operating condition can be better assessed by comparing equipment at representative reduced capacities.

Standard EN 14825 provides part-load conditions and calculation methods for calculating the SEER and SCOP of such units when they are used to fulfil the cooling and heating demands.

Other energy consumptions can occur when the unit is not used to fulfil the cooling and heating demands such as those from a crank case heater or when the unit is on standby. These consumptions are considered in the calculation methods for SEER and SCOP.

Cooling mode	Heating mode
Performances in Standard rating conditions (according EN 14511 standard)	
Cooling Capacity @ 35°C	Heating Capacity @ 7°C
EER @ 35°C	COP @ 7°C
Seasonal Performances (according EN 14825 standard)	
Cooling Capacity @ 35°C	Heating Capacity @ 7°C
EER @ 35°C	COP @ 7°C
ηsc	ηsh
Sound Power Level (according EN 12102 standard)	

Certification for Rooftops

All the conditions involved in the calculation of ηsc and ηsh are continuously tested by Eurovent certita Certification. In case of failure on any condition, the seasonal efficiency will be rerated according the result. The models in the same group (same overall dimension as the tested model) will be rerated by the deviation found on the tested model.

These Seasonal Energy Efficiency Ratio for cooling mode (ηsc & SEER) and Seasonal Coefficient of Performance for heating mode (ηsh & SCOP) came in addition to the well-known Energy Efficiency Ratio (EER and COP) and Sound Power Levels (Outside & Indoor sides), already certified.

Table 3. Part load conditions used for calculation of seasonal efficiencies ηsc and ηsh.

Cooling mode			Heating mode for Average Climate		
Conditions	Outdoor T°	Part load ratio	Conditions	Outdoor T°	Part load ratio
A	35°C	100%	A	–7°C	84%
B	30°C	74%	B	2°C	54%
C	25°C	47%	C	7°C	35%
D	20°C	21%	D	12°C	15%
			Bivalent	between –10°C and 2°C	100%

Existing Eurovent Energy labelling

The purpose of Eurovent Energy Efficiency Classes is to simplify the selection of the best units for each type of Rooftops. The classification is entirely voluntary, not related to any European Directive. The energy efficiency of Rooftops is designated by "Eurovent Certita Certification Class A" or "Eurovent Certita Certification Class B" in catalogues and in the Eurovent Certita Certification Directory of Certified Products.

The current Eurovent Energy Labelling has been defined according to the EER & COP at standard Rating conditions (EN14511).

The switch to Seasonal efficiencies will impact the Eurovent labelling. In the coming months, the New Eurovent Efficiency Classes will be based on ηsc & ηsh.

Data publication

Making the certified data easily available for end-users and consultants has always been a priority for Eurovent Certita Certification. Our directory of certified data, available since the creation of the company, and launched as an interactive website around 2001, brings reliable data to end-users. In addition to the certified data a dedicated description page for each certification programme containing the outline of the programme, definitions and rating conditions is made accessible and constantly updated to help visitors understand the value of certified data (http://www.eurovent-certification.com)

Conclusion

The usual energy efficiencies achieved at full load* are going to disappear gradually in order to be replaced by new performances which will allow specifying these units on a more representative way in terms of energy consumption.

The implementation of seasonal efficiencies and minimum requirements for rooftops will force the current market to change. The less efficient products will disappear progressively. With these new requirements, the verification of the published data by a third-party body, as Eurovent Certita Certification, remains a useful added value to verify the announce performance as a complement to the market surveillance, and to help comparing the products thanks to its online database.

In parallel to this regulation implementation, Eurovent Certita Certification is working on several topics of rooftops as the creation on a specific seasonal efficiency taking into account the free cooling and the certification of 3 & 4 damper rooftops including the heat recovery mode. ■

* Rating Standards Conditions according to EN 14511

REHVA Office Responsibilities

NATHALIE WOUTERS – Office and Membership Manager

- Office management, HR
- Membership liaison
- REHVA Student competition
- REHVA Awards
- REHVA Board meetings' secretariat
- REHVA Newsletter, Bulletin publication
- REHVA Annual meetings, General Assembly secretary
- EC, AC secretary
- MoU-s: follow-up and coordination

ANITA DERJANECZ – Managing Director

- REHVA office executive management
- REHVA Legal representative
- Business development
- EU policy and public affairs
- Commissioning certification scheme project
- EU project development and implementation
- ERC, TRC secretary

CHIARA GIRARDI – Publication and Promotion Officer, RJ Editor Assistant

- Publication of REHVA Guidebooks and Journal (as Editor Assistant)
- REHVA website content management
- REHVA promotional services and sales
- Supporters Contact
- REHVA Dictionary and App development
- REHVA presence at events and fairs, events management and promotion of REHVA events
- SC, PMC, COP secretary

TIZIANA BUSO – Project Officer

- TRC secretary, support of Task Forces, and technical publications
- EU project implementation
- EU proposal writing
- Supporting REHVA technical seminars
- Commissioning certification scheme project

GIULIA MARENGHI – Project Assistant

- Administrative support of general office management
- Financial and administrative reporting of EU projects
- EU project implementation – communication activities
- Reception and secretarial support

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

Ancient technology of ‘Evaportaive Cooling’ proven by independent accredited product certification programme

IAN BUTLER
Project Manager,
Eurovent Certita Certification

The cooling effect of evaporating water into air is a simplistic, ancient method for building cooling. A simple example shows how effective it can be: Blow over the top of your hand. Now lick it and blow over it again. Which felt cooler? Even though you added a warm liquid (your saliva) to your skin, it felt cooler when you blew over it the second time. Why is this? It’s an effect known as evaporative cooling. The state change of water absorbs energy, lowering the dry bulb temperature to a point where it approaches the wet bulb (saturated) temperature of the air, causing a cooling effect.

Now take this simple principle into a real world business environment and ask yourselves; do we know the realistic cooling performance of the evaporative cooling equipment that we are expecting and paying for. Do we have reliable data?

Today with the ever increasing need to reduce energy consumption designers look to evaporative cooling solutions especially in the application of data centre cooling, also with Zero Net Energy (ZNE) a growing building design and energy policy trend, design firms and owners are striving to meet heating, ventilation and air-conditioning (HVAC) loads with optimum comfort and minimal energy. PUE (Power Usage Effectiveness) is a key industry measure of how efficiently a computer data centre uses energy, so it will be important for energy consultants to use trusted real performance data from the equipment suppliers to be able to calculate this effectiveness with confidence.

Let’s take a more detailed view on Data Centre demand trends: In the last 5 years the data centre air conditioning market has grown with a CAGR (compound annual growth rate) of approx. 12% with a market value from \$4.91 billion in 2013 to \$8.07 billion by 2018. The global data centre IP traffic has set a constant growth path, with a CAGR of 25% during the period 2012–2017 with particular growth being driven by three main factors: The need for bigger online storage resources; requirements to analyse bigger amounts of data and growing demands on cloud applications. Yes, we all have at least one mobile phone, a computer, smart TV, etc. Cloud traffic represents 69% of all total data centre traffic in 2017 and significant promoters of cloud traffic growth are the rapid adoption of and migration to cloud architectures, so this need for energy efficient cooling equipment is not going away.

So how you as consumers, owners and investors can be sure what cooling ‘effect’ is being declared by the manufacturers of such technology equipment especially when market pressures and strong competition is so high. We know from recent experiences that some well know brand names have been found to fall to these pressures and provide something that really is not true or acceptable to industry regulations. Today more questions are being asked, does one really trust the energy performance and savings that I am being given!

Manufactures want to promote trust and provide reliable product data in their evaporative cooling equipment (it does what it says on the tin)

One way that evaporative cooling equipment manufacturers are looking to promote 'trust' in its declared equipment performance to its purchasers & owners is to put their products through a 3rd party voluntary certification programme. Evaporative Cooling equipment manufacturers will put their products through industry know standards: AS 2913-2000 and ASHRAE 133-2015 standard for DEC, ASHRAE 143-2015 standard for IEC & for ECE specific calculations using the ASHRAE 133-2015 standard, together with an annual verification factory audit to confirm what has been declared is actually what is being manufactured.

With so much emphasis on reducing energy consumption or enabling the energy to be used for other demanding needs, can we be sure the system will perform when the equipment performance and build verification has not been checked through certification.

Eurovent Certita Certification (ECC)

ECC an accredited industry leader in product certification to ISO17065 with over 20 years history of product certification has developed with input from leading evaporative cooling industry manufacturing experts a Eurovent Certified Performance (ECP) programme for Evaporative Cooling with three sub-product groups, these being: Direct Evaporative Cooling (DEC), Indirect Evaporative Cooling (IEC) & Evaporative Cooling Equipment (ECE).

Brief Overview & Definition of each Product Group

Direct Evaporative Cooling (DEC): A self-contained unit, including a fan and fan motor, whose primary functions are (a) the conversion of the sensible heat of unsaturated air passing through the cabinet to latent heat by the process of evaporating recirculating or non-recirculating water directly exposed to this air and (b) the movement of this air through the unit.

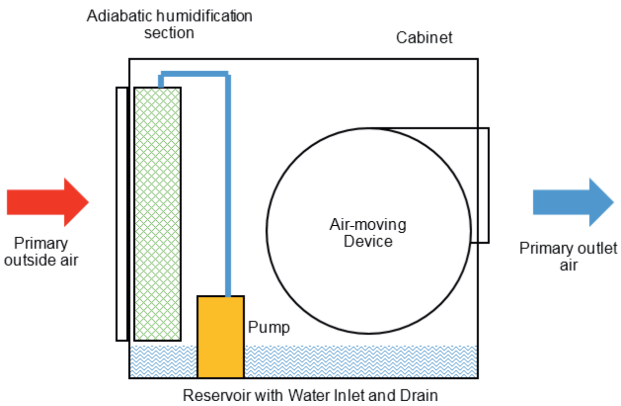


Figure 1. Direct EC.

DEC performance data to be certified: Cooling Capacity (kW), Air Flow [m³/hr], Evaporation Efficiency [%], EER & Water Consumption [l/hr].

Tests shall be conducted in accordance with the AS 2913-2000 standard, and ASHRAE 133-2015 shall be used for the water consumption testing.

The evaporation efficiency is calculated as follows:

$$e = \frac{(t_i - t_o)}{(t_i - t_{wi})}\ x\ 100\%$$

Where:

t_i is the air inlet dry bulb (as measured from test) [°C]

t_o is the air outlet dry bulb (as measured from test) [°C]

t_{wi} is the air inlet wet bulb (as measured from test) [°C]

The cooling capacity of a DEC unit is the cooling effect of the cooler calculated from the following equation, the nominal rating is calculated where the conditions, specified for nominal rating below, are substituted as shown:

$$S = \frac{q_v\ \rho\ c_p}{1000}\left(\frac{e}{100}(t_i - t_{wi}) + t_r - t_i\right)$$

Where:

S is the cooling capacity (kW)

Q_v is the airflow (l/sec) = as measured from test

ρ is the air density (1.20 kg/m³ for standard air)

c_p is the specific heat of air = 1.024 kJ/kgK

t_i is the standard inlet dry bulb condition for rating calculation

t_{wi} is the standard inlet wet bulb condition for rating calculation

t_r is the standard room air outlet dry bulb condition for rating calculation

e is the evaporation efficiency

The Energy Efficiency Ratio (EER) is the ratio of cooling capacity to the power input:

$$EER = \frac{Cooling\ Capacity\ (\text{kW})}{Power\ Input\ (\text{kW})}$$

Where:

Cooling capacity is as calculated above.

Power input is as measured from the test

Indirect Evaporative Cooling (IEC): (1) With primary outside air or (2) With separation of external and room air. The following units are specifically excluded from the scope: Units with an air flow < 2,500 m³/hr or > 120,000 m³/hr.

Case A: an indirect evaporative cooler with integrated primary and secondary air passages and provided with both primary and secondary air-moving devices. Depending on product configuration a single air-moving device may be used for primary and secondary air. This device also includes the entire water distribution, collection, and might also include recirculation system with pump and piping. This type may have provisions for installation of other heat and mass transfer devices, such as a direct evaporative cooler and auxiliary heating and cooling coils. These additional devices are not covered by this certification programme. Primary air is always drawn from outside. Some discharged primary air may or may not be used as secondary air (from ASHRAE 143:2015 packaged indirect evaporative cooler (packaged IECU) definition, pg3).

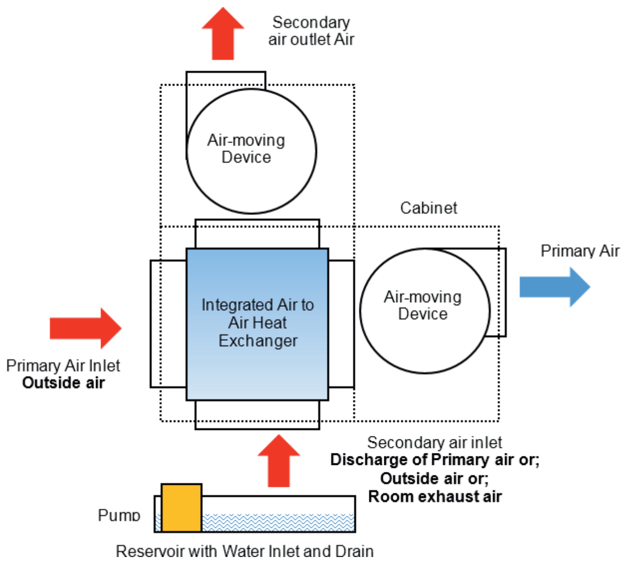


Figure 2. Indirect EC - Case A.

Case B: a packaged indirect evaporative cooling unit with integrated primary and secondary air passages and provided with both primary and secondary air-moving devices. This device also includes the entire water distribution, collection, and recirculation system with pump and piping. This type may have provisions for installation of other heat and mass transfer devices, such as a direct evaporative cooler and auxiliary heating and cooling coils. These additional devices are not covered by this standard (definition from ANSI/ASHRAE standard 143-2015 page. 3 packaged indirect evaporative cooler).

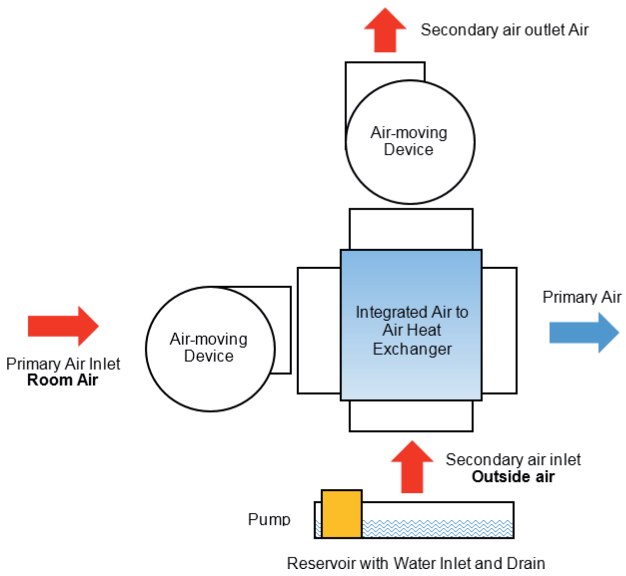


Figure 3. Indirect EC - Case B.

Performance data to be certified: **Case A**: Total Cooling Capacity [kW], Room Cooling Capacity [kW], Air flow [m³/hr], Cooling Effectiveness [%], Water Consumption [l/hr] & Energy Efficiency Ratio (EER).

The cooling effectiveness is calculated as follows:

$$e = \frac{(t_{d1} - t_{d2})}{(t_{d1} - t_{w3})} \ x\ 100\%$$

Where:

t_{d1} is the Primary air inlet dry bulb temperature (as measured from test) [°C]

t_{d2} is the Primary air outlet dry bulb temperature (as measured from test) [°C]

t_{w3} is the Secondary air inlet wet bulb (as measured from test) [°C]

The cooling effectiveness is calculated for case A only.

The total cooling capacity is calculated as follows:

$$q = 1.21\ Q_p(t_{d1} - t_{d2})$$

Where:

t_{d1} is the Primary air inlet dry bulb temperature (as measured from test) [°C]

t_{d2} is the Primary air outlet dry bulb temperature (as measured from test) [°C]

Q_p is the Primary air flow rate

For **case A** only a second cooling capacity shall be calculated as follows, this cooling capacity is named hereafter "Room cooling capacity":

$$q = 1.21\,Q_p(t_{d2} - t_{de})$$

Where:

t_{d2} is the Primary air outlet dry bulb temperature (as measured from test) [°C]

t_{de} is the Room exhaust air dry bulb temperature (fixed at 27.4°C for the tests) [°C]

Q_p is the Primary air flow rate

The Energy Efficiency Ratio (EER) is the ratio of the total cooling capacity to the power input:

$$EER = \frac{Total\ Cooling\ Capacity\ (\text{kW})}{Power\ Input\ (\text{kW})}$$

Where:
Total Cooling capacity is as calculated as above
Power input is as measured from the tests

Case B: Total Cooling Capacity [kW], Air flow [m³/hr], Wet bulb approach effectiveness [%], Dry bulb approach effectiveness [%], Water Consumption [l/hr] & Energy Efficiency Ratio (EER).

Tests shall be performed as per ASHRAE standard ANSI/ASHRAE 143-2015 Method of Test for Rating Indirect Evaporative Coolers. Wet bulb approach effectiveness calculation as per section III.9 and tests as per ANSI/ASHRAE 143-2015. Dry bulb approach effectiveness calculation as per section III.10 and tests as per ANSI/ASHRAE 143-2015. Cooling Capacity calculation as per ANSI/ASHRAE Standard 143-2015, Section 11.5.

Wet bulb approach effectiveness:

$$\varepsilon_{Wet\ Bulb\ approach\ effectiveness} = \frac{t_{d1}-t_{d2}}{t_{d1}-t_{w3}}$$

The wet bulb approach effectiveness is calculated for **case B** only.

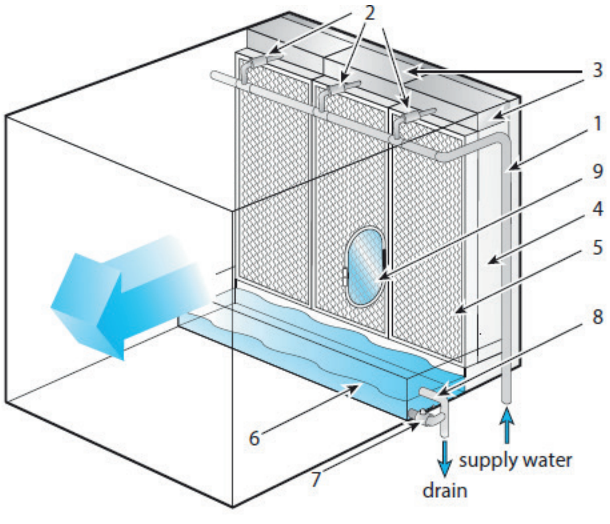
Dry bulb approach effectiveness:

$$\varepsilon_{Dry\ Bulb\ approach\ effectiveness} = \frac{t_{d1}-t_{d2}}{t_{d1}-t_{d3}}$$

The dry bulb approach effectiveness is calculated for **case B** only.

Evaporative Cooling Equipment (ECE): With different types of media being: a) Water Spray System, b) Wet pads/media or c) Ultrasonic units. The following products are specifically excluded from the scope: Product with a water flow < 0.5 l/hr, or > 5000 l/hr, or ECE with integrated heat exchangers.

a) **A water spray system** is a device connected to the water supply through an automatically or manually actuated flow control cabinet with or without pressurizing equipment (e.g. pump). Water is piped to specially designed nozzles which distribute water over a given area.



1	Distribution manifold
2	Constant flow valves
3	Water distribution heads
4	Humidifying elements
5	Mist eliminator
6	Collection sump
7	Manual drain valve
8	Overflow
9	Inspection porthole

Figure 4. Water spray system.

b) **A wet media** is a product made out of corrugated sheets of glass fibre paper, cellulose paper or other material. The incoming air going through the media is in contact with a wet surface and thus enabling the water to evaporate, cool and humidify the supply air.

c) **Ultrasonic units:** One or more piezoelectric transducers immersed in a reservoir of water. The transducer converts an electronic signal into a mechanical oscillation. The mechanical oscillation is directed at the surface of the water, where it creates a fine mist.

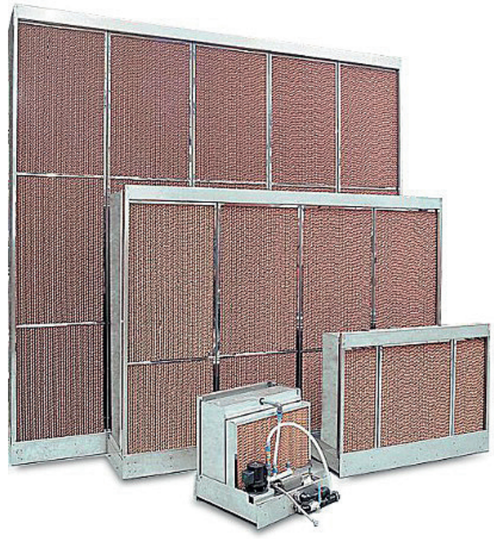
Performance data to be certified: Cooling Capacity [kW], Evaporation Efficiency [%], EER, Water Consumption [l/hr], Wet Pressure drop [Pa]* & Dry Pressure drop [Pa]*.

For specific calculations use ASHRAE 133-2015. Air flow shall be measured before the ECE as per the ASHRAE 133-2015. Water consumption shall be tested as per the ASHRAE 133-2015. Pressure shall be measured as per the ASHRAE 133-2015. Pressure difference shall be measured as per the ASHRAE 41.3. Power Consumption shall be measured as per the ASHRAE 133-2015.

The evaporation efficiency is calculated as follows:

$$e = \frac{Evaporated\ water}{Supplied\ water}\ x\ 100\%$$

Where:
Evaporated water: quantity of water that has been evaporated (l/hr)
Supplied water: quantity of water supplied to the equipment (l/hr)



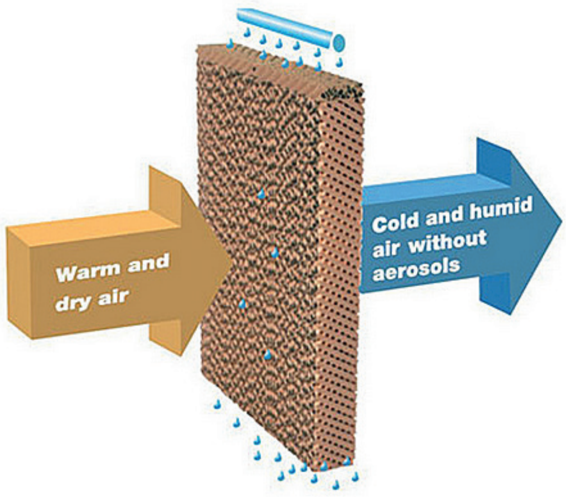
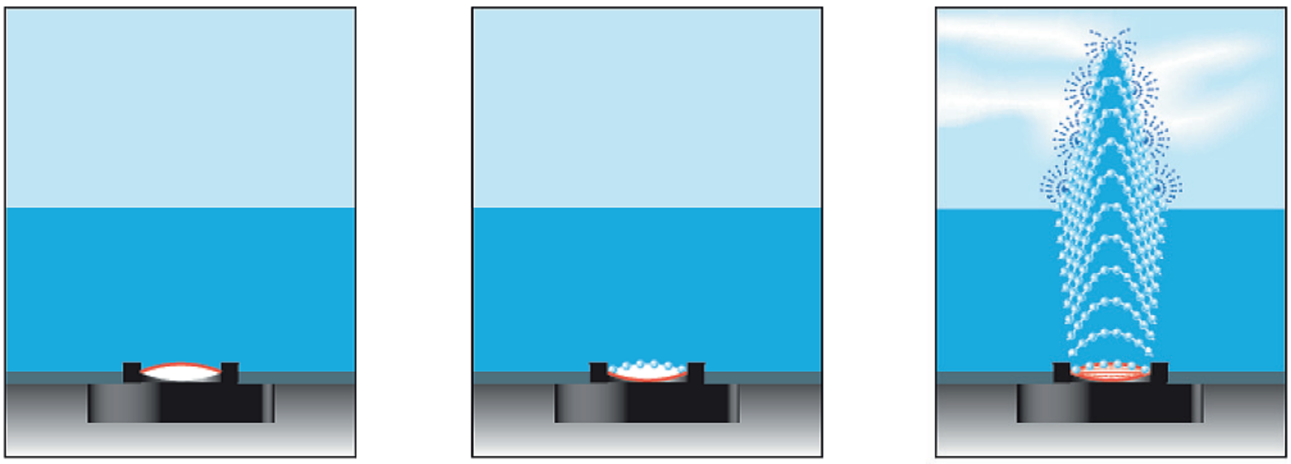


Figure 5. Wet media.



The humidifier is switched on. The oscillator amplitude is positive.

The oscillator amplitude is negative. The inertia of the water creates a vacuum.

After approx. 10 amplitudes, the ultrasonic humidifier reaches 100 % of its output.

Figure 6. Ultrasonic unit principle.

* For water spray & wet pad media.

The cooling capacity is the cooling effect of the cooler calculated from the following equation, the nominal rating is calculated where the conditions, specified for nominal rating below, are substituted as shown:

For Direct EC application:

$$S = \frac{q_v \, \rho \, c_p}{1000} \left(t_{outlet} - t_{inlet}\right)$$

Where:

S	is the cooling capacity (kW)
q_v	is the airflow (l/sec) = as declared by manufacturer
ρ	is the air density (1.20 kg/m³ for standard air)
c_p	is the specific heat of air = 1.024 kJ/kgK
t_{outlet}	is the dry-bulb temperature downstream
t_{inlet}	is the dry-bulb temperature upstream

The Energy Efficiency Ratio (EER) is the ratio of cooling capacity to the power input:

$$EER = \frac{Cooling\ Capacity\ (\text{kW})}{Power\ Input\ (\text{kW})}$$

Where:
Cooling capacity is as calculated as above
Power input is as measured from the tests

Is Product Certification needed? Don't take our word for it listen to the Evaporative Cooling industry. Don't leave it to chance that units are performing the risks could be too high, make a conscious intelligent decision with the Eurovent Certified Performance brand product mark. ■

DEFINING A **WORLD OF COMFORT** WITH PURMO

ONE SUPPLIER, MULTIPLE BENEFITS
In a world of choice, few things are simple. As an contractor, architect or specifier, you are faced with countless decisions every day, as you work to ensure your plan comes perfectly to life. Thankfully, there is one decision we can help you with— which supplier to choose when you're working on how best to provide the perfect indoor comfort for your project.

LONG HISTORY OF RELIABILITY
Purmo is part of Rettig ICC, a global leader in radiators and underfloor heating. One supplier, with a vast array of products and an international logistics network to make sure they reach you on time, every time.

PROVEN AND TRUSTED
When you choose Purmo, you choose a reliable partner with over 60 years of experience. We pride ourselves in being the first choice for architects and specifiers the world over. They keep coming back because of our quality, reliability and service.

Take a look at what we offer on our website **www.purmo.com**

°CLEVER LOW TEMPERATURE RADIATORS

bsi. ISO 9001 Quality Management

PURMO clever heating solutions

Rettig Lämpö Oy, PL 16, Tupakankatu, FI-68601 Pietarsaari, Finland Tel. 06-786 9111 info@purmo.fi www.purmo.fi

European Certification of HVAC&R products

Discover a top European Third-party certification body dedicated to guaranteeing worldwide consumers comfort and satisfaction via product performance certification.

Today, professionals face new challenges in complying with the objectives of carbon footprint reduction and addressing the constraints of building code regulations that require precise calculations based on performance data.

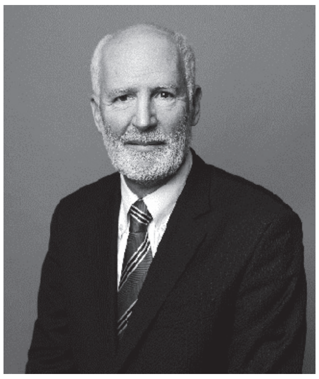
In addition, with the rising costs of energy and the growing demand for cooling in buildings, supermarkets, or data centers, monitoring energy consumption is becoming key to reduce both the financial and environmental impact.

In this challenging and fast-moving context, reliable product performance has become a main driver for business decisions and product investments. When it comes to reducing the energy bill, third-party certification offers a real value.

Trusted as a highly skilled and experienced partner, Eurovent Certita Certification has positioned itself as the number one Third-Party certification provider in Europe in the field of Indoor Climate, Ventilation and Air Quality, Process Cooling & Food Cold Chain.

Based on a voluntary scheme, our certification is open to all manufacturers as well as to distributors who can apply via our Brand Name scheme. We deliver independent and reliable expertise for residential, commercial, and industrial applications. We certify product performances according to both European and international standards, and our certification processes include yearly factory assessment audits, software audits, and third-party product testing.

Whether in response to the rapid growth of hybrid systems involving multiple energy sources or technologies, or to new directives and regulations, Eurovent Certita Certification's mission is to continuously adapt its programmes, methods, and protocols to meet the expectations of the market and its stakeholders.



ERICK MELQUIOND
President
Eurovent Certita Certification

Consultants, buyers and contractors benefit from a fair and competitive market, supporting the dimensioning of energy efficient projects

Commercial buildings consume 40% of all electrical energy; with the introduction of the Energy Performance Building Directive (EPBD) in Europe, reducing energy consumption is one of the challenges consultants and contractors have to face. Dimensioning projects that assess the energy consumption of buildings and highlight its true cost quickly illustrate the power and value of certified data.

The mission of Eurovent Certita Certification is to create common set of criteria for rating products, that apply to all manufacturers, thus increasing the integrity and accuracy of data while ensuring the needed level of transparency to guarantee a fair and competitive comparison. With over 95,000 models certified, our database provides professionals with all the information needed to dimension equipment and match the technical constraints of the specifications with the financial target of the project.

Third-Party certification enables compliance monitoring to achieve environmental goals

Performance data certified by Eurovent Certita Certification is instrumental for State authorities to enable compliance monitoring. It provides valuable data to document and track market information. Eurovent Certita Certification is an accredited certification body, trusted to deliver a consistently reliable and impartial service which meets the appropriate, internationally recognised standards.

Third-Party certification offers guarantees of integrity, independence, impartiality and competence while remaining compliant with European Competition Laws.

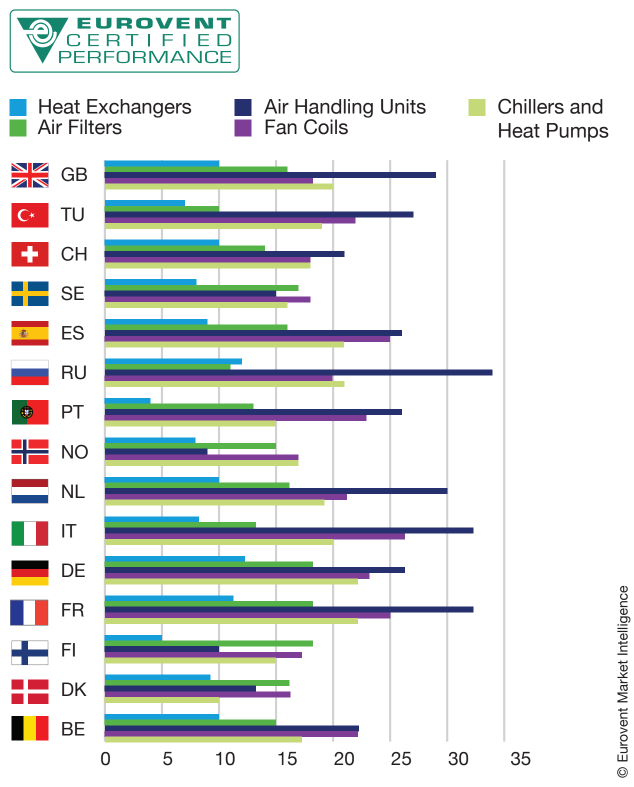
Product performance certification delivered by Eurovent Certita Certification plays a key role to ensure transparency and deliver high quality and reliable data

Certified data can be used in many instances: tax incentives, national implementation of EPBD, building energy labels, green public procurements, white certificates. As certified performances provide confidence in the quality and the compliance of the products they can be required in voluntary schemes (e. g. building energy labels, green public procurements, white certificates) or being considered with an advantage over non-certified products in regulatory schemes (e.g. national implementation of EPBD).

Example of such use can be found in the French Building energy efficiency calculation method which applies a penalty for non-certified heat-pumps and air to air heat exchangers. Consultancies use approved software in order to assess the compliance of a building with the French EPB regulation (RT 2012). This software is linked to database of products which are fed directly with Eurovent certified performance data.

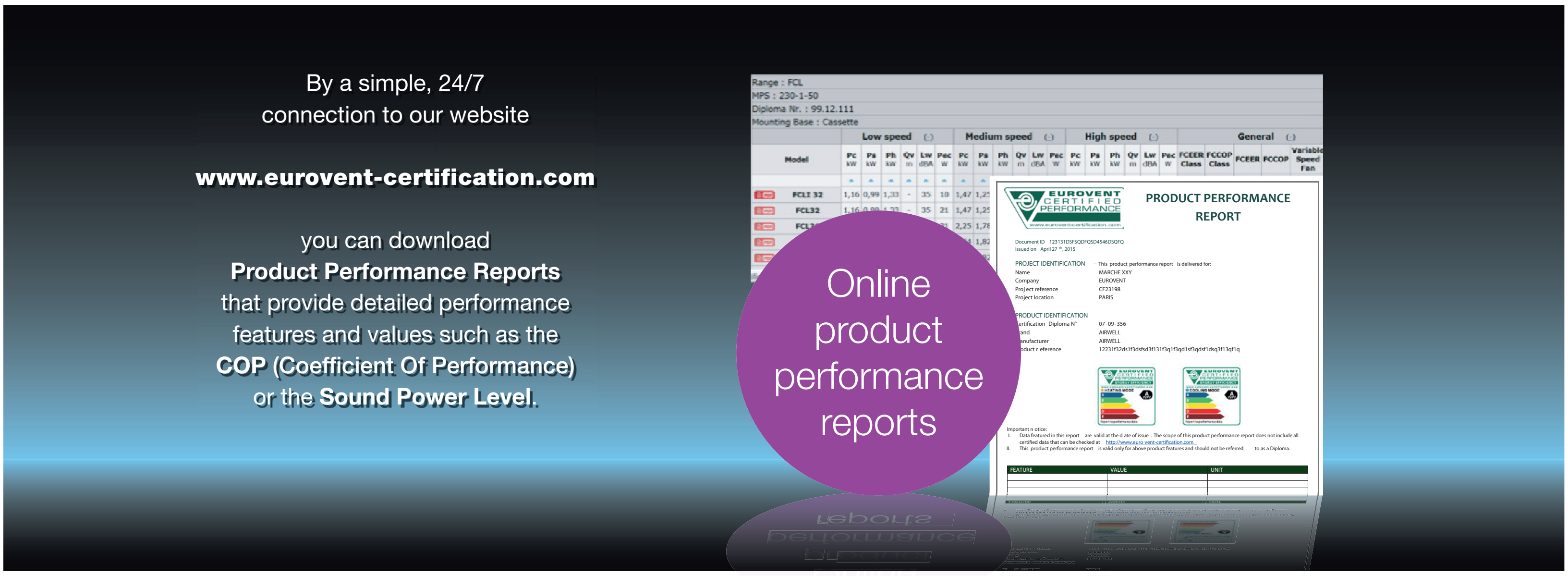
All certified references and performances are listed in our online directory freely available www.eurovent-certification.com. This directory gathers more than 300 certified trademarks and more than 50 000 references. For each product category, characteristics and certified performances are listed according to the same data structure and the latest European and international standards. This allows finding and comparing the certified data easily and with the assurance that the data have been checked.

Manufacturers that sell Eurovent certified products – 2014 (in number) – examples for 5 family products



Integrity, Independence and Impartiality

- We operate with the commissions responsible for the harmonisation and the integrity of our certification programmes, including authorities, end-user groups, scientific and technical bodies, and manufacturer associations.
- All 30 laboratories and testing agencies that are a part of the Eurovent Certita Certification process are regularly assessed according to ISO 17025. They are located in 11 countries worldwide.
- Our testing protocols include independent tests, manufacturing audits, selection software checks, product sampling, product purchasing, cross data coherence algorithms per product family, and product dismantling after testing.



Our Events in 2018 – Exhibition and Conferences

14 – 16 Jan	HVAC-R expo Saudi	Stand 2E30
7 – 10 Feb	ISK Sodex – Istanbul	Stand A33
22 – 24 Feb	Acrex India – Bengaluru	Stand 4L3
27 Feb – 2 March	Climate World – Moscow	Stand 2B15
5 – 9 March	Mostra – Milan	Stand 22F55
21 – 22 March	Data Center World – London	Stand D80
10 – 13 April	NordBygg – Stockholm	Stand A44-52
9 – 11 April	China Refrigeration Expo – Beijing	Stand E3B27
8 – 10 May	ARBS – Sidney	Stand 3133
25 – 29 Sept	Eurovent Summit – Seville	
16 – 18 Oct	Chillventa – Nüremberg	Stand location to confirm
29 Oct	SIFA – Lyon	Stand location to confirm

Find all our information on our website: www.eurovent-certification.com

Our commitment in adding value along the renewable energy decision chain goes one step further and extends to **installers**, **household buyers** or **contractors** for whom we are implementing on-line tools to support them at every stage of their projects, from the quotation to the filing for local incentives or tax rebates.

Conclusion

The challenging normative and regulatory background in the fields of HVAC&R induces a complex environment. Assessing the quality and compliance of products is therefore more and more difficult for end-users. In this context the Eurovent Certified Performance online directory provides an easy and straightforward way to get up to date, trustful and exhaustive data. Such information can be (and are already) used in various voluntary and regulatory compliance schemes.

With this special issue of the RHEVA journal, we welcome the opportunity to present 20 years of Third-Party performance certification expertise and know-how. ■

EUROVENT CERTIFIED PERFORMANCE

CERTIFICATION PROGRAMMES

FOR DOMESTIC, COMMERCIAL AND INDUSTRIAL FACILITIES

Indoor Climate

- Chilled Beams *
- Comfort Air Conditioners *
- European Heat Pumps
- Fan Coils Units *
- Rooftops (RT) *
- Variable Refrigerant Flow (VRF) *

Ventilation & Air Quality

- Air Cleaners (ACL)
- Air Filters Class M5-F9 *
- Air Handling Units *
- Air to Air Plate Heat Exchangers *
- Air to Air Regenerative Heat Exchangers *
- Hygienic Air Handling Units (HAHU)
- Residential Air Filters (RFIL)
- Ventilation Ducts (DUCT)
- Residential Air Handling Units (RAHU)

Process Cooling & Food Cold Chain

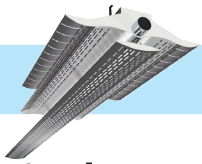
- Cooling & Heating Coils
- Drift Eliminators
- Cooling Towers
- Heat Exchangers *
- Heat Recovery Systems with Intermediate Heat Transfer Medium (HRS-coils)
- Liquid Chilling Package & Heat Pumps *
- Remote Refrigerated Display Cabinets

* All models in the production have to be certified

▼ Indoor Climate

Chilled Beams

CERTIFY ALL



Scope of certification

This Certification Programme applies to all Active and Passive Chilled Beams. Chilled Beams are presented by ranges but all ranges must be certified. This applies to all product ranges which have either catalogue leaflets with product details including technical data or similar product information in electronic format.

Certification requirements

For the qualification procedure (yearly): 3 units are selected from regular production and tested in the independent Laboratory selected by Eurovent Certita Certification.

For the repetition procedures: the number of units selected is limited to 1 unit/range.

Obtained performances shall be compared with the values presented in the catalogues or electronic selection from manufacturer's website.

Certified characteristics & tolerances

Cooling capacity: 3 conditions are required.

- Active: 80 – 100 – 120% of the nominal air flow rate (for 8°C temperature difference)
- Passive: 6 – 8 – 10°C temperature difference

Tolerance = 12% and +24% for the 3 single values; –6% for the average value.

Water pressure drop: tolerance = maximum (2 kPa; 10%)

ECC Reference documents

- Certification manual
- Operational Manual OM-12-2017
- Rating Standard RS 2/C/001-2017

Testing standards

- EN 14518: "Testing and rating of Passive Chilled Beams"
- EN 15116: "Testing and rating of Active Chilled Beams"

Comfort Air Conditioners

CERTIFY ALL

Scope of certification

This certification programme includes:

- AC1: comfort air cooled AC and air to air HP with cooling capacity up to 12 kW, except double duct and single duct units.
- AC2: comfort units with cooling capacity from 12 to 50 kW
- AC3: comfort units with cooling capacity from 50 to 100 kW

This programme applies to factory-made units intend¬ed to produce cooled air for comfort air conditioning (AC1, AC2, AC3). It also applies to units intended for both cooling and heating by reversing the cycle. AC1 programme units out of Regulation 206/2012 are excluded. AC2 and AC3 programme units out of Regulation 2016/2281 are excluded.

Participating Companies must certify all production models within the scope of the programme. For multi-split air conditioners, the number of indoor units is limited to 2, with same mounting type and capacity ratio 1±0.05. However, AC2 & AC3 units with 3 or 4 indoor units can be declared as an option.

Certification requirements

For the qualification & yearly repetition procedures: AC1: 8% of the units declared are selected and tested by an independent laboratory, and 30% of the selected units are tested at part load conditions. AC2 & AC3: 10% of the units declared are selected and tested by an independent laboratory.

Certified characteristics & tolerances

- Capacity (cooling and heating) –5%
- Efficiency (EER and COP) at standard rating conditions and part loads: –8%
- AC1 Seasonal Efficiency (SEER and SCOP): –0% (automatically rerated when Part Load efficiency criteria fails)
- AC2 & AC3 Seasonal Efficiency (SEER/η_{sc} and SCOP/η_{sh}): –0% (automatically rerated when Part Load efficiency criteria fails)
- A-weighted sound power level +0 dB (A) Auxiliary power +10%
- Minimum continuous operation Load Ratio: *LRcontmin* [%], COP/EER at *LRcontmin* and Performance correction coefficient at *LRcontmin* *CcpLRcontmin*.

ECC Reference documents

- Certification manual
- Operational Manual OM-1
- Rating Standard RS 6/C/001 • RS 6/C/001A • RS 6/C/006

Testing standards

- EN 14511 • EN 14825 • EN 12102

▼ Indoor Climate

European Heat Pumps

The programmes AC, VRF, RT & LCP-HP also participate to the programme European Heat Pump

Scope of certification

- Electrically driven heat pumps for space heating (incl. cooling function)
- Electrically driven heat pumps used for heating swimming pool water (outdoors or inside)
- Dual-mode heat pumps, i.e. designed for space heating and domestic hot water production,
- Gas absorption heat pumps (incl. cooling function)
- Engine-driven gas heat pumps (incl. cooling function)

Certification requirements

- Qualification campaign: 1 test per range declared + 1 audit/factory
- Repetition campaign: between 1 and 3 machines/year (depending on the number of certified range) + 1 audit/ year/factory

Main certified characteristics and tolerances

- Heating and/or Cooling capacities P_h and/or P_c [kW], Electrical Power inputs P_e [kW] and Coefficient of performance COP
- Design capacity $P_{designh}$, Seasonal Coefficients of Performance *SCOP*, $SCOP_{net}$ and Seasonal efficiency η_s
- Minimum continuous operation Load Ratio *LRcontmin* [%], COP at *LRcontmin* and Performance correction coefficient at *LRcontmin CcpLRcontmin*
- Temperature stabilisation time t_h [hh:mm], Spare capacity P_{es} [W], Energy efficiency for water heating [COP_{DHW} & WH] or Global performance coefficient for a given tapping cycle COP_{global}, Reference hot water temperature θ'_{WH} and Maximum effective hot water volume V_{MAX} [l]
- Daily consumption for the draw-off cycle in question (Qelec)
- Annual consumption (AEC)
- Sound power levels L_w [dB(A)]

ECC Reference documents

- Certification manual
- Operational manual OM-17
- Rating standard RS 9/C/010

Main testing standards

Thermal performance:

- Heat pumps with electrically driven compressors
- Space heating & cooling: EN 14511-1 to 4; Seasonal performance: EN 14825
- Domestic hot water: EN 16147
- Direct exchange ground coupled heat pumps: EN 15879-1
- Gas-fired heat pump: EN 12309-1 to 5

Acoustics:

- Heat pumps and dehumidifiers with electrically driven compressors: EN 12102
- ISO 3741: Reverberant rooms or ISO 9614-1: Sound intensity, measurements by points

Fan Coils Units

CERTIFY ALL

EUROVENT CERTIFIED PERFORMANCE ENERGY EFFICIENCY CHECK ENERGY CLASS ON www.eurovent-certification.com

Scope of certification

This Certification Programme applies to Fan Coil Units using hot or chilled water. It concerns both non ducted and ducted fan coils:

- Non-ducted units: Fan Coil Units with air flow less than 0.7 m^3/s and a published external static duct pressure at 40 Pa maximum.
- Ducted units: Fan Coil Units up to 1 m^3/s airflow and 300 Pa available pressure.
- District cooling units and 60 Hz units can be certified as an option

Participating companies must certify all production models within the scope of the programme. Selection tools (software) are checked.

Certification requirements

Repetition procedure: the number of units to be tested each year will be proportional to the number of his basic models listed in the Directory, in an amount equal to 17% for Fan Coil Units with a minimum of one test.

Certified characteristics & tolerances

- Sensible capacity* **: –8%
- Total cooling & heating capacity * **: –7%
- Water pressure drop* **: +20%
- Fan power input*: +10%
- A-weighted sound power **: +2 dB(A)
- Air flow rate: –10%
- Available static pressure 0 Pa for medium speed and –5 Pa for other speeds
- FCEER & FCCOP
- Eurovent energy efficiency class

(*) At standard and non-standard conditions
(**) Tolerances for capacities are increased by 2% for variable speed units.

ECC Reference documents

- Certification manual
- Operational Manual OM-1A
- Rating Standard RS 6/C/002
- Rating Standard RS 6/C/002A

Testing standards

- Performance testing: EN 1397:2015
- Acoustic testing: EN 16583:2015

Rooftops (RT)

CERTIFY ALL

The Eurovent rooftop certification (RT) program covers air-cooled packaged rooftop cooling only and reversible units below 100 kW (in cooling mode), with an option to certify air to air units from 100 kW to 200 kW and water-cooled packages rooftops.

The Rooftop program regroups 11 participants of which the five main European manufacturers.

Eurovent certifies indoor and outdoor sound levels, cooling and heating capacity and efficiency. Certified performances provide transparency and fair comparison between manufacturers. It is also the basis for the reliable study of HVAC system energy performance.

For two years the program has evolved towards tests at part load conditions in order to prepare the certification of seasonal efficiencies (SEER & η_{sc}, SCOP & η_{sh}) of which the publication on the Eurovent Certified Performance (ECP) website is expected for mid-2018.

It was a strong willing of manufacturers involved in the program to be completely in line with the new Eco design Regulation (N° 2016/2281) applicable from 1st of January 2018 for several HVAC products as the rooftop units.

The next challenges of the programme will be the taking into account of the free cooling for the cooling efficiency and the heat recovery mode for the 3 & 4 damper rooftops, but obviously, the software certification will be a key item to comply with existing and coming certification of building energy calculations in the EU countries.

Committee chair:
Mr Alain Compingt
Regulatory and External Relationship, LENNOX EMEA

Mr Arnaud Lacourt
Head of Thermodynamics Department, Eurovent Certita Certification

Scope of certification

- This Certification Program applies to air-cooled packaged rooftop cooling only and reversible units below 100 kW (in cooling mode).
- Air to air units from 100 kW to 200 kW and water-cooled packages rooftops can be certified as an option.

Certification requirements

- For the qualification and repetition procedures (yearly) between 1 & 3 units are selected and tested, depending on the number of products declared.

Certified characteristics & tolerances

- Capacity (Cooling or Heating): –5%
- EER or COP: –8%
- Seasonal Efficiency in cooling: SEER & η_{sc}
  Expected in mid 2018
- Seasonal Efficiency in heating: SCOP & η_{sh}
  Expected in mid 2018
- Condenser water pressure drop: +15%
- A-weighted Sound Power Level: +3 dBA
- Eurovent Energy Efficiency class (cooling and heating)
- Eurovent Energy Seasonal Efficiency class.
  Expected in 2019

ECC Reference documents

- Certification manual
- Operational Manual OM-13
- Rating Standard RS 6/C/007

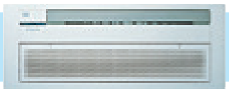
Testing standards

- EN 14511 for Performance Testing
- EN 14825 for Seasonal Efficiencies
- EN 12102 for Acoustical Testing

▼ Indoor Climate

Variable Refrigerant Flow (VRF)

CERTIFY ALL



Launched in 2013, the VRF programme started with a restricted scope: outdoor units up to 50 kW, testable combinations up to limited number of indoor units (2 cassettes or 4 ducted units). But it was a first step to increase the integrity of the products performances on the market.

From 2015, an annual factory audit has completed the requirements of the VRF programme.

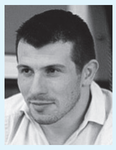
From 2018, an extended scope is proposed:

- Outdoor units up to 100 kW
- Combinations up to 8 indoor units (cassette or ducted) depending of the outdoor unit capacity
- Certified seasonal efficiencies (according to Ecodesign Regulation No 2016/2281, applicable from 2018)

The VRF program has prepared this change during 2017, testing the first units at the part load conditions and extreme ambient temperature (up to –10 kW) in order to be able to publish from Mid-2018:

- certified SEER and η_{sc} for the cooling mode
- certified SCOP and η_{sh} for the heating mode

Early 2018, the VRF program regroups henceforth 15 participants of which the world's leading manufacturers.



Mr Arnaud Lacourt
Head of Thermodynamics Department, Eurovent Certita Certification

Scope of certification

The certification programme for Variable Refrigerant Flow (VRF) applies to:

- Outdoor units used in Variable Refrigerant Flow systems with the following characteristics:
  - Air or water source, reversible, heating-only and cooling-only.

VRF systems with data declared and published as combinations are excluded from the scope.

Heat recovery units are included in the scope but the heat recovery function is not certified.

High ambient systems are included in the scope but tested under standard conditions as specified in RS 6/C/008.

Certification requirements

- Qualification: units selected by ECC shall be tested in an independent laboratory selected by ECC.
- Repetition procedure: units selected from regular production shall be tested on a yearly basis.
- A factory visit is organized every year in order to check the production

Certified characteristics & tolerances

- Outdoor Capacity (cooling and heating): –8%
- Outdoor Efficiency (EER, COP) at standard rating conditions and part loads: –10%
- Seasonal Efficiency (SEER/ηsc and SCOP/ ηsh): –0% (automatically rerated when Part Load efficiency criteria fails)
- A-weighted sound power level: 2 dB

ECC Reference documents

- Certification manual
- Operation manual OM-15
- Rating Standard RS 6/C/008

Testing standards

- EN 14511 • EN 14825 • EN 12102

Air Cleaners (ACL)

Scope of certification

The scope of this new certification programme includes devices for collecting and/or destroying indoor air pollutants for residential or tertiary sector applications, such as:

- Devices equipped with a fan that circulates an air flow of between 15 m³/h and 1,000 m³/h
- Independent electrically-powered devices.
- Residential (domestic) and tertiary sector applications: bedrooms, living rooms, offices, waiting rooms, retail stores, etc.
- All types of technology: mechanical filtration, electrostatic filtration, plasma, ionization, UV-A or UV-C lamp, etc.

Certified characteristics and tolerances

At maximum operating speed:

- Purification efficiency: purified air volume flow rate for each pollutant category treated such as
  - Breathable particles suspended in the air
  - Gaseous pollutants (formaldehyde, toluene, etc.)
  - Microorganisms (bacteria and mould)
  - Cat allergen
- Energy efficiency: (purified air volume flow rate / absorbed electrical power).
- Recommended room area for each pollutant category.

At 1, 2 or 3 operating speeds:

- Device air circulation flow rate.
- **Energy**: absorbed electrical power.
- **Noise impact**: sound power level.

When tested in the laboratory the obtained performance data shall not differ from the declared values by more than the following tolerance values:

- Air circulation flow rate [m³/h]: –5%
- Initial purified air flow rate [m³/h]: –5%
- Sound power level [dB(A)]: +2 dB(A)
- Absorbed electrical power [W]: Maximum [+5%; +1 W]

ECC Reference documents

- Certification manual
- Operation manual OM-20
- Rating Standard RS/4/C/002

Testing standards

- NF B44-200:2016
- NF-536
- XP-B44-013:2009 may notably be used as a supplement in some particular cases identified in the NF-536 reference document.

Air Filters Class M5-F9

CERTIFY ALL

Today, people spend most of the time inside of buildings. Hence, indoor air quality is a key factor to human health. Air filters removing fine dust from the air stream are the key component in building heating, ventilation and air conditioning systems to supply air of the required cleanliness and to ensure a high level of indoor air quality. With the air filter certification program, reliable and transparent filter data are ensured to customers. On a yearly base, four different filters are selected out of the product range of each participant for testing at independent laboratories according to EN 779:2012, verifying the initial pressure drop, the filter class and the initial and minimum efficiency, as well as the energy efficiency class to Eurovent document 4/11. Additionally, with the new energy efficiency label, Eurovent provides valuable data to enable users to select the most energy efficient air filters.

Committee chair: Dr. Thomas Caesar
Head of Filter Engineering Industrial Filtration Europe
Freudenberg Filtration Technologies SE & Co. KG

Scope of certification

- This Certification Programme applies to air filters elements rated and sold as "Medium or Fine Air Filters M5–F9" as defined in EN 779:2012 and with a front frame size of 592 x 592 mm according to standard EN 15805.
- When a company joins the programme, all relevant air filter elements shall be certified.

Certification requirements

- For the qualification procedures: 6 units will be selected and tested by an independent Laboratory selected by Eurovent Certification.
  Then each year 4 units will be selected & tested

Certified characteristics & tolerances

- Filter class: no tolerance.
- Initial pressure drop: +10% + 5 Pa (minimum 15 Pa)
- Initial efficiency for F7 to F9: 10% – point
- Discharge efficiency for F7 to F9: 10% – point
- Annual energy consumption +10% +60 kWh/a

ECC Reference documents

- Certification manual
- Operational Manual OM-11
- Rating Standard RS 4/C/001

Testing standards

- EN 779:2012
- Eurovent 4/21

Air Handling Units

CERTIFY ALL

Swegon has participated in the program for Air Handling Units from the start. The first priority at that time, and still is, was to find a way for fair competition. This is a long-term struggle were we try to cover all aspects from manufacturing to software performance predictions and its agreement with tests. We discuss and take decisions about mandatory performance in software printout, rules for the energy labelling, how to test and what to apply in the, on site, auditor check. Customers should go for Eurovent certified products, to get reliable data, and then they can cut the main cost and take care of the environment by minimising the use of energy.

Committee chair:
Mr Gunnar Berg
Development Engineer, Swegon

Scope of certification

This Certification Programme applies to ranges of Air Handling Units that can be selected in a software. Each declared range shall at least present one size with a rated air volume flow below 3 m²/s. For each declared range, all Real Unit Sizes available in the software and up to the maximum stated air flow and all Model Box configurations shall be declared.

Participants shall certify all models in the selected product range up to the maximum stated air flow.

A range to be certified shall include at least one size with a rated air volume flow up to 3 m³/s.

Certification requirements

For the qualification procedure: the selection software will be verified by our internal auditor. A visit on production site will be organized. During that visit, the auditor will select one real unit per range, as well as several model boxes that will cover all mechanical variations.

The selected units will be tested and performances delivered by the selection software will be compared to the performances measured in an independent laboratory.

For the repetition procedures, the auditor will annually check the software conformity against the production data, and tests will be repeated every 3 to 6 years.

Certified characteristics & tolerances

- External Pressure: 4% or 15 Pa
- Absorbed motor power: 3%
- Heat recovery efficiency: 3%-points
- Heat recovery pressure drop (air side): max. of 10% or 15 Pa
- Water coil performances (heating/cooling): 2%
- Water coil pressure drop (water side): max. of 10% or 2 kPa
- Radiated sound power level casing: 3 dB(A)
- Sound power level unit openings:
  - 5 dB @ 125 Hz
  - 3 dB @ 250 – 8 000 Hz
- Casing Air Leakage: same class or higher

ECC Reference documents

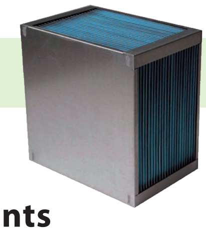
- Certification manual
- Operational Manual OM-5
- Rating Standard RS 6/C/005

Testing standards

- EN 1886: "Ventilation for buildings – Air handling units – Mechanical performance"
- EN 13053: "Ventilation for buildings – Air handling units – Rating & performance for units components and sections"
- RS/6/C/011-2016 Hygienic AHU

Air to Air Plate Heat Exchangers

CERTIFY ALL



Scope of certification

This Certification programme applies to selected ranges of Air to Air Plate Heat Exchangers. Participants shall certify all models in the selected range, including:

- cross flow, counter-flow and parallel flow units
- all sizes
- all materials
- all airflow rates
- all edge lengths
- plate heat exchanger with humidity transfer

Heat Exchangers with accessories such as bypass and dampers shall not be included.

Manufacturers shall declare production places and provenance of products is randomly chosen. The programme does not cover other types of Air to Air Heat Exchangers like Rotary Heat Exchangers or Heat Pipes. Combination of units (twin exchangers) are also included in the scope of the program.

Certification requirements

For each range to be certified, 3 units for qualification and 1 for yearly repetition will be selected by Eurovent Certita Certification and tested in an independent Laboratory.

Certified characteristics & tolerances

- Dimensions: ± 2 mm
- Plate spacing: ± 1% or ± 1 plate
- Temperature efficiency Dry: –3 percentage points
- Temperature efficiency Wet: –5 percentage points
- Humidity efficiency: -5%
- Pressure drop: +10%, minimum 15 Pa

ECC Reference documents

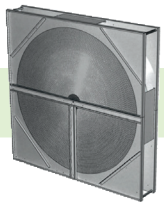
- Certification manual
- Operational Manual OM-8
- Rating Standard RS 8/C/001

Testing standards

- EN 308

Air to Air Regenerative Heat Exchangers

CERTIFY ALL



Scope of certification

This Certification Programme applies to all ranges of Air to Air Regenerative Heat Exchangers (RHE) including sealing systems. Units sold without casing and sealing systems are also included. Participants shall certify all models in the ranges, including:

- all classes: condensation (non-hygroscopic, non-enthalpy) RHE, hygroscopic enthalpy RHE, hygroscopic sorption RHE
- all RHE geometry (wave height, foil thickness)
- all sizes (rotor diameters and rotor depths and surface areas of Alternating Storage Matrices - ASM)
- all materials
- all airflow rates
- all different types of sealing (if available)

Certification requirements

For the qualification procedures 1 unit per class of rotor will be selected and tested by an independent laboratory. For yearly repetition, 1 unit will be selected.

Certified characteristics & tolerances

- Temperature Efficiency: –3% points
- Humidity Efficiency: –5% points (min. tolerance 0.2 g/kg in absolute humidity of leaving supply air)
- Pressure Drop: +10% (min 10 Pa)
- Outdoor Air Correction Factor (OACF): 0.05
- Exhaust Air Transfer Ratio (EATR): +1% point

ECC Reference documents

- Certification manual
- Operational Manual OM-10
- Rating Standard RS 8/C/002

Testing standards

- EN 308
- ARI 1060

▼ Ventilation & Air Quality

Hygienic Air Handling Units (HAHU)

Scope of certification

This programme applies to hygienic ranges of Air Handling Units. As an option of the Certification programme for Air Handling Units, only an already ECP certified range is eligible for the hygienic option.

The hygienic aspect of the AHU is certified based on a 3 levels classification, each level declaring an AHU suitable for different application:

- Level 1: Offices, commercial buildings, schools, hotels
- Level 2: Hospitals
- Level 3: Pharmaceutical, food processes, white rooms

The previous list is not exhaustive and must be used as a reference only. Final customer/user who has complete and detailed knowledge of the building application shall decide which Hygienic rating level is appropriate.

Certification requirements

Same as in the Air Handling Unit programme.

Certification characteristics & tolerances

Services characteristics:
The following services characteristics are certified.

1. Manufacturing
2. Maintenance
3. Quality Management System
4. IOM (Installation and Operational Manual)
5. Shipment

Hygienic characteristics:
The following hygienic characteristics are certified:

1. Materials
2. Casing performance
3. Components arrangement and performances (filters, coils, heat recovery systems, fans, humidifiers, dehumidifiers and silencers)

ECC reference documents

Certification manual

- OM-5-2016-rev1
- RS/6/C/011-2016 Hygienic AHU

Testing standards

- RS 6/C/005-2016
- EN ISO 846:1997
- EN ISO 2896:2001
- EN 10088-3:2014
- EN 1993-1-2:2005
- DIN 1946/4-6.5.1:2008
- EN 779:2012
- EN 1822:2010
- EN ISO 12944-2:1998

Residential Air Filters (RFIL)

Scope of certification

The programme scope covers the particulate and combination (particulate and gas) filters used in a residential ventilation unit and for which the following applies:

- the rated maximum air flow rate is comprised between 70 and 1000 m³/h included;
- the initial efficiency ePM10 is higher than or equal to 50%;
- the initial efficiency ePM1 is strictly lower than 99%;
- the ratio between effluent and influent concentrations measured at time zero is strictly lower than 20% (for combination filters only, see Rating Standard RS/4/C/003 for further details).

The programme scope covers filters for which the face area is lower than or equal to 300 mm x 600 mm. For the RFIL programme, the certify-all requirement as defined in the Certification Manual is applicable from January 1st of 2020 (see Operational Manual OM-21 for further details).

Certified characteristics and tolerances

When tested in the laboratory the obtained performance data shall not differ from the declared values by more than the following tolerance values:

- Initial pressure drop values: +10%+Mt or +10 Pa +Mt
- Initial efficiency values: −5 percentage points (absolute deviation)
- Minimum efficiency values: −5 percentage points (absolute deviation)
- Filter ISO ePMx class reporting value: −5 percentage points (absolute deviation)
- Adsorption capacity: −10%

ECC Reference documents

- Certification manual
- Operation manual OM-21
- Rating standard RS/4/C/003-2017

Testing standards

- Eurovent 4/22:2015 (particulate filters and combination filters)
- SO 11155-2:2009 (combination filters only)

Ventilation Ducts (DUCT)

Scope of certification

The programme scope covers rigid and semi-rigid ventilation ductwork systems divided into the following sub-programmes:

- Rigid metallic ductwork systems with circular cross-section (DUCT-MC);
- Rigid metallic ductwork systems with rectangular cross-section (DUCT-MR);
- Semi-rigid non-metallic ductwork systems predominantly made of plastics (DUCT-P)

Each sub-programme applies to ductwork systems fitted with integrated sealing solution as described in relevant Rating Standard.

Certification requirements

The certification programme is based on product performance testing by independent testing laboratories as well as production sites auditing.

Certification characteristics & tolerances

The product performance testing will enable the verification of the following ratings accuracy:

- Air tightness class (all sub-programmes)
- Positive and negative pressure limits (all sub-programmes)
- Dimensions (DUCT-MC and DUCT-MR)
- Minimum and maximum service temperatures (DUCT-P)
- Resistance to external pressure (DUCT-P)

ECC reference documents

- OM-19-2016
- RS/2/C/002MC-2016
- RS/2/C/003MR-2016
- RS/2/C/004P-2016

Testing standards

- Air leakage and strength testing:
  – EN 12237:2003 (DUCT-MC and DUCT-P)
  – EN 1507:2006 (DUCT-MR)
- Service temperature and resistance to external pressure (DUCT-P):
  – RS 2/C/004P-2016

Residential Air Handling Units (RAHU)

CERTIFY ALL

The objective of the Eurovent RAHU certification programme is, through tests performed by a third-party, to verify the performance of a unit bought somewhere on the open European market. It is important for the RAHU certification to use a unit out of the serial production – no special samples. For us, as a manufacturer, it pays to develop good products that deliver what we promise. By utilizing certified products, the designers' task is easier as they do not need to make detailed comparisons or perform advanced tests. Consultants, engineers and users can select a product and be assured that the catalog data is accurate.

Certification is important for a designer/consultant/end user:

- No unnecessary risks – they can only use products that deliver what they promise "Eurovent certified".
- Well-functioning systems – the product delivers the promised capacity and performance
- Safer calculations on energy consumption is expected

Mr. Tobias Sagström
Global Product Manager Residential at Systemair AB

Scope of certification

This programme applies to balanced residential AHUs (supply and exhaust) with heat recovery sys-tems such as:

- Air-to-air **plate** heat exchangers
- Air-to-air **rotary** heat exchangers
- **Heat-pumps** with a nominal airflow below 1 000 m³/h.

Certification requirement

- Qualification test campaign: 1 test per heat recovery type.
- Repetition test campaign: 1 test every 2 years for each heat recovery type.
- Units are sampled directly from selling points.

Certified performances

- Leakage class
- Aeraulic performances:
- Airflow/pressure curves
- Maximum airflow [m^3/h]
- Electrical consumption [W]
- Specific Power Input SPI [$W/(m^3/h)$]
- Temperature efficiency / COP
- Performances at cold climate conditions
- SEC (Specific Energy Consumption) in [$kWh/(m^2.an)$]
- A-weighted global sound power levels [dB(A)]

Tolerances

- Leakage class 0
- Airflow –10%
- Temperature efficiency –3%-point
- Temperature efficiency at cold climate –6%-point
- COP / EER –8%
- A-weighted global sound power levels +2dB(A)
- Electrical consumption +7%
- Specific Power Input SPI +7%
- Disbalance ratio 0

ECC Reference documents

- Certification manual
- Operation manual OM-16
- Rating standard RS 15/C/001

Testing standards

- European standard EN 13141-7:2010

▼ Process Cooling & Food Cold Chain

Cooling & Heating Coils

Heating Cooling Coils (HCCs) which enable the conditioning of different zones and flexibility in application in buildings are generally employed in compact and central station AHU. To meet the required extra capacity in various processes, they are also used as heating or cooling devices.

With the application of these coils to high energy efficient heat recovery systems, the entire system becomes more compact as well as it avoids occupation of large spaces. Besides, they can be applied to Variable Air Volume (VAV) systems used for conditioning of hospitals, shopping centers and convention facilities.

The Certification programme for the HCCs has increased integrity and accuracy of the industrial performance ratings which provides clear benefits for end users who can be confident that the product will operate in accordance with design specifications. Also, by means of this certification programme users can collect reference data on the fundamental characteristics of the HCCs, such as capacity, pressure drop, mass flow complying with the standard of EN 1216.

Engin Söylemez, R&D
Test Engineer, Friterm A.Ş

Scope of certification

The rating standard applies to coils operating:

– with water or with a 0–50% ethylene-glycol mixture, acting as cooling or heating fluid.

– and without fans.

Certification requirements

- Qualification and repetition procedures: units declared will be selected and tested by an independent laboratory.
- The number of units will depend on the variety of coil material configurations and their applications for the applied range.
- The selection software will be verified in comparison with the test results.
- On-site audits (checking of software)

Certified characteristics & tolerances

- Capacity: –7%
- Air side pressure drop: +20%
- Liquid side pressure drop: +20%

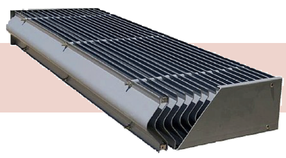
ECC Reference documents

- OM-9-2016
- RS 7/C/005

Testing standards

- EN 1216:1998+A1/2002

Drift Eliminators



Scope of certification

The Certification Programme for Drift Eliminators applies to Drift Eliminators used for evaporative water-cooling equipment.

Certified characteristics & tolerances

The following characteristics shall be certified by tests:

- For counter-flow and cross-flow film fill, the average drift losses of the two tests at 3.5 m/s are less than 0.007% of circulating water flow rate.
- For cross-flow splash fill, the average drift losses of the two tests at 3 m/s are less than 0.007% of circulating water flow rate.

No tolerance will be applied on the average drift losses.

ECC Reference documents

- Certification manual
- Operational Manual OM-14-2014
- Rating Standard RS 9/C/003

Testing standards

- CTI ATC-140

ACREX2018.indd 84 29.1.2018 22:25:53

Cooling Towers

The importance of air conditioning and industrial cooling is constantly increasing in modern architecture and industrial process cooling. The human perception of comfort and the new challenges to reduce the electrical power consumption and CO_2 foot-print have designers striving for optimal system performances with the highest possible efficiencies. Reliable thermal performances are crucial to ensure these best efficiencies which are typical for cooling circuits driven by evaporative cooling equipment. On a yearly basis, one random picked cooling tower of each Eurovent-CTI certified product line will be full scale thermal tested by applying the CTI standard 201.

Eurovent Certita Certification guarantees the consistency of thermal testing and manufacturing of European and non-European companies that subscribe to the program.

Committee chair:
Mr Rob Vandenboer
Product Manager, Quality Manager
Evapco Europe, BVBA

The first ECC / CTI collaborative certification program for Cooling Towers

The Eurovent Certification Company (ECC, Brussels, Belgium) is pleased to announce the Certification programme for cooling tower thermal performance developed in cooperation with the Cooling Technology Institute Est.1950 (CTI, Houston, Texas, USA). The scope of the program includes standardized model lines for open circuit cooling towers, typically factory assembled. Standardized model lines are composed of individual models that are required to have published thermal rating capacities at corresponding input fan power levels.

Thermal performance certification via this program offers a tower buyer assurance that the capacity published for the product has been confirmed by the initial and on-going performance testing per the requirements of the program using CTI STD-201. It also offers for regulators of energy consumption related to cooling towers, that the capacity of the towers has been validated. Mini-mum energy efficiency standards such as the Eurovent Industry Recommendation / Code of Good Practice Eurovent 9/12-2016 and ASHRAE 90.1, which requires cooling tower energy

efficiency validation by the CTI certification process, are used by governments and by green building certification programs such as LEED™.

Scope of certification

This Certification Programme for Cooling Towers applies to product ranges (or product lines) of Open-Circuit series and Closed Circuit Cooling Towers that:

- Are manufactured by a company whose headquarter or main facility are located in Europe, Middle-East, Africa or India. After getting the Eurovent Certification, the CTI certificate could be requested.
- Have already achieved and hold current certification by the Cooling Technology Institute (CTI) according to CTI STD-201.

Certification requirements

For the qualification & yearly repetition procedures our internal auditor visits the production place and reviews the conformity of Data of Records. One unit per range is selected and tested by an independent test agency.

Certified characteristics & tolerances

- Certified characteristic shall be per CTI STD-201
- Entering wet bulb temperature: 10°C to 32.2°C (50°F to 90°F)
- Cooling range > 2.2°C (4°F)
- Cooling approach > 2.8°C (5°F)
- Process fluid temperature < 51.7°C (125°F)
- Barometric pressure: –91.4 to 105.0 kPa (27” to 31” Hg)

ECC Reference documents

- Certification manual
- Operational Manual OM-4-2017
- Rating Standard RS 9/C/001-2014

Testing standards

- CTI STD-201 RS
- ECC OM-4-2017

▼ Process Cooling & Food Cold Chain

Heat Exchangers

CERTIFY ALL

The purpose of the Eurovent "Certify-All" certification programme for heat exchangers is to encourage honest competition and to assure customers that equipment is correctly rated.

The programme covers 3 product groups:

- Unit Air Coolers
- Air Cooled Condensers
- Dry Coolers

The "Certify-All" principle ensures that, for heat exchangers, all models in the three product categories are submitted for certification, not just some models chosen by the manufacturer.

A product energy class scheme has been incorporated into the certification program, based on 6 classes from "A+" to "E" in order to provide a guide to the best choice of product: this enables the user to minimize life-cycle costs, including running costs which account for a much superior sum than the initial investment cost.

EVOLUTIONS OF THE PROGRAMME:

Extension of the scope of certification programme for Heat Exchangers

- to CO_2 applications. Implementation expected in 2018
- to NH_3 applications

Committee chair:
Stefano Filippini
Technicalmanager - LUVE

Air coolers for refrigeration

Dry coolers

Air cooled condensers

Scope of certification

The Eurovent Certification Programme for Heat Exchangers applies to products using axial flow fans. The following products are excluded from the Eurovent Certification Programme for Heat Exchangers:

- Products units using centrifugal type fans.
- Units working at 60 Hz

In particular, the following products are also excluded from the certification programme for Dx Air Coolers and Air Cooled Condensers:

- Product ranges of Dx Air Coolers with maximum standard capacity SC2 below 1.5 kW
- Product ranges of Air Cooled Condensers with maximum standard capacity under TD1 15 K is below 2.0 kW

Certification requirements

- Qualification: units selected by Eurovent Certita Certification shall be tested in an Independent Laboratory selected by ECC
- Repetition procedure: units selected from regular production shall be tested on a yearly basis.

Certified characteristics & tolerances

- Standard capacity –8%
- Fan power input +10% with a minimum of 3 W
- Air volume flow ±10%
- Dimensions and number of fins: Finned length ±0,5%, with a minimum of 5 mm
  - Height of the coil ±5 mm
  - Depth (width) of the coil ±5 mm
  - Total number of fins* ±4%, at least 2 fins
  - Diameter of (expanded) tube outside the coil* ±1 mm

  (*) except for the micro-channels
- Energy ratio R
- Energy class

For Dry Coolers:

- Liquid side pressure drop +20%

For Air Cooled Condensers and Dry Coolers:

- A-weighted sound power level: +2 dB(A)

ECC Reference documents

- Certification manual
- Operational Manual OM-2
- Rating Standard RS 7/C/008

Testing standards

- Thermal Performance EN 328
- Thermal Performance EN 327
- Thermal Performance EN1048
- Acoustics EN 13487

Heat Recovery Systems with Intermediate Heat Transfer Medium (HRS-COIL)

Scope of certification

This certification programme covers the heat recovery exchangers with intermediate heat transfer medium corresponding to the category IIa ("without phase change") of the EN 308:1997 standard, that is Run Around Coils systems.

Certification requirement

Qualification procedure

- Product performance testing:
  - 1 coil per BMG to be selected
  - Selected coils paired into systems (1 "exhaust" coil + 1 "supply" coil)
- Operating software checking
- Audit of the manufacturing facilities

Repetition procedure:

- Product performance testing: 1 system to be selected (1 "exhaust" coil + 1 "supply" coil)
- Operating software checking
- Audit of the manufacturing facilities

Certification characteristics & tolerances

- Dry heat recovery efficiency [%]
- Air side pressure drop at standard conditions for each coil [Pa]
- Fluid side pressure drop for each coil [kPa]

When tested in the laboratory the obtained performance data shall not differ from the recalculated values ("test-check") by more than the following tolerance values:

- Dry heat recovery efficiency: –3 percentage points (abs. deviation)
- Air side pressure drop: Maximum [+10%; +15 Pa]
- Fluid side pressure drop: Maximum [+10%; +2 kPa]

ECC reference documents

- Certification manual
- OM-18-2016
- RS 7/C/009 – 2016

Testing standards

- EN 308:1997

Liquid Chilling Package & Heat Pumps (LCP-HP)

CERTIFY ALL

The historical ESEER, first seasonal efficiency for cooling, created in 2007 by Eurovent Certita Certification, and deeply recognized on the European Market is living its last moments.

With the implementation of the new Ecodesign Regulation No 2016/2281, the year 2018 will be a crucial year for the chillers industry. The European Market has to change its reference efficiency and turn towards SEER and ηsc, the new seasonal efficiencies for cooling mode.

The LCP-HP program has prepared this change since 2 years, testing yearly a significant number of units at the new part load conditions in order to be able to publish from January 2018, certified SEER and ηsc. The SEER has to become the new reference also for the certification program.

Moreover, the scope of the program has been extended for 2018:

- Previously limited to 1500 kW, the water-cooled chillers above 1500 kW can be henceforth certified in option, up to the maximum capacity of the manufacturer laboratory.
- The 4 pipe units can be certified also in option.

Although the program was originally attended for comfort chillers, it is important to remind that process chillers and their SEPR can also be certified as an option.

Lastly, face to these recently regulatory changes for the industry, the certification will be always a strong way to guaranty the reliability of our declared performances to our clients.

Committee chair:
Mr Rafael Berzosas
Water Cooled Chillers Product Manager
Trane Europe, Middle East & Africa

According to the last Ecodesign Regulations (No 811/2013 - No 813/2013 – No 2016/2281) the programme proposes the certification of Seasonal efficiency for heating (ηs & SCOP) for Chillers & Heat pumps with a design capacity below 70kW, Seasonal efficiency for cooling (ηsc & SEER) for all comfort chillers and the seasonal energy performance ratio (SEPR) for process chillers.

Scope of certification

- This programme applies to standard chillers and hydronic heat pumps used for heating, air conditioning and refrigeration.
- They may operate with any type of compressor (hermetic, semi-hermetic and open) but only electrically driven chillers are included.
- Only refrigerants authorized in EU are considered. Chillers may be air cooled, liquid cooled or evaporative cooled.

Can be certified as an option:

- Heating-only hydronic heat pumps, 60 Hz units, 4-pipe units, Air-cooled units between 600 kW and 1500kW,
  Water-cooled units above 1500 kW.

Certification requirements

Qualification and repetition: a certain number of units will be selected by Eurovent Certita Certification and tested every year, based on the number of ranges and products declared.

Certified characteristics & tolerances

- Cooling & heating capacity, EER & COP at standard rating conditions, TER : < –5%
- Seasonal efficiencies SCOP & η_s: automatically rerated when Part Load efficiency criteria fails
- Seasonal efficiencies SEER & η_{sc}: automatically rerated when Part Load efficiency criteria fails
- Seasonal efficiency SEPR: automatically rerated when Part Load efficiency criteria fails
- A-weighted sound power level: > +3 dB(A) (> +2 dB(A) for units with *Pdesignh* below 70 kW)
- Water pressure drop: +15%

Testing standards

- Performance testing: EN 14511
- Seasonal Performance testing: EN 14825
- Sound testing: EN 12102

ECC Reference documents

- Certification manual
- Operational Manual OM-3
- Rating Standard RS 6/C003 – RS 6/C/003A

Remote Refrigerated Display Cabinets

CERTIFY ALL

Remote refrigerated display cabinets (RRDC) are the appliances for selling and displaying chilled and/or frozen foodstuff to be maintained within prescribed temperature limits.

Typically, food and beverage retailers are the direct customers of the refrigeration industry while the supermarket's customers are the end users of food and beverage retailers.

Food and beverage retailers ask for food safety and also for appliances with high-energy efficiency, supermarket's customers ask for food safety. Refrigeration industry has to face the hard challenge of satisfying both needs.

How is it possible to assure that the refrigeration appliances perform accurately and consistently to the reference standards? How is it possible to assure that what is rated by the manufacturer is properly rated?

There is only one way: It is necessary to join a globally recognized and industry respected certification program.

Eurovent Certita Certification program for RRDC is the only certification program in Europe that can assure that performance claims have been independently measured and verified. The factory audits and the product's performances tested in an independent and third-party laboratory make the difference!

Since 2011, Eurovent Certita Certification has also launched a voluntary energy label certification scheme, anticipating what only nowadays EC DG Energy is doing in the framework of Ecodesign and Energy Label Regulations. What better way to rate RRDC's energy consumption and to promote their energy efficiency?

What would you trust more: a self-declaration by the Manufacturer or what an independent, globally recognized and forerunner certification program is able to assure? Which one is better?

Maurizio Dell'Eva
Project manager
EPTA S.p.A. – MILANO (ITALY)

Scope of certification

- 100 basic model groups divided in 5 categories of remote units: semi-verticals and verticals (with doors); multi-deckers; islands; service counters; combi freezers.
- At least two references per basic model group representing 80% of sales shall be declared.
- One Bill of Material for each declared reference.

Certification requirements

- Qualification: sampling and test of one unit & Audit of one factory.
- Repetition test of one unit per brand every 6 months & Annual audit of each factory.

Certified characteristics & tolerances

- Warmest and coldest product temp. ±0.5°C
- Refrigeration duty (kW) 10%
- Evaporating temperature –1°C
- Direct elec. Energy Consumption (DEC) +5%
- Refrigeration elec. Energy Cons (REC) +10%
- M-Package T_{class}: ±0.5°C
- Total Display Area (TDA) –3%

ECC Reference documents

- Certification manual
- Operational Manual OM-7
- Rating Standard RS 14/C/001

Testing standards

- EN ISO 29953 and amendments

Product news

Condensing Units

– Call for Launching Committee

Eurovent Certita Certification launches a new certification programme for Condensing Units designed for commercial and industrial refrigeration applications.

This programme is intended to cover Condensing Units designed for **commercial and industrial refrigeration applications** as defined in regulation 2015/1095: "product integrating at least one electrically driven **compressor** and one **condenser**, capable of cooling down and continuously maintaining low or medium temperature inside a refrigerated appliance or system, using a vapour compression cycle once connected to an evaporator and an expansion device".

Every company manufacturing Condensing Units is eligible to be part of the Launching Committee.

The mission of the Launching Committee is to:

- Establish the specific requirements and rules that will allow the evaluation of the products.
- Prepare all relevant reference documents and guidance on the choice of laboratory/test agency/audit agency when applicable.

Interested or want to know more?
Please contact Mrs Marie-Clémence BRIFFAUD mc.briffaud@eurovent-certification.com.

PRODBIM

to deploy BIM product database for the HVACR sector at the beginning of 2019

THE MULTINATIONAL INITIATIVE IS DRIVEN BY EUROVENT SERVICES COMPANY AND REALISED IN CLOSE COOPERATION WITH KNOWLEDGE PARTNERS SUCH AS REHVA AND CSTB

In the context of the construction sector's ongoing digital transformation, the HVACR industry finds itself increasingly impacted by BIM (Building Information Modelling). Manufacturers are being challenged to comply with new BIM standards and working methods. The objective of ProDBim is to support manufacturers in making effective use of the constantly evolving BIM market. A product database is going to be launched at the beginning of 2019.

PRODBIM is an initiative driven by Eurovent Service Company – a wholly-owned, independent subunit of the Eurovent Association in Brussels. The project is realised in cooperation with knowledge partners such as REHVA (Belgium), TIPEE (France), ISC Gmbh (Germany) and CSTB (France).

Although many formats of BIM services coexist today, there is observably a strong need for a harmonised, HVACR-focused European product database. A critical objective to keep manufacturers competitive.

PRODBIM's services are going to cover the entire European market. They will be adapted to different building codes and practices. A compliance with the ISO 16 739 IFC standard and local regulations is being ensured.

Launching Committee

PRODBIM is inviting interested HVACR manufacturers to participate in their Launching Committees "BIM HVAC Product Database for Manufacturers", which are commencing in February 2018. A first target is going to be the validation of product group and templates.

For detailed information, please contact:
Thibaud de Loynes, Project Director - ProDBim, t.deloynes@prod-bim.com

Send information of your event to Ms Chiara Girardi cg@rehva.eu

Events in 2018

Exhibitions 2018

Feb 27 – Mar 2	AQUA THERM Prague	Prague, Czech Republic	http://www.aquatherm-praha.com/en/
Mar 13–16	MCE – Mostra Convegno Expocomfort 2018	Milan, Italy	www.mcexpocomfort.it
Mar 18–23	Light + Building 2018	Frankfurt, Germany	https://light-building.messefrankfurt.com/frankfurt/en.html
May 22–24	ISH China & CIHE 2018	Beijing, China	http://ishc-cihe.hk.messefrankfurt.com/beijing/en/visitors/welcome.html
Jul 17–19	ASEAN M&E	Kuala Lumpur, Malaysia	http://aseanmne.com/
Sep 3–5	ISH Shangai & CIHE 2018	Shangai, China	http://ishs-cihe.hk.messefrankfurt.com/shanghai/en/visitors/welcome.html
Oct 10–12	FinnBuild 2018	Helsinki, Finland	http://finnbuild.messukeskus.com/?lang=en
Oct 16–18	Chillventa	Nuremberg, Germany	https://www.chillventa.de/en

Conferences and seminars 2018

Feb 28 – Mar 2	WSED	Wels, Austria	http://www.wsed.at/en/world-sustainable-energy-days.html
Mar 12–15	Cold Climate HVAC Conference 2018	Kiruna, Sweden	http://www.cchvac2018.se
Mar 20	REHVA Seminar "Smart building & digitalisation in the new EPBD. Policies and implementation in practice"	Frankfurt, Germany	http://bit.ly/2rKa1Zk
Apr 12–14	13th International HVAC&R Technology Symposium	Istanbul, Turkey	http://bit.ly/2BvXgB6
Apr 21–23	REHVA Annual Meeting	Brussels, Belgium	http://roomventilation2018.org/
Jun 3–6	ROOMVENT & VENTILATION 2018	Espoo, Finland	http://www.roomventilation2018.org/
Sep 11–12	Building Simulation and Optimization 2018	Cambridge, UK	https://www.bso2018.event.cam.ac.uk/
Sep 18–19	39th AIVC Conference: "Smart ventilation for buildings"	Juan-les-Pins, France	http://aivc2018conference.org/