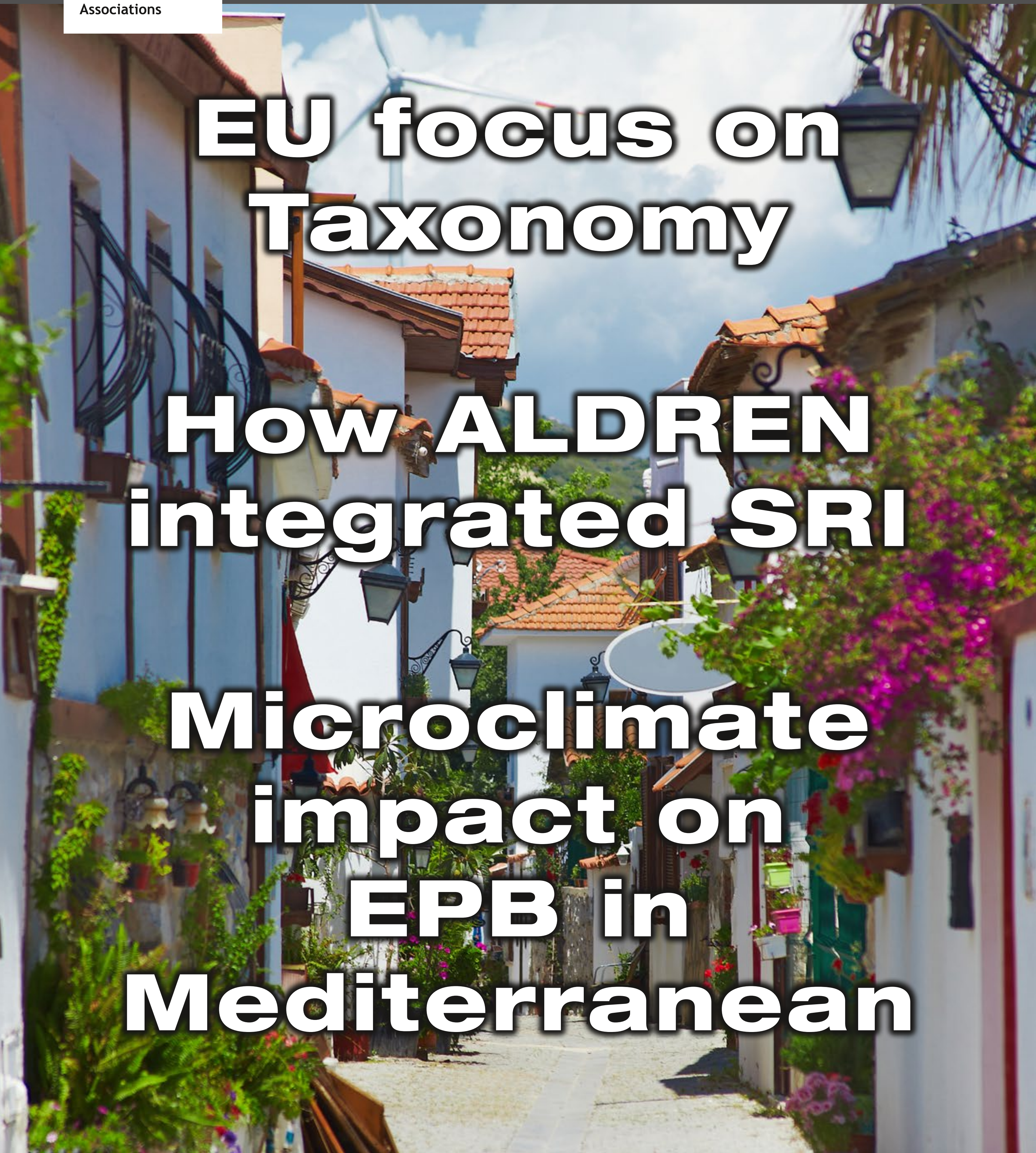
ISSN 1307-3729

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

The REHVA European HVAC Journal

Volume: 58 Issue: 1 February 2021 www.rehva.eu



EU focus on Taxonomy

How ALDREN integrated SRI

Microclimate impact on EPB in Mediterranean

Cold Climate HVAC & Energy 2021 goes online

Tallinn Estonia **20-21 April 2021**

The full virtual congress with keynote speakers, presenters, workshops and sponsors will be available online on virtual platform as a two-day conference on April 20-21, 2021.

Check the new reduced registration fees on the webpage! www.hvac2021.org

HVAC 2021 scope

International SCANVAC HVAC conference has extended the scope to cover energy performance and management of buildings. All four conference themes received good number of papers:

- Modern ventilation and air conditioning technology, including COVID-19 studies
- Energy efficient heating and cooling systems
- Building automation and monitoring systems
- Nearly zero energy and carbon buildings

Announcement of keynote speakers

Atze Boerstra
REHVA, bba binnenmilieu, The Netherlands:
Ventilation solutions to reduce the spread of COVID-19

Bjarne Olesen
DTU, Denmark:
Whole year evaluation of thermal comfort using international standards

Ala Hasan
VTT, Finland:
Multiple-source energy flexibility in buildings

Contact us

HVAC2021 TALLINN, @Tallinn University of Technology | hvac2021@taltech.ee | www.hvac2021.org

TAL TECH EKVÜ SCANVAC REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

The REHVA European HVAC Journal

www.rehva.eu

Volume: 58 Issue: 1 February 2021

Editor-in-Chief: Jaap Hogeling
jh@rehva.eu

Associate Editor: Stefano Corgnati, Italy
stefano.corgnati@polito.it

Editorial Assistant: Nicoll Marucciová,
nm@rehva.eu

General Executive: Ismail Ceyhan, Turkey

ADVERTISEMENTS
Nicoll Marucciová, nm@rehva.eu

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

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

Cover photo: Door AdaCo / Shutterstock.com

Contents

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

Advertisers

Next issue of REHVA Journal

Instructions for authors are available at **www.rehva.eu** (> Publications & Resources > Journal Information). Send the manuscripts of articles for the journal to Jaap Hogeling **jh@rehva.eu**.

Global solutions

COVID-19 epidemic and the way the global community addressed this threat is an example or rehearsal on handling global threats. We don't yet know the final ending and the impact on our society. Most of us expect that the future will not be the same: less travel and face to face meetings and more virtual and mixed meetings, conferences and workshops. As HVAC professionals we have to pay more attention to well performing ventilation systems which will help to reduce health risk when new infectious viruses emerge. The programmed REHVA course Safe building operation during COVID-19 (rehva.eu) [1] will support professionals to address this epidemic now and in the years to come.

Many of us are hoping that this global crisis, which is not yet over, teaches us to address the climate crisis we are facing. We as HVAC&R professionals have an important key in hands. When doing our projects our designs and performance choices we are mostly driven by economics and building regulation. It is our responsibility to advice and inform our clients that more sustainable and low carbon solutions are possible. Going beyond the boundaries of short-term cost effectiveness and just following the building requirements is not enough to save our planet for our children and grand-children.

REHVA's mission is to develop and disseminate economical, energy efficient, safe and healthy technology for mechanical services of building; to serve its members and the field of building engineering (HVAC&R) by facilitating knowledge exchange, supporting the development of related EU policies and their national level implementation. I want to add to this: to serve humanity and preserve our planet for future generations.

Listening to the speech of **Sir David Attenborough**, I want to quote the following:

"If we continue on our current path, we will face the collapse of everything that gives us our security: food production, access to fresh water, habitable ambient temperature, and ocean food chains," he said, adding "and if the natural world can no longer support the most basic of our needs, then much of the rest of civilization will quickly break down." While there is no going back, Sir David stressed that if countries act fast enough, "we can reach a new stable state." He pointed to the immense public support worldwide for climate action. "People today all over the world now realize this is no longer an issue which will affect future generations," he said. "It is people alive today, and, in particular, young people, who will live with the consequences of our actions."

This address was primarily meant to be heard by our politicians and world leaders, but we should not underestimate our own role as professional in our daily job and also as associations at national and European level.

I advise to listen to his compassioned speech: Sir David Attenborough on Climate and Security – UN Security Council Open VTC, 23 February 2021. [2] ■

JAAP HOGELING
Editor-in-Chief
REHVA Journal

[1] https://www.rehva.eu/pre-registration-safe-building-operation-during-covid-19

[2] https://news.un.org/en/story/2021/02/1085452

Green or not green

– Feedback on the EU classification system for green investment

Proposals to improve the delegated EU regulation 2020/825

JOHANN ZIRNGIBL
Ingenieurunion – Germany
johannzirngibl@aol.com

JANA BENDŽALOVÁ
ENBEE s.r.o. – Slovakia
bendzalova@enbee.eu

About the authors:

Johann Zirngibl is an independent expert, a senior scientist who spent the major part of his professional career as the head of division for energy efficiency of buildings in a public French technical and scientific centre. He works as an expert for the European Commission and also international banks. He managed research project at national and European level and for the International Energy agency. He is also a convenor of CEN and ISO technical committees.

Jana Bendzalova, CEO of ENBEE s.r.o., has worked many years on implementation of EPBD on a national and international level. She is also an accredited real estate valuer and involved in economic evaluation procedure of energy systems in buildings in the European standardisation. ENBEE s.r.o participate in several international and European projects and provide contribution to EU Member States standby committees for the transposition of European Directives.

The EU Taxonomy is a classification system to channel private investments into clean technologies. The EU Taxonomy technical screening criteria will have an important impact on the investment decisions in the European building and HVAC sector. This article recalls proposed criteria for new and existing buildings and make comments for revisions.

Keywords: Green investment, Green Deal, Renovation wave, Taxonomy, EU standards, Energy efficiency, Buildings

Building professionals will be strongly impacted by the channelling of green investment into clean technologies (e.g. from fossil fuel boilers to renewables). They will play a key role to make the EU policies happen by implementation the new technologies and by reporting the benefits from green investment in the building sector. Regulation (EU) 2020/852 [2] (the 'Taxonomy Regulation') provides the framework and requirements for technical screening criteria. The taxonomy will provide investors with an EU common framework definition of what is green and what is not. The technical screening criteria for climate change mitigation and adaptation are under preparation as a delegated regulation. A public second phase consultation was running until 18th of December 2020.

To have a real positive impact on the planet, reliable technical screening criteria are needed, which will not only intend but also deliver what is promised. They must be widely accepted by the market participants who should implement the necessary actions that will transform the EU policies into real results. There is the need for common definitions and methods at European level to provide comparable, reliable results with a sustainable, transparent and affordable ambition level.

Hereafter extracts of the draft "Delegated regulation supplementing Regulation (EU) 2020/852)" are provided and proposals for revision are made.

Chapter 7.1. Construction of new buildings

The eligibility criteria stated in the draft regulation in Annex 1 - Chapter 7.1. Construction of new buildings are reported hereafter (extract):

> "The Primary Energy Demand (PED)[511], defining the energy performance of the building resulting from the construction, is **at least 20% lower** than the **threshold set for the nearly zero-energy building** (**NZEB**) requirements in **national** measures implementing Directive 2010/31/EU of the European Parliament and of the Council. The energy performance is certified using an as built Energy Performance Certificate (EPC).
>
> Footnote[511]: The calculated amount of energy needed to meet the energy demand associated with the typical uses of a building expressed by a numeric indicator of total primary energy use in kWh/m² per year and based on the relevant **national** calculation methodology and as **displayed on the Energy Performance Certificate** (**EPC**)."

The taxonomy bases the threshold on national methods. In Europe more than 30 **national or regional** regulations are used. Several studies (e.g. EC ENER/C3/2013425 Technical assessment of national/regional calculation methodologies for energy performance of buildings [6]) showed that national or regional regulations have:

- **different levels of technical qualities** e.g. new technologies, some renewables, are missing;
- **different boundaries conditions and definitions** e.g. export of on-site PV electricity production;
- **different indicators** e.g. total primary energy, non-renewable primary energy;
- **different ambition levels for NZEB definition.**

Therefore, there is **no comparability** between all national calculation methodologies. The figure hereafter shows the results on **primary energy demand** (PED) for the **same building**, for the **same climate conditions**, but with **different boundary conditions and definitions**. The results vary from 73,5 kWh/(m².a) to – 5,0 (kWh/m².a) depending on the type of primary energy and the way how and if PV production is considered (source: ALDREN project https://aldren.eu/).

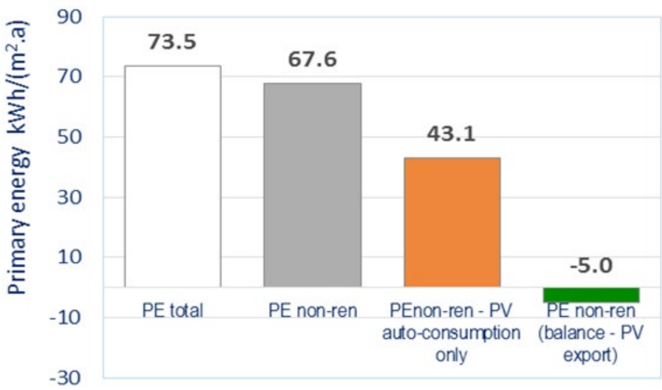


Figure 1. Primary energy demand for the same building but with different boundary conventions.

These **high differences** between the results **lead to a fragmentation of the EU market** because it does not allow to create an EU wide level playing field for technical neutral solutions and tools.

National EPCs are official documents and should be used for the technical screening to avoid additional administrative burden for the EU taxonomy. But **their quality should be verified** and improved if necessary (the improvement of the EPCs is already requested in EPBD [4]). **EU funding** should be based on a **comparable ambition level** to ensure that in all countries the activities in construction sector are treated equally.

Proposal 1:

The **proposal 1** is made to compare the results of national and regional methods with those of EU standards developed under Mandate 480. The results of EU standards itself should have been checked against measurements. Only verified methods should be allowed to be used for the technical screening criteria for EU taxonomy.

The taxonomy proposes as threshold for eligibility "at least 20% lower than NZEB". The NZEB level will be mandatory in MSs for all new buildings from 1st of January 2021 however the ambition levels differ.
Proposal 2:

The **proposal 2** is to replace the threshold "**at least 20% lower than NZEB"** by "**the comparable NZEB level**" based e.g. on the values in Commission Recommendation (EU) 2016/1318 on guidelines for the promotion of NZEBs [5] as a **starting point of the eligibility**. To motivate building owners going beyond the NZEB level towards the net zero or energy positive buildings the eligibility of the **project capital expenditures** could be based on an **improvement target** proportional **to the difference between the mandatory NZEB level and the net zero level of a building** (e.g. entirety of capital expenditures at net zero level).

The taxonomy sets the Primary Energy Demand (PED) as an indicator for the energy performance of building. But using PED as unique indicator, a low Primary Energy Demand can be reached by compensating a low level of building envelope insulation by using energies with a low primary energy factor. This is a negative side effect. A green building should be resilient, should have the high quality of the building envelope, of the building technical systems, and use renewables to satisfy the small amount of energy still to be delivered while ensure good indoor environment quality. This approach corresponds to the definition on NZEB in the EPBD [4].

Proposal 3:
The **proposal** 3 is to **complete the Primary Energy Demand** (**PED**) **by additional indicators** and thresholds. The PED should be only allowed to be used to characterise the building performance if other indicators (thresholds) are reached before (e.g. final energy, energy efficiency, indoor environment quality). This approach is recommended in **EN ISO 52000-1 Annex H** [8]. The thresholds are defined for example in the H2020 ALDREN project [7]. These additional indicators are not an additional administrative burden because they are needed in any case to calculate the PED. They have been used in most EU countries in former building regulations (see **Figure 2**).

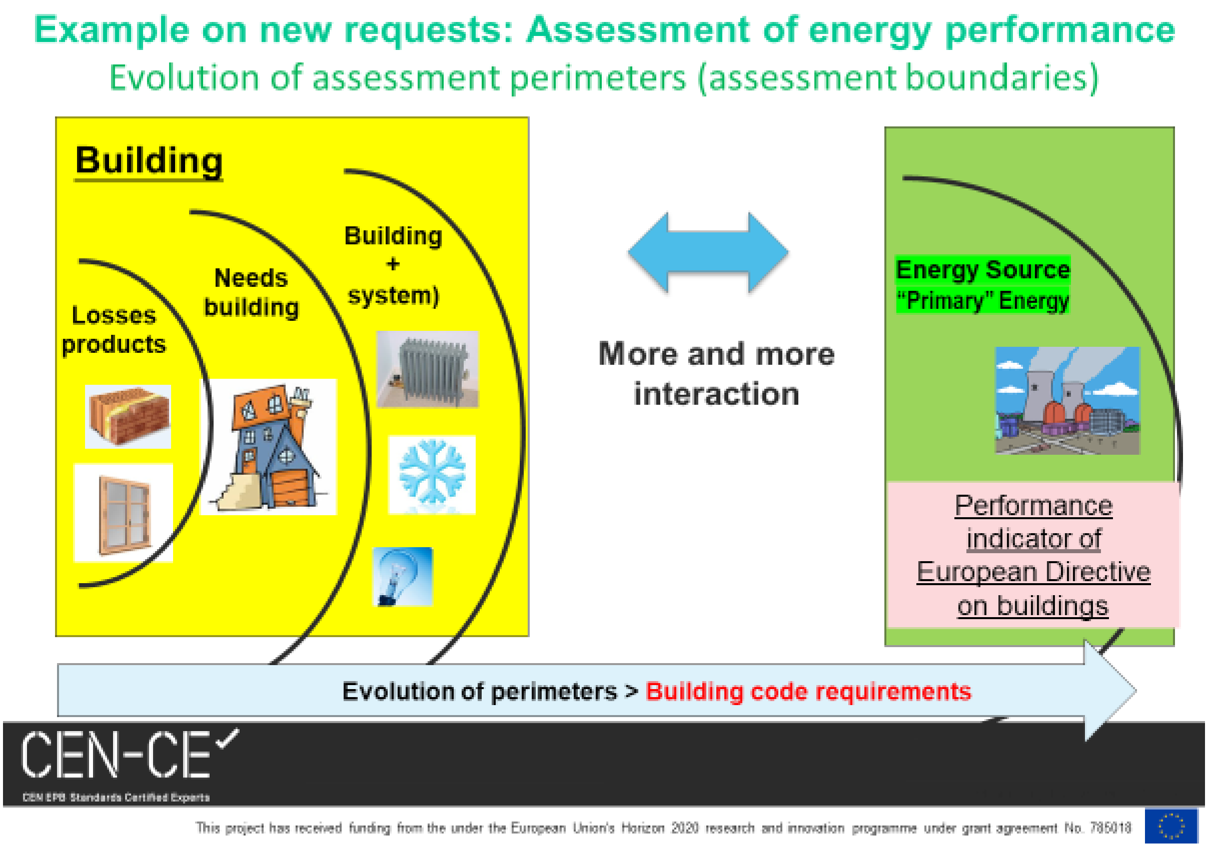


Figure 2. Evolution of request in building regulations.

Chapter 7.2. Renovation of existing buildings

The eligibility criteria stated in the draft regulation in Annex 1 - Chapter 7.2. Renovation of existing buildings are reported hereafter (extract):

"A renovation is eligible when it meets one of the following thresholds:

- Either building renovation complies with the applicable requirements for **major renovations**[534]
- Footnote [534)] As set in the applicable **national and regional** building regulations for 'major renovation' implementing Directive 2010/31/EU. The energy performance of the building or the renovated part upgraded **meets cost-optimal minimum energy performance requirements** in accordance with the respective directive.
- Alternatively, it leads to a reduction of primary energy demand (PED) **of at least 30%**[535] in comparison to the energy performance of the building before the renovation.
- Footnote [535)] The initial energy performance and the **estimated improvement** shall be based on a detailed building survey, an energy audit conducted by an accredited independent expert or **any other transparent** method and **validated through an Energy Performance Certificate.**
- The **30% improvement results** from an **actual** reduction in primary energy demand (where the reductions in **net** primary energy demand through renewable energy sources are not taken into account) and can be achieved through **a succession of measures within a maximum of 3 years.**"

The taxonomy allows two eligibility criteria: one based on the national and regional regulations for major renovation and another on the reduction of the PED. Allowing two eligibility criteria is **confusing** and could lead to **choose the less ambition solution.**

Proposal 4:
The **proposal** 4 is to keep only the eligibility criteria based on an improvement target on the annual PED.

The taxonomy states a **30% improvement threshold for eligibility** (compared to the existing stage). This would probably motivate building owners towards building renovation. But the real renovation potential is much higher, especially for major or deep renovation. In some countries the requirements for major renovations are the same as for new buildings.

Taking **the existing stage** of the building as the **reference** for the 30% improvement is **critical.** For example, the 30% threshold for an old building with a primary energy consumption of 200 kWh/(m².a) before renovation would lead to an energy consumption of 140 kWh/(m².a) after renovation. This is far from a possible NZEB building level of e.g. 50 kWh/(m².a) PED. A building consuming 140 kWh/(m².a) after renovation cannot be qualified as "green".

The 30% threshold on the existing stage may lead to **low ambition level**, **untapped energy savings potential** and a lock-in effect for further renovation towards NZEB level.

EPBD [4] requires MSs to facilitate the cost-effective transformation of existing buildings into NZEB. Renovated buildings have to meet minimum energy performance requirements (NZEB from 2021) in so far as this is technically, functionally and economically feasible.

Proposal 5:
With regard to the climate change mitigation only NZEB should be the target of renovation when it is possible. The **proposal 5** is to **replace** the threshold **related to the existing stage** and to set as reference the comparable NZEB level. The NZEB threshold **for existing buildings** could be **different** from the **NZEB level of new buildings** (e.g. 120% of PED for NZEB) not only because in existing buildings not all possibilities to increase the energy efficiency could be used, but because **the embodied energy to be spent for renovation is lower than for new buildings construction**. As for new buildings, it is proposed also for existing buildings to link the capital expenditures proportionally to the difference between the NZEB level and the net zero level of a building (entirety of capital expenditures at net zero level).

The taxonomy offers the possibility to reach eligibility by measurements *"The 30% improvement results from an actual reduction in primary energy demand can be achieved through a succession of measures within a maximum of 3 years"*. The actual performance of the buildings is key for EU targets and building owners. Therefore, the gap between the modelled and actual performance of the buildings must be reduced.

Proposal 6:
The **proposal 6** is to **precise the conditions of the measurements** to be real savings assessed and confirmed. Parameters as climate, use, occupation density, occupancy patterns, etc. should be considered. Reference to EN standards and to H2020 projects (e.g. ALDREN or QUANTUM) could be made.

Resume

A **coherent EU Taxonomy** can only be established if there is a common basis, a "**common language**". In Europe, more than 30 national or regional and several well-known European or international methods are used. Because **the methods are directly linked to the indicators and thresholds**, the first thing to do is to verify if the different methods provide **comparable** results. Otherwise, a taxonomy referring to them would not be coherent, activities will not be treated equally and they will not contribute equally towards the environmental objectives. The methods should be compared to a **reference method**.

It is **proposed** to use the **EU standards** (financed by Commission to establish a Union methodology) as a **reference method** and to check all existing methods. If relevant, the EU standards should be compared to measured data.

Once the "common language" for calculation methodology is agreed, there is a need to define **common indicators** and to set **comparable thresholds** (e.g. NZEB).

The **common performance indicator** in the EPBD for the energy demand in buildings is the **primary energy use**. There is a need to define additional boundary conditions, for example if exported energy is considered which Primary energy conversion factors are used. It is **proposed** to refer to **EN ISO 52000-1** [8].

The **threshold for the EU taxonomy should be the NZEB level.** It is the target of building regulations. A new or existing building should not be considered as "green" if this target is not reached. The results of European funded H2020 projects (e.g. ALDREN project [7]) based on Commission recommendation [5]) could be used as a basis to define the NZEB threshold for the EU taxonomy. The **EU taxonomy should give benefit to a higher ambition level, going beyond the mandatory NZEB level**. It is **proposed** to **link the capital expenditures proportionally to the difference between the NZEB level and the net zero level of a building** (e.g. entirety of capital expenditures at net zero level).

Conclusion

To make the EU taxonomy coherent and unambiguous there is a need for a common method, common indicators and common threshold to ensure that the activities contribute equally towards the environmental objectives. The common method and common indictors are already defined in the EU standards financed by Commission under mandate 480 given to CEN.

Regarding the climate change mitigation, only NZEB levels should be the target or reference for new and existing buildings renovation. The common threshold could be based on EU legislation and EU funded H2020 projects. The cost-optimality based only on the running costs is not the best approach. The non-energy benefits, risks and future costs from the climate change should be included (see experience from ALDREN project [7]).

EU wide common methods and thresholds will not prevent the EU Member States to set the ambition level according to their national needs and specifications. But it will avoid market fragmentation and distorting competition in the EU market, by setting a level playing field in connection with green financing.

The EU taxonomy could be a powerful tool to start the transition to a more coordinated approach on Energy Performance Certificates at EU level and push their quality. The Commission could contribute by putting in place the Voluntary common European Union certification scheme for the energy performance of buildings as requested in EPBD article 11/9. It could serve as an example for the EU member States when upgrading their national EPCs. ■

References

Please see the references in html-version of this article at https://www.rehva.eu/rehva-journal

Thermal impact of street canyon microclimate on the energy performance of courtyard under Mediterranean climate




ADNANE M'SAOURI EL BAT
ETTE UAE/U10FST, Abdelmalek Essaâdi University, Morocco

ZAID ROMANI
LaRAT, National School of Architecture Tetouan, Morocco

EMMANUEL BOZONNET
LaSIE, La Rochelle University, France

ABDESLAM DRAOUI
ETTE UAE/U10FST, Abdelmalek Essaâdi University, Morocco

In order to improve the prediction of the building's energy performance, it has become necessary to evaluate their interactions with the urban microclimate. Currently, there are few tools allowing to simulate the buildings energy consumption taking into account the impact of the urban microclimate with a satisfactory precision and acceptable computing time. In this study, the topic is addressed by investigating the effects of the local microclimate on the energy performance of courtyard buildings. To achieve this, an integrated approach in the TRNSYS software validated in previous studies was used. The analysis was conducted for 8 Mediterranean cities. The obtained results highlight potentially large discrepancies between the usual practice of building energy simulation, and the advanced simulation which takes into account local urban effects. This approach would improve to adapt HVAC system choices, especially by considering the urban morphology. Significant heating and cooling need variation were observed for high aspect ratio of courtyards within several Mediterranean cities.

In architectural design history, the courtyard represents one of the major building models whose characteristics depend on the environment and culture of the region [1]. Courtyards are still widely used worldwide, as a traditional urban pattern in Asia, Middle East, South America and specifically in Mediterranean countries [2]. This type of building creates local microclimate conditions, which may improve thermal comfort conditions [3]. Actually, this is an effective sustainable strategy to control the microclimate and the energy consumption of buildings. However, the complex interactions between the microclimatic and thermal functions of the courtyard make simultaneous simulation of indoor and outdoor thermal conditions an unavoidable requirement.

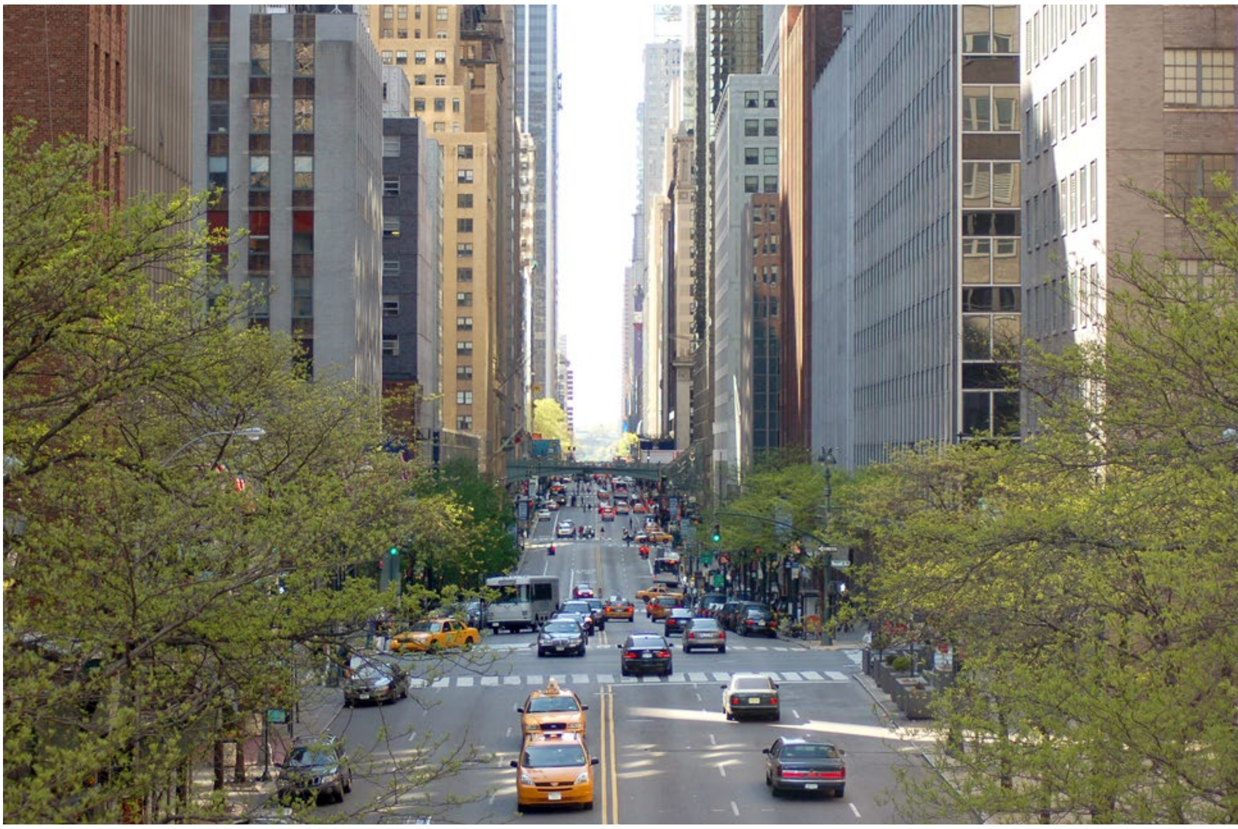
In this context, a review of the related literature showed that seventeen percent of studies focused on the thermal function of the courtyard, while sixty-three percent of studies focused on the microclimatic function of the courtyard, and only one-fifth considered the thermal and microclimatic function of courtyards simultaneously [4]. Furthermore, there are limitations to understanding the complex interactions between indoor and outdoor thermal conditions. One of them is the lack of suitable simulation programs. To this end, it appears advantageous to develop a more complete approach to evaluate the thermal and microclimatic (indoor and outdoor) performance of courtyard and their energy consumption.

For this purpose, the aim of this study is to quantify the influence of the street canyon microclimate on building courtyard energy performance, considering the case of the Mediterranean cities. For that, a simplified approach that we have developed and integrated in the TRNSYS 18 software is used [5–7]. This approach allows the description of thermal as well as aeraulic and radiative phenomena not only in the building's, but also at the microclimatic scale.

Methodology

Numerical model

In this research work, the TRNSYS 18 software was used for the energy simulation knowing that this software does not include urban modelling. Indeed, we developed a model integrated in this software in order to achieve the microclimatic simulation. The transfer function method of Mitalas and Stephenson [8] is used to express heat conduction through the walls. The heat transfer coefficient value of building façades is assumed to be constant on the inside surfaces of the building (6.1W/m²K for the ceiling, 1.6 W/m²K for the floor and 4.1 W/m²K for the vertical walls [9]). For the outside surfaces, the heat transfer coefficient by convection was evaluated using the Hagishima and Tanimoto correlation [10]. The modelling of ground heat transfers is based on standard EN ISO 13370 "Thermal performance of buildings -Heat transfer via the ground - Calculation methods" and Type 77 of TRNSYS [11]. This represents the sinusoidal evolution of the temperature over the year.



A street canyon in Manhattan, New York City, USA. [Wikimedia commons / David Brooks. (CC BY 2.0)]

For radiative exchanges, TRNSYS distinguishes between short-wavelength and long-wavelength exchanges. These are modelled differently for indoor and outdoor surfaces. More specifically, solar irradiation on outdoor surfaces is considered as a gain while the longwave radiation is treated as a heat loss to the cold sky. A 3D radiation model that takes account of multiple reflections is provided only on interior zones. The street canyon building and the courtyard are modelled as an outdoor environment, which the radiative model does not consider either the shortwave or the longwave inter-reflections between the façades of street canyon buildings.

As the ultimate aim of this study is to investigate the influence of microclimatic phenomena generated by the street canyon and the courtyard on the energy needs of a building. The street canyon and the courtyard are modelled by a simplified approach developed and validated in previous studies [5–7]. In this approach, the radiative model is based on the Gebhart factor [13] to calculate radiative exchanges and inter-reflections as well as the solar radiation distribution coefficients. While the aeraulic model is based on the Harman model [14] and the Soulhac model [15] which allows to take into account the effects of dominant winds. The originality of the method is its capacity to model the microclimatic phenomena generated by the street canyon and the courtyard (**Figure 1**), using dynamic thermal simulation software.

Description of the case study: Courtyard energy simulation model

In order to analyse the studied courtyard heating and cooling demand, an energy modelling was carried out for three different cases: a stand-alone courtyard in an open field by using TRNSYS software only, the same courtyard by using the developed approach (SACM) and the same courtyard located in an urban environment with a street canyon in front and behind the considered building. A street canyon with aspect ratios of 0.5, 1 and 2 (aspect ratio *H/W* with *H*: height of the building, *W*: street canyon width) are considered. **Figure 2** show the studied courtyard surrounded by street canyons with an aspect ratio of 1.

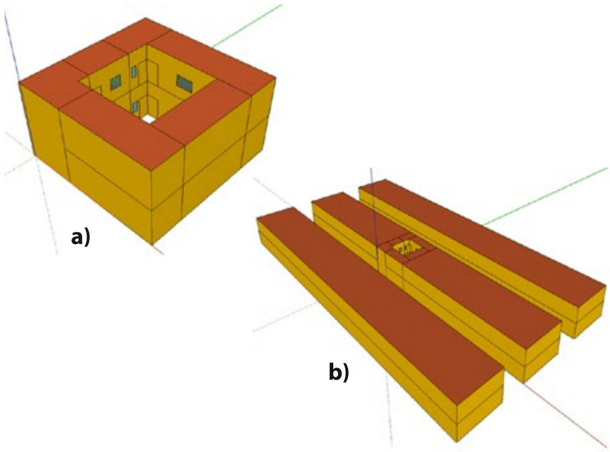


Figure 2. Overview 3d of the courtyard building (a) and the street canyon (b).

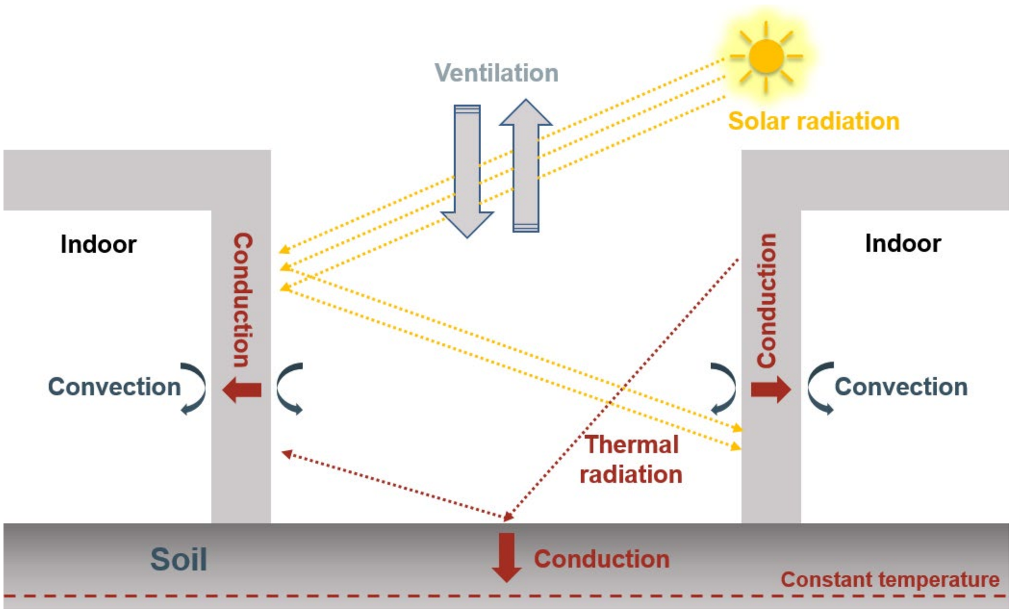


Figure 1. Illustration of the heat and aeraulic exchange processes in the courtyard or in the street canyon.

The considered courtyard has a total area of 169 m² (13 m of width and 13 m of length) and the height is of 3.5 m, with 10% of this area occupied by the courtyard. The total area of the window is 12.2 m². **Figure 3** and **Table 1** give the description of the courtyard model used as a case study.

The **Table 2** shows the glazing characteristics used.

Table 2. *Windows characteristics.*

Envelope element	Material	U-value [W/m².K]	G-value	ε
Windows	Glass	1.4	0.6	0.84

Table 1. *Thermophysical properties of courtyard and soil materials [16].*

Envelope element	Materials	Thickness [cm]	λ [W/m².K]	C_p [J/Kg.K]	ρ [kg/m³]
Outside Wall	Cement	1.5	1.15	1000	1700
	Brick	7	0.3	741	1200
	Air	10	–	1000	1.25
	Brick	7	0.3	741	1200
	Cement	1.5	1.15	1000	1700
Adjacent Wall	Cement	1.5	1.15	1000	1700
	Brick	7	0.3	741	1200
	Cement	1.5	1.15	1000	1700
Roof and ceiling	Tile	0.7	1.4	1000	2500
	Screed	5	0.42	1000	1800
	Concrete	4	2.3	1000	2350
	Hollow block	16	0.6	880	1000
	Cement	1.5	1.15	1000	1700
Ground floor	Tile	0.7	1.4	1000	2500
	Screed	5	0.42	1000	1800
	Concrete	20	2.5	1000	2350
Sidewalk	Ceramics	0.7	1.4	1000	2500
	Concrete	10	0.04	1000	2350

Where λ is the conductivity, C_p is the heat capacity and ρ is the density.

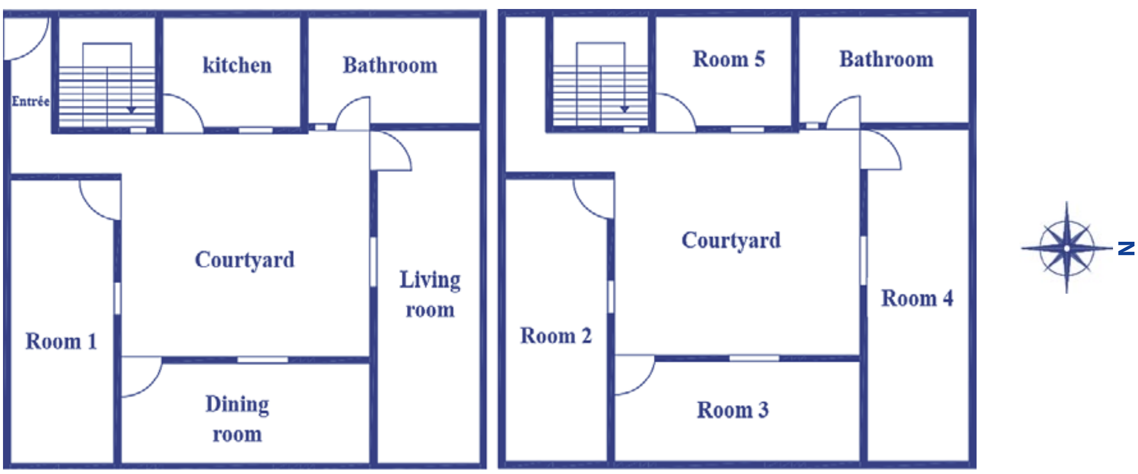


Figure 3. Ground floor (left) and first floor (right) plans.

During the modelling, we supposed that the courtyard is occupied by five people. The rooms are occupied every day from 22h to 7h 30 min. The living room is used for relaxing during the day. It is occupied from 7h30 to 8h, from 13h to 18h and from 20h to 22h. The kitchen is occupied from 7h to 7h30, from 12h30 to 12h and from 18h to 19h.

The internal gains due to the lighting system are 5 W/m² (incandescent lamp). The other appliances that produce the internal loads in the building are presented in **Table 3**.

Table 3. *Specific values of internal gains.*

Appliance	Area	Operating time	Power [W]
Refrigerator	Kitchen	24/24	125
TV	Living room	In occupation	75
Cooking appliances	Kitchen	In occupation	200
Computer	Bed-room	In occupation	100

The ventilation rate is 0.5 vol/h while the envelope infiltration rate is assumed to be 0.2 vol/h. The cooling and heating temperature set point are respectively 26°C and 20°C. The climatic data taken into account are those of the Mediterranean cities: Tangier (Morocco), Algiers (Algeria), Nice (France), Tripoli (Libya), Athens (Greece), Rome (Italy) Tunis (Tunis) and Barcelona (Spain).

Results and discussion

Figures 4 and 5 show the cooling and heating energy needs of courtyard building in different urban contexts. The results were given according to the aspect ratio of street canyons for the different Mediterranean cities.

First, based on the comparison between different simulation results obtained, we can see that the cooling energy needs estimated using TRNSYS 18 only are underestimated by about 70% compared to those of SACM, and the heating energy needs generated by TRNSYS 18 are about 10% higher than those obtained by our models (SACM). This is due to the fact that the courtyards generate microclimatic phenomena such as radiative trapping and inter-reflections of solar radiation, which have the effect of increasing the building's external surface temperature and consequently increasing the cooling energy needs. Moreover, TRNSYS 18 software does not allow to model the courtyards microclimate and therefore the shading effect as well as the thermoaeraulic exchange between the courtyard and the outside environment is not modelled. On the other hand, the radiative exchanges between the surfaces of the courtyard are not modelled if TRNSYS is used only.

For the impact of the street canyon microclimate on the energy needs of buildings in different Mediterranean cities under summer period (**Figure 4**), the cooling

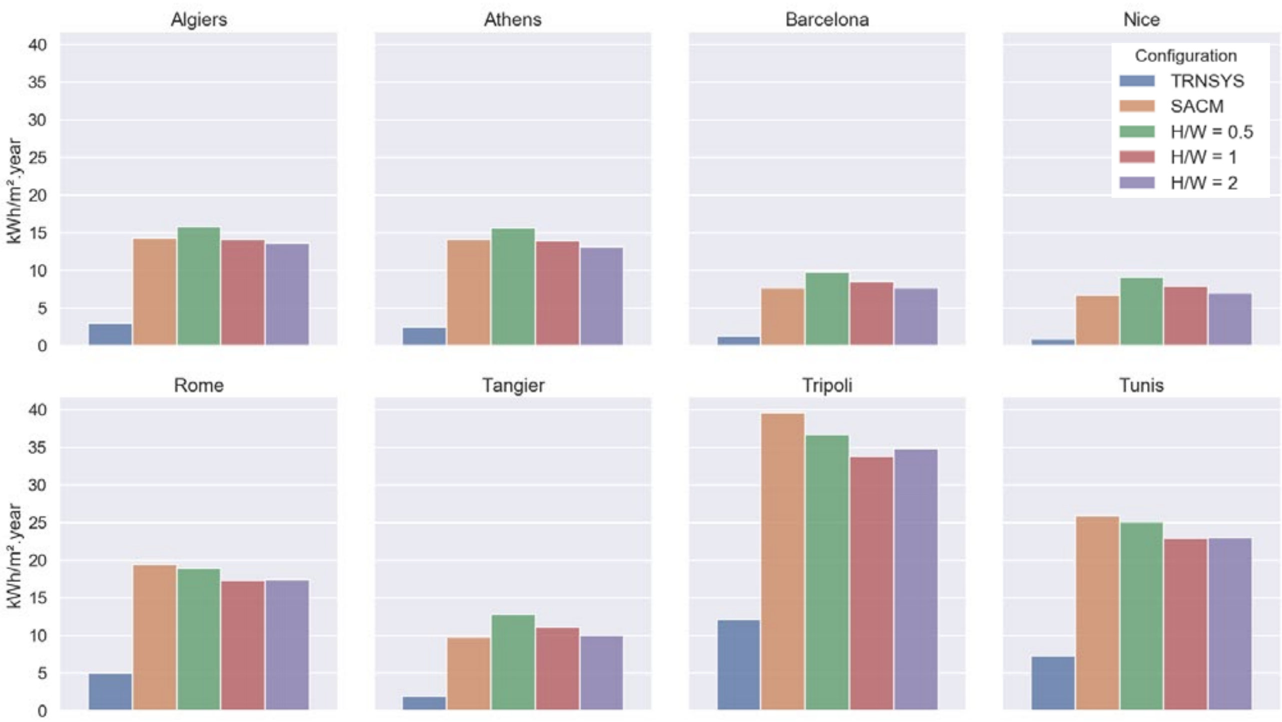


Figure 4. Cooling energy needs.

demand for courtyard building in wide canyon street is higher than the building in narrow canyon street configuration (and even more than a stand-alone courtyard building). Since more solar radiation can penetrate the wide canyon street and be trapped inside this canyon.

The lowest space cooling energy needs is associated with the *H/W* = 2 configuration. In fact, in this case, the building is flanked by narrower canyons, being therefore more sheltered from direct solar radiation. In addition, the shading effect is greater for narrow canyon than the wide one. Consequently, the narrow canyon, preventing the entry of solar radiation, offers energy advantages during the summer period, while it has the opposite effect in winter.

For the stand-alone courtyard building (SACM), the simulation results show that the cooling energy needs are very low compared to other configurations while the heating energy needs are high. During the summer, this is expected as the courtyard's openings are shaded and located in a controlled microclimate of the courtyard space. However, in winter, this is due to the fact that solar radiation is the engine of energy demand trends. If more solar radiation reaches the building envelope, the heating system requires less energy demand.

Finally, these results show the importance of considering the urban microclimate in the simulations carried out at the design stage, given its effects on energy needs and consequently on the decisions and choices adopted by deciders. It is therefore necessary to confirm the drastic effect of considering the urban microclimate in the building energy simulations. This leads to a significant error to dimensioning the HVAC systems.

Conclusion

Most neighbourhoods in Mediterranean cities are traditionally designed with street canyons, and enclosed courtyards between buildings. These courtyards had several spiritual, organizational, climate and social roles, as well as practical functions such as daylighting and building ventilation. The obtained results demonstrated the variety of courtyard effects, depending on its characteristics and locations.

The results for 8 Mediterranean cities confirmed that any changes in the microclimate affect the building energy needs in urban context, but their relative impact depends on the climate of the region. Moreover, the results obtained show that the use of regional climate data is not representative enough of the specificities of urban sites, which might lead to incorrect HVAC sizing.

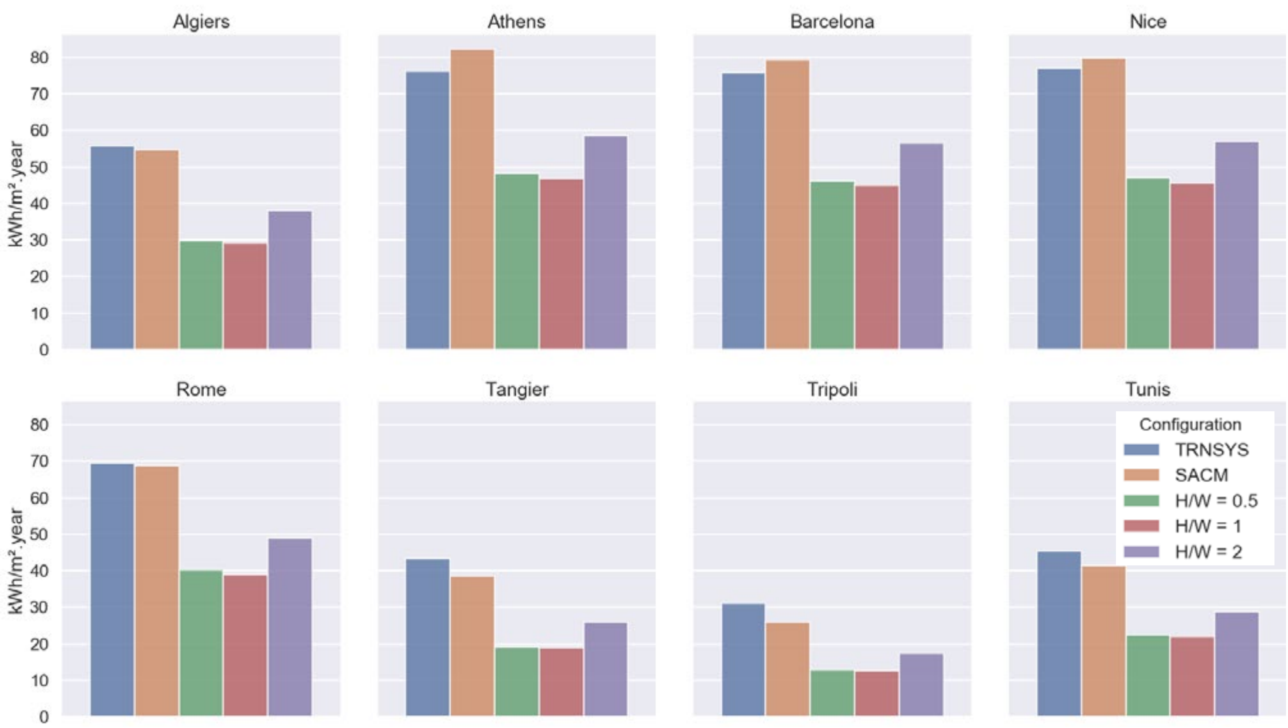


Figure 5. Heating energy needs.

Finally, the simulation methodology used in this study can be applied to similar urban contexts and to other building typologies. Moreover, it can be used by architects, planners and modelers to better understand the relationship between urban morphology, urban microclimate and the energy performance of urban buildings in order to improve thermal comfort and energy efficiency. ■

References

[1] B. Edwards, M. Sibley, P. Land, M. Hakmi, Courtyard Housing: Past, Present and Future, 2006.

[2] X. Xu, F. Luo, W. Wang, T. Hong, X. Fu, Performance-Based Evaluation of Courtyard Design in China's Cold-Winter Hot-Summer Climate Regions, (2018) 1–19. https://doi.org/10.3390/su10113950.

[3] R. Saxon, Atrium buildings: development and design, LONDON Archit. Press. 182 PP. ISBN 0-85139-849-9. 182 ILLUS. BIBLIOG. (General). (1983).

[4] Z. Zamani, S. Heidari, P. Hanachi, Reviewing the thermal and microclimatic function of courtyards, Renew. Sustain. Energy Rev. 93 (2018) 580–595. https://doi.org/10.1016/j.rser.2018.05.055.

[5] A. M'Saouri El Bat, Z. Romani, E. Bozonnet, A. Draoui, Impact Of Urban Microclimate On The Energy Performance Of Riad-type Buildings, in: Proc. Build. Simul. 2019 16th Conf. IBPSA, 2020: pp. 3771–3778. https://doi.org/10.26868/25222708.2019.211272.

[6] A. M'Saouri El Bat, Z. Romani, E. Bozonnet, A. Draoui, Integration of a practical model to assess the local urban interactions in building energy simulation with a street canyon, J. Build. Perform. Simul. 13 (2020) 720–739. https://doi.org/10.1080/19401493.2020.1818829.

[7] A. M'Saouri El Bat, Z. Romani, E. Bozonnet, A. Draoui, Thermal impact of street canyon microclimate on building energy needs using TRNSYS: A case study of the city of Tangier in Morocco, Case Stud. Therm. Eng. 24 (2021) 100834. https://doi.org/https://doi.org/10.1016/j.csite.2020.100834.

[8] G. Stephenson, DG ; Mitalas, Calculation of heat conduction transfer functions for multi-layers slabs, Air Cond. Engrs. Trans; (United States). (1970).

[9] A. Rodler, S. Guernouti, M. Musy, J. Bouyer, Energy & Buildings Thermal behaviour of a building in its environment : Modelling , experimentation , and comparison, Energy Build. 168 (2018) 19–34. https://doi.org/10.1016/j.enbuild.2018.03.008.

[10] A. Hagishima, J. Tanimoto, Field measurements for estimating the convective heat transfer coe cient at building surfaces, 38 (2003) 873–881. https://doi.org/10.1016/S0360-1323(03)00033-7.

[11] S.A. Klein, TRNSYS 17: A Transient System Simulation Program, Sol. Energy Lab. Univ. Wisconsin, Madison, USA. 1 (2010) 1–5. http://www.trnsys.com/.

[12] T. Kusuda, P.R. Achenbach, Earth Temperatures and Thermal Diffusivity at Selected Stations in the United States, ASHRAE Trans. (1965) 61–74. http://www.dtic.mil/dtic/tr/fulltext/u2/472916.pdf.

[13] B. Gebhart, Surface temperature calculations in radiant surroundings ofarbitrary complexity –for gray, diffuse radiation, Int. J. Heat Mass Transf. 3 (1961) 341–346.

[14] I.N. Harman, J.F. Barlow, S.E. Belcher, Scalar fluxes from urban street canyons. Part II: Model, Boundary-Layer Meteorol. 113 (2004) 387–409. https://doi.org/10.1023/B:BOUN.0000045526.07270.a3.

[15] L. Soulhac, R.J. Perkins, P. Salizzoni, Flow in a Street Canyon for any External Wind Direction, (2008) 365–388. https://doi.org/10.1007/s10546-007-9238-x.

[16] Z. Romani, A. Draoui, F. Allard, Metamodeling the heating and cooling energy needs and simultaneous building envelope optimization for low energy building design in Morocco, Energy Build. 102 (2015) 139–148. https://doi.org/10.1016/j.enbuild.2015.04.014.

PV Assisted Heat Recovery Ventilation System for nZEB at Mediterranean Climate

ASLI BIRTÜRK
Solar Energy Institute, Ege University, Izmir, Turkey

ORHAN EKREN
Solar Energy Institute, Ege University, Izmir, Turkey

SINAN AKTAKKA
Loadstar Izmir, Turkey

MACIT TOKSOY
VANSAN A.Ş., Izmir, Turkey

Keywords: Ventilation, solar energy system, nZEB, heat recovery

Abstract

Recently, across the world, indoor air quality has become one of the most spoken issue in consequence of COVID 19. People spend time at houses, offices, schools and the other indoor environments for social activities and personal necessities. Indoor ventilation by opening windows and doors does not always meet the requirements as air pollution increases outside. However, building related illnesses are inevitable for people who are frequently exposed to indoor pollutant such as biological (viruses, bacteria etc.). Therefore, the determined precautions should be taken without any delay and excuse.

Energy consumption because of the mechanical ventilation could be problem for the most buildings. In this direction, by the end of 2020, all new buildings in Europe must be proper to achieve the target of the nearly net zero energy building (Directive 2010/31/EU). As a solution, an off-grid solar assisted system was designed to supply the electrical load of heat recovery ventilation system with the intention of an example of nZEB concept. In detail, this paper presents some sample residential heat recovery ventilation designs for different types of dwellings in Mediterranean countries such as Portugal, Spain, France, Italy, Greece, Turkey. The solar PV system was simulated by PVsyst which is known as one of the most widely used software.

Introduction

The building sector has a considerable influence on global warming and is responsible for around 40% of the energy consumption in the member states of the European Union [1]. Therefore, building strategies have gained speed by reason of increasing CO_2 emissions. nZEB concept includes renewable energy sources and innovative applications which meet the zero energy targets as it becomes compulsory by the end of 2020 [2]. Especially, designing efficiency and heat insulated structures is as significant as using renewable energy powered domestic appliances. The other remarkable points such as climate conditions and building facades play a significant role on energy efficiency.

Therefore, housing strategies have been become more of an issue as building caused environmental pollution has been increasing. Moreover, people are intensively exposed polluted air in closed spaces unless there is no mechanical or natural ventilation [3]. In some cases, natural ventilation does not supply sufficiently fresh air and mechanical ventilation remains as the only solution in highly polluted cities [4]. At this point, polluted air must be taken seriously as well as any kind of pollutants otherwise, long term and short term affects, called sick building syndrome symptoms might be eventually inevitable [5]. Considering fresh air needs, the utilization of renewable sources and ventilation systems can reduce global warming potential and its effects.

In this paper, residential ventilation requirements from the standards and CO_2 calculations were examined for the comparative assessment of ventilation designs in Mediterranean countries. In EN 16798-1:2019 (Revision of EN 15251), CO_2 concentration rate should be under 800 ppm in the case of CO_2 controlled ventilation. On the other hand, 1000 ppm CO_2 concentration limit (published by Pettenkofer) is well accepted and used at present as a reference value (Recknagel and et al.,1996) [6]. Besides, housing regulations were researched for each country to specify room areas of the sample dwellings and determine the correlation between the minimum floor area and the number of occupants. The system was designed based on a daily usage scenario with a PV system and a heat recovery mechanical ventilation unit.

Housing regulations

Cultural and social differences influence building designs and comfort levels. In almost every country, modern and innovative architectures become prominent as well as traditional architecture. Thus, the dwelling types are important for the space area to assess indoor air quality and efficiency conditions for residential buildings. In a statistic including the Mediterranean countries (except Turkey), the preferred housing types in the countries are given in the **Figure 1**.

According to the HC (House Corporation) funding system, dwelling area is determined through the number of occupants (**Table 1**).

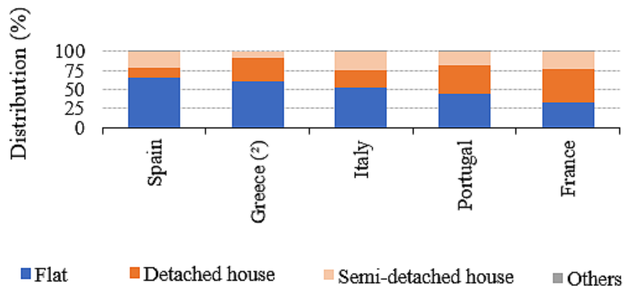


Figure 1. Dwelling types in Mediterranean Countries. [7]

Table 1. *Minimum Space Requirements [8] and Dwelling Area [9].*

Room (#of bdr/ocp.)	2/4	3/6	4/8
Dining Area	5	6	8
Living room	13	16	18
Kitchen	7	8	8
Bedroom (parents)	14	14	14
Bedroom 2	12	12	12
Bedroom 3	-	12	12
Bedroom 4	-	-	12
Bathroom with WC	4	-	4
Bathroom, no WC		4	-
Separate WC		1.2	1.2
Total	**56.5**	**76.2**	**93.7**

Occupancy	Dwelling Area (m²)
1	25-40
2	30-60
3	50-80
4	60-90
5	70-100
6	80-120
7	100-120
8	110-120

In 1988, World Health Organization published guidelines for healthy housing which explains the minimum comfort boundaries by taking into consideration of relation between the number of bedrooms and occupants [8].

Ventilation standards/regulations

One of the most widely used standard, EN 16798 is to contain four different indoor environmental factors such as thermal comfort, air quality, lighting, and acoustics. The approach of the standard in determining indoor air quality is to calculation a ventilation level depending on the number of occupants and the floor area. There are 3 categories in EN standard that are determined according to comfort needs. Minimum air flow rates per square meter given by category are 1.4 ℓ/s, 1 ℓ/s and 0.6 ℓ/s, respectively [10].

Although the ASHRAE Standard is published considering to North America, it is used all around the world as a source to calculation ventilation requirements. The minimum flow rates of ASHRAE for dwellings are 2.5 ℓ/s per occupant and 0.3 ℓ/s per square meter. In the ASHRAE 62.2, the exhaust flow rate for the kitchen and the bathroom is 50 ℓ/s. For the rooms, the recommended minimum ventilation rate is 3.5 ℓ/s per occupant and 0.15 ℓ/s per square meter [11].

National standards published in each Mediterranean country have been examined:

- In the Greek regulation, the air flow rate per capita is 4.72 ℓ/s [12].
- In Italian regulation, the air flow rate per person for the hall is 4.16 ℓ/s [12].
- In the Portuguese regulation, it is stated that ventilation is required once every hour [12].
- In the Spanish national standard (DB HS3), the air flow rate per person is given 5 ℓ/s for the bedroom and 3 ℓ/s for the living room [13]
- In the French national standard (Arrêté du 24 Mars 1982), the total amount of airflow is given per room. Flow rate is 35 m^3/h for 1 room, 60 m^3/h for 2 rooms, 75 m^3/h for 3 rooms, 90 m^3/h for 4 rooms [14]
- Turkey does not have a national ventilation standard and uses EN 16798 standard.

System design

Within the scope of the study, minimum and average space requirements per occupant were taken into consideration and 4 different dwelling types were determined. It is assumed that the dwelling types, whose number of bedrooms increase from 1 to 4, have areas of 50 m^2, 70 m^2, 90 m^2 and 110 m^2, respectively. The number of occupants has been determined by keeping the maximum level and each bedroom is used by 2 people for all dwelling types. The periods are given to describe the time spent in the different parts of dwellings.

According to the scenario, it is assumed that all the occupants are participated during all the periods. It is assumed that WC, bathroom, and kitchen are used between 07:00 – 08:00, 13:00 – 14:00 and 18:00 – 19:00. The whole dwelling is ventilated between 08:00 – 13:00, 14:00 – 18:00 and 20:00 – 00:00. It is accepted as a sleeping period between 00:00 – 07:00 and the bedrooms are ventilated during this period.

If mechanical ventilation is preferred to increase the indoor air quality at acceptable levels, it is necessary to heat or cool the fresh air given to the environment depending on the seasons. Furthermore, the CO_2 amount, which is a basic indicator for pollutants, is kept at allowed levels of concentration [15]. For the solar power ventilation system, PV system sizing is simulated using PVsyst. The optimum inclined placement of the PV modules offers the opportunity to make better use of the sun's daily movement.

Results

Calculating the required total flow rate according to CO_2 ratio gives a more realistic result for personal preferences. The important point to note here is, in the case where the number of people living in different sized dwellings is the same, the total air flow required for the smaller dwelling type and the total air flow required for the bigger dwelling type are very close. According to this result, the number of occupants is more important parameter than the size of dwelling.

In this study, the maximum amount of 1000 ppm CO_2 was accepted as the limit, and the minimum air flow per person was calculated using the iteration method depending on the number of people and the volume of the area. Due to meet the total air flow requirement, the necessary electrical energy was supplied from the PV system.

On grid PV system details for 1 room 1 living room and 4 room 1 living room dwelling types are given in the **Table 2**. PV system sizing is calculated according to the lowest solar irradiation month (December). In case the system is off grid, more energy produced in spring and summer is stored as unused energy in batteries. Therefore, the performance ratio (PR) drops considerably. In one example for Spain, the same components in the on-grid system were also selected for an off-grid system and only a battery was added. System performance has decreased to 60.6% for 1-bedroom residence and 75.3% for 4-bedroom residence.

As seen in the PV system results, the number of PV modules did not change in the sizing for the Mediterranean countries. Since different components are preferred, there are differences in the PR. The main factors affecting the PR such as the amount of solar irradiation, the efficiency between energy production and consumption, the efficiency of the components, the current and voltage values are the parameters to be considered during sizing.

Conclusion

In this paper, different residential designs based on ventilation standards were compared for Mediterranean countries such as Portugal, Spain, France, Italy, Greece, Turkey. The first aim of the study is to find out the difference of ventilation requirements among National Standards (if it exists) and European Standard, under the same design conditions (total number of occupants, total area of indoors and daily scenario). Additionally, CO_2 concentrations were calculated to determine the closest approach of occupant needs to the reality by using daily scenario.

The second aim is to design PV systems with proper sizing. The combination of solar energy system and ventilation system gives new opportunities to reduce the building caused carbon emissions. The proper

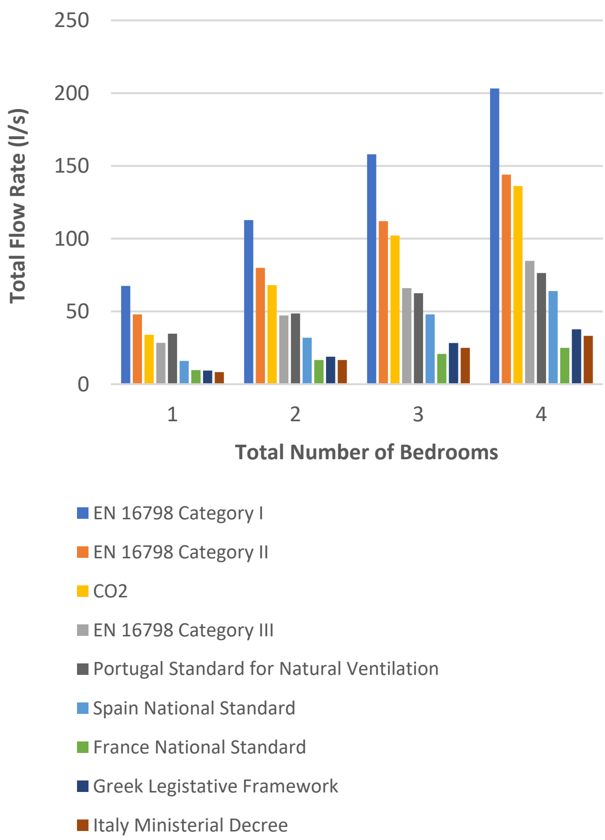


Figure 2. The Comparison of Total Flow Rates.

Table 2. *PV sizing results for Mediterranean countries*

	Portugal		Spain		France		Italy		Greece		Turkey	
PV Tilt (°)	33		33		36		36		32		32	
Dwelling Type (#of bed flat)	1	4	1	4	1	4	1	4	1	4	1	4
Planned Syst Power (kWp)	0.2	0.9	0.2	0.9	0.2	0.9	0.2	0.9	0.2	0.9	0.2	0.9
Number of PV Module	1	3	1	3	1	3	1	3	1	3	1	3
PV Module Power [Wp]	250	290	215	280	285	330	290	300	275	310	230	320
PR (on-grid) [%]	81.6	83.1	80.6	83.1	83.9	83.9	84	82.9	82	82.1	80.6	83

calculation of flow rate is important while designing a system and its efficiency. In this way, a comparison of the flow rates obtained from the CO_2 calculation with the scenario requirements was provided. The resulting differences contributed to an understanding of the perspectives on the application of standards to buildings in each Mediterranean country.

Furthermore, designing PV systems is also significant as well as ventilation needs. The performance of PV system was simulated by PVsyst tool. The tilt for each Mediterranean country was considered the location where the cities were chosen. The minimum air flow differences between the existing standards create uncertainty for the user in the selection of the ventilation unit. In this regard, it is important to develop methods for the compatibility of the required minimum air flows in the current standards and the air flows that the existing ventilation units can meet to improve the indoor air quality. The fact that the ventilation demand of ventilation systems is high, this demand can meet by clean and renewable energy sources in nature rather than being met by the fossil energy sources, is an important contribution to the protection of the climate balance.

PV system sizing has been calculated separately for Mediterranean countries and different components were preferred as much as possible. Due to the climatic conditions of the Mediterranean countries, the solar irradiation amounts are very close to each other. Therefore, when conducting PV system sizing, examining the dwelling types with the same consumption with different components under similar solar irradiation amounts gives us an idea about the preferable PV module power range. As a result of this study, which are obtained by increasing the indoor air quality and using PV systems, show that the Mediterranean countries have similar needs. Mediterranean countries, whose climate characteristics are similar, have a great benefit potential within the framework of common measures taken against global warming. ■

References

[1] IEA, *Electronic Tables for Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems*. 2015.

[2] R. HICKEL, 'Contribution à l'exploration radiologique des vertèbres lombaires agrandies et des quatre derniers interlignes vertébraux sur un seul film.', *Presse Med.*, vol. 63, no. 30, p. 619, 1955.

[3] J. I. Freijer and H. J. T. Bloemen, 'Modeling relationships between indoor and outdoor air quality', *J. Air Waste Manag. Assoc.*, vol. 50, no. 2, pp. 292–300, 2000.

[4] O. Ekren, Z. H. Karadeniz, I. Atmaca, T. Ugranli-Cicek, S. C. Sofuoglu, and M. Toksoy, 'Assessment and improvement of indoor environmental quality in a primary school', *Sci. Technol. Built Environ.*, vol. 23, no. 2, pp. 391–402, 2017.

[5] ISIAQ-CIB Task Group TG 42, 'Performance Criteria of Buildings for Health and Comfort', *Perform. Criteria Build. Heal. Comf.*, no. 292, pp. 1–68, 2004.

[6] M. Liddament, 'AIVC Guide to Energy Efficienct Ventilation', p. 274, 1996.

[7] Eurostat.eu, 'Distribution of population by degree of urbanisation, dwelling type and income group - EU-SILC survey - Eurostat', p. 1, 2019.

[8] WHO, 'Guidelines for Healty Housing', in *Guidelines for Healthy Housing*, vol. 29–30, no. 2, 1988, pp.

[9] A. Drury, J. Watson, R. Broomfield, D. Levitt, and R. Tetlow, 'Housing Space Standards', *Gt. London Auth.*, no. August, pp. 1–188, 2006.

[10] Council of the European Union, 'EN 15251 CEN/TC 156 Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics', pp. 1–52, 2006.

[11] I. S. Walker *et al.*, 'ASHRAE 62.2:2016 - Ventilation and Acceptable Indoor Air Quality in Residential Buildings', vol. 2016, 2016.

[12] C. Dimitroulopoulou, 'Ventilation in European dwellings: A review', *Build. Environ.*, vol. 47, no. 1, pp. 109–125, 2012.

[13] S. Guillén-Lambea, B. Rodríguez-Soria, and J. M. Marín, 'Review of European ventilation strategies to meet the cooling and heating demands of nearly zero energy buildings (nZEB)/Passivhaus. Comparison with the USA', *Renew. Sustain. Energy Rev.*, vol. 62, pp. 561–574, 2016.

[14] R. QUILLIOT, E. HERVÉ, and J. RALITE, 'Arrêté du 24 mars 1982 relatif à l'aération des logements', 1982.

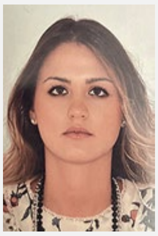
[15] T. Kalema and M. Viot, 'Methods to reduce the CO_2 concentration of educational buildings utilizing internal ventilation by transferred air', *Indoor Air*, vol. 24, no. 1, pp. 71–80, 2014.

AiCARR
Cultura e Tecnica per Energia Uomo e Ambiente

This article has been first published in AiCARR Journal / Vol 62, n. 3, 36 - 39, 2020, DOI: 10.36164/AiCARRJ.62.03.04

Theoretical and actual energy behaviour of a cost-optimal based NZEB





I. ABBÀ G. CRESPI C. LINGUA C. BECCHIO S.P. CORGNATI

TEBE-IEEM Group, Energy Department, Politecnico di Torino, Torino, Italy
Corresponding author: cristina.becchio@polito.it

Keywords: Nearly-Zero Energy Building (NZEB), cost-optimal analysis, occupant behaviour, energy simulation, theoretical and actual consumptions

Abstract

Building energy simulation proves to be an effective tool for the preliminary design phase to evaluate different retrofit scenarios. However, theoretical consumptions still differ from actual ones, especially in NZEBs, mainly due to occupants' presence and interaction with energy systems. This paper aims to verify the gap between theoretical and actual values for an existing Italian NZEB.

Introduction

Nowadays, the ambitious decarbonisation targets for the building sector, proposed by the European Commission, could be reached through the large-scale deployment of Nearly-Zero Energy Buildings (NZEBs). In NZEBs, the aim of reducing energy consumption and CO_2 emissions can be easily achieved since the planning stage, through the design and implementation of high-performing building envelopes coupled with efficient Heating, Ventilation and Air-Conditioning (HVAC) systems and appropriate renewable technologies. These concepts are the basis of the 2010 recast of the Energy Performance of Building Directive (EPBD, European Commission, 2010), which firstly introduced the concept of NZEB and stated that retrofit solutions for existing buildings need to be evaluated through a comparative methodology framework able to identify the cost-optimal levels of minimum energy performance requirements. During the planning phase, energy simulations are typically implemented to evaluate the energy performances of different technological scenarios; however, the theoretical energy consumptions are usually different from real ones. Two factors result to be the main cause of gap: the climate conditions considered in the simulation, as well as the presence of occupants in the building. First, the climatic files used by the simulation software, though plausible, are slightly different from real weather conditions. Moreover, occupant behaviour represents a key factor to uncertainty of building performance, due to its high impact on energy consumptions. For this reason, it is necessary to take into account not only the energy and the financial perspectives, but also to recognize the central role of occupants. To emphasize the importance of considering occupant behaviour within the energy analysis of buildings, the revised EPBD (European Commission, 2018), amended in 2018, introduced a new focus on indoor environmental quality (IEQ), stressing the need for optimizing occupants' health, comfort, and well-being.

In this paper, a single-family house, the so-called CORTAU House, located in Piedmont region, is analysed. Its requalification is of interest, being an example of energy retrofit in the Mediterranean area towards the NZEB targets achievement. Indeed, it is well known that the difference between NZEBs located in Northern and Southern European countries depends on climate conditions. On one hand, in Northern countries, the control of thermal loads in heating periods is crucial and the external climate conditions are favourable for free cooling. On the other hand, in Southern and Mediterranean areas, the goal is to minimize energy consumptions for both heating, in winter season, and cooling, in summer period. In many countries included in the Mediterranean climate area, due to the presence of a variety of climates (e.g. cold dry winters and hot wet summers), unknown in North Europe, there are extremely different scenarios that need to be faced.

In this work, once retraced the design procedure, which implemented the cost-optimal methodology to show to owners/private investors the most convenient retrofit solutions to reduce both energy consumptions and life-cycle costs, the theoretical results coming from the energy dynamic simulation of CORTAU House and from the energy certificate prepared before the occupancy period are compared with the actual consumptions during the year 2017 (as gathered from electricity bills). Moreover, given the key role played by occupants in the difference between theoretical and actual consumptions, a survey submitted to CORTAU final users allowed exploring the main criticalities and potentialities of living and operating an NZEB.

Materials and Methods

The paper aims to compare the theoretical and actual energy performance of an NZEB and to identify the major causes behind the discrepancies of the results. To do this, the work is divided into two stages. The first stage can be identified as the pre-occupancy phase; in particular, this stage consists in the preliminary study of the building through the performance of energy simulations (using EnergyPlus energy dynamic software) and the analysis of the building energy certificate, delivered prior to occupancy period, in order to obtain theoretical energy consumptions. The second stage, also identified as post-occupancy phase, considers the interaction of the occupants with the building systems, by collecting and critically analysing the energy bills, to compare the real consumptions with the simulated ones.

Finally, considering that the occupant has become the centre of the concept of NZEB (European Commission, 2018), a survey was submitted to the inhabitants, to have feedback from the final users, highlighting benefits and criticalities of living in such a complex and high-performance building.

Case study

The case study for the pre- and post-processing of occupants' behaviour is CORTAU House (see **Figure 1**), an all-electric NZEB recently obtained from the retrofit of a traditional rural building (namely "*curmà*"). The building, located in Piedmont region, in the North-West of Italy (climate zone E), has a 147 m² floor area. Its construction started in March 2014 and finished in 2016.

In accordance with the afore-mentioned 2010 EPBD Recast, the building is a representative refurbishment example, since the cost-optimal methodology was implemented during the preliminary design phase, allowing to identify the package of retrofit measures able to minimize both primary energy consumption and global cost. In the case of CORTAU, different envelope and HVAC system configurations were evaluated on energy and financial basis. Four envelope strategies were considered (identified with progressive numbers from 1 to 4), each defined according to specific regulation requirements, in force at national (1), city (2), and international levels (3,4) (Barthelmes et al., 2015). Similarly, four HVAC system configurations were identified (with a letter from A to D), varying in terms of energy production system, as well as of installed renewable energy technologies. In particular, configurations A and B consider the use of condensing gas boiler and radiant floor for space heating, and multi-split air conditioner for space cooling. Configurations C and D, instead, consider the introduction of a water-to-water heat pump, coupled with radiant floors, for both space heating and cooling. Configurations A and C use natural ventilation, while configurations B and D assume the use of a controlled mechanical ventilation (CMV) system. Finally, all configurations consider the use of solar collectors for covering the domestic hot water (DHW) production, and of photovoltaic (PV) panels for matching part of the electricity demands (even if with different installed peak power: 2.6 kW_{peak} for configuration A, 3.4 kW_{peak} for configuration B, and 7 kW_{peak} for C and D). The combination of envelope and system strategies led to the definition of 16 energy design scenarios (see **Figure 2**), which were compared using the cost-optimal methodology. All scenarios were simulated using EnergyPlus software, for evaluating their energy performances, while the economic assessment was done based on the global cost calculation, as defined by (EN 15459-1:2017).

Based on the described methodology, the cost-optimal level for the refurbishment of CORTAU House is identified in the scenario 2C. However, in the design phase, team designer and owners have opted for the configuration 2D (see **Figure 2**), which differs from the cost-optimal level for the adoption of the CMV system (Barthelmes et al., 2015). Moreover, thanks to the use of PV panels and water-to-water heat pump, the national requirements in terms of Renewable Energy Sources (RES) coverage were largely met, thus not asking for the need to install the solar collectors on the roof. CORTAU House, today fully occupied, presents a water-to-water heat pump with 4.4 COP and 4.2 EER, coupled with radiant floor for space cooling and heating, and a CMV system equipped with heat recovery. A 6.3 kW_{peak} PV plant is installed on the roof. The thermal properties of the envelope are in line with Turin regulation (0.15 W/(m²K) for external walls and ceiling, 0.19 W/(m²K) for the slab and 0.96 W/(m²K) for the windows). Starting from the real characteristics of CORTAU House, a model was simulated with EnergyPlus, including standard occupants' behaviour in terms of heating and cooling set-points (20°C and 26°C, respectively), while schedules for occupancy, lighting and equipment usage were set according to existing standards (Barthelmes et al., 2016).

Results

The following section describes the results of the analysis, aiming to show and discuss the gap between theoretical and real consumption values. Theoretical results are assessed either with preliminary energy certifications of the building or with energy dynamic simulations during the design and operation phases. First, looking to the energy certification, performed at the end of 2015 (and thus during the pre-occupancy period), a primary non-renewable energy value of 11.08 kWh/(m²·year) was obtained, which considers only the energy consumption for space heating, space cooling, ventilation and domestic hot water production (being electricity consumption for

Figure 1. CORTAU House current architectural design (Barthelmes et al., 2015).

lighting and electric equipment excluded). In order to compare the value with the real consumptions in the post-occupancy phase, electricity bills were collected for the year 2017 (total electricity from the grid equal to 4 457 kWh/year), while thanks to the on-going monitoring campaign of the PV production, the electricity locally produced in 2017 was gathered (equal to 6 513 kWh/year). Moreover, by estimating the usage profiles of the main interior electrical equipment installed within the building, it was possible to isolate the real electricity consumption for space heating, space cooling, ventilation and domestic hot water production (equal to 7 663 kWh/year). Therefore, parallelly to what assumed for the energy certification (namely to consider the PV production as available for matching the climatization consumption only), it was possible to obtain an overall electricity consumption from non-renewable sources equal to 7.82 kWh/(m^2·year). The correspondent value of primary non-renewable energy of 15.3 kWh/(m^2·year) was obtained (with a 1.95 conversion factor). As expected, this value is higher than the value shown in the energy certification, showing a percentage discrepancy of 38% between theoretical and real value.

Similar comparison was performed, considering the ideal results coming from the simulation of the EnergyPlus model. The differences between model and real values, in terms of electricity consumption, PV production and purchased electricity from the grid, are shown in **Figure 3**.

Ideal results from simulations are influenced by standard settings in terms of occupancy schedules, lighting and electrical equipment densities and schedules of usage. For this reason, it is well known that energy dynamic simulations, besides being fundamental to understand the energy behaviour of a building, represent ideal situations, far from the reality. Indeed, electricity consumptions reported in the energy bills, gathered from CORTAU occupants, show that the electricity purchased from the grid in the real situation is higher than what expected from simulations.

The differences between theoretical and real results might be conducted to two main causes. The first one can be defined as external climate, since irradiation, external temperature and humidity vary year by year (and thus differing from climatic data used for the simulations),

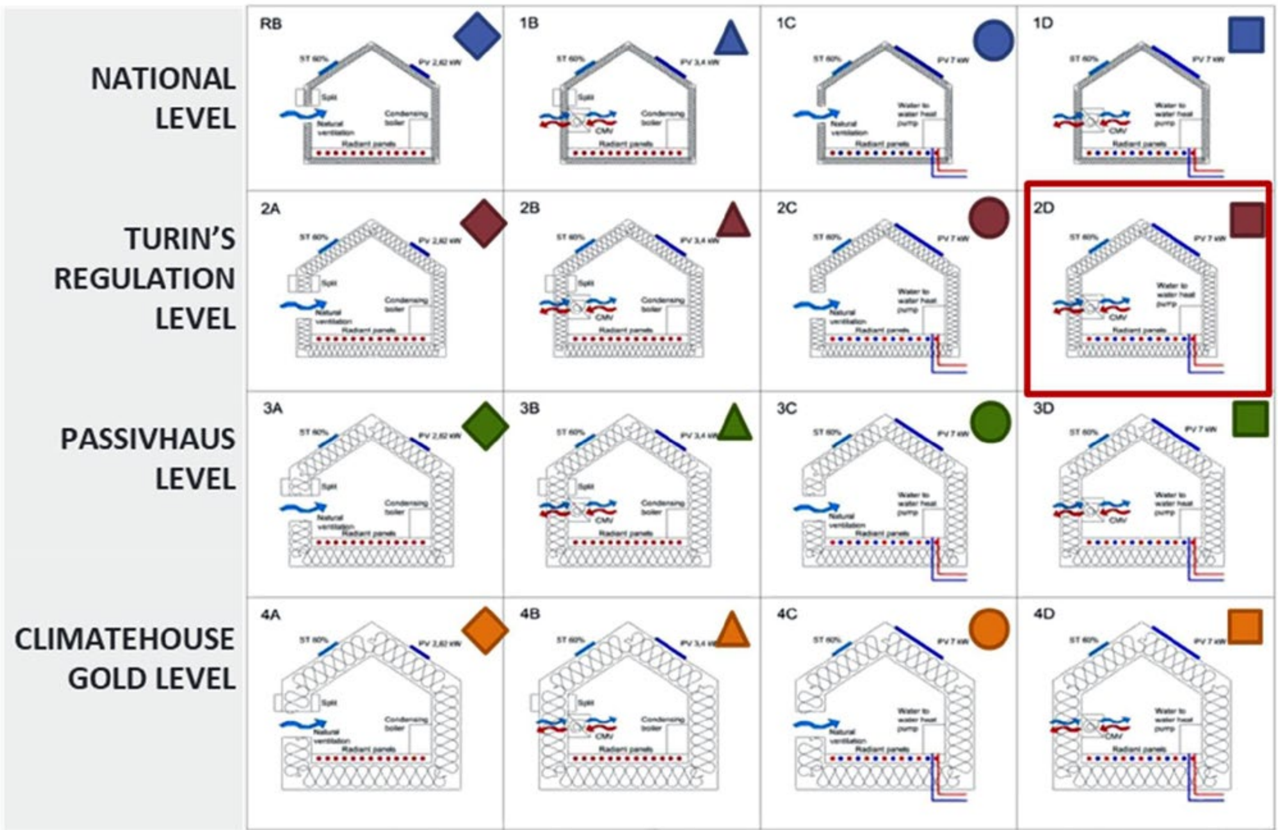


Figure 2. Matrix of 16 energy design scenarios for CORTAU House retrofit (Barthelmes et al., 2014).

influencing the real consumptions of the building. This result is shown in **Figure 3**, since the electricity produced by the PV system in 2017 is higher than what simulated in the EnergyPlus model. Furthermore, the second cause of discrepancy is represented by occupants, whose real behaviour can be very different from existing standards, due to different perceptions in terms of thermal comfort, and therefore different settings in terms of temperature set-points or ventilation requirements. The effect that occupant behaviour can have on consumptions was well captured in (Barthelmes et al., 2016), where different lifestyles were simulated in EnergyPlus, showing that a low consumer profile (representative of an occupant attentive to energy matters) could reduce overall energy use up to 28%, just operating electrical equipment in a more conscious way.

In this framework, given the importance that occupant behaviour plays in the overall building consumptions, it is important to better capture which are the feelings that occupants have when dealing with an NZEB, as well as the difficulties they may feel in case of smart buildings, in which their control over the building systems could be reduced. Thanks to an interview submitted to CORTAU occupants, it was possible to identify the main pros and cons perceived by NZEB users. The main criticalities emerged from users' feedbacks are mainly related to the interaction with the HVAC systems installed within the building:

- Difficulty in getting used to a DHW temperature different from that produced by a boiler system;
- Difficulty in getting used to the CMV system;
- Understanding the crucial role of dehumidification associated with the use of radiant floor cooling system during summer season, in order to reduce air humidity and to avoid condensation on the surfaces;
- Difficulty in getting used to the thermal inertia of the floor radiant system.

Conversely, the main potentialities defined by CORTAU occupants derive from a better thermal comfort within the internal spaces, achieved thanks to the use of radiant system coupled with CMV:

- Feeling of a better indoor comfort and air temperature distribution thanks to the presence of the radiant system;
- Possibility to maintain a lower indoor air temperature during the heating season, obtaining energy savings;
- Perception of a pleasant indoor temperature in winter season thanks to solar load;
- Use of shading systems to reduce the solar radiation entering the building, obtaining energy savings.

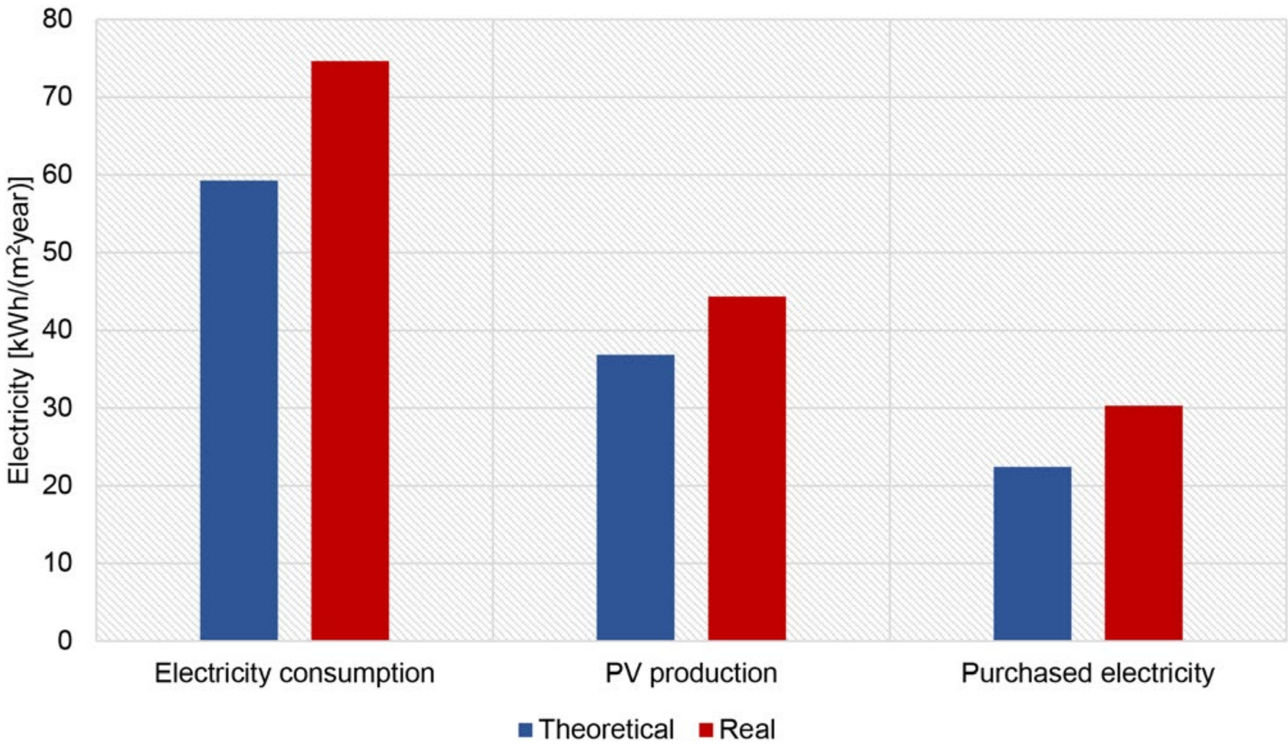


Figure 3. Comparison of electricity features between theoretical and real values.

Conclusions

Nearly-zero energy buildings represent sustainable solutions to reach the ambitious decarbonization targets suggested by the European Union for the building sector. Nowadays, although efficient design and existing technologies allow to reach the NZEB targets, the role of occupants in the final consumptions is considerable. For the above-mentioned reasons, it is necessary to realize an accurate preliminary design phase to evaluate consciously the effect of different system technologies and envelope solutions. Moreover, an estimation of the possible causes of energy consumption diversions due to the modification of the condition of use, caused by different occupant behaviours, should be performed.

In this paper, the single-family CORTAU House was analysed in order to compare the theoretical energy consumptions estimated from the dynamic simulation of EnergyPlus and from the preliminary energy certification of the building during the pre-occupancy period, with the actual consumptions reported in the electricity bills. Results show a discrepancy of 38% between the certification value and the real one, in terms of primary non-renewable energy. Moreover, the comparison between energy simulation and electricity bills shows a real electricity consumption of 26% higher than the simulated value. Besides the effect that climate external conditions can have on results, a significant gap is due to occupant behaviour.

It is necessary to underline that the comparison between theoretical and actual energy consumption is based on an annual assessment. In order to achieve a more complete view, it would be interesting to consider more years in the evaluation of the energy bills, to potentially explore the effects of diverse climate conditions on overall results, as well as to increase the temporal granularity of the analysis, including monthly reports from energy bills.

To conclude, it can be said that the NZEB market is ready to be successful from a technology standpoint, however, there are still some critical issues to be carefully addressed, from design and construction phases, to the operational one. First, it is fundamental to find trained manpower able to concretely realize the NZEB project. Moreover, it is extremely important to have an occupants' education phase, before their entrance into the house. Indeed, NZEB building could be seen as a complex machine to be managed, which misuse can lead to excessive energy consumptions, despite the high-performance level of technologies and envelope components installed. ■

Acknowledgement

Authors want to thank Rhoss S.p.A, HVAC company which followed the refurbishment works of CORTAU House.

Conflict of interest

Authors declare that there are no economic or other conflicts of interest on the presented article.

References

Barthelmes V.M., Becchio C., Bottero M.C., Corgnati S.P. 2014. The Influence of Energy Targets and Economic Concerns in Design Strategies for a Residential Nearly-Zero Energy Building. Buildings 4, 937-962.

Barthelmes V.M., Becchio C., Corgnati S.P., Guala C. 2015. Design and construction of an nZEB in Piedmont Region, North Italy. Energy Procedia, 78, 1925-1930.

Barthelmes V.M, Becchio C., Corgnati S.P. 2016. Occupant behaviour lifestyles in a residential nearly-zero energy building: Effect on energy use and thermal comfort, Science and Technology for the Built Environment 22, pp 960-975.

European Parliament (2010). Directive 20/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Brussels.

European Parliament (2018). Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Brussels.

EN 15459-1:2017, Energy performance of buildings - Economic evaluation procedure for energy systems in buildings - Part 1: Calculation procedures, Module M1-14, Annex D.

ALDREN

Smart Readiness Indicator for building – integration in the ALDREN EPC

JOHANN ZIRNGIBL
CSTB, France
johannzirngibl@aol.com

PIERRE BOISSON
CSTB, France

OLIVIER GRESLOU
CSTB, France

JANA BENDZALOVA
ENBEE s.r.o. – Slovakia

The smart readiness, achieved by better automation, new functionalities related digitalisation and electromobility, contribute to a better building quality and increase the building value. The Commission Delegated Regulation (EU) 2020/2155 (oct 2020) establish a smart readiness methodology defining a Smart Readiness Indicator (SRI). This article presents the EU methodology and the practical implementation by the ALDREN Energy Performance Certificate.

Keywords: Building automation, Commission Regulation, smart Buildings, Smart Readiness Indicator, Energy Performance Certificate

Context

DIRECTIVE (EU) 2018/844 of 30 May 2018 amending the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) complete the energy assessment of buildings by an optional indicator called "Smart Readiness Indicator" (SRI). The intention is to support building digitalisation, new functionalities, automation and monitoring of technical building systems for improvement of energy efficiency. The Commission Delegated Regulation (EU) 2020/2155 of 14 October 2020 establish an optional common Union scheme for rating the smart readiness of buildings defining the smart readiness indicator and a common methodology for calculation [1].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 754159.

The integration of the SRI underlines the more and more holistic approach of the building assessment, (e.g. by enlarging the assessment from energy to health and wellbeing), digitalisation and the integration of the building in the infrastructure of an overall decarbonisation of the economy, e.g. by including the transport sector. Car batteries, and their smart charging - discharging, make possible to use them as a source of power and storage, e.g. to secure intermittent energy supply of on-site renewable energy production.

The smart readiness indicator measures the capacity of buildings to use information and communication technologies to adapt the operation of buildings to the needs of the occupants and the grid, to improve the energy efficiency of the building and the energy chain (supply and demand optimisation).

The SRI should raise awareness and confidence of the value of building automation, new enhanced-functionalities and equipment by showing the Smart readiness level of the building. The SRI, based on transparent advisory tools, will also contribute to reduce the risk of investments in the building sector if used in due diligence.

The SRI completes the information of the building owner and user on the quality of the building and should therefore be integrated in the Energy Performance Certificate as the ALDREN EPC (https://aldren.eu/) [3] and the EPC RECAST (still ongoing) [4].

The structure of the SRI rating system – SRI methodology

Three "SRI key functionalities"

Annex IA of the Directive establish a general framework for the rating of the smart readiness of buildings.

The framework relies on three SRI key functionalities:

- the ability to maintain the energy performance by the adaptation of the energy consumption;
- the ability to maintain healthy indoor climate conditions, by adapting its operation mode to the needs of the occupant and to report on energy use;
- the ability to establish a grid flexibility of the building's overall electricity demand (e.g. load shifting).

To work out the details and to support Member States in the transposition of the general framework, the EU Commission financed a service contract [2]. To illustrate the three SRI key functionalities a tri-partite mnemonic is proposed (see **Figure 1**).

Seven smart ready service impact criterion

The rating of the SRI is based on "smart ready services". Smart-ready service means a function, or an aggregation of functions provided by one or more technical components or systems. Examples of Smart ready services are heat emission control, control of distribution pumps, generator control for cooling, etc. The information source to define the smart ready service are largely based on European standards. A smart ready service can provide several impacts. An impact criterion means a key impact that smart-ready services are designed to achieve. In the proposed approach, a set of seven "impact criteria" is evaluated (see **Figure 2**).

Figure 1. Tri-partite mnemonics illustrating the three SRI key functionalities. (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

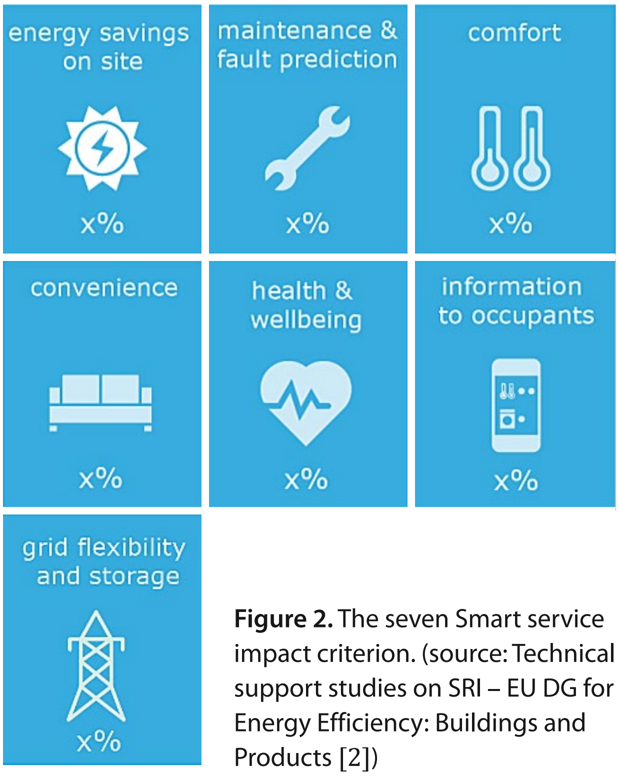


Figure 2. The seven Smart service impact criterion. (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

The seven impact criterion are linked to the three SRI key functionalities in the following way:

a) Key functionality "**Energy savings and maintenance**" is linked to the impact criterion:
   - "Energy savings on site" which refers to energy saving capabilities (e.g. resulting from better control of room temperature settings);
   - "Maintenance and fault prediction" which may significantly improve the operation of the technical building systems;

b) Key functionality "**Comfort, ease & wellbeing**" is linked to the impact criterion:
   - "Comfort" which refers to conscious and unconscious perception of the physical environment, including thermal comfort, acoustic comfort and visual performance (e.g. provision of sufficient lighting levels without glare);
   - "Convenience" which refers to services which "make life easier" for the occupant (e.g. systems requiring fewer manual interactions);
   - "Health and well-being" which refers to smarter controls that can deliver an improved indoor air quality compared to traditional controls;
   - "Information to occupants" which refers to the provision of information on building operation.

c) Key functionality "**Grid flexibility**" is linked to the impact criterion:
   - "Grid flexibility and storage" which refers to the energy flexibility potential of the building on the grid (e.g. electricity grids, district heating).

In the actual proposal a list of 55 smart ready services is proposed.

"Functionality level" and "impact score"

Each of the services can be implemented with various degrees of smartness. The degree (level) of smartness is expressed by the "functionality level". For each service up to 5 functionality levels (level 0 – level 4) are defined. A higher functionality level reflects a "smarter" implementation of the service, which provides more beneficial impacts to the building.

For each functionality level an "impact score" (e.g. 0 – 3) has been defined for each of the seven impact criteria (see **Figure 3**). While most of the impacts are positive, some of them may also be negative (e.g. uncontrolled charging of batteries on grid flexibility).

Figure 4 shows the example of the smart ready service "Heat emission control" where five functionality levels are defined ranging from "no automatic control" (level 0) to "occupancy detection" (level 4). It is considered that the impact score for level 0 is 0 for the seven impact categories. Functionality level 4 has an impact score of 3 on impact category "Energy savings on site".

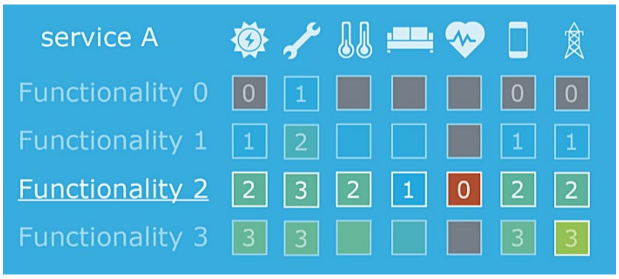


Figure 3. Functionality levels and impact scores for the seven impact categories of "service A" (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

domain heating								
code	service	1						
Heating-1a	**Heat emission control**	Service group: Heat control - demand side						
Functionality levels		IMPACTS						
		Energy savings on site	Flexibility for the grid and storage	Comfort	Convenience	Health & wellbeing	maintenance & fault prediction	information to occupants
level 0	No automatic control	0	0	0	0	0	0	0
level 1	Central automatic control (e.g. central thermostat)	1	0	1	1	1	0	0
level 2	Individual room control (e.g. thermostatic valves, or electronic controller)	2	0	2	2	2	0	0
level 3	Individual room control with communication between controllers and to BACS	2	0	2	3	2	1	0
level 4	Individual room control with communication and occupancy detection	3	0	2	3	2	1	0
	Information sources							
	Standard?	EN 15232						

Figure 4. Example of service "Heat emission control" and impact scores for the seven impact categories (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

"Technical domains"

A technical domain means a collection of smart-ready services which, together, realise an integrated and consistent part of the services expected from the building or building unit such as heating. In the developed SRI service catalogues the smart ready services are structured within nine "technical domains": heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, monitoring and control.

The technical domains are also the most detailed level of smartness scores information (see **Figure 5**).

Smart readiness score (%) – from the smart ready service to the single building score

The smart readiness score means the score obtained by a building or building unit as part of the process for rating smart readiness. The process of scoring starts with the assessment at domain level, per impact criterion by evaluating the impact scores (absolute values).

Once all these individual services impact scores are known, an aggregated impact score is calculated for each technical domain. The domain impact score is calculated as the ratio (expressed as a percentage) between individual scores of the domains' services and theoretical maximum individual score.

For each impact criterion, a total impact score is then calculated as a weighted sum of the domain impact scores. The weight of a given domain will depend on its relative importance for the considered impact. The weighting factors for the technical domains are derived from the importance of the domain in the overall energy balance of the building. For example, the heating domain will gain importance in northern areas of Europe, whereas the relative importance of the cooling domain would increase in southern areas of Europe. For domains where no direct link with an energy balance can be made (e.g. monitoring & control), a weighting factor can be defined based on the estimated impact.

The proposed methodology provides default weighting factors which are differentiated by building type and climate zone.

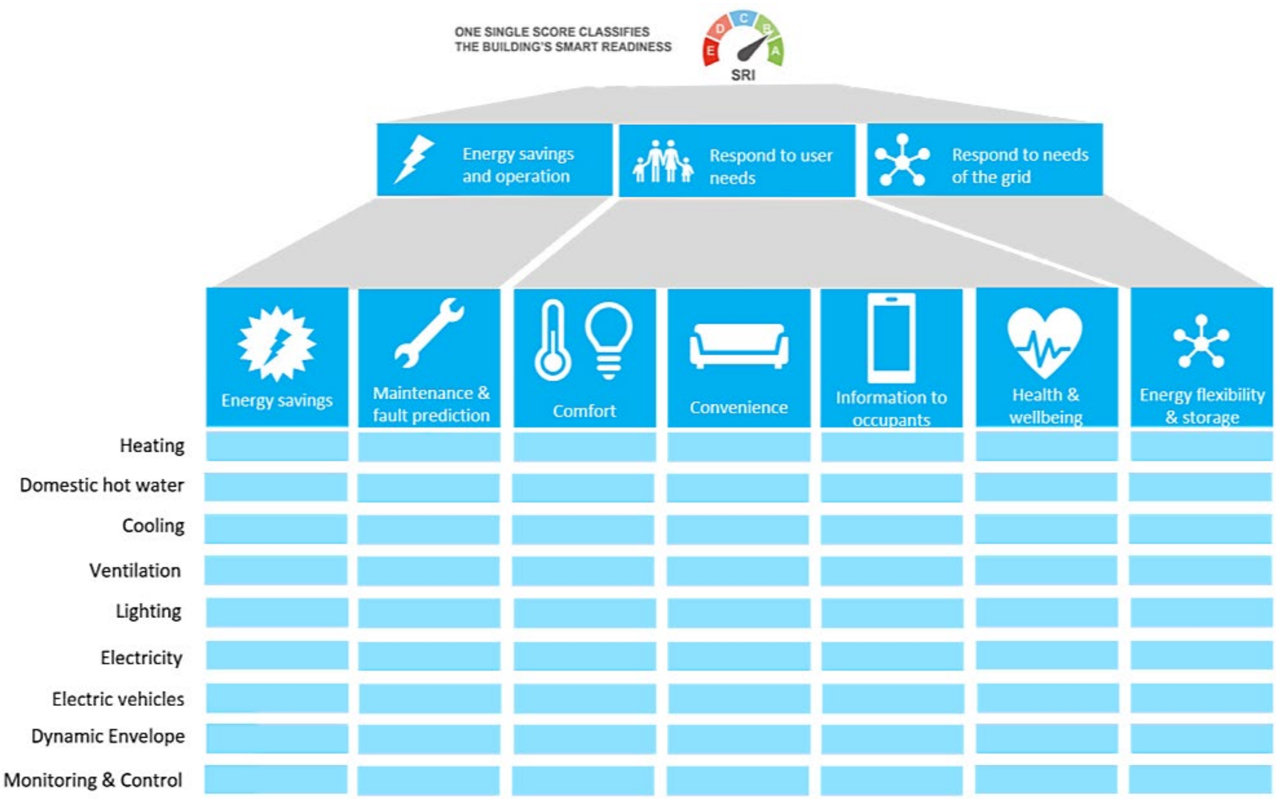


Figure 5. Overall structure of 9 domains, 7 impact criterion, 3 SRI key functionalities and the final single score. (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

The final single building SRI score (see **Figure 6**) is the weighted sum of the 3 SRI key functionalities. The aggregated SRI score indicates the overall smartness level of the building, while sub-scores allow to assess specific domains and impact categories.

The ALDREN-SRI contribution and integration in the ALDREN EPC

The objective of the European Commission funded H2020 project ALDREN (**AL**liance for **D**eep **REN**ovation in buildings) is to support the holistic approach of the EPBD building assessment by providing practical common methods and tools to help the Member States to implement the new requirements of the amended EPBD (2018). The backbone of ALDREN is the European Voluntary Energy Performance Certificate (ALDREN-EPC [5] including the most detailed set of indicators, e.g. non-renewable primary energy, indoor environment score and quality indicator ALDREN-TAIL, financial risk, reliability (see **Figure 7**).

The ALDREN EPC is completed by the ALDREN-BRP (Building Renovation Passport) [6] which contains a Building data depository (the building logbook) and a Building Renovation Roadmap (see **Figure 8**). The optional building renovation passport and the step-by-step renovation roadmap is a recommendation in the amended EPBD.

The ALDREN EPC has a modular structure that allows Member States to adopt specific modules to complete the official certification scheme and comply with other duties of MSs coming from EU commitments, such as the reporting for SRI.

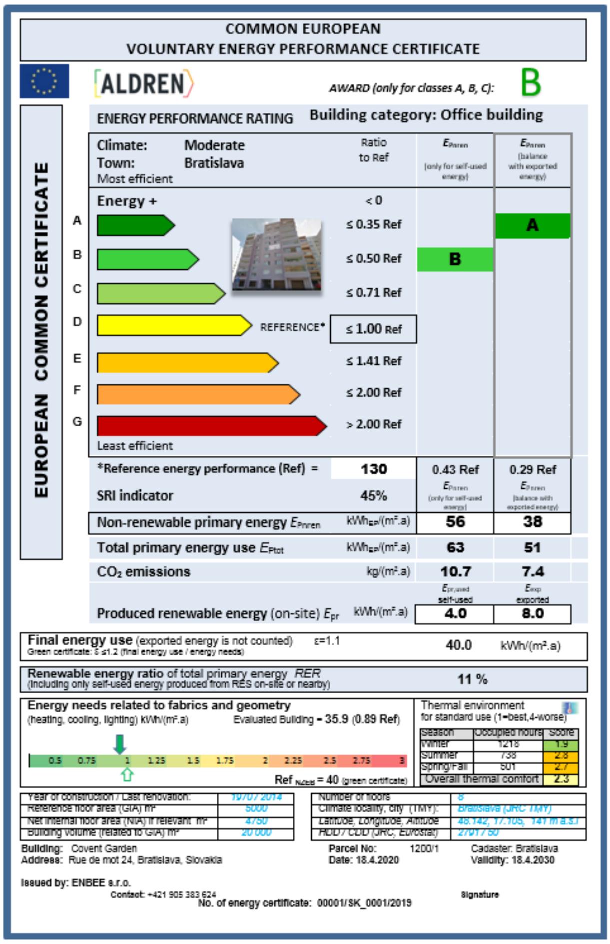


Figure 7. Front page of the ALDREN-EPC (source: The ALDREN project https://aldren.eu/)

Figure 6. Example of final single building SRI score (source: Technical support studies on SRI – EU DG for Energy Efficiency: Buildings and Products [2])

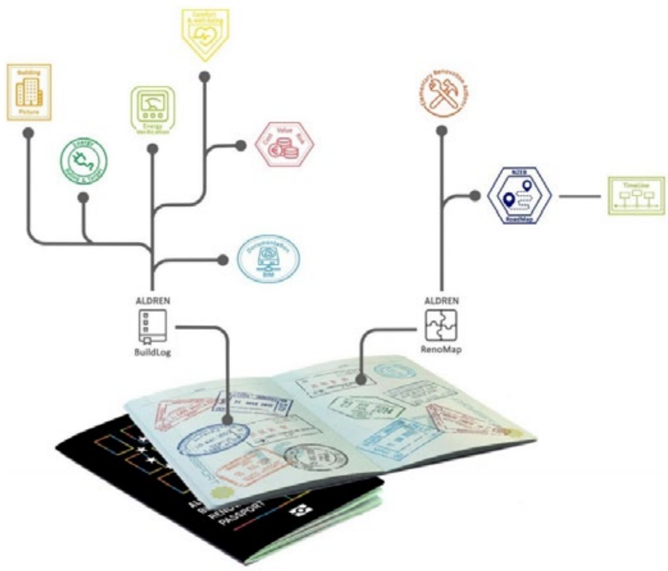


Figure 8. ALDREN BRP elements and modules (source: The ALDREN project https://aldren.eu/)

Assessment procedure and Data structure / collection (Inspection protocols)

In the proposed SRI methodology, three SRI assessment procedures are described:

- Method A is based on a simplified and limited service list (e.g. for residential buildings). The assessment should take less than one hour for a single-family home;
- Method B is based on a full catalogue of smart services (e.g. for more complex non-residential buildings). The assessment could take 0,5 to 1 day;
- Method C could be a metered/measured method.

The assessment time depends on the degree of complexity of the SRI, but also on the available data. Therefore, ALDREN included in the ALDREN-BRP data catalogue a section related to the SRI, considering the Smart Readiness services and the functionality levels (see **Figure 9**).

During an ALDREN EPC inspection, the needed SRI data should be collected at the same time. Some of the SRI data are redundant with the ALDREN EPC data, for example the Heating control data are needed for the SRI and the EPC. By harmonising the SRI data with the ALDREN modules, synergies will be created, redundancy and overlapping data collection will be avoided. Common Inspection and Data collection protocols will be further developed in the EPC RECAST project.

Recommendations – the ALDREN "upgrade action package"

One of the main targets in Energy Performance Certificates (EPC) is allowing building owners, investors to better understand the quality of the existing building, e.g. on controls, services and the potential for improvements. In the SRI methodology the potential improvements are indicated in functionality levels of each of the 55 Smart ready services. This leads to the fragmentation of the information and makes it complicated for the SRI evaluator to formulate a coherent and understandable recommendation to the building owner.

In the SRI proposal, the Smart Ready services and related functionality levels are structured by technical domain. In addition, ALDREN developed a tool, clustering potential upgrades in "action packages". For example, the possible recommendations to reach a higher SRI score by control functionalities are resumed in the following upgrade action packages:

- Presence of controllable flexibility;
- Interactions with the grid;
- Demand Side Management (DSM) & control.

In the ALDREN-EPC a page is dedicated to the Smart Readiness Indicator. The SRI scores are presented for

ALDREN ALliance for Deep RENovation in buildings

Building Picture

S.C.	CODE	INDICATORS	VALUE
	7	SMART READINESS SERVICES (SRI)	
	7,1	HEATING	
	7.1.1	Heat emission control	Select
	7.1.2	Emission control for TABS (heating mode)	Select No automatic control Central automatic control (e.g. central thermostat) Individual room control (e.g. thermostatic valves, or electronic co Individual room control with communication between controllers Individual room control with communication and occupancy dete
	7.1.3	Control of distribution fluid temperature (supply or return air flow	
	7.1.4	Control of distribution pumps in networks	
	7.1.5	Thermal Energy Storage (TES) for building heating (excluding TABS)	
	7.1.6	Heat generator control (all except heat pumps)	Select
	7.1.7	Heat generator control (for heat pumps)	Select
	7.1.8	Sequencing in case of different heat generators	Select
	7.1.9	Report information regarding heating system performance	Select

Figure 9. ALDREN-BRP data catalogue considering SRI Smart Readiness services and functionality levels. (source: The ALDREN project https://aldren.eu/)

the current situation and the potential score after a proposed improvement. **Figure 10** shows an example related to the impact criteria "Energy demand flexibility". The recommendations to improve the flexibility score of the building are reported under the table based on the three action packages shown before.

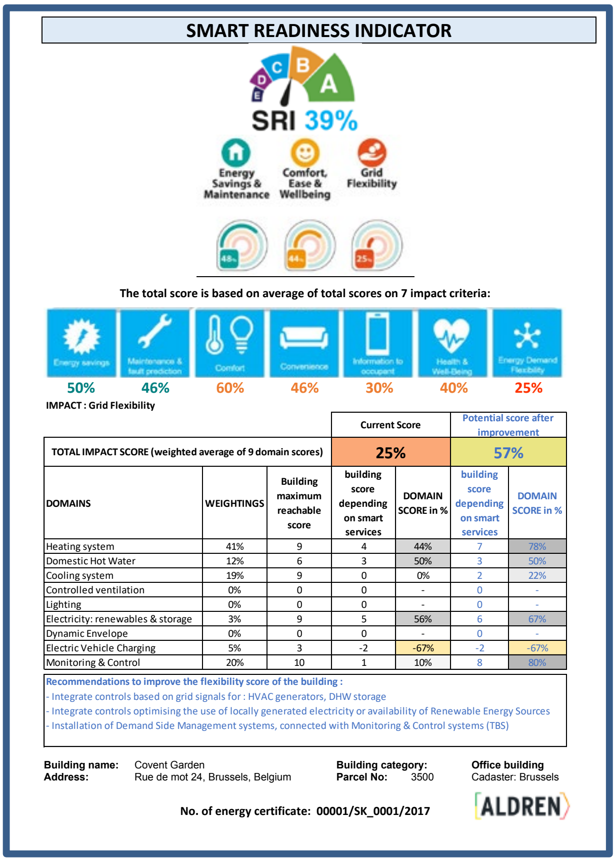
The SRI, not stand-alone but part of the EPBD ecosystem

The EPBD "ecosystem" is mainly composed by Building quality assessment (EPC, BRP) and qualified experts using both national or common European methods based on European Standards.

The SRI is an additional and complementary indicator of the EPBD for building quality assessment. The EPBD defined already other indicators as the Renewable Energy Ratio (RER), the non-renewable Primary Energy Indicator (PEnren) etc. All together they contribute to inform about the quality of the building via the Energy Performance Certificate and the Building Passport.

Therefore, the SRI should not be considered as a "stand-alone" but as a part of the EPBD ecosystem. As already mentioned, this holistic approach will avoid misleading information and will allow to create and take benefit of the synergies, for example in common Inspection and data collection protocols.

The training on SRI assessment and the qualification of SRI expert should also be part of an integrated training on the EPBD (e.g. the methodology for calculating the energy performance of buildings (Article 3), the issue of energy performance certificates (Article 12), the inspection and report on technical building systems (articles 14,15,16), the quality check (Article 18) etc). Article 17 on Independent experts also request that the certification of buildings and the inspection of systems are carried out in an independent manner by qualified and/or accredited experts. It is likely that the SRI training and certification of expert only on SRI is economically not sustainable and technically not suitable because the synergies mentioned before would not be reached. The SRI training should be part of a modular training and certification structure of experts (see **Figure 11**) as proposed in the H2020 CEN-CE project [7].



SMART READINESS INDICATOR

SRI 39%

Energy Savings & Maintenance — Comfort, Ease & Wellbeing — Grid Flexibility

The total score is based on average of total scores on 7 impact criteria:

Energy savings	Maintenance & fault prediction	Comfort	Convenience	Information to occupant	Health & Well-Being	Energy Demand Flexibility
50%	46%	60%	46%	30%	40%	25%

IMPACT : Grid Flexibility

DOMAINS	WEIGHTINGS	Building maximum reachable score	Current Score: building score depending on smart services	Current Score: DOMAIN SCORE in %	Potential score after improvement: building score depending on smart services	Potential score after improvement: DOMAIN SCORE in %
TOTAL IMPACT SCORE (weighted average of 9 domain scores)			25%		57%	
Heating system	41%	9	4	44%	7	78%
Domestic Hot Water	12%	6	3	50%	3	50%
Cooling system	19%	9	0	0%	2	22%
Controlled ventilation	0%	0	0	-	0	-
Lighting	0%	0	0	-	0	-
Electricity: renewables & storage	3%	9	5	56%	6	67%
Dynamic Envelope	0%	0	0	-	0	-
Electric Vehicle Charging	5%	3	-2	-67%	-2	-67%
Monitoring & Control	20%	10	1	10%	8	80%

Recommendations to improve the flexibility score of the building :
- Integrate controls based on grid signals for : HVAC generators, DHW storage
- Integrate controls optimising the use of locally generated electricity or availability of Renewable Energy Sources
- Installation of Demand Side Management systems, connected with Monitoring & Control systems (TBS)

Building name: Covent Garden — Building category: Office building
Address: Rue de mot 24, Brussels, Belgium — Parcel No: 3500 — Cadaster: Brussels

No. of energy certificate: 00001/SK_0001/2017

ALDREN

Figure 10. ALDREN EPC page reporting SRI example on Energy demand Flexibility (source: The ALDREN project https://aldren.eu/)

CEN-CE
CEN EPB Standards Certified Experts

Certificate
Registration number: HR-01-C-029-2019
confirming that
Mirko Boljevic
born on 17.09.1966

attended training, passed exam
and is a CEN EPB Standards Certified Expert for the following EPB Standards:

Overarching standard EN ISO 52000-1:2017 (M1-1, M1-2, M1-3, M1-5, M1-7, M1-8, M1-9, M1-10)
Heat load EN 12831-1:2017 (M3-3)
Emission & controls EN 15316-2:2017 (M3-5)
DHW needs EN 12831-3:2017 (M8-2)
Distribution systems EN 15316-3:2017 (M3-6)
Measured energy EN 15378-3:2017
Generation - Boiler EN 15316-4-1:2017
Inspection of boilers EN 15378-1:2017
Generation – Heat pump EN 15316-4-2:2017
Economics EN 15459-1:2017
Generation – Solar, PV EN 15316-4-3:2017 — 4.12.2019 ✓
Wind turbines EN 15316-4-10:2017 (M11-
Integrated cogeneration EN 15316-4-4:2017 (M3-8-4)
District Heating & Cooling EN 15316-4-5:2017
Storage systems EN 15316-5:2017 (M3-8-7) — 4.12.2019 ✓
Generation - Local heaters EN 15316-4-8:2017
EQF level 5, 6

Zagreb, 4.12.2019
Emilien Paron
Central Scheme Operator

TO / Fakultet strojarstva i brodogradnje Ivana Lučića 5, 10002 Zagreb, p.p. 102, Croatia / Reg. No: TO-HR-01
CSO / CSTB, 84 avenue Jean Jaurès, Champs-sur-Marne, 77447 Marne-la-Vallée Cedex 2, France

This project has received funding from the EU's Horizon 2020 research and innovation programme under GA No. 78501

ENBEE — FSB — CSTB — SLR — REHVA

Figure 11. Examples of CEN-CE modular training Certificate (source: The CEN-CE project https://www.cen-ce.eu/

As the EPBD is a framework Directive, the final technical details of transposition on national level are defined by the Member States. The Commission Delegated Regulation (EU) 2020/2155 stipulates:

- Annex III: Member States shall define the respective weighting factors of relevant impact criteria;
- Annex VI: Member States make available at least one smart-ready catalogue. It includes the related functionality levels, and corresponding individual scores for the impact criteria.

In the EU there are around 30 different regional and national methodology for calculating the energy performance of buildings transposing Article 3/EPBD. This leads to a fragmentation of the EU market, where easy comparability and rating of energy performance is impossible. The consequence are also barriers for the qualification of experts EU wide and additional costs for the industry and the user.

This situation should be avoided for the SRI implementation. To help the Member States to harmonise their calculation methodologies, the Commission supported the development of European Standards (mandate 480). When possible, these standards (e.g. EN 15232 [8], EN ISO 52000-1 [9]) should also be the basis of the smart-ready catalogue and the related functionality levels. The link to the EU standards will also facilitate further development of the SRI methodology, for example from a purely qualitative methodology to a more quantitative appreciation. The EN ISO standard 52000-1 proposes already in Annex G Electrical grid load matching indicators (Use matching fraction, Production matching fraction, Grid interaction indicators) which could be used as **quantitative SRI indicators** in further SRI methodology development and applied consistently with the calculation of energy performance of building.

Resume and Conclusion

The definition of the SRI was a needed to show the value and contribution of building automation + control, of new enhanced-functionalities (e.g. operation flexibility) and equipment (e.g. electro vehicle loading station). The definition of a Smart Readiness Indicator is recommended in the amended EPBD (DIRECTIVE 2018/844 of 30 May 2018). An SRI methodology was worked out in an EU Commission financed "Technical support study on SRI". The principle of this study has been overtaken in the Commission Delegated Regulation (EU) 2020/2155 of 14 October 2020.

The ALDREN project integrated the SRI methodology in the ALDREN Energy Performance Certificate (EPC) and the ALDREN Building Renovation Passport (BRP) to demonstrate the practical implementation of the SRI methodology and to show the synergies between SRI, EPC and BRP. ALDREN harmonised the data structure of the SRI assessment with the data structure of the EPC / BRP to make the data collection more efficient, to avoid overlaps and redundancy. Common inspections and data collection protocols will be further developed in the EPC Recast project. ALDREN also developed a tool to structure the recommendations allowing building owners, investors to better understand the quality of existing controls/services and the potential for improvements.

The ALDREN SRI is a practical implementation of the Commission Delegated SRI regulation in the ALDREN EPC / BRP and an example of the integration in the EPBD ecosystem. A stand-alone SRI will complicate the market uptake because synergies with other EPC indicators would be missed, for example with the energy calculation in EN ISO 52000-1, which would complete the actual qualitative SRI approach by the quantification of the SRI impact.

Europe is the front runner in climate change mitigation. Several tools are under development or update (e.g. the EPBD, the EU green taxonomy, etc). It is key that all these tools talk a common language to keep consistency and to reduce the reporting burden. The synergies of SRI, EPC and the European Standards related to smart ready services should be used to create practical applications (e.g. inspection protocols, training and qualification of experts). A consistent approach would also allow to complete in future developments the purely qualitative approach of the actual SRI by a quantitative impact of smart ready services e.g. by using the software tools related to the EPBD.

The ALDREN-EVC, the ALDREN-BRP, the ALDREN-SRI are pieces which, if up taken by the EU Member States and other building key actors, contribute to build a common, coherent EU methodology to successfully reach the overall decarbonisation in the EU building sector by 2050. ■

References

Commission documents

[1] Commission delegated regulation (EU) 2020/2155 of 14 October 2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings.

[2] Stijn Verbeke (VITO), Dorien Aerts (VITO), Glenn Reynders (VITO), Yixiao Ma (VITO), Paul Waide (WSEE) Final report on the technical support to the development of a smart readiness indicator for buildings, Directorate-General for Energy (European Commission) , Vito, June 2020, https://op.europa.eu/en/publication-detail/-/publication/f9e6d89d-fbb1-11ea-b44f-01aa75ed71a1/language-fr

H2020 projects (ALDREN, CEN-CE, EPC Recast)

[3] Greslou O., Zirngibl J., Rivallain M., "ALDREN – A voluntary and modular European framework to support Deep Renovation in the Building sector", REHVA journal, August 2020.

[4] EPC RECAST - New toolbox to assess building energy performance and retrofit needs https://cordis.europa.eu/project/id/893118.

[5] BENDŽALOVÁ J., "ALDREN European Common Voluntary Certification Scheme and energy ratings", REHVA journal, August 2020.

[6] Sesana M., Salvalai G., Ligier S., Rivallain M., "The ALDREN Building Renovation Passport for Non-Residential buildings", REHVA journal, August 2020.

[7] Zirngibl J.; Paron E.; "CEN-CE in a nutshell - Upskilling HVAC professionals, the linchpin of the EU Green Deal"; REHVA journal, June 2020.

European Standards

[8] Standard EN 15232: Energy Performance of Buildings – Influence of Building Automation and Control and Building Management.

[9] Standard EN ISO 52000-1 Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures.

The original version of the article was published in the Journal of Heating, Ventilation and Sanitation, published by the Czech Society of Environmental Engineering.

Citation: Hemerka, J.; Vybíral, P.: Filter Classes Conversion between ČSN EN 779 and ČSN EN ISO 16890-1. In: Heating, ventilation, installation. 2020, 29 (4), 201-207. ISSN 1210-1389.

Filter Class Conversion between EN 779 and EN ISO 16890-1

JIŘÍ HEMERKA
doc. Ing, CSc
Department of Environmental Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague
jiri.hemerka@fs.cvut.cz

PAVEL VYBÍRAL
Ing., Ph.D.
Department of Environmental Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague
pavel.vybiral@fs.cvut.cz

With respect to the seriousness of the issue and the time delay concerning the filter classes conversion between EN 779:2012 and EN ISO 16890-1:2016 for filters for general ventilation, the following chapters briefly present the characteristics of the new filter classification and summarise the main differences between the two classification systems. An overview of the available approximate conversion relationships that can contribute to the accelerated implementation of the new filter classification system is presented.

Keywords: filtration, filter classification, filter classes, filters for general ventilation, conversion relationships between filter classes, standardization in the field of filters for general ventilation

Introduction

The correct use of atmospheric air filters for general ventilation is based on the separation ability of the filters, expressed as a function of the fractional efficiency on the particle size, on the particle size distribution and the concentration of the particles in the carrier air in a given case.

The ISO 16890-1 standard from December 2016 [1] brought, in comparison with EN 779 [2], new valuable direct information about the separation abilities of filters and after incorporation into the structure of EN in 2016 ([3], [4], [5], [6]), was expected to be widely used, especially in Europe. The concurrence of the EN 779 and EN ISO 16890 standards ended in the middle of 2018. Since then, there should have been only two systems in the world – ISO 16890 (EN ISO 16890) and the American ASHRAE 52.2.

The reality of the transition to the new standard during 2020 is somewhat different than from what was envisaged in the transition schedule. The revision and repeal of EN 13779:2007 [7] in the field of ventilation of non-residential buildings and the creation of the new EN 16789-3:2017 guideline (Energy performance of buildings - Ventilation of buildings – Part 3: For non-residential buildings) [8] also “contributed” to the delay. In this basic and widely used standard, in the field of ventilation of non-residential buildings, revised with effect from August 2017, the basic text in Table 17 shows the minimum filtration efficiency requirements in [%] for 15 combinations of internal and external pollution; however, in Annex B Default choices in Table B.3 of the recommended minimum filter classes for each combination of external pollution category (ODAi) and the required quality (category) of the supply air (SUPi), there is a recommendation to still use the filter classes according to EN 779, and not to the ePM_x filter class according to EN ISO 16890 (Revision of the EN 16798-3:2017 is ongoing.).

As stated in contribution [9], to successfully transfer to a new classification system, the designers would need to answer the basic question: "For the specific application, the proven filter class has been used according to EN 779 so far. Which filter class is to be used according to the new standard?"

The answer is not simple, because due to the differences in the classification systems, there is no direct conversion between the two systems. In addition, there is a solution duplication, because, for example, some $ePM_{2.5}$ base group filters with a higher efficiency can be replaced by the ePM_1 base group filters with a lower efficiency.

With regard to the seriousness of the issue of the filter class conversion between EN 779 and EN ISO 16890-1, the following chapters briefly present the characteristics of the new filter classification, summarise the main differences between the two sorting systems and provide an overview of the available conversion relationships.

The aim of the paper is to contribute to overcoming the existing, and going beyond the expectations of a long and undesirable, transition period and to put the new sorting system into practice.

Testing and classification of filters for general ventilation according to ISO 16890

ISO 16890-1, from December 2016 [1], introduces new indicators for the testing and classification of filters – the particulate matter fractions PM_{10}, $PM_{2.5}$ and PM_1.

The individual filter classes are defined according to the achieved ePM_x efficiency for the stated atmospheric dust fractions, starting with a particle size of 0.3 µm.

This standard was included in the structure of the EN standards as early as December 2016 as [3], [4], [5], [6].

The particulate matter fractions PM_{10}, $PM_{2.5}$ and PM_1 are defined in air pollution control as atmospheric dust particles smaller than the aerodynamic particle size of 10, 2.5 and 1.0 µm. The particle size of the atmospheric dust is expressed in the form of the so-called aerodynamic particle size, i.e., the diameter of a spherical particle with a unit density of a particle material of 1000 kg/m^3, which has the same kinetic properties as a true non-spherical particle.

The ISO 16890 regulation itself works with the ePM_x efficiency, which expresses the mass efficiency of the "device" separation (filter efficiency), determined for the particulate matter fractions in the range of the optically determined particle sizes of 0.3 to x µm - see **Table 1**. This regulation, thus, ignores the difference between the aerodynamic diameter of a particle and the optically determined particle size. The limitation of the ePM_x value, only for particles $x \geq 0.3$ µm, is given by the limitation of the resolution of conventional optical instruments for particles of size < 0.3 µm.

When testing the filter, its separation abilities should be measured in the range of the optically determined particle sizes of 0.3 to 10 µm in a KCl aerosol at twelve size intervals, first with a clean and electrically unconditioned filter according to the procedure given in ISO 16890-2. The individual values of the separation efficiency E_i [%] are obtained by measurement.

After neutralisation of the charge in the filter material according to ISO 16890-4 (discharge of the charge in the isopropyl alcohol (IPA) vapours), the separation abilities of the electrically neutral filter are again determined in twelve size intervals in the particle size range of 0.3 to 10 µm, the $E_{D,i}$ values [%]. The dependence of $E_D(a)$ is considered to be the minimum value of the fractional efficiency of the filter.

By loading the filter with fine synthetic dust, L2, according to ISO 15957 (base dust without soot and fibre admixtures) and following the procedure given in

Table 1. *Particle size range for the definition of the efficiencies.*

Separation efficiency	Range of optically determined particle sizes [µm]
ePM_{10}	$0.3 \leq x \leq 10$
$ePM_{2.5}$	$0.3 \leq x \leq 2.5$
ePM_1	$0.3 \leq x \leq 1$

ISO 16890-3, the initial value of the filter gravimetric arrestance of the synthetic dust is determined, then the dependence of the change in the pressure loss of the filter on the weight of the collected dust and the value of the filter test dust capacity is determined.

From the individual determined values of E_i and $E_{D,i}$, the mean arithmetic values of $E_{A,i}$, are determined, which are further considered as the mean values according to which the filter will behave in real conditions.

The individual values of $E_{A,i}$ [%], with respect to the dependence $E_A(a)$ is further used in the calculation of the particulate matter efficiency ePM_x of the filter in the range of the particle sizes of 0. 3 to x µm.

The average composition of atmospheric dust in urban areas and in rural areas is used to calculate the ePM_x values [%]. The distribution of the particle sizes by mass (volume), in the form of the expression of the frequency (discrete) and the cumulative distribution curve, is shown in the contribution [10] in Figure 4. The bimodal frequency mass distribution is a characteristic feature of the particle size distribution of both typical atmospheric dusts. For a better comparison of the differences, the cumulative mass curves of the two atmospheric dusts used are expressed in linear particle size coordinates in **Figure 1**.

The mass fraction of the particles smaller than 0.3 µm (undersize cumulative mass) depends on the air pollution, which is not negligible and generally reaches values of the order of 30%. According to the data in **Figure 1**,

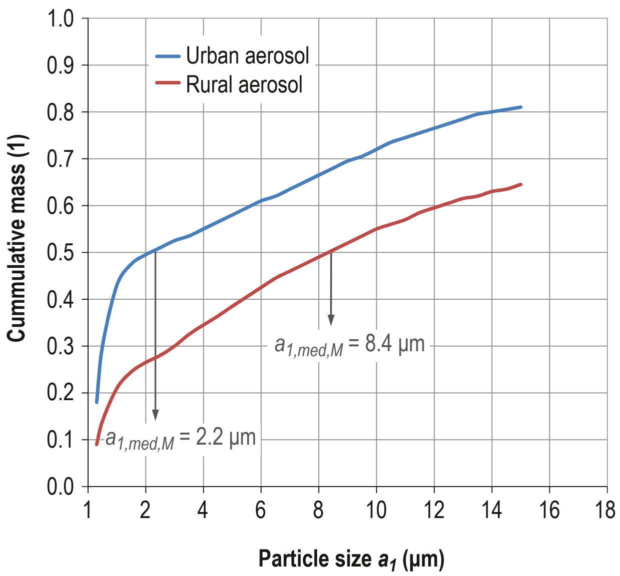


Figure 1. Average composition of the atmospheric dust in urban and rural areas.

the proportion of the particles smaller than 0.3 µm in these atmospheric dusts is 18 and 9%, respectively. From a common point of view, it follows that there are significant differences between the two atmospheric dusts. The most used characteristic feature of the particle granularity is the mass median $a_{med,M}$, which reaches values of 8.4 and 2.2 µm for these dusts, respectively.

According to the recommendations in ISO 16890, the filters, which are mostly used for the separation of PM_1 and $PM_{2.5}$ particulate matter fractions, are classified according to the particle size distribution of the atmospheric dust in urban areas and the filters primarily intended for the separation of the PM_{10} particulate matter fraction are classified according to the particle size of the dust in rural areas. The calculated values of ePM_1 and $ePM_{2.5}$ [%] are, therefore, based on the distribution curve for an urban aerosol, the value of ePM_{10} [%] is based on the distribution curve for a rural aerosol. We remind you that the calculated mean arithmetic values of the $E_{A,i}$ efficiencies [%] for the individual size fractions, are used to calculate the ePM_x values [%].

In addition to these mean values, which are among the main reported filter parameters (class reported value), when processing the measurement results, the calculation is supplemented by determining the minimum values of $ePM_{1,\ min}$ and $ePM_{2.5,\ min}$ [%] according to the detected values of the minimum $E_{D,i}$ efficiencies [%] for the individual size fractions.

Based on the test results, the filters are classified according to the requirements for $ePM_{1,\ min}$ and $ePM_{2.5,\ min}$ [%] and for ePM_{10} [%] into the following 4 basic groups – ISO coarse, ISO ePM_{10}, ISO $ePM_{2.5}$ and ISO ePM_1, see **Table 2**.

Table 2. *Filter classification according to ISO 16890.*

Basic group of filters	Filter group requirement			Class reporting value
	$ePM_{1,min}$	$ePM_{2.5,min}$	ePM_{10}	
ISO coarse	-	-	< 50%	Initial arrestance for synthetic dust
ISO ePM_{10}	-	-	> 50%	ePM_{10}
ISO $ePM_{2.5}$	-	> 50%	-	$ePM_{2.5}$
ISO ePM_1	> 50%	-	-	ePM_1

In addition to this basic classification, the value of ePM_x [%] found for each filter tested, determined according to the mean values of the fractional efficiencies $E_{A,i}$ [%] (the value in the last column of **Table 2**) is presented. The ePM_x value [%] is rounded down to a multiple of 5%.

For the basic ISO coarse class, the initial test value for synthetic dust, rounded down to a multiple of 5%, is given as the test result.

As follows from the interpretation of the requirements for the classification of the filters according to the values in **Table 2** and as stated in the EUROVENT Guidebook [11] from 2017 and in the contribution [9] from 2018, the following filter quality options exist according to ISO EN (**Table 3**).

From **Table 3**, it follows that, theoretically, there are a total of 49 classes of filters in 4 different basic groups (classes), 10 classes each in PM_1, $PM_{2.5}$ and PM_{10} and 19 classes in the basic ISO coarse group.

Summary of the differences between EN 779 and EN ISO 16890

As already mentioned in the introductory chapter, a direct conversion relationship between the filter classes according to EN ISO 16890 [3], [4], [5], [6] and EN 779 [2] does not exist and cannot exist, because both classification systems are too different. The existing conversion relationships serve only as a rough guide on how to use the existing experience with the use of filter classes according to EN 779 in the new system, which is only slowly being applied in practice. This chapter briefly summarises the basic characteristics and differences of both classification systems.

The classification, according to EN 779, is based on the class F and M filters on the mean filtration efficiency E_m for 0.4 µm particles (DEHS aerosol particles with an optically determined particle size) during the dust loading test and on the coarse G filters on the average gravimetric efficiency (arrestance) of the A_m filter on the loading test dust. This is, therefore, the efficiency of the medium-loaded filters. The loading dust contains admixtures of soot and cotton linters in addition to the fine desert dust. In the 2012 amendment, a requirement for determining the minimum filtration efficiency for 0.4 µm particles, for electrically discharged filter materials, was introduced for the F filter classification, which respects the observed significant change in the separation capabilities of some synthetic fibre filter materials.

The classification, according to EN ISO 16890, is based on the determination of the separation abilities of the clean electrically untreated and electrically neutral material in the range of optically determined KCl aerosol particle sizes of 0.3 to 10 µm. The range of the particle sizes is divided into twelve size intervals and, for each interval, the mean arithmetic value $E_{A,i}$ is determined, which is further considered as the mean value according in which the filter will behave in real conditions. The individual values of $E_{A,i}$ [%], respectively, the dependence $E_A(a)$ – are further used in the calculation of the filter efficiency value ePM_x in the particle size range of 0.3 to x µm.

Table 3. *Filter classification table according to ISO 16890.*

ePM_1 classification	$ePM_{2.5}$ classification	ePM_{10} classification	ISO coarse
ePM_1 (95)	$ePM_{2.5}$ (95)	ePM_{10} (95)	Gravimetric arrestance reported in full 5%
ePM_1 (90)	$ePM_{2.5}$ (90)	ePM_{10} (90)	
ePM_1 (85)	$ePM_{2.5}$ (85)	ePM_{10} (85)	
ePM_1 (80)	$ePM_{2.5}$ (80)	ePM_{10} (80)	
ePM_1 (75)	$ePM_{2.5}$ (75)	ePM_{10} (75)	
ePM_1 (70)	$ePM_{2.5}$ (70)	ePM_{10} (70)	
ePM_1 (65)	$ePM_{2.5}$ (65)	ePM_{10} (65)	
ePM_1 (60)	$ePM_{2.5}$ (60)	ePM_{10} (60)	
ePM_1 (55)	$ePM_{2.5}$ (55)	ePM_{10} (55)	
ePM_1 (50)	$ePM_{2.5}$ (50)	ePM_{10} (50)	
Requirements: > 50% initial efficiency > 50% discharged efficiency	*Requirements: > 50% initial efficiency > 50% discharged efficiency*	*Requirements: > 50% initial efficiency No minimum discharge efficiency*	*No discharge requirements*

The average composition of the atmospheric dust in urban areas and in rural areas is used to calculate the ePM$_x$ values [%]. The calculated values of ePM$_1$ and ePM$_{2.5}$ [%] are based on the distribution curve for an urban aerosol, the value of ePM$_{10}$ [%] is based on the distribution curve for a rural aerosol. In addition to these ePM$_x$ values [%], which are rounded down to a multiple of 5% and which are among the main reported filter parameters (class reported value), when processing the measurement results, the calculation is supplemented by setting the minimum values of ePM$_{1,\ min}$ and ePM$_{2.5,\ min}$ [%] according to the determined values of the minimum $E_{D,i}$ [%] efficiencies for the individual size fractions.

By loading the filter with the fine synthetic dust L2 according to ISO 15957 (base dust without admixtures of soot and linters), the initial value of the filter efficiency to the synthetic dust (gravimetric arrestance) is determined, furthermore, the dependence of the change in the pressure loss of the filter on the weight of the collected dust and the value of the test dust capacity is determined.

Existing conversion relationships between filter classes EN 779 and EN ISO 16890

This chapter summarises the conversion relationships (tables) between the two classification systems provided by some reputable manufacturers and suppliers of general ventilation filters, or the conversion relationships reported by some major foreign standards or interest group publications, such as the EUROVENT Air Conditioning Manufacturers Association, the and European Ventilation Industry Association (EVIA).

PM1 – Fine Dust Hazard to Health, Clean Air Solutions, Camfil, 2017

The first information on the separation abilities of the EN 779 filter classes for *PM$_x$* particulate matter fractions was provided by Camfil in its publication [12] from 2017, which we have already cited in the article [10]. The disadvantage of this work from today's point of view, according to ISO 16890, is the fact that the stated limit efficiencies apply to the whole range of particle sizes of the *PM$_x$* fraction, i.e., to particles smaller than 0.3 µm, and the stated limit values do not exactly correspond to the values of ePM$_x$ efficiencies. The second disadvantage of the cited publication from today's point of view, according to ISO 16890, is that it does not state which atmospheric dust that the efficiencies of the individual filter classes according to EN 779 were determined for.

The limit efficiency values of the *PM$_x$* fractions for the individual filter classes of groups M and F are given in **Table 4.**

For the above reasons, the information in the **Table 4** cannot be directly used to convert filters from EN 779 to EN ISO 16890. However, with regard to a possible error in calculating the ePM$_x$ value, in our opinion, it is possible to use the stated PM$_{10}$ values as "indicative" values for ePM$_{10}$, because, for atmospheric dust in general, the proportion of fine particles of size 0 to 0.3 µm is relatively small and the possible error in determining the value of ePM$_{10}$ is also small.

Table 4. *Typical efficiency of the individual filter classes EN 779 for the particulate matter fractions PM$_1$, PM$_{2.5}$ and PM$_{10}$ [12]*

Filter class EN 779	Efficiency for the particulate matter fractions PM$_1$, PM$_{2.5}$ a PM$_{10}$		
	PM$_1$	PM$_{2.5}$	PM$_{10}$ *)
M5	< 20%	< 40%	> 50%
M6	< 40%	50 – 60%	> 60%
F7	50 – 75%	> 70%	> 80%
F8	70 – 85%	> 80%	> 90%
F9	> 85%	> 90%	> 95%

*) Authors' note: ISO 16890 works with the ePM$_x$ efficiency determined for the atmospheric dust particles in the particle size range of 0.3 to *x* µm. The mass fraction of particles smaller than 0.3 µm (undersize) is not negligible for atmospheric dust and, according to the data in **Figure 1**, it makes up 18% (urban dust) and 9% (rural dust) of the total mass of the particles for the used atmospheric dusts. As can be seen from the graphs of the initial fractional efficiencies E_f (a) shown in our publication[10] in Figures 1 and 2, the dependence E_f (a) on lower classes of general ventilation filters generally has a decreasing tendency with a decreasing particle size. An exception is the F class of filters, where the diffusion effect already begins to be applied to fine particles smaller than 0.3 µm and the resulting fractional efficiency starts to increase slightly. If we want to determine the filter efficiency for the whole *PM$_x$* particle fraction, then the contribution of the separated particles in the size range 0 to 0.3 µm will vary significantly depending on the filter class and the particle size range used and will increase with an increasing filter class.

German standard VDI 3804 - 4 and Swiss standard SWKI VA101-01

The EUROVENT Guidebook [11] from March 2017 contains a conversion table according to the revised national standards - German VDI 3804 - 4 and Swiss SWKI VA101-01. This conversion table is given in **Table 5** and only applies to the selected filters of the M5, F7 and F9 classes.

Table 5. *Conversion table between the selected filters according to EN 779:2012 and ISO 16890-1:2016* [11]

Filter class		Notes
EN 779:2012	**EN ISO 16890-1:2016**	
M5	ePM_{10} ≥ 50%	
F7	$ePM_{2.5}$ ≥ 65%	In the case that this is not the last stage of filtration
F7	ePM_1 ≥ 50%	In the case that this is the last stage of filtration
F9	ePM_1 ≥ 80%	

A similar conversion table of selected filters of the M5, F7 and F9 classes, as a recommendation of the expert working group VDI – SWKI, is presented in the TROX Technik materials [13]. The only difference, compared to the data in **Table 5**, is the indicated value of efficiency without the ≥ sign.

FGK Status Report No. 44

A simple indicative conversion table was presented in 2017 in Status Report No. 44 from the professional association Fachverband Gebaude-Klima e.V. [14]. The conversion data are given in **Table 6**.

Table 6. *Conversion table between the filters according to EN 779 and ISO 16890 according to* [14]

Filter class according to EN 779	ISO ePM_1	ISO $ePM_{2.5}$	ISO ePM_{10}	ISO coarse
G2				> 30%
G3				> 45%
G4				> 60%
M5			≥ 50%	
M6		≥ 50%		
F7	≥ 50%			
F8	≥ 70%			
F9	≥ 80%			

EVIA (European Ventilation Industry Association)

According to the Systemair [15] documents, the European Ventilation Industry Association EVIA (see **Table 7**) shows almost the same conversion table, as seen in **Table 6**.

As in the previous two cases, the transfer between the two systems is given in the form of the minimum efficiencies, i.e., open separation ranges of ePM_x. The only difference compared to the data in **Table 6** is the use of the sign ≥ for the class G filter separation ranges also.

Systemair

The Systemair [15] presentation provides an indicative conversion table between the filter classes according to EN 779 and the "closed" ePM_x and the ISO coarse efficiencies ranges according to ISO 16890.

Table 8 is unconventionally arranged according to the particulate matter fractions and the achieved ePM_x efficiencies. From **Table 8**, it also shows the alternative use of the filters for different particle size distributions, e.g., the possibility of using the equivalents of filter class F7 for the separation of fine PM_1 fractions and, at the same time, for the separation of the $PM_{2.5}$ fractions.

In addition to this valuable form of filter conversion, the presentation [15] also presents a simple conversion table of the selected filter classes in the form of characteristic efficiencies, see **Table 9**.

From the comparison of these data with the values in **Table 6** and 7, it is clear that the stated efficiencies in **Table 9** do not express the minimum values of the efficiencies achieved for the class of filters according to EN 779, but they express the "characteristic" or "mean" values of the efficiencies.

Table 7. *Conversion table between filters according to EN 779 and ISO 16890 according to* [15]

Filter class according to EN 779	ISO ePM_1	ISO $ePM_{2.5}$	ISO ePM_{10}	ISO coarse
G2				> 30%
G3				> 45%
G4				> 60%
M5			≥ 50%	
M6		≥ 50%		
F7	≥ 50%			
F8	≥ 70%			
F9	≥ 80%			

Robatherm

The same indicative conversion table between the filters according to EN 779 and ISO 16890, as seen in **Table 8**, is stated by Robatherm [16] in its material.

Table 8. *Conversion table between the filters according to EN 779 and ISO 16890 according to Systemair [15]*

PM_1		$PM_{2.5}$	
ISO ePM_1 95%	F9	ISO $ePM_{2.5}$ 95%	F7
ISO ePM_1 90%		ISO $ePM_{2.5}$ 90%	
ISO ePM_1 85%		ISO $ePM_{2.5}$ 85%	
ISO ePM_1 80%		ISO $ePM_{2.5}$ 80%	
ISO ePM_1 75%	F8	ISO $ePM_{2.5}$ 75%	
ISO ePM_1 70%		ISO $ePM_{2.5}$ 70%	
ISO ePM_1 65%	F7	ISO $ePM_{2.5}$ 65%	
ISO ePM_1 60%		ISO $ePM_{2.5}$ 60%	M6
ISO ePM_1 55%		ISO $ePM_{2.5}$ 55%	
ISO ePM_1 50%		ISO $ePM_{2.5}$ 50%	

PM_{10}		Coarse	
ISO ePM_{10} 95%	M6	ISO coarse 95%	G4
ISO ePM_{10} 90%		ISO coarse 90%	
ISO ePM_{10} 85%		ISO coarse 85%	
ISO ePM_{10} 80%		ISO coarse 80%	
ISO ePM_{10} 75%		ISO coarse 75%	
ISO ePM_{10} 70%		ISO coarse 70%	
ISO ePM_{10} 65%		ISO coarse 65%	
ISO ePM_{10} 60%	M5	ISO coarse 60%	
ISO ePM_{10} 55%		ISO coarse 55%	G3
ISO ePM_{10} 50%		ISO coarse 50%	
		ISO coarse 45%	
		ISO coarse 40%	G2
		ISO coarse 35%	
		ISO coarse 30%	

Table 9. *Conversion table between the filters according to EN 779 and ISO 16890 according to [15]*

Filter class according to EN 779	ISO ePM_1	ISO ePM_{10}	ISO coarse
G2			> 30%
G3			> 50%
G4			> 60%
M5		55%	
F7	60%		

Following the arrangement of the table, according to the application for the separation of particulate matter fractions PM_1, $PM_{2.5}$, PM_{10} and the L2 synthetic dust, the equivalents of the fine filters intended for the separation of the PM_1 fractions are required to have a minimum efficiency of 50% for filters in an untreated and electrostatically discharged state.

The same is required for medium filters, where the minimum efficiency for the separation of the particulate matter fraction $PM_{2.5}$ for the filters in the untreated and electrostatically discharged state is 50% ($ePM_{2.5}$).

For the medium filters designed to separate the particulate matter fraction PM_{10}, a minimum efficiency of 50% (ePM_{10}) is required for the untreated filters. There are no electrostatic discharge requirements.

There are no electrostatic discharge requirements for the coarse filters.

Guideline EUROVENT 4/23 – 2018

A similar approach, when comparing the applicability of the filters according to EN 779: 2012 and EN ISO 16890-1: 2016, is used in the EUROVENT Directive 4/23 - 2018 [17], where Annex 1 compares class M and F filters with the filter classification according to ePM_x in the form of the corresponding ePM_x efficiencies ranges. The stated values are the result of the comparative tests performed on the manufacturers, members of the EUROVENT association, who have a 70% share of the European market. The results of the comparison are shown in **Table 10**.

Table 10. *Conversion table between the filters according to EN 779:2012 and EN ISO 16890-1:2016 [17]*

Filter class EN 779	Efficiency for the particulate matter fractions PM_1, $PM_{2.5}$ a PM_{10}		
	PM_1	$PM_{2.5}$	PM_{10}
M5	5 – 35%	10 – 45%	40 – 70%
M6	10 – 40%	20 – 50%	60 – 80%
F7	40 – 65%	65 – 75%	80 – 90%
F8	65 – 90%	75 – 95%	90 – 100%*)
F9	80 – 90%	85 – 95%	90 – 100%*)

*) Authors' note: With respect to the stated upper limit of 100%, all the values given in the table probably indicate the calculated values of the ePM_x efficiencies before rounding downwards to 5%.

Comparison of the conversion relationships by the individual source

For mutual comparisons, **Table 11** to **15** summarise the conversion relationships between EN 779: 2012 and EN ISO 16890-1: 2016 for the individual filter classes according to EN 779: 2012.

The comparison tables of the individual filter classes show a very good agreement in the achieved efficiencies for the L2 synthetic dust according to ISO 15957, according to the individual sources for the G2 to G4 coarse filters. The particle size distribution of the synthetic dust is shown in [9] in Figure 1 and the mass median is about 10 µm.

Also, for the medium M5 and M6 filters, the data from the individual sources are in good agreement, with the only exception being for the M6 filters and the $ePM_{2.5}$ efficiency. According to the Eurovent data [17], the efficiency of these filters is 20 to 50%, while according to other sources, the efficiency is ≥ 50%, respectively 50 to 60%.

For fine F7 to F9 filters, the data from the individual sources are in good agreement, again with the exception of the data according to Eurovent [17], where, for the F8 filters and the ePM_1 efficiency, the given wide range of efficiencies 65 to 90% does not correspond to narrower range 70 to 75% according to the data from [15] and [16].

Table 11. *Summary of the conversion relationships for the coarse filters of group G.*

Source	G2	G3	G4
	ISO coarse [%]	ISO coarse [%]	ISO coarse [%]
FGK [14]	> 30	> 45	> 60
Systemair [15]	30 – 40	45 – 55	60 – 95
Systemair [15]	30	50	60
EVIA in [15]	≥ 30	≥ 45	≥ 60
Robatherm [16]	30 – 40	45 – 55	60 – 95

Table 12. *Summary of the conversion relationships for the medium filters of group M.*

Source	M5			M6		
	ePM_1 [%]	$ePM_{2.5}$ [%]	ePM_{10} [%]	ePM_1 [%]	$ePM_{2.5}$ [%]	ePM_{10} [%]
Camfil [12]	-	-	> 50	-	-	> 60
VDI – SWKI in [11]	-	-	≥ 50	-	-	-
VDI – SWKI in [13]	-	-	50	-	-	-
FGK [14]	-	-	≥ 50	-	≥ 50	-
EVIA in [15]	-	-	≥ 50	-	-	-
Systemair [15]	-	-	50 – 60	-	50 – 60	65 – 95
Systemair [15]	-	-	55	-	-	-
Robatherm [16]	-	-	50 – 60	-	50 – 60	65 – 95
Eurovent [17]	5 – 35	10 – 45	40 – 70	10 – 40	20 – 50	60 – 80

Table 13. *Summary of the conversion relationships for the fine filters of class F7.*

Source	F7		
	ePM_1 [%]	$ePM_{2.5}$ [%]	ePM_{10} [%]
Camfil [12]	-	-	> 80
VDI – SWKI in [11]	≥ 50 last stage	≥ 65	-
VDI – SWKI in [13]	50 > 50 last stage	-	-
FGK [14]	≥ 50	-	-
EVIA in [15]	≥ 50	-	-
Systemair [15]	50 – 65	65 – 95	-
Systemair [15]	60	-	-
Robatherm [16]	50 – 65	65 – 95	-
Eurovent [17]	40 – 65	65 – 75	80 – 90

Table 14. *Summary of the conversion relationships for the fine filters of class F8.*

Source	F8		
	ePM_1 [%]	$ePM_{2.5}$ [%]	ePM_{10} [%]
Camfil [12]	-	-	> 90
FGK [14]	≥ 70	-	-
EVIA in [15]	≥ 70	-	-
Systemair [15]	70 -75	-	-
Robatherm [16]	70 – 75	-	-
Eurovent [17]	65 – 90	75 – 95	90 – 100

A comparison of the reported "open" efficiency ranges (≥ XY%) and the "closed" efficiency ranges (from - to) for all the filters, also results in a realistic estimate of the actual efficiency range for the reported "open" efficiencies.

Conclusion

A fundamental change in the classification and use of filters for general ventilation was brought about by the ISO standard 16890, which introduces new indicators for the testing and classification of filters – the PM_{10}, $PM_{2.5}$ and PM_1 particulate matter fractions and uses the values of the total ePM_x filter efficiency, based on the experimentally determined dependence of the fractional efficiency on the particle size in the range 0.3 µm to x µm.

The paper summarises the main differences between the original classification of the filter according to EN 779 and the new classification according to EN ISO 16890 and explains the problem of the direct reclassification of the filter classes of EN 779 to the filter classes according to EN ISO 16890.

The main content of the paper is a list of the known conversion relationships between the original and the new classification of filters, which are listed by some renowned manufacturers of filters for general ventilation, some national standards or publications of interest groups, such as the association of air conditioning manufacturers EUROVENT and the European Ventilation Industry Association (EVIA).

Although the stated transfer relationships between the two classification systems are only indicative and, due to the diversity of the systems, they cannot be otherwise different, we believe that they can contribute to the successful transition to the new classification system and its implementation. ■

Table 15. *Summary of the conversion relationships for the fine filters of class F9.*

Source	F9		
	ePM_1 [%]	$ePM_{2.5}$ [%]	ePM_{10} [%]
Camfil [12]	-	-	> 95
VDI – SWKI in [11]	≥ 80	-	-
VDI – SWKI in [13]	80	-	-
FGK [14]	≥ 80	-	-
EVIA in [15]	≥ 80	-	-
Systemair [15]	80 – 95	-	-
Robatherm [16]	80 – 95	-	-
Eurovent [17]	80 – 90	85 – 95	90 – 100

Acknowledgement

Article reviewed by doc. Ing. Vladimír Zmrhal, Ph.D.

References

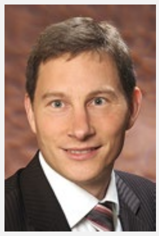
[1] ISO 16890-1 Air filters for general ventilation – Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM), ISO 2016.
[2] EN 779 Particulate air filters for general ventilation – Determination of the filtration performance, 2012
[3] EN ISO 16890-1 Air filters for general ventilation – Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM), 2016.
[4] EN ISO 16890-2 Air filters for general ventilation – Part 2: Measurement of fractional efficiency and air flow resistance, 2016.
[5] EN ISO 16890-3 Air filters for general ventilation – Part 3: Determination of the gravimetric efficiency and the air flow resistance versus the mass of the test dust captured, 2016.
[6] EN ISO 16890-4 Air filters for general ventilation – Part 4: Conditioning method to determine the minimum fractional test efficiency, 2016.
[7] EN 13779 Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems, 2007.(replaced by EN 16789-3)
[8] EN 16789-3 Energy performance of buildings – Ventilation of buildings – Part 3: For non-residential buildings – Performance requirements for ventilation and room-conditioning systems, 2017.
[9] MOJŽÍŠ, M. Komentář a doplnění článku „Normalizace a odlučovací schopnosti filtrů pro všeobecné větrání" (VVI č. 1/2018) a současné problémy s měřením a tříděním filtrů, *VVI 4/2018*, s. 246–250.
[10] HEMERKA, J., VYBÍRAL, P. Normalizace a odlučovací schopnosti filtrů pro všeobecné větrání, *VVI 1/2018*, s. 29–35.
[11] EUROVENT Guidebook „Air filters for general ventilation, March 2017.
[12] PM1 – Fine Dust Hazard to Health, Clean Air Solutions, Camfil, 2017.
[13] ISO 16890 – The new standard for coarse dust and fine dust filters, TROX Technik, 2017.
[14] Status Report Nr. 44, Fachverband Gebaude-Klima e.V., 2017.
[15] ISO 16890 – Air filters for general ventilation, Systemair, MBM 2018 – 15. and 16. May 2018.
[16] 49 tříd filtrace místo 9 – Norma ISO 16890 pro vzduchové filtry přehledně, Robatherm, 2018.
[17] EUROVENT Guideline 4/23 – 2018 Selection of EN ISO 16890 rated filter classes for general ventilation applications, Second edition, October 2018.

Can we still trust in EN 442?

New Operating Definitions for Radiators – *Part 1: Measurements and Simulations*





R. GRITZKI
TU Dresden

C. FELSMANN
TU Dresden

M. RÖSLER
TU Dresden

A. GRITZKI
BAuA, formerly TU Dresden

M. IIVONEN
Purmo Group

J. NAUMANN
GWT-TUD, Dresden

Abstract

Forced by the increased use of renewable energies, there is a need to lower the temperature level of space heating systems and heating networks. Lower water temperatures in heating systems again require larger heat emitting surfaces. Consequently, part load operating conditions with very large temperature spreads at very low mass flows can be observed more frequently. These situations also occur in district heating networks. Experiments at typically used radiator types with convection plates performed by the authors showed, that the heating power in case of reduced mass flow rates (below 30% of the design flow rates) is considerable higher than the heat output reported by the manufacture's submittal predicted based on the calculation approaches according to EN 442-2 [1]. This effect is in contrast to previous investigations of the part load behaviour of radiators. In [2] and [3] for example the authors assume a reduction of the heat output in case of lower mass flow rates and not an increase.

In order to be able to physically substantiate and mathematically describe the effect detected by means of first measurements, detailed additional measurements of the heat output of different radiator types were performed as well as detailed numerical investigations in a virtual test cabin. In both cases the studies have been designed according to the specifications in EN 442-2. Specifically, different radiator types with and without convection plates (type 22, type 20 and type 10) such as two tubular radiators (12 sections, two/three tubes) were examined. In case of the heat output measurements the radiator mass flow rates were further reduced up to 20% of the nominal flow rates. In case of the numerical investigations the determination of heat output data was done at much lower mass flow rates (up to 3% of the nominal mass flow).

The results of the investigations show, that in case of radiator type 22 the widely used EN 442-2 approach was not suitable to reliably predict radiator heating power neither in dependency on supply water temperature levels nor for typical mass flow rates. The mismatch was about 10%! In this Part 1 of the article results of both the measurements and the numerical analyses are presented; in Part 2 a new calculation approach is introduced to overcome the mismatch.

Introduction

A radiator is a water-air-heat exchanger installed in buildings used to provide heat for space heating (see **Figure 1**).

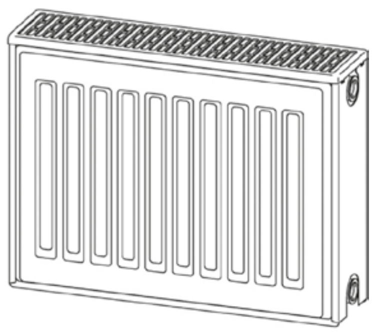


Figure 1. View of radiator with profiled front. [VDI6036]

For dimensioning purposes heat output of radiators has to be estimated under steady state conditions to check if it fits with nominal heat load requirements. So far it is assumed that heat output Φ mainly depends on the difference between mean radiator temperature and room temperature (the so-called over-temperature ΔT) and can be calculated according to

$$\Phi = K_m \Delta T^n \tag{1}$$

where parameters K_m and n are derived from laboratory tests accounting for heat transfer mechanisms. Test conditions in terms of supply and return temperature as well as mass flow rate are defined in EN 442-2 and are seemed to be constant, i.e. independent on operating conditions. Once K_m and n are known heat output at any operating point can be calculated by referring to a standardized reference point that is set at supply temperature of 75°C, return temperature of 65°C, and over-temperature of 50 K by applying equation

$$\Phi = \Phi_{50} \left(\frac{\Delta T}{50}\right)^n \tag{2}$$

Heat supply mass flow rate through the radiator has to be fixed according to a given temperature difference between supply and return flow to fulfil heat balance at the radiator. Calculation of the over-temperature ΔT can be done in two ways, as arithmetic over-temperature ΔT_{ar} or as logarithmic over-temperature ΔT_{ln}. In both cases it is assumed that mean radiator over-temperature can be determined simply on the basis of supply and return temperatures T_{in} and T_{out} and room temperature T_r.

$$\Delta T_{ar} = \frac{T_{in} + T_{out}}{2} - T_r \quad \text{and} \quad \Delta T_{ln} = \frac{T_{in} - T_{out}}{ln\left(\frac{T_{in} - T_r}{T_{out} - T_r}\right)} \tag{3}$$

Symbols

- k heat transfer coefficient, W/(m² K)
- K_m radiator model constant, –
- ΔT_m, ΔT_{ar} over-temperature (logarithmic or arithmetic), K
- $\dot{m}$ mass flow rate, kg/h
- $\dot{Q}$ heat output, W
- Φ heat output (EN 442-2), W
- T_{in} supply temperature, °C
- T_{out} return temperature, °C
- T_r room air temperature (control point), °C
- c_p specific heat capacity, J/(kg K)
- ΔT difference supply – return temperature, K

Normally radiators are designed for temperature differences (the spread) of about 10…20 K and in this temperature range both calculation approaches are almost equivalent. But in [2] and also in the underlying investigations, it was found that the arithmetic over-temperature is only valid to a limited extent ($(T_{out} - T_r)/(T_{in} - T_r) > 0.7$) and therefore the more general logarithmic over-temperature should be used, especially for larger temperature spreads. In this case the logarithmic over-temperature is a much better representation for the difference between mean surface temperature of the entire radiator, which is relevant for the heat transfer to the environment, and room temperature. Accordingly, the logarithmic over-temperature is used here.

Nowadays there is a trend to increase the temperature spread because heat system operators are interested in getting back a low return temperature (for example in case of district heating). That leads to quite low heat supply flow rates through the radiators not only in part load but also at design conditions. See the following example where a radiator of type 22 (two panels and two convection plates, see **Figure 1**) with a construction height of 0.4 m and a length of 1.4 m has been analysed. The heat output was measured for the temperature pairing **60-30-20** (radiator supply temperature 60°C, return temperature: 30°C, room temperature 20°C, and it was found heating power of 640 W while a heating power of 554 W was expected according to the EN 442-2 calculations. The measured heat output of the radiator in that operating point is about 15.5% higher! So, it has been shown that the heat output of typical radiators at higher temperature spreads and thus mass flow rates less than 30% of the design is significantly higher than expected from the above given calculations according to EN 442-2 (based on the log. over-temperature), i.e. calculations are not valid anymore.

The higher heat output in these operating points leads to oversized radiators, an unstable control behaviour and tends to increase the room temperatures. From that perspective there is a clear interest to better know if we still can rely on standardized calculation methods and to understand why standardized calculation fails some time.

In a first step measurements of the heat output of different radiator models of type 22 (two panels with

Indices

- N nominal point / design point
- ar arithmetic
- ln logarithmic
- 50 design point (at 50 K over-temperature, EN 442-2)

two convection plates) with various mass flow rates were carried out at RETTIG ICC. Measurements are done in a climate chamber according to EN 442-2 and deviations between measured and calculated heat outputs have been observed. The main purpose of the studies presented here is to find a physical based explanation for these deviations for radiator heat output, which is also valid in the low partial load range.

To extend the data base for the studies, in addition to the measurements detailed numerical simulations of different radiator types are performed in a virtual test cabin according to the specifications in EN 442-2. The underlying coupled and transient simulation model allows investigations for a very wide range of operating points, especially at very low mass flow rates.

Measurements

All measurements presented in this section were carried out by RETTIG ICC. During the laboratory testing the radiator heat outputs at several operating points have been measured and the design heat output according to EN 442-2 has been rated including the estimation of parameters K_m and n.

Table 1 summarizes data based on measurements following EN 442-2 (sets of three different measurements based on different over-temperatures per rating) for three radiator models and two different mass flow rates per model. The white line in **Table 1** always stands for the nominal mass flow rate and the grey one for the reduced mass flow rate. Based on temperatures and corresponding radiator heat output measured, radiator model parameters K_m and n have been derived following the EN 442 rules for each operating point. It is remarkable that radiator model parameters vary and depend on test conditions.

Based on equation (1) these parameters than have been used to predict the heat outputs for the operating conditions **75-65-20** (nominal point with over-temperature ΔT = 50 K) and **60-30-20** (ΔT = 22 K), see last column of **Table 1**.

As can be seen from the table the calculated heat outputs vary for the same radiator model in dependence on the mass flow rate. As expected, in most cases the predicted data based on the definitions in EN 442-2 are higher for larger temperature spreads (i.e. lower over-temperatures) caused by small mass flow rates.

This is obviously a result of the parameters K_m and n that are assumed to be constant in EN 442 but may depend on mass flow. It shows some interesting tendencies but it does not lead to the solution of the problem. In case of lower mass flow rates K_m increases and n decreases. So the heat output deviations are higher if the over-temperatures ΔT are smaller ($\Phi = K_m \cdot (\Delta T)^n$).

Numerical studies – Program- and Model Description

The laboratory tests have been modelled in a virtual test cabin to gain more insight into physical phenomena. In this section the used coupled simulation programs, the simulation model of the and essential details of different radiator models are introduced.

Simulation Tool

The simulation tool is a combination of three highly coupled program parts to assure that all relevant physical and technical aspects for the simulation of radiators are considered. In detail it consists of the thermal building and system simulation code TRNSYS-TUD [4], the indoor air flow simulation code ParallelNS [5], and the commercial CFD-code Ansys Fluent® [6]. Ansys Fluent®

Table 1. *Temperatures, mass flow rates (measured), model parameters and heat outputs (calculated using exponential approach according to data sheet); radiator type 22.*

Radiator type 22 height / length in mm	Measured				Calculated	
	Temp. spread for T_{in} = 75°C in K	Mass flow rate in kg/h (%)	EN 442 Radiator model parameters		Predicted Heat output Φ in W (in%)	
			K_m	n	ΔT = 22 K	ΔT = 50 K
600 / 1400	10	189 (100)	13.7	1.30	768	2240
	27	56 (30)	16.6	1.26	814 (+6%)	2291 (+2%)
900 / 500	10	96 (100)	6.4	1.32	383	1134
	27	29 (30)	7.8	1.28	404 (+5%)	1157 (+2%)
300 / 2000	10	165 (100)	10.0	1.35	642	1939
	26	55 (33)	14.1	1.27	721 (+12%)	26 (+6%)

is applied for the simulation of the radiator, ParallelNS for the air flow calculation inside of the cabin, and TRNSYS-TUD for the spatial highly resolved radiant heat transfer, the heat conduction of the surrounding surfaces of the cabin, the controlling and the technical equipment, for example the control systems.

Due to the coupling within the transient simulation process these three single codes together result in a very complex simulation tool which is able to satisfy the demands of practical applications, like radiator test chambers. Subsequently the three modules and the coupling algorithm are briefly described.

TRNSYS-TUD is a further development (at TU Dresden) of the commercial building simulation tool TRNSYS® based on version 14.2 and is used in the coupling process as the building and system simulation unit for combined simulations, see [4]. It can communicate with different CFD programs via PVM (Parallel Virtual Machine), in order to get detailed information about the convective heat transfer or about parameters of technical equipment.

ParallelNS is a finite-element research code developed at Göttingen University and Dresden University of Technology. Based on the Reynolds-averaged Navier-Stokes equations for incompressible non-isothermal fluids two turbulence models, a k-ε model with special functions for the wall treatment and a ϕ-f-k-ε model are used for calculating the effects of turbulence. Moreover, it is possible to consider a wide variety of additional transport equations [7]. The interaction with the thermal building simulation program and with the radiator simulation in Ansys Fluent® is also managed by PVM.

Ansys Fluent® is responsible for the detailed simulation of the radiator parts (radiator shell, convection plates). Due to the ability to handle hybrid mesh types it is possible to model very complex three-dimensional geometries, thus also the interior of multi-section radiators, or very thin convection plates. The coupling with the building simulation was done by means of the implemented user defined functions (UDF). Therefore, the ability to exchange data via PVM was implemented in the UDF-code. For more information see the Ansys Fluent® user manual [5].

The complete coupling algorithm works transient, across the transfer of boundary condition (BC) values at predefined BC interfaces. To ensure a realistic approximation of the interaction among the wall faces of the surrounding walls and the flow field, all the walls are split into a number of such BC interfaces. For the two flow solvers, the BC interfaces are additionally further refined to gain more stability due to the use of mean BC-values. More information about the coupling algorithm can be found in [7] to [9].

Virtual Test Cabin – Boundary and Operating Conditions*, Model Description*

The numerical investigations of the heat emission and the thermal behaviour of the different radiator models were performed in a virtual test cabin according to EN 442-2 by means of the coupled building, system and flow simulation described above at different temperature levels and different heating medium mass flow rates. For this purpose, coupled transient simulations of the test cabin with its control loops as well as the cabin air and the thermal behavior of the radiator were carried out for each needed operating point. As result very detailed analyses of the flow and heat conduction processes in and around the radiator models based on water and surface temperatures and their local distributions as well as the evaluation of the heat output (with convective and radiative part) of the radiator models based on different temperature pairings are available.

The modelled test cabin has the overall dimensions of L × W × H = 4 m × 4 m × 3 m, see also **Figure 2**.

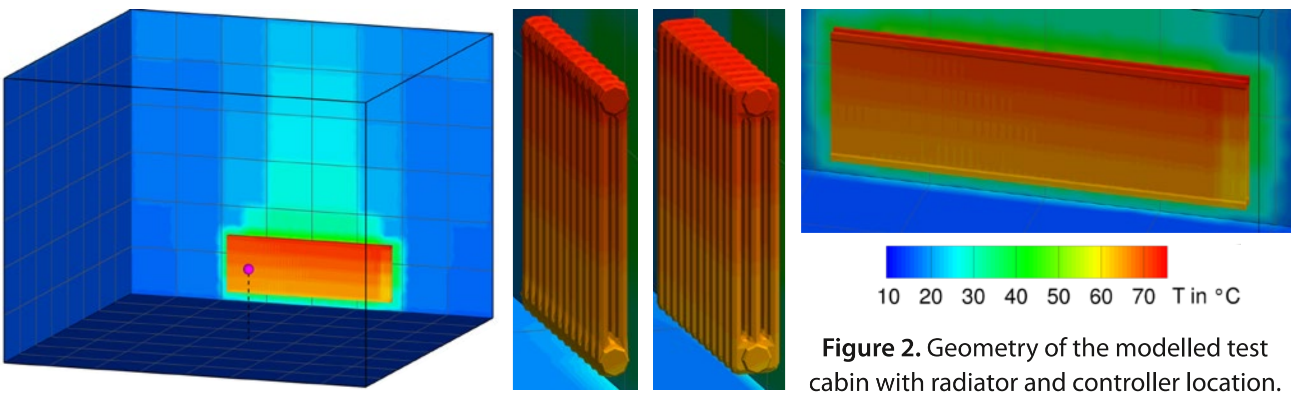


Figure 2. Geometry of the modelled test cabin with radiator and controller location.

The investigated radiator models are, as postulated in [1], located centered in front of the backside of the cabin, 0.11 m above the floor and 0.05 m away from the backside. All walls of the test cabin except the backside are controlled tempered walls. The materials and the wall constructions correspond to the guidelines in [1]. The sensor point for the temperature control (red point) is located in the middle of the test cabin at a height of 0.75 m above the floor. The model of the test cabin is equipped with two different control loops. One loop controls the tempered walls in order to keep the temperature at the measure point at a constant value of 20°C. The other loop controls the water influx against the radiator outflow temperature. The simulations were performed unsteady until steady state conditions were reached.

The radiators and the wall behind them are divided into a large amount of very small "tiles" (up to 7200 BC faces, depending on the complexity of the radiator geometry). This way their real geometry and their real physical behavior, especially in respect to the radiant and the convective heat transfer and the temperature distribution are reflected. The mesh resolution of the air flow simulation in the cabin varies from 1.0 to 1.3 million elements, dependent on the specific radiator type.

Radiator Models

In the underlying investigations up to now six radiator models were considered. **Figure 3** shows the outer surfaces of the investigated radiators along with their temperature distributions in the steady state for the temperature pairing 75-35-20. In all cases the water inflow is located at the upper right side while the outflow is located at the same lower side (view from the centre of the cabin).

In detail the following six radiator types, each one of a height of 0.6 m were modelled:

- two **radiators of type 22**, different lengths, two layers and two convection plates, (*upper left and upper middle*) length: 1.0 m and 1.4 m, depth: 0.102 m, heat output: 1709 W/m, radiator resolution: up to 3.6 million elements, up to 7200 BC-interfaces,
- one **radiator of type 20** with two layers and without convection plate, (*upper right*) length: 1.0 m, depth: 0.015 m, heat output: 1085 W/m, radiator resolution: 1.7 million elements, 4100 BC-interfaces,
- one **radiator of type 10** with one layer and without convection plate, (*lower left*) length: 1.0 m, depth: 0.015 m, heat output: 639 W/m, radiator resolution: 0.7 million elements, 2050 BC-interfaces,
- one **tubular radiator with 2 tubes** and 12 sections, (*lower middle*) length: 0.54 m, depth: 0.065m, heat output: 564 W, radiator resolution: 0.69 million elements, 3700 BC-interfaces and
- one **tubular radiator with 3 tubes** and 12 sections, (*lower right*) length: 0.54 m, depth: 0.105m, heat output: 781 W, radiator resolution: 1.0 million elements, 4600 BC-interfaces.

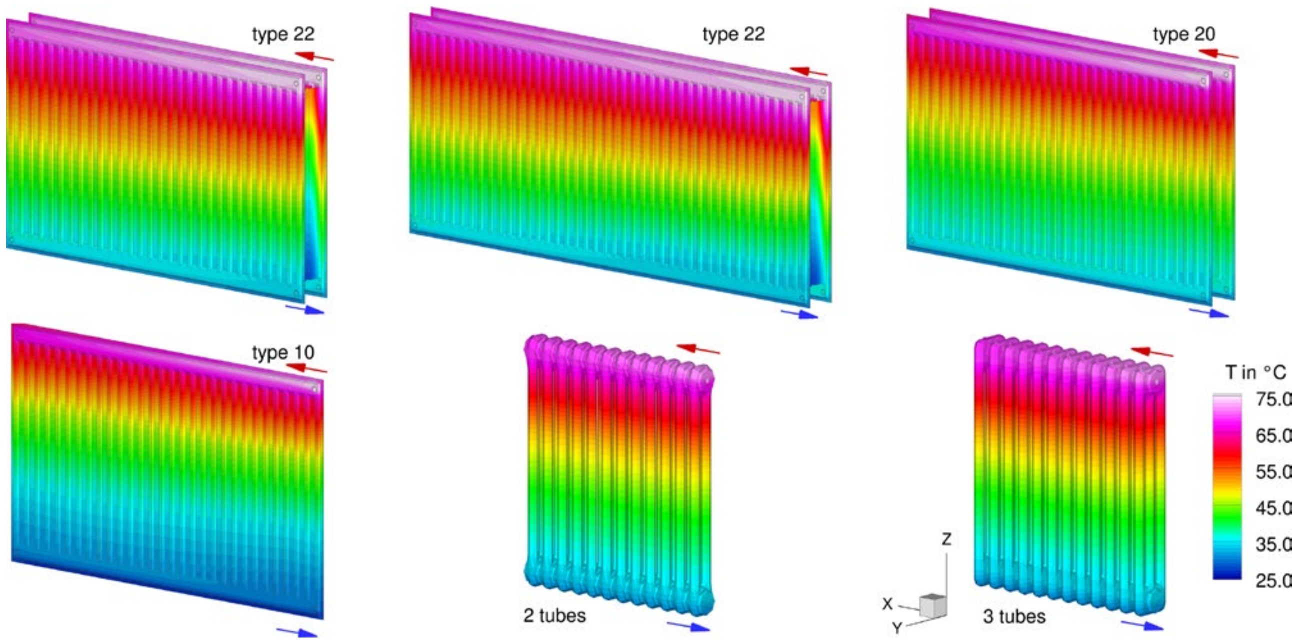


Figure 3. Geometries of the six radiator models along with their temperature distributions in the steady state, temperature pairings 75-35-20.

Results – Investigations according to EN 442-2

Model validation: Comparisons with catalogue data according to EN 442-2

First, the simulation model results are compared to the EN 442 approach for different temperature pairings based on the manufactures submittal (over-temperatures at ΔT_{ar}=30 K, 50 K, and 60 K). As results of EN 442 approach are communicated in the manufactures submittal they are referred to as catalogue data. (By the way: measurements showed that it is difficult to reach the higher over-temperatures of the radiators (50 K and 60 K) required by EN 442-2 if mass flow rates are low). Furthermore, it has to be mentioned that the logarithmic over-temperature is used for analysis as discussed earlier. That is why results in the diagrams do not exactly fit the standardized data of 60 K, 50 K, and 30 K, respectively (logarithmic over-temperature is 59.44 K, 49.83 K, and 29.72 K instead).

In **Figure 4** and **Figure 5** exemplary the results of these validations for four of the six investigated radiator types are collected. Heating power data is

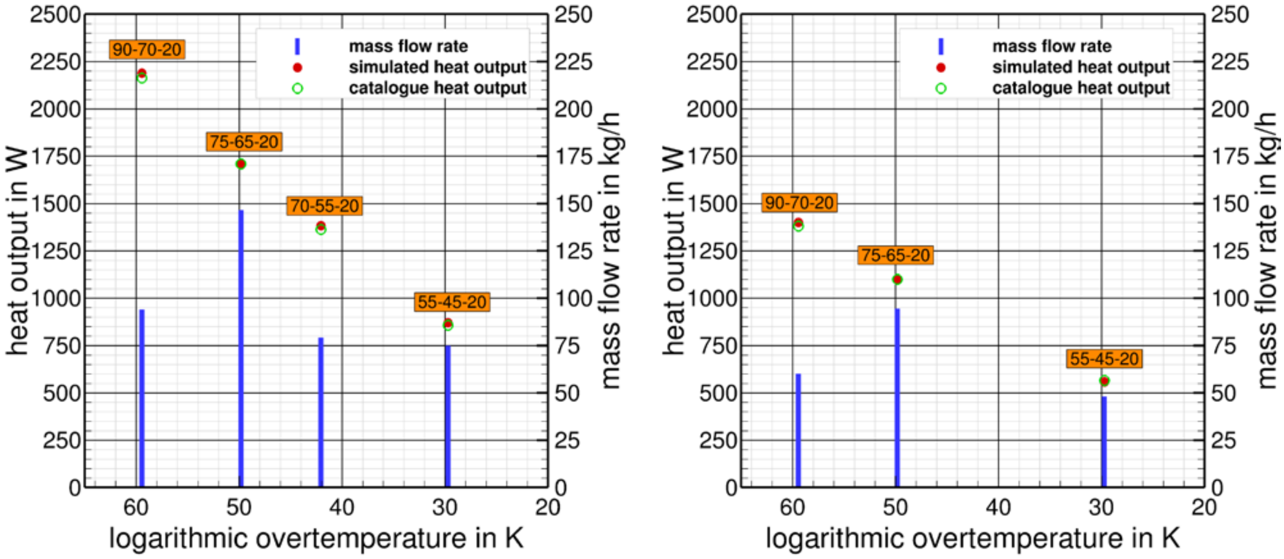


Figure 4. Simulated and catalogue heat output data and mass flow rate of panel radiators (length: 1.0 m) at different typical operation points – **left: type 22, right: type 20.**

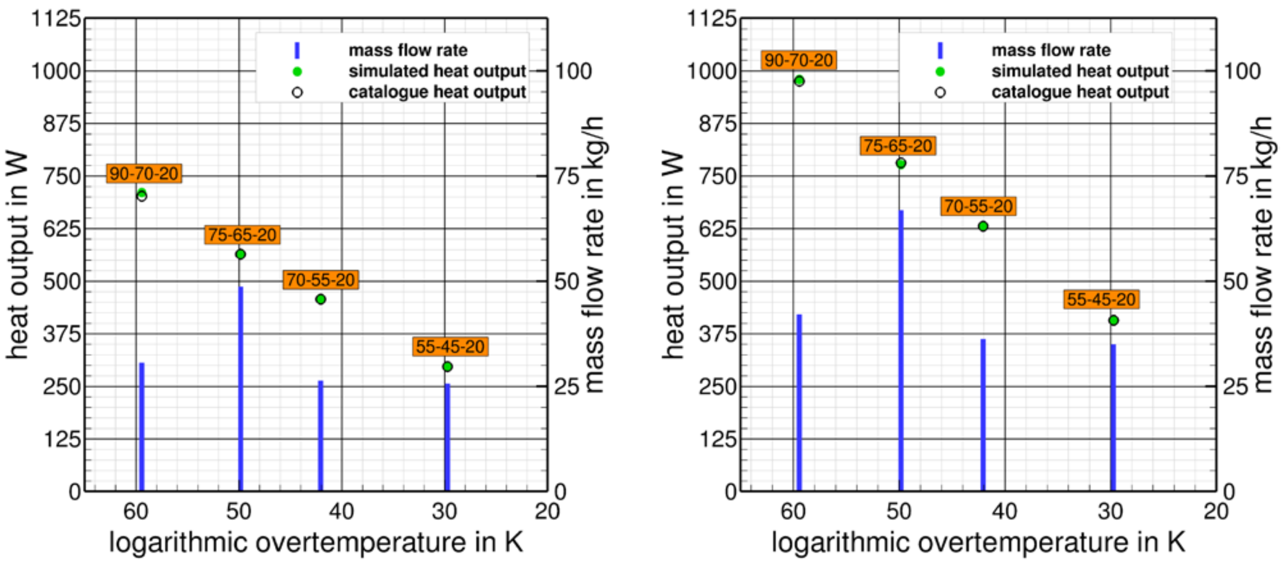


Figure 5. Simulated and catalogue heat output data and mass flow rate of the tubular radiators at different typical operation points – **left: two tubes, right: three tubes.**

displayed as bullet point whereas the mass flow is represented by columns. Keep in mind, that heat output mainly depends on over temperature while mass flow depends on temperature spread. As one can see, the simulation results and the catalogue data in all cases are in very good agreement. The differences between the simulated heat output data and the data based on the data sheets in all temperature pairings are less than 2 percent, in most cases even smaller. Taking into account those results it can be concluded, that the numerical models of the radiator types as well as the numerical models of the cabin are very well suited for the investigations of the partial load behaviour that are presented in the following sections.

In **Figure 6** the surface temperatures at different mass flows and return temperatures for the modelled tubular radiators are displayed.

These diagrams give a good overview of the vertical and horizontal temperature distribution of the radiators. However, it is not possible to say whether the vertical temperature drop is linear or non-linear.

Results based on different Mass Flow Rates

Based on the validated radiator models now the impact of reduced mass flow rates on the heat output of the radiators has been analyzed. The studies were done for three different supply temperatures, 90°C, 75°C and 55°C. In this section the results for the supply temperature 75°C are discussed as this a representative case and the behavior of the radiator models is in principle similar for other supply temperatures.

Panel radiators with convection plates (type 22)

Mass flow rate through the radiator has been reduced and subsequently the difference between supply and return temperature increases. In **Figure 7**, the calculated heat output data and the mass flow rates of the two panel radiators with convection plates in dependence on that temperature difference between supply and return temperature is displayed and compared to the catalogue data based on the logarithmic over-temperature ΔT_{ln} and the standardized reference point. In addition, the diagrams also show the results predicted by the exponential approach according to EN 442 based on the arithmetic over-temperature ΔT_{ar}. Each discrete dot represents one simulation with its specific constant mass flow rate needed to match the return temperature.

The results clearly show now the mismatch between the simulation results and the catalogue data when mass flow rates differ from the standardized reference flow. The heat output data expected by the digital twin of the radiator are up to 10% higher than the data predicted by the exponential approach according to EN 442. This is according to the measurement results presented in **Table 1**. If the arithmetic over-temperature is used, the mismatch is even more pronounced. It clearly shows that the EN442 approach is valid only for operating conditions similar to the standard but should be applied with care when the radiator is operated in part load (at lower flow rates).

Summary

The performance of six different radiator models has been analyzed using a digital twin. Various supply

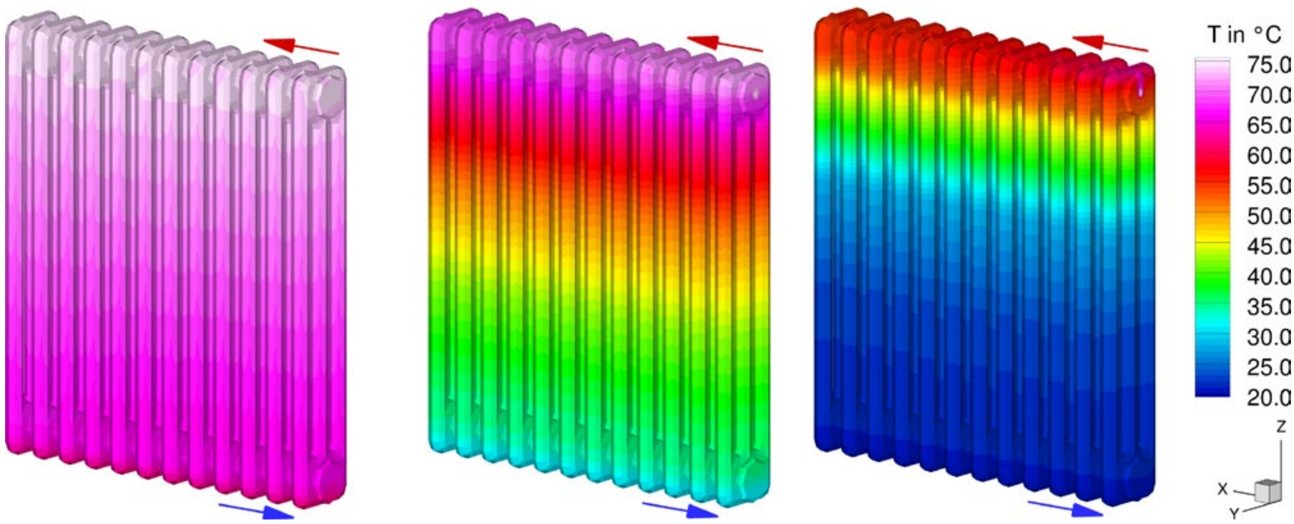


Figure 6. Surface temperatures at different mass flows and return temperatures, tubular radiators with three tubes – left: 75-65-20, middle: 75-35-20, right: 75-21-20.

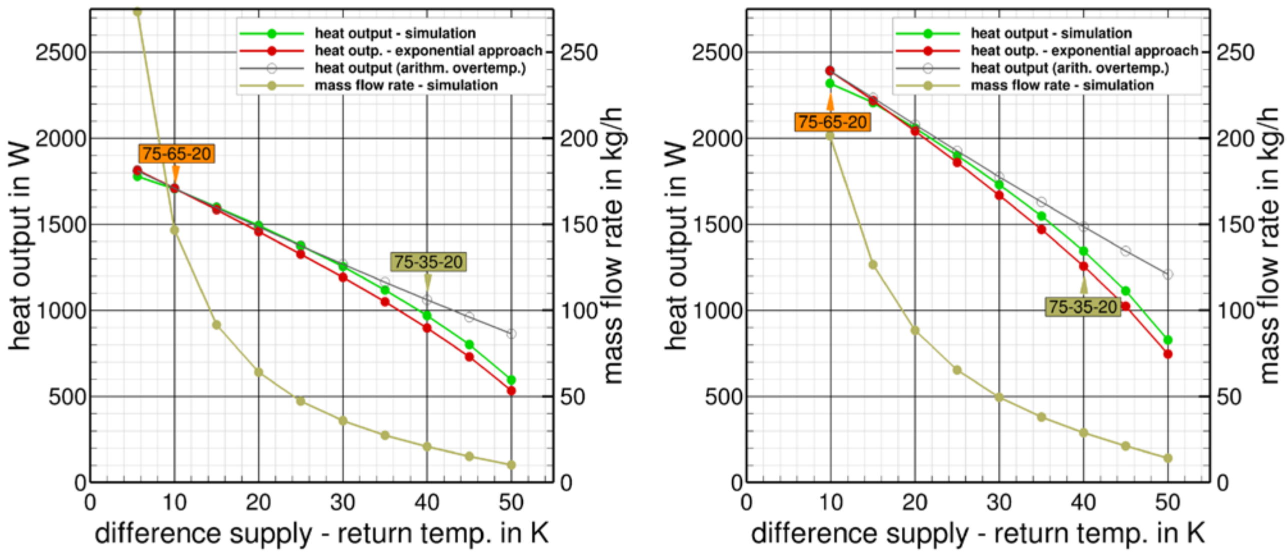


Figure 7. Simulated (green) and catalogue heat output data based on exponential approach (red/gray) at constant supply temp. of 75°C and changed mass flow rates, panel radiators with convection plates, type 22 **– left: 1.0 m length, right: 1.4 m length.**

temperatures and mass flow rates were taken into account resulting in about 150 simulation runs.

The heat output results of the simulated radiators under reference conditions (taken from the manufacture's catalogue data) were in all cases in very good accordance to the design data in the data sheets. Therefore, the simulation models are very well-suited to further investigate the impact of different mass flow rates on the heat output of radiators.

In case of commonly used radiator type 22, measurements and simulations generate higher heat outputs (up to approx. 10%) than compared to the catalogue data based on the logarithmic over-temperature ΔT_{ln} and the standardized reference point. This applies to all supply temperature levels already in the range of typical mass flow rates. It is assumed that convection plates will have an impact because radiators without such devices may not show any mismatch. More details on this are given in Part 2 of the article. ■

References

[1] EN 442-2. 2014. Radiators and convectors – Part 2. Test methods and rating. Beuth Verlag, Berlin.

[2] H. Bach, D. Schlapmann. 1977. Effektive Übertemperatur zur einheitlichen Darstellung der Wärmeleistung von Raumheizkörpern. Ki 10/77, Teil 6, S. 592-597.

[3] Knabe G. 1992: Gebäudeautomation. Verlag für Bauwesen Berlin, München.

[4] Perschk, A. 2010. Gebäude- und Anlagensimulation – „Ein Dresdner Modell". GI Gesundheitsingenieur / Haustechnik / Bauphysik / Umwelttechnik, Bd. 131, Nr.4.

[5] ParallelNS user's guide: University of Göttingen / Technical University of Dresden 2001.

[6] Ansys Fluent Inc. 2019. Ansys Fluent User's guide for Fluent. Release 19.0.

[7] Gritzki, R, Richter, W, Rösler, M. 2003. How to predict the air exchange efficiency for hybrid ventilation systems. Int. Journal of Ventilation, Vol.1, HybVent SE:33-39.

[8] Gritzki, R., Perschk, A., R., Rösler, M., Richter, W. 2009. Modeling of Heating Systems and Radiators in Combined Simulations. Proceedings of Clima 2007 WellBeing Indoors, 2007.

[9] Gritzki, R., Perschk, A., R., Rösler, M., Richter, W. 2009. Gekoppelte Simulation zur Spezifikation von Heiz- und Kühlkörpern. Bauphysik Heft 1, 2009.

CO_2 monitoring and indoor air quality

Photos: istockphoto.com

ÖZGÜR KÜÇÜKHÜSEYIN
Testo Sales Director
Climate Product Management
– Testo SE & Co. KgaA, Turkey
okucukhuseyin@testo.com.tr

Formation and effect on human health

Carbon dioxide is a colourless and odourless gas. It is a natural component of ambient air, at a concentration of around 400 ppm (parts per million). CO_2 is formed during the complete combustion of carbonaceous substances with sufficient oxygen supply. In the organisms of living creatures, it is formed as a metabolite of cell respiration. [1] At higher concentrations upwards of 1000 ppm, significant negative effects on the general well-being can occur (headaches, fatigue, lack of concentration). [2]

Carbon dioxide is produced in the body's cells (at quantities of 0.7 kg per day) and diffuses from there to the surrounding capillaries. It is transported in the blood after chemically binding onto proteins such as haemoglobin, or in dissolved form. CO_2 is largely physically dissolved, only a small part is converted by carbonic anhydrase in the red blood corpuscles into carbonic acid which disintegrates into hydrogen and hydrogen carbonate ions in the aqueous environment. The carbon dioxide is exhaled via the alveolar membrane of the lung. A crucial physiological function of the carbon dioxide in the organism consists in its regulation of breathing via the chemical receptors of the aorta and the medulla oblongata, which stimulate the respiratory centre in the brain stem. Increased CO_2 concentrations in inhaled air increase the breathing frequency and the tidal volume. During this process, CO_2 has a dilatory effect on the bronchia, which causes an increase in the dead space volume (the space in the respiratory system which is not involved in gas exchange). However, the dilatory effect of the CO_2 on peripheral and central arterioles does not lead to a decrease of blood pressure, since an increased adrenalin production causes a compensatory vasoconstriction. [3]

Concentration	Effect
350 to 450 ppm	Typical atmospheric concentration
600 to 800 ppm	Reliable indoor air quality
1 000 ppm	Upper range of reliable indoor air quality
5 000 ppm	Max. workplace concentration over 8 hours
6 000 to 30 000 ppm	Critical, only short-term exposure
3 to 8%	Increased breathing frequency, headaches
> 10%	Nausea, vomiting, loss of consciousness
> 20%	Rapid loss of consciousness, death

Fig. 1. Effect of different CO_2 concentrations.

CO_2 in indoor air

CO_2 is viewed as a leading parameter for human-induced air pollution, since the increase of indoor CO_2 concentration correlates well with the increase of the intensity of odours arising from human metabolism. The CO_2 content of the indoor air is thus a direct expression of the intensity of a room's use. It is therefore also suitable as an orientation marker for other areas of regulation such as for the dimensional planning of ventilation and air conditioning systems or for ventilation instructions in naturally ventilated, densely used rooms such as schoolrooms or assembly rooms. [4]

In indoor spaces which are in use, the CO_2 concentration depends mainly on the following factors:

- Number of persons in the indoor space, space volume
- Activity of the indoor space's users
- Duration spent by the users in the indoor space
- Combustion processes in the indoor space
- Air exchange and outer air volume flow

A rapid increase of CO_2 concentration in the indoor air is the typical consequence of the presence of many persons in relatively small spaces (e.g. assembly, conference or schoolrooms) with a low air exchange rate. Critical CO_2 concentrations generally occur together with other air contamination factors, in particular odorous substances from sweat or cosmetics, as well as microorganisms. In airtight constructions with their very low air exchange rates, the CO_2 concentration can increase even in the presence of only a few people (e.g. in apartments or offices). In both cases, the CO_2 has a direct influence on how comfortable people in feel in a room. The European Collaborative Action (ECA) has arrived at the following levels of dissatisfaction based on model calculations. From 1 000 ppm, around 20% of room users can already be expected to be dissatisfied, rising to approximately 36% at 2000 ppm. [5]

While assembly or conference rooms are as a rule only used occasionally and for short periods, schoolrooms, in the light of the regular presence of students and teachers over hours, must be viewed as particularly critical regarding the CO_2 concentration in the classroom air. Current and past studies in several German states on the carbon dioxide contamination of indoor air in schoolrooms have consistently demonstrated considerable deficits in indoor air quality regarding this parameter. [6]

The CEN EPB standard EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1–6 [7] provides in the informative Annex B values for ventilation rates. In B3 of this annex you the basis for the criteria for indoor air quality and ventilation rates is presented. Values and classifications presented in the tables in B3 are not limited to the pollution level due to persons but also due to the emission of building materials.

External air volume flow, ventilation rate and ventilation traffic light

The outer air volume flow or ventilation rate describes the volume of the flow (in ℓ/s or m³/h) of external air into a room or a building, either through the ventilation system or by infiltration through the building shell.

For rooms which are intended for human presence, the required external air volume flows are stated with reference to people, i.e. ℓ/s per person or m³/h per person. The air exchange rate (*n* in 1/h) is the quotient from the air input volume flow in m³/h and the room volume in m³.

An indoor climate is perceived to be comfortable when the temperature is between 20 and 23°C and the air humidity between 30 and 70%RH. However, a maximum of 50%RH is recommended for those allergic to house dust mites. Occasional checks using an officially calibrated hygrometer are to be recommended in this case. Air flows in rooms should not exceed values of 0.16 m/s (in winter) and 0.25 m/s (in summer), depending on the season.

When entering a room in which people are present, there is sometimes an impression of "used-up air". This can be traced to exhaled carbon dioxide, water vapour and emitted body odours. [8]

The ventilation traffic light is useful for a modern evaluation of CO_2 level in indoor air (**Fig. 3**).

Max von Pettenkofer.

150 years ago, the German chemist and hygienist Max von Pettenkofer had already indicated "bad air" as a negative influence after longer stays in living quarters and teaching institutions, and identified carbon dioxide as the most important leading component for the evaluation of indoor air quality. He set 0.1 vol% (= 1000 ppm) as a standard for indoor CO_2 – the so-called Pettenkofer number, which was the valid guideline for a long time. The first signs of impaired well-being, such as headaches, fatigue and lack of attentiveness start to show upwards of this concentration. [9]

Fig. 2. Max von Pettenkofer.

	Carbon dioxide concentration (ppm)	Ventilation traffic light	Hygienic evaluation	Recommendations
Concentrations under 1000 ppm carbon dioxide in indoor air: Uncritical	< 1000	Green	Hygienically uncritical (target value)	No further measures
Concentrations 1000 and 2000 ppm: Critical	1 000 to 2 000	Yellow	Hygienically critical	Ventilation measures (increase external air quantity/air exchange). Check and improve ventilation behaviour
Concentrations over 2000 ppm: Unacceptable	> 2 000	Red	Hygienically unacceptable	Check ventilation options of room. Check possible further measures

Fig. 3. Evaluation of CO_2 level in indoor air with the ventilation traffic light. [10]

Sick building syndrome

The term "sick building syndrome" (SBS) can be read two ways. On the one hand, it refers to buildings which make their inhabitants sick as they work, and on the other hand, the buildings themselves are described as "sick".

The cause of sick building syndrome is usually air conditioning or insufficient air hygiene in buildings. There is a broad spectrum of symptoms, including the following: Irritations of the eyes, nose and throat; a perception that the mucus membranes and the skin are drying out; mental fatigue; frequent respiratory infections and coughing; hoarseness, shortness of breath, itching and non-specific hypersensitivity.

An American study in buildings with air conditioning and ventilation systems was able statistically to demonstrate significant, positive correlations between complaints such as dryness in the throat and irritations of the mucus membranes, and the increase of CO_2 concentrations, even in concentration ranges below 1 000 ppm absolute.

More recent studies have shown that the costs for remedying problems arising from an unfavourable indoor climate are often higher for the employer, the building owner and society than the energy costs of the affected building. It has also been proven that a suitable indoor climate quality can improve total performance at work and study, while lowering absentee rates. [11]

Indoor air quality in schools

In Germany alone, there are 34 000 general education schools and 10 000 professional training schools. Accordingly, the monitoring of CO_2 is of special significance here. Outdoor air contains an average carbon dioxide component of 400 ppm. [12]

In a classroom, this proportion increases just though the air breathed by students and teachers in one class period to over 1 500 ppm, and after 90 minutes, values of 2 700 ppm have been measured. In the end, this leads to increased fatigue and decreasing attentiveness – symptoms which are direct obstacles to learning and teaching. [13]

A study from the USA concludes that the CO_2 concentration in classrooms has a direct influence on student attendance. An increase of 1 000 ppm CO_2 leads to an increase of absenteeism by 10 to 20%. According to another study, every 100 ppm increase of CO_2 reduces the annual attendance of students by 0.2%. [14] It has also been established that raising the ventilation rate can lower absenteeism due to illness by 10 to 17%. [15]

CO_2 therefore influences attendance in the schools surveyed. However, the extent of this influence remains unclear. Not least because the individual circumstances in the schools need to be considered.

With the introduction of the Energy Saving Bill in Germany in 2002, (revised in 2007), all those involved

in the refurbishment of school buildings are facing new challenges. The building shell and the windows are consciously being made airtight, to fulfil the energy stipulations. In cases of insufficient ventilation, the downside of this can be an accumulation of chemical and biological substances in the indoor air. [16]

Although the carbon dioxide problem in rooms with many people has long been known, convincing solutions have hitherto not been found in the education sector. At the same time, there is no clearly regulated responsibility as to when and by whom the classroom windows are to be opened, especially in the winter months. The consequences are, as expected, high to very high CO_2 values (3000 ppm and more). This also has a direct effect on the risk of infection in schools: Where there is much CO_2, a particularly large number of germs are also to be found. [17]

In 2003, for example, the American scientists Rudnick and Milton studied the risk level of flu infection in a classroom. 30 people were present in a classroom for four hours, one person was suffering from acute influenza. The result: At 1 000 ppm CO_2, five people were infected, at 2 000 ppm there were twelve, and at 3 000 ppm, even 15. [18]

The current situation in many schools shows that in some places, the instruction to ventilate regularly and intensively is not enough to manage the CO_2 problem. Technological ventilation measures become unavoidable, to achieve a user-dependent and permanent air quality with low CO_2 concentrations. [19]

Guidelines for CO_2 content in indoor air

In Germany and Europe, there are no comprehensive legally binding regulations for quality requirements regarding indoor air. Instead, several evaluation values exist, which are called guide values, orientation values or target values, for example. In Germany, a CO_2 value of 0.15 vol% (= 1 500 ppm) applies as a hygienic guide value according to DIN 1946 Part 2. The indoor guide values for CO_2 were published by the Indoor Air Hygiene Commission (IRK) of the Federal Ministry of the Environment and the State Health Authority. [20]

Several neighbouring countries have published guidelines and recommendations for the ventilation of buildings, including schools, which include stipulations for the limitation of CO_2 concentrations in indoor air. In Finland, the maximum permitted CO_2 concentration in indoor air under usual weather conditions and when the room is in use is 1 200 ppm. The Norwegian and Swedish guidelines fix a maximum CO_2 concentration of 1 000 ppm for living rooms, schools and offices. In Denmark, according to the Work Protection Authority guideline, the carbon dioxide concentration in children's day care centres, schools and offices should not exceed 1 000 ppm. The air exchange is described as insufficient when the CO_2 concentration exceeds the value of 2 000 ppm several times a day for a short time. [21]

At workplaces which are subject to the stipulations of the Dangerous Substance Directive (German TRGS 900) a workplace limit value of 5 000 ppm CO_2 applies.

CO_2 measurement technology

There are three possibilities available for the measurement and monitoring of carbon dioxide in indoor rooms:

CO_2 measuring instruments

Portable and suitable for long-term measurements, they measure the CO_2 content quickly and precisely.

CO_2 data loggers

Measure temperature and humidity without interruption, in addition to CO_2. Measurement values are transmitted by wireless LAN to the Cloud, allowing alarm notifications of limit value violations by e-mail or SMS. The easily visible air quality traffic light also ensures that the responsible people see the indoor air quality status immediately.

Air velocity and IAQ measuring instruments

In addition to CO_2, they measure all other ventilation and air conditioning parameters such as air flow velocity, temperature, humidity, turbulence level, CO or lux. ■

Sources.

[1] Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung, page 1358.

[2] Müller-Limroth (1977): quoted in Luftqualität in Innenräumen (1997). Bundesamt für Umwelt, Wald und Landschaft, Schriftenreihe Umwelt Nr. 287, quoted in Komfortlüftung.at gesund & energieeffizient, Physikalische Faktoren Kohlenstoffdioxid als Lüftungsparameter, Aktualisierte Fassung August 2011, authors (Dipl.-Ing. Dr.Rolf Boos, Dipl.-Ing. Bernhard Damberger, Dipl.-Ing. Dr.Hans-Peter Hutter, Univ.-Prof. Dr. Michael Kundi, Dr.Hanns Moshammer, Dipl.-Ing. Peter Tappler, Dipl.-Ing. Felix Twrdik, Dr. Peter Wallner), http://www.komfortlüftung.at/.

[3] Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung, page 1362.

[4] Komfortlüftung.at gesund & energieeffizient, Physikalische Faktoren Kohlenstoffdioxid als Lüftungsparameter, Aktualisierte Fassung August 2011, page 6, authors (Dipl.-Ing. Dr.Rolf Boos, Dipl.-Ing. Bernhard Damberger, Dipl.-Ing. Dr.Hans-Peter Hutter, Univ.-Prof. Dr. Michael Kundi, Dr.Hanns Moshammer, Dipl.-Ing. Peter Tappler, Dipl.-Ing. Felix Twrdik, Dr. Peter Wallner), http://www.komfortlüftung.at/.

[5] ECA (1992) Guidelines for ventilation requirements in buildings. European Collaborative Action Indoor Air Quality & its Impact on Man. Report no. 11. EUR 14449, quoted in: Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung, page 1366.

[6] Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung, page 1358f.

[7] EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

[8] https://www.allum.de/stoffe-und-ausloeser/schadstoffe-der-innenraumluft/allgemeines-zur-innenraumluftqualitaet.

[9] Umweltbundesamt Innenraumlufthygiene-Kommission des Umweltbundesamtes, Leitfaden für die Innenraumhygiene in Schulgebäuden, authors Dr. Heinz-Jörn Moriske and Dr. Regine Szewzyk, 2008, page 32, http://raumluft.linux47.webhome.at/fileadmin/dokumente/uba_innenraumhygiene_schulgebaeude.pdf.

[10] Fig. 3: Ad-hoc AG IRK/AOLG, 2008: Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Bundesgesundheitsbl-Gesundheitsforsch-Gesundheitsschutz.

[11] Über das Sick-Building Syndrome, author Dr-Ing. Ahmet Cakir, Zeitschrift für Arbeitswissenschaft 1994 ((http://ergonomic.de/wp-content/uploads/2015/03/sick_building-2002.pdf.

[12] Umweltbundesamt Innenraumlufthygiene-Kommission des Umweltbundesamtes, Leitfaden für die Innenraumhygiene in Schulgebäuden, authors Dr. Heinz-Jörn Moriske and Dr. Regine Szewzyk, 2008, page 10.

[13] Frauenhofer IBP, Frauenhofer Institut für Bauphysik IBP, Study Report Titel Impact of the indoor environment on learning in schools in Europe, authors Gunnar Grün, Susanne Urlaub, Stuttgart, 10. Dezember 2015, https://www.ibp.fraunhofer.de/content/dam/ibp/de/documents/Presseinformationen/Velux-Prestudy_WhitePaper_141205_amended.pdf.

[14] Shendell DG, Prill R, Fisk WJ, et al. (2004) Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. Indoor Air 14:333–341, quoted in: Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung.

[15] Frauenhofer IBP, Frauenhofer Institut für Bauphysik IBP, Study Report Titel Impact of the indoor environment on learning in schools in Europe, authors Gunnar Grün, Susanne Urlaub, Stuttgart, 10. Dezember 2015, (https://www.ibp.fraunhofer.de/content/dam/ibp/de/documents/Presseinformationen/Velux-Prestudy_WhitePaper_141205_amended.pdf).

[16] Umweltbundesamt Innenraumlufthygiene-Kommission des Umweltbundesamtes, Leitfaden für die Innenraumhygiene in Schulgebäuden, authors Dr. Heinz-Jörn Moriske and Dr. Regine Szewzyk, 2008 (http://raumluft.linux47.webhome.at/fileadmin/dokumente/uba_innenraumhygiene_schulgebaeude.pdf, Seite 7.

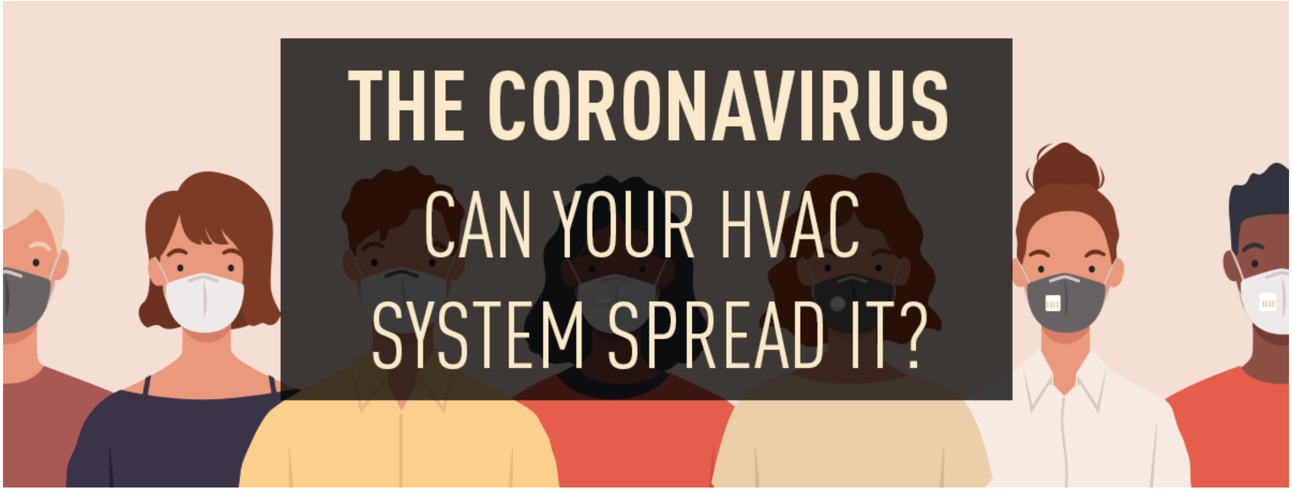
[17] Mensch-Umwelt-Gesundheit, Bericht CO_2, http://raumluft.linux47.webhome.at/natuerliche-mechanische-lueftung/co2-als-lueftungsindikator/, page 2.

[18] Rudnick SN, Milton DK (2003) Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. -245 Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschung, page 1365.

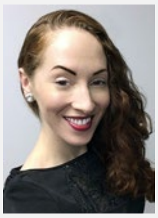
[19] Umweltbundesamt Innenraumlufthygiene-Kommission des Umweltbundesamtes, Leitfaden für die Innenraumhygiene in Schulgebäuden, authors Dr. Heinz-Jörn Moriske und Dr. Regine Szewzyk, 2008 (http://raumluft.linux47.webhome.at/fileadmin/dokumente/uba_innenraumhygiene_schulgebaeude.pdf, page 39.

[20] Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, page 1358-1369, http://www.komfortlüftung.at/, gesund&energieeffizient, Komfortlüftungsinfo No. 4, Gesetzliche Vorgaben und Regelwerke, Herausgegeben am 15.10.2010, page 7.

[21] SF-Ministry of the Environment (2003) Indoor climate and ventilation of buildings. Regulations and Guidelines 2003. D2 National building code of Finland, http://www.environment.fi/default.asp?contentid=68171&lan=en, zitiert bei: Bundesgesundheitsbelehrung, Gesundheitsforschung-Gesundheitsschutz des Umweltbundesamtes 2008, Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft, Springer Medizin Verlag Ergonomic Institut für Arbeits- und Sozialforschun.



Can HVAC Systems Spread the Coronavirus / COVID-19?



CATE SHAW
cshaw@gatewaymecahnical.ca

We rely on heating, ventilation, and air conditioning (HVAC) systems for clean, safe air. Frighteningly though, you may have heard how they can spread the coronavirus / COVID-19.

Can HVAC systems spread viruses and other pathogens? In a word, yes.

Now before you terrify your friends by sharing that tidbit on social media, read on. There's much more to it.

For the full picture, this article gives an overview of what prompted concerns about HVAC systems spreading the virus—and why reducing that spread still matters. More importantly, we review how it spreads—including through your facility's central air. But the best part? Properly configured heating, ventilation, and air conditioning (HVAC) systems can neutralize the virus and help stop it from spreading.

Skip ahead to any chapter if you know what you're looking for

This article gives an overview of how the coronavirus / COVID-19 spreads, particularly as it affects your building, facility, or space's HVAC system.

Chapter 1: The CDC Coronavirus Report That Shook the HVAC Industry

Early in the pandemic, this case prompted concern about heating, ventilation, and air conditioning (HVAC) systems spreading the coronavirus / COVID-19.

A CDC early report [1] mentioned how the coronavirus / COVID-19 spread among diners at adjacent tables in a busy restaurant in Guangzhou, China in late January. Reports shared this single source widely, while missing some pretty important points.

Let's start with what happened.

A family traveled from Wuhan, eating lunch at a restaurant in Guangzhou. One family member started feeling symptoms later that day and within two weeks, nine others from that restaurant had become ill. Four of these were at the table with the "index patient," the first to fall ill. More uncomfortably, there were also five more people infected at two adjacent tables. The going theory was that the restaurant's air conditioning system had re-circulated virus particles from dried up droplets.

The case and initial report were widely spread—without all the report's details.

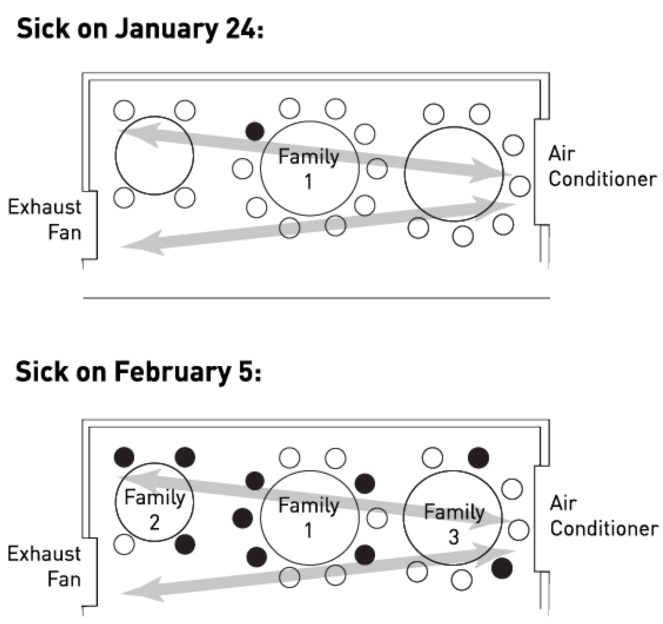
These points are consistently under-reported when discussing this April CDC case study about the restaurant:

1. No virus particles were present [3] in the air conditioning unit and duct work.
2. The CDC report never suggested turning off air circulation units to reduce risks. It also cites improper social distancing measures and uneven air distribution as possible culprits (air velocities over 40 cfm). [4]
3. There were strong air flows, pointing to uneven air distribution [5]. FYI this is something a well-designed, operated, and maintained HVAC system ideally won't do, anyways.
4. When the researchers published the article, airborne spread wasn't yet widely accepted. The authors themselves also acknowledge their study's limits, explicitly focusing on strong crosscurrents spreading droplets, not airborne spread. Aerosol transmission was also initially ignored because the staff, other diners, and air conditioner all tested negative.

Make no mistake, we're not faulting the report. And heck, we're actually grateful to the people who helped bring HVAC into the conversation about slowing the coronavirus / COVID-19 from spreading.

The big takeaway here: there's more to the story about how the virus spreads.

Before you shut off your HVAC system in a panic—know that it can be part of the solution.



Adapted from McKinsey & Company, original available at www.mckinsey.com

Image source: [2]

There's new information arriving daily, yet some takeaways stay relevant. The next section covers a few of these basics before we dive too deeply into how the virus spreads.

Chapter 2: The Basics: What You Should Know About the Virus

This section addresses a few basics—including why the coronavirus / COVID-19 is still so serious today.

The coronavirus / COVID-19 pandemic changed how we think about buying groceries, to how we work, to our thoughts on personal space. There's so much that's new that the word 'unprecedented' just falls painfully short. While we collectively struggle through lockdown fatigue, we've surely all met someone who only sees protective measures as an annoyance limiting their freedom.

First, what we're calling it here.

The World Health Organization's naming convention [6] describes the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2), and the resulting disease it causes (COVID-19). Here, we'll mostly use the term coronavirus / COVID-19. (We may also say novel coronavirus, if we're also discussing the 2003 SARS-CoV-1 outbreak).

Second, it affects all of us.

Severe outcomes disproportionately affect some demographics, but everyone's at risk. Between 25 – 80% of people aren't aware they have the virus [7], so it's easy to spread. Even if you're not in a high-risk group, you can still get sick and expose a loved one (or someone else's) to severe infection.

Third, it's really contagious.

Rate of infection (R0) refers to how many people a sick person can infect. According to the American Council on Science and Health, the novel coronavirus is more infectious than seasonal flus, but not as infectious as the measles [8]. (Someone with seasonal flu spreads to an average of 1.3 people, coronavirus / COVID-19 to an average 2.5 people, measles to an average 12 – 18 people).

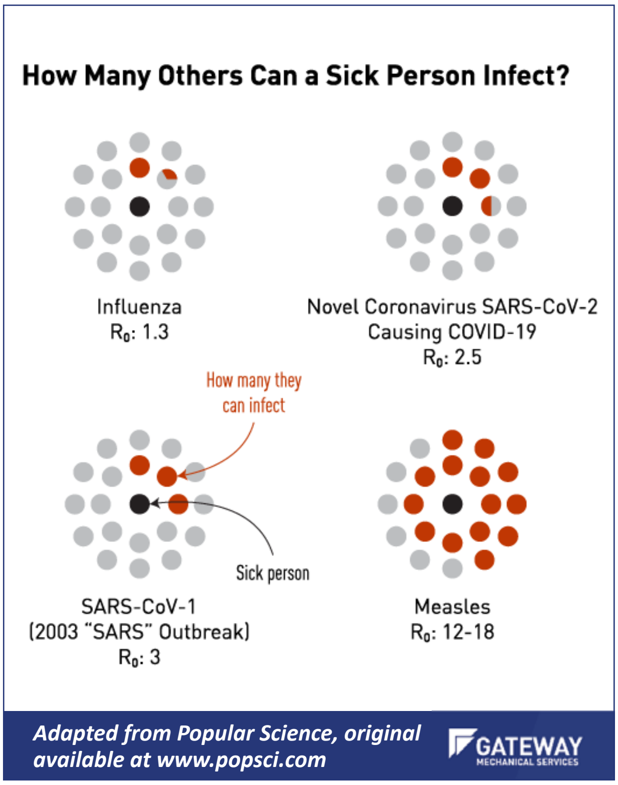


Image source: [10]

Compared to the coronavirus SARS-CoV ("SARS") epidemic in 2003, and the flu pandemics of 1918 ("Spanish flu") and 2009 (H1N1), the novel coronavirus is harder to contain [9]. That's because people with the coronavirus / COVID-19 (a) are more likely to be asymptomatic carriers, and (b) tend to infect more people.

Fourth, it's spreading—and while some grow complacent, it's far from over.

Many places are experiencing a second and third wave [11], before the first has finished. Looking at the World Health Organization's numbers [12] half a year into the pandemic, there are almost 110 million confirmed infections—that's almost 3 times the population of Canada. Almost 2.5 million people have died from COVID-19—imagine massive cities like Caracas, Dubai, Houston, Manchester, or Vancouver dropping off the map in mere months.

Ok, so if reducing transmission risks are still important today, what we can do about it?

Well, if the virus spreads many ways, we'll need a multi-layered approach. To get started, the next section's a primer on how it spreads.

Chapter 3: I Keep Hearing Different Things... How Exactly Does the Coronavirus / COVID-19 Spread?

Before you start putting HVAC strategies in place to make your air safer, it helps to know more about how the coronavirus / COVID-19 spreads in the first place. Here's that primer we promised you.

Research linking the spread of the coronavirus / COVID-19 to heating, ventilation, and air conditioning (HVAC) systems often centers on whether it's airborne.

There's a lot we're still learning about this new virus. Here's what many reputable sources seem to agree on though: the coronavirus / COVID-19 can be spread through droplets, surface transfer, and through small particles that hang in the air like an aerosol.

Droplets

The World Health Organization currently says we're most likely to be infected by direct contact with respiratory droplets [13].

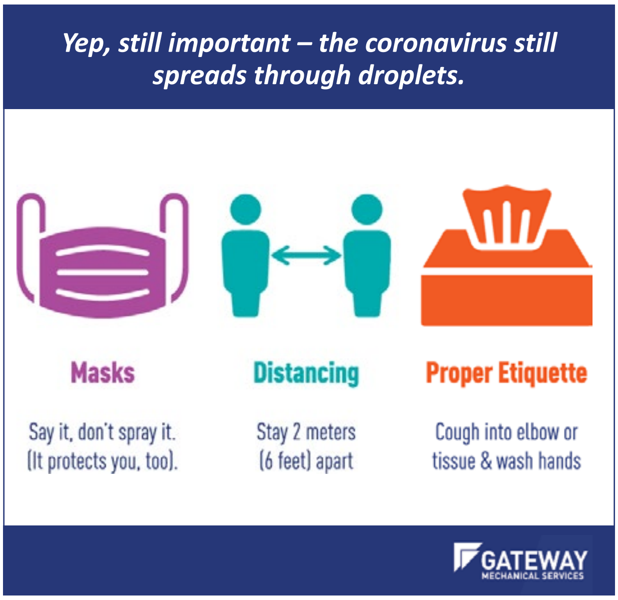
The virus lives in the mucus membranes of the nose and mouth. When an infected person coughs, talks, and exhales, droplets spread into the air. These comparatively large droplets are typically too heavy to hang in the air but pose a threat to whomever they land on. When these droplets contact the eyes, nose or mouth of another person, they may also contract the virus. That's why authorities ask people to wear masks, and practice social distancing and good respiratory etiquette [14] (coughing / sneezing into an elbow / tissue, and immediately washing hands). Health Canada currently advises a minimum of 2 meters [15] (6 feet) for social distancing.

Contaminated Surfaces

Droplets sprayed out land on surfaces around the infected person. The fancy word for this is fomites [16], inanimate surfaces that may carry pathogens. The next person to touch the fomite may pick up the live virus, which clings to their hands, and transfers to the new host when they touch their face. That's why there's so much emphasis on thorough hand-washing and surface disinfection.

Researchers are investigating how long the coronavirus can survive on various surfaces [17]. The New England Journal of Medicine found under lab conditions, the virus is "viable up to 72 hours on plastics, 48 hours on stainless steel, 24 hours on cardboard, and 4 hours on copper." Researchers found that 72 hours after contamination, the amount of viral material detected on these surfaces is less than 0.1% of the original amount [18].

The likelihood of infection from contaminated surfaces declines over time, and we're now learning there's less evidence for this mode than originally thought [19]. That said, contaminated surfaces are still possible disease-carriers with simple prevention methods. That's why authorities ask people to wash hands, sanitize surfaces, and not touch their faces in public [20].



Chapter 4: Is the Coronavirus / COVID-19 Airborne?

Yes, by now most parties agree that the coronavirus / COVID-19 is airborne.

When it comes to circulating air, the concern is that small virus particles are light enough to be recirculated through the system as well. As a result, airborne viruses directly affect heating, ventilation, and air conditioning systems (HVAC).

Following pressure from 239 scientists [21], the World Health Organization recently acknowledged aerosol transmission as a possible means of infection. The line between droplet and aerosol comes down to the size of particle carrying the virus. Particles as small as viruses are measured by their diameter in microns (AKA, micrometers, µm, or a millionth of a meter). As a reference point, the droplets are bigger than 60 microns and aerosol particles are smaller than 10 microns.

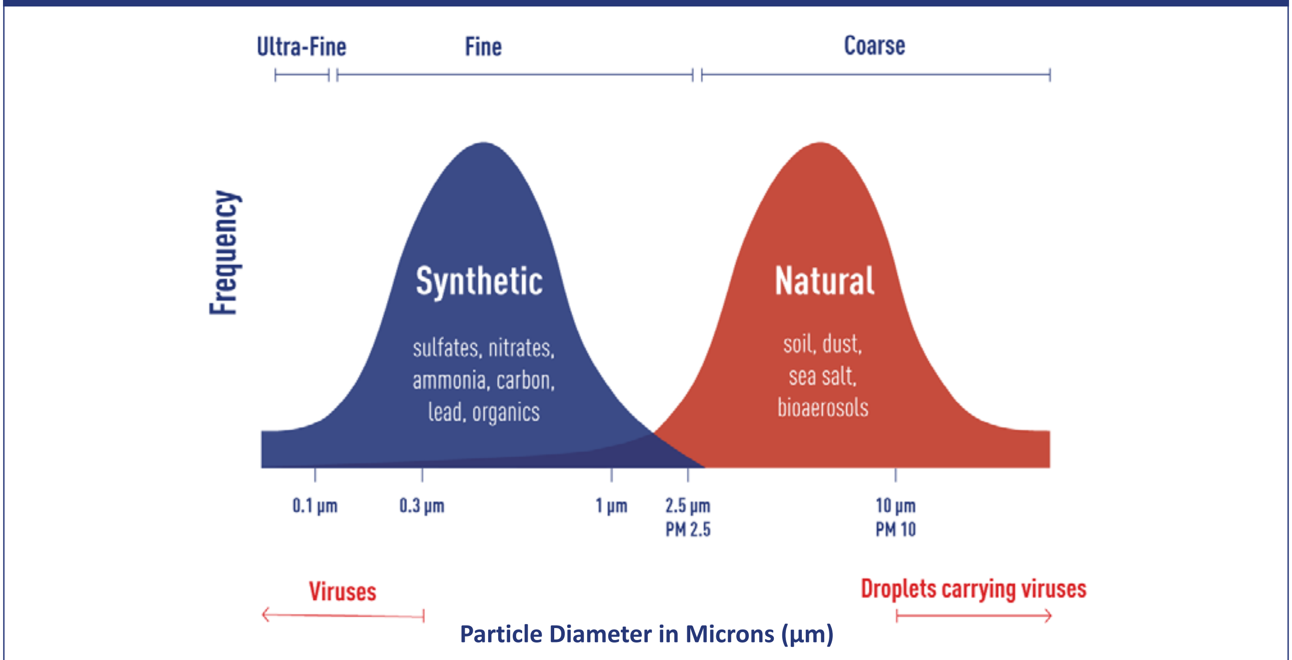
Though the WHO only cautiously declared this recently, researchers have been looking at airborne spread since the pandemic began ramping up. For example, earlier evidence from reputable sources agreed aerosol transmission is a significant vector [22] in spreading the coronavirus / COVID-19, and that the coronavirus / COVID-19 remains detectable in the air for three hours [23].

The novel coronavirus / COVID-19 is airborne—which means it's relevant to your heating, ventilation, and air conditioning (HVAC) system.

What Else Do I Need to Know, Given the coronavirus / COVID-19 is Airborne?

- **If there's one thing to learn from this article, it's that you can put your heating, ventilation, and air conditioning (HVAC) system to work in neutralizing the coronavirus and helping to stop its spread** [24].
- Airborne transmission may only infect others at short range (where it's hard to tell how a person was infected) [25]. Yep, we mean "say it, don't spray it," that's why authorities ask people to wear masks.
- Putting your HVAC to work in improving ventilation and disinfecting your air doesn't replace low-tech measures that need to continue. (For example, self-isolation, social distancing, wearing a mask, hand-washing, not touching your face, staying guarded against misinformation, disinfecting very contaminated areas like bathrooms and doorknobs, etc.). Those measures are still important—clean air won't do you much good if someone sick coughs in your face. Gross.
- It's airborne, but researchers are still looking into how infectious it is in when airborne. Why? Some infections with multiple transmission modes behave differently in different circumstances. Research

Relative particle sizes



GATEWAY MECHANICAL SERVICES *Adapted from the EPA Air Quality Communication Workshop San Salvador 2012 https://www.epa.gov* suggests the flu may work this way. For example, that influenza's airborne transmission may be less infectious than other modes, but lead to a more severe form of the illness [26]. The fancy word for that is anisotropic. And you're likely already familiar with the idea—like how a block of wood's easier to break *with* the grain, rather than *against* it. Basically, it just means behaving differently under different circumstances.

- We always recommend making the World Health Organization [27], Health Canada [28], and the Centers for Disease Control and Prevention [29] your primary sources for up-to-date health information on the coronavirus / COVID-19.

Need a pep-talk?

We get it. Given how many ways the coronavirus / COVID-19 can spread, it can feel overwhelming at times. And there are many moving parts—but remember every bit we each do counts in making our facilities safer. In the words of Anita Roddick, "If you think you're too small to have an impact, try going to bed with a mosquito in the room."

So, my heating, ventilation, and air conditioning (HVAC) system can spread the coronavirus / COVID-19... should I just turn off the system? Nope, nope, nope. Nope.

Here's why: a properly configured and maintained HVAC system can also help neutralize the coronavirus and help stop it from spreading [30] through your facility. Yes, really.

Chapter 5: Wait… HVAC Systems Can Also Help Stop the Coronavirus / COVID-19 from Spreading?

Earlier in the pandemic, the New York Times [31] remarked sagely "while dense urban conditions can aid the spread of viral illness, buildings can also act as barriers to contamination. It's a control strategy that's not getting the attention it deserves."

Evidence is stacking up now for using buildings as barriers to contamination—especially in the HVAC industry. This next caught our eye, since it's close to home for our writing team.

A group of Canadian mechanical engineers and researchers from the University of Alberta recently secured federal funding to investigate potential coronavirus spread through heating, ventilation, and air conditioning (HVAC) systems [32]. The project's still underway but has been approved for rapid review [33].

The team will:

1. Review existing research on viruses and air circulation,
2. Develop a strategy to prevent or reduce airborne spread of the coronavirus / COVID-19 through HVAC systems, and
3. Test the strategy at the University of Alberta campus.

They cite their goal as advancing safe HVAC systems using new designs, modifications, or maintenance adjustments [34].

And that team of researchers is in good company.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) is a reputable source of industry oversight and information. In light of current events, they established an Epidemic Task Force [35] to investigate all angles of the relationship between HVAC and current and future epidemics. ASHRAE released these official statements and position documents [36]:

1. It's likely airborne, which should be controlled. Adjusting building operations, including your heating, ventilating, and air conditioning (HVAC) systems, can reduce airborne exposures.
2. Ventilation and filtration through heating, ventilating, and air-conditioning (HVAC) systems

can reduce how many coronavirus / COVID-19 particles are in your air. Fewer particles in your air reduces airborne transmission risks.
3. The ASHRAE Position Document on Infectious Aerosols [37] acknowledges the (minimum) requirements for responsible facilities and building management to reduce airborne spread of the coronavirus / COVID-19.

We unpack these goodies in greater detail soon. Stay tuned for our follow up article. Our experts will share specific strategies and tactics when using your heating, ventilation, and air conditioning (HVAC) system to neutralize the coronavirus and help stop its spread.

Chapter 6: Summing It All Up: How an Airborne Coronavirus Affects Your HVAC System

To recap, this article walked you through:

1. An early highly publicized case. This case and other similar partially-reported stories helped bring heating, ventilation, and air conditioning (HVAC) systems to the forefront of conversations about the coronavirus / COVID-19.
2. How amidst lock down fatigue and apathy, discussing slowing the coronavirus / COVID-19 is as important as ever. This virus (not just pandemic restrictions) affects us all, regardless of demographic. It's also very contagious, difficult to contain, and continues to spread rapidly.
3. As promised, we shared scientifically-founded, authoritatively-sourced information on just how the virus spreads. We discussed the pathways it follows: droplets, contaminated surfaces—and that it's indeed airborne. We also discussed the implications that airborne transmission has on your HVAC system.
4. Finally, we discussed that while HVAC systems can indeed spread the coronavirus / COVID-19, when properly configured they can also neutralize the virus and help stop it from spreading [38].

Conclusion

We hope that sharing our expertise on how the coronavirus / COVID-19 spreads helped you understand what prompted this concern and why reducing that spread still matters—all in relation to your heating, ventilation, and air conditioning (HVAC) system.

There are also glimmers of hope in a time when we all need a boost. There's so much research happening on purifying air in public spaces to reduce transmission risks specific to the coronavirus / COVID-19.

As essential workers on the front lines, we've learned a lot during the pandemic. We're absorbing as much as we can every day. Stay tuned for our next article, where we detail just how to configure your HVAC system to help slow the coronavirus' spread. Spoiler alert: we focus heavily on ventilation, filtration, and disinfection.

Have we missed anything about how the coronavirus / COVID-19 spreads, and how that relates to your heating, ventilation, and air conditioning (HVAC) system? We'd love to hear from you, so please do take a moment to leave a comment below.

We wish good health to you and your loved ones. ■

References

[1] https://wwwnc.cdc.gov/eid/article/26/7/20-0764_article

[2] https://www.mckinsey.com/industries/advanced-electronics/our-insights/can-hvac-systems-help-prevent-transmission-of-covid-19

[3] https://www.shareddocs.com/hvac/docs/1001/Public/02/COVID-19-WHITE-PAPER.pdf

[4] https://www.shareddocs.com/hvac/docs/1001/Public/02/COVID-19-WHITE-PAPER.pdf

[5] https://www.mckinsey.com/industries/advanced-electronics/our-insights/can-hvac-systems-help-prevent-transmission-of-covid-19

[6] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it

[7] https://www.healthline.com/health-news/50-percent-of-people-with-covid19-not-aware-have-virus

[8] https://www.acsh.org/news/2020/04/13/covid-19%E2%80%99s-math-why-dont-numbers-add-14711

[9] https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30484-9/fulltext

[10] https://www.popsci.com/story/health/how-diseases-spread/

[11] https://www.ctvnews.ca/canada/what-constitutes-a-second-wave-in-canada-1.5035650

[12] https://covid19.who.int/?gclid=Cj0KCQjwpNr4BRDYARIsAADIx9xjmiq9Vwepg27xojNf7SUSzJLVnHOtgaTn8myxgvNm-zwZ3OuElGkaAnNeEALw_wcB

[13] https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions

[14] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/q-a-on-covid-19-and-masks

[15] https://www.canada.ca/en/public-health/services/publications/diseases-conditions/social-distancing.html

[16] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1828811/

[17] https://www.nejm.org/doi/full/10.1056/NEJMc2004973?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed

[18] https://hub.jhu.edu/2020/03/20/sars-cov-2-survive-on-surfaces/

[19] https://www.cbc.ca/news/health/coronavirus-surfaces-groceries-packages-playgrounds-1.5645602

[20] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

[21] https://academic.oup.com/cid/article/doi/10.1093/cid/ciaa939/5867798

[22] https://onlinelibrary.wiley.com/doi/full/10.1111/risa.13500

[23] https://www.nejm.org/doi/full/10.1056/NEJMc2004973?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed

[24] https://gatewaymechanical.ca/hvac-and-air-purification/

[25] https://www.scientificamerican.com/article/how-coronavirus-spreads-through-the-air-what-we-know-so-far1/

[26] https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-019-3707-y

[27] https://www.who.int/emergencies/diseases/novel-coronavirus-2019

[28] https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html

[29] https://www.cdc.gov/

[30] https://gatewaymechanical.ca/hvac-and-air-purification/

[31] https://www.nytimes.com/2020/03/04/opinion/coronavirus-buildings.html

[32] https://nationalpost.com/health/covid-19-likely-spread-by-building-ventilation-say-canadian-researchers-working-on-an-hvac-fix

[33] https://www.albertahealthservices.ca/assets/info/ppih/if-ppih-covid-19-sag-risk-transmission-hvac-systems-rapid-review.pdf

[34] https://cihr-irsc.gc.ca/e/51976.html

[35] https://www.ashrae.org/about/news/2020/ashrae-epidemic-task-force-established

[36] https://www.ashrae.org/technical-resources/resources

[37] https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

[38] https://gatewaymechanical.ca/hvac-and-air-purification/

virtual event

Protecting Transportation Workers and Passengers from COVID:

Gaps in Safety, Lessons Learned and Next Steps" – Testimony of William P. Bahnfleth, ASHRAE

Before the U.S. House of Representatives Committee on Transportation and Infrastructure: Hearing on "Protecting Transportation Workers and Passengers from COVID: Gaps in Safety, Lessons Learned and Next Steps" [1]

Editorial introduction.

This news item is included in the REHVA Journal to demonstrate how professional association may be able to play a role at policy level by sharing their information with responsible policy makers, like in this case the U.S. House of Representatives. I can imagine that our REHVA members may be in a similar position towards their national legislative authorities. This news item demonstrates how this can be done and how we may effectively make use of the information that is widely available via the IEQ-GA website (www.IEQ-GA.net) and at our REHVA website.

Jaap Hogeling, Editor in Chief REHVA Journal; Secretary/treasurer of IEQ-GA Board.

I am testifying today on behalf of ASHRAE, a professional and technical society made up of more than 55,000 individual members founded in 1894. The President of ASHRAE, Charles Gulledge, also wants to extend his thanks for your investigation of this important subject. He asked me to share his message: “Protecting the transportation workforce and passengers, many of whom are essential workers, is critical for all of us, as those traveling can rapidly spread the coronavirus over large distances. I am delighted that you have called upon the Chair of ASHRAE’s Epidemic Task Force who is one of the leading experts in this field. On behalf of the entire ASHRAE organization, we offer continued technical support to your committee as you work on policies and legislation to make transportation systems safer and healthier.”

In response to the pandemic, ASHRAE formed an Epidemic Task Force last March, which I was appointed to chair. The Task Force is comprised of volunteer members who are experts in the fields of air conditioning, ventilation, filtration and air cleaning. It includes practitioners as well as researchers and academics like myself who have focused their careers on making indoor environments safer and healthier. Importantly, as part of ASHRAE, the task force like all activities at ASHRAE, is free from commercial interests. Our guidance, standards, and other resources are based on science and consensus. The Task Force has produced hundreds of pages of guidance materials, conducted more than a hundred instructional webinars and courses, held briefings for policy makers, and developed summaries of this guidance that can be more accessible to the general public.

ASHRAE’s Epidemic Task Force has produced a 43-page guidance document specific to transportation systems (see 2). This guidance is based on current understanding of how COVID-19 is transmitted and on the principles of infection controls applicable to indoor environments generally, which includes mobile environments such as cars, trains, buses, aircraft, and ships. I will begin by reviewing those foundational considerations and then relate them to the transportation applications.

According to the US Centers for Disease Control and Prevention (CDC) as well as other public health authorities such as the World Health Organization (WHO), COVID-19 transmission is believed to be possible through three modes:

- Short range “droplet” transmission that occurs when an infected person and a susceptible one are sufficiently close together that large virus-containing droplets emitted by the infector through activities such as breathing, speaking, talking, coughing, and sneezing land in the eyes, nose, or mouth of the susceptible person. This mode of transmission is addressed by social distancing and use of masks, which limits the distance that infectious droplets travel and also the quantity of droplets. It should be noted that while the customary guideline in use for distancing is six feet, it has been shown experimentally that a sneeze may project a cloud of infectious droplets more than 25 ft from the source in still air. Air currents in an indoor environment may carry these infectious clouds over even larger distances. There is strong evidence for droplet transmission.
- Intermediate surface or “fomite” transmission that occurs when an infected person contaminates a surface that is touched by a susceptible person who infects themselves by touching their eyes, nose, or mouth. Fomite transmission is controlled primarily by personal hygiene, i.e., not coughing or sneezing into one’s hands, regular hand washing, and not touching the face, and by disinfection of surfaces, especially high touch surfaces like door handles. While still deemed possible, the perceived importance of fomite transmission has decreased over the course of the pandemic and there is little evidence that it is a significant mode of transmission.
- Airborne transmission resulting from the inhalation of infectious aerosols, the particles produced by drying of respiratory droplets that are sufficiently small to remain airborne for long periods of time and to become distributed throughout an indoor environment. Airborne transmission has been divided by some into short range and long range airborne transmission, as aerosols are always present even within the range associated with droplet transmission and may contribute significantly to risk within the 6 ft distancing radius.

Airborne transmission risk is controlled by “engineering controls” associated with heating, ventilating, and air-conditioning (HVAC) systems, including dilution with outdoor air, exhaust of contaminated air at its source, control of indoor air flows, filtration to remove infectious particles from the air, and air cleaners that capture or destroy infectious particles. Risk is also reduced through the use of masks, which reduce the amount of infectious material emitted into the air as well as the amount inhaled by a susceptible person. The focus of ASHRAE’s COVID-19 guidance is mitigation of airborne infection risk, but within the context of a layered infection control strategy that addresses all significant modes of transmission.

Early in the pandemic, WHO, CDC, and other health authorities were highly skeptical of the significance – or even possibility – of airborne transmission. Based on evidence of airborne transmission at the time, ASHRAE and some other organizations concluded that while definitive proof might not yet be available, there was sufficient reason to suspect airborne transmission that it should develop guidance to prevent it. Over time, the potential for airborne transmission became clearer and, since October of last year, however, both WHO and CDC have recognized that it can occur under certain circumstances and now recommend taking precautions against it. An important characteristic of airborne transmission is that it is proportional to airborne concentration of infectious particles, duration of exposure of susceptible persons, and the type of activities taking place. For example, an infected person exercising in a fitness center will shed infectious droplets at a higher rate than a sedentary individual and susceptible exercisers will inhale droplets at a faster rate.

These modes of infection may occur in any type of indoor environment, but the extent of the risk represented by each mode and the extent to which it can be mitigated varies with the characteristics of a particular environment.

ASHRAE's COVID-19 guidance currently addresses nine different facility types: residential, multifamily, healthcare, residential healthcare, commercial, communities of faith, school and university, laboratory, and transportation. Additional guidance is under development. The recommendations for each of these indoor environment types involve applications of the same engineering controls in ways appropriate to the specific indoor environment.

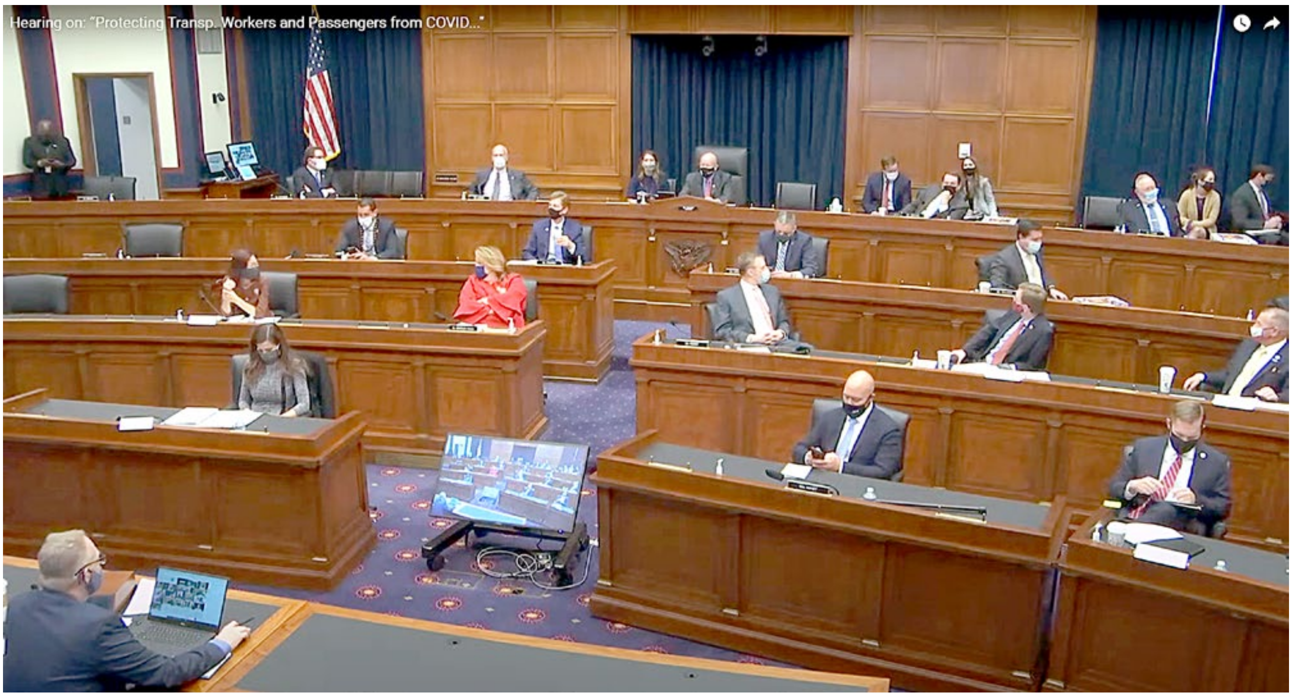
- Ventilation with outdoor air. Outdoor air is normally free of indoor pathogens, particularly viruses, which do not survive well outside the body. Outdoor air is mixed with indoor air, diluting viral aerosol it may contain and replacing potentially contaminated air that is exhausted at an equal rate. Ventilation is the most fundamental control for control of all contaminants. For buildings, a minimum amount of ventilation based on the type of use, number of occupants, and floor area is generally required by codes that are based on ASHRAE Standard 62.1 for non-residential buildings, Standard 62.2 for residential buildings, and Standard 170 for healthcare facilities. For non-healthcare facilities, the minimum ventilation requirement specified in the standard is not sufficient to provide a high degree of protection from airborne transmission.
- Air distribution. Air movement in indoor spaces can have positive and negative impacts on infection risk. Poor circulation of air in a space can result in poor removal of contaminants by ventilation. High velocity currents of air created by HVAC systems can create risk of extended droplet transmission. However, directional airflow can also be used to efficiently remove contaminants when the location of the source is known, for example, when an infected patient is in bed in a hospital patient room.
- Filtration. The filters used to remove particles from indoor air are typically composed of densely matted fibers. A range of filter efficiencies are available. The MERV rating system established by ASHRAE Standard 52.2-2017 is most commonly used for filters found in HVAC systems. MERV ratings range from 1 – 16 with higher numbers representing filters that are more efficient, particularly for small particles in the size range associated with respiratory aerosols. Current minimum filter efficiency requirements in ASHRAE Standards 62.1 and 62.2 are MERV 8 and MERV 6, neither of which removes fine particles with high efficiency. As in the case of minimum ventilation rates, minimum filtration requirements do not provide much protection against airborne transmission.
- Air cleaners. A large number of technologies are available that disinfect air via different process. This includes many for which the evidence for efficacy and safety is lacking. If effective, air cleaners can be adjuncts to ventilation and filtration. The best-established technology currently is disinfection with germicidal ultraviolet light, which can be applied in a number of different ways, both inside occupied spaces and in HVAC systems.

ASHRAE's Core Recommendations for Reducing Airborne Infectious Aerosol Exposure 3 summarize guidance for HVAC system design and operation changes to reduce risk of COVID-19 transmission. The recommendations address the following key points:

- *Public health guidance should be followed.* Social distancing and good hygiene help reduce droplet and fomite risk and indoor mask use in public spaces during the pandemic reduces both short and long-distance exposure.

- *Minimum levels of ventilation and filtration should be maintained and may be exceeded if necessary, to achieve desired levels of exposure reduction*. Code minimum ventilation and MERV 13 or better filter efficiency should be viewed as baseline requirements that may not be sufficient. A requirement to increase outdoor air is not needed if exposure can be reduced sufficiently by other controls.
- *Air cleaners may be used as a supplement to minimum ventilation and filtration to achieve risk targets*. Only those demonstrated to be safe and effective should be used.
- *Ventilation, filtration, and air cleaners may be combined to achieve exposure reduction goals while minimizing energy use*. The energy cost of increased outdoor air flow, which must be brought to the indoor temperature, can be significant and a disincentive to increase protection. Filters and air cleaners can also reduce the amount of active virus in the air and may be able to do it with lower energy use and operating cost.
- Unless a directional airflow strategy is applicable, *air distribution should not create strong air currents in the occupied part of a space that can blow large droplets from person to person and should thoroughly mix the air in a space*. As noted previously the range of droplet transmission can be extended by high velocity air flows. Some studies of ventilation in healthcare facilities have found that in many cases good mixing of room air results in lower exposure than stratified air distribution.
- *Ventilation systems should operate whenever occupants are present and outdoor air flow should not be reduced from its design values*. Systems should remain in operation when, for example, janitorial or maintenance crews are present. Demand controlled ventilation, which reduces outdoor air flow in proportion to the number of people in a space, should not be used because it slows the removal of infectious particles and increases their concentration in the air.
- *Re-entry of potentially contaminated air should be limited to safe values*. Infections may be transmitted by recirculation of exhaust air in in some types of energy recovery devices, placement of exhausts too close to outdoor air intakes, and by unintentional air flows through plumbing and ventilation shafts. Unintentional airflows were identified as the cause of outbreaks during the SARS epidemic. Recent investigations indicate that COVID-19 can be transmitted in this way.
- *Systems should be commissioned to verify that they are functioning as designed*. Many existing HVAC systems are not properly maintained and, as a result, use more energy than necessary and may not provide good control of indoor air quality.

Further, in assessing risk related to transportation, an end-to-end approach should be taken that includes the entire trip, not only, for example, time spent on an airplane. An air traveller may take a train to the airport, then spend time in the terminal prior to boarding and, after arrival must again move through the terminal and may again use public transportation to reach their destination. Any of these steps in the process may be the cause of transmission.



Ground facilities associated with transportation, including terminals, stations, hangars, garages, barns, and business offices have much in common with facility types for which extensive guidance is already available from ASHRAE and others. It should be possible to apply effective airborne protections to such facilities. A primary concern for public facilities such as terminals is the combination of large transient populations passing through them and the difficulty of maintaining distancing and of keeping the many high touch surfaces disinfected.

Although they are not stationary, aircraft, ships, cars, buses, and trains are, nevertheless, indoor environments typically provided with some level of HVAC system. Therefore, the same engineering controls applied to buildings potentially can be applied to them. However, they are by no means simply small moving buildings. Aircraft, ships, cars, buses, and trains are all relatively small enclosed volumes in which the density of people is ordinarily much higher than in buildings. This density inherently increases the risk of short-range transmission and it is difficult, if not impossible, to isolate passengers and workers in some cases, for example, in taxis. Ships, particularly cruise ships, bear more resemblance to land facilities but still provide many opportunities for close contact and fomite transmission.

Transportation HVAC systems vary greatly in terms of the levels of ventilation and filtration they provide. Aircraft HVAC utilizes high recirculation rates through very efficient (HEPA) filters to greatly reduce airborne transmission risk, and aircraft maintenance is typically very thorough. There is a much wider range of conditions in trains and buses. Ventilation rates are likely to be low, and filter efficiencies not sufficient to provide good control of infectious aerosols. Ability to provide protected environments for workers that are isolated from the passenger environment also vary. Bus and taxi drivers, in particular, are exposed to the same environment as passengers in an enclosed environment that may not be well ventilated. HVAC systems on ships may be more like those in buildings with respect to ventilation and filtration, but the layout of ships can make distancing difficult. These differences affect the requirements for, and even the feasibility of making substantial reductions in risk. In some cases, control options are limited by security concerns, for example the risk of fire from malfunctioning electronic air cleaning devices in buses.

Numerous case studies have been published investigating the transmission of COVID-19 during the current pandemic, mostly focused on aircraft, cruise ships, and buses. Similar studies in the past have investigated transmission of SARS and other diseases, particularly influenza. A few examples will serve to illustrate typical findings. Even in the highly ventilated, HEPA filtered environment of aircraft, transmission of COVID-19 has been observed during long-haul flights. In general, infections traced to travel tend to be passengers or workers who are in proximity to the index patient. For example, during a roughly 10-hour flight from London to Hanoi carrying 217 travellers that resulted in 14 infections among passengers and one among crew members, 12 of the infected were in the business class cabin where the index patient was located (Khanh, et al. 2020). Significant outbreaks have been associated with even sparsely occupied planes, as in the case of a flight to Ireland that yielded 13 in-flight cases – 12 passengers and one crew member - even though it was only at 17% capacity with 49 of 283 seats filled (Murphy, et al. 2020). In this case, there were several groups of infected travellers in adjacent seats. While these incidents suggest close contact transmission because of the clustering of cases, investigations of other incidents suggest airborne transmission. For example, during a 100-minute round-trip by bus to a religious event, 24 of 68 passengers were infected by a single index patient. The air conditioning system on the bus was in recirculation mode during the trip, i.e., no outdoor air was being brought in to dilute air contaminants (Shen, et al. 2020). In the case of the Diamond Princess Cruise ship incident, in which 712 of 3711 passengers and crew members contracted COVID-19, one analysis of infection data concluded that long range aerosol transmission accounted for most of the cases, even though the HVAC system on the ship was not recirculating air, while a second implicated close contact (Xu, et al. 2020).

Like most buildings, our means of transportation have not been designed to protect us from the risk of airborne infection. Aircraft, with their well-maintained systems that provide good ventilation and filtration of air still have proved vulnerable to infection transmission because of passenger density and the long duration of some flights. Other transportation modes provide greater opportunities to transmit disease to passengers and workers because of their designs that provide only modest ventilation and filtration and that may not be subject to the stringent maintenance requirements of aircraft. The COVID-19 pandemic has exposed the extent of these limitations as documented in forensic studies of transportation-related outbreaks. For the present, the best way to minimize infection risk related to travel remains to do so only when necessary and, even then, by observing all recommended safety and hygiene measures, particularly distancing and use of masks.

For the safety of those who must travel, it may be possible to upgrade the HVAC systems of some modes of transportation by improving ventilation, increasing filter efficiency and adding air cleaning technologies where applicable. However, as noted previously, there are limitations to the kind and extent of upgrades. This lesson – that risk can be significant and that our transportation systems currently may not provide the desired level of protection to workers and passengers, should be reflected in the design of future trains, buses, automobiles and ships. Improvements could include the obvious measures of increasing ventilation rates and filter efficiencies as well as making use of emerging air cleaner technologies. Some of the technologies we need are available now, but there are many opportunities for applied research to improve system design. Providing isolated, clean environments for workers is also important, given the higher level of risk they experience due to spending a much greater amount of their time exposed to the risks inherent in transportation. Clear instructions to passengers regarding safe travel practices that are enforced is also a way to make existing transportation system safer while new and better protected fleets are developing. Given the rate at which vaccines for COVID-19 are being deployed, follow through in addressing all of these needs is essential. ASHRAE is committed, within its sphere of expertise, to helping ensure that the safest possible conditions are provided for all who need and want to travel, today and in the future.

I appreciate the committee's desire to investigate this important topic and your consideration of my testimony. Protecting transportation workers and passengers is vital, especially for essential workers and those with critical needs such as doctor appointments. I hope my perspective focused on the built environment and HVAC systems proves useful, and I look forward to answering your questions. I also would be happy to provide any additional technical assistance from ASHRAE's Epidemic Task Force to advance the work of this committee. Thank you. ■

References

Azimi, P., Keshavarz, Z., Laurent, J.G.C., Stephens, B.R. and Allen, J.G., 2020. Mechanistic transmission modeling of COVID-19 on the Diamond Princess cruise ship demonstrates the importance of aerosol transmission. *medRxiv*.

Khanh, N.C., Thai, P.Q., Quach, H.L., Thi, N.A.H., Dinh, P.C., Duong, T.N., Mai, L.T.Q., Nghia, N.D., Tu, T.A., Quang, L.N. and Dai Quang, T., 2020. Transmission of SARS-CoV 2 during long-haul flight. Emerging infectious diseases, 26(11), p.2617.

Murphy, N., Boland, M., Bambury, N., Fitzgerald, M., Comerford, L., Dever, N., O'Sullivan, M.B., Petty-Saphon, N., Kiernan, R., Jensen, M. and O'Connor, L., 2020. A large national outbreak of COVID-19 linked to air travel, Ireland, summer 2020. Eurosurveillance, 25(42), p.2001624.

Xu, P., Qian, H., Miao, T., Yen, H.L., Tan, H., Cowling, B.J. and Li, Y.J., 2020. Transmission routes of Covid-19 virus in the Diamond Princess Cruise ship. *medRxiv*.

Shen, Y., Li, C., Dong, H., Wang, Z., Martinez, L., Sun, Z., Handel, A., Chen, Z., Chen, E., Ebell, M.H. and Wang, F., 2020. Community outbreak investigation of SARS-CoV-2 transmission among bus riders in eastern China. *JAMA internal medicine*, *180*(12), pp.1665-1671.

Endnotes

[1] February 4, 2021: introduction to the testimony: Thank you for the opportunity to address the committee today. I appreciate that Chairman DeFazio and Ranking Member Graves recognize the importance of transportation worker and passenger safety as the COVID-19 pandemic continues to threaten health and life worldwide. I also want to thank the leadership of this committee for their foresight in holding a hearing on this topic last summer when few imagined that the worst days of the pandemic lay ahead. Today, COVID continues to take a terrible toll, so it is more important than ever to understand the tools available to us to reduce risk of disease transmission in aircraft, ships, trains, and buses, as well as the stationary facilities that support transportation. The lessons of this unprecedented public health crisis must be applied upon now to reduce case numbers and save lives, and absorbed so we will be better prepared to confront future epidemics that threaten our lives and livelihoods.

This testimony can be viewed: https://transportation.house.gov/committee-activity/hearings/protecting-transportation-workers-and-passengers-from-covid-gaps-in-safety-lessons-learned-and-next-steps

[2] www.ashrae.org/technical-resources/transportation

[3] www.ashrae.org/file%20library/technical%20resources/covid-19/core-recommendations-for-reducing-airborne-infectious-aerosol-exposure.pdf

Interview with Tuba Bingöl Altıok
– Recipient of the 2020 REHVA Fellow award

The 11th of February 2021 was the International Day of Women and Girls in Science. An occasion to celebrate the achievements and place of women in the science field. Women have led ground-breaking research into public health, vaccines, treatments and innovative technology, and been on the front lines of COVID-19 response as scientists, health care workers and more. In this context, REHVA wanted to reflect on and highlight some achievements from the past year.

For instance, the REHVA Fellow award granted to Tuba Bingöl Altiok for her long-term collaboration with our organization. As representative of TTMD since 2011, Tuba attended all committee meetings. The following interview was made in 2020 following Tuba's award nomination.

Tuba Bingöl Altıok

- General Manager of Iklim Ltd.Sti. Turkey
- 25+ years' experience in management position in HVAC industry
- 30+ years' experience in HVAC sector
- Part of REHVA Committees since 2011
- Ambassador of TTMD for ASHRAE
- Became a REHVA Fellow in 2020

AD: Tell us a few words about you, your specialisation and career.

TBA: My father is a mechanical engineer and a designer/consultant in HVAC area. Thanks to this, HVAC area has become my target since the beginning. I graduated as a mechanical engineer from Middle East Technical University in Ankara, the capital of Turkey. During my education, I took part in orientation studies in design and production. My business life started as a system sales engineer and since then I can say that this is my profession. During my business life I had a short time period of mechanical subcontracting experience. For the past 21 years, I have continued to work in my company, mainly as a marketing and sales representative but also as distributor with the hinterlands in Turkey as well as all over the World through Turkish contractors.

AD: Since when are you involved in the REHVA community? Thank you for your commitment. Why do you think it's worth to invest time in the REHVA network as volunteer?

TBA: I was aware and was hearing about REHVA since I started my education. When I became a member of TTMD, I also became closer to REHVA. I remember, my first contact was in 2003, by joining the Symposium Organization Committee of TTMD. I met many people from REHVA during TTMD Symposiums, and from then then on. I can say that I have learned the most during the Clima 2010 conference, being a member of the Organization Committe of TTMD. Eversince this activity, I got to know REHVA much more into detail. Between 2011-2013 being a member of TTMD Board I was the ambassador in REHVA meetings. Since 2015 till today I am a member of External Relations Committee of TTMD and attending most of the General Assembly/annual/committee meetings and the Clima/Climamed Organizations.

AD: What do you consider as the main challenge of our sector? (NOTE: E.g. having in mind the global & EU goals on delivering decarbonised, high performing building with good IEQ. Feel free to change a bit the question & answer the one you prefer. The idea is to have your vision about challenges & trends)

TBA: I belive in the strength of non-for profits and NGO's. REHVA is a great source of information and knowledge. Some sources provide information and knowledge, others add some value, and many people benefit from all these. Once joinining such networks, as scientists or academia, the potential of reaching people is far greater, as they teach and inform a way bigger audience. I am not a scientist nor an academician but an engineer. As I mentioned during the ceremony in last GA, my aim is to build bridges between everybody so that whatever the case is, I will be there on behalf of TTMD/members and all individuals in Turkish HVAC sector with the responsibilty of providing the conditions for the people reaching to what they expect. This is so much worth to invest time as a volunteer.

Human beings mainly need to: breathe and drink water. Our main activity is to deal with air and water. Since they are vital, our activities are as well. Climate Change, and starting from Covid-19 any other possible future threats for air and water will bring the importance of our studies. I think we are lucky for this awareness.

AD: Anything else you want to share with REHVA community?

TBA: I am very happy to be in REHVA family. I hope I can provide many more bridges to REHVA in the future. ■

REHVA Student Competition 2020

Under the leadership of Manuel Gameiro da Silva, REHVA Vice-President from Portugal, the REHVA Student Competition was held, online due to the current conditions, on the 11th of January 2020.

This year, the sixteen representatives from 14 different countries took a part in the competition. Paulo Fernandes from Portugal presented his work on Energy Potential in Using a Bypass to the AHU's Heat Recovery System. The Netherlands has been represented by Maaike Leichsenring presenting her work on Flow Visualization of Ammonia inside a Corrugated Plate Heat Exchanger Condenser. Czech Republic was represented this year by David Stanek, he presented his work on Reuse of waste heat from IT equipment. Denmark has been represented by a team of two students, Amalie Dokkedal Jensen and Cathrine Schermer Riis presented their work on Modification of the Comfort Equation by P.O. Fanger for Elderly People. Also, Turkey was presented this year by a team of two students, Basak Dere and Zeynep Hazal Gumusluol, presented their work on Numerical and Experimental Analysis of Innovative Greenhouse Air Conditioning System. Representative from Romania, Mihai Baiceanu presented his work on Experimental and simulation performance investigation of a hybrid PV/T solar panel. Representative from Serbia, Damir Kovcic, presented his work on Faculty of Technical Sciences Department of Energy and Process Engineering University of Novi Sad; Anastasija Zeiza-Seleznova from Latvia presented her work on Impact of flue gas recirculation on the efficiency of hot-water boilers; Asur Pablo Menéndez Inchusta from Spain presented his work on Experimental characterization of a transcritical CO_2 vapor compression system with thermoelectric subcooling; Tej Zizak from Slovenia presented his work on Guidelines for Single-side Airing of Primary School Classrooms during Breaks. Representative from Italy, Anna Cazzola presented her work on Photovoltaic cogeneration to activate a double source heat pump. Helena Kuivjogi from Estonia presented her work on Patients and surgical staff thermal comfort in operating rooms at St. Olavs Hospital in Norway. Representative from France, Aurore Wurtz presented her work on Application of life cycle assessment to a building sample in order to help in projects evaluation. And Slovakia's Martina Mudrá presented her work on Application of Alternative Energy Sources in a District Heating System.

The Jury was composed by Manuel Gameiro da Silva (Portugal), Jorma Säteri (Finland), Murat Çakan (Turkey), Francis Allard (France), Prof. Ivan Chmúrny (Slovakia), Karel Kabele (Czech Republic), Robert Gavriliuc (Romania) and Ivo Martinac.

After very intense deliberation, the jury declared winner Maaike Leichsenring from The Netherlands for her work on "Flow Visualization of Ammonia inside a Corrugated Plate Heat Exchanger Condenser". The second prize was awarded to David Stanek from Czech Republic and the third prize was awarded to Asur Pablo Menéndez Inchusta from Spain.

Manuel Gameiro da Silva also thanked all contributors for their excellent work, emphasized the high quality of the works presented and the members of the jury for their excellent task. ■

Interview of the winners of the REHVA Student Competition 2020

1st place:
Maaike Leichsenring

- Mechanical engineer & lecturer in thermodynamics
- Born in 1990 in Muscat, Oman
- She did a bachelor in Industrial Design Engineering at the Delft University of Technology
- She graduated as mechanical engineer at the Delft University of Technology with a Master in Process & Energy technologies under Professor Carlos Infante Ferreira's supervision
- Held a board position as Chairman in the student association of Process & Energy Technology in the Delft University
- After graduation started working as a thermal engineer in the flue gas recuperation & heat exchanger business
- Currently member of the core team of young cool, an initiative of the Royal Dutch Association of Refrigeration knvvk&youngcool
- Interests involve painting, poetry and flora

1. Congratulations on your 1st place! How does it feel to be the winner?

Thank you very much! First of all, I would really like to thank the jury of REHVA for this election, I am very honoured to be selected first place. Also, I would like to thank the TVVL with a special mention to Arash Rasooli for the selection and guidance during the preparations.

The event was very well organised, and it was really fun to watch all the presentations from the other contestants. I was impressed with their work and therefore also aware of the strong competition. Therefore, winning the competition was a great surprise.

2. How did you prepare yourself for this competition?

I practised my presentation multiple times, focusing on the ideology that I wanted people to really understand the content and the relevance of the research. This was quite a challenge for a time slot of 12 minutes, so I chose to practise my presentation for people with and without a technical background. I became aware of the elements that needed further explanation and finished off the story. It made me feel confident that it was a clear story, without compromising important in-depth details of the research.

3. What was the inspiration for your project? Why this subject?

In Delft there is much attention for start-up companies, of which one well known company Bluerise was developing an OTEC cycle for generating renewable energy. The fact that it was about renewables and innovative techniques drew my attention. Bluerise and professor Infante Ferreira proposed the topic on two-phase flow visualization of ammonia. Two-phase flows were already my favourite topic and the fact that it was not done on NH3 in this type of heat exchanger made it extra exciting, but also very challenging.

4. What challenges have you encountered during this project?

Ammonia is aggressive and dangerous when inhaled or in contact with skin or eyes. It was therefore important to ensure a safe setup, as the ammonia is under pressure of 7 – 8 bar. The material of the first tailor made visualization plate absorbed the ammonia and degraded immediately when in contact with the pure ammonia, even though material resistance charts were promising regarding this material. The search for a strong, transparent and ammonia resistant material that could be CNC-machined into a detailed corrugation pattern was challenging. Especially knowing that resistance charts aren't very reliable, as most charts don't state the experimental conditions. I was lucky to find a material that fit all requirements and was also available in the Netherlands.

5. What are your ambitions regarding the applications of your project?

Ammonia is making a comeback towards commercial refrigeration. I hope the work motivates other researchers to do more flow visualization on ammonia and therefore extend the applicability of flow pattern maps of ammonia. Flow visualization experiments combined with heat transfer measurements will gain more insight in the behaviour of ammonia and condensing mechanisms. The more we know about the physical phenomena that occur during condensation, the more the theoretical performance calculations can be improved, while being less dependent on empirical correlations.

6. Congratulations on your Best Poster Award! What elements did you focus on while creating it?

Thank you very much! It was another big surprise to win the best poster award. I focused on designing a poster that was both graphically pleasing and showing a clear structure. I thought a poster should be easy to read while giving a clear overview of the work, so I tried to find a balance between the amount of text and the portrayed images.

2nd place: David Stanek

- Born in Prague in 1993
- Graduated master studies at the Czech Technical University in Prague (CTU) in 2019
- Currently studying post graduate at CTU and working in a local Energy simulation company.
- Member of Rehva's Czech member association
- Enjoys hiking, football and swimming in his free time

1. Congratulations on your 2nd place! How does it feel to be on the podium?

Thank you! It feels great, notably due to all the wonderful projects presented by the other competitors. Sadly, we could not experience a real-life conference this year. I believe a contact meeting would allow for a deeper connection between the participants. However, the competition was excellently prepared by the organisers.

2. How did you prepare yourself for this competition?

As the presentation was based on my diploma thesis, I had previous experience with this presentation. Of course, not in English! But as with every presentation, I presented the slideshow for myself several times, especially to figure out the correct length of the presentation.

3. What was the inspiration for your project? Why this subject?

I had the first idea for the topic three years ago. The theme has changed along the way, from decentralised data centres to centralised concepts. The reason was a pleasant combination of data centres, which are used in our everyday lives even if we do not realise it, and energy efficient buildings, which is my study focus.

4. What challenges have you encountered during this project?

The main challenge was gathering information about data centres functionality. Many DCs were not very communicative and I personally had no previous experience in the topic. Other than that, I encountered no main challenges, that I would not be able to overcome.

5. What are your ambitions regarding the applications of your project?

The topic is very relevant today and I am studying it deeper in my Ph.D. studies. We can see the ideas are being implemented today in many different scenarios.

3rd place: Asur Menéndez Inchusta

- Born in 1996, Spain.
- Master's in Industrial Engineering.
- First price in Atecyr's national HVACR award for the bachelor's degree thesis.

1. Congratulations on your 3rd place! How does it feel to be on the podium?

I feel really proud and humbled. The simple fact of having been able to participate was already a great joy for me and now that I was awarded third place, the pride and personal satisfaction I feel is incredible.

It is an experience I will always remember. When I realized where I was and what I had achieved, in addition to observing the high level of the other participants, I felt an extra boost that greatly increased the desire to continue working and setting high goals.

2. How did you prepare yourself for this competition?

Due to the delays caused by the pandemic, the preparation has been separated and stretched in time. This, coupled with the fact that I am finishing my master's degree in industrial engineering, has meant that the preparation has been much more concentrated in time than I would have liked.

However, this is a project in which I invested a lot of time and effort, so it is not too time consuming to remember every aspect of it. So, I was re-reading every step done in the project and all the papers used for reference so as not to leave any loose ends.

On the other hand, although my degree was taught in English, I was practicing my conversation skills in order to be able to express myself in a totally clear and fluent way. In my opinion, this is a particularly important aspect of the preparation, since the key to connect with listeners is not only to get a global understanding of your ideas, but to defend clearly and strongly the key aspects of the project. And language cannot be an obstacle to this aspect.

3. What was the inspiration for your project? Why this subject?

Ever since I attended my first subject on heat transfer, it was clear to me that this was one of the areas of engineering that I was particularly interested in. Later, as I took subjects related to the application of this field of study, I confirmed this thought.

It was in the last year of my bachelor's degree that I began to analyze the possibilities of a final project. At first, I strongly considered doing a project related to business economics applied to the energy industry, which is another of my favorite subjects of study.

However, I asked a professor who taught me one of the subjects I enjoyed the most, PhD Patricia Aranguren Garacochea. She was the one who introduced me to the topic to be investigated and I made the final decision to carry out this project due to its great projection and exclusivity. The urgent need to find economically and energetically viable cooling systems that also comply with current environmental regulations was an incredible challenge and motivation.

4. What challenges have you encountered during this project?

The greatest challenge was at the same time the greatest virtue of the project; it was a very new and practically untested design. Thanks to a previous computational study, we knew the trends to be obtained, however, there was some uncertainty with the values to be obtained.

The complete design of the installation was carried out in the university's workshop, so the materials and tools available were used. By this statement I mean that it was an installation that only we knew how to start it up and change its parameters, and in case of any vicissitude, we were the ones in charge of repairing it.

I will give a real example to explain this point, the first month of testing the installation was work which, although it was not in vain, since it meant that I ended up understanding and mastering the operation of the equipment; were data that have not been included in the paper since they were erroneous data. We obtained values that were far from those expected and we began to study the possible reasons. We ended up discovering that this dissonance of results was due to an effect of absorption of refrigerant by the compressor oil that we had not considered initially. A purging system was installed that managed to solve this problem reported. But this implied that a month worth of work was almost entirely wasted.

It was a challenge both theoretically and experimentally, we had to perform each step carefully to obtain the desired values. On the experimental level, it was a work of many hours. Being an experimental characterization of a thermal system, each variation in any parameter either: ambient or inner temperature of the cabin, refrigerant charge, or flow, etc.; resulted in a wait to reach the stationary state due to the large thermal inertia present. On the theoretical level, the study of a transcritical fluid and its performance in the installation was the hardest part of them all.

It can be concluded that it was a project in which we invested many hours and much effort, but to be doing something that filled you and had this projection, the effort was compensated with ambition.

5. What are your ambitions regarding the applications of your project?

My main ambition with the project is that it becomes viable for its inclusion in markets in countries with warm temperatures.

As I mentioned both in the paper and in the defense of the project, the research carried out provides a very promising start to the future of the system. Once this initial hopeful point has been reached, the installation requires a broader study to be able to reach points of competitiveness with conventional installations.

It is known that it is rather difficult to reach the efficiency levels achieved with conventional refrigerants. However, current regulations have meant a paradigm shift, since these conventional fluids are restricted. Therefore, the designed installation is a breakthrough. It is an inexpensive system that complies with environmental regulations and has great capacity for improvement.

One of the conclusions of this project is the great impact of the thermoelectric system in the installation. The inclusion of a thermoelectric subcooling system has been confirmed as a cheap and reliable option as an auxiliary system to provide extra power to the system. Therefore, at the present time, when research is still required for its inclusion in hot country markets, there is a real possibility of inclusion. In countries located in higher (or much lower if it is located in the southern hemisphere) latitudes the maximum temperatures reached do not produce adverse effects on the refrigerant, the inclusion of this device is the possibility of increasing the power of the system in a cheap way. ■

The Evolution of Building Energy Performance Assessment and Certification Schemes in Europe

This briefing article aims to capture for the reader's benefit the outlook for Energy Performance Assessment and Certification schemes in Europe using as basis the European Union's recent policy developments, most notably the Renovation Wave strategy [1] as integral component of the EU's Green Deal [2] and topic related recently ended and ongoing Horizon 2020 coordination and support, and innovation actions. Readers are empowered via the references to attain more in-depth insights as deemed useful and needed.

Keywords: building, performance, assessment, certification, evolution, renovation, financing, people-centred, energy, indoor environmental quality, health, well-being, CO_2 emissions, costs, smart readiness indicator, digitalization, digital transformation

ANDREI VLADIMIR LIȚIU
REHVA, Brussels, Belgium
avl@rehva.eu

JAAP HOGELING
REHVA, Brussels, Belgium
EPB Center, Rotterdam, Netherlands
jh@rehva.eu, jaap.hogeling@epb.center

The European Union is striving to be the first climate-neutral continent. As the building sector is one of the largest energy consumers in Europe

and is responsible for more than one third of the EU's emissions, effective action on the existing building stock is crucial (roughly 75% of the building stock is energy inefficient, yet almost 85 – 95% of today's buildings will still be in use in 2050). Renovation of both public and private buildings is an essential measure in this context and given the labour-intensive nature of the building sector, which is largely dominated by local businesses, renovations of buildings also play a crucial role in the European recovery of the COVID-19 pandemic.

To pursue this ambition of energy gains and economic growth, the European Commission published on 14 October 2020 a new strategy to boost renovation called "A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives" [3]. In parallel to the strategy, the European Commission adopted new rules for the smart readiness of buildings Implementing regulation on optional scheme for rating smart readiness of buildings [4] | Annex [5], Delegated regulation on optional scheme for rating smart readiness of buildings [6]| Annex [7].

Energy performance certificates are instrumental in the EU renovation wave

With the Renovation Wave Strategy, the European Commission aims to at least double renovation rates in the next ten years and make sure renovations lead to higher energy and resource efficiency. This will enhance the quality of life for people living in and using the buildings, reduce Europe's greenhouse gas emissions, foster digitalisation and improve the reuse and recycling of materials.

For supporting this overarching aim the European Commission plans to further improve the EU Energy Performance of Buildings Directive (EPBD) having foreseen in its 2021 work programme [8] a legislative proposal to revise the EPBD, together with an accompanying impact assessment, to be adopted in Q4 2021.

What's at stake for Energy Performance Certificates?

According to Building Performance Institute Europe [9], these are the most salient aspects in the EU Renovation Wave Strategy reinforcing the role of Energy Performance Certificates:

- Introducing mandatory minimum energy performance requirements (MEPS): When gradually phased in, **enabled by well-functioning energy performance certificates (EPCs)** and financing, MEPS can successfully tackle the worst performing buildings.
- **More effective EPCs, integrated with a digital building logbook, building renovation passport, smart readiness indicator, Level(s)**: As quality and increased availability of EPCs are necessary to guide occupants' choices, the Renovation Wave suggests reinforcing and strengthening existing EPCs, introducing a more standardised format for digital use and improved accessibility, supported by smart technologies.
- **Better data for buildings**: Effective building policies and measures can only be designed and implemented with consistent and reliable data, for example on energy consumption or environmental performance. The Renovation Wave proposes the introduction of a digital building logbook as a common repository for all relevant data over the entire lifecycle of the building, and to **strengthen data collection through an updated EPC framework, with stringent rules on availability and accessibility of databases**. The European Commission will also explore if and how the European Building Stock Observatory can become more reliable and robust.

An additional noteworthy development is **the soon to become intrinsic link between Energy Performance Certificates and financing** dealt with also via the Platform on Sustainable Finance [10] assisting the European Commission in developing its sustainable finance policies, notably the further development of the EU taxonomy [11] (classification system, establishing a list of environmentally sustainable economic activities). The renovation wave is considered as an opportunity to spur the development of green loan and mortgage financing. **An upgraded system of Energy Performance Certificates demonstrating efficiency gains will allow banks and other financial institutions to offer credit and mortgage financing to green their portfolios and to pool buildings as a collateral for the issuance of covered bonds**. A number of market-led initiatives are already piloting innovative schemes for energy efficiency loan and mortgage financing. In a next step, whole life-cycle carbon can be included in this assessment and linked to financing for circular solutions. [12]

Breeding ground for the evolution of Energy Performance Certificates

At the beginning of 2021 there are 7 ongoing Horizon 2020 projects contributing to the evolution of the existing energy performance assessment and certification process (at national level in EU's Member States). Additional 3 to 4 Horizon 2020 projects will be funded and commence later this year.

Coordination and Support Actions (CSA) started in 2019 (H2020_LC-SC3-EE-5-2018-2019 [13]).

- X-tendo [14] eXTENDing the energy performance assessment and certification schemes via a mOdular approach (project website [15]).
- U-CERT [16] Towards a new generation of user-centred Energy Performance Assessment and Certification; facilitated and empowered by the EPB Center (project website [17]) – REHVA and several of its Member Associations are partners.
- QualDeEPC [18] High-quality Energy Performance Assessment and Certification in Europe Accelerating Deep Energy (project website [19]).

These projects are geared to:

- Involve relevant stakeholders (including national and regional certification bodies) to stimulate and enable the roll-out of next-generation of energy performance assessment and certification, with a view to achieve enhanced reliability, cost-effectiveness and compliance with the set of EPB standards [20] and the Energy Performance of Buildings Directive.
- Develop strategies to encourage convergence of EPC practices and tools across the EU so as to ensure a comparable level of high quality, independent control and verification.
- Assess applicability through a broad set of well-targeted and realistic cases, featuring various locations, building types, climatic conditions and field practices including existing national EPC schemes.
- Embed the EPCs and their recommendations in broader concepts such as energy audits, wider-buildings related databases (e.g. national EPC databases, national housing surveys, EU Building Stock Observatory) and one-stop-shops including administrative, financial and supply side information.
- Link EPCs to related concepts such as buildings renovation passports, individual buildings renovation roadmaps or building logbooks should also be considered.

Innovation Actions (IA) started in 2020 (H2020_LC-SC3-EE-5-2018-2019 [21])

- D^2EPC [22] Dynamic Digital EPCs for Enhanced Quality and User Awareness (project website [23])
- E-DYCE [24] Energy flexible DYnamic building Certification (project website [25])
- EPC RECAST [26] Energy Performance Certificate Recast (project website [27]) – REHVA is partner
- ePANACEA [28] Smart European Energy Performance AssessmeNt And CErtificAtion (project website [29])

These projects are geared to:

- Address the definition and demonstration of innovative approaches for the assessment of building energy performance – be more reliable, user-friendly as well as cost-effective and compliant with the set of EPB standards [30] (technology neutral and transparently presented) and rely on the combination of existing and proven technology components.
- Consider implications when using EPCs in building passports and renovation roadmaps.
- Involve relevant stakeholders (including national and regional certification bodies).
- Value buildings in a holistic and cost-effective manner across several complimentary dimensions: envelope performances, system performances and smart readiness (i.e. the ability of buildings to be smartly monitored and controlled and, to get involved in demand-side management strategies).
- Take into account output measures of performance (actual measured data) making use of available and increasing number of building energy related data from sensors, smart meters, connected devices etc.
- Demonstrate how these could be strengthened, modernised and best linked to integrated national/regional certification schemes within a framework that aids compliance checking and effectiveness of financial support.

Support from underlying activities

In addition to being partner in U-CERT and EPC RECAST consortia, REHVA is part of the following underlying activities:

- ALDREN [31] (ALliance for Deep RENovation in buildings) Horizon 2020 project (recently closed, project website [32]) acting as precursor: support the holistic approach of the EPBD building assessment by providing practical common methods and tools to help the Member States to implement the new requirements of the amended EPBD (2018). The backbone of ALDREN is the European Voluntary Energy Performance Certificate (ALDREN-EPC). The ALDREN EPC is completed by the ALDREN-BRP (Building Renovation Passport) which contains a Building data repository (the building logbook) and a Building Renovation Roadmap. The ALDREN EPC has a modular structure that allows Member States to adopt specific modules to complete the official certification scheme and comply with other duties of MSs coming from EU commitments, such as the reporting for SRI.
- EPB Center [33] service contract with EC DG ENER [34]: Support Member States and National Standardization Bodies (NSB) to complete the national annexes of the overarching EPB standards mentioned in the EPBD, disseminate and promote the use of the overarching and other EPB standards, information services for all involved stakeholders, such as industry, researchers, engineers building professionals, financial institutions
- **Smart Readiness Indicator (SRI) Topical Group C**: The scope of this self-managed (volunteer based) working group is to discuss and identify future pathways of updating the existing methodology and furthermore implementing the assessment method C of SRI, which is based on measured data of the actual performance of buildings. Within the scope the SRI Topical Group C experts also analyse how to make the transition to an in-use/performance-based SRI exploring the most effective means on one hand for automating the checklist evaluation process and on the other hand for leveraging measured data and define an additional in-use SRI methodology. The main outcome of the SRI Topical Group C activities in 2020 is the 1st recommendations report prepared with the support of REHVA Technology and Research Committee members and involved stakeholders [35] (published in June 2020, however kept under embargo till the publication of the final report). Many of these recommendations have also been inserted as copy-paste in the final report by the SRI study team [36].

STAY informed!

Keep an eye out for the next issues of REHVA Journal which will feature further dedicated articles encompassing the activities of the Horizon 2020 cluster of projects on the topic of next generation energy performance certificates delving into selected specific (more technical) aspects uncovering each project's particularities and thus creating additional insights while still maintaining an overview. ■

Acknowledgement

This article is prepared within the scope of U-CERT project [37], which has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement number 839937. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' views.

References

[1] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[4] https://ec.europa.eu/energy/sites/ener/files/smart_readiness_buildings_implementing_act_c2020_6929.pdf

[5] https://ec.europa.eu/energy/sites/ener/files/smart_readiness_buildings_implementing_act_annex_c2020_6929.pdf

[6] https://ec.europa.eu/energy/sites/ener/files/smart_readiness_buildings_delegated_act_c2020_6930.pdf

[7] https://ec.europa.eu/energy/sites/ener/files/smart_readiness_buildings_delegated_act_annex_c2020_6930.pdf

[8] https://ec.europa.eu/info/publications/2021-commission-work-programme-key-documents_en

…

…
[9] https://www.bpie.eu/publication/4180/
[10] https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/overview-sustainable-finance/platform-sustainable-finance_en
[11] https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en
[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662
[13] https://cordis.europa.eu/programme/id/H2020_LC-SC3-EE-5-2018-2019-2020
[14] https://cordis.europa.eu/project/id/845958
[15] https://x-tendo.eu/
[16] https://cordis.europa.eu/project/id/839937
[17] https://u-certproject.eu/
[18] https://cordis.europa.eu/project/id/847100
[19] https://qualdeepc.eu/
[20] https://epb.center/
[21] https://cordis.europa.eu/programme/id/H2020_LC-SC3-EE-5-2018-2019-2020
[22] https://cordis.europa.eu/project/id/892984
[23] https://www.d2epc.eu/en
[24] https://cordis.europa.eu/project/id/893945
[25] https://edyce.eu/
[26] https://cordis.europa.eu/project/id/893118
[27] http://epc-recast.eu/
[28] https://cordis.europa.eu/project/id/892421
[29] https://epanacea.eu/
[30] https://epb.center/
[31] https://cordis.europa.eu/project/id/754159
[32] https://aldren.eu/
[33] https://www.rehva.eu/activities/epb-center-on-standardization
[34] https://epb.center/about/ec-service-contract/
[35] https://smartreadinessindicator.eu/stakeholder-consultation
[36] https://www.rehva.eu/news/article/final-report-smart-readiness-indicator-sri-for-buildings
[37] https://www.rehva.eu/eu-projects/project/u-cert

REHVA ONLINE COURSE

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

Safe operation of buildings and HVAC systems during the COVID-19 pandemic

Who is it for?

- Facilities and Building Managers
- Occupational health and safety specialists
- Building Services Contractors
- Mechanical & HVAC Engineers
- Ventilation and air conditioning system inspectors
- Public authorities' technical representatives
- Other building professionals

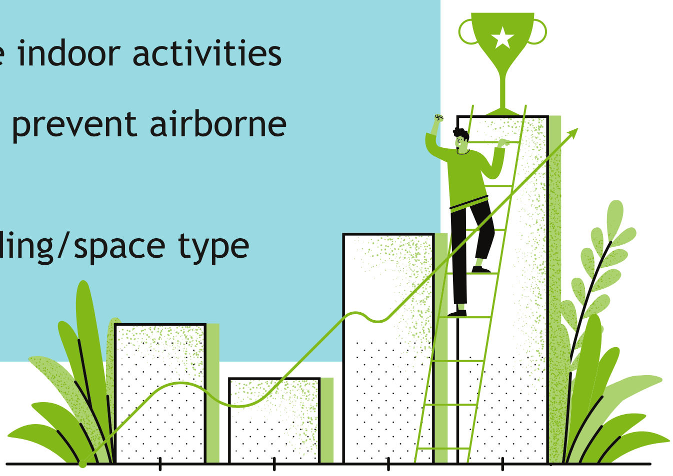
What will you learn?

The science behind and the role of HVAC systems during COVID-19

How to resume and continue indoor activities

How to use HVAC systems to prevent airborne viral transmission

Tailored guidelines per building/space type



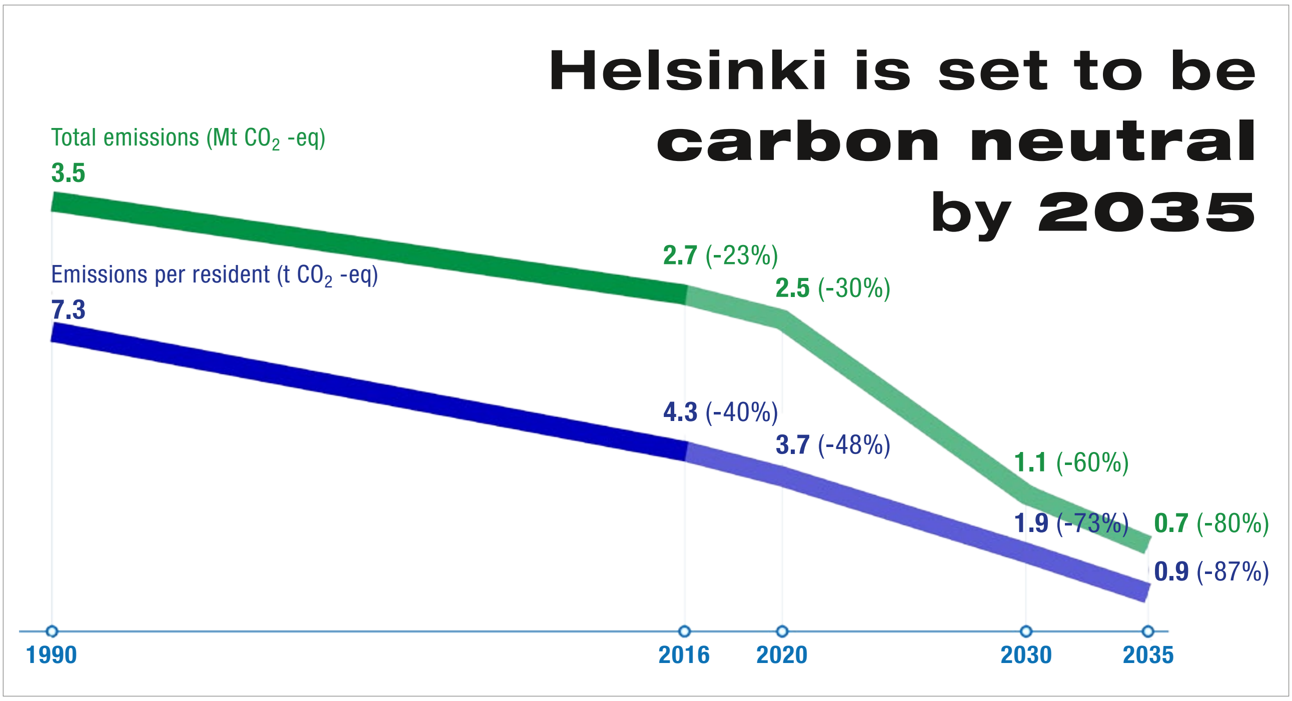
FIND ALL INFORMATION ON THE REHVA WEBSITE

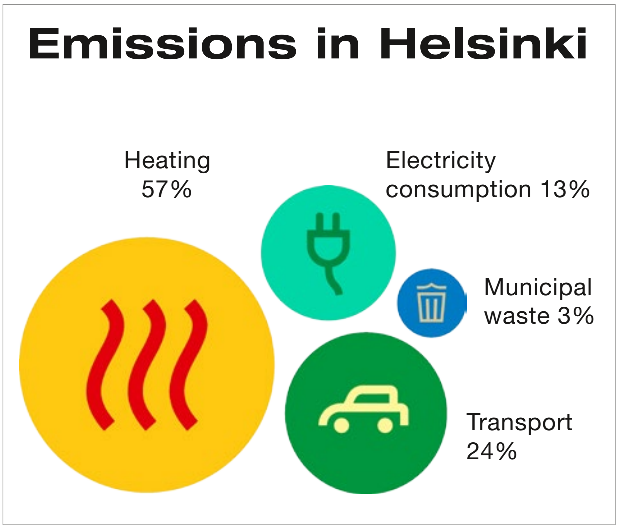
Cities have a key role to play in environmental issues – The COVID-19 pandemic did not slow down Helsinki's climate work

OLLI SEPPÄNEN

Climate change is the biggest challenge of our time, and cities have a key role to play in mitigating it. Despite the COVID-19 pandemic, the City of Helsinki keeps investing heavily in its climate work. Helsinki's goal is to be carbon-neutral by 2035. At the moment, more than half of Helsinki's carbon dioxide emissions come from heating buildings. Currently, more than half of Helsinki's heating energy is produced with coal, the use of which will have to stop by 2029.

Helsinki wants to find long-term sustainable solutions to heat the city in the future and to act as a platform for new and innovative solutions that also other cities around the world can benefit from. For this purpose, it opened the international Helsinki Energy Challenge competition in 2020. Helsinki Energy Challenge inspired 252 teams from 35 countries from around the world to participate. The teams in the first phase of the competition included a total of 1,528 experts and





What does it mean in practice?

GOALS of the year 2035

- Increase the share of electric and plug-in hybrids cars from 0.7% to **30%**
- Decrese the total heat consumption by **20%**
- Increase the share solar power from 0.1% to **15%**

innovators from around the world to seek a solution for Helsinki's heating challenge. The competition's first prize is **one million euros**. The finalist teams were selected in November 2020.

The ten teams selected for the final phase of Helsinki Energy Challenge have submitted their final competition entries. The finalist entries include many different proposals on how Helsinki can stop using coal for heat production as sustainably as possible by 2029.

The final proposals include many different solutions to solve Helsinki's heating challenge. The proposals include diverse overall solutions, some of which make use of various heat sources and combine existing technologies in new ways. The entries also include those that make use of new technology. Among the solutions, there are new approaches to heat storage and transfer, waste heat utilization, energy consumption control and consumer activation. There are also non-technical innovations that enable the realization of future sustainable solutions and the combination of decentralized and centralized solutions.

The international jury will review the finalist teams' final entries and select the winner in February 2021. The winner will be announced in March 2021, and reported also in the next issue of REHVA journal. ■

NEW GUIDEBOOK COMING SOON:

"NZEB Design Strategies for Residential Buildings in Mediterranean Regions – Design Guideline Part 2"

AHMET ARISOY

This guideline has been prepared by a REHVA Task Force whose members are mainly from Mediterranean member countries. The aim of the guideline is to support, in a practical way, a design process for realizing Nearly-Zero Energy Buildings (NZEB) in the context of Mediterranean-climate, focusing more on the mechanical systems than on the building envelope, which has previously been treated in **Part 1**. The Guidebook covers the design of Heating, Ventilation and Air Conditioning (HVAC) systems, energy recovery and free cooling aspects, renewable energy adaptation, and innovative system design approaches. Fundamental design and selection methodology has also been included.

The main objectives and the perspective behind this guidebook are as follows:

- To present and promote the use of equipment, technology and systems appropriate to the cooling-demand–dominated requirements of the Mediterranean climate.
- To ensure collaboration between industrial competence and academic knowledge towards achieving a robust approach for Mediterranean building type design.
- To strengthen the 'integration' approach which covers
- whole-system integration instead of considering only equipment and technology itself
- integration of the systems with the building considering the building's typology and climate

The challenges posed by the Mediterranean climate can be summarised by the following key points:

- Identification of passive cooling techniques that can reduce the cooling demand, e.g. thermal mass activation, window size and exposure, solar shading, ventilated roofs and all other passive techniques already applied in the past, including the ancient times Mediterranean buildings.
- Selection of the right ventilation strategy: ventilation cooling is an important strategy, which can reduce summer cooling loads and also improves comfort during cooler seasons, when the cooling system is usually switched off.
- Covering the heating demand, which can still be important even in Mediterranean countries (e.g. at high-altitude sites), as much as possible using on-site, renewable energy sources.
- Exploiting the high solar energy potential of Mediterranean sites: photovoltaic panels to produce electricity (PV), thermal solar collectors (TC) to produce hot water for sanitary use or for direct heating or indirect cooling, and any kind of combined heating and cooling system which can benefit from solar electricity and/or heating.
- Balancing fenestrations and shading device design to capture the abundant natural light without increasing the cooling load while reducing the heating load: correct management of both artificial lighting and natural daylighting, avoiding glare.
- Indoor environmental quality needs to be assured while reducing the energy needs and the non-renewable energy use.

The system design procedure for a Med-NZEB building must be energy-based, and must consider continuous loading, rather than the usual practice of considering only peak loads. The Med-NZEB axiom (very low energy use, high system efficiency, lowest possible non-renewable primary energy use) requires that the system must be selected for performance evaluation in terms of cost–benefit analysis. For this reason, simulation tools are indispensable for Med-NZEB design.

The design procedure phases are described and key issues for a Residential Building Design are discussed in detail in the guideline.

System selection is a very important step of the design. The aim of system selection is to establish recommendations and guidelines for planners, designers and engineers for the most appropriate and cost-effective solutions in specific climate conditions.

The efficiency of thermal systems depends mainly on outdoor air temperature, water and ground temperatures. This means that energy efficiencies of different HVAC systems depend strongly on the site's climate, as does the availability of different sources such as solar energy, wind, etc.

Case studies show that, in the Mediterranean region:

1. Air-source heat pumps, especially VRF air conditioners, can be used successfully for air conditioning.
2. Heat recovery measures, free cooling and natural ventilation should be considered.
3. PV panels seem to be the best solution for on-site renewable energy production.
4. Thermal solar energy is a good solution for producing domestic hot water.

In this guide, mechanical ventilation systems are considered in order to set the fundamental principles for good design practice and design essentials and equipment are given for residential ventilation.

Evaporative cooling can be combined with, or in some cases replace, traditional or refrigerant-based cooling systems to significantly reduce cooling energy use. Evaporative cooling matches Mediterranean needs well at the same time it uses 100% fresh outdoor air, improving indoor air quality. This fact suits very well with the purposes of fighting against the pandemic. Again fundamental principles for good design practice and design essentials and equipment are given for evaporative cooling in this guide.

In general, heat pump-based technologies provide suitable heating and cooling for Mediterranean NZEB and HVAC design. Heat pumps offer several unique features to the NZEB design process, including:

- High performance values, reducing the need for on-site energy production.
- Multiple building services — e.g. space heating, space cooling, DHW — in a single unit, even in simultaneous operation.
- Load-shifting opportunities in combination with thermal and electric storage, in order to optimize on-site solar PV self-consumption and grid-supportive operation.

Different types of heat pumps are discussed and design methods of the systems are given. Especially variable refrigerant flow (VRF) systems are considered extensively. In a case study, VRF selection and performance calculations are demonstrated. Other high efficiency system solutions are also discussed briefly in the guide.

Renewable energy solutions and integration is very important for Mediterranean regions. The first energy sources to consider in Mediterranean regions for the HVAC systems in NZEB residences are:

- Photovoltaic solar energy
- Solar thermal energy
- Biomass

All these systems are presented, design and calculation procedures are given and typical installation schemes are indicated. Calculation examples, case studies and operation characteristics are also given. This section of the guide is extensive.

Last section of the guide is devoted to cost effectiveness, optimality, benefit and co-benefit issues. Above mentioned technologies are often characterized by high costs that discourage their adoption. For this reason, it is essential to explore new economic evaluation tools to establish the goodness of innovative technologies that are considering both the costs and also the health and well-being benefits. This section presents the main objective of a cost–benefit analysis, as well as the structure and a range of valuation support techniques to monetize non-market benefits. In addition, the aggregation of costs and benefits and the calculation of the performance indicators are shown.

The guide concludes with general conclusions. Achieving the NZEB goal in Mediterranean residential contexts requires energy-saving strategies for cooling. Designs must be based on very simple and passive solutions. ■

Send information of your event to Ms Nicoll Marucciova nm@rehva.eu

Exhibitions, Conferences and Seminars in 2021*

22-26 March 2021	ISH 2021	**Online**	https://ish.messefrankfurt.com/frankfurt/en.html
8-9 April 2021	Mostra Convegno Expocomfort 2021	Milan, Italy	https://www.mce-livedigital.it/MCE_ENG.html
12-19 April 2021	REHVA Annual Meeting 2021	**Online**	https://www.rehva.eu/events/details/rehva-annual-meeting-2021
20-21 April 2021	Cold Climate HVAC & Energy 2021	**Online**	https://hvac2021.org/
03 May - 05 May 2021	40th Euroheat & Power Congress	Vilnius, Lithuania & **Online**	https://www.ehpcongress.org/
12 – 14 May 2021	ISH China & CIHE	Beijing, China	https://ishc-cihe.hk.messefrankfurt.com/beijing/en.html
31 May - 04 Jun 2021	EU Green Week 2021	Lahti, Finland & **Online**	https://www.eugreenweek.eu/
21-23 June 2021	Healthy Buildings Europe 2021	**Online**	https://www.hb2021-europe.org/
21 Jun - 25 Jun 2021	World Sustainable Energy Days 2021	Wels, Austria & **Online**	https://www.wsed.at/
15-18 August 2021	Ventilation 2021	Toronto, Canada	https://www.ashrae.org/conferences/topical-conferences/ventilation-2021
25 Aug - 27 Aug 2021	8th International Buildings Physics Conference	Copenhagen, Denmark	https://www.ibpc2021.org/
31 August-2 September 2021	ISH Shanghai & CIHE	Shanghai, China	https://ishs-cihe.hk.messefrankfurt.com/shanghai/en.html
03 Sep - 04 Sep 2021	52nd AiCARR International Conference 2021	Vicenza, Italy	http://www.aicarr.org/Pages/Convegni/52%20CONV%20INTERNAZIONALE/presentaz_call_for_paper_ing.aspx
13-15 September 2021	IAQ 2020	Athens, Greece	https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches
22 Sep - 24 Sep 2021	Aquatherm Tashkent 2021	Tashkent, Uzbekistan	https://www.aquatherm-tashkent.uz/en/
29 Sept-2 Oct 2021	ISK Sodex 2021	Istanbul, Turkey	http://www.sodex.com.tr/
29 September 2021	Danvak Dagen 2021	København, Denmark	https://danvak.dk/produkt/danvak-dagen-2021/

* Due to the COVID19 circumstances, the dates of events might change. Please follow the event's official website.

Webinar

Air Infiltration and Ventilation Centre

AIVC Spring Workshop Webinar 1
Building ventilation: How does it affect SARS-CoV-2 transmission?

The Air Infiltration and Ventilation Centre (AIVC) in collaboration with IEA EBC Annex 86 are organizing a spring workshop consisting of a series of three webinars on:

- April 1st , 2021 (17:00-18:30 CET): Building ventilation: How does it affect SARS-CoV-2 transmission?
- April 8th, 2021 (09:00-10:30 CET): IAQ and ventilation Metrics
- April 13th, 2021 (17:00-18:30 CET): Big data, IAQ and ventilation

In the first webinar, we address the potential mitigating role of building ventilation in the spread of the COVID-19 pandemic. In the first part of the webinar, we look at building ventilation as one of the mechanisms that affects exposure to infectious aerosol and the uncertainty in relating exposure to airborne transmission of the virus. In the second part of the webinar, we focus on the airflow in real indoor environments, with results from field experiments with aerosol sources and the use of pressure difference in buildings to control the spread of aerosols.

This webinar is organized by the Air Infiltration and Ventilation Centre (https://www.aivc.org/) & the IEA EBC Annex 86 "Energy Efficient Indoor Air Quality Management in Residential Buildings" (https://annex86.ieaebc.org/). The webinar is facilitated by INIVE (http://www.inive.org/).

Programme (Brussels time):

17:00 | Introduction, Arnold Janssens – chair of AIVC WG COVID-19, Ghent University, Belgium

17:10 | The Role of Building Ventilation in Indoor Infectious Aerosol Exposure, Andrew Persily – NIST, USA

17:25 | Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission, Cath Noakes – University of Leeds, UK

17:40 | Questions and Answers

17:50 | Field measurements of aerosol exposure in indoor environments, Wouter Borsboom- TNO, Netherlands

18:05 | Ventilation system design and the risk areas for spreading airborne contaminants in office buildings, Alireza Afshari – Aalborg University, Denmark

18:20 | Questions and Answers

18:30 | Closing & End of webinar

See for more details: https://www.aivc.org/event/1-april-2021-webinar-building-ventilation-how-does-it-affect-sars-cov-2-transmission

For the earlier November 20, 2020 webinar see: https://www.aivc.org/event/20-november-2020-webinar-covid-19-ventilation-related-guidance-ashrae-and-rehva).

To download AIVC newsletters, please visit https://www.aivc.org/resources/newsletters

IAQ 2020: Indoor Environmental Quality Performance Approaches

Transitioning from IAQ to IEQ

September 13-15, 2021 | Athens, Greece

IAQ 2020 Rescheduled

After careful consideration by the Steering Committee and from input by authors, ASHRAE and AIVC have decided to postpone the conference, which was scheduled for September 14-16, 2020 in Athens, Greece.

The IAQ 2020 conference is being postponed by one year to September 13-15, 2021 as a face-to-face conference in Athens, Greece.

The Steering Committee has decided to make environmental impacts of COVID19 a part of the conference. See the Topics list below. Because of the postponement, a new call for submissions will be opened. Already accepted abstracts and submitted papers will be kept valid for the new conference dates.

The conference is organized by ASHRAE and AIVC and will take place in Athens, Greece. The conference will also be the 9th TightVent and 7th venticool conference. Indoor Air Quality (IAQ) has been the core of ASHRAE'S IAQ series of conferences for the past 30 years. This conference will expand from Indoor *Air* Quality to Indoor *Environmental* Quality (IEQ). IEQ includes air quality, thermal comfort, acoustics, and illumination and their interactions. The particular focus of this conference is on performance approaches including the metrics, systems, sensors and norms necessary to implement them.

TOPICS:

- **Health and Well-being:** Appropriate technical and operational definitions
- **Performance Metrics:** For all aspects of IEQ
- **Interactions:** Interactions between IEQ parameters
- **Occupant Behaviour**: How behaviour impacts IEQ and how IEQ impacts behaviour - psychological dimensions of IEQ
- **Smart Sensors and Big Data**: Sensor properties, data management, cybersecurity, applications
- **Smart Controls**: Equipment properties, commissioning, equivalence
- **Resilience and IEQ**: Responding to climate change and disasters
- **Ventilation**: Mechanical, passive, natural and hybrid systems
- **Air Tightness:** Trends, methods and impacts
- **Thermal Comfort**: Dynamic approaches, health impacts and trends
- **Policy and Standards:** Trends, impacts, implications
- **Role of ventilation and building airtightness in epidemic preparedness**
- **Filtration and disinfection options to control COVID19.**
- **Face-covering impacts on indoor air quality**
- **HVAC and IEQ in a post-COVID world**

See: IAQ 2020: Indoor Environmental Quality Performance Approaches (ashrae.org) ■

AiCARR at MCE Live+Digital with a Seminar about Air conditioning systems and life

The Covid-19 pandemic has definitively changed the consolidated paradigm between air conditioning and comfort, introducing a new interest in the impact that air conditioning systems have on health. As a consequence, the concept of sustainability in the HVAC sector must no longer be thought only in terms of energy consumption and environmental impact but rather in terms of health in residences, public buildings and generally in all workplaces.

This change of perspective certainly represents a challenge but it is also a unique opportunity for the entire HVAC sector to accelerate the transition to sustainable solutions in line with environmental, social and economic "pillars" of the 2030 agenda.

The Seminar about Air conditioning systems and life is organized by AiCARR on April 9 at *MCE live+digital 2021, the on-life experience*, a special event by Mostra Convegno Expocomfort that provides an integrated meeting experience with both physical presence, at the MICO Centro Congressi Fiera Milano, and rich web platform. The Seminar will focus on critical issues, perspectives and opportunities resulting from new scenario, offering ideas for in-depth analysis that will be the subject of the 52nd AiCARR International Conference, scheduled in Vicenza on September 3–4, 2021. ■

Call for Papers for 52nd AiCARR International Conference "HVAC and health, comfort, environment. Equipment and design for IEQ and sustainability"

There is a general awareness of the leading role played by HVAC in improving the health and quality of humans' life. In the past, most of the attention in the scientific literature has been devoted to energy consumption and environmental impact of air conditioning while preserving the comfort of occupants with a relatively lower attention for the repercussion on health. Nowadays, the pandemic caused by Covid-2019 has dramatically shifted a large number of efforts of the HVAC sector towards the key role of HVAC in reducing the risk of virus infection. The consequence of this perspective change is twofold. First, it represents a unique opportunity to properly address the potential benefits of HVAC also on other relevant pathologies (cardiac, respiratory, infection by other pathogens, among others) while improving the comfort and the person productivity, with the consequent social and economic advantages. Second, it may play a key role to accelerate the transition towards new environmentally friendly technologies in compliance with the 2030 agenda. In general, there is a clear need of new integrated approach for the equipment, systems and building design under the paradigm of a healthy built environment.

The 52nd AiCARR International Conference, which will take place in Vicenza, Italy, on September 3–4, 2021, welcomes any contribution in the HVAC sector dealing with new components and systems, new design approaches, studies about the related impact on comfort and health of occupants and operators, new monitoring and control systems, insights about the relation between HVAC and pathologies or pathogens diffusion, environmental impact of the new technologies, economic and social consequences.

Deadline for abstracts: March 2, 2021

Please visit the English section of AiCARR website www.aicarr.org to download the Call for Papers and to send an abstract. ■

IIR with AiCARR and Unipd for the 2021 International Conferences in Vicenza

IIR, in collaboration with AICARR and the University of Padua, organizes two international events which will be held in parallel in Vicenza, Italy, on September 1 to 3: the 6th IIR Conference on thermophysical properties and transfer processes of refrigerants (TPTPR) and the 13th IIR Phase Change Material (PCM) Conference.

The 6th IIR TPTPR Conference

The International Institute of Refrigeration (IIR) has established a series of Commission B1 (Thermodynamics and Transfer Processes) Conferences, held every 4 years, to discuss thermophysical properties and transfer processes of refrigerants.

The first version of the European Regulation F-GAS fixed in January 1st 2011 the formal start of the phase out of refrigerants having GWP>150 in automotive air conditioning. This date can be considered a milestone for most of the intense research and technological activity carried out in the recent years for the development and use of low GWP refrigerants. After 10 years, the TPTPR2021 Conference will be a standout opportunity for analyzing the state of the art about the thermophysical properties and transfer processes of low GWP refrigerants: the aim will be to outline future perspectives in order to achieve the lowest possible impact of refrigeration on global environment.

For more information: www.gest.unipd.it/TPTPR2021

The 13th IIR PCM Conference

Phase change materials and slurries are becoming key components in the energy structure of the future as envisioned by European Commission. Changing from a carbon-based energy society to one relying on renewable energy from the sun, wind, geothermal and biomass will necessitate to match the energy demand with the source availability. This result can be only achieved through energy storage. Thermal energy storage is one of the most efficient ways to store energy and phase change materials can make thermal energy storage compact and competitive. Furthermore, refrigeration and air conditioning can be considered as one of the most energy consuming technologies, which impacts on our daily life. The possibility to store energy in latent cold or hot thermal energy storage is also becoming more and more investigated and applied by both the scientific and industrial communities.

For more information: www.gest.unipd.it/PCM2021

The two Conferences provide an international forum to all researchers and practitioners to exchange updated information, present new developments and discuss the future directions and priorities in these important technological challenges.

WHY SUBSCRIBE TO THE REHVA EXPERTS AREA?

It's a platform for international networking, and knowledge exchange, contributes to technical and professional development, follows EU policy developments, and represents the interests of its members in Europe and in the world.

Tailored EU Policy tracking

Access to eGuidebooks

Workshops and Webinars

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

MEMBERS

ATIC vzw–asbl – Belgium
www.atic.be

STP – Czech Republic
www.stpcr.cz

DANVAK – Denmark
www.danvak.dk

EKVU – Estonia
www.ekvy.ee

FINVAC – Finland
www.finvac.org

AICVF – France
www.aicvf.org

VDI–e.V. – Germany
www.vdi.de

ÉTÉ – Hungary
www.eptud.org

MMK – Hungary
www.mmk.hu

AiCARR – Italy
www.aicarr.org

AHGWTEL/LATVAC – Latvia
www.lsgutis.lv

LITES – Lithuania
www.listia.lt

AIIRM – Republic of Moldova
www.aiirm.md

TVVL – The Netherlands
www.tvvl.nl

NEMITEK – Norway
www.nemitek.no

PZITS – Poland
www.pzits.pl

ORDEM DOS ENGENHEIROS – Portugal
www.ordemdosengenheiros.pt

AIIR – Romania
www.aiiro.ro

AFCR – Romania
www.criofrig.ro

AGFR – Romania
www.agfro.ro

ABOK – Russia
www.abok.ru

KGH c/o SMEITS – Serbia
www.smeits.rs

SSTP – Slovakia
www.sstp.sk

SITHOK – Slovenia
web.fs.uni–lj.si/sithok

ATECYR – Spain
www.atecyr.org

SWEDVAC – Sweden
www.energi–miljo.se

DIE PLANER – Switzerland
www.die–planer.ch

TTMD – Turkey
www.ttmd.org.tr

CIBSE – United Kingdom
www.cibse.org

Network of 26 European HVAC Associations joining 120 000 professionals

REHVA Office: Rue Washington 40, 1050 Brussels - Belgium • Tel: + 32 2 514 11 71 - info@rehva.eu - www.rehva.eu