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EN 16798-3: Ventilation for Non-residential Buildings
New Concept of Natural Air Conditioning
History of Indoor Environment

Interviews with Hannu Saastamoinen, CEO of Swegon and Jyri Luomakoski, CEO of Uponor


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The Revised EPBD – A STEP FORWARD

Long debates finally resulted in a revised version to be adapted in April 2018 by the European Parliament (see also article on page 70). The renewed EPBD will push EU Member States to increase their efforts to reduce the energy use and CO_2 emission in the built environment.

It is up to us as professionals in the HVAC&R and building design community to design, retrofit and install more energy efficient and smart buildings and building systems. The cost-efficiency of the solutions to meet the national energy performance requirements will also be influenced by the choices made by the national building regulating authorities. Such as their choices and assumptions assessing the Primary Energy Factors (PEF's) and CO_2 emission factors of the various energy sources. This is one of the reasons why the Annex 1 of the EPBD requires EU-MS's to report and motivate their choices according the EN ISO 52000-1 and several other of the overarching EPB standards. These national choices will influence the role of bio-fuels, district-heating and cooling systems, CGHP and HP systems. How PV and Wind-energy is awarded in relation to the Energy Performance declarations of buildings (the Energy Certificate and related regulation on the requirement levels) is also an important issue. Are these sustainable sources just rewarded as the sustainable part of the national energy grid or can they be considered as integral part in the building system and, if so, under which conditions and circumstances (e.g. to optimize implementation and allocation of renewable resources and to avoid double counting)? These choices have an impact on a cost-efficient equilibrium between decarbonised energy supply and reducing the final energy use of buildings to achieve the 2030, 2040 and long-term 2050 objectives.

The revised EPBD doesn't always give clear answers or guidance. But it is clear that related concepts like energy storage capability and to be developed Smart Readiness Indicators will become more relevant. This may help to develop transparency regarding the interaction between energy grids and built environment. Annex 1 of the EPBD requires EU-MS's to declare their national EP assessment procedures on basis of a group of overarching EPB standards (Member States shall describe their national calculation methodology following the national annexes of the overarching standards (EN- ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1). This is a first step to more overall transparency in Europe. In addition to what is already included in these overarching EPB standards, more clarity on the assessment background of PEF's and CO_2 emission factors for various systems and energy sources is needed. CEN/TC371-WG1 currently works on an additional EPB standard "Determination and reporting of Primary Energy Factors (PEF) and CO_2 emission factors". This standard will provide a uniform procedure to describe how the (national) Primary Energy Factors and CO_2 emission factors related to energy delivered to or exported from buildings have been assessed: the elements that are or are not taken into account and related assumptions. It is expected that this standard will lead to more transparency throughout Europe and an increased understanding of the impact of the choices. This will help both policy makers and the designers and retrofitters of our buildings and their systems and connected energy grids to make the correct choices towards an effective reduction of the energy use and CO_2 emission of buildings in Europe. ■

JAAP HOGELING
Editor-in-Chief

CEN Standard EN 16798-3:2017 on ventilation for non-residential buildings: PERFORMANCE REQUIREMENTS

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Introduction

August 2017, CEN published the new standard EN 16798-3:2017 "Energy performance of buildings - Ventilation for buildings – Part 3: For non-residential buildings – Performance requirements for ventilation and room-conditioning systems (Modules M5-1, M5-4)", which supersedes the EN 13779:2007. This standard has been produced to meet the requirements of Directive 2010/31/EU 19 May 2010 on the energy performance of buildings (recast), referred to as "recast EPDB", while the substituted EN 13779:2007 was produced to meet the requirements of previous Directive 2002/91/EC 16 December 2002 on energy performance of buildings referred to as "EPBD". Today, a new recast of the energy performance buildings directive is ongoing and should be finalized on April 2018 (see article page 70), but that should not have a significant influence on this specific standard at least for other ten years. This standard shall be given the status of a national standard at the latest by February 2018.[1]

This European Standard is part of a series of standards aiming at international harmonization of the methodology for the assessment of the energy performance of buildings under a mandate given to CEN by the European Commission, called 'recast EPBD' standards or just EPB standards. These standards have a new common format: two documents for each standardized item, a true standard EN xxxx and a supporting technical report CEN/TR xxxx. The former reports a set of normative rules, while, the latter explains how to apply the related EN standard and gives informative additional rules and data. Because the EPB standards have been produced with the aim of supporting the recast EPBD and its application at national level, a certain degree of freedom in their application was a mandatory request. Thus, these standards provide a certain flexibility regarding the methods, the required

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1 Meanwhile CENTC156WG20 works on an update of this standard. This to optimise the convergence with other EPB standard and the future TS's regarding natural and hybrid ventilation systems (see article in RJ 2018-01). This update may also include a better aligning with the filter standards and ErP standards on ventilators.
The purpose of this revision is to consider further developments in the framework for this standard
- Revision of filtration aspects considering ISO 16890 in particular: (Chapter 9.7 and Annex a 4.2. and B.4.2.)
- Possible conflict between FprEN 16798-3 and EN 15287-1 (which might have consequences TR 16798-4)
- Check of mandatory requirements on conflicts with national EPBD requirements (including the recast version of 2018), relevant for Annex A and B and the clearly split between EPBD and general design aspects)
- Editorial improvements.
- Links in to new work on natural ventilation shall be clarified (including TR 16798-4 if needed).
- Aspects considering climate change in particular the design temperatures for ventilation and cooling (Chapter 8).
- Clarification regarding ongoing work on EN 13053 and EN 308.
- Check possibilities to add informative (non EPBD related) Annexes based on TR 16798-4 information.

input data and references to other EPB standards, by the introduction of a normative template in Annex A and Annex B with informative default choices. The normative annex A is just an empty format that has to be filled at the national level to customize the standard in a way of complying to national legal requirements.

Nevertheless, the main goal of this standard is the energy performance of ventilation systems, EN 16798-3 also provides requirements especially for designers, installers, manufacturers, building owners and users, on ventilation, air-conditioning and room-conditioning systems in order to achieve a comfortable and healthy indoor environment in all seasons with acceptable installation and running costs. It focuses on the system-aspects for typical applications and covers the following:

- Important aspects to achieve and maintain a good energy performance in the systems without any negative impact on the quality of the indoor environment.
- Definitions of design and performances data.

Changes respect to EN 13779

The new EN 16798-3:2017, and its supporting technical report: CEN/TR 16798-4:2017, is just the revision of EN 13779:2007, which covers exactly the same items; this revision concerns mainly the following aspects:

- The document was split in a normative part, containing all the normative aspects and a supplementary technical report containing additional information and informative annexes, i.e. CEN/TR 16798-4:2017;
- The standard allows a normative national annex;
- New structure to clarify designing and calculation aspects;
- Clear coordination with prEN 16798-1:2015, outdoor air volume flows have been shifted to prEN 16798-1:2015;
- All indoor air quality aspects have been deleted and reference is made to prEN 16798-1:2015, supply air quality have been introduced;
- Update of definitions of systems;
- Update of SFP definitions and links to EU 327/2014 regulation;
- Update of heat recovery aspects;
- Update of filtration aspects;
- Update of leakages aspects;
- Aspects of energy performance have been updated;
- The standard was supposed to be updated to cover hourly/monthly/seasonal time-step, but this is not really done.

Coordination with prEN 16798-1:2015

Apparently, the major issue related to this review is the "clear coordination with prEN 16798-1:2015", the revision of the EN 15251:2017 dealing with indoor environmental input parameters didn't pass the formal vote and is under editorial revision (i.e. not yet available)[2]. Thus, the default standard outdoor air volume flows, not any more included in the EN 16798-3:2017, are not defined until the revised prEN 16798:2015 will become a standard (probably after summer 2018). Of course, this could not be a problem if we recall the sentence reported in the superseded EN 13779:2007 at paragraph 7.4.1, "*The design shall be based whenever possible on the real data for the project*". But, "*However, if no values are declared, the default values given in Table 12 shall be applied.*" That means that we have a lack of standardized information only when the standard is used for design purposes, while, when assessing the energy performance flow rate, design values should be already defined and available, i.e. declared. Anyhow, some information can be taken from the still in force EN 15251:2007, informative Annex B, until the revised prEN 16798-1:2015 will be approved and published.

What has been lost in this revision is the basic classification of the indoor air quality (from IDA 1 to IDA 4, table 5 of EN 13779:2007). This is not included in the prEN 16798-1:2015, while, in all table dealing with indoor air quality, both in normative and informative annexes, the flow rates are referred to undefined I, II, III and IV classes. Hopefully, its revision can include this lost definition.

Actually, the major issue is the delay on the approval of the prEN 16798-1:2015 itself, because this standard defines the target parameters for designing a high quality indoor environmental building, other than for assessing its yearly energy performance. This affects not only some input to EN 16798-3:2017 but to the whole EPB package of standards. Again, this delay can be fruitful used to improve that standard, which does not clearly define how the quality class of each aspect of the indoor environment (thermal, air quality, humidity, acoustics and lighting) is weighted or not to define the IEQ (Indoor Environmental Quality) class of the building. In addition, some indoor environmental aspects are qualified with three classes, some with four classes, and again no rules are given how to combine them to obtain the IEQ class.

2 It is expected that the second formal vote on FprEN16798-1 is expected around May 2018.

Update of definitions of systems

In the 16798-3:2017 the ventilation system paragraph has been improved including definitions for basic system types of ventilation systems (**Table 1**) as unidirectional ventilation system (UVU), bidirectional ventilation systems (BVU), natural ventilation system and hybrid ventilation systems.

The EN 13779:2007 "pressure conditions in the room" paragraph is now more clearly renamed as "design air flow balance" and explicitly refers to balanced mechanical ventilation system (BUV type), where the extract airflow rate is given as function of the supply airflow rate and the air balance class needed.

Another comprehensive table (**Table 2**) is added to classify ventilation or air-conditioning systems based on ventilation and thermal functions.

A clear definition of cooling is also given as "any component in the unit or the room lowering the supply air or room air enthalpy (for example cooling coil with chilled water, cooling water or ground source water or brine)".

Table 1. Basic system types of ventilation systems.

Description	Name of the system type
Ventilation system with a fan assisted air volume flow in only one direction (either supply or exhaust) which is balanced by air transfer devices in the building envelope.	Unidirectional ventilation system (UVU)
Ventilation system with a fan assisted air volume flow in both direction (supply and exhaust)	Bidirectional ventilation system (BVU)
Ventilation relying on utilization of natural driving forces	Natural ventilation system
Ventilation relying to both natural and mechanical ventilation in the same part of a building, subject to control selecting the ventilation principle appropriate for the given situation (either natural or mechanical driving forces or a combination thereof).	Hybrid ventilation system

Table 2. Types of Ventilation-, Air-conditioning-, and Room Conditioning-Systems based on functions.

System — X equipped with; (x) equipped with, but function might be limited; – not equipped with; o may or may not be equipped with depending on requirements.	**Supply Air Fan**	**Extract Air Fan**	**Secondary Fan**	**Heat Recovery**	**Waste heat pump**	**Filtration**	**Heating**	**Cooling**	**Humidification**	**Dehumidification**
Unidirectional supply air ventilation system (Positive pressure ventilation)	x	-	-	-	-	o	o	-	-	-
Unidirectional exhaust air ventilation system	-	x	-	-	o	-	-	-	-	-
Bidirectional ventilation system	x	x	-	x	o	x	o	-	-	-
Bidirectional ventilation system with humidification	x	x	-	x	o	x	o	-	x	-
Bidirectional air-conditioning system	x	x	-	x	o	x	o	(x)	o	(x)
Full air-conditioning system	x	x	-	x	o	x	x	x	x	x
Room air conditioning system (Fan-Coil, DX-Split-Systems, VRF, local water loop heat pumps, etc.)	-	-	x	-	-	o	o	x	-	(x)
Room air heating systems	-	-	x	-	-	o	x	-	-	-
Room conditioning system	-	-	-	-	-	-	o	x	-	-

Update of SFP definitions

The specific fan power classification has been extended respect to EN 13779:2007 adding a SPF 0 category for less than 300 W/(m³/s)) and its definition is now clearly stated through a formula:

$$P_{SFP} = \frac{P}{q_v} = \frac{\Delta p_{tot}}{\eta_{tot}} = \frac{\Delta p_{stat}}{\eta_{stat}} \quad \left[\frac{\mathrm{W}}{\mathrm{m}^3/\mathrm{s}}\right]$$

(for the meaning of the symbols refer to the standard).

Paragraphs have been added to give as normative formulas and calculation methodologies for calculating:

- the power demand of the fan;
- Specific Fan Power of an entire building;
- Specific Fan Power of Individual Air Handling Units (I-AHU);
- AHU related PSFP values.

Similar formulas and calculation methodologies were also reported in the superseded EN 13779-2007, but only as informative options in the informative Annex D.

Update of heat recovery aspects

The heat recovery paragraph has been completely rewritten, updated and extended. The "dry" recovery efficiency has been introduced, as stated in EN 308 and EN 13053, but, unfortunately, a wrong symbol has been used: Φ_t instead of η_t. Some information is then reported on transfer of humidity, icing and defrosting, transfer of pollutants.

Update of filtration aspects

The filtration paragraph[3] is entirely new and gives guidance in filters selection. In fact, depending on outdoor particle pollution level and desired supply air quality, different levels of filtration are required. The filtering of outdoor air shall be chosen to meet the requirements of the indoor air in the building, taking into consideration the category of outdoor air. Tables are given to define the minimum required filtration efficiency according to the selected outdoor air (ODA) quality and the supply air (SUP) class (**Table 3**) and to indicate when optional gas filtration is recommended or required (**Table 4**).

[3] All specifications are based on EN 779 which currently is replaced by ISO 16890. The ongoing review on EN 16798-3 will revise this paragraph keeping the basic principle.

Table 3. Minimum filtration efficiency based on particle outdoor air quality.

Outdoor air quality	Supply air class				
	SUP 1	SUP 2	SUP 3	SUP 4	SUP 5
ODA (P) 1	88%[a]	80%[a]	80%[a]	80%[a]	Not specified
ODA (P) 2	96%[a]	88%[a]	80%[a]	80%[a]	60%
ODA (P) 3	99%[a]	96%[a]	92%[a]	80%[a]	80%

[a] Combined average filtration efficiency over a single or multiple stage filtration in accordance to average filtration efficiency specified in EN 779.

Table 4. Application of gas filter as complement to particle filtration based on gaseous outdoor air quality,

Outdoor air quality	Supply air class				
	SUP 1	SUP 2	SUP 3	SUP 4	SUP 5
ODA (G) 1	recommended				
ODA (G) 2	required	recommended			
ODA (G) 3	required	required	recommended		

G = Gas filtration; should be considered if design SUP quality category is above design ODA quality category.
Dimensioning should be done in accordance with EN ISO 10121-1 and EN ISO 10121-2.

The formula to calculate the combined filtration efficiency when different filters are used in series is given as:

$$E_t = 100 \cdot \left(1 - \left(\left(1 - \frac{E_{s,1}}{100}\right) \cdot \left(1 - \frac{E_{s,2}}{100}\right) \cdot \ldots \cdot \left(1 - \frac{E_{s,n+1}}{100}\right)\right)\right)$$

where

E_t is the total filter efficiency

$E_{s,j}$ is the efficiency of each j filter step

Update of leakages aspects

The leakages in ventilation system paragraph is completely new. This paragraph was added because leakages of the air distribution or the AHU casing affect energy efficiency and function, as well as hygiene aspects (e.g. condensation). Thus, it is important to minimize leakages.

This paragraph specifically deals with leakages in heat recovery section (HRS) (internal leakages), leakages of the AHU casing (external leakages) and leakages of the air distribution (ducts) including components.

For leakages in heat recovery section, two new quantities are defined to quantify them:

- Exhaust Air Transfer ratio (EATR) [%]: ratio of the supply air mass flow rate leaving the HRS originated by air internal recirculation due to HRS internal leakages and the supply air mass flow rate leaving the HRS;
- Outdoor Air Correction Factor (OACF) [-]: ratio of the entering supply mass airflow rate and the leaving supply mass airflow rate.

With these two values, the leakage situation is fully defined. EATR and OACF shall be calculated by the heat recovery manufacturer for the nominal design condition of the air handling unit.

Based on the OAC Factor a classification is given as reported in **Table 5**.

Table 5. Classification of outdoor air correction factor – Internal leakages.

	OACF	
Class	**Outdoor to exhaust air**	**Extract to supply air**
1	1,03	0,97
2	1,05	0,95
3	1,07	0,93
4	1,01	0,90
5	Not classified	

For leakages of the AHU casing, reference is made to EN 1886:2007 - Ventilation for buildings. Air handling units. Mechanical performance, which specifies test methods, test requirements and classifications for air handling units.

For leakages of the air distribution, ducts mainly, a classification is given based on EN 12599 - Ventilation for buildings - Test procedures and measurement methods to hand over air conditioning and ventilation systems, as reported in **Table 6**.

Table 6. Classification of system air tightness class.

Air tightness class		**Air leakage limit** (f_{max}) $m^3\ s^{-1} \cdot m^{-2}$
Old	**New**	
	ATC 7	not classified
	ATC 6	$0{,}0675 \times p_t^{0{,}65} \times 10^{-3}$
A	ATC 5	$0{,}027 \times p_t^{0{,}65} \times 10^{-3}$
B	ATC 4	$0{,}009 \times p_t^{0{,}65} \times 10^{-3}$
C	ATC 3	$0{,}003 \times p_t^{0{,}65} \times 10^{-3}$
D	ATC 2	$0{,}001 \times p_t^{0{,}65} \times 10^{-3}$
	ATC 1	$0{,}00033 \times p_t^{0{,}65} \times 10^{-3}$

Some information on system air tightness was given also in the superseded EN 13779-2007, but only as informative option in the informative Annex A.

Update of energy performance aspects

The calculation and energy rating paragraph deals with the air volume flows calculations, which was partially included in EN 13779:2007 in the supply airflow rate section, and a new part devoted to the energy rating of the ventilation systems.

The major update to the air volume flows calculations is the explicit introduction of the ventilation effectiveness, ϵ_V, when calculating the ventilation air volume flow (i.e. outdoor air flow to dilute indoor contaminants) starting from normalized standard requirements as in the referred prEN 16798-1:2015.

Another update is the calculation of the required ventilation rate for humidifying or dehumidifying, if such services are provided by the ventilation systems.

What is not reported is a procedure or a criterion for selecting the effective supply airflow rate, when the ventilation air volume flow, the air volume flow required for balancing heating and cooling loads and, eventually, required ventilation rate for humidifying or dehumidifying have to be contemporary or not satisfied.

The new paragraph is on the energy rating of ventilation system, which starts with a wrong internal reference to sub-paragraph 8.8.2 to 8.8.4 (which is a typo, they do not exist and should be 9.8.2 and 9.8.4; the same in clause 10.3.2 where the references should be 9.5.4 and 9.5.6); while probably, that should be just points 3, 4, 5 and 11 of 8.8 and 8.9 paragraph. The new quantities herewith introduced, but already defined in the EN 13053 standard in a bit different way (in terms of powers instead of annual energies), are:

- Annual heat recovery efficiency,

$$\eta_e = 1 - \frac{Q_{H;V;in;req}}{Q_{H;V;tot}}$$

- Annual coefficient of performance

$$\varepsilon_{HRS} = \frac{Q_{hr}}{E_{V;hr;gen;in;el}}$$

where

$Q_{H;V;in,req}$ is annual heating energy of ventilation supply (or/and intake) air including defrosting, in kWh

$Q_{H;V;tot}$ is annual heating energy of supply (or/and intake) air without heat recovery, in kWh

Q_{hr} is *annual* heat transferred by heat recovery, in kWh

$E_{V;hr;gen,in;el}$ is *annual* electric energy of the heat recovery section required by fans and auxiliaries, in kWh.

It should be noted that a wrong symbol is used in the standard for the heat recovery efficiency compared to the EN 13053 symbols (ε_{SUP} instead of η_e) and wrong unit symbol and in the wrong position appears in the Q_{hr} and $E_{V;hr;gen;in;el}$ explanation (kW instead of kWh). In addition, the annual attribute is lost in such explanations.

Finally, a section is added that deals with primary energy use of ventilation in kWh/(m³/h)/a. A formula to calculate this primary energy use is given but it is useless because of some undefined and unreferenced terms (see below).

$$E_{P,AHU} = \frac{\left(E_V + W_{V,aux} + W_{HU,aux}\right) \cdot f_{P,E} + Q_H \cdot f_{P,H} \cdot f_H + (Q_C + Q_{DH}) \cdot f_{P,C} \cdot f_C + E_{HU} \cdot f_{P,HU} \cdot f_{HU}}{q_{V;SUP;AHU;nom}}$$

where

$f_{P,E}$, $f_{P,H}$, $f_{P,C}$, and $f_{P,HU}$, are primary energy factors, respectively, for electricity, heating, cooling and humidification; ($E_V + W_{V,aux} + W_{HU,aux}$), Q_H, ($Q_C + Q_{DH}$) and E_{HU} the related energies required as input to the air handling unit, and f_H, f_C, and f_{HU} are reported to be "delivered energy factor for" respectively heat, cold and humidification "(taking into consideration distribution and generation). Such factors are not defined in any place of the standard and there is no reference to any other standards where their definition can be found. It is opinion of the authors that such delivered energy factor has the meaning of ratio of required energy carrier delivered to the building for such service (Heating, Cooling, and Humidification) and the required energy input to the AHU for the same service. With this definition it automatically accounts for distribution and generation losses, as mentioned in the description.

Is it able to cover hourly/monthly/seasonal time-step as declared?

In the European Foreword to these standards is mentioned that "*the standard was updated to cover hourly/monthly/seasonal time-step*". Instead, there is no mention of this update or possibility that the energy performance parameters are defined on annual basis. Nevertheless, this standard is useful as it is because its main goal is to define design flow rates complying with ventilation, heating, cooling and humidification requirements and to size the ventilation unit or AHU ventilation section according to the design requirements. The energy performance calculation is instead carried out, taking into consideration different calculation time step, in other standards like EN 16798-5-1:2017 or EN 16798-5-2:2017.

Supporting technical report, CEN/TR 16798-4:2017

The technical report, CEN/TR 16798-4:2017, is the supporting report of EN 16798-3:2017. As stated at the beginning, the technical report includes additional non-normative information and application examples.

In this case, almost all the materials included in the superseded EN 13779:2007 as informative appendixes have been moved to this reports, updated and expanded. ■

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On the history of indoor environment and it's relation to health and wellbeing

This article describes research and developments in the past that had influence on how people thought and now think about indoor environment. The emphasis is on indoor air quality and thermal comfort.

Keywords: Indoor Environment, Thermal Comfort, Indoor Air Quality, History

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From ancient times until the 18th century

Thermal Comfort - Heating

The history of indoor environment begins 1,5 million years ago when early humans began using campfires. At some point the campfire was brought inside caves and huts. The oldest arrangement was a central fire and a central roof opening for smoke to escape. Later the fire was moved to different parts of a dwelling and various schemes were tried to improve the efficiency of the fire by using stones. However, even the best open fire was only 20% efficient considering that most of the heat escaped with the smoke. Open fireplace heating was used as early as the 800s BC and became widespread across Europe by the 13th century. Romans already had underfloor heating to make the indoor climate in their palaces and spas comfortable (**Figure 1**). The next important advance in heating which had influence on thermal comfort was the invention of the chimney in the 15th century. It took the next 200 years to be widely adopted. The first freestanding warm air stoves were produced in the 17th century.[1]

Indoor Air Quality - Ventilation

Throughout history, man understood that polluted air could be harmful to health. Greeks and Romans were aware of the adverse effects of polluted air in, e.g., crowded cities and mines (Hippocrates, 460–377 BC). Throughout the medieval era, small steps forward have been done in this field. Bad air was held responsible for the spread of diseases and for the unpleasant sensations that were experienced in poorly ventilated rooms. Around 1700, the general idea was that breathing was primarily a way of cooling the heart. But it was also common knowledge that expired air was unfit for breathing until it had been refreshed. [2]

The role of oxygen in breathing was pointed out by Lavoisier (1781), even though Boyle (1627–1691), and Hooke (1635–1703) 100 years earlier (1667) had found that the supply of air to the lungs was essential for life. The work of **Antoine Lavoisier** (1743– 1794) was especially important for understanding the human metabolism, including the quantitative association between oxygen consumption and carbon dioxide (CO_2) release. During the following half century it was accepted that the concentration of CO_2 was a measure of whether the air was fresh or stale. [2]

19th century

Indoor Air Quality - Ventilation

In 1853 **Max J. Pettenkofer** (1818–1901) – the first professor in hygiene in Munich - noted that the unpleasant sensations of stale air were not due merely to warmth or humidity or CO_2 or oxygen deficiency, but rather to the presence of trace quantities of organic material exhaled from the skin and the lungs. He stated that 'bad' indoor air did not necessarily make people sick but that such air weakened the human resistance against agents causing illness. In Pettenkofer's view CO_2 was not important but was an indicator of the amount of other noxious substances produced by man. Pettenkofer stated that air was not fit for breathing if the CO_2 concentration (with man as the source) was above 1000 ppm and that good indoor air in rooms where people stay for a long time should not exceed 700 ppm, in order to keep the people comfortable. [2]

The first estimate of the required minimum amount of ventilation air was published in 1836 by a Cornish mining engineer Thomas Tredgold. He calculated that one person needed 2 ℓ/s of fresh air for breathing and candle burning. [3]

ASHRAE recommended in 1895 as a minimum rate for ventilation 15 ℓ/s per person. This ventilation rate was based on the work of **John Billings** *(1836-1913), medical doctor and the American authority in the field of ventilation at that time.*

For several centuries, there were two schools of thought with respect to ventilation. Architects and engineers were concerned with providing comfort, absence of noxious odors and carbon dioxide accumulation. Physicians, on the other hand, were concerned with minimizing the spread of disease. [3]

Indoor Air Quality & Thermal Comfort

Possibly the most complete overview of the relationship between indoor environment & health had **Florence Nightingale** (1820–1910). According to Wikipedia she was 'an English social reformer and statistician, and the founder of modern nursing'. According to Chris Iddon she was 'nurse & structural engineer' [4]. Nightingale (**Figure 2**) wrote the first modern handbook for the nursing of sick 'Notes on Nursing, What It Is, and What It Is Not' [5]. In her foreword she wrote that her book was meant as 'tips for women who are personally responsible for the health of others'.

Figure 2. Florence Nightingale.

The first chapter of her book focuses not on patient care, but on ventilation. She wrote: 'The first task of nursing: to keep the air that breathes the patient as pure as the outside air, without cooling them.' In the second chapter she

Figure 1. The Hypocaustum. Romains system of underfloor heating.

mentioned five essential points to ensure the health of houses:

- Pure air
- Clear water
- Efficient waste water drainage
- Hygiene
- Light

Nightingale has seen and approached the problems of the indoor environment in its entirety. Other recommendations from her, which are being rediscovered today, are:

- Bring air from outside. Open your windows and close your doors.
- (Natural) air temperature fluctuations are necessary to stay healthy.
- Light is essential for both health and recovery.
- The body and mind degenerate without sunlight.

In the beginning, thinking about the indoor environment was in the realm of philosophy. Much later, in the 19th century, indoor environment concerns were covered by two separate disciplines: medicine and engineering.

20th century

In the 20th century researchers were increasingly convinced that ventilation is mainly a matter of comfort and not of health. There was a growing resistance to heating the large amounts of outside air prescribed for ventilation.

Air Conditioning – Thermal Comfort

The beginning of the 20th century marks also the birth of air-conditioning, an invention that turned out to have a major impact on the indoor environment. Probably the first building with cooling (without using ice) is the Stock Exchange building in New York, USA. **Alfred Wolff** (1859–1909) designed the cooling system that used three ammonia absorption chillers, with a cooling capacity of 1,582 kW [6]. Yet he did not become the best-known air-conditioning engineer.

Willis H. Carrier (1876–1950) is known as the inventor (or father) of modern air-conditioning. Carrier designed his first system in 1902 to control temperature and humidity in a printing plant in Brooklyn (New York, USA). Unfortunately, this system did not work well and the design conditions couldn't be maintained. However, this design is generally marked as the first application of air-conditioning. Since then, air-conditioning has been defined as a system that must have four basic functions:

- Temperature regulation
- Humidity control
- Air circulation and/or ventilation
- Air purification (filtration)

Carrier designed in 1904 a spray-type air-conditioner, a very sophisticated air washer, with which he could control the absolute humidity of the air leaving the conditioner and, ultimately, the relative humidity of the conditioned space. In January 1906, he obtained the patent called 'Apparatus for Treating Air' [7]. (The term 'air-conditioning' was first coined by the American textile engineer Stuart Cramer).

In 1911 Carrier presented his 'Rationale Psychrometric Formulae' at a meeting of ASHRAE. This became the basis for the fundamental calculations in the air-conditioning industry. His work helps to determine the precise relationship between temperature and humidity in order to be able to regulate the indoor climate throughout the year. With his scientific work, his vision of a new industry – air-conditioning - and with his entrepreneurial activities, Carrier has had a very strong influence on the indoor environment field (**Figure 3**). However, he was never really involved in comfort-related issues.

Figure 3. An example of air conditioning industry.

Indoor Air Quality

Leonard Hill (1866–1952) dedicated his life and work to research improving the physical well-being of people. He didn't find any evidence that high concentrations of CO_2 can cause discomfort and, therefore, he concluded that heat and odor (caused by physical emissions) are the main sources of uneasiness in rooms with poor ventilation [8].

Using an instrument known as the 'kata thermometer', he determined the cooling capacity of air movement on the human body. This was used to monitor workplace conditions in the United Kingdom, including the House of Commons, where Hill was concerned that 'cold feet and stuffy heads result - just the wrong conditions for legislators' [9].

In 1923, ASHRAE Journal published the article 'Determination of the comfort zone' (Houghten & Yaglou) [10], in which the conditions for comfort were presented on a psychrometric diagram. They used the index 'Effective Temperature' (ET), which was used extensively over the next 50 years [11]. ET is defined as the dry bulb temperature (DBT) of a uniform environment with a relative air humidity of 50%, which would have the same heat exchange, by radiation, convection and evaporation, as the environment in question (**Figure 4**).

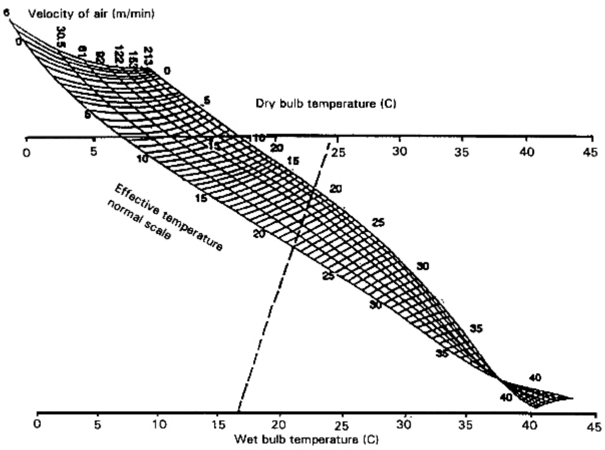

Figure 4. Effective Temperature nomogram (Yaglou).

Constantin Yaglou[1] (1897–1960) also studied the relationship between body odor and ventilation flow. He concluded that these odors are not really harmful to building users and that CO_2 concentration cannot be a good indicator of the air quality in buildings. Yaglou noted that odors are probably related to temperature and humidity[12]. Ventilation requirements were measured by using the human nose as a sensor.

In 1936 ASHRAE recommended 7.5 ℓ/s per person on the basis of work of C. Yaglou.

[1] Yaglou's original name was Yagloglou but in 1947 he shortened his surname.

Thermal Comfort

Adolf P. Gagge (1908-1993) introduced his 'Two-node model' in 1936. It calculates the thermal response by means of two energy balance equations, one for the core node and one for the skin node. This model (sometimes called Pierce model because Gagge made it together with his colleagues at JB Pierce Laboratories of Yale University) assumes that the sum of the heat exchange between humans and their environment through metabolism, activity, evaporation, radiation and conduction is zero. [13] With his model Gagge applied the first law of thermodynamics (conservation of energy) on man and his environment. [14] This model was expanded later (after World War II.).

Gagge's work helped define the study area of energy exchange between the human body and the immediate environment. It's application had an impact on health and safety at work, in the military, in space exploration and in the design and operation of buildings [14].

From the early 1960s there were many researchers working in the field of thermal comfort. The most well-known and influential was **Povl Ole Fanger** (1934–2006). Fanger (**Figure 5**) focused on the relationship between the physical parameters of the environment, the physiological parameters of people and the perception of comfort expressed by people themselves. In 1970, he published his dissertation 'Thermal Comfort' [15] in which he defined a new discipline: the study of the condition of comfort and well-being in indoor environments. [14] The conceptual leap introduced by Fanger, compared to previous studies, is the introduction of the judgment scale by people themselves.

Using Fanger's comfort theory, it is possible to predict to what extent a certain indoor environment will be experienced by building users as 'cold', 'neutral' or 'warm'. The prediction of the mean thermal sensation, which is

Figure 5. P. O. Fanger.

associated with a combination of six environmental and personal parameters (air temperature, mean-radiant temperature, relative humidity, air velocity, activity level and thermal resistance of the clothing), is given as 'Predicted Mean Vote' (PMV-index). The PMV-index indicates the predicted opinion of a group of people with identical metabolism and clothing regarding their thermal sensation. It does not predict the acceptability of the environmental conditions (**Table 1**). As a follow-up to the PMV-index, Fanger introduced the PPD-index (Predicted Percentage of Dissatisfied) that does predict the acceptability (**Figure 6**). Fanger's model was developed for the applications in air-conditioned buildings but, from the 1980s, it was also used for other applications (non-air-conditioned rooms). In other words, the interpretation of Fanger's work in practice is not entirely correct [16].

Table 1. Scale of the PMV index. [Source: NEN-EN-ISO 7730]

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

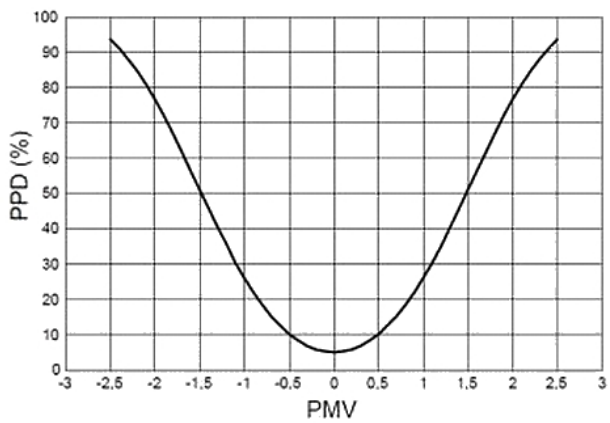

Figure 6. The relationship between PMV and PPD (Fanger)

Environmental movement

Environmental aspects largely focused on indoor air quality until the 1960s. In 1962, **Rachel L. Carson** (1907–1964) wrote her book 'Silent Spring'. In this book she describes the harmful effects of pesticides on the environment. It is widely credited with helping launch the environmental movement. Environment was suddenly synonymous with outside air and industrial environment. Environmental protection received worldwide attention but IAQ (indoor air quality) in non-industrial indoor environments was not on the list of environmental problems.

In 1973, ASHRAE published its first Standard 62 with the recommended amount of supplied air of 7.5 ℓ/s per person.

In 1981, ASHRAE divided the recommended amount of fresh supply air into two categories. For non-smoking rooms 2 ℓ/s per person and for rooms where smoking was allowed 10 ℓ/s per person.

Many different studies have shown that indoor air quality is influenced by the quantity and quality of the supplied fresh air, pollution by people themselves and emissions of the materials used in buildings. More and more specific studies have been carried out with regards to radon, tobacco smoke, VOC (volatile organic compounds), formaldehyde, (fine) dust, asbestos, dust mites and other agents that influence the indoor air quality.

Sick Building Syndrome

With the amount of fresh supply air minimized to 2 ℓ/s per person (as a result of the energy crisis in the 1970s), there were more and more problems with the indoor environment, especially in office buildings (**Figure 7**). Many different terms were used to indicate the phenomenon of reported high occurrences of health problems and diseases. From 1982, the World Health Organization (WHO) used the term Sick Building Syndrome (SBS) and this became the most commonly used term. SBS relates to a number of symptoms that are experienced by several building occupants when they are in a building and which reduce or disappear completely when they leave the building. Since 1989, Healthy Buildings congresses have been organized to bring researchers from medical sciences together with engineers and technicians from practice to solve the problems that cause SBS.

A major challenge is that research and practice mostly focus on individual components. It is only during

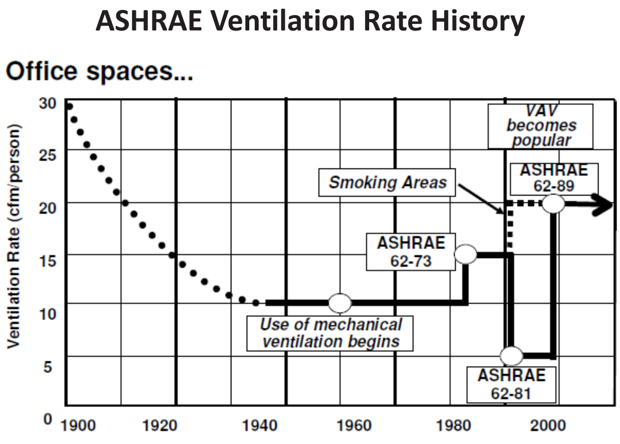

Figure 7. The overview of the recommended amount of air supply in ASHARE standards (Source: Olesen, 2011: PowerPoint-How much ventilation and how to ventilate in the future)

the last decades of the twentieth century that the first attempts towards more holistic approaches to indoor environmental problems were made [17]. With the holistic approach of the indoor environment, 'soft' factors are also taken into account. After the decades in which medical doctors and engineers had investigated the problem separately, these disciplines began to learn from each other. In the research on Sick Building Syndrome many psychological studies were conducted which focused on the perception of people. Many buildings are designed in a way that does not connect with evolutionary old 'software' in our brain; i.e., the basic laws that govern our behavior. [18] The relevant laws are:

- People and animals need change. This applies in particular to thermal comfort. A homogeneous environment means that people feel less comfortable.
- Man wants to constantly intervene in his environment. This law also applies mainly to the thermal comfort but also to ergonomics (furniture).
- A meaning must be given to stimuli. For example, a smell that is present in the building and that cannot be recognized, leads to a state of chronic alarm.
- Man always strives to have his own territory. This becomes a problem, for example, in open plan offices.
- Man has been living in artifacts for only several centuries and this has broken his contact with the natural environment. That's why the view to outside is very important. [18]

Thermal Adaptation

The 1980s saw the start of the discussion about adaptive principles related to thermal comfort. The initiator was **Michael A. Humphreys**. An English physicist who does a lot of research into thermal adaptation of building occupants. In 1998, he wrote together with **J. Fergus Nicol**, an article 'Understanding the Adaptive Approach to Thermal Comfort [19]. The starting point of their discussion was: 'If a change occurs such as to produce discomfort, people react in way that tend to restore their comfort'. They explain adaptation as 'all those physiological, psychological, social, technological, cultural, or behavioral strategies people might use to try to secure their comfort'. Some other researchers confine the term adaptation to that kind of physiological or psychological acclimatization through which a person might come to prefer or accept a different set of skin temperature or sweat rates for comfort. [19]

Gail S. Brager and **Richard J. de Dear** published in 1997 a literature study on thermal adaptation in the built environment [20] and developed an adaptive model of thermal comfort [21] (**Figure 8**). This research was subsequently included in ASHRAE Standard 55. The field studies made it clear that Fanger's PMV-index might be too strict for non-air-conditioned buildings where users themselves could have control over the indoor environment. In other words, where people have the possibility to influence their environment (for example by opening windows).

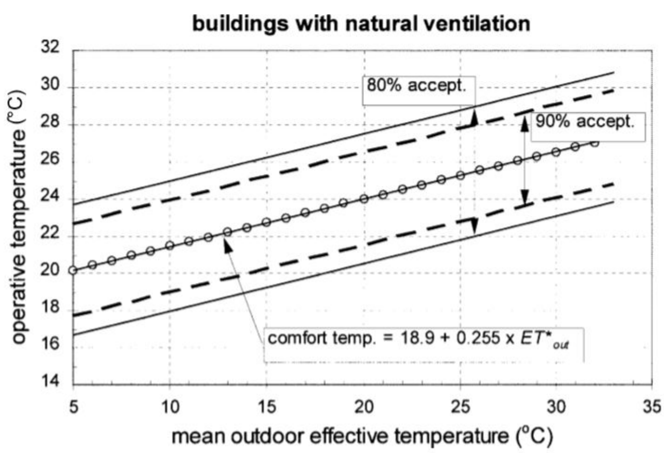

Figure 8. The shift in attention to the three health aims of building services that constitute complete health (Source: reference 22)

Before the 21st century

From the indoor environment developments during the past three centuries it can be concluded that health had priority in the beginning. In the 18th century people wanted to have a healthy environment in buildings in order to prevent the spread of diseases. Later, the indoor environment problems were dominated by comfort issues [22] (**Figure 9**). People wanted to be able to realize comfortable indoor conditions throughout the year. After the oil crisis in the 1970s, the main goal was to save as much energy as possible on indoor environment conditioning. Towards the end of the 20th century, sustainability became very important. In the Netherlands, sustainability was primarily seen in the form of fossil energy. For example, Trias Energetica with special attention for energy saving (isolation of buildings) and generation of sustainable energy (use of solar boilers and later PV panels). Only a few years ago (beginning of the 21st century) people regained interest in health in the build environment. New topics regarding indoor environment are being discussed, such as influence of the indoor environment on productivity or supporting health and well-being of building occupants. These are nowadays topics which don't belong to history yet. ■

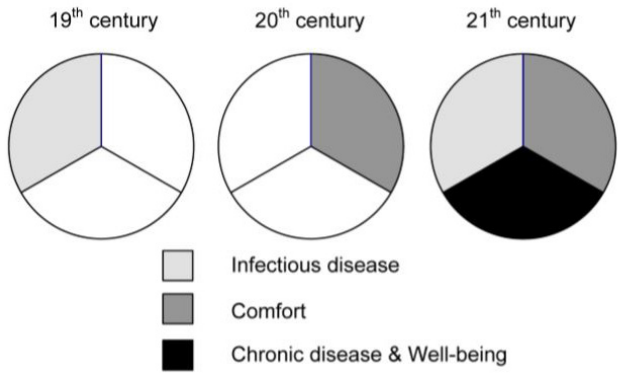

Figure 9. Indoor environment problems dominated by comfort issues.

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Natural air conditioning: what are we waiting for?





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Air conditioning is expensive and very energy inefficient. We cannot live without it, nor do we really like it. Sometimes, it is even bad for our health. But there is hope: a natural air conditioning concept is now ripe for large-scale application in existing and new buildings. Fan noise, draughts and dry throats and eyes will all become a thing of the past, and the air quality is just as good as outside. And as for energy consumption? The most stringent European standard is easily exceeded by a factor of ten. What are we waiting for?

The following essay is based upon the doctoral research of the main author as published in his thesis "Earth, Wind & Fire – Natural Airconditioning" (Bronsema, B. 2013). It explains and stresses the importance of this disruptive concept, which probably can be considered the most important innovation since the invention of air-conditioning at the beginning of the 19th century. At the end of 2018 hotel BREEZE in Amsterdam, the first naturally air-conditioned building in the world, will open its doors, and the time is right to start an offensive in the HVAC community to promote the EW&F concept in the engineering practice. Academics are invited to have a look at my thesis, but this essay is in the first place meant for HVAC practitioners as they form the clear majority in the REHVA member associations.

Introduction

The invention of air conditioning at the beginning of the last century[1] and its subsequent further development has brought many benefits to society. Comfortable indoor environments have significantly improved the well-being and productivity of people at their work. Nevertheless, many people are unsatisfied with the indoor climate at their workplace. There are many complaints about annoying fan noises, air quality, draughts and dry throats and eyes, which are notorious phenomena of the so-called sick building syndrome. Furthermore, the high energy consumption of air conditioning systems is increasingly becoming an issue, particu-

[1] Willis Carrier, 1902

larly in the light of the energy-neutral built environment that must become a reality soon.

The responses to these challenges vary.

- 'We promise to improve'[2], said the manufacturers and installers of HVAC systems, and the authors did their best to contribute. Regrettably, this only made things more complicated in practice, which was the last thing people wanted.
- 'We need to get rid of air conditioning', some building physicists called, and they put forward a case for natural ventilation. Of course, this was a step in the right direction, but it was not good enough! Were we going to accept that employees would have to sit and sweat in their workplaces? Could we accept the loss of productivity in hot weather?
- The authors are proponents of Buckminster Fuller's[3] approach to problem solving: "*You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.*"

Modern air conditioning

But first, let us start by examining the essence of modern air conditioning. **Figure 1** is an exploded view drawing of a modern air handling unit, a beautiful product of Dutch industry (OC Verhulst). This is a 'bidirectional ventilation unit (BVU), which produces an air flow between indoors and outdoors and is equipped with both exhaust and supply fans'.[4] Air is sucked in and conditioned in the bottom of the unit and exhausted from the top section. The sections are connected by a heat wheel that exchanges thermal energy between the two air flows. The essence of the air handling unit lies in the elements for heating (1) and cooling (2) in the supply side. Here, the air is sucked through the fan (3) at a speed of approx. 2 metres per second. We do not want too much fan noise in the workplace, nor outside the building, so a silencer (4) is installed. The fan must compensate for the resistance of this silencer, and so it consumes more energy and produces more noise. This in turn must be compensated by the silencer. An air filter (5) is installed to prevent the elements for heating (1) and cooling (2) from becoming fouled with dust from the outdoor air and impeding the operation of the system. The fan must also compensate for the resistance of this air filter and, so, it consumes more energy and produces more noise that again must be compensated by the silencer. At the end of the lowest section, you can also see a compartment that ensures air humidification (7) during the heating season. A fan (3) is also required for air extraction, for which another silencer (4) is installed. To limit energy use, a heat wheel (6) has been installed in the air handling unit. This device does not only cause a considerable amount of air resistance, it is sensitive to fouling too. Another air filter (5) is installed to prevent this. Its resistance must also be compensated by the fan, which results in more energy use and noise. The fans use a lot

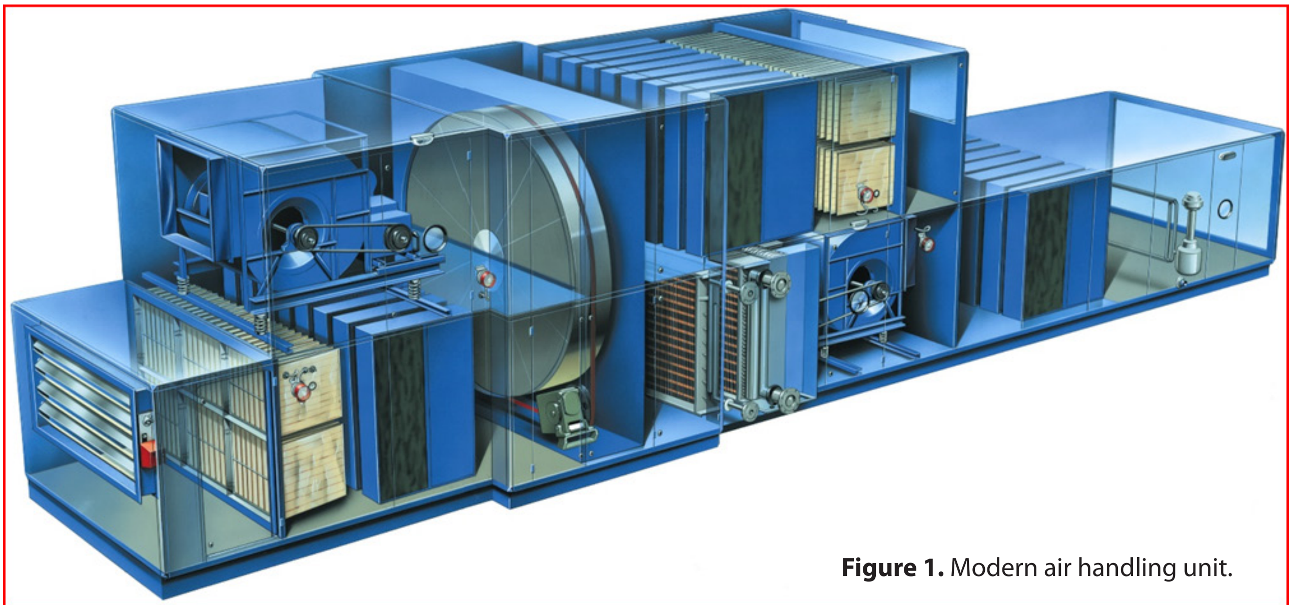

Figure 1. Modern air handling unit.

[2] 'Let's make things better!'

[3] American architect, systems theorist, writer, designer, and inventor (1895-1983)

[4] Technology based on EC regulation 1253/2014

of energy, but that is not the only problem. Although the noise produced is reduced by the silencers, they only effectively dampen the high frequencies. The low frequencies penetrate the workplace, where they are heard as a low hum, which many people find very annoying. As for the air filters, they filter the dust out of the air, but they become fouled after a time and when not replaced timely will emit odours. Although these odours occur only in low concentrations, this means that the air inside is less fresh than outside. Finally, in addition to transferring thermal energy, the rotating wheels of the heat wheel can also transfer odours from the exhaust air to the supply air. Many indoor climate experts say that heat wheels contribute to the degeneration of indoor air quality.

Conclusion

The primary functions of ventilation (3), heating (1) and cooling (2) are the only essential functions of air conditioning. All other functions, which are largely responsible for the bulkiness of HVAC systems and the use of energy, are solely used to control the undesirable side effects (except for the heat wheel).

A new model that makes the old one obsolete

Figure 2 displays a conceptual cross section of a building with natural air conditioning. This building does not have an air handling system installed. Instead, the building itself functions as an air conditioning *machine* using the sun, wind and gravity. This means it must be designed in close cooperation with the architect. This is climate-responsive architecture!

Just as with the air handling unit, the system is based on separate sections for air supply and extraction.

Air supply is provided by the climate cascade (2), which is a structural shaft. Outside air flows into the building at roof level and into the climate cascade by way of the overpressure chamber (1). Cold water with a temperature of 13°C is sprayed at the top of the cascade, so that in the summer the air is cooled to approx. 18°C and in winter it is preheated to approx. 7 or 8°C. Cold is extracted from the ground using a TES (Thermal Energy Storage) system.

The hundreds of thousands of droplets in the spray together form a heat exchanger with a very large surface area, so that the system can generate tiny temperature differences between water and air. This heat exchanger has no air resistance, and in fact produces pressure. This is because the specific mass of the water/air mixture in the cascade is considerably larger than that of the outside air, so that pressure is built up at the base of the climate cascade which is used to distribute air throughout the building by means of the vertical supply shaft (3).

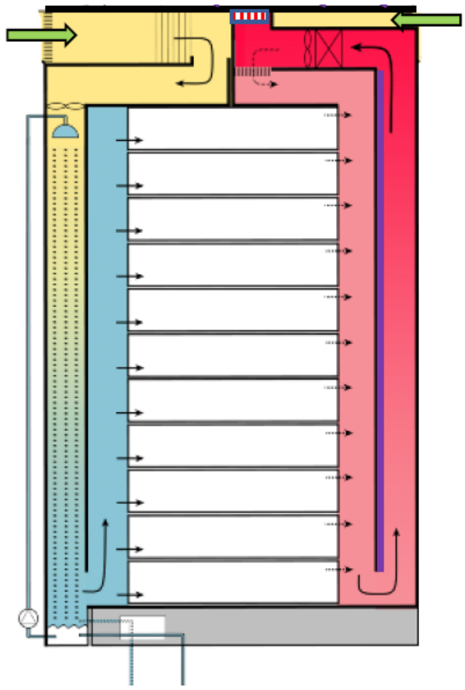

Figure 2. Earth, Wind & Fire 2.0 Natural Air Conditioning[5]

Due to the high level of contact between the spray spectrum and the air, various matter carried by the outside air – possibly including particulate matter – is absorbed by the water and so improves the air quality. In the summer, the air is dried somewhat due to condensation of water vapour on the cold-water droplets. In winter the air is automatically humidified. The spray water must of course be thoroughly cleaned and disinfected.

This *'silent air conditioning'* concept does not require fans and, hence, also no silencers. The odour-enhancing spray spectrum replaces air filters. Air humidification is inherent to the system. Finally, the energy use of the spray pump is only a fraction of that of the fans use in traditional air conditioning.

The ventilation air is extracted through the exhaust/recirculation shaft (8), which is connected to the base of the solar chimney (4), a structural shaft provided with

5 Figure 2 illustrates the EW&F 2.0 concept. The original EW&F 1.0 concept had a Venturi roof system for ex-tracting air. An EW&F 3.0 concept with wind turbines on a convex roof is currently under study.

insulating glass and installed on or in a south-facing wall. The air in the solar chimney is heated by solar radiation, and the resulting thermal draught functions as an *extraction fan* for the air.

A heat recovery system (5) at the top of the solar chimney recovers heat from the building and the sun. The heat is either used directly in the building or transported by the TES system to the ground to restore the thermal balance. During business hours, the used air is exhausted from the roof. The air is recirculated by the extraction shaft (8) to recover solar heat outside business hours, for example during the weekend.

Auxiliary fans (6) ensure that air circulation is maintained under all circumstances. The energy for the fans is supplied by solar panels on the roof and in the solar chimney (7).

The Earth, Wind & Fire concept described above was developed as part of PhD research in a joint venture involving TU Delft, TU Eindhoven and external partners. This research demonstrated that the system is suitable for application in practice[6].

Climate-responsive architecture

The integration of the solar chimney, climate cascade and air distribution system in the structural design requires close cooperation with the architect, who will, therefore, play a key role as technical and artistic co-designer of the climate system. In principle, the intensive cooperation between the architect and the climate engineer should improve the quality of the building while, at the same time, reducing the failure costs.

Energy consumption

EU Regulation 1253/2014 has set 'ecodesign requirements' on ventilation units (air handling units). As of 1 January 2016, the maximum internal specific fan power (SFP_{int_limit}) is 900 $W.(m^3.s^{-1})^{-1}$ and will be reduced to 800 $W.(m^3.s^{-1})^{-1}$ as of 1 January 2018. In practice, these requirements can only be satisfied by using much lower air velocities in the air handling unit. Experts assume that this may result that the space required for the system will increase by approx. 20%.

The energy use of a natural air conditioning system based on the EW&F concept is largely caused by the spray pump and to a lesser extent by the auxiliary fans.

[6] *Earth, Wind & Fire – Natuurlijke Airconditioning*, Uitgeverij Eburon, Delft, ISBN 978 90 5972 762 5.

The system can be very energy efficient by using several spray units which are switched on and off depending on the outside temperature (in summer) or the desired relative humidity in the room (in winter). Depending on the height of the climate cascade, the spray water flow rate and the infrastructure used for the air distribution system, the system could exceed the levels set by EU Regulation 1253/2014 by a factor of 10!

The climate cascade and the solar chimney generate only a modest pressure difference for air transport. This means that the air supply and exhaust system must have larger dimensions than a traditional air conditioning system. This system can best be made as an integrated part of the building, for example by using the spaces above suspended ceilings and under raised floors. Hollow-core slab floors and hollow structural components can be installed in new buildings or as part of major renovations. The cooperation of the architect in the integration of the climate system is an essential element of the concept.

The supply shaft (3) and the exhaust shaft (8) are dimensioned for an air velocity of approx. 3 ms^{-1} and, therefore, need to be considerably large. For traditional air conditioning, a higher air speed of approx. 6 ms^{-1} is required but the gross shaft space needed to accommodate the air ducts is usually double the cross section of the duct. This means that the two climate systems have similar spatial footprints.

The three Ps of sustainable development are harmoniously combined in the Earth, Wind & Fire Natural Air Conditioning System:

People → A better indoor climate

Planet → Less consumption of energy and materials

Profit → Lower costs – less sickness absence

See also the overview for Hotel BREEZE **Figure 3**.

People – Planet – Profit Hotel BREEZE

Hotel BREEZE in Amsterdam IJburg will be the first building in the world with Earth, Wind & Fire Natural Air Conditioning[7]. EW&F helps the building to achieve an high energy performance level. The concept

[7] We applaud Maarten Quist (director of Dutch Green Company), the developer of Hotel BREEZE and initiator of the first practical application of the EW&F concept in the construction industry.

The Earth, Wind & Fire concept in perspective

Hotel BREEZE 25.000 $m^3.h^{-1}$

ASPECT	TRADITIONAL AC	EW&F NATURAL AC
Space requirement plant-room 2 AHU's	220 m^2 (EN 13779)	50 m^2
Cross-section of shafts Air velocity	2,5 m^2 ≈ 6 $m.s^{-1}$	2,5 m^2 ≈ 3 $m.s^{-1}$
Energy consumption EU 1253/2014-$SPF_{int-limit}$	50 $MWh.a^{-1}$ 0,8 $kW.(m^3.s^{-1})^{-1}$	10 $MWh.a^{-1}$
Maintenance KISS factor - simplicity	Very extensive low	Little extensive high
Average life span	15…20 years Mechanical facilities	40 years Architectural facilities
Construction costs Excluding solar chimney	Neutral	

Figure 3. The EW&F concept in perspective.

has been adapted to the specific requirements of a hotel. The hotel has applied for BREEAM innovation credits for the climate cascade and the solar chimney. **Figure 3** compares a few parameters with those of traditional air conditioning. It is important to realise that a hotel has a higher specific energy use than an office building. The reasons for this are the relatively high-pressure loss of the air distribution system due to the complex infrastructure and the requisite fire and constant flow valves usually applied in hotel rooms.

What does this mean for the climate industry?

The introduction of natural air conditioning may have impact on the scale of the HVAC industry, but the overall effect will certainly not be dramatic. In the first place, the *Earth, Wind & Fire* concept is primarily intended for climate systems in high rise buildings, these could be offices, schools, residential buildings etc. This means that plenty of areas of application will be needed for traditional air conditioning. Secondly, natural air conditioning will always be combined with systems for heating and cooling. Finally, installing the *Earth, Wind & Fire* concept requires various HVAC and hydronic equipment, such as pumps, pipes, spray-water treatment, control technology and the entire thermo-hydraulic infrastructure, including Thermal Energy Storage systems. ■

Reference

Bronsema, B. 2013 -TU Delft Repository Earth, Wind & Fire: "Natuurlijke Airconditioning"[8]

[8] Some sound advice: Never Stop Reinventing Yourself: 'Who wants to just "retire"? Banish that word from your vocabu-lary. You've got to constantly reinvent and take a chance on something you've always wanted to do — it's what keeps you alive. You're never done.'(Jack Welch (1935-) – former CEO of General Electric)

Guidance for standard evaluation procedures of indoor environmental parameters in schools

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A meta study "Fundamentals and concept development for the analysis of practice-oriented ventilation concepts for mechanical or window ventilation" shows with the focus on Germany an evaluative overview of the current state of research regarding to CO2-concentration during lessons in schools. For a systematised comparison of measurement results a number of options to the graphical presentation like Carpet-Plots, Box-Plots and scatter diagrams were examined. The analysis shows that caused by the different aims of the individual studies a direct comparison between different studies is hardly possible and many questions are still open. Future studies regarding this subject should be oriented towards the defined "ideal study" taking into consideration minimum requirements for the documented information and factors.

Keywords: ventilation, sustainable building, school, CO_2

Within the framework of the further development of the "Assessment System for Sustainable Building" (Bewertungssystem Nachhaltiges Bauen - short BNB) and the evaluation criteria profile for "indoor air hygiene" respectively, a number of parameters (CO_2 measurements, indoor climate, indoor thermal comfort, surveys on individual comfort experience) are evaluated for a number of field-tested ventilation solutions. With the focus on classrooms, recommendations for action for practice-oriented ventilation concepts as well as proposals for a well-argued evaluation approach in relation to the CO_2 requirements are established.

Background

The Federal Government of Germany has defined mandatory specifications for holistically improved buildings in the "Guideline for Sustainable Building" and the "Assessment System for Sustainable Building" (short BNB). Since October 2013, the BNB system is compulsory for the design and realisation of Federal Government buildings and was partially revised and updated in 2015. With regard to indoor air hygiene, particularly indoor air pollution by pollutants from building products and by carbon dioxide emissions from users are in focus.

Both the current normative requirement for outdoor air volume flow per person and the recommendations within the relevant workplace directive do not take into account all necessary parameters which govern the effectiveness of a suitable air exchange rate. From technical discussions and practical experience, it is known that poor ventilation leads to problems with respect to indoor air CO_2 concentration and, where appropriate, with respect to thermal comfort. This is especially true for rooms with high occupancy. It is also especially true for rooms with window ventilation but it affects also rooms with mechanical ventilation or a combination of both.

Concept

For the further development of BNB (evaluation system for sustainable buildings) the meta study "*Grundlagen- und Konzeptentwicklung für die Analyse von praxisgerechten Lüftungskonzepten bei mechanischer oder Fensterlüftung*" (fundamentals and concept development for the analysis of practice-oriented ventilation concepts for mechanical or window ventilation) shows with the focus on Germany an evaluative overview of the current (published) state of research regarding to CO_2-concentration during lessons in schools. 6 studies of the requested 15 studies could not be analysed, because no measurement values were available or no feedback was received. The raw data of the other 9 studies (see **Table 1**) could be prepared according to a standard procedure.

Table 1. Summary of the considered studies.

Considered studies	Brief description
Müller [Müller]	9 schools in Berlin were examined. They were different regarding to type of building, implemented restructuring measures and ventilation concepts. For a period of one day of class respectively one week of class random measurements in selected classrooms were done with regard to indoor air temperature, relative humidity, CO_2-concentration, sound pressure level and air velocity. Window ventilation as well as mechanical ventilation were considered.
Bischof [Bebersdorf, Bischof1, Bischof2]	10 schools in Erfurt were selected for this study. During the study the classrooms where not ventilated during the lessons, but only in the breaks in all classrooms for two days CO_2-concentrations, relative humidity and operative temperature and additionally in some classrooms the airborne germ rate was measured. The classrooms were ventilated by window ventilation, shaft ventilation and mechanical ventilation systems.
Fromme [Fromme1, Fromme2]	Schools located in Munich and in the District of Dachau were chosen for this study. During the measurement in the winter 46 schools (in total 62 days) and during the measurement in the summer 38 schools have been more closely analysed. CO_2-concentration, relative humidity, temperature and sometimes further air chemistry parameters were measured. So far as this is known, the classrooms were ventilated by window ventilation.
Lambertz [Lambertz]	This study took a closer look at a vocational college in Aachen after renovation. Different mechanical ventilation systems were compared among each other by measuring the CO_2-concentration, temperature, relative humidity, VOC emissions and energy consumption. For comparative purposes measurements with window ventilation were done bevor the renovation started.
Dietz/Sick [Dietz]	The primary school Hohen Neuendorf has been equipped with a hybrid ventilation (mechanical ventilation for the basic ventilation in combination with automatically opening windows and normal windows with a "ventilation signal light"). In two selected classrooms detailed parameters with regard to indoor air quality (CO_2-concentration, relative humidity, air temperature, radiation temperature and climate data) were recorded.
Bolsius [Bolsius]	The individual elements of the rehabilitation were assessed after the energy rehabilitation of the school complex in Olbersdorf. The energy-efficient school ventilation consists of supply box-type windows (windows with framed grounds) in combination with a CO_2 controlled exhaust ventilation system. For selected classrooms the CO_2-concentration, temperature, illuminance and outside climate were recorded.
Wargocki [Wargocki]	A Danish study took a closer look at two mechanically ventilated classrooms of a comprehensive school (age of pupils: 6 to 16 years). In a blind crossover design with new and soiled filters, high and low ventilation rates performance test, indoor air parameters (CO_2-concentration, temperature, relative humidity, etc.) and as well questionnaires were documented. The boundary conditions were defined for one week. The experiment was performed both in winter and in summer.
Lahrz [Lahrz]	A closer look at energetically rehabilitated schools in Berlin regarding the air quality during the heating period was taken in this study. Classrooms with window ventilation were considered as well as classrooms with mechanical ventilation. Parameters like carbon dioxide, temperature, relative humidity and diverse dust fractions were documented for a school week.
Birmili [Sinphonie]	Study to determine the „Leitfaden für die Innenraumhygiene in Schulgebäuden" (Guideline for Indoor Air Hygiene in schools) of the Federal Environmental Agency (UBA) as well as the EU joint project "Sinphonie" (further information are not available, because no publications are available)

To evaluate CO_2-concentrations measured over a longer period usefully, it is necessary to know the school hours. Studies where the school hours remained unknown are analysed by a VBA-based evaluation.

For a systematised comparison of measurement results a number of options to the graphical presentation like Carpet-Plots, Box-Plots and scatter diagrams were examined (see **Figure 1**). In this study the evaluation was carried out mainly with scatter diagrams for individual lessons or individual classrooms to avoid possible increased weighting caused of individual studies.

In the framework of this study the following measurements of CO_2-concentration exist:

- Window ventilation (5 studies): 652 lessons in 121 classrooms in at least 16 schools
- Hybrid ventilation (1 study): 375 lessons in 2 classrooms in 1 school
- Mechanical ventilation (5 studies): 513 lessons in 38 classrooms in 12 schools.

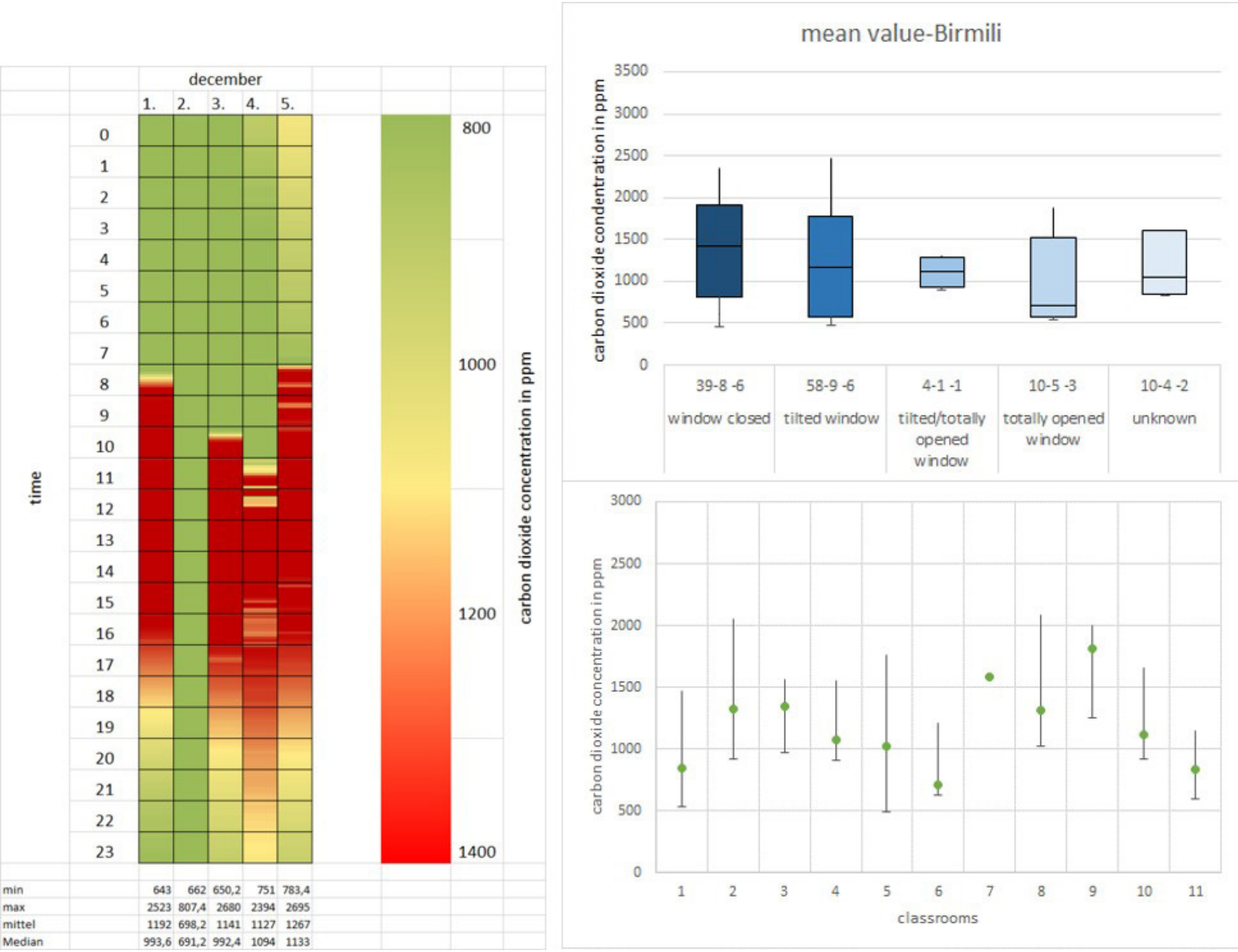

Figure 1. Exemplary presentation as Carpet-Plot (left) – Box-Plot (top right) – scatter diagram (on the bottom right).

Results

The following recommendations can be concluded for the individual ventilation concept due to the findings of the meta study as well as of the publications on individual studies and the participation in the AIVC-Workshop:

Window ventilation

Figure 2 shows that:

- 16% of the lessons have an arithmetic mean of the CO_2-concentration that meets the quality level 1 or 2 of BNB and comply with a positive BNB evaluation of the building and with the workplace regulation ASR A3.6. 35% of the lessons meet the quality level QN 0 (1000 ppm to 1400 ppm = 0 points according to BNB / non-compliance with ASR (workplace regulations)), 10% quality level QN 1 (800 to 1000 ppm) and 6% quality level QN 2 (< 800 ppm).
- The arithmetic mean of the CO_2-concentration depends clearly on time. In later hours of the day the probability that the arithmetic mean is under 1000 ppm decreases. (1. and 2. lesson with 23% and. 21% < 1000 ppm vs. 6. and 7. lesson with 7% respectively 3% < 1000 ppm).
- A clear dependence of the CO_2-concentration on the ventilation habits could not be shown. Lessons with tilted windows and closed windows lead to similar frequency of mean CO_2-concentrations under 1000 ppm (35% respectively 40%), whereas full opened windows lead to a decreased room air quality (only 15% of lessons with arithmetic mean < 1000 ppm). Causal should be that in the questionnaires the duration of ventilation processes was not documented.

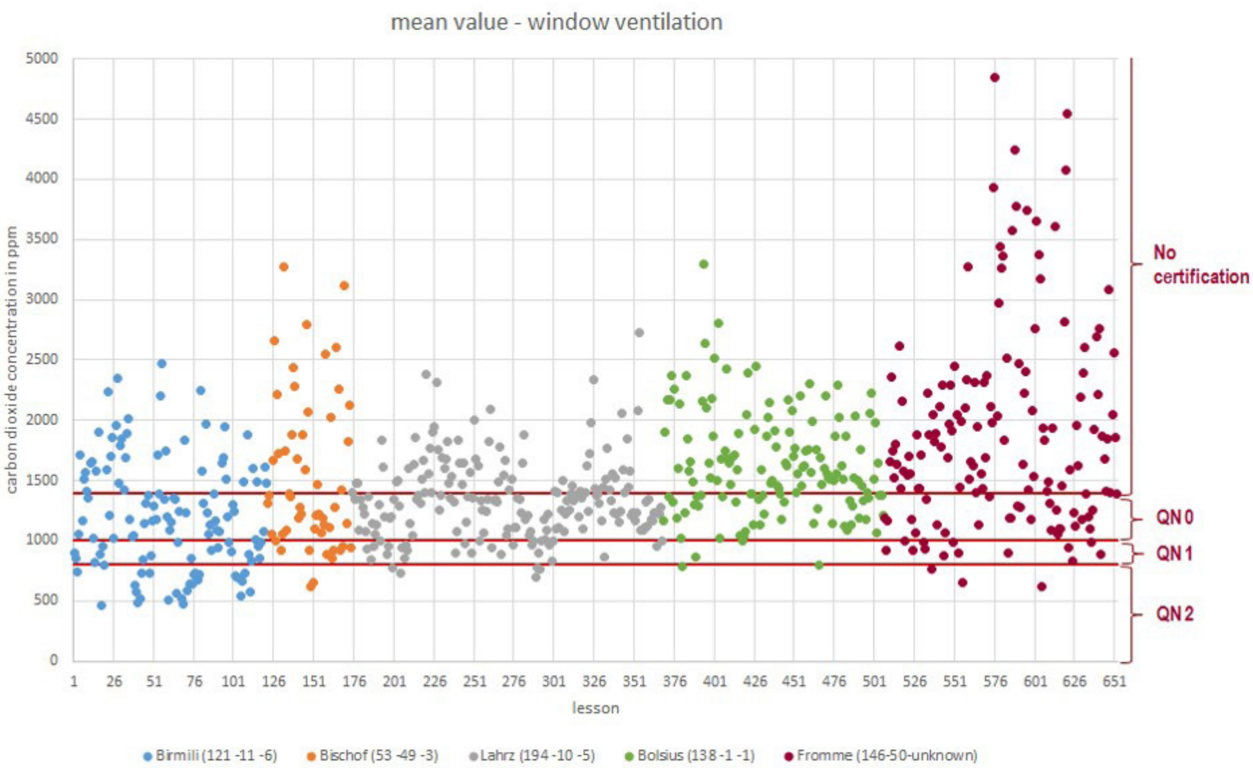

Figure 2. Scatter diagram of the arithmetic mean for window ventilation of the considered studies (lessons).

Hybrid ventilation

In the framework of this study hybrid ventilation is the combination of mechanical ventilation which is designed for the basic ventilation and a user-independent automatically window ventilation for example with servomotors at the windows.

Figure 3 shows that:

- 7% of the lessons have an arithmetic mean of the CO_2-concentration that meets the quality level 1 or 2 of BNB and comply with a positive BNB evaluation of the building and with the workplace regulation ASR A3.6. 42% of the lessons meet the quality level QN 0 (1000 ppm to 1400 ppm = 0 points according to BNB / non-compliance with ASR (workplace regulations)), 5% quality level QN 1 (800 to 1000 ppm) and 2% quality level QN 2 (< 800 ppm).
- The arithmetic mean of the CO_2-concentration depends clearly on time. In later hours of the day the probability that the arithmetic mean is under 1000 ppm decreases. (1. lesson with 52% < 1000 ppm vs. 5. lesson with 4% < 1000 ppm). The observed increase in the room air quality after the 5. lesson can be probably traced back to a change in use in the afternoon. Characteristic of elementary schools are also whole-day classes in smaller groups for example joint ventures or homework done under supervision.

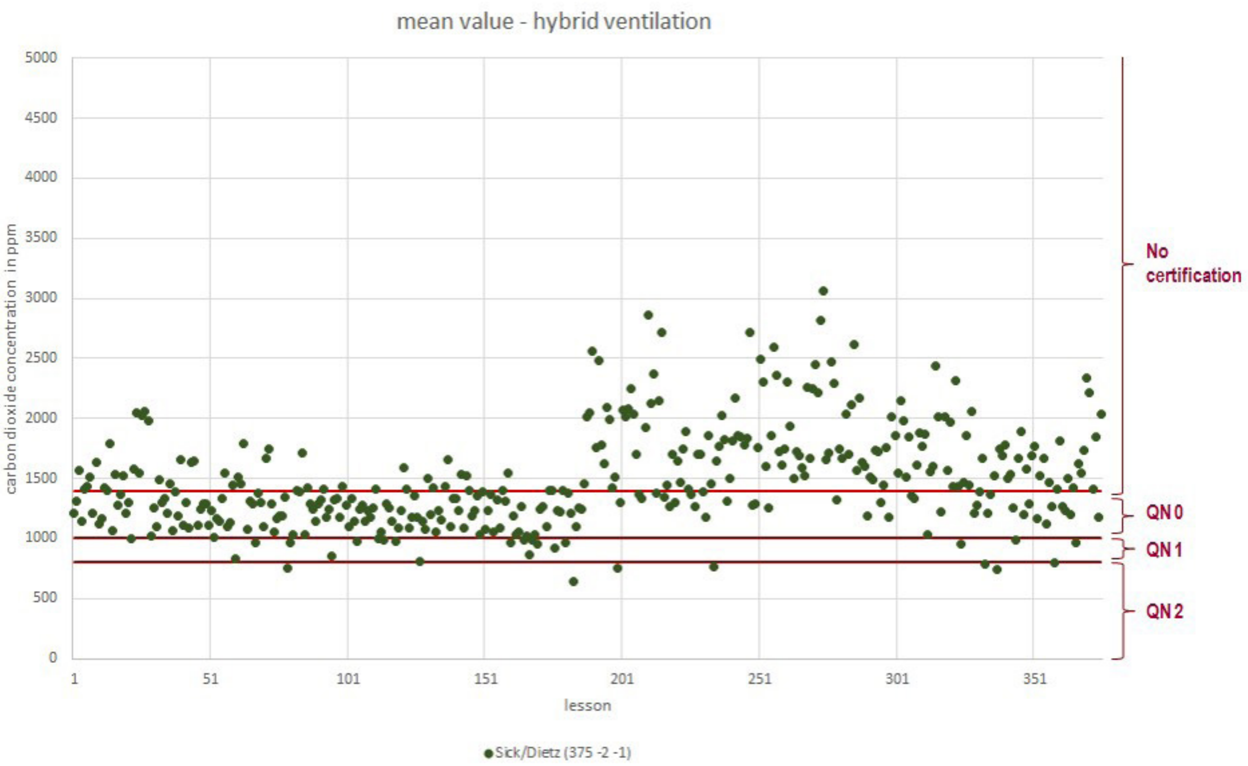

Figure 3. Scatter diagram of the arithmetic mean for hybrid ventilation of the considered studies (lessons)

Mechanical ventilation

Figure 4 shows that:

- 39% of the lessons have an arithmetic mean of the CO_2-concentration that meets the quality level 1 or 2 of BNB and earns a certification of the building according to BNB. 53% of the lessons meet the quality level QN 0 (1000 ppm to 1400 ppm = exclusion from building certification according to BNB / non-compliance with ASR (workplace regulations)), 27% quality level QN 1 (800 to 1000 ppm) and 12% quality level QN 2 (< 800 ppm).
- Based on arithmetic mean values and maximum values of the measured CO_2-concentration statistical parameters (median as well as 10. and 90. percentile) were determined for classrooms if there are measurement values for more than one lesson per classroom.

A comparative overview of the CO_2-concentrations shows that with mechanical ventilation 38% in the total of 513 considered lessons meet an average value under 1000 ppm, respectively under 1500 ppm are 94% of the lessons. The arithmetic mean of the CO_2-concentration of a lesson with window ventilation is under 1000 ppm in 16% of cases in the total of 652 considered lessons, 58% meet under 1500 ppm.

Regardless of the ventilation concept a reduction of number of students respectively an increase of classrooms, finally a larger area per person, results in lower CO_2-concentrations in classrooms.

Arithmetic mean values of the CO_2-concentration under 1000 ppm can be met for window ventilation and hybrid ventilation easiest in the early lessons. In the later lessons of the day a lower CO_2-concentration can

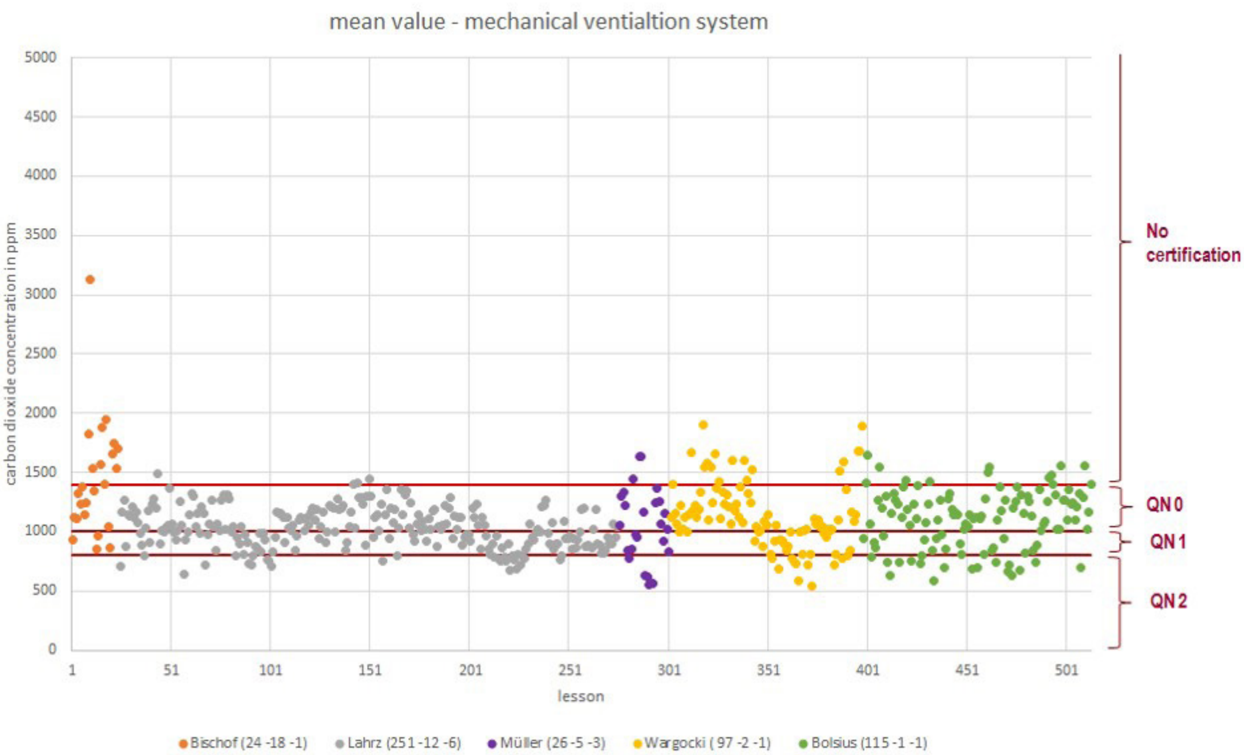

Figure 4. Scatter diagram of the arithmetic mean for mechanical ventilation of the considered studies (lessons).

only be reached taking into account certain boundary conditions like for example long break with intensive cross ventilation, a longer duration without teaching or smaller students per class.

Hybrid ventilation concepts combine mechanical ventilation with user-independent automatically window ventilation (for example motorised casements). The mechanical ventilation system provides a cost- and sound-optimised basic ventilation. This basic ventilation is supported by the automatically window ventilation in case of peak loads.

Ventilation systems should be designed for example according to DIN EN 13779 IDA 2, so no additional ventilation during the lesson is necessary. Organisational restrictions, discomfort of the persons in the room (temperature, draft risk) and disturbance through sound by window ventilation could be avoided with such a design. By optimising the control and operation mode of mechanical ventilation an improvement of the indoor air quality and an increase of acceptance can be reached.

In the current evaluation system BNB for school buildings the evaluation of the CO_2-concentration is made on the basis of requirements regarding to the (arithmetic) mean value and the maximum value of a lesson of 45 minutes. In future, the following extension options could be considered:

- Determination of maximum values based on the moving average over 5 minutes
- Determination of mean values based on the acceptable frequency of CO_2-values per lessons over a limit value (mathematical: percentile)
- Determination of a cumulative CO_2-exposure in ppmh (per lesson, school day, school week)
- Creation and if necessary BNB certification of a tool to classify according to BNB evaluation system

The analysis shows that caused by the different aims of the individual studies a direct comparison between different studies is hardly possible. For future studies, especially in the context of the evaluation and optimization of the BNB, the requirements for the parameters of an "ideal study" can be derived (see **Table 2**).

Table 2. Parameter of the „ideal study".

<table>
<tr><th colspan="2">General parameters</th></tr>
<tr><td colspan="2">– Ventilation system (window ventilation, mechanical ventilation, hybrid ventilation)
– Number of schools
– Type of school (primary school, secondary school)
– Number of classrooms (same number of ventilation system)
– Number of lessons (same number of lessons per classroom)
– Room occupancy (protocol)
– Age of pupils (class level)
– Area and volume of the classroom
– Lesson and break time
– Measurement period (for example one week in summer, winter, transition period) define minimum standards
– Measurement of outdoor air conditions where the school is located (wind, temperature, CO_2, etc.)
– Measurement of carbon dioxide in classrooms (one-minute interval)
– Logging of the situation in the breaks
– Uncertainty of the measurement technique, automation → Analysis not immediately after the commissioning, after all errors have been eliminated, stable running system
– Calibration of the measurement technique
– Measurement technique (arrangement, type, precision)
– Comfort (thermal comfort, sound…) as measurement or/and questionnaire</td></tr>
<tr><th>Additionally, with window ventilation</th><th>Additionally, with mechanical ventilation system</th></tr>
<tr><td>– Window profile (dimensions, number of casement, opening options [buttom hung, side-hung])
– documentation of ventilation with information about window position and duration of the ventilation for the lessons and the breaks including information which window is opened
– Kind of ventilation (one-sided or cross ventilation)
– Ventilation concept</td><td>– Information of the ventilation system (operating period, operating mode, contact switches at the windows, CO_2-control, combination of automatically casements etc.)
– Volume flow rate (development, actual state)
– Planned size (CO_2, temperature, volume flow etc.)</td></tr>
<tr><th colspan="2">Additionally, with hybrid ventilation</th></tr>
<tr><td colspan="2">Combination of the listed parameters of window ventilation and mechanical ventilation system
- planned volume flow rates (shares mechanical ventilation and window ventilation)</td></tr>
<tr><th colspan="2">Supplementary (optional) recommendations</th></tr>
<tr><td colspan="2">– Measurement of pollutants in classrooms (formaldehyde, radon, particulate matter etc.) (particulate matter PM based on the aerodynamic diameter 10 µm, 2,5 µm respectively 1 µm with PM10, PM2,5 and PM1classified)
– Performance tests</td></tr>
</table>

The research project shows that although so many different studies were implemented many questions are still open respectively have not been finally clarified yet. Answering these open questions should be tried in future studies. Such future studies regarding this subject should be oriented towards the defined "ideal study" taking into consideration minimum requirements for the documented information/factors. ■

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Modern developments of high-performance industrial fans



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Modern centrifugal and axial impellers were developed on the basis of domestic and foreign experience. Highly efficient centrifugal and axial fans of different aerodynamic schemes for different practical applications were designed on the basis of those impellers. Optimal technological solutions allowed to master the serial production of the developed fans in short time. Realized technical decisions will allow to reduce energy consumption of ventilation systems of modern buildings and structures.

Keywords: centrifugal fan; axial fan; impeller; free impeller; tubular fan; efficiency

Introduction

The main directions of the development of general industrial fans are:

- increase in energy efficiency,
- expansion of the working area for air flow rates at specified dimensions and speeds,
- noise reduction,
- optimization of design performance in accordance with classes of tasks to be solved.

The most significant fact is that, firstly, fan science has been developing for a long time and high levels of efficiency have been achieved (up to 92%), therefore, every step in its development requires more and more efforts. Secondly, today the development is, as a rule, at the junction of directions, when it is necessary, for example, not only to reduce the power consumption of the fan, but also to reduce its noise. Or increase the pressure of the fan while increasing the temperature of the pumped medium. One can cite other examples of concrete tasks at the junction of two or three different branches of science. We strive to be at the level of modern requirements and we are engaged in research, development and practical implementation of new promising technical solutions in the field of ventilation equipment. In this article, we will offer several technical solutions for radial and axial general industrial fans from the spectrum of problems we solve.

Centrifugal fans

Aerodynamic scheme "free impeller"

The last 20 years, the development of fans with the aerodynamic "free impeller" principle has been developing. This principal is based on a scheme of a radial impeller with backward curved blades and an inlet cone on the frame, without a housing. The impeller can be located either directly on the shaft of the electric motor or connected to it via a pulley-belt transmission. It should be noted that this scheme has been used for a long time, for example, in roof fans. Today - this is one of the most used schemes in supply and exhaust systems.

The outlet of the flow from the impeller occurs in the volume of the casing of sufficiently large dimensions [1,2] and the velocity head is lost, the impeller operation is estimated on basis of static parameters. In accordance with modern energy saving trends, research and development work is conducted in the direction of increasing the static efficiency of such impellers by optimizing their geometry.

Currently the upper limit of the capabilities of such an aerodynamic scheme seemed to be reached. The problem solving has an optimum: to increase the static efficiency of the impeller, it is necessary to reduce the angle of the blades at the outlet, however, in order to increase the flow and pressure coefficients it is necessary to increase the angle of installation of the blades at the impeller outlet and its width. A number of other factors are also of influence. The actual efficiency for static pressure corresponds to approximately FEG71 (Fan efficiency grade 71) see[3,4]. Obviously, further improvement of the "free impeller" scheme will be very difficult and may prove to be economically unjustified, since it will not be possible to completely get rid of the lost dynamic pressure at the outlet of the free impeller.

Regarding the modern impellers with backward curved blades, it is worth mentioning the impellers of the companies "Ziehl-Abegg", "EBM Papst", "Flakt Woods", "Comfrey" (see, for example, [5]). These impellers were designed, according the aerodynamic scheme of the fan "free impeller", for application in supply and exhaust systems. In our country schemes such as "free impeller" began to be used in the early 2000s. At the same time, the most popular were centrifugal impellers with backward curved blades having a flat front disc of an enlarged diameter (in comparison with the blades) with a smooth turning radius at the impeller inlet (**Figure 1**).

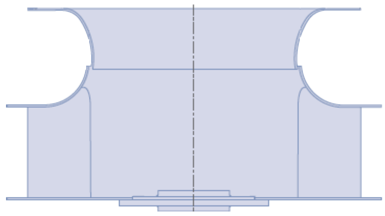


Figure 1. The basic unit of the "free impeller" scheme.

In this article, we want to demonstrate the basics of aerodynamics of the best foreign and domestic centrifugal impellers with backward curved blades. This to identify opportunities, generalize their advantages and minimize shortcomings. Our experiments showed the dependence of the aerodynamic performance and efficiency on the width of the impeller (**Figure 2**), with other geometric parameters of the impeller also affecting its efficiency, but the main effect is on the width. As the width of the impeller increases, the flow in it loses stability, there is a flow separation near the front disc, which leads to a decrease in the aerodynamic parameters and efficiency, volume flow growth is disproportionate to the width of the impeller. The best impellers with a flat front disc have optimum performance at widths of about (25 … 28%) of the diameter of the blade system. For smaller widths, efficiency also falls off rather quickly,

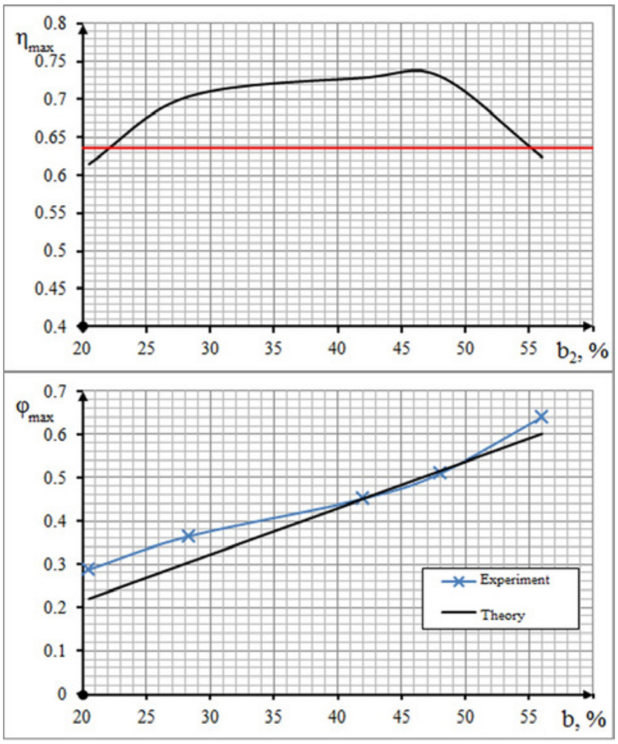


Figure 2. Dependence of the maximum efficiency and the flow coefficient on the width of the impeller divided by blade system diameter..

which is already associated with a suboptimal relationship between the inlet diameter and the width of the impeller. For example, in the book [6], one can find the results of work related essentially to the effects observed in a centrifugal impeller with a change in its geometry.

These results were obtained from the results of a cycle of experiments to optimize the geometry of the impeller, including the shape and relative dimensions of the front disc, the shape of the blade and the angles of its installation at the inlet and outlet of the impeller, the shape of the rear disc (**Figure 3**). In addition to the tests, estimates of the aerodynamics of impellers were made for a deeper understanding of the influence of the basic geometric dimensions and parameters.

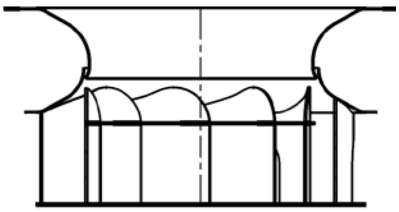


Figure 3. The newly developed basic unit of the "free impeller" scheme.

The smooth inlet cone, in combination with the conical front disk of the impeller and the curvilinear shape of the sheet blades, made it possible to obtain aerodynamic, power and noise characteristics similar to the best "free impeller" schemes. It should be noted that there is a significant difference: the developed aerodynamic scheme allows creating impellers of greater width, providing a significant expansion of the aerodynamic characteristics of the "free impeller" without loss of pressure and, accordingly, the efficiency of the fan (**Figure 4**).

The developed scheme can be used without a noticeable reduction in efficiency to impeller widths of at least 25% of the diameter of the blade system. At smaller widths, the efficiency of the circuit decreases and it is necessary to apply other aerodynamic parameters of the "free impeller" principle.

Volute casing

The need for unification led us to inspect the performances of new impellers as part of a fan with a volute casing. As the width of the impeller widens its working zone by the volume flow rate of air, it is necessary to change the geometry of the volute casing accordingly. For unification reasons, it was decided not to change the front and rear walls of the volute casing. The effect of the change in the spiral wall of the casing (its axial extension) proportional to the width of the impeller was studied. The completed cycle of works allowed designing two types of fan, differing in width (axial extension) of impeller and the volute casing correspondingly. One fan made it possible to obtain wide aerodynamic characteristics corresponding best industrial centrifugal fans and is distinguished by the reliability and stability of these characteristics. The second fan has a wider impeller, a wider volute casing and its aerodynamic performance is significantly wider, while maintaining high efficiency values (**Figure 5**). An essential advantage of the second scheme is a high proportion of the static pressure in the total pressure of the fan, which simplifies its matching with the ventilation systems.

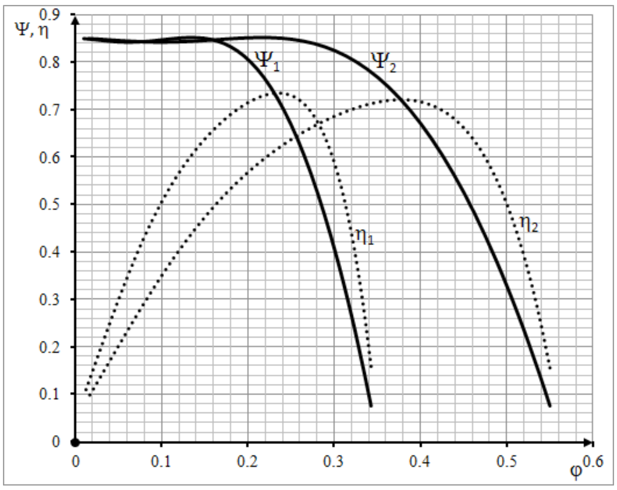


Figure 4. Dimensionless operating characteristics of the developed "free impeller" scheme for two impeller widths (here $\varphi = L/(FU)$; $\psi = \rho U^2/2$; $U = \pi Dn/60$; $F = \pi D^2/4$; *D*-diameter of the impeller blade system, m; *n*-impeller speed, rpm; η - fan efficiency).

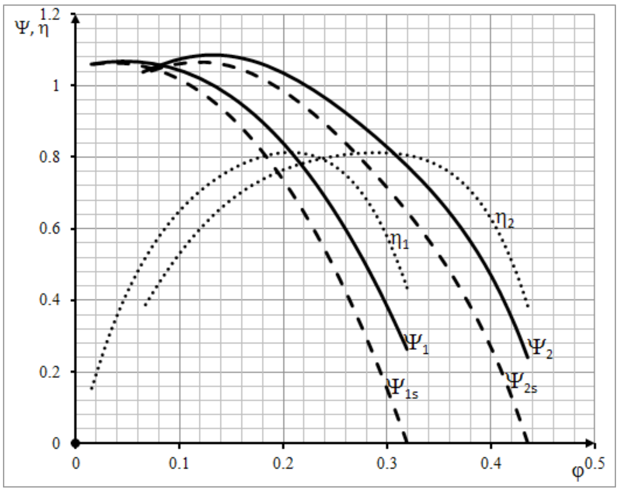
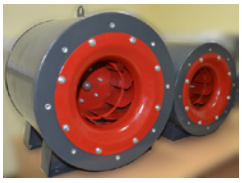


Figure 5. Dimensionless performance of two fans with a volute casing, differing in the width of the impeller and volute.

Tubular fan

For practical applications of considerable interest are radial ducted direct flow fans with a cylindrical casing (for example, [7]). In our country, fans of this type started to be studied in the fifties [8], but unlike at the foreign market where they were widely spread are called "tubular fan", they have not yet been applied. These fans are close to fans with a volute casing, but smaller in size, having a larger static pressure part in total pressure, higher static efficiency, strait direction of flow, which in some cases simplifies the connection of the fan with the network with lower noise levels. Such fans can successfully replace corresponding fans with a volute casing. The impeller can be centrifugal, centrifugal with profile blades, mixed flow, or mixed flow with profile blades. At the same time, the centrifugal impeller with backward curved blades is characterized by higher pressures than the mixed flow impeller, but the use of a mixed flow impeller makes it possible to expand the performance zone (with other things being equal). The possibility of changing the width of the centrifugal impeller in a large range allows you to combine the advantages of mixed flow and centrifugal impellers. (**Figure 6**).



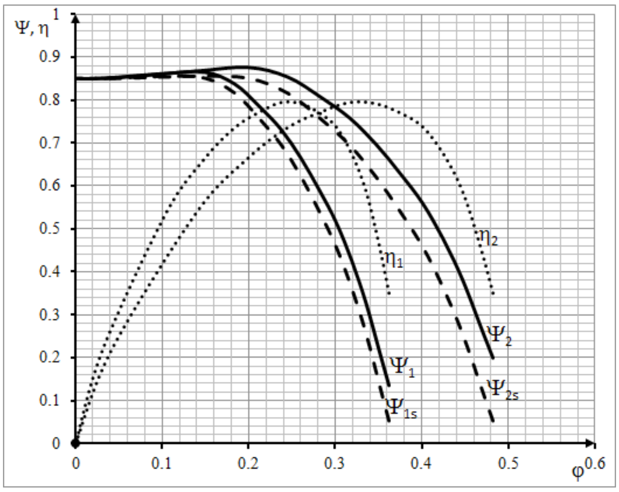


Figure 6. Centrifugalin-line fan with a round casing. Performance data are given for two impeller widths.

As a result of a series of experiments, the aerodynamic characteristics of the created fan were confirmed, providing a sufficiently wide aerodynamic characteristic for air volume flow coefficient. At the same time, it was possible to regulate the working volume flow area by changing the width of the impeller, without changing the fan casing. According to aerodynamic parameters and efficiency, the fan replaces the corresponding fans with a volute casing, but with higher static parameters. According to aerodynamic and power characteristics, the fan is at the level of the best analogues and exceeds in the width of the flow rate working zone.

Thus, the new centrifugal impeller has allowed to a significant extent, to unify the technology and design of several types of centrifugal fans, and to obtain new high-efficiency low-noise general industrial fans for modern ventilation systems of energy-efficient buildings, structures and technologies.

Axial fans

Unlike the radial fans calculation methods, which are mostly based on semi-empirical and empirical dependencies and require experimental investigation and refinement of each individual design, the calculation methods of axial fans have theoretical design bases which allows providing a set of accurate, specific design parameters.

One of such methods is the technique developed in Central Aero-hydrodynamic Institute (TsAGI) (for example [9,10]). This technique allows determining all the optimal parameters, starting with the maximum allowable diameter of the axial fan hub (the works of Brusilovsky I.V. and Mitrofovich V.V.) and ending with the prediction of aerodynamic characteristics (the works of Brusilovsky I.V., Gegin A.G., Kolesnikov A.V., Dovzhik S.A., and others). The developed technique also allows you to design an axial vane diffuser under an existing axial impeller blade system.

Unfortunately, the forms of the blades obtained as a result of calculations by this method as, indeed, for any other, are quite complex and usually have the form of a saddle surface. This makes it impossible to fabricate them with simple technological operations such as bending and rolling, not to mention profile blades. For this reason, some manufacturers either manufacture sheet blades with forms just like the calculated geometry (with several bends or along a cylindrical surface). Some users acquire blades of known companies specialized in axial blades manufacturing with known characteristics in a wide range according to angles of installation, number of blades as well as changes when pruning blades and installing on hubs of different diameters. It is obvious that the blade rings made by geometry only approximate to the optimal and have much reduced levels of efficiency and pressure. Impellers with several types of blades used for all applications cannot have high efficiency in all designs due to too wide unification. In addition, axial vane diffuser has to be coordinated with impeller geometry if not, most part of dynamic pressure associated with swirling the flow at the outlet of the impeller will be lost and consequently with increased pressure coefficients, the efficiency will decrease.

To solve problems in which high flow rates, medium and low-pressure coefficients are required at high efficiency values, fan blades with sheet blades were designed with observance of the calculated geometric parameters corresponding to the optimal aerodynamic scheme (**Figure** 7). The technology of such blades available in applications has been developed which allows creating dimension rows of fans.

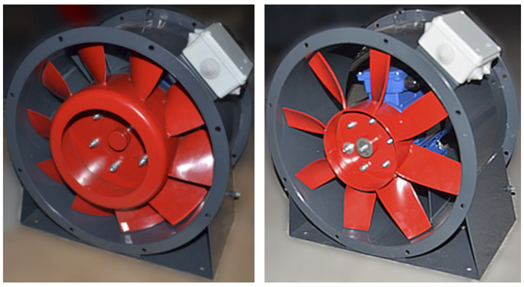


Figure 7. Axial fans according to the scheme "impeller + axial vane diffuser" and scheme "impeller" with sheetblades of spatial curvature.

A wide dimensions range and the possibility to use fans with or without axial vane diffuser, as well as, in some cases, the creation of a complete system with axial guide vanes for regulation, allow solving a wide range of problems with high efficiency levels (**Figure 8** and **Figure 9**). Such fans can successfully compete with the best samples of other companies. High levels of efficiency allow them to be used in the construction of ventilation systems of energy-efficient buildings and structures. ■

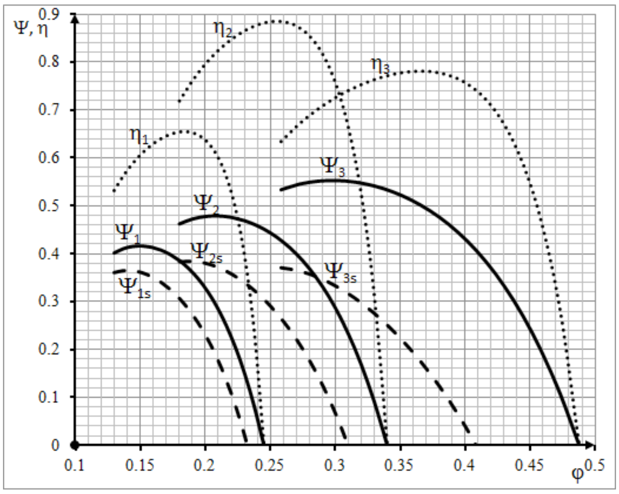


Figure 8. Dimensionless aerodynamic characteristics of a medium-pressure fan according to "impeller + axial vane diffuser" scheme.

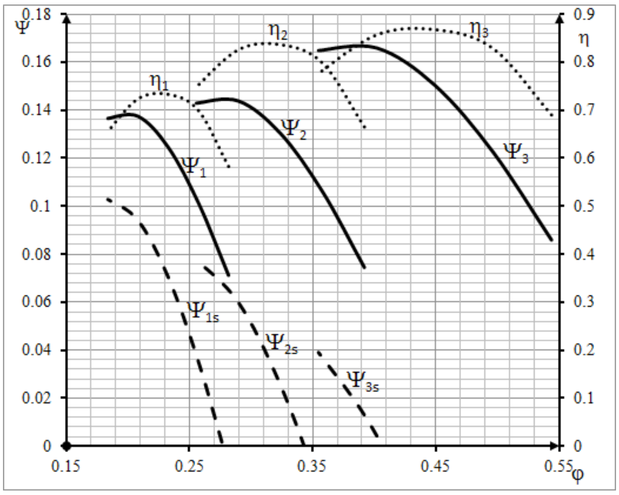


Figure 9. Dimensionless aerodynamic characteristics of a low-pressure fan according to the "impeller" scheme.

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The KUEHA project - A new solution for space cooling during summer

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This report presents a research project on space cooling in summer season with the objective to establish a theoretical preliminary analysis on how to cool through an existing hydronic heating system, not being floor/wall heating systems integrated in floor/wall contraction. The project is intended to prove that innovative, cost-effective and energy-efficient cooling solutions during the summer season can be implemented even in already existing buildings.

Motivation

Especially in urban areas, there are increasing thermal loads during the summer months. Various men-made factors (see **Figure 1**) cause specific local climatic conditions. These differ from those of the surrounding area mainly by significantly higher temperature stress and radiation loads, the latter leading to higher short and the long-wave temperature radiation appearance.

Against this background, the increasing thermal insulation of buildings can worsen the thermal situation in summer. The effect of the solar and internal heat loads in this case means that the surface temperatures of effective storage masses do not fluctuate at a constant, i.e. the level following the day/night change, but steadily increase, since the nocturnal cooling is greatly limited due to improved heat insulation or the absence of ventilation during the night.

During the planning and operation phases of non-residential buildings, the question of how to cool spaces during the summer heat is often not considered. This often leads to a considerable decrease of thermal comfort levels leading to difficult working conditions and expressed user complaints, which in turn are can lead to a decrease in work performance. In residential buildings, the decrease of thermal comfort can lead to significant health impairments, especially among the elderly. This stands in contrast to humans being able to benefit from increasingly sophisticated air-conditioning solutions - however, these are mainly used in vehicles or in the commercial leisure sector, which makes the difference to the thermal comfort enjoyed in buildings even more apparent.

Retrofitting spaces to meet thermal comfort during summer is often challenging: Frequently, so-called decentralized split air conditioning systems are used with problematic arrangements of the condenser (see **Figure 2**). Of particular concern is the inefficient fundamental and temporal use of electrical energy and the significant emission of waste heat into the surroundings. Although these divided systems are able to achieve the desired air temperatures, the thermal comfort is often not satisfying based on the often-considerable high air velocities in the form of drafts in combination with too low air temperatures.

In addition, unregulated relative humidity reaching a too low level could lead to health problems such as inflammations in the eye area and may result in increased risks of nasal infections due to the dehydrating

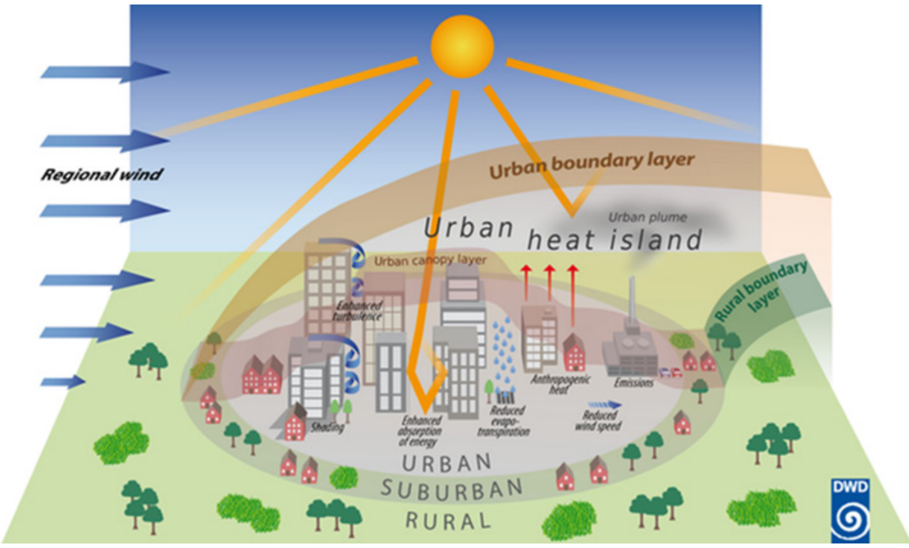

Figure 1. The urban climate and its influencing factors [5]

Figure 2. Space cooling during Summer - Typical sight in areas with high occurrence of split air conditioning systems.

of membranes. The inappropriate maintenance of the evaporator units can lead to filters and condensate pipes becoming breading grounds for microbes.

To remedy these problems, this project proposes to achieve the cooling of spaces through the (existing) heating system, preferably combined with an effective cooling arrangement. Such arrangement could be achieved through a co- or tri-generation, e.g. in the form of a gas engine CHP or a fuel cell. The exhaust waste heat which could be used in the summer by adsorption or adsorption refrigeration machine. District heating systems are also suitable to be used as cooling systems. For this case, brine-water heat pumps with surface or subsoil water as a heat sink offer particularly favorable possibility to cool. When only the brine circuit is used for the recooling of the brine but not a compressor, these systems are very cost effective over long periods of time.

Particularly interesting in this regard is the use of near-surface subsoil water, deeper inland water layers or the use of running water.

In specific circumstances, a further reduction of the electricity demand for soil-coupled heat pumps can be expected as the soil can regenerate better during the summer heat input for the winter.

It should also be considered that in residential buildings the heating of domestic hot water often occurs in parallel to the cooling of rooms in summer. For these scenarios, the heat extracted from the building can nearly completely contribute to an increase in efficiency.

Current state of knowledge

Due to the limited cooling capacities of radiators and the problem of condensing water, in Germany cooling with radiators is met with skepticism. Yet in Japan, this method has been present for several decades (see **Figure 3**). In the Japan case, where the dew point is passed constantly, the resulting condensate is collected and removed. This pragmatic approach allows very low surface temperatures of radiator surfaces and results in an improved heat transfer. The possibility of air drying is an additional system advantage in regions with a particularly humid ambient climate.

In Europe, drying air in a room by cooling the air over free heating surfaces/radiators is currently not feasible. From a scientific view, this is a rather interesting area for research due to its high potential for future application. Avoidance of the dew point below leads to lower benefits of the free heating surfaces/radiators but allows for the use of cooling at a relatively high temperature levels. Realization is, therefore, a return-side cold extraction from existing plants, the use of natural sources or the use of adsorption refrigeration machine with a low temperature level on the drive side and a cold supply at a relatively high temperature level.

Practical studies on cooling with free heating surfaces/radiators have so far been carried out only to a very limited extent in Germany and more under laboratory-like conditions (see [7]).

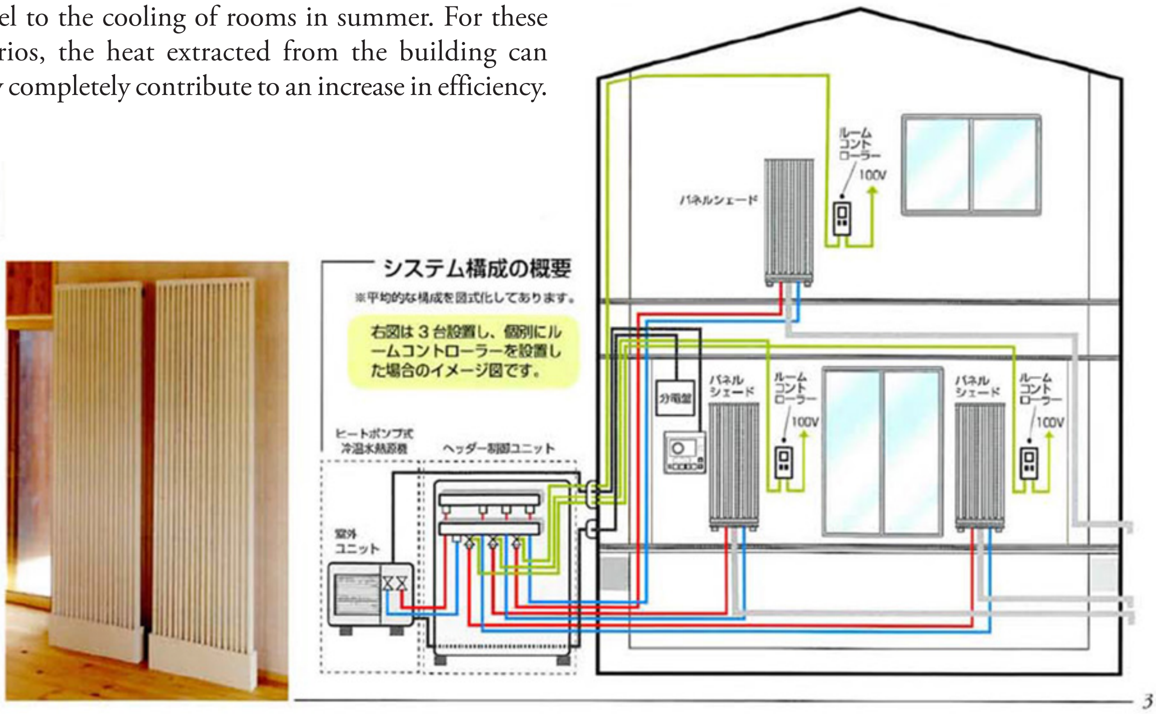

Figure 3. Heating and cooling by heating surfaces/radiators offered by a Japanese private enterprise. [8]

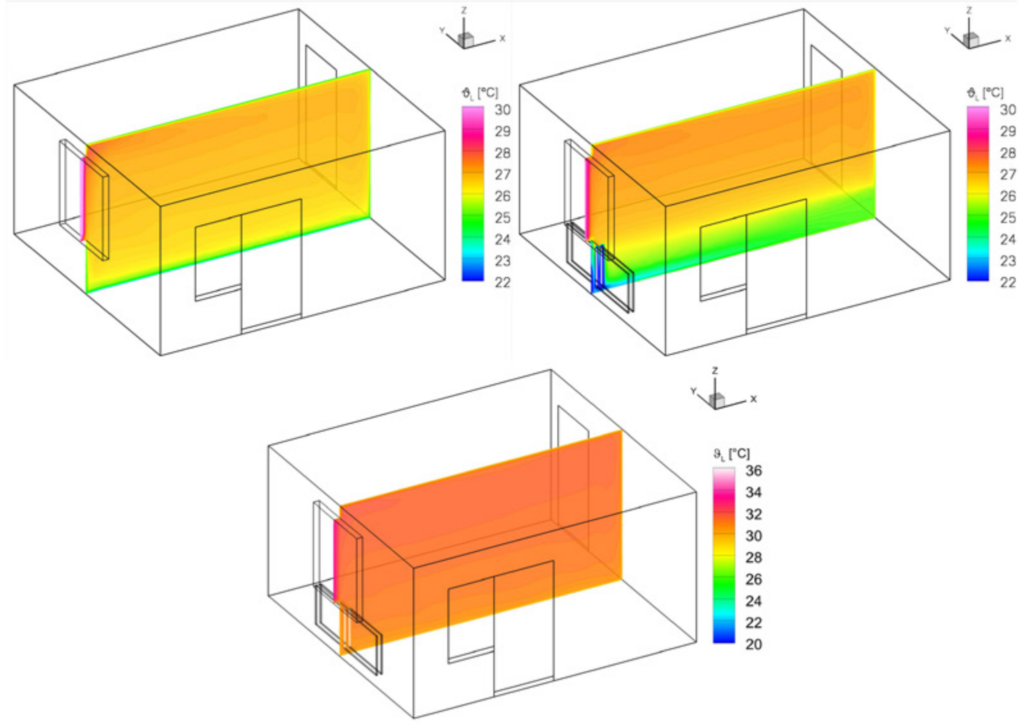

Figure 4. Cooling through free heating surfaces/radiators (right) compared to floor cooling (left) and the non-cooled comparative example. [9]

A detailed theoretical study of the possibilities and challenges of cooling using free heating surfaces/radiators was given in [9] and [6]. These include studies on the effect of buoyancy forces on the inside water flow of free heating surfaces/radiators and their influence on the room air flow and the thermal comfort. **Figure 4** shows the basic effects of cooled heating surfaces. Compared to the uncooled comparison case, despite the limited heating power, a significantly lower room temperature is reached. Particularly interesting is the applying the cold-air lake principle, as is normally achieved by using cold water in floor-heating systems. This can directly cool the heat sources, while their heat loads being dissipated by the self-adjusting buoyancy current of the occupied area towards the ceiling. The described local cooling effect eludes previous general balances and is therefore a particularly interesting subject of further investigations. An important point on the way to practical implementation is the consideration of the heating surface flow. Regardless of the manifold design possibilities of the radiator connections, the inner tube guide ensures that the flow medium flows in the upper distributor and exits form the lower collector. This ensures a uniform temperature profile on the surface of the radiator. In the case of cooling, an upper inflow may cause the water introduced to drop as soon as it flows into the radiator because of gravity. As a result, a short-circuit flow sets in on the connection side. The radiator surface is not cooled uniformly (see **Figure 5**). A short-circuit flow can be avoided by reversing the flow or increasing the mass flow.

The KUEHA project [11][1]

Future work: The previous theoretical findings on cooling using free heating surfaces/radiators are to be put to practical use in the context of the project. This requires proof of the fundamental effects and evaluation of their effects under practical conditions of use. Furthermore, it is to be examined to what extent the impact of these effects can be optimized by control engineering or planning measures. Regarding the installed radiator types, there should initially be no application

1 The sponsor of the research initiative is the Federal Ministry for Economic Affairs and Energy (BMWi) [1]. The short name KUEHA is derived from the German short title "Cooling with the existing heating system".

Partners of the project are the State Enterprise Saxon Real Estate and Construction Management (SIB) [4], the Kermi GmbH [2] and the Ohra Energie GmbH [3]. The project is supported by partners with excellent expertise in the practice of planning and management of buildings, in the development of radiators/heatsinks with the associated control systems and refrigerators, as well as in the field of energy supply.

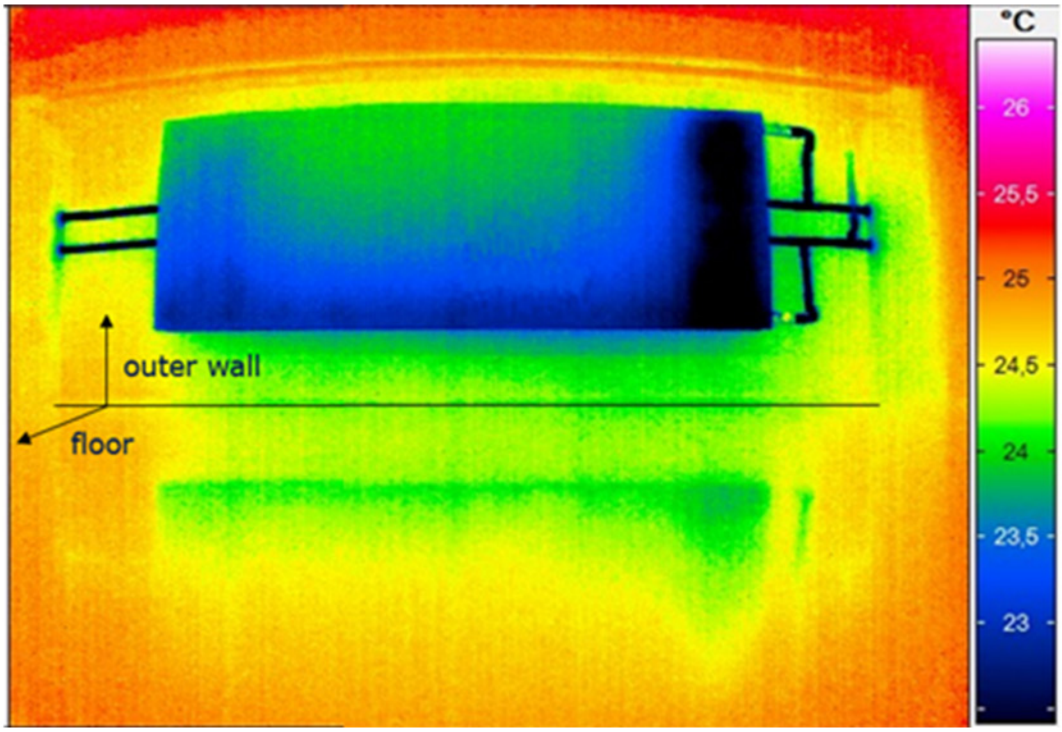

Figure 5. Thermography image of a short-circuit flow.

Figure 6. KUEHA - field objects. [11]

restrictions. However, as part of the project, design recommendations for improving the cooling effect are being developed.

The focus of the methodological approach is the monitoring of executed facilities. For this purpose, several field testing facilities will be determined within the scope of the project (see **Figure 6**). The objects were selected or rebuild with the objective that not only examining different space cooling systems but also to evaluate different types of cooling. The field studies are supplemented by investigations in a climatic room

[10]. The transferability of the measurement results to changed boundary conditions is examined with the help of the coupled plant and building simulation. Simulation tools are available for the detailed evaluation of the thermal conditions in the room, simulating the room air flow with high resolution. The field measurements will start in the summer of 2018. In [11] the authors will inform about the current status of the investigations. ■

Acknowledgment

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Project of HVAC systems for the meteorological station




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This project presents the three proposed design concepts of heating, ventilation and air conditioning systems for a new single-story government meteorological and housing building in the Diego Ramirez Islands (Islas Diego Ramirez) in Chile. It was created to participate in the 2017 Student Design Competition organized by American Society of Heating, Refrigerating and Air Conditioning Engineers. All design concepts were made in accordance with ASHRAE Standards, especially 90.1, 62.1, 55.1. The final aim of a thesis is to show the selection process of the best design option, based on a multi-criteria analysis, including Life Cycle Cost Analysis with a 50 years long Life Cycle. Considered design concepts shall address the following major design goals: low Life Cycle Cost, low environmental impact, comfort and health, creative high performance green design, synergy with architecture. The scope of study included creating the design of heating (including both room heating and preparing Domestic Hot Water), ventilation and air-conditioning systems for a given building.

Keywords: ASHRAE, heating, cooling, air-conditioning, mechanical ventilation, thermal comfort, concept design, BIM modelling, hourly analysis, life cycle cost analysis (LCCA)

The team from the Warsaw University of Technology has been awarded with the first-place prize at the 2017 Student Design Competition in the HVAC System Selection category. The competition is annually organized by the American Society of Heating Refrigeration and Air-Conditioning Engineers. It was the first time in history that a team from Poland participated in this competition. The team consisted of 4 students: Dagmara Ćwiek, Karolina Kowal, Tomasz Kolsicki and Bartłomiej Tokarzewski. The prize was handed out during the ASHRAE Winter Conference held in January 2018 in Chicago.

The students' task was to design the heating, ventilation and air-conditioning system for the meteorological station building in the Diego Ramirez Islands (Islas Diego Ramirez) in Chile, South America. The team was supposed to consider three different options and choose the optimal one, basing on a multi-criteria analysis, including factors like Low Life Cycle Cost (building's considered life cycle equalled 50 years), Low Environmental Impact, Comfort and Health, Creative High Performance Green Design, Synergy with architecture. The project was realized in compliance with American standards, especially 90.1, 62.1 and 55.1. The scope of study did not include designing water supply or sewage systems, it was also forbidden by the competition rules to interfere with the given attributes of the building envelope.

The building in the scope of study was a new, single-story, government meteorological and housing building. It included dwelling units for 8-people crew, office and a large car service hall along with a small garage, even though, in reality, Diego Ramirez Islands are inhabited and there is no infrastructure available there, all teams were supposed to assume that there are water and sewer district systems, natural gas and electricity grid available.

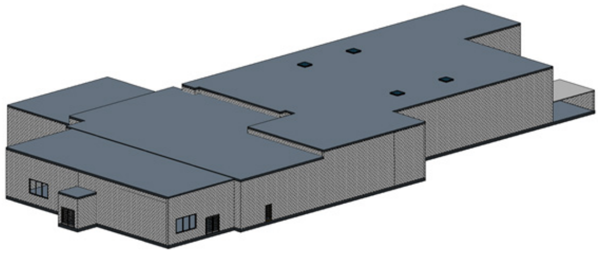

Figure 1. Meteorological Station Building 3D Model.

The climate of Islands is mild, with low DBT amplitude throughout the year. There is no clear boundary between summer and winter. Wind direction is focused and its speed is high enough to consider usage of wind generated energy. Due to geographical location and significant cloud cover, the values of solar radiation are relatively low, which suggests that using solar energy may transpire to be unprofitable.

Computer modelling

The team has created a parametric model of the building, in compliance with Building Information Modelling philosophy. The model contained information about the considered envelope, which was used for calculations and running detailed energy analyses. Students used *Integrated Environmental Solutions Virtual Environment (IES VE)* software for this purpose. It allowed them to create a dynamic, hourly analysis of all systems' behaviour during all year. Some calculations, were also handled manually in Microsoft Excel.

Baseline System

A baseline system was considered to compare all the other options to a basic and typically used one. This approach requires the designer to analyse all systems with the same design conditions. The baseline system was chosen in accordance with ASHRAE 90.1 Standard, considering the climate zone type and size of the building. The chosen system included Packaged Rooftop Air-Conditioner with fossil-fuel furnace. It covers building heat demand with a central hot-air heating system in a direct-fired technology. A Constant Air Volume system delivers warm air to all zones throughout the building. The system depends on a furnace, powered by natural gas. Domestic Hot Water is produced by Gas Storage Water Heater.

Option 1 – Brine-to-water Heat pump with sea water loop

Building is located on the Island surrounded by the Pacific Ocean. This fact created the possibility of using seawater as a source of energy for the heat pump. Main source of heat for this system is created by brine-to-water heat pump with sea water loop. An additional source of heat for the system is created by the server room. Heat recovery from the servers operating in the building has been applied.

Heat pumps pull heat out from the sea to heat the building, but to do so, heat pumps main component compressors need to be powered by the electricity. Electricity for the HVAC unit is supplied by the green energy coming from wind turbines and photovoltaic panels, but during the times when energy is not generated on site or energy demand is high, electricity is supplied from the grid.

The weather conditions on the island make it possible to effectively use wind turbines. The energy generated by the turbines supply the heat pump system that heats the building, as well as the electrical equipment in the building. This allows even greater reduction of primary energy consumption, which reduces the environmental impact and lowers the operating costs of the system.

Since the amount of renewable electricity produced is not constant and unrelated to the current demand of the building, energy accumulation was applied. When the amount of the produced energy exceeds the building's demand, it is possible to accumulate surplus energy, to use it later, for example during peak demand. This technology also creates the opportunity to use power from the grid only during periods of lower electricity prices, storage in the battery and consumption when the building's demand proves to be high.

Energy from renewable sources accounts for about 60% of the total energy demand of the building. As a result, the consumption of primary energy, produced using fossil fuels significantly decreases. It also allows reduction of greenhouse gas emissions, especially CO_2. However, a serious disadvantage of this solution is the large amount of refrigerant is used in the heat pump circuit.

Option 2 – Gas Heat Pump & Condensing Boiler

The system is based on a hybrid heat source – a gas-powered air-to-water heat pump combined with a condensing boiler. Heat source is equipped with advanced controls that automatically select the current most efficient way of operation. During warm days (outside temperature higher than 4°C a heat pump

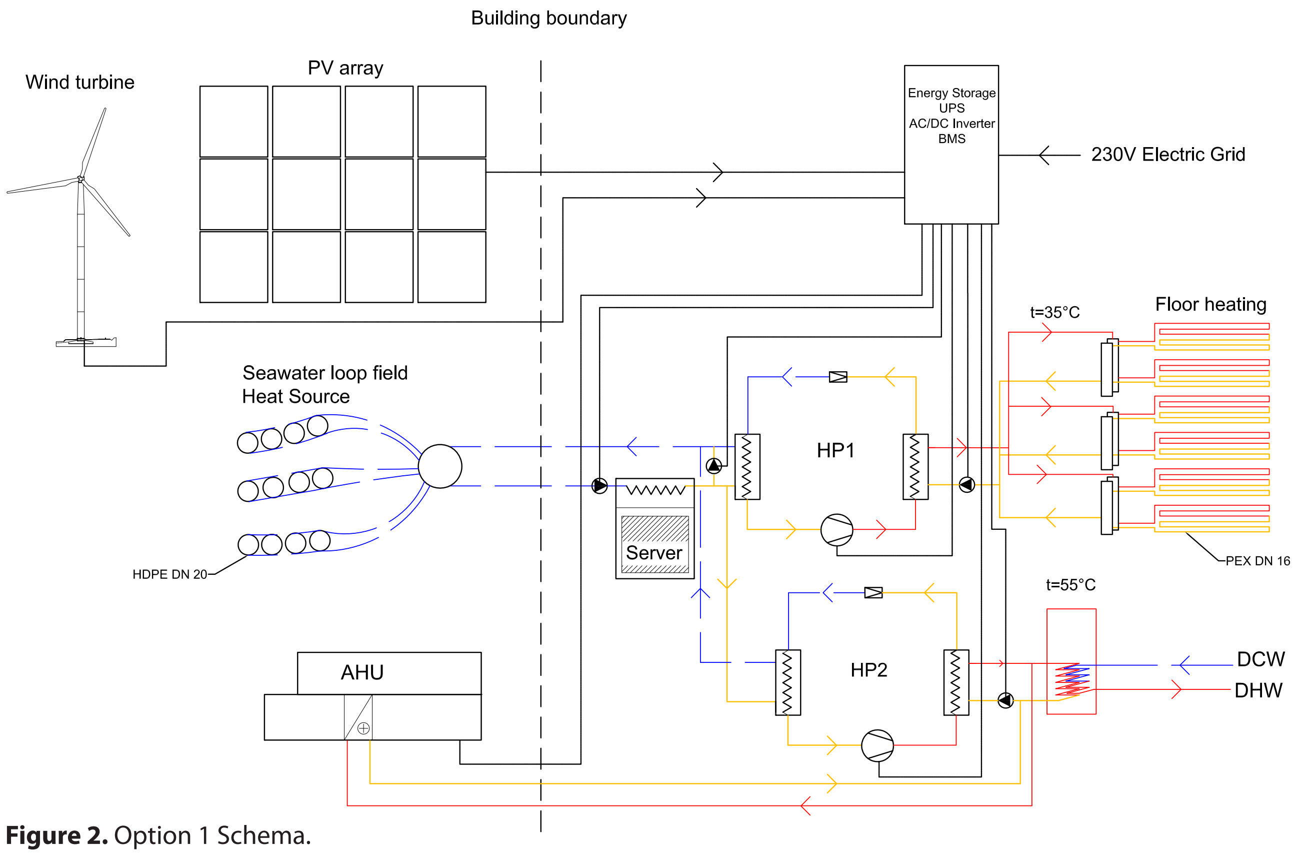

Figure 2. Option 1 Schema.

works efficiently, and its COP factor is high, so it works in a "heat pump only mode". As observed in considered weather data, in Diego Ramirez conditions it happens on 65% of year. When outside temperature falls (between –7 and +4°C), it automatically switches to a hybrid mode – a gas condensing boiler turns on and cooperates with a heat pump – it performs a supportive role. Device has also a third operation option – although, in given conditions it has a minor meaning. If temperature falls below minus 7°C it switches to a "boiler only mode" and this happens only for 11 hours a year what makes it almost unnoticeable. However, this system is flexible and could work efficiently even in lower temperatures, which is an advantage.

Gas boiler used in a hybrid device is a condensing one. It means that it recovers latent heat from exhaust fumes, rather than letting it directly to atmosphere, like in a conventional boiler. It allows this device to achieve efficiency as high as 97%.

The Heat Pump component of system contains R-410a refrigerant. It's widely used thanks to not being an ozone-depleting substance. However, it has a high Global Warming Potential. A disadvantage of this system is that it relies on a non-renewable energy source. GHP&CB system (option2 system) also involves using a refrigerant which is not fully environment neutral.

Additionally, thanks to combining two different appliances (a heat pump and a boiler) a total life expectancy of a hybrid device can get even doubled due to periodic heat source switching. Another advantage is that such systems are well known and easy to install, so it minimizes the risk of maintenance issues. It is important to notice that servicing and replacement of appliances is difficult on an isolated island.

Option 3 – Wind Energy Radiant Heating

In that option water systems were replaced by electrical heating. Wind turbines and photovoltaic panels supplied building with an electrical energy utilized to heat the building, domestic water and supply air. In case of peak demands, these renewable energy sources provide electrical energy simultaneously with grid.

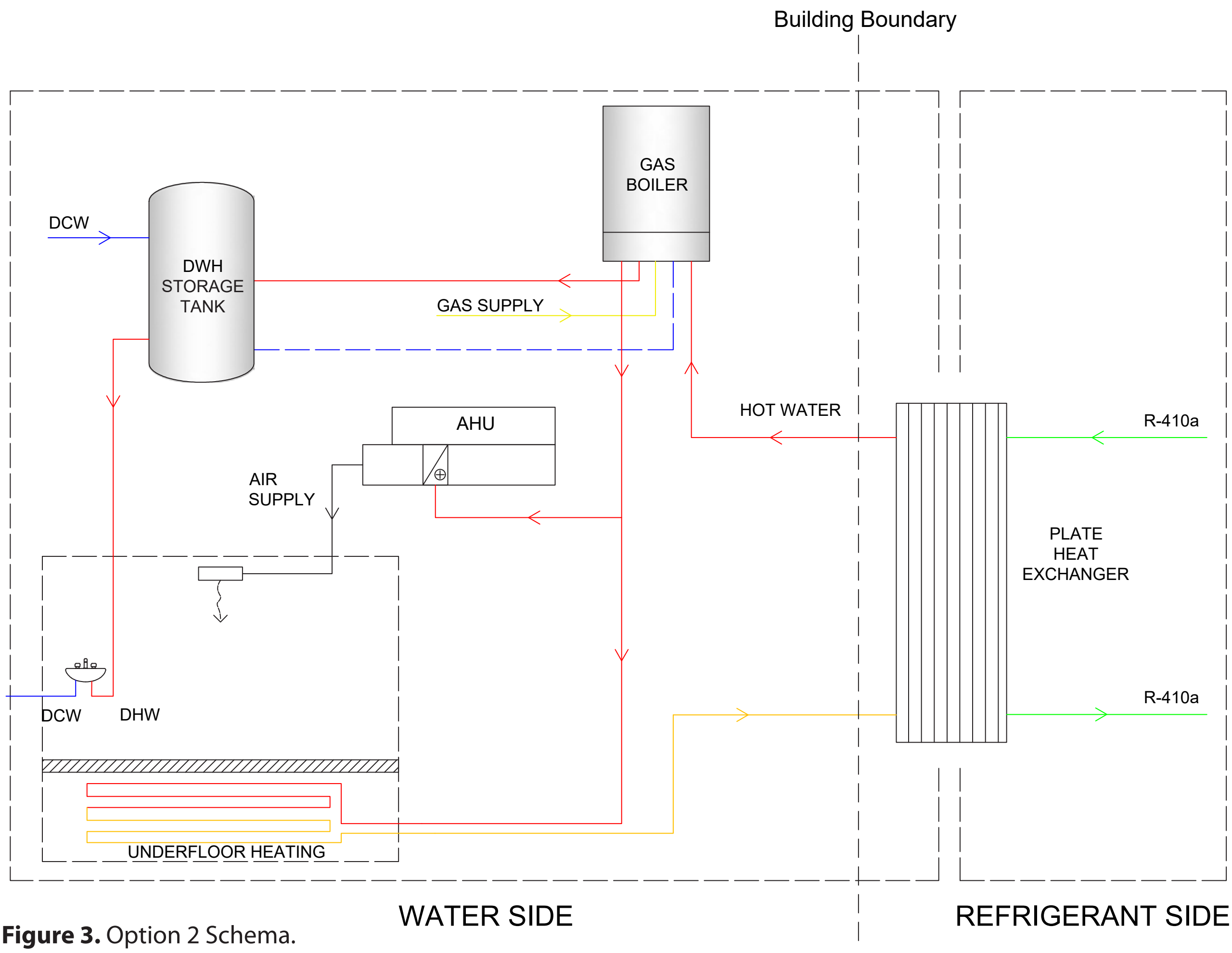

Figure 3. Option 2 Schema.

Nevertheless, it is a cost-effective solution. Moreover, excess energy can be sold to the grid, which compensate all expenses intertwined to on-peak periods.

Heat is distributed to spaces by electrical system. Electrical energy is transferred to heat energy by infrared panel heaters. To be precise, due to temperature difference these devices are radiating infrared heat through the air.

The disadvantages of this solution are high Initial Cost and noise generated by the turbines. It is important to carefully locate turbines on a site, preserving a proper distance from the building to minimize acoustic discomfort. The large size of turbines is also a significant factor, it makes them tamper with the natural landscape. On the contrary, the main advantage of the Wind Energy system is a big share of renewable energy – it leads to lowering CO_2 emissions and the Operational Cost.

Data Center

Another important part of the project was designing a system serving a small Data Center located in the building. Trying to find a solution that would be eco-friendlier and energy-efficient than conventional ones, the team decided to apply a two-phase immersion cooling, instead of widely used traditional air-conditioning systems. Servers are placed in semi-open containers containing directly a special fluid with a low boiling point. They are submerged in the fluid, so when they get warm while operating, the fluid starts to boil and cools down the electronic equipment. The fluid turns to vapour and due to buoyancy, it raises to the top of container and meets the condenser surface, where it turns to fluid again and passively recirculates to the bottom. The cycle is repeatable and doesn't require any external energy usage to keep the fluid circulating. This process happens under atmospheric pressure. Immersion cooling works with HFE fluids – they do not conduct electricity and have low Global Warming Potential, so it makes them environmental-friendly. This solution doesn't require preserving any specific conditions in the server room volume, just like in traditional systems. It doesn't occupy large volume of space, so it allows to locate server units in a more efficient, denser way. Immersion cooling allows achieving a significant energy efficiency – PUE can get as low as barely 1,02.

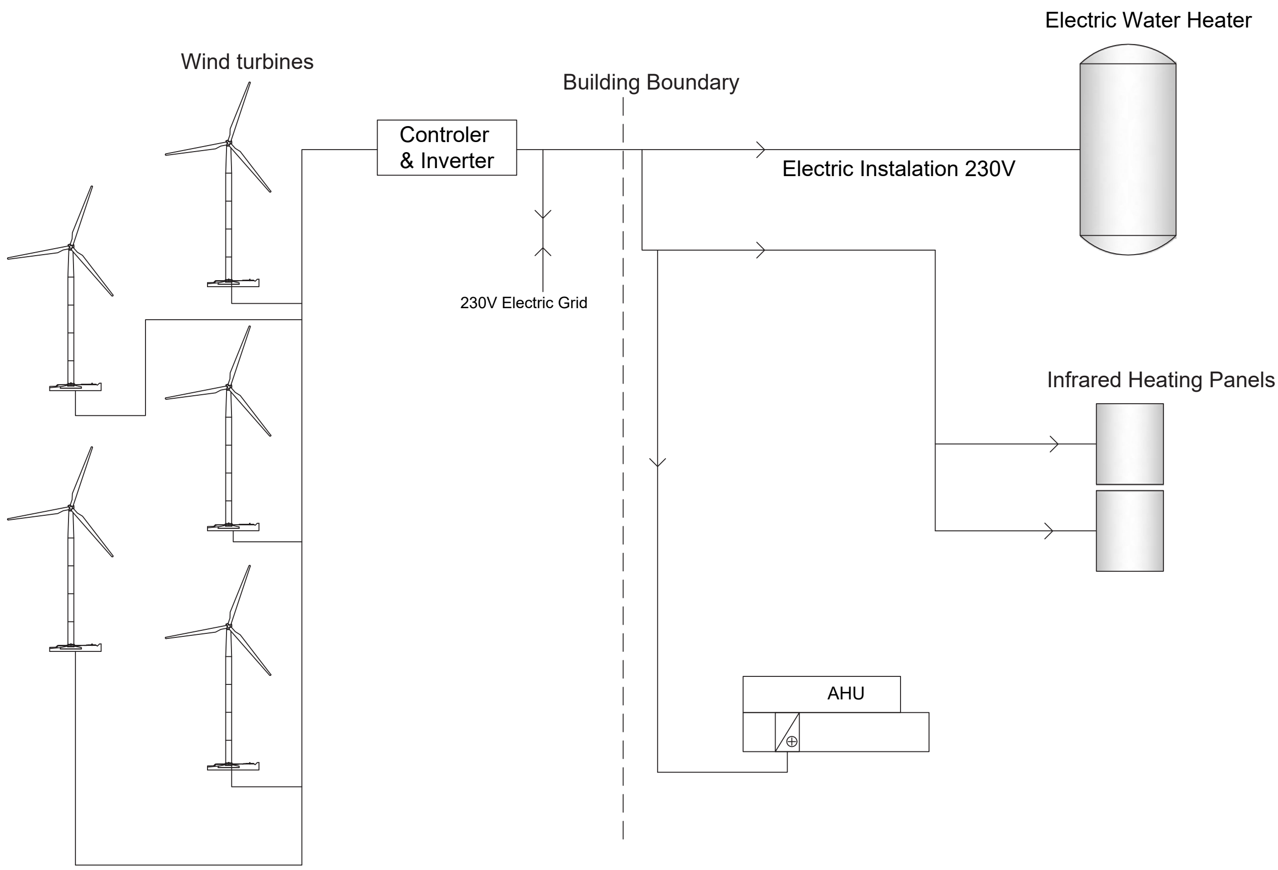

Figure 4. Option 3 Schema.

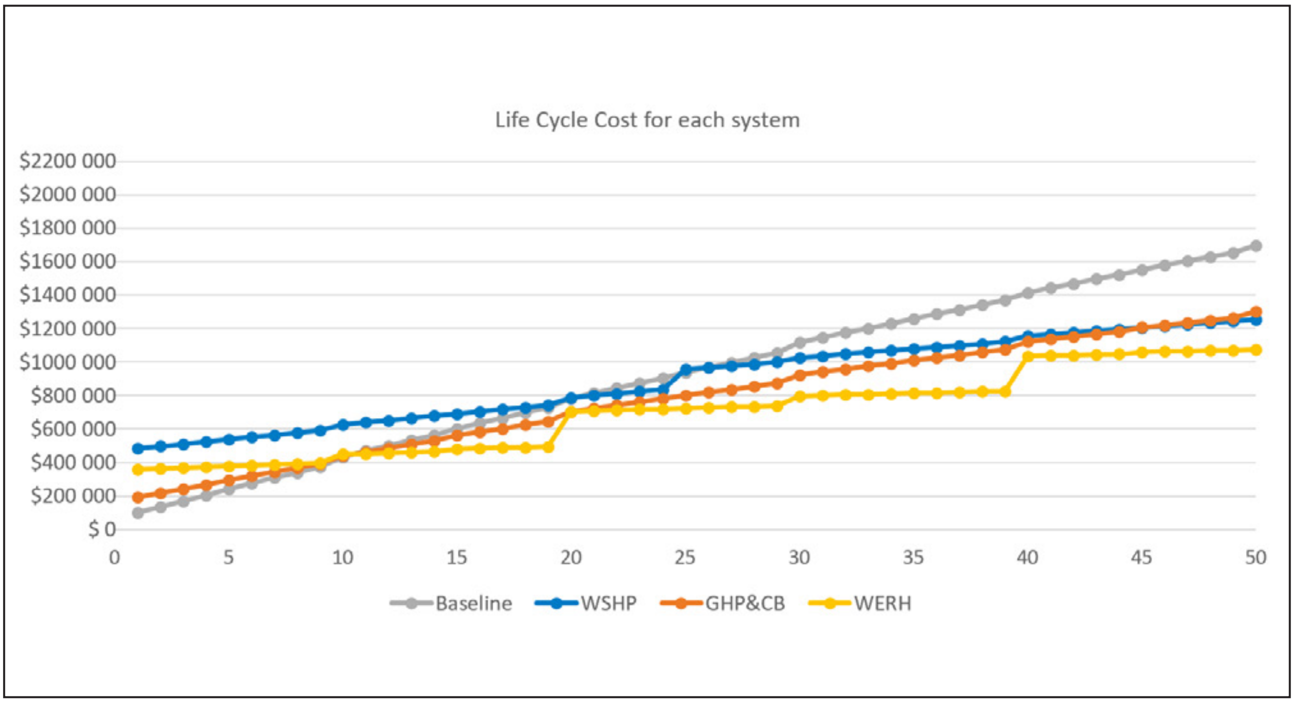

Figure 5. Lifecycle Costs.

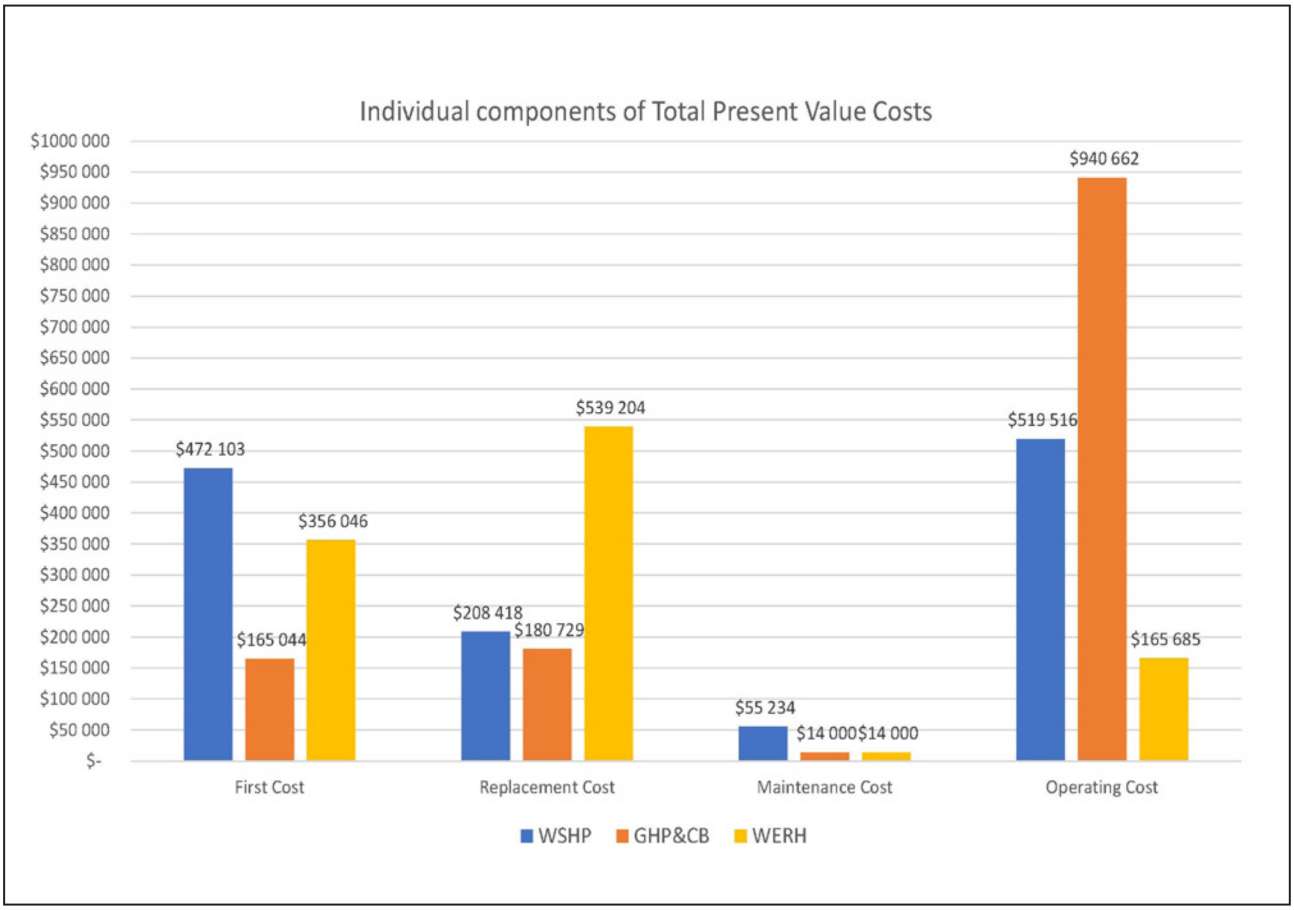

Figure 6. Components of Present Value Costs.

Choosing the best option

To choose the suitable system for considered meteorological station, the team has analysed a 50 year long building lifecycle. The costs of operating all of 3 concept systems were compared with the cost of the baseline option, including both initial and maintenance & operating costs. It was observed that WSHP system (Option 1) had the highest Initial Cost, while GHP&CB's (Option 2) was the lowest. WERH system (Option 3) has the highest Replacement Cost, because of using expensive wind turbines, that need to be replaced. The most evident difference between systems is observable in Operating Costs, where GHP&CB transpires to be the most expensive of all, due to usage of non-renewable, expensive energy source. At last, WERH system was estimated to have the lowest life cycle cost in general. The other systems are more expensive, and their costs have similar values, comparing one to another. The most expensive of all considered options was obviously the baseline system.

Moreover, all of systems were judged in accordance with the LEED v4 rating system. Only credits applicable to HVAC design, that matched the scope of study were taken into consideration.

All these factors, along with the quality of fulfilling major design goals, were taken into consideration when choosing the optimal solution. A multi-criteria matrix of evaluation was created to determine the best system.

The optimal solution – Wind Energy

Finally, it was concluded that the Wind Energy Radiant Heating is the optimal option. It gained the biggest number of points in multi-criteria analysis matrix created by the team and by the LEED Rating System. This system showed a 37% overall cost improvement over the Baseline, which is the best result of all considered alternatives. This system fulfils all design goals specified by the team. It has the lowest Life Cycle Cost from all considered options. Comfort of Indoor Environment is maintained. System fully meets sustainability requirements – is energy efficient, low-carbon and environmental-friendly. It relies on renewable energy sources – wind and solar power – they are main source of energy for the building, making it almost emission free. The only non-renewable resource consumed in this design is electricity from the power grid, used at the moments of high building power demand. However, it is used in an acceptable amount, in an efficient way, thanks to load shifting and energy accumulation strategy.

Conclusions

Thanks to incorporating modern technologies, following the rules of energy conservation and sustainable usage of natural resources, it was achievable to fulfil all the design goals. It is also crucial to take into consideration the whole lifecycle of the object, since the Initial Cost does not decide about the outcome of the analysis. It is also important to use System Benchmarking analysis, rather than focusing on a single solution, because as proven in this report, differences between systems are significant enough to be considered in a design process. One of the most important aspects of the design process was using BIM technology – it allowed the team to gather, analyse and manage all data about the designed building in an efficient way.

At the end, it is critical to continue an approach presented in the project during the following building life cycle phases – including construction and exploitation. Proper commissioning process must be ensured. Only such approach allows full usage of the proposed design potential. ■

Literature

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ANSI/ASHRAE Standard 55-2013 – Thermal Environmental Conditions for Human Occupancy

ANSI/ASHRAE Standard 62.1-2016 – Ventilation for Acceptable Indoor Air Quality

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ASHRAE Standard 34-2013 – Designation and Safety Classification of Refrigerants

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LEED v4 for Building Design and Construction

Articles

Evaluation of the Performance of Phase Change Materials in relation to Balanced Distribution of Heating Energy Cost in Residential Buildings

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A significant part of the total energy consumed in Turkey is used to heat residential buildings. Various measures have been made mandatory by regulation to reduce energy consumption for heating purposes and achieve a balanced cost distribution. The heat cost allocator system, one of the mandatory measures has been implemented in residential buildings since May 2, 2012. Since different indoor temperatures are observed in zones in buildings when heat cost allocator is used, heat is transferred through inner walls. Phase change materials which reduces heat transfer with the latent heat storage (LHS) system and with their low thermal conductivity can possibly reduce the fluctuations of the indoor air temperature of the zones and create a balanced heating energy cost [1][2]. In this study, application of phase change materials (PCM) on inner walls, external walls, floors and roof of a zone was evaluated using modelling and simulation.

Keywords: Phase change materials (PCM), heat cost allocators, heating energy saving, envelope, directing, zone organization.

Eighty-two per cent of the energy consumed in buildings is used for heating. Therefore, given our dependency to export energy resources, reducing the energy spent for heating purposes in buildings has become a necessity. Reducing heating energy expenditure in buildings is possible by making correct decisions for the design variables affecting the heating energy load of the building [3]. The most important design variable that directly affects thermal comfort and energy consumption is the building envelope. The objective of using heat cost allocator in Turkey is to ensure that users pay for only the amount of heating energy they actually consume. However, due to difference in directions and locations of zones, energy consumed in each zone differ significantly from others. As a result of this, heat is transferred between zones that

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have different indoor temperatures and unbalanced heating energy consumptions become inevitable[4]. Thermal energy storage capacity of PCMs is used to reduce energy consumption for heating in buildings. Latent heat is the heat that the material receives from or releases to the environment during phase change [5]. PCMs are materials that store thermal energy as latent heat.PCM storage systems allow conservation of heat on the surfaces they are applied and therefore they are used in buildings for their high energy storage capacities.

In this study heating energy generated by applying PCMs on inner walls, external walls, roofs and floors was calculated using a simulation program and analyzed according to different locations of apartments.

Properties of Phase Change Materials

We often see heat storage systems in traditional architecture together with the concept "thermal mass". Thermal mass absorbs heat all day, stores and release the heat to the interior by delaying the effects of outdoor climatic elements and reducing their amplitude thus preventing over heating of the interior spaces [2]. Time lag and decrement factor refer to the heat storage and insulation capacity of a building component. PCM can be defined as contemporary version of thermal mass. PCMs show varying performances depending on to the climate types [3]. Thermal energy which PCMs store day and night and release to the interiors is known to have reducing effect on not only heating energy consumption in winter but also cooling energy consumption in summer. Based on the studies, PCMs are known to show the best results in areas where temperature between day and night is bigger. [6]. In hot climatic regions, with the heat they store during night, PCMs can optimize indoor temperature. Thus, it reduces cooling requirement in hot dry climatic regions. However, in cold climatic regions their working principle is to prevent a decrease in indoor temperature, therefore, PCMs tend to reduce the energy spent for heating in cold climatic regions [5][7]. Thermal energy storage methods are classified into two groups, the first being sensible heat and the other is latent heat. Sensible heat is the storage of energy by using the heat storage capacity of a material, either solid or liquid. By increasing the temperature of the heat storage material, the energy is stored as sensible heat. The ambient temperature changes during sensible heat storage. Latent heat is the heat that the material receives from or release to the environment during phase change. Storage capacity required for latent heat storage methods is smaller than that required for sensible heat [3][8].

Heat storage capacity of PCMs per unit mass or unit volume is higher than the storage capacity of sensible heat storage materials. Since PCM's temperature remains almost constant during the energy storage process, it is quite suitable for energy storage and recovery applications at a constant temperature [5][9].

Another thermophysical property of PCMs is their melting and solidifying temperature. Melting temperature quantifies the point at which a material liquefies (becomes completely liquid). The most suitable melting temperature for PCMs is the temperature which is the closest to the indoor temperature. Solidifying temperature quantifies the point at which a material solidifies (becomes completely solid). Based on the findings of the applications, the most suitable PCM is the one which has the melting temperature which is the closest to the indoor temperature [4][10].

Evaluation of the performance of Phase Change Materials in relation to balanced distribution of heating energy use in residential buildings

In this study, several options for building envelopes were developed that can be used to reduce and balance heating energy consumption. These options were applied on a building in Istanbul using Design Builder program. Design Builder is a user friendly visual interface program that uses Energy Plus program as the simulation motor, which is an integrated simulation program.

Determination of Building Specific Variables

Heating energy efficiency of phase change materials was evaluated on a three-storey building with 12 zones (4 zones on each floor) and a flat roof with a floor area of 10x40 metres on a flat land in Istanbul. The transparency ratio of the building on south and north façades was accepted as 45%. The zones in which the evaluation is carried out are shown in **Figure 1**.

In order to evaluate PCM performance, building envelope alternatives did not have PCM in the first stage whereas PCM was applied in the second stage. The

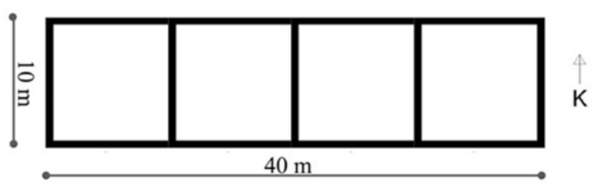


Figure 1. 10x40 m building used in the evaluation study.

following alternatives were created based on the location of the PCM applications. In the alternatives where PCMs are applied on inner walls and inner floors, they are applied on both sides of the building components.

A1. Application without PCM
A2. PCM application on exterior walls, ground floor and roof
A3. PCM application on external walls, inner walls, ground floor and roof
A4. PCM application on external walls, inner floors, ground floor, and roof
A5. PCM application on external walls, inner walls, inner floors, roof and ground floor

The building envelope layering details are shown in **Table 1**.

Calculation Variables

In this study the advanced modelling tool, Design Builder 5.0.3.007 application software was used to evaluate energy efficiency of phase change materials by applying them on building components. Design Builder is a dynamic thermal simulation software that uses "finite difference method". Thus, it is possible to analyse thermal performance of phase change materials. In calculations, the comfort value for indoor air temperature was accepted as 21°C for heating and 19°C as the lower limit value to turn on the heating system; as 26°C for cooling and 28°C as the upper limit value to turn on the cooling system.

Calculation of Heating and Cooling Loads for Different Zones with Different Building Envelope Alternatives

In the first stage of the calculations PCM was not used on any wall (without PCM-A1). In other alternatives with PCM, 3 cm PCM was used on all exterior walls, inner walls, floors and roof. Based on the calculations, heating energy loads were compared with each other to compare energy efficiency of different zones in the building.

When energy consumptions for heating were evaluated, heating energy consumption was lower on the ground floor and first floor in zone 2, zone 3, zone 6 and zone 7; and higher in Zone 9 and Zone 12 on the second floor in all alternatives. The alternative 1 without any PCM application had the highest heating energy expenditure in all zones. When Alternative 2 with PCM application on the whole building envelope is used, the resultant heating energy consumption was always lower than the alternative without any PCM application (alternative 1). However, when PCM was applied on floors and inner walls and other alternatives with varying PCM applications are compared, the lowest heating energy consumption was in zone 1, zone 2, zone 3, zone 4, zone 5, zone 6, zone 7 and zone 8 in Alternative 5. The lowest heating energy consumption in Zone 9, zone 10, zone 11 and zone 12 was achieved in Alternative 3. When PCM was applied only on inner walls i.e. when heat loss between horizontal zones was prevented, (alternative 3) heating energy consumption decreased in zone 9, zone 10, zone 11 and zone 12 on the upper floors but increased in other zones (zone 1 to zone 8) and the lowest heating energy consumption was in zone 2 and zone 3. When PCM was applied only on inner floors i.e. when heat loss between vertical zones was prevented, (alternative 4) heating energy consumption increased in zone 9, zone 10, zone 11 and zone 12 on the upper floors but decreased in other zones (zone 1 to zone 8) the lowest heating energy consumption was in zone 6 and zone 7. When PCM was applied both on the entire building envelope and on inner floors and inner walls (alternative 5), heating energy consumption increased in zone 9, zone 10, zone 11 and zone 12 on the second floor but minimum consumption was achieved in all other zones leading to most favourable conditions. Heating loads of all 12 zones in the building according to their locations are shown in **Figure 2**.

Heating, cooling and total energy consumptions for the entire building are shown in **Figure 3**; a,b and **Figure 4**.

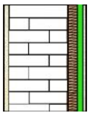
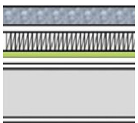
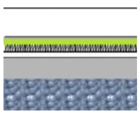
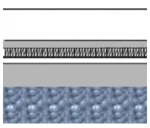
The best result for reduced heating energy consumptions in the entire building was obtained in the alternative A5. The alternative A5 where the lowest heating energy was achieved showed 8.6% better performance than A1, 3.74% than A2, 4.14 than A3, 0.77% than A4.

The best result for reduced cooling energy consumptions in the entire building was obtained in the alternative A5. The alternative A5 where the lowest cooling energy was achieved showed 10.1% better performance than A1, 9.47% than A2, 10.48 than A3, 1.45% than A4.

The best result for reduced energy consumptions in the entire building was obtained in the alternative A5. The alternative A5 where the lowest total energy consumption was achieved showed 9.18% better performance than A1; 6.01% than A2, 6.66 than A3, 1.03% than A4.

In the entire building, the alternative A5 had the best results for both the heating and cooling periods.

Table 1. Layering details of the building envelope.

Without PCM	External Wall	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Gypsum Plastering XPS Extruded Polystyrene Brick Cement/Plaster/Mortar	0.02 0.04 0.24 0.01	0.72 0.034 0.72 0.4	1860 35 1920 1000
With PCM	External Wall	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Gypsum Plastering PCM/BioPCM® M51/Q21 XPS Extruded Polystyrene Brick Cement/Plaster/Mortar	0.02 0.03 0.04 0.24 0.01	0.72 0.2 0.034 0.72 0.4	1860 235/J/kg·K 1970 35 1920 1000
Without PCM	Inner Wall	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Gypsum Plastering Brick Gypsum Plastering	0.01 0.1 0.01	0.4 0.72 0.4	1000 1920 1000
With PCM	Inner Wall	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Gypsum Plastering PCM/BioPCM® M51/Q21 Brick PCM/BioPCM® M51/Q21 Gypsum Plastering	0.01 0.03 0.24 0.03 0.01	0.4 0.2 0.72 0.2 0.4	1000 235/J/kg·K 1970 1920 235/J/kg·K 1970 1000
Without PCM	Flat Roof	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Aggregate-sand-gravel Mastic Asphalt XPS Extruded Polystyrene Bitumen/ Felt Layer Polyethylene Concrete Gypsum Plastering	0.06 0.002 0.06 0.003 0.003 0.15 0.02	1.30 0.19 0.034 0.50 0.33 1.13 0.4	2240 950 35 1700 920 2000 1000
With PCM	Flat Roof	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Aggregate-sand-gravel Mastic Asphalt XPS Extruded Polystyrene PCM/BioPCM® M51/Q21 Bitumen/ Felt Layer Polyethylene Concrete Gypsum Plastering	0.06 0.002 0.06 0.03 0.003 0.003 0.15 0.02	1.30 0.19 0.034 235 0.50 0.33 1.13 0.4	2240 950 35 235 / J/kg·K 1970 1700 920 2000 1000
Without PCM	Ground Floor	d(m)	Conductivity(W/mK)	Density (kg/m³)
	Gravel Concrete Bitumen/ Felt Layer XPS Extruded Polystyrene Gypsum Timber Cover	0.15 0.10 0.006 0.04 0.03 0.14	0.36 1.4 0.5 0.034 1.13 0.14	1840 2100 1700 35 2000 650
With PCM	Ground Floor	d(m)	Conductivity(W/mK)	Density (kg/m³
	Gravel Concrete Bitumen/ Felt Layer PCM/BioPCM® M51/Q21 XPS Extruded Polystyrene Gypsum Timber Flooring	0.15 0.10 0.006 0.03 0.04 0.03 0.14	0.36 1.4 0.5 235 0.034 1.13 0.14	1840 2100 1700 235/J/kg·K 1970 35 2000 650
Without PCM	Inner floor	d(m)	Conductivity(W/mK)	Density(kg/m³)
	Plaster Concrete Plaster	0.01 0.1 0.01	0.4 1.13 0.4	1000 2000 1000
With PCM	Inner floor	d(m)	Conductivity(W/mK)	Density(kg/m³)
	Plaster PCM/BioPCM® M51/Q21 Concrete PCM/BioPCM® M51/Q21 Plaster	0.01 0.03 0.1 0.03 0.01	0.4 235 1.13 235 0.4	1000 235/J/kg·K 1970 2000 235/J/kg·K 1970 1000

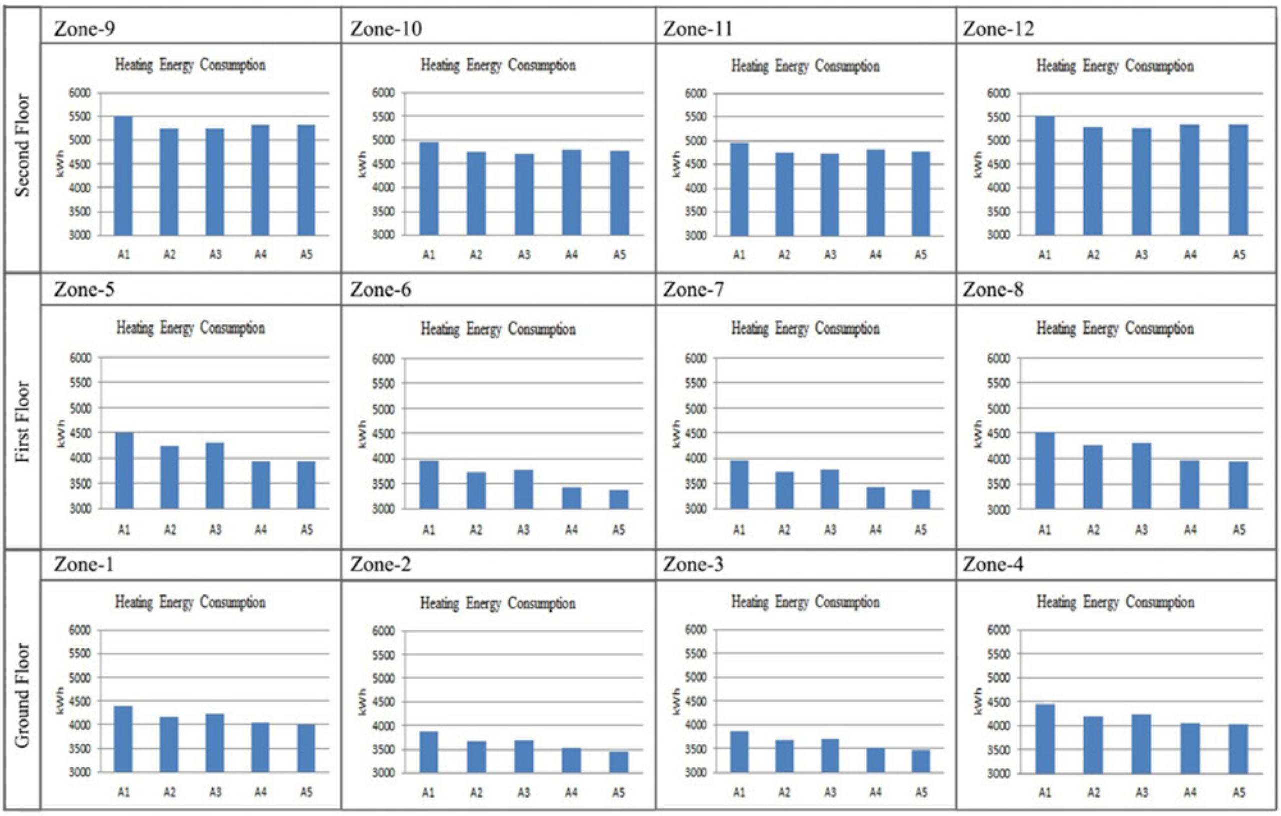
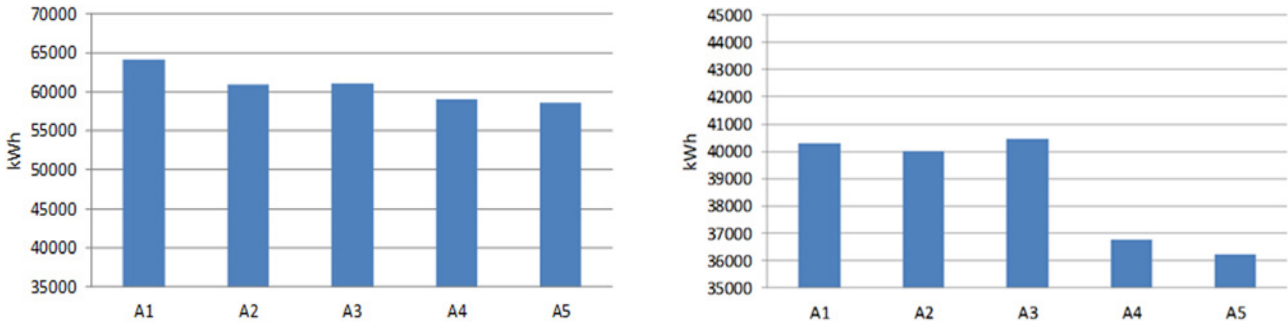
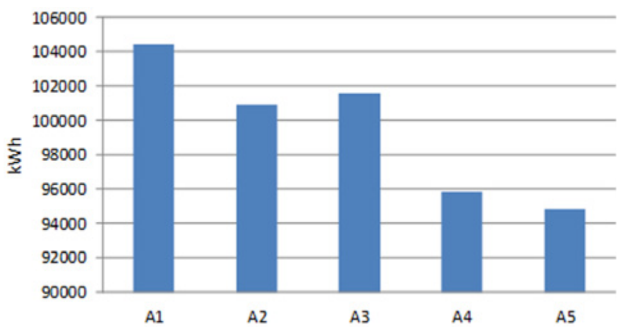


Figure 2. Heating energy consumption of different zones in the building



a) Heating energy consumptions **b) Cooling energy consumptions**

Figure 3. Variations in annual energy consumption in the building with different building envelope applications.



Total energy consumption

Figure 4. Variations in annual total energy consumption in the building with different building envelope applications.

Conclusion

When analysing the current statistics of energy consumption today the energy used in buildings has a significant share in the total energy consumption. This situation should be evaluated both in relation to energy consumption costs and eco-friendly building design criteria.

- In this study, Phase Change Materials which are considered to be contemporary alternatives to thermal mass which is the conventional heat storage system were evaluated. Based on the findings of the study, the contribution of the use of PCMs in different building components to the building's energy consumption performance was comparatively evaluated. When correct decisions about design are taken, PCM seems to contribute to the reduction of total annual energy consumption in buildings. The findings of the study are summarized below:
- The reason why some zones have minimum energy consumption is the fact that other zones with less favourable conditions surrounding them consume more energy which they cannot control due to their positions and larger external walls.
- The zone with minimum energy consumption cannot possibly have minimum energy consumption without the apartment with highest energy consumption. In other words, the zone with the best conditions can only have these best conditions as a result of the existing conditions of other zones. Therefore, energy consumption values in the zones as a result of the use of heat cost allocators are not the result of users' preferences but due to the positions of the zones in the building.
- When we try to balance the difference in heating energy consumption of zones due to the use of heat cost allocators, we saw that single type of application could not provide balanced comfort conditions in all apartments and different measures were required for different zones.
- When PCM was applied on exterior walls, inner walls, inner floors, ground floor and roof (A5) low energy consumption was achieved both separately in every zone and in the building as a whole. Therefore, it can be suggested that PCM applications can decrease unbalanced heating energy consumptions that occur when heat cost allocators are used.
- If the heat loss that occurs when PCM is applied on inner floors and inner walls is evaluated specifically for each zone, zone specific improvement alternatives can be created depending on the positions and external walls of zones.
- PCM's contribution consumption performance was observed to be higher in cooling period. Therefore, for PCM applications, the climatic region (cooling priority / heating priority) in which the building is in should be taken into consideration.

For future studies; PCM performance evaluations can be diversified by using different design criteria and PCM's areas of use and properties can be improved. Thus, a variety of solutions can be created to reduce energy consumption. ■

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Active Room-Human Feedback System: Design and Discussion

A set of communicating sensors with a microcomputer is designed to enable an interaction between the room and the occupant through a dynamic feedback system and easy-to-understand signals. This approach represents a method of using the new advances in microcontroller technology to promote indoor air quality especially in residential buildings.

Keywords: Eco-Feedback, Information and communication technology, CO_2-meter, Human-Room Interaction

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People in industrialized societies spend most of their lives indoors. In the past decades, energy saving measures have led to the construction of airtight buildings. This can negatively impact the indoor air quality by allowing a build-up of air contaminants within a building section if sufficient ventilation is not provided. In residential buildings in Germany the dominant mode of ventilation is natural ventilation through hand operated windows. Healthy indoor air depends on the rate of delivering fresh air to the environment and also on the indoor production rate of the contaminants. Especially in heating season an excessive ventilation time or an incorrect ventilation type can result in higher heating energy consumptions, whereas a less-than-necessary ventilation time leads to an accumulation of contaminants in a room and therefore causes dissatisfaction of the occupants.

Poor indoor air quality (IAQ) in residential buildings can also have direct economic drawbacks. An increasing number of employees working from their homes signify the economic importance of the IAQ in residential buildings. Better IAQ results in more productive and happier occupants. While it is difficult to exactly quantify these benefits, there is continuing evidence of higher productivity in areas with better IAQ.

The sensitivity towards the actions controlling air quality is very diverse. About 59% of Europeans seem to lack information about the air quality issues in their country [1]. The survey was conducted mainly to assess the topic of general air quality, but it gives an impression of the number of people who may also be uninformed about the topic of IAQ in their homes.

Many studies have shown the effectiveness of feedback systems in persuading occupants to have a more IAQ-aware and energy-efficient ventilation in their buildings (see e.g. [2] and [3]). The advantages of feedback systems are twofold. They represent a low-cost method to promote efficient behaviour and therefore decrease energy consumption, and behavioural persuasions are less likely to produce the undesired rebound effect.

In most cases feedback is carried out through information campaigns and printed media, which address the general consumer and aim at listing and describing all relevant cases of efficient behaviour. With the advent of modern low-cost sensors and communication, as well as data processing technology, there is an opportunity for a dynamic and active feedback system. The purpose of this study is to provide the proof of concept for a personal feedback system using low-cost sensors with a controller unit to increase awareness of the state of the IAQ and to promote better indoor air quality, and efficient ventilation behaviour in naturally ventilated rooms among occupants in residential buildings.

System description

The ambient status is gathered by a set of sensors that relay data to a single-board computer (Raspberry Pi with a USB power source) where the processing and storing of the data are carried out using an open source robust data collection and automation software. The data is stored locally on a memory disk and on an external hard drive for further analysis. The concept of this system does not introduce actuators like in classical smart home systems therefore eliminating the related investment, maintenance and operational costs. The system acts as a suggestion platform and actively provides feedback to the occupants. **Figure 1** shows the schematic of the design principle.

The recorded data includes temperature, relative humidity, CO_2 concentration, illuminance and occupant presence. Also, the duration of certain occurrences (such as the duration of a temperature drop, or open window status or the time it took for the occupant to react on the recommendation) can be recorded. These data can generally be used to give feedback in the areas of lighting, window shades' status, heating and ventilation. The setup is compact and can be placed near the sitting area in a living room or on the work desk in a home office. In the current stage, the feedback rules are kept simple and straight-forward. The recommendations are given using messages on displays, optional short beeps and coloured LEDs. **Figure 2** demonstrates the test values of the CO_2 concentration, the type of the display used and the possibility of input parameters through the software used.

Feedback possibilities that can be achieved using these sets of sensory data are very diverse and still in development. In the following, an example of active IAQ-feedback on efficient natural ventilation behaviour is described.

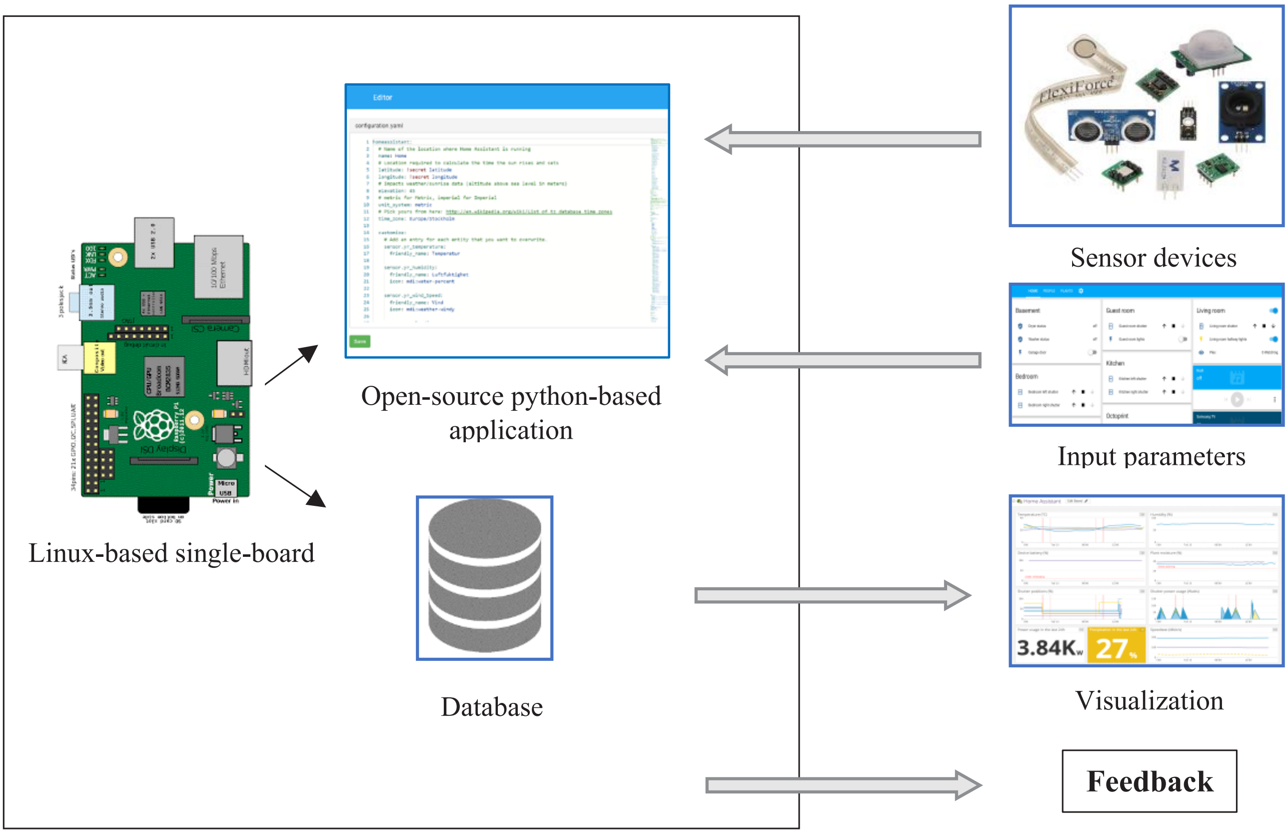


Figure 1. Schematic of the design principle.

Efficient natural ventilation habit

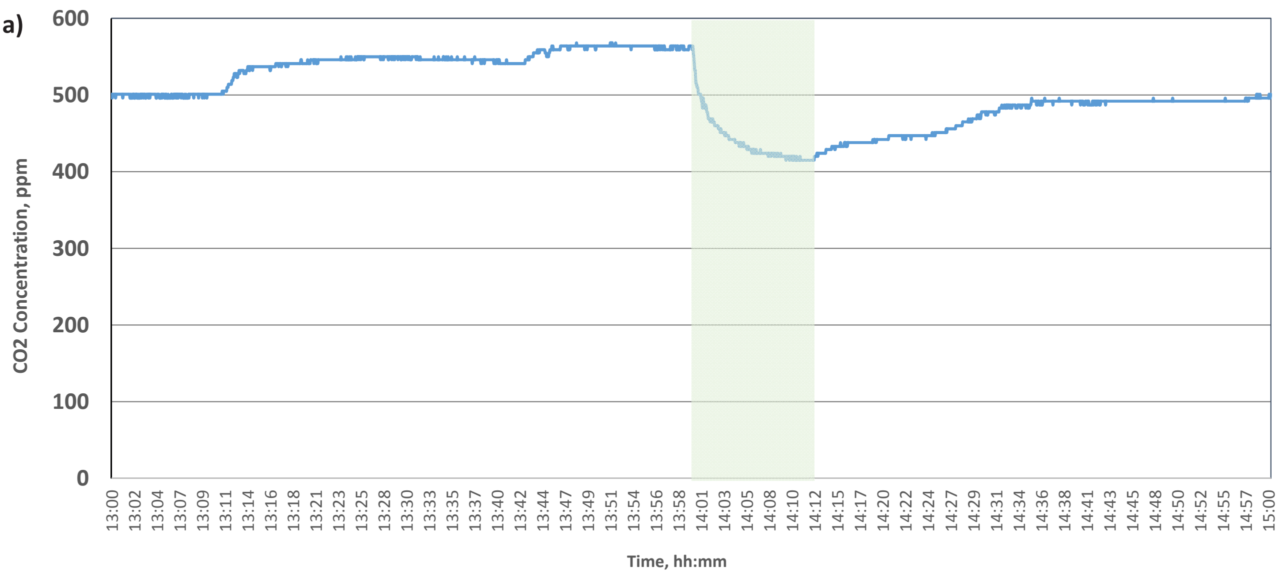
In this study, the basis of identifying the quality of indoor air is the CO_2 concentration. There are two operational modes for the IAQ-Feedback: "continues monitoring" and "feedback on demand". In both modes, an average is taken every minute from continuous measurements. The value is used in the following feedback algorithm of the "continues monitoring" mode and also stored for further analysis.

Whenever the value raises above 1000 ppm the feedback device performs a short beep and using its displays, gives a recommendation on the necessity of acquiring fresh air through fully opening the windows and a hint on closing the radiator valves. If the concentration value continues to increase, another beep at 1500 ppm will alert the user(s). At the concentration of 2000 ppm a red light emitting diode (LED) points out the importance of conducting ventilation with blinking and subsequent on-status. If the system assesses a drop in the CO_2 values, the red LED will go off.

A beep is provided when a concentration of 700 ppm is reached as a sign of sufficient air quality and the display message will vanish. In this design, the limits of the CO_2 concentration follow the Pettenkofer value and the recommendation of the German environmental agency (UBA) for a traffic lights concept for schools. These limits can be adjusted as input parameters.

In "feedback-on-demand" mode the feedback on the CO_2-based quality of the room air is only given when the user asks for feedback by pressing a button. In the background, however, the concentration measurements are carried out continuously. If the feedback-on-demand button was not used on one day or if the CO_2 concentration values were above 1000 ppm, a short

a)



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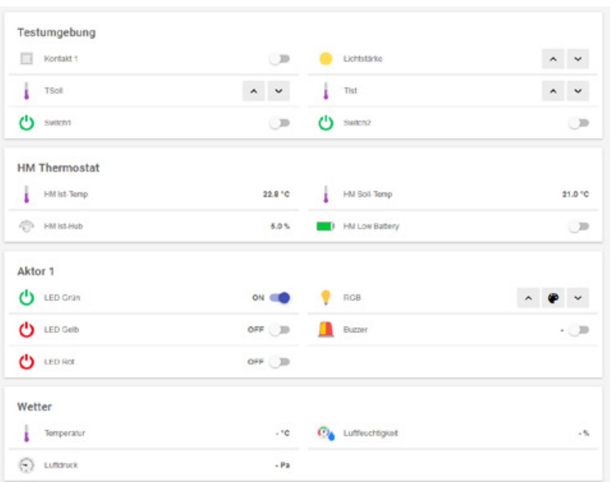

c)

Figure 2. a) Test values of the CO_2 concentration. b) Possibility of input parameters. c) Prototype display used for message communication (© RaspberryPi)

report will mention the number of minutes with a CO_2 concentration above 1000 ppm on the next day.

Discussion

Feedback systems on CO_2 can also represent a low-cost solution to increase the energy efficiecny in resdential buildings, since a fundamental factor in energy-efficiency of heating a household is the behaviour of the occupants, particularly how they ventilate rooms. This approach belongs to the category of behavioural interventions. A recent study also showed that a 'CO_2-meter' can change user's behaviour and improve indoor air-quality [4].

Furthermore, surveys have shown that a determining portion of the society in Germany is still feeling 'uneasy' with the increasing amount of automated processes in their homes [5]. Some mention that they would like to have the feeling of control over the events more often. The product resulting from the prototype in this study can represent a solution for this part of the society to still benefit from the advantages of the modern technology to receive environmental feedback, yet keep the decision-making power for themselves.

It is important to remember that the feedback system does not fully replace the decision-making or judgment ability of the occupant. It suggests that the occupant has the opportunity to improve the indoor air quality by opening the windows if possible. If the outdoor air is of particularly low quality the user does not have this option. In these cases (for example in polluted cities) the feedback system of next generation will use an outdoor unit and focus on delivering feedback on the time of the day where outdoor air pollution (defined according to DIN EN 16798 or WHO – World Health Organization - Air quality guidelines including PM10 and PM2,5) is lower than the indoor air pollution.

Conclusion and future steps

The described solution is at the design stage. The CO_2 sensor is integrated on a sensor box (see **Figure 3**) which includes further sensors for future applications. In the next generations,

- the window state will be available directly using wireless magnet sensors.
- the temperature data will be integrated to dynamically determine the feedback time for closing the windows.
- the concepts of the design of human-building-interaction are applied to promote the interaction between the occupant and the room and raise the probablity of action on feedbacks.

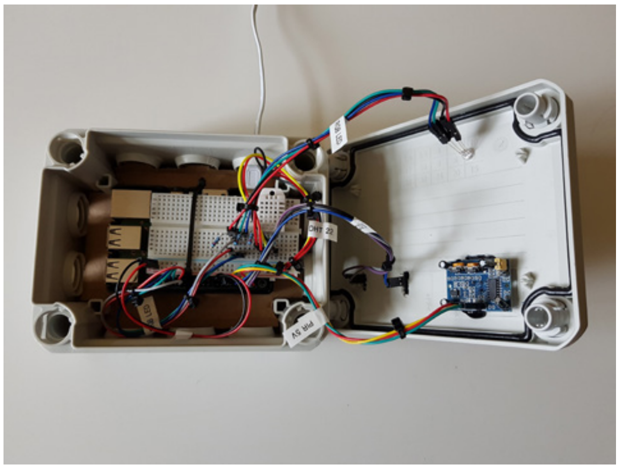

Figure 3. Prototype of the sensor box (© D.Boehnke)

The significance of integrating occupants into the operation of the building is increasingly acknowledged by the building research community. The author's vision is to combine the effective know-how on the positive influence of eco-feedbacks with the new possibilities of the modern information and communication technology (ICT) to develop a system for real-time human-centred interactions between rooms and humans with a focus on improving indoor environmental quality and energy efficiency. In the concept of human-room interaction, the rooms in residential buildings will not be considered only as places of rest and gathering but as active dynamic entities interacting with the occupants resulting in increased satisfaction and wellbeing of the citizens. ■

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Interview with Mr. Hannu Saastamoinen, Chief Executive Officer of Swegon AB

INTERVIEWER: **ANITA DERJANECZ,** REHVA MANAGING DIRECTOR

AD: Swegon is well-known HVAC manufacturer that has been producing high quality solutions for excellent indoor climate for more than 60 years. What do you see as key factors of being successful and growing to a global company? How would you introduce today's SWEGON in 3 sentences?

HS: Our international progress from a Swedish based company to one of the main ventilation & cooling players in Europe is based on a couple of fundamental drivers. As a progressing international business, we have developed a stable and profitable base over many years. Stability and profitability needs to be applied before you can successfully grow any company. Also having a very ambitious, professional and financially sound owner, in Swegon's case Investment AB Latour, gives a solid fundament to our growth plans. As a third component, I would like to add our very strong innovation-based products and services combined with the good brand image that Swegon is having on the markets. And finally, all the committed and professional people in Swegon.

Hannu Saastamoinen

- born in 1960 in Finland
- graduated in M.Sc. (Econ.) at Helsinki Business School.
- lived as an expat in Sweden, Netherlands and Norway.
- Chief Executive Officer of Swegon AB since 2013.
- President and Chief Executive Officer by Huurre Group Oy, between 2006 and 2012.

Swegon today, can be described as a professional and ambitious company with the aim to deliver the best possible indoor air quality, with lowest possible life cycle cost and with a high focus on our customers.

AD: What are the most important technology and market trends that influence SWEGON and the HVAC sector in general?

HS: Clearly one of the biggest changes recently is the very fast consolidation of the industry globally and probably much specifically in Europe. Many of the European ventilation companies (including Swegon) are active with acquisitions. Simultaneously, the big global HVAC players are also entering more actively in the European playfield.

On the other hand, basically everything around big data, IoT, AI etc. that is currently emerging, will most likely dramatically change even HVAC industry – nobody knows how specifically and into what direction, but I am sure completely new opportunities will emerge for both our customers and us as suppliers. Moreover, the convergence between cooling, heating and ventilation technologies is also a clear and interesting trend. We will most likely see more "combination products" on the market in the future. Swegon was early out – probably even too early - testing a combination product Tellus to the commercial market. Currently, we are introducing a fantastic GOLD AHU with integrated heat pump solution giving fresh air, heating and cooling, when needed in an energy efficient way.

AD: What are the research objectives of Swegon? Which important innovations and exiting new products / services is SWEGON working on?

HS: We are systematically continuing to develop the company towards being one of the leading suppliers of indoor climate system solutions. Hence, understanding of various customer applications and connecting this to our R&D plans is a very important driver for our research.

Moreover, we are also active in developing the connectivity of the products. The best ongoing demonstration of this is our new demand-controlled ventilation system "WISE". It is a good example of combining modern and advanced technology; in this case wireless radio communication; to respond to a "simple" customer needs of getting the best possible indoor climate with the lowest possible installation and operational cost.

Concept of the WISE demand-controlled ventilation system.

We are also active in developing "soft services" to our customers to make their life easier. These various projects are connected to the digitalisation development and with addressing these opportunities in a smart way.

AD: Swegon has been a true supporter of REHVA for 12 years now, and you are among the few companies that pro-actively participate in the actual REHVA activities. What values do you see in being part of the REHVA "family"? What else would you expect from the REHVA Association in the future?

HS: In every industry, it is good for the overall industry development that competitors, or rather peers, have a structured forum to share information and competences. This will benefit in a long term for the whole industry and most importantly our customers. It is clearly our common interest to have and drive an "industry agenda" that profiles the HVAC industry in positive light when it comes to the sustainable development of our build environment and improved quality of life.

I think it is important to REHVA to continue offering this "neutral arena" within HVAC. Regarding the future agenda, I think it is important to focus on limited number of critical items and not split the resources to too many issues. In my opinion, driving the better and sustainable Indoor Air Quality for people's health and comfort, should be high up on the agenda.

AD: Swegon has an excellent Air Academy for professionals, where several REHVA experts have been involved as teachers over the years. SCANVAC will offer a well-deserved award to acknowledge this initiative at the REHVA Annual Meeting this year. What are the hot topics and priorities now in the academy? What are the plans and future directions of the initiative?

HS: I fully agree that this has been a great initiative, created way before my time in Swegon. It has given us and other industry professionals a very good arena to drive the important industry questions. It has also offered a very valuable "networking arena" to many people – this is important in order to enable sharing the best practices in a positive manner. However, we have a lot of ideas to further develop our Academy. We have a clear ambition to make it not only a technology focused discussion forum but adding on features that are connected to other competence areas as well. We will gradually introduce these to the market and they will be closely connected to our ambition to deliver superior indoor climate.

AD: REHVA plans to launch a new initiative called "REHVA Next Generation" targeting freshly graduated engineers and young professionals across Europe. A part of this idea is to create links between companies and young professionals across Europe to develop their skills and professional career. What are your experiences and expectation of the young generation of engineers? Would Swegon be interested in joining such an initiative?

HS: We would definitely be interested in this. This is a typical industry wide initiative that will contribute to all companies in HVAC industry. We need to understand that we as an industry are competing against other (technical) industries regarding the best young resources – and it is obvious that the more "traditional manufacturing industries" are not necessarily on the top of the mind of the young talents. We have a common interest to send a clear message to this target group that our industry is "working for the greater good of the mankind" in terms of sustainability, people's health and comfort etc. These things are important for the young generation – which is fantastic! We also need to give them a picture of an industry that will be part of the future development of modern societies in "digital terms" as well. To put it simple; HVAC IS THE FUTURE INDUSTRY! ■

Interview with Mr. Jyri Luomakoski, Chief Executive Officer of Uponor Corporation

INTERVIEWER: **ANITA DERJANECZ,** REHVA MANAGING DIRECTOR

AD: Congratulations to UPONOR for its 100-years anniversary! How has the company started, in the year after Finnish independence? What do you see as key factors of being successful and growing over the past 100 years?

JL: The original company started as a carpentry workshop producing furniture and interior elements for offices and homes. Indeed, it was founded in the first year of Finnish independence, in a period of civil war. In the late 30's of the past century, a new company was established that produced cast iron products and household appliances aiming to make better life for people, a mission followed till today. In the 40's the company switched metallic pipes for the construction sector, a whole new product group. In the 60's Uponor commenced producing plastic pipes, and in the 70's it launched the production of PEX pipes for radiant heating and water systems. Uponor got stock listed in the late 80's and has become a global manufacturer with a wide range of hot water, heating and cooling system products.

Jyri Luomakoski

- Born in 1967.
- MBA, President and Chief Executive Officer at Uponor Corporation since 2008.
- Acted as CFO in 2002- 2008.
- He has been serving Uponor since 1996.

We have been a stock listed company for more than three decades, and we have one industrial investor as the largest shareholder. Thanks to that we have the stability to invest in long-term plans and research. We enjoy the luxury that Uponor is not a stock company focusing on quarterly figures only. The company has changed its profile a few times from a carpentry workshop to a global HVAC manufacturer. I see the key of success in the continuous strive to be at the frontline of change instead of being a follower. If I look to the future from the perspective of our 100-years history, I expect within the next decade the same magnitude of change as what occurred in the past 70-80 years. Change is much faster today due to digital technologies.

AD: What do you see as the most important technology trends that influence UPONOR and the HVAC market in general?

JL: Digitalization, AI and data science will dramatically change our industry. And it is an excellent tool to answer the increasing demand for sustainability, energy and resource efficiency. This is a new era. We must make sure that we use the scare resources, whether energy, or drinking water for the right things and minimise waste. Digitalisation is useful to drive sustainability and efficiency. It enables that building technologies and construction sector components are designed and used efficiently. For example, with the current smart data analysis technologies we can develop new solutions to monitor the use of domestic hot water and optimise the operation to the most efficient and sustainable levels.

Prefabrication is another important technology we are exploiting. The integration of systems, and the necessity to comply with a more demanding regulatory framework increase the complexity of works in the construction process. Prefabrication has a big impact on ensuring consistent quality while coping with the complexity of regulatory and common-sense efficiency requirements. They also help in preventing that this complexity results in budget or time overrun during the construction and installation works. Uponor wants to be an active change driver in this field as well, being the disruptor and not the disrupted.

AD: Uponor has some testing and production facilities for prefab modules. Can you tell us about them?

JL: We have several facilities. In Sweden we started on a greenfield building preconfigured manifold stations, while in Finland we have a manufacturing facility for bigger modules and complex wall elements integrating HVAC and electrical components. Initially this technology was meant to facilitate building refurbishment, but now we have a lot of new construction where the developers figured that it is accelerating also new construction projects and makes the maintenance and life cycle cost management more transparent. Beginning of 2016 we acquired two German companies that were active in the prefab area, developing modules with integrated fresh water stations and heating circuits. The modules are developed to avoid heat loss and decrease the risk of legionella, improving hygiene and energy management aspects of the systems at the same time.

In the drinking water and plumbing area, it is striking to me that hygiene is not sufficiently considered. For example, I was told that in Germany, a country with no speed limits on its highways, more people die as consequence of pneumonia caused by legionella than in car accidents. Consider how many billions the automotive industry is investing in car safety technologies, while in building technologies we miss such a high investment in research for safety and hygiene. We see a clear need here and there are opportunities in the prefabricated technology to supply these needs, which is fantastic. Prefabricated modules have clear interfaces, and it is easier to integrate sensors and tools to monitor hygiene requirements and water waste. Without data you just have a black box, knowing that you are wasting energy somewhere. But what you can measure, you can manage. With proper data measurement and analysis, these problems can be identified and solved.

AD: How does Uponor find these new ideas and technologies coming from different disciplines?

JL: We have a continuous process of scouting and screening start-up technologies and even crazy sounding ideas to find spearheading innovations. We were screening start-ups for example at the SLUSH Fair in Helsinki, which is the world's leading start-up event in the tech sector. There, we met UWater, a company we have worked with for a few years, then we ended up buying it. UWater developed a new digital monitoring concept to diagnose microbes and particles in flowing water, suitable for the prevention of legionella among others. This is especially important for higher risk groups, for example elderly people with lower immune resistance. If you notice these bacteria after contamination, it is too late. But if you monitor it in the network online, you can immediately send an alert to suggest cooking the drinking water or disinfecting the water system and prevent the disease. This company was working with laser holography and they figured that you can see different shapes in the flowing water if there are certain bacteria or particles present and diagnose microbes. This is a relative basic technology if you come from the tech side, but for HVAC professionals it's beyond the usual field of ideas.

Another good example of a spearheading innovation is the company Phyn, which is a joint venture of Belkin and Uponor. Belkin is originally producing computer peripherals and is the second largest router manufacturer. We met them at the Consumer Electronics Show (CES) in Las Vegas, where we sent our scouting team to look for new ideas and technologies. Belkin acquired the IPR of machine-learning algorithms back then, initially meant for electrical devices in smart homes. Typically, people from the field of electronics are afraid of water, while electronics is an area where plumbing and HVAC sector professionals feel uncomfortable. This was though a perfect marriage, a joint venture owned now 50-50 % by both partners. Belkin has access to the talent in electric engineering and machine learning, while we have excellence in the building and HVAC engineering side. By merging the knowledge of the two sides, we could develop a new product. We launched it at CES in January and received 2 innovation awards! I was amazed by the fact that one of the big tech magazines, *digit*, awarded our Phyn Plus smart water device as one of the most interesting innovations of the show, together with tech companies such as LG, LENOVO and Samsung. It makes me especially proud that we won also an official CES award in the category "technology for a better world", which is very much close to our heart. The design was also awarded, because the product looks nice, not like a traditional plumbing device. It is very flattering to get recognised in a completely different domain, not at an event with HVAC or pipe manufacturers.

Phyn Plus smart water assistant, awarded at CES2018.

AD: How do you see the trend of going cross-disciplinary? How far do you need to reach in the future? Do you have any strategy on that?

JL: Yes, digitalisation means that we will need computer scientists, and electrical engineers. We have a software development team, but I don't think we will produce the electronic equipment. We have always had contract manufacturers who produced the hardware on which we run our software developed in-house. For energy and water efficiency, a better understanding of the consumption is a key factor. It may be that most of our heating and water networks are wrongly dimensioned and could be designed more efficiently if we would have a perfect view of the need. Data analysis, and data science is a fast-growing field, where we want to be in the front, driving the change and define the new solutions. Therefore, we want to grow in computer and data science, beside the traditional mechanical and chemical engineering. That's why I made my blunt statement, or threat as you wish, to our four thousand Uponorians recently: the speed of change will accelerate, and the magnitude of change will be the same as what we saw in the past century.

AD: How much does Uponor invest in research? Do you have your research centres in Finland or also abroad? REHVA and UPONOR work together in some European research projects. What is the value of public funding for you?

JL: Uponor is committed to drive the change and we recognise that we can't do it without investing in research. Generally, we invest 2% of our revenue in R&D, but with the Phyn joint venture last year the company surpassed this significantly. Our investment in R&D was at record height in 2017. Around 100 development engineers work in our technology and R&D organisations. Some of them are based in Finland, but the biggest hubs are in Sweden, Germany, and the US. We never believed that all the wisdom would reside in the country of the headquarters.

I think there is value in public funding, especially to finance research where you take big risk. These are usually the cases which may result in disruptive innovations. However, public funding is tied up with a quite high level of bureaucracy. And we also know that the speed of change is sometimes faster than what a public funding framework can handle. Today it is more fashionable to fail fast if things are not moving into the right direction, but public funding projects, in my experience, may become shackles, where you must push through an original plan instead of being able to change it.

AD: UPONOR has been a true supporter of REHVA for 12 years, and you are among the few companies that pro-actively participate in our activities. What values do you see in being part of the REHVA "family"? What do you expect form REHVA in the future?

JL: It is important to recognise the significant value of the huge network which REHVA has within Europe. As a consequence, REHVA has a very good reputation in contact with EU institutions, and the policy makers us very important for our sector – even if they sometimes also add to the complexity of the business. However, as we say in Finnish, it is better to be at the table eating than on the table being eaten. We also value the information services that REHVA has been developing for the sector via publications and events, and to contribute to this with our humble resources makes sense for us.

AD: How do you see EU regulations for the HVAC sector? Are they an opportunity or a burden?

JL: EU regulations are both a burden and an opportunity. The biggest problem from economic point of view is that we deal sometimes with 27 different regulations, either because the EU directives were implemented in different ways or, especially in the field of drinking water, because there are strong, sometimes protectionist national regulations. This has an enormous impact on our products, when we cross borders. Europe is not yet a united market. I was recently in the UK at an investor forum and I was asked why Uponor's profitability is so much better in US than in EU? I said it is because the US is the same market, while the EU is de facto 27 different markets. There is different scale efficiency in US thanks to their united market. We need common smart regulation in the EU, and we should act as a united market to have a level playing field for our industries and increase our competitiveness globally. This would bring economical advantage both to the industry and to the society.

AD: REHVA plans to launch a new initiative called "REHVA Next Generation" targeting freshly graduated engineers and young professionals across Europe. A part of this idea is to create links between companies and professionals to develop their skills and professional career. What are your experience with the young generation of engineers? Would UPONOR be interested in joining such an initiative?

JL: Our industry is rather conservative, and a bit inbound. We know on the other hand that our future customers are from the younger generation. It's clear that we need young professionals to understand their needs. But also, we need un-biased, un-contaminated minds for the new technological developments. This is a question of survival. Generally, we are open and interested in this REHVA initiative, and we are of course interested to hear more about the details as the initiative develops.

Just let me share with you what we do at Uponor. We just launched the 4th round of our international trainee programme, where we select 5-10 trainees, fresh MSc graduates who typically studied abroad. This is 2-years programme, where the trainees spend 4x6 months touring around the company to get a broad introduction into the company and our business. We have had very good experience with this initiative and received 800 applications in the latest round. We also arrange an annual business boot camp, where we select 20-30 talents each year, including some participants from the trainee programme. They must survive on their own in receiving management training; the aim is to train future leaders. As a word of warning, the workload you need for such an initiative is very high.

AD: Can you tell us about your story at Uponor?

I joined Uponor in 1996, more than 20 years ago after a career in the IT / software business and logistics. I started as controller, then became corporate controller, and joined the executive leadership team in 1999 as the CFO. The Board of Directors appointed me deputy CEO in 2002. I took over as CEO in 2008 when the global financial crisis started. Adjusting and reshaping a company working for the construction sector was a hard job. Back then, 75% of the new residential construction market disappeared only in the US, but we got the bottom line in black all the time throughout the crisis. When I look back at my 20 years at Uponor I see a tremendous change. When I joined, Uponor was an infrastructure piping company with some building technology. Today three quarters of our business is related to advanced building technologies.

AD: How do you see the future?

As a society we need to focus on and invest into solutions that are sustainable, whether in the built environment, or in mobility, or in any other field. And we must make sure that we leave this world to the next generation not in worse condition than inherited, but in a better shape, in a shape we can be proud of. This is our responsibility. Helping our customers and helping the industry as such to drive this change is our key role and a clear opportunity for Uponor. ■

Jaap Hogeling, EPB Center, jaap.hogeling@epb.center
Anita Derjanecz, REHVA Managing Director

The 2nd recast of the Energy Performance of Buildings Directive (EPBD)

Member States' confirmed the political agreement on the revised EPBD on 31 January 2018, so the legislative process reached the run-in phase more than 1 year after the European Commission (EC) unveiled its proposal within the "**Clean Energy for All European**"[1] Package November 2016. The European Parliament (EP) will approve the formal legal text in April 2018, Member States will have 20th months for the transposition. This article summarises some important changes, and the position that REHVA has been advocating during the legislative process and will continue to promote in the national level implementation phase.

Over the course of the past year EU institution and stakeholders conducted long negotiations on the 2nd review of the EPBD. REHVA has worked with its Member Associations to define its position about the draft legislation and contributed with its comments during the legislative process. As expected, the EP proved to be more ambitious and listened to the voice of EU level stakeholders in key issues for REHVA, including the strengthening of IEQ requirements, ensuring proper maintenance supported by effective inspections schemes and committing to ambitious EU energy efficiency targets. Members States (MS) were reluctant to approve additional binding requirements, the difference in the positions even resulted in a temporary collapse of the trialogue talks between Council and EP end of 2017. Finally, the parties reached an agreement just before Christmas in an 8-hours intense 3rd negotiation round. This agreement was confirmed by the ambassadors of MS on 31 January 2018, so the compromise directive text can be approved in April 2018.

Novelties of the 2nd EPBD recast

National renovation strategies and the quality of energy renovation

The recast EPBD integrates many requirements regarding the acceleration of deep energy renovation of buildings in Europe. A major success of the political negotiations was that MS agreed to develop **national renovation strategies** to achieve an energy efficient and decarbonised European building stock by 2050 reducing the EU greenhouse gas emissions by 80–95% compared to 1990. The strategies shall set mid-term goals for 2030 and 2040 and define milestones with measurable progress indicators.

The consideration shows that MS's are seeking the cost-efficient equilibrium between a decarbonised energy supply and reducing the final energy use of buildings, implying an average 3% renovation rate towards nearly zero energy level, where "nearly" is understood as cost-effective and therefore depends on the costs of a non-renewable energy unit (the carbon emission part of the energy supply) and the cost of measures to reduce the energy use of buildings.

The strategies shall also address healthy indoor climate conditions, fire safety and risks related to intense seismic activity.

National renovation strategies should address the following aspects:

- an overview of the national building stock and expected share of refurbished buildings in 2020;
- identification of cost-effective approaches to renovations relevant to building type and climatic zone, considering potential trigger points in the building life-cycle
- policies and actions to stimulate cost-effective deep renovations, including staged deep renovations or building renovation passports;
- policies and actions to target the worst performing segments of the national building stock, split-incentive dilemmas, market failures, and actions to alleviate energy poverty;
- policies and actions to target public buildings; national initiatives to promote smart technologies and communities, as well as skills and education in the construction and energy efficiency sectors;
- an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality.

The directive advises MS to ensure that the measures to improve energy performance don't focus only on the building envelope but include all relevant elements and technical systems. When buildings undergo major renovations, MS shall encourage that technical building systems are replaced or upgraded to high efficiency ones as far as technically and economically feasible. Technical building systems play an important role in reducing costs and maintaining or improving the IEQ in our buildings.

[1] http://europa.eu/rapid/press-release_MEMO-16-3986_en.htm

The directive puts more emphasis on the quality and compliance of energy renovation and encourages that financial measures related to energy efficiency are linked to quality, and to certified performance improvements, which should be assessed by comparing EPCs issued before and after the renovation, or by adequate energy audits.

Inspection of heating, ventilation, and air conditioning systems

Inspection was another tough part of the talks and here the Council set through its position. The EP proposed mandatory regular inspections and cancelled "adequate advice" as an alternative, a position strongly supported by REHVA and several EU level stakeholders. Both requirements were modified in the final compromised version.

The articles 14 and 15 on inspection of heating and air-conditioning systems have been changed on mayor points. The threshold for inspection of heating systems is changed from 20 to 70 kW rated effective output (ventilation included). MS have the sole competence to decide on the appropriate measures and frequency, including "advice, so even avoid having inspection schemes. MS can opt for not requiring repeated inspection until the systems or the buildings heating and cooling requirements have changed. For small scale installations, the documentation of the system performance by installers is approved as sufficient support of compliance with performance requirements. Technical building systems of buildings that are part of an energy performance contract are exempted from regular inspection.

To directive states the importance of inspection in achieving building energy performance improvements and improve the operational energy performance of HVAC. Inspections should assess the sizing and the capabilities of the equipment to improve system performance also under part load operating conditions and encourage the upgrade and replacement of inefficient HVAC systems.

Building automation and control (BAC) systems are considered as the most cost-effective alternative to inspections in large non-residential and multi-apartment buildings. The directive requires that non-residential buildings above an effective rated heating or combined heating and ventilation system output of 290 kW are equipped with BAC-s by 2025, where technically and economically feasible. Buildings with BAC installed are exempted from regular inspection. REHVA had a different position regarding the role of BAC and their capacity to replace inspection, advocating for mandatory third-party testing.

The Directive also mandates the Commission to conclude, by 2020, a feasibility study about the possibilities and timeline to introduce the inspection of stand-alone ventilation systems and an optional building renovation passport complementary to Energy Performance Certificates (EPCs) providing long-term, step-by-step renovation roadmap for specific buildings to improve energy performance. This can support the development of a possible Indoor Environmental Quality declaration as part of the EPCs.

A voluntary smart readiness indicator

The Council has agreed on the establishment of a voluntary Smart Readiness Indicator (SRI) promoting digitalisation and smart technologies. The Commission shall adopt a delegated act by 31 December 2019 establishing an optional common European Union scheme for rating the smart readiness of buildings. This rating shall be based on assessment of the buildings' or building units' capabilities to adapt its operation to the needs of the occupant, and the grid, and to improve its energy efficiency and overall performance, including indoor comfort and heath.

The SRI shall cover features for enhanced energy savings, benchmarking and flexibility, enhanced functionalities and capabilities resulting from more interconnected and intelligent devices. The methodology shall consider features such as smart meters, building automation and control systems, self-regulating devices for indoor temperature, built-in home appliances, recharging points for electric vehicles, energy storage and detailed functionalities and the interoperability of these features, as well as benefits for the indoor climate condition, energy efficiency, performance levels and enabled flexibility.

Three key functionalities are listed:

- the ability to use energy from renewable sources in a flexible way,
- the ability to adapt its operation mode in response to the needs of the occupant in a user-friendly way, to maintaining healthy indoor climate conditions and to report on energy use,
- the flexibility of a building's overall electricity demand, including demand-response in relation to the grid.

The methodology shall not negatively affect existing EPC schemes and build on related national initiatives, while considering occupant ownership, data protection, privacy and security. Is shall set out the most appropriate format of the SRI parameter, be simple, transparent, and easily understandable for consumers, owners, investors, and demand response market participants.

Currently a consortium of consultants contracted by DG Energy is working on a study defining the criteria and a calculation methodology based on related international and European standards, and a feasibility study about the SRI indicator. REHVA follows the process and provides inputs to the work of the experts.

Health aspects and IEQ

REHVA has been advocating for strengthened IEQ requirements and health aspects in the EPBD, supported also by the European Parliament. The compromise legislation contains some improvements, although it doesn't set binding European IEQ criteria. The IEQ related relevant point of the directive are the following:

- For new buildings and buildings undergoing major renovations, MS should encourage high-efficiency alternatives while also addressing healthy indoor climate conditions. MS should support that energy performance upgrades of existing buildings contribute to achieving a healthy indoor environment.
- The directive refers to the 2009 WHO guidelines concerning indoor air quality, and better performing buildings that provide higher comfort levels and wellbeing and improve health.
- The Annex I of the directive indirectly mandates MS-s to define comfort and indoor air quality levels to safeguard the health of the building users by requiring that the energy needs for space heating, space cooling, domestic hot water, lighting, ventilation and other technical building systems shall be calculated in order to optimise health, indoor air quality and comfort levels defined by Member States at national or regional level.
- Long-term renovation strategies shall contain evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety, and air quality.
- The feasibility study on the inspection of stand-alone ventilation systems that shall be carried out by the EC before 2020 can support the development of a possible Indoor Environmental Quality declaration as part of the EPCs.

Energy performance calculation and EPB standards

The energy performance of a building shall be determined based on calculated or actual energy use reflecting the typical energy use for heating, cooling, domestic hot water, ventilation and built-in lighting and other technical building systems. The energy performance shall be expressed by the numeric indicator of primary energy use in kWh/(m².y). The calculation methodology shall be transparent and open to innovation. MS shall describe their national calculation methodology following the national annexes of the overarching standards (EN- ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1.) developed by CEN under mandate M/480. However, this doesn't constitute any legal codification of standards in the MS.

Member States have the competence to define **primary energy factors** or weighting factors to calculate primary energy be energy carrier, which may be based on national, regional or local annual, and possibly also seasonal or monthly weighted averages, or on more specific information made available for an individual district system. In the application of these factors MS shall ensure that the optimal energy performance of the building envelope is pursued. MS may consider renewable energy sources supplied through the energy carrier and generated on-site when calculating the primary energy factors if the methodology applies on a non-discriminatory basis. MS may also define additional numeric indicators of total, non-renewable and renewable primary energy use, and greenhouse gas emission produced in kg of CO_2 equivalent per m² per year.'

CENTC371 is currently developing the standard "Energy performance of buildings — Determination and reporting of Primary Energy Factors (PEF) and CO_2 emission factors procedure — Part 1: General Principles and Methodological approach". This standard could become a good basis for the harmonisation of these procedures throughout Europe in the future.

The new set of EPB standards should be implemented in all EU member states. Using the same energy performance assessment procedures throughout Europe would stimulate innovative energy saving solutions that can be applied everywhere in Europe, because they will be awarded according to the same principles in a transparent way. Sticking to separate national procedures in the EU countries crates and a market barrier for energy saving products, systems and technologies.

REHVA has been advocating for the harmonised and ambitious application of EPB standards in MS-s and promotes the harmonization of national calculation methodologies to ensure the reliability and transparency of the energy performance assessment. REHVA is committed to further actions to convince and support national regulators to follow this route. ■

ISH China & CIHE 2018 announces its largest ever exhibition space catering to strong demand from exhibitors

As an unparalleled trading platform for the HVAC and plumbing industries in Asia, ISH China & CIHE – China International Trade Fair for Heating, Ventilation, Air-Conditioning, Sanitation & Home Comfort Systems returns to the New China International Exhibition Center in Beijing from 22 – 24 May 2018.

ISH China & CIHE has received a positive response from exhibitors with more than 98% of the exhibition space at the upcoming show already booked. The fair will increase its capacity by adding two additional halls – halls E5 and E6 – to house exhibitors showcasing clean energy heating solutions. The expansion reflects the industry's commitment to providing alternatives to direct coal combustion with various forms of heating solutions, as well as an effort to support recent government policies that reduce air pollution across China.

The 2018 edition of the fair will operate on an unprecedented scale due to its increase in size spanning 10 halls and 116,000 sqm of exhibition space. Around 1,300 exhibitors are expected to participate at the show, while it is estimated that 65,000 visitors will come to explore the latest products and innovations on the market.

Government-led 'Coal-to-natural gas' initiatives stoke the clean energy heating market potential

Deteriorating levels of air quality in China and its hazardous effects on human health are a major cause for concern in the country, especially during the winter heating season. This has led to recent "Coal-to-natural gas" initiatives which encourage boiler retrofits to reduce emissions of nitrogen oxide. Low-nitrogen and condensing technologies are being developed for the next generation of boilers which are safer, more environmentally friendly and energy-efficient.

With a spotlight on "Coal-to-natural gas" initiatives and energy-saving, the products on display in halls E5 and E6 will include low-nitrogen boilers, condensing wall-hung boilers, condensing boilers, modular boilers and low-nitrogen burners. Confirmed leading brands participating at the fair include Airfit, ARCIO, Bailang, Baiwei, Berte, Blue Tech, Boroa, Bowei, Bozhi, Dafu, Domusa, Eacoon, Emperor Horse, Esin, FPB, Fulton, Gel spa, HELMSBURG, ICI, Industrial Combustion, Inse, Jiuxuyangguang, JNOD, kaaniche, kenuo, LD, Luma, Manling, Quanyong, Shenzhou, Shuaikang, Topz, Valpo, Vigas, Xinhuida, Xinmaifa, Yinglang, Zeta and Zhengsen.

ISH China & CIHE is headed by the biennial ISH event in Frankfurt, Germany, which is the world's leading trade fair for the Bathroom Experience, Building, Energy, Air-Conditioning Technology and Renewable Energies. The mother event will take place from 11 – 15 March 2019 (Monday to Friday). For more information, please visit www.ish.messefrankfurt.com. Furthermore, this year's ISH India powered by IPA was held from 22 – 24 February at Bangalore International Exhibition Centre.

The next edition of ISH Shanghai & CIHE will be held from 3 – 5 September 2018 at the Shanghai New International Expo Centre. ■

For more information, please visit www.ishc-cihe.hk.messefrankfurt.com or email info@ishc-cihe.com

Re-thinking Organizational Savings through HVAC

Insufficient ventilation causes human-produced carbon dioxide to build up indoors, decreasing employee well-being and productivity substantially. With accurate CO_2 measurement both energy efficiency and employee well-being can be achieved simultaneously.

HVAC systems make up a significant portion of the energy expenditure of an office building, around 42% of the total energy costs according to the US Environmental Protection Agency.

Green building initiatives, like the US Green Building Council's LEED v4, British BREEAM and Australian Energy Rating, all encourage commercial constructors and building operators to reduce their environmental impact by increasing energy efficiency in buildings. Especially LEED v4 stresses the importance of precise ventilation automation controls, which can be achieved when using accurate sensors. Also, the ASHRAE Green Standard 189.1 (USA) and the European standard EN 13779 recommend using primarily demand controlled ventilation (DCV) to reduce energy consumption while generating fresh and healthy indoor air.

CO_2 Level as an Indicator of Indoor Air Quality

The European EN standard 13779: 2007 sets the normal expectation for indoor CO_2 level at 400–600 ppm, which is slightly above the normal levels in outdoor air (400 ppm). The modern ventilation systems are built around this assumption to ensure good enough indoor air quality while remaining energy efficient.

Field studies show that regular office conditions have a 1,500 ppm concentration of CO_2, which may seem a very high level, but the regulatory limit considered safe for people is even higher: 5,000 ppm of carbon dioxide over an 8-hour period.

Recent studies challenge good indoor air quality. A study conducted by the National Institute of Environmental Health Sciences (NIEHS) in 2015 focused on the effects that indoor air quality has on employees' cognitive abilities. The extensive study setting simulated office conditions and compared conventional offices to WWF Green and Green+[1] offices. Cognitive scores in crisis response, information usage and strategy, among other variables, were evaluated on the test subjects. The study showed dramatic results (**Figure 1**).

The results of the NIEHS study show how cognitive skills are decreased by the increase of CO_2 in indoor air. According to this finding, strategic skills are decreased only to 20% in indoor air with a concentra-

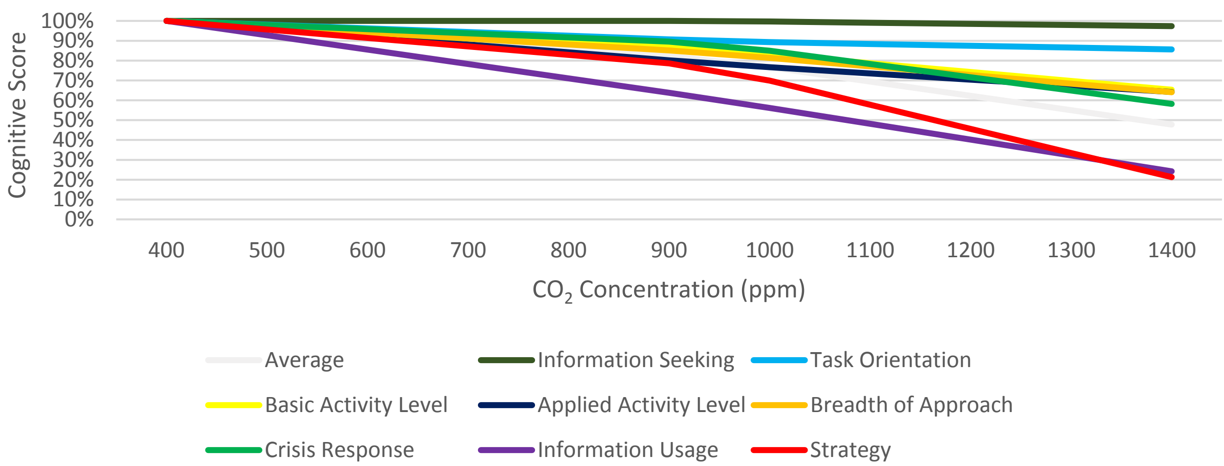


Figure 1. Impact of Changes in CO_2 Levels on Employees' Cognitive Abilities.

[1] https://wwf.fi/en/green-office/

tion of 1,400 ppm of CO_2 compared to the normal outdoor level of 400 ppm. Cognitive skills that require more advanced application of information, like crisis response, information usage and strategy, are affected the most whereas routine work like information seeking and task orientation, were not affected as much. The study shows clearly that managing more advanced tasks becomes much more difficult when the indoor carbon dioxide levels rise.

When comparing good indoor air quality of 800–1,000 ppm of CO_2 to the typical level of 1,500 ppm in office buildings, it's easy to see why indoor air quality is an emerging topic. Accurate measurement of indoor air and better ventilation are vital to maintain good cognitive abilities of people working in offices.

When taking a look at the typical operating costs of an office building, we can see that energy costs stand only at 1% and rental at 9% of the overall costs, whereas employee costs stand at 90% (**Figure 2**).

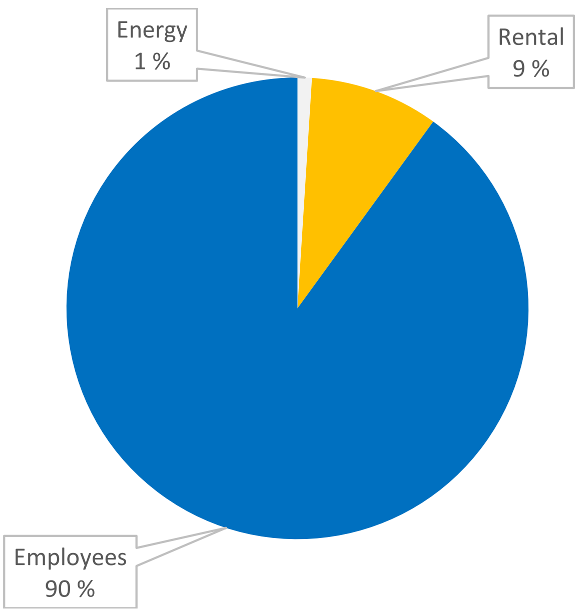


Figure 2. Typical Office Operating Costs.

Better Productivity through Employee Well-Being

Let's take a closer look at the three cognitive abilities affected the most by CO_2 concentration: crisis response, information usage and strategy. A decrease in the ability to manage crisis response leads to mistakes and maybe even to dangerous situations. Decreased ability to use information also has a negative impact on employees' learning and productivity. Decreased ability in strategy may lead to belated or poor decisions. In the long run, continuous insufficient ventilation may lead to many problems regarding employee well-being and may increase direct and indirect costs.

Some the effects of poor and insufficient ventilation may be difficult to quantify. Productivity, on the other hand, can be measured. Studies indicate that better indoor air and ventilation has a positive impact on productivity. The Continental Automated Buildings Association (CABA) conducted a comparison between better buildings and employee strategies like workplace health programs and bonuses. With a meta-study including 500 different studies, they found out that better buildings increase productivity by 2–10%. The Federation of European Heating, Ventilation and Air Conditioning (REHVA) state that decreased ventilation lowers productivity, for example typing speed by 10%. The US Green Building Council commenced a meta-study in 2003 and concluded that delivery of fresh air and reduced levels of pollutants improve productivity by 11%. Furthermore, according to the analysis of the Carnegie Mellon University, better ventilation improves productivity by 3–18%.

In conclusion, better ventilation improves productivity from 2% to 18%. How does this affect costs? If the annual average expense of an employee is 50,000€ for a company, the yearly cost benefits of improved ventilation range from 1,000€ up to 9,000€ per person; a company with 100 employees is looking at financial savings in the range of 100,000 – 900,000€. Companies with over 1,000 employees reach savings worth millions of euros, even with the most conservative estimates. These figures are only the cost savings gained in measurable productivity.

Coming back to the typical operating costs of an office building, where employee costs stand at 90%, whilst energy represents 1% of the total costs, it is easy to understand the importance of ensuring good indoor air quality over unnecessarily strict energy management. The magnitude of the difference between energy and employee costs is definitely immense. Energy efficiency is as important as before, but when optimizing the HVAC systems, occupants' well-being needs to be considered even more carefully. ■

Lars Stormbom
MSc, Senior Product Manager, Vaisala Oyj

REHVA at MCE 2018

Mostra Convegno Expocomfort was the occasion for REHVA to dive into Supporters' world and offer them interesting insights on the most recent EU policy developments and research trends. The mutual collaboration between REHVA and AiCARR led to the organization of two international seminars, on Tuesday 13 and Wednesday 14 March. Moreover, beside the various supporters that REHVA visited during the fair, REHVA representatives were guest speakers at Rhoss 50th anniversary celebration.

REHVA-AiCARR seminar, 13 March

On Tuesday afternoon the REHVA-AiCARR seminar dealt with the opportunities and critical aspects of the EPBD 2nd recast. First, AiCARR President, Prof. Francesca Romana D'Ambrosio, and REHVA President, Prof. Stefano Paolo Corgnati, welcomed the participants with introductory speeches. The presentation by Anita Derjanecz, REHVA Managing Director, provided then an overview of how the key points of REHVA advocacy activities – attention for IEQ and health aspects, inspection of building systems, harmonized application of EPB standards –- are addressed in the new EPBD, which is going for formal approval by the European Parliament in April. Jaap Hogeling, chair of the Programme Committee on EPBD, explained how the flexibility of the new set of Energy Performance of Buildings standards are expected to pave the way for a harmonized implementation across Europe. The presentation by Prof. Stefano Paolo Corgnati, REHVA President, stressed one of the conceptual shift that the HVAC sector is currently facing: digitalization. In the near future, HVAC energy data will have higher value than the value of energy itself, and the HVAC sector needs to use ICT and IoT to grab the opportunities that this change implies. The last speech of the seminar, given by Prof. Livio Mazzarella, AiCARR Vice-President, offered an interesting overview of the ongoing study promoted by the European Commission on the development of a Smart Readiness Indicator, pointed out its potential weaknesses and suggested how to possibly address them. Seminar presentations are available on REHVA website.

Figure 1. REHVA and AiCARR presidents welcome the audience of the seminar on Tuesday afternoon.

AiCARR-REHVA-ASHRAE seminar, 14 March

The seminar organized by AiCARR in collaboration with REHVA and ASHRAE focused on Indoor Environmental Quality requirements and practices. AiCARR, REHVA and ASHRAE presidents were invited to give speeches as eminent experts in the field. Francesca Romana D'Ambrosio (AiCARR President) offered the big picture of the role of IEQ in shaping a sustainable future. ASHRAE President Bjarne Olesen spoke about the new ventilation requirements and design criteria, stressing the importance of perceived air quality beside the measured one.

REHVA President Stefano Paolo Corgnati presented the evolution of scientific research related to thermal comfort from Fanger's theory to the most recent proposals of motivational comfort. Then the floor

Figure 2. REHVA President Stefano Paolo Corgnati gives a speech on the most research trends about comfort in buildings.

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

extend their heartfelt congratulations to

RHOSS

acquiring a strong and recognisable image of technological leadership, investing in constant research and development, adopting the most innovative technological solutions

ON THE OCCASION OF THEIR 50th ANNIVERSARY

Milan, Italy, 14 March 2018

Stefano P. Corgnati
President

was given to Prof. Laura Bellia, who highlighted throughout her presentation the role of human perception in designing visual comfort, and Prof. Giovanni Semprini, who dealt with the same issue in terms of acoustic comfort.

Celebrating Rhoss' 50th Anniversary

Rhoss, REHVA supporter company, celebrated its 50th anniversary at MCE with an expert meeting where REHVA President, Stefano Corgnati and REHVA Managing Director, Anita Derjanecz were invited to talk about the IEQ aspects in the upcoming EPBD review, as well as about a research conducted for Rhoss by POLITO regarding the performance and global cost analysis of air filters produced by Rhoss compared to other products on the market. Stefano Corgnati handed over a REHVA award to Rhoss General Manager Andrea Corradi, Sales Director Stefano Canali and Marketing Manager Leonardo Prendin to commemorate the 50-years anniversary and the strong technological leadership of the company proved by investing in constant research and development striving for the most innovative technological solutions. After the expert meeting, Rhoss organized a cocktail reception at their booth attended by 150 employees and partners from across Europe. ■

The REHVA-ISHRAE seminar team and speakers.

REHVA at ACREX 2018

ACREX 2018 upheld the collaboration between REHVA and ISHRAE, ongoing since 2012. From 22 to 24 February, REHVA was present at the largest South Asia Exhibition on HVAC with a booth, where the activities in and beyond Europe of our federation were showcased to visitors.

ACREX was also the occasion to make evident to Indian HVAC professionals the ongoing technical collaboration between REHVA and ISHRAE experts. On 23 February, the two associations co-organized a seminar about Indoor Environmental Quality and energy efficiency in schools and they officially launched a joint statement on the same topic during the ACREX Hall of Fame event. This statement will result next year in the publication of a joint Guidebook on the topic.

REHVA representatives were also deeply involved in institutional meetings with ISHRAE and ASHRAE, to foster the creation of a worldwide alliance representing the voice of the HVAC sector at the global scale and to further strengthen the exchange of knowledge between Europe and India, by the set-up of new REHVA-ISHRAE initiatives. In this framework can be inserted the meeting organized by the "Women in ISHRAE" group with REHVA and ASHRAE representatives. This was the occasion for mutual enrichment to understand how gender equality issues are and can be tackled in this sector, paving the way for future coordinated actions.

REHVA booth at ACREX.

Women in ISHRAE meeting with REHVA and ASHRAE representatives.

REHVA-ISHRAE seminar "Designing healthy nearly Zero Energy schools"

On Friday 23 February afternoon REHVA and ISHRAE organized a joint seminar about "Designing healthy nearly Zero Energy schools". Speakers from ISHRAE, REHVA and Eurovent Certita Certification and NEEV Academy provided the around 100 seminar attendants with interesting insights about the current situation of Indian and European schools in terms of thermal comfort and IEQ, the most suitable technologies to improve these conditions and how to manage the energy implications of an IEQ-oriented design.

ISHRAE President Elect Chandrasekaran Subramaniam introduces the REHVA-ISHRAE seminar.

ISHRAE President Elect Chandrasekaran Subramaniam welcomed the audience introducing the joint REHVA-ISHRAE Task Force on IEQ in Schools. This Task Force builds upon and further develops the work of REHVA Guidebook 13 "Indoor Environment and Energy Efficiency in Schools", by updating contents and opening up to the Indian context. The various speeches started a lively discussion among the participants about how to drive Indian HVAC sector attention towards this issue, summarized in ISHRAE president Vishal Kapur's closing remarks.

The contents of each presentation of the seminar are summarized below and the full presentations are available on REHVA website.

Status quo about IEQ in schools, health & learning performance effects

Dr.Atze BOERSTRA, REHVA Vice-president, Managing Director at BBA IEQ Consultancy

Several field studies results were displayed to prove the link between ventilation and absenteeism and learning performances at school. Despite the evidences, both in Europe and India Indoor Air Quality (IAQ) in schools has still big room for improvement. By displaying results of studies conducted in several schools, Dr. Boerstra pointed out that IAQ issues in India and in Europe are very different. While in Europe CO_2 concentration is the most critical aspect, in India PM2.5 concentrations are worryingly high. To define common strategies and adapt them to the local contexts, REHVA and ISHRAE has set up a joint Task Force for IEQ in nZEB schools.

Thermal comfort in schools

Dr.-Ing. Jyotirmay MATHUR, Professor in Mechanical Engineering and the Centre for Energy and Environment, Malaviya National Institute of Technology Jaipur

The presentation focus on thermal comfort in schools is justified by the specific users and activities of occupants of these buildings. Indeed, tolerance band for thermal conditions are different for children and adults and the academic performance of students can be significantly affected by comfort levels. By displaying results for fields studies display the mismatch between objective temperature measurements and subjective thermal responses in schools in India and Australia and among students and teachers. Country- and school-specific case studies are needed to develop thermal comfort guidelines.

Authentic school environments

Kavita GUPTA SABHARWAL, Founder & Managing Trustee at NEEV Academy, Bengaluru

NEEV Academy is a private school in Bangalore, whose founder's vision is "building knowledge, self-awareness and relationships with people and the environment to seek happy, healthy, impactful lives". Ms. Gupta presented to the audience how the campus buildings are designed to represent the circular philosophy of this institution. Design strategy prioritizes students' comfort, social and natural interaction and environmental consciousness.

Kavita Gupta Sabharwal's presentation.

Improving energy & IEQ performance in practice – the case of Indian Schools

Maija VIRTA, Founder Director at Santrupti Engineers

The presentation well depicted the different conditions and possible solutions to improve IEQ in Indian private and Government school. The first required to reduce CO_2 emission, the latter more problematic in terms of PM2.5 and thermal comfort. The effects of these two aspects on human health are well documented by research both in terms of health consequences and

Maija Virta's presentation.

Launching the REHVA-ISHRAE joint paper at ACREX Hall of Fame.

productivity. Technical recommendations to improve schools IEQ include ventilation and air filtration, with special attention to pressurization with clean air and selection of purification technologies.

IAQ in Schools: Certification of Energy Efficient solutions

Eric FOUCHEROT, Director of International Affairs at Eurovent Certita Certification

Mr. Foucherot framed the HVAC products Certification activity of Eurovent Certita Certification into the current regulatory framework, which put more and more attention to Indoor Environmental Quality. In this view, an increasing number of certification programmes in now dedicated to IAQ-related products. Among others, Hygienic Air Handling Units certifications, Residential Air Filters Efficiency rating, Air cleaners Efficiency labelling, and Ducts certifications are pivotal to ensure the desired system performances for optimal IAQ.

Energy performance of schools: past, present, future

Dr. Nitin DEODHAR, Chief Designer at N. M. Deodhar Consulting Engineers and Managing Director at VISION Electro Mechanical Consultants

The presentation explored the nexus Indoor Environmental Quality (IEQ)-Energy, proposing solutions to overcome a direct relation between them. A number of standards are available to provide guidance on IEQ requirements. Among them, ISHRAE published in 2016 the Indoor Environmental Quality Standard. With these IEQ benchmarks in mind, building professionals should include in their design objectives both IEQ and reduced energy use. These design strategies constitute indeed the future of HVAC industry. For instance, fresh air and heat recovery management are key strategies to reduce heat loads, while monitoring systems and predictive controls are strategic to reduce operational costs. Dr. Deodhar also suggested possible approaches to optimise energy consumption while considering IEQ a constraint parameter: a prescriptive approach by calculating probability distribution and a descriptive approach by convex linear programming.


The audience of the REHVA-ISHRAE seminar.

The REHVA-ISHRAE statement on Indoor Environmental Quality and Energy Performance of Schools

In the evening of Friday 23 February, Atze Boerstra and Frank Hovorka from REHVA, and Nitin Deodhar and Vishal Kapur from ISHRAE launched the REHVA-ISHRAE joint statement on Indoor Environmental Quality and Energy Performance of Schools from the stage of the ACREX 2018 Hall of Fame. This statement is the manifesto of the ongoing REHVA-ISHRAE Task Force, which gathers EU and Indian experts to produce a guidebook providing technical recommendations and guidelines on the topic.

The joint statement was distributed in paper copy to the hundreds of participants to the event and it is now published in this Journal. ■

REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

ISHRAE

REHVA-ISHRAE statement on **Indoor Environmental Quality and Energy Performance of Schools**

Indoor Environmental Quality (IEQ) is an important determinant of health and wellbeing. This is true for adults, but even more so for **children.** Children are continuously developing their lungs and other organs, which explains why they are more susceptible to e.g. air pollution. Traditionally, research and policy have been focusing on the environmental quality *outdoors*, while missing to address the fact that most people, including children, spend most of their time indoors. The two dominant indoor environments for children are the **home environment** and the **school environment.** In this statement we focus on the latter one.

According to the World Health Organisation, everybody has the **right to breath in healthy air** indoors[1]. In the last decade a lot of attention has been paid to health problems and indoor climate complaints of those working indoor. As a result, in recent years many office buildings have been transformed from 'sick' to 'healthy' buildings. However, similar interventions are still missing in school buildings, where scholars are often not consulted with regard of their satisfaction about indoor comfort conditions. Without intervention, fine particles and CO_2 concentrations in schools could be higher (even three times or more) than in offices. Similarly, indoor temperatures in classrooms are often uncomfortably warm or cold and lighting conditions are far from optimal, while office buildings have well-filtered, airconditioned, well-illuminated and acoustically insulated spaces.

Several studies have shown that poor IEQ reduces children's **learning performances**. Furthermore, we know that suboptimal air quality in classrooms can have severe health consequences, like the development of chronic **respiratory diseases** and (indoor climate-related) allergies. In many European countries more than 20% of children have developed such diseases by the age of 12. This number in India is probably similar or even higher.

To warrant a healthy indoor environment, especially at school, we need to use energy for heating, cooling, ventilation or lighting of classrooms. **Energy performance** of schools should be optimized ensuring proper air quality, thermal, acoustic and visual comfort as mandatory goals. To have a proper balance between the initial investment and the recurring energy bills, the comprehensive approach of carefully designed school envelope and HVAC system should be followed, and not only reducing the delivered services to save energy. Another reason to minimize energy use in schools is of course to fight global warming. European countries as well as India have decided to ratify the Paris Agreement on Climate Change, which implies that all buildings, including schools, should be optimized, not just in terms of IEQ but also in terms of energy performance.

School is the place where young people stay for most of their day: a comfortable and healthy environment is necessary to safeguard their well-being indoor and to make sure they make the most out of their learning opportunities. Therefore, such indoor environments should be designed/ redesigned with the health of children (and teachers) in mind, while making sure that the energy use of the schools is as low as reasonably achievable. Ideally, such energy use should be at the **Net Zero Energy level** with respect to non-renewable energy. Existing schools, all around the world, often do *not* meet neither the energy performance nor the IEQ criteria that children (and other school building users) are entitled to, as prescribed in standards and building codes. This is not

1 WHO, 2000. Right to good healthy indoor air. World Health Organisation (WHO), Bilthoven, The Netherlands.

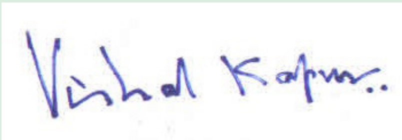
acceptable because children are our future and we must take care of them as we must take care of the environment. Hence, immediate **action is needed**.

As a first step to make this happen, REHVA and ISHRAE are committed to **develop a comprehensive guidebook** that describes how to design a school building with high IEQ and energy performance levels, promoting increased learning performance by enhancing climatization, ventilation and lighting systems. A team of European and Indian experts from ISHRAE and REHVA is currently working on this guidebook, whose publication is foreseen in early 2019. The contents build upon an existing REHVA guidebook[2] and will be organized in two parts; Part I will cover the necessity of good IEQ and energy sustainability, basic principles of healthy building design and reduction of energy use. Reference to the distinct life cycle stages that a school building goes through will be presented. Part II will present practical examples from European and Indian case studies, where technical solutions enable the designer to achieve the expected goals in terms of health and energy performance.

Besides the guidebook, other actions are needed, for example, at the policy and school funding level. REHVA and ISHRAE are committed to teaming-up with governmental institutions, national and international organisations that are as motivated as we are to invest in **future generations** and to improve the Indoor Environmental Quality and Energy Performance of schools wherever they are placed. ■

[2] d'Ambrosio F.R. (ed.) et al, 2010. Indoor environment and energy efficiency in schools – Part 1 Principles, summary of the key contents of REHVA Guidebook no 13. REHVA, Brussels, Belgium

Stefano Paolo Corgnati
REHVA President



Vishal Kapur
ISHRAE President

CLIMA 2019
Built environment facing climate change
REHVA 13th HVAC World Congress
26 - 29 May, Bucharest, Romania

The 13th REHVA Congress, CLIMA 2019, will be held from 26thh till 29th of May 2019 in Romania. The venue is the capital Bucharest which is the 6th European town in population terms and the largest city of Romania. It is a beautiful and very alive Romanian cultural, industrial and financial centre, offering historical and modern conference venues, very cosy hotels, appealing restaurants, robust infrastructure and a lot of quite unique places like traditional museums, recreational green areas and genuine "shopping arcades". Bucharest is known as the most prosperous city in Romania (the living level is over the EU average) and it is one of the main transportation hubs of Eastern Europe. So there will be no concern about your arrival at the congress location. We are convinced that all CLIMA participants will be charmed by Bucharest urban diversity and kindness of its inhabitants.

Under the congress theme: "Built environment facing climate change", the proposed main topics for the 13th CLIMA Congress will highlight discussion on the professional capacity building given the need for new and refurbished buildings inclusive their HVAC&S&R technical systems, to counteract in an energy efficient manner the climate changes respecting the comfort, and security requirements of occupants:

I. Modern HVAC&R&S Technology and Indoor Environment Quality
II. High Energy Performance and Sustainable Buildings
III. Information and Communication Technologies (ICT) for the Intelligent Building Management
IV. Sustainable Urbanization and Energy System Integration

Some expected figures of CLIMA 2019 congress:

- more than 100 CLIMA 2019 ambassadors and 50 partners promoting this event worldwide;
- more than 1000 attendees (researchers, engineers, architects, students etc.…);
- more than 750 papers (with a special care for the selection of those to be published in Scopus or Web of Science indexed journals);
- more than 20 technical and scientific workshops.

As the REHVA World Congress CLIMA has never been held in Eastern Europe, we greatly appreciate, as your hosts in May 2019, the opportunity to reciprocate the hospitality we have received from the REHVA society members throughout the years.

You can find more details on our website www.clima2019.org or ask for more information at our e-desk found on info@clima2019.org.

Belimo's contribution to a good room climate

Prevent poor air quality indoors!

Or what kind of air are you inhaling?

Humans spend around 90% of their lifetimes inside closed rooms, so a good room climate is important. Air quality in particular has a huge impact on our health and well-being. Air tight building shells may well be superior in terms of energy, but they prevent natural air exchange. However, they can be fully automated using appropriate ventilation systems and sensors.

A good room climate is essential

People can survive around thirty days without food, up to four days without water, but only a matter of minutes without air. The most important component of air, i.e. oxygen, is needed to burn nutrients. The brain is particularly sensitive to a lack of oxygen. In rooms without ventilation, the concentration of CO_2 increases, performance drops rapidly, we are unable concentrate, feel tired, suffer from headaches and much more besides. But it's not just oxygen as well as the CO_2 content of the air which indicate a good room climate. The air humidity (ideally 40–60%), air temperature, differential temperature, air ions, air quality and air velocity are also important for a healthy room climate.

There are very few specifications governing indoor areas

While there are statutory requirements for outdoor air and compliance with them is monitored carefully, there are few binding limit values for indoor air. Because humans spend the majority of their lives indoors, it should be in everyone's interest to insist on a good room climate. Especially because poor air quality impacts on our health, performance and productivity. The WHO and Swiss Lung Association believe that, in 2020, chronic obstructive pulmonary disease (COPD) will be one of the most common causes of death worldwide. Therefore, indoor air needs to be "clean" if our health and well-being are not to be jeopardised. This can be achieved with a good ventilation system. Belimo's solutions for the heating, ventilation and air conditioning industry are making a vital contribution towards this. Belimo provides an entire range of sensors for measuring the most important factors affecting room climates, such as air quality, temperature, air humidity and flow. Our Variable Air Volume (VAV) technology and pressure-independent control valves ensure a perfectly balanced flow of air and water at all times, resulting in optimum comfort.

Good air quality for greater performance

The air around us comprises 21% oxygen, 78% nitrogen, 0.04% carbon dioxide (CO_2), as well as traces of noble gases, water vapour and pollutants. Today, one of the most important indicators of air quality in closed rooms is the CO_2 value. Because humans also produce CO_2 by breathing and add this to the air, the concentration of CO_2 continually increases in closed rooms where people are present. An air tight building shell means that the air exchange rate falls, resulting in an increased concentration of harmful substances in the indoor air. This can be counteracted by regularly venting rooms or, if this isn't possible, by fitting a ventilation system to take on this task. Because a ventilation system can also reliably remove air pollutants, it improves the air quality of rooms in which people are present over the long term. If such rooms are equipped with sensors, which provide the ventilation plant room with a permanent supply of data, the system will run in a reliable and independent manner.

Air quality measurements in over 250 classrooms

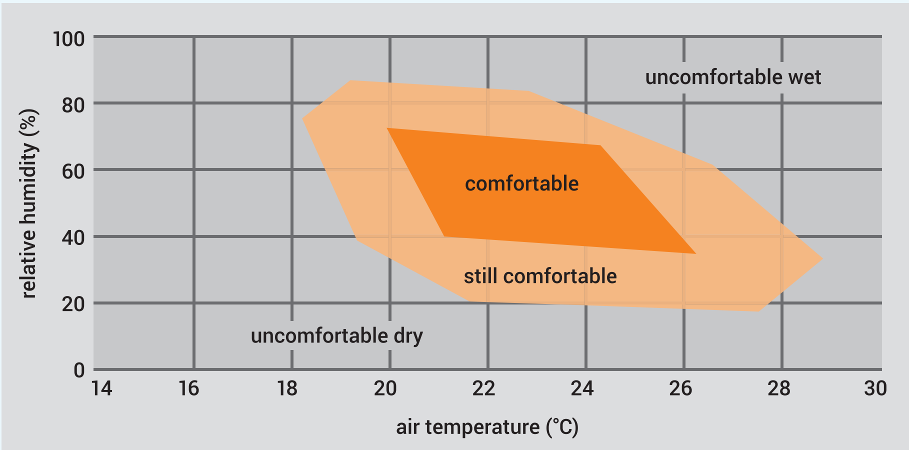
Currently, more than 30% of children in Europe suffer from allergy-related illnesses, such as asthma, hay fever or neurodermatitis. A link with pervasive environmental pollution cannot be ruled out. After all, in closed rooms in particular, pollutants can accumulate and also enter the body through the air inhaled. In addition to chronic illnesses, "poor air" also has further implications for our well-being.

In order to discover how air quality affects pupils and teachers, the MeineRaumluft.ch platform joined forces with the Zurich Teachers' Association (Züricher Lehrerverband) and the Zurich Lung Organisation (Organisation Lunge Zürich) to install measuring devices in over 250 classrooms, which have been in place since November 2016. One positive effect was that simply installing the measuring devices affected the ventilation habits of teachers and pupils, because as soon as the concentration of CO_2 in the room got too high, the windows were opened to let air in.

Despite this, **Figure 1** shows that CO_2 levels were found to be excessively high. In over 13% of the measurements taken at the end of the lesson, the CO_2 level was above 2000 ppm, which is the upper limit value for CO_2 concentrations in occupied rooms according to the SIA 180 standard. **Figure 2** shows that the relative humidity was below 30% in a quarter of the measurements. This may result in health complications, such as a drying out of the airways' mucous membranes. Dust, dirt and germs are then not removed from the airways quickly enough. If these spend a long time in the respiratory tract, the risk of respiratory illnesses increases. Typical consequences include coughs, bronchitis, colds and sinus infections. The only good news is that from **Figure 3** it can be seen that, with a few exceptions, the temperature in degrees Celsius was in an acceptable range.

Achieving good air quality with smart HVAC components

Standardised guidelines exist for the composition of indoor air. To a great extent, these correspond to the feel-good factor. HVAC building automation is key to maintaining these. The ventilation plant room is networked with controllers and sensors. Air values in the rooms can be automatically optimised if the components that are fitted with sensors communicate reliable information to the plant room in order to control fans and regulate temperature, CO_2 content and air humidity. The building management technology then automatically compares the incoming information about the actual and nominal status in the room and gives the actuators the corresponding



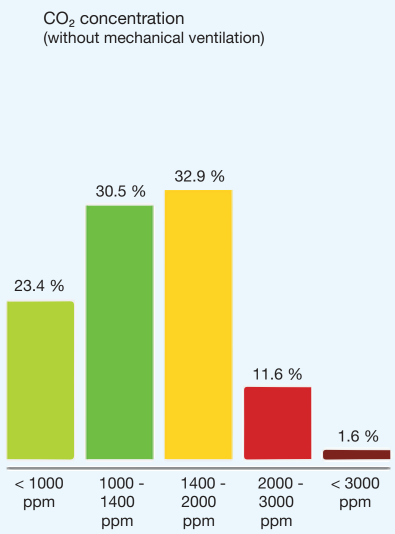


Figure 1

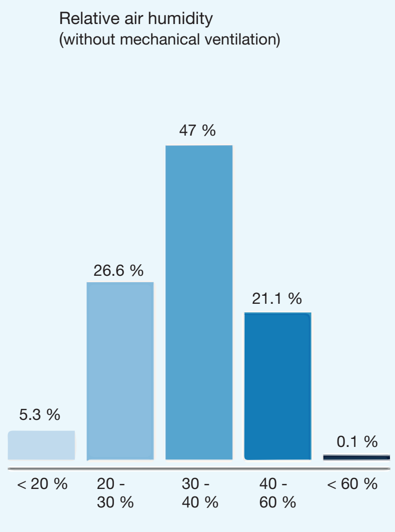


Figure 2

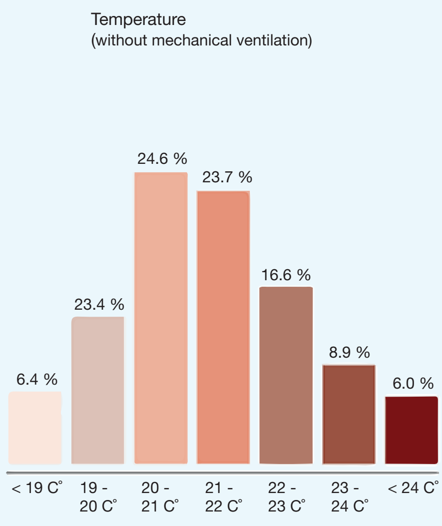


Figure 3

Evaluations from more than 100 classrooms between November 2016 and May 2017

Per classroom, at the end of each lesson the teacher entered the values recorded into a protocol for one week.

Air Quality

Application	Type code	Measured values					Output signal			Measurement range			Application/comment
		CO_2	Temperature	Humidity	VOC	Mix CO_2/VOC	Active	Modbus RTU	BACnet MS/TP	CO_2	Temperature	Humidity	
 Duct	22DC	•					•			0…2000 ppm	–	–	Duct sensor CO_2
	22DTC	•	•				•			0…2000 ppm	–	–	Duct sensor CO_2, T
	22DTM	•	•	•				•	•	0…2000 ppm	0…+50 °C	0…100% rH	Duct sensor CO_2, H, T
	22DCV	•			•		•			0…2000 ppm	–	–	Duct sensor CO_2, VOC
	22DCM	•	•		•		•			0…2000 ppm	0…+50 °C	–	Duct sensor CO_2, VOC, T
	22DCK	•	•		•	•	•			0…2000 ppm	0…+50 °C	–	Duct sensor CO_2, VOC, CO_2/VOC, T

Belimo sensors – essential for the very best room comfort

Belimo HVAC sensors offer superior reliability, easy installation and seamless integration with major building automation systems. The innovative housing design allows for quick and tool-free installation, easy commissioning and provides NEMA 4X/IP65 protection. The product range includes accurate sensors for measuring temperature, humidity, pressure, CO_2 and volatile compounds (VOCs) in pipe and duct applications.

Belimo – innovative HVAC solutions for the success of our customers

Belimo Automation AG is a world market leader in the development, production and sales of actuator solutions for controlling heating, ventilation and air conditioning systems. The company's core business includes actuators, water final control elements and sensors.

command to open or close dampers and valves or move them to an intermediate position. This enables the desired supply of air at a comfortable temperature, with the ideal level of humidity and a rich oxygen content.

Attempts to please everyone

Studies based on measurements of the room situation and user surveys reveal that the tolerance ranges need to be drastically widened if 80 percent of users are to describe the room climate in closed buildings as comfortable. Building automation for room air has a major role to play in terms of room comfort. The focus here is not only on complex system solutions for controlling heating, ventilation and air conditioning systems, but also on individual components, such as smart air damper actuators, control valves and sensors. Belimo is also working to develop intelligent Cloud solutions to further optimise the control and maintenance of such components.

One thing is for sure, whether you look at schools, hotels, offices, public buildings, production halls or commercial premises, attempts to find the best possible solutions for an optimum room climate are important. This can have a positive impact on people's well-being and performance. Who doesn't want the best possible performance to be achieved in all rooms at all times? By controlling air quality and using components such as those available from Belimo, this is incredibly easy in both new builds and renovation projects.

More information: **www.belimo.eu**

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

SUPPORTERS

LEADERS IN BUILDING SERVICES

Network of 27 European HVAC Associations
joining 120 000 professionals

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Send information of your event to Ms Chiara Girardi cg@rehva.eu

Events in 2018

Exhibitions 2018

May 22-24	ISH China & CIHE 2018	Beijing, China	https://bit.ly/2EMnJOl
July 17-19	ASEAN M&E	Kuala Lumpur, Malaysia	http://aseanmne.com/
September, 3-5	ISH Shangai & CIHE 2018	Shangai, China	https://bit.ly/2EbonUp
October 10-12	FinnBuild 2018	Helsinki, Finland	http://finnbuild.messukeskus.com/?lang=en
October 16-18	Chillventa	Nuremberg, Germany	https://www.chillventa.de/en

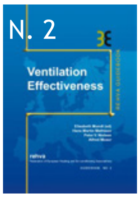
Conferences and seminars 2018

April 12-14	13th International HVAC&R Technology Symposium	Istanbul, Turkey	https://bit.ly/2BvXgB6
April 21-23	REHVA Annual Meeting	Brussels, Belgium	www.rehvam2018atic.eu
June 3-6	ROOMVENT & VENTILATION 2018	Espoo, Finland	http://www.roomventilation2018.org/
June 23–27	2018 ASHRAE Annual Conference	Houston, TX, USA	www.ashrae.org/conferences/annual-conference
September 11-12	Building Simulation and Optimization 2018	Cambridge, UK	https://www.bso2018.event.cam.ac.uk/
September 18-19	39th AIVC Conference: "Smart ventilation for buildings"	Juan-les-Pins, France	http://aivc2018conference.org/

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

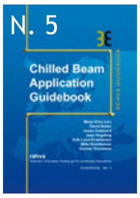
REHVA GUIDEBOOKS

written by teams of European experts



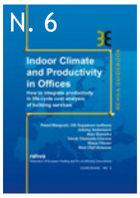
Ventilation Effectiveness

Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher costs and energy consumption associated with increasing the ventilation rates. This Guidebook provides easy-to-understand descriptions of the indices used to measure the performance of a ventilation system and which indices to use in different cases.



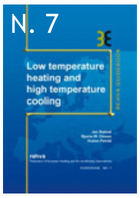
Chilled Beam Application Guidebook

Chilled beam systems are primarily used for cooling and ventilation in spaces, which appreciate good indoor environmental quality and individual space control. Active chilled beams are connected to the ventilation ductwork, high temperature cold water, and when desired, low temperature hot water system. Primary air supply induces room air to be recirculated through the heat exchanger of the chilled beam. In order to cool or heat the room either cold or warm water is cycled through the heat exchanger.



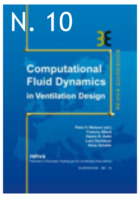
Indoor Climate and Productivity in Offices

This Guidebook shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available. The quantitative relationships presented in this Guidebook can be used to calculate the costs and benefits of running and operating the building.



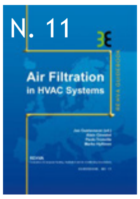
Low temperature heating and high temperature cooling

This Guidebook describes the systems that use water as heat-carrier and when the heat exchange within the conditioned space is more than 50% radiant. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in all types of buildings and work with heat carriers at low temperatures for heating and relatively high temperature for cooling.



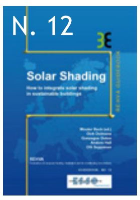
Computational Fluid Dynamics in Ventilation Design

CFD-calculations have been rapidly developed to a powerful tool for the analysis of air pollution distribution in various spaces. However, the user of CFD-calculation should be aware of the basic principles of calculations and specifically the boundary conditions. Computational Fluid Dynamics (CFD) – in Ventilation Design models is written by a working group of highly qualified international experts representing research, consulting and design.



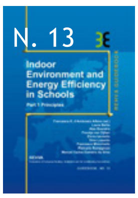
Air Filtration in HVAC systems

Air filtration Guidebook will help the designer and user to understand the background and criteria for air filtration, how to select air filters and avoid problems associated with hygienic and other conditions at operation of air filters. The selection of air filters is based on external conditions such as levels of existing pollutants, indoor air quality and energy efficiency requirements.



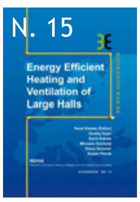
Solar Shading

Solar Shading Guidebook gives a solid background on the physics of solar radiation and its behaviour in window with solar shading systems. Major focus of the Guidebook is on the effect of solar shading in the use of energy for cooling, heating and lighting. The book gives also practical guidance for selection, installation and operation of solar shading as well as future trends in integration of HVAC-systems with solar control.



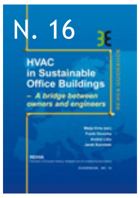
Indoor Environment and Energy Efficiency in Schools

School buildings represent a significant part of the building stock and also a noteworthy part of the total energy use. Indoor and Energy Efficiency in Schools Guidebook describes the optimal design and operation of schools with respect to low energy cost and performance of the students. It focuses particularly on energy efficient systems for a healthy indoor environment.



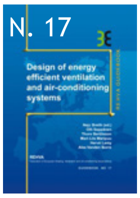
Energy Efficient Heating and Ventilation of Large Halls

This Guidebook is focused on modern methods for design, control and operation of energy efficient heating systems in large spaces and industrial halls. The book deals with thermal comfort, light and dark gas radiant heaters, panel radiant heating, floor heating and industrial air heating systems. Various heating systems are illustrated with case studies. Design principles, methods and modelling tools are presented for various systems.



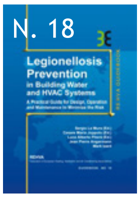
HVAC in Sustainable Office Buildings

This Guidebook talks about the interaction of sustainability and heating, ventilation and air-conditioning. HVAC technologies used in sustainable buildings are described. This book also provides a list of questions to be asked in various phrases of building's life time. Different case studies of sustainable office buildings are presented.



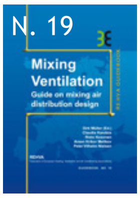
Design of energy efficient ventilation and air-conditioning systems

This Guidebook covers numerous system components of ventilation and air-conditioning systems and shows how they can be improved by applying the latest technology products. Special attention is paid to details, which are often overlooked in the daily design practice, resulting in poor performance of high quality products once they are installed in the building system.



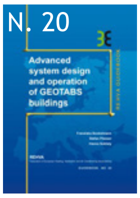
Legionellosis Prevention in Building Water and HVAC Systems

This Guidebook is a practical guide for design, operation and maintenance to minimize the risk of legionella in building water and HVAC systems. It is divided into several themes such as: Air conditioning of the air (by water-humidification), Production of hot water for washing (fundamentally but not only hot water for washing) and Evaporative cooling tower.



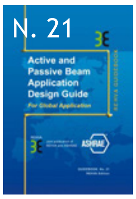
Mixing Ventilation

In this Guidebook most of the known and used in practice methods for achieving mixing air distribution are discussed. Mixing ventilation has been applied to many different spaces providing fresh air and thermal comfort to the occupants. Today, a design engineer can choose from large selection of air diffusers and exhaust openings.



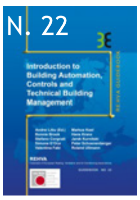
Advanced system design and operation of GEOTABS buildings

This guidebook provides comprehensive information on GEOTABS systems. It is intended to support building owners, architects and engineers in an early design stage showing how GEOTABS can be integrated into their building concepts. It also gives many helpful advices from experienced engineers that have designed, built and run GEOTABS systems.



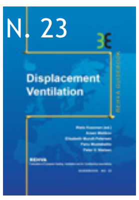
Active and Passive Beam Application Design Guide

This Guidebook is the result of collaboration by worldwide experts. It provides energy-efficient methods of cooling, heating, and ventilating indoor areas, especially spaces that require individual zone control and where internal moisture loads are moderate. This publication provides up-to-date tools and advice for designing, commissioning, and operating chilled-beam systems to achieve a determined indoor climate and includes examples of active and passive beam calculations and selections.



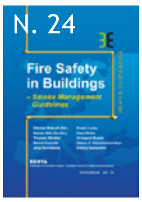
Introduction to Building Automation, Controls and Technical Building Management

This Guidebook provides an overview on the different aspects of building automation, controls and technical building management and steer the direction to further in depth information on specific issues, thus increasing the readers' awareness and knowledge on this essential piece of the construction sector puzzle. It focuses on collecting and complementing existing resources on this topic in the attempt of offering a one-stop guide.



Displacement Ventilation

The aim of this Guidebook is to give the state-of-the art knowledge of the displacement ventilation technology, and to simplify and improve the practical design procedure. The Guidebook discusses methods of total volume ventilation by mixing ventilation and displacement ventilation and it gives insight of the performance of the displacement ventilation. It also shows practical case studies in some typical applications and the latest research findings to create good local micro-climatic conditions.



Fire safety in buildings. Somke Management Guidelines

This guidebook describes the different principles of smoke prevention and their practical implementation by way of natural and mechanical smoke extraction systems, smoke control by pressurization systems and appropriate partition measures.

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