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Towards HEAnZEBs!

Recently, I was invited by a group of civil servants engaged in the update of the current Dutch EPB regulation based of the expected EPBD revision. My contact person asked me, beforehand, to focus my presentation on health and comfort of building occupants in nearly Zero Energy Buildings (nZEBs).

I started my presentation saying: 'I'm worried about this and I truly believe that it is high time that you start worrying about this too.' That maybe wasn't what they wanted to hear, but they asked for my honest and professional opinion which I was happy to share.

Which are my worries? Since the Paris Agreement, everybody seems to be interested in nothing but the energy performance of both existing and new buildings. I do see the need to fight global warming and drastically cut back on CO_2 emissions. There is no time to lose. However, during the last couple of years I have seen (and investigated) a lot of transformed and new buildings, (re)designed with an energy agenda that had unwanted and serious side effects.

For example, some problems that I have come upon in class A (A+) energy performing dwellings, schools and offices include: overheating in summer, underventilation in winter, severely limited daylight penetration, too noisy HVAC systems and overcomplicated climate controls. These are important issues, as a suboptimal Indoor Environmental Quality (IEQ) will affect the wellbeing and productivity of building occupants.

Fortunately, REHVA is aware of the need to look beyond just energy performance improvement. In a previous issue of REHVA Journal, we presented the REHVA position paper on the European Commission proposal of the revised Energy Performance of Buildings Directive (EPBD). In this position paper*, the recommendation No. 1 was: '*Ensure high indoor environmental quality and energy efficiency at the same time*'.

This recommendation is in line with the thoughts behind the original political document, the 2010 EPB Directive. That document states that measures designed to improve the energy performance of (new or existing) buildings should consider indoor climate conditions in order to avoid possible negative effects 'such as inadequate ventilation'. It, furthermore, states that aspects like indoor air quality, adequate natural light and shading should be taken into account when (re)designing energy-efficient buildings.

The good news is that countries that want to ensure that the Indoor Environmental Quality of our future nearly Zero Energy Buildings is adequate can now find examples of IEQ performance criteria in FprEN 16798-1 (the upgraded version of EN 15251). This CEN standard presents requirements that can be used when one wants to avoid problems with overheating, underventilation, installation noise, etc.

Several articles in this special issue of REHVA Journal support the hypothesis that the health and comfort performance of buildings is as important as the energy performance. Authors from Europe, South-America, China and India explain that aspects like fine particle exposure, personal control options and sensor technology aimed at local IEQ improvement should be addressed too.

I ended my presentation with the Dutch EPBD recast group saying that, in my opinion, we should start to systematically create buildings that are *both* healthy and energy efficient. It's a real risk to keep focusing only on energy performance. 'Instead let's create HEAlthy nearly Zero Energy Buildings (I use the abbreviation HEA for HEALTH here, in line with the BREEAM certification scheme). What we need is not nZEBs but HEAnZEBs!

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* http://www.rehva.eu/fileadmin/Publications_and_resources/Position_papers/EPBD_proposal_REHVA_position.pdf

PEOPLE FIRST!
Interview with Bjarne Olesen

Professor Bjarne Olesen is Head of the International Centre for Indoor Environment and Energy (ICIEE) at the Danish Technical University (DTU) in Lyngby, just North of Copenhagen. Bjarne has 45 years of experience working in the HVAC field, both as a researcher and as a practitioner. Besides his employment at the Technical University of Denmark and 1½ year at Virginia tech, he has worked many years in the industry. He worked 11 years part-time at Brüel&Kjær and 11 years for Velta and for Uponor. Bjarne has published over 400 scientific papers and conference papers. He was president of the international Indoor Air conference that was held in Copenhagen in 2008 and, for more than 35 years, he has been involved in standard writing (e.g. within ASHRAE, DIN, DS, CEN and ISO). Several of the EPBD & EPBD recast standards have been developed under his supervision. From 2011 till 2014 he was member of the REHVA board of directors. This summer – at the ASHRAE summer meeting that is held June 24th–28th in Long Beach, California – he will be installed as president of ASHRAE.

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Keywords: thermal comfort, indoor air quality, productivity, policy, net zero energy buildings (nZEB), standardisation, ventilation, heating, cooling.

What makes your heart beat faster? What are you really passionate about?

BJARNE OLESEN

I think that it is essential that we create a good indoor environment in our buildings, that we built and maintain offices, schools, dwellings etc. and their building service systems in such a way that healthy and comfortable living environments are provided for all. Of course, all in such a way that low energy use is guaranteed too.

For me the people-factor has always been important. As a Master student in the early 70's I had planned to get a summer job as a land surveyor in Greenland, at that time, that paid really well. They did not select me and, then, a certain Professor Fanger asked me to do some summer work instead. He involved me in a lab study with subjects that looked at mental performance and thermal comfort. To my own surprise, the relation between environment and technology on the one hand and people, comfort and productivity on the other really triggered me. So, I decided to study with Professor Fanger, to do a Master thesis and after that a PhD thesis. The subject of course had to be people-related: it dealt with local discomfort, floor temperature and radiant floor heating/cooling.

Since then, of course, HVAC technology has developed, but I still think that it is important to put people first, to always look beyond the technology, to work with IEQ requirements that are system independent and to strive at optimizing the energy and health performance of buildings simultaneously.

What are the most important changes that you saw in more than 4 decades of activity in our field?

Certainly, a lot has changed over the years. It is maybe hard to imagine now but, till the 60's, we kind of only looked at air temperatures when we designed HVAC systems. Then, we and others from the US came up with the suggestion to systematically include radiant temperature, air speed and humidity, and, at the same time, to look at the combined influence of several parameters such as clothing and metabolism when objectifying thermal comfort.

In the 80's, the focus shifted away from thermal comfort to Indoor Air Quality (IAQ) partly due to a growing number of stories in the media about Sick Buildings. In retrospect, I think that the oil crisis in the 70's and the fact that we started building more airtight buildings without well-functioning ventilation systems caused a lot of IAQ problems. Until the 70's, we all thought that the only thing we had to deal with were people as dominant source of air pollution inside buildings and CO_2 as a tracer for people. At the Denmark Technical University, we were able to show that interior materials and HVAC components could be strong emitters too, e.g. thinking about volatile organic compounds and micro-organisms.

Of course, there is smoking and exposure to second hand tobacco smoke too. In the 80's, in many countries (including Denmark) people were still allowed to smoke in offices, in restaurants, in schools, in airplanes, etc. My colleague Geo Clausen, at the time, showed that if you smoke in a building, any other source becomes more or less irrelevant.

From the beginning of the 90's, we saw a growing interest in field studies and in task performance. We started to look beyond environmental parameters and investigated how suboptimal conditions affect productivity in offices or call centres as well as learning performance in schools. At that time, we also saw the introduction of a couple of innovative climate technologies that work with a separation of the functions of temperature control and fresh air supply. Think of systems such as TABS (Thermal Active Building Systems) and micro-climatisation or personal ventilation systems.

As far as IAQ and materials are concerned, at the end of the 90's, low emission labels for materials were introduced (like the Danish Indoor Climate label).

Since about 15 years ago, also health effects were on the agenda as, for example, the studies of Carl-Gustav Bornehag and Jan Sundell that linked exposure to phthalates in the air (in dust samples) and asthma in young children.

Since the Paris Agreement on Climate Change, the society seems to be speeding up when it comes to decarbonization of our world, and improving the energy performance of our buildings. Some are afraid that this will have negative side-effects, especially in terms of building occupant health and comfort. What is your opinion about this?

I recognize that an overfocus on energy performance can lead to health and comfort problems. I know of nZEB projects that had severe overheating problems after they were occupied. Problems that, of course, could have been avoided doing the right kind of calculations or simulations beforehand. Furthermore, the fresh air supply can be an issue, in fact, energy efficient buildings come with very airtight facades, so, when the ventilation system is not well designed or the system has not been correctly installed, it will for sure lead to IAQ problems. That is one other reason why we should pay more attention to the commissioning of HVAC systems.

Nevertheless, I am convinced that the different aspects can be combined. It is just a matter of good design and smart choices. When a new building is designed or an existing building is renovated, the energy performance requirements and, also, thermal comfort, indoor air quality and noise from building service systems should be taken into account. One of the EPBD standards that we have been working on, addresses this: FprEN 16798-1 (formerly known as EN 15251). This standard describes indoor environmental input parameters that can be used for the design and assessment of energy performance of buildings. As a sector, we need to help create nZEB buildings that are not just energy efficient but that are also healthy, comfortable and that meet relevant IEQ requirements.

The third week of June you will be installed as ASHRAE president. Are there specific aspects that you will focus on during your presidency?

First of all, I want to make ASHRAE more global and show that we are not only a North-American society. We need to improve our services to our membership outside North-America. This will be done in collaboration and not in competition with other HVAC societies. For example in Europe, REHVA is a very important partner. Even if our memberships are different we have the same goal to provide health and comfort for the occupants in a sustainable way.

Then, I will push for more focus on IEQ and energy use in dwellings. Traditionally, organisations like REHVA and ASHRAE focus on offices, schools, hospitals and other commercial or public buildings. In my eyes, the residential sector will bring a lot of new opportunities in the coming years. Our homes have to be made more energy efficient, and all this in a smart way with adequate attention to the health and comfort needs of occupants. To do this we will have to introduce much more advanced heating, ventilation and cooling technologies in both new and existing dwellings. In that respect, I plan to increase ASHRAE's involvement in the student competition "Solar Decathlon" not only in USA; but around the world.

I would also like to capitalize on the research findings we have now about IEQ and people-effects, especially task performance. Most decision makers are not overly interested in technology per se or IEQ requirements. Nonetheless, most of them certainly are interested in end-user effects like productivity, especially when we can link it to property value assessment and a concrete return on investment.

A third thing that I will focus on is public health in relation to the design and operation of building service systems. Not just in North America and Europe but especially in emerging economies. Certain public health risks can be minimized when building technology is introduced in the right way. Think for example of advanced ventilation systems and ditto filtration systems that are designed to keep the particles out in a building that is located in an area with suboptimal outdoor air quality.

You are one of the initiators of the Global Alliance IEQ that is also supported by REHVA. Can you tell a bit more about this?

Originally, this was ASHRAE's Bill Bahnfleth's idea and I have been involved in this from the start. I am very happy that REHVA has decided to join us, as did AIVC (the Air Infiltration and Ventilation Centre).

The basic idea is to create a platform for organizations that want to stimulate good indoor environments. The goal of the Indoor Environmental Quality Global Alliance (IEQ-GA) is to be the world's primary source for information, guidelines and knowledge on the indoor environmental quality in buildings. Via this new global alliance, we hope to establish better contacts with global organisations like the United Nations and the World Health Organisation.

We do not just focus on thermal aspects and indoor air quality, we are also talking to organisations that are specialized in light and noise. So the idea is to become an IEQ alliance in the broad sense. For more information about the Global alliance, see the alliance's website: http://ieq-ga.net/.

Any specific message to those that just entered our field? A word of wisdom for young HVAC professionals and young researchers, the leaders of tomorrow?

Interesting question. I am determined, during my presidency, to convince more young professionals to come join our sector and to help us make a better world.

Recently one of my PhD students walked into my office at DTU and he asked: 'What do I have to do to become like you?'. After laughing about the question for more than a minute, I answered him and gave him 3 tips-for-live.

First, I said, you have to select 1 or 2 areas that you want to become one of the best in. You really have to be specialized. If you try to be good at too many things you will never excel in anything.

The next thing, I said, was: always make sure that whatever you say, as a professional, is evidence-based. Each argument that you use during a discussion or in a paper has to be backup by either your own data, or by research data from others. No room for fake news in our field, sorry!

My third and last tip was: develop a good, international network and put people first now and then. Start with the network built already as a student to get things done in the future. To initiate a change, you need to cooperate with others and you can only do that if, beforehand, you have invested lots of time in meeting the right kind of people, e.g. at international conferences and during ASHRAE or REHVA events. ■

Performance-based approaches to residential smart ventilation

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Energy-efficient homes require rethinking the ventilation and the air change rates, because of their increased impact on thermal losses. For these high performance homes, envelope airtightness treatment becomes crucial (Erhorn et al., 2008) and should be combined with efficient ventilation technologies.

Indoor air quality is another major area of concern in buildings which is influenced by ventilation. Because people spend most of the time in residential buildings (Klepeis et al., 2001), especially in their bedrooms (Zeghnoun et al., 2010), and 60–90% of their life in indoor environments (homes, offices, schools, etc.) (Klepeis et al., 2001; European commission 2003; Brasche and Bischof, 2005; Zeghnoun et al., 2010; Jantunen et al., 2011), indoor air quality is a major factor affecting public health. Logue et al. (2011b) estimated that the current damage to public health from all sources attributable to IAQ, excluding second-hand smoke (SHS) and radon, was in the range of 4,000–11,000 µDALYs (disability-adjusted life years) per person per year. By way of comparison, this means that the damage attributable to indoor air is somewhere between the health effects of road traffic accidents (4,000 µDALYs/p/yr) and heart disease from all causes (11,000 µDALYs/p/yr). According to the World Health Organization (WHO, 2014), 99,000 deaths in Europe and 81,000 in the Americas were attributable to household (indoor) air pollution in 2012. Health gains in Europe (EU-26) attributed to effective implementation of the energy performance building directive, which includes indoor air quality issues, have been estimated at more than 300,000 DALYs per year.

In order to conciliate energy saving and indoor air quality issues, interest in a new generation of smart ventilation systems, including demand-controlled ventilation (DCV), has been growing for 30 years. A number of ventilation standards and national regulations have progressively integrated an allowance for smart ventilation strategies and/or DCV systems in residential buildings. Simultaneously, progressively energy performance regulations include the opportunity to claim credit in energy calculations for savings from such systems. In Europe, several countries enable the use of DCV systems in ventilation codes, including Belgium, France, Spain, Poland, Switzerland, Denmark, Sweden, the Netherlands, Germany (Savin and Laverge, 2011; Kunkel et al., 2015; Borsboom, 2015). The corresponding energy regulations are more or less recent.

Thanks to "performance-based approaches", such systems must often be compared either to constant-airflow systems ("equivalence approaches") or to fixed IAQ metrics thresholds. Given these opportunities, DCV strategies have been used at massive scale, notably in France and in Belgium, for more than 30 years. On August 1st, 2016, 23 DCV systems in France, 34 in Belgium, 37 in the Netherlands have received an agreement. Most of them are CO_2 or humidity-based strategies.

IAQ performance-based approaches could be used in many ways. Table 1 gives an overview of the performance-based approaches used in 5 standards and regulations. Each country uses different IAQ indicators, calculated through different methodologies and compared to different thresholds. The common thread in all of these methods is the use at a minimum, of the exposure to a pollutant generated indoors (very often the CO_2), sometimes combined with the condensation risk. A minimum airflow rate for unoccupied periods is also often required.

Pushed by the international movement toward nearly-zero energy buildings, smart ventilation system success is not about to end. In Europe, two recently published directives n°1253/2014 regarding the eco-design requirements for ventilation units and n°1254/2014 regarding the energy labelling of residential ventilation

Overview of performance-based approaches to residential smart ventilation in 5 standards and regulations.

Country	Person in charge	Ventilation Equivalence method	Calculated IAQ indicators
USA and Canada (ASHRAE 62.2 2016)	The manufacturer, specifier or designer is supposed to certify that the calculation meets the requirements.	Single zone modelling, $\Delta t < 1$ h, constant pollutant emission rate.	No specifically defined pollutant. Yearly average relative exposure R<1. At each time-step $R_i<5$.
France	The manufacturer for each (humidity) DCV system shall pass through an agreement procedure.	Multizone modelling with MATHIS, $\Delta t = 15$ min, Conventional entry data.	**Per room, over the heating period:** 1/CO_2 cumulative exposure indicator $E_{2000} < 400,000$ ppm.h. 2/Number of hours $T_{RH>75\%}$ <600 h in kitchen, 1000 h in bathrooms, 100 h in other rooms.
Spain (<2017)	The manufacturer for each DCV system shall pass through an agreement procedure.	Multizone modelling with CONTAM, $\Delta t = 40$ s, Conventional entry data.	**Per room, over the year:** 1/ Yearly average CO_2 concentration < 900 ppm. 2/ Yearly cumulative CO_2 exposure over 1600 ppm $E_{1600} < 500,000$ ppm.h.
Spain (summer 2017)	The designer of the building, of the base of information given by the manufacturer.	A performance-based approach for all ventilation systems is going to be implemented, using a software and conventional data at the design stage of each building.	**Per room, over the year:** 1/ Yearly average CO_2 concentration < 900 ppm. 2/ Yearly cumulative CO_2 exposure over 1600 ppm $E_{1600} < 500,000$ ppm.h.
Belgium (<2015)	The manufacturer for each DCV system shall pass through an agreement procedure.	Multizone modelling with CONTAM, $\Delta t = 5$ min, conventional entry data both deterministic and stochastic.	**Per room, over the heating period:** 1/CO_2 cumulative exposure indicator E'_{950}. 2/Monthly average RH> 80% on critic thermal bridges from December 1st to March 1st. 3/Exposure to a tracer gas emitted in toilets and in bathrooms. They must be at least equal that the worst performing reference system.
Belgium (since 2015)	The person involved in EP-calculation and manufacturer for each DCV system.	No-more existing. An advanced equivalence method has been performed by (Caillou et al., 2014) on all the systems having an agreement.	No-more existing.
The Netherlands	The person involved in EP-calculation (standard approach) OR he manufacturer for each DCV system (equivalence approach).	Even if correction factors are given in the standard, a complementary equivalence approach can be performed, using the multizone pressure code COMIS, in a semi-probabilistic approach.	**Per person, over the heating period:** Cumulative CO_2 exposure over 1200 ppm: $LKI_{1200} < 30,000$ ppm.h.

units (European Parliament and the Council, 2014) are moving toward a generalization of low-pressure systems, DCV systems and balanced heat recovery systems at the 2018 horizon.

The common thread in all of these performance-based approaches is the use, at a minimum, of the exposure to a pollutant generated indoors (very often the CO_2) and condensation risk. Such approaches and corresponding selected IAQ indicators could be criticized in many ways but they exist and have been tested for few years. They could be considered as an interesting background for future IAQ performance-based approaches at the design stage of every new residential building. ■

	Credit in EP-calculation	Minimum airflow
	No.	Can be null if the total airflow rate equivalence is required over any 3-hour periods.
	Average equivalent exhausted airflow (m^3/h) can be implemented in the EP-calculation.	Switch off not allowed, minimum airflow is 10-35 m^3/h according to the number of rooms in the building.
	Yearly average ventilation airflow could be implemented in the EP-calculation.	
	Yearly average ventilation airflow could be implemented in the EP-calculation.	The minimum airflow during unoccupied periods is set to 1.5 $l.s^{-1}$ in each room.
	An energy saving coefficient f_{reduc} is extrapolated and can be implemented in the EP-calculation.	
	Published conventional energy saving coefficients can be used directly in the EP-calculation. They depend on the sensing type, type of spaces and the regulation type	Minimum airflows over 10% of the minimum constant airflow for each room. An intermittent ventilation is allowed if the average on 15 minutes enables to comply with this 10%.
	Either, correction factors given in the standard for quite a few DCV systems, are used directly in the EP-calculation, OR Correction factors from the equivalence procedure can be used.	A function of the number of type of occupants.

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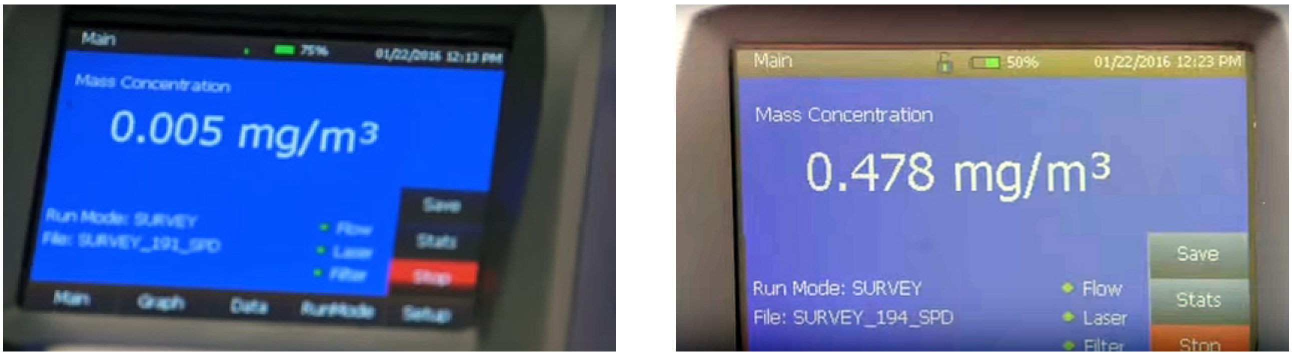
Indoor Air Quality Improvement in a School Building in Delhi

MAIJA VIRTA

Mrs. Maija Virta is the Founder and Director of Santrupti. She has 30 years of experience in construction and HVAC-industry and she has been in India for the last 5 years. Her key areas of expertise are IEQ, energy efficiency of buildings as well as sustainable building policies and technology. Prior to moving to India, Maija was the CEO of the Green Building Council Finland. Among her various contribution to this field, she has authored many books and publications on sustainable buildings and technology. She has lectured on innumerable topics for ISHRAE, REHVA and ASHRAE. She is the member of ISHRAE IEQ task force preparing the IEQ standard for India as well as the member of IGBC task force that is developing local wellbeing standard.

After the indoor air quality measurements, occupant satisfaction surveys and system performance analysis in March 2014, the target was set to reduce indoor air particulate matter PM2.5 (2.5 $\mu g/m^3$ and smaller) level to be 70% below ambient air level, to remove traffic emissions (gases) from supply air and improve the cooling in classrooms. Before carrying out this project, the indoor air was as bad as outdoor air or in some cases worse. After finishing the project, the indoor air quality was measured and compared with ambient air measurements. During the first measurement period, ambient air PM2.5 level was 142 $\mu g/m^3$ and the air in the classrooms 95% less i.e. 7 $\mu g/m^3$. To monitor this improvement continuously, the school has installed in 2016 the continuous Indoor Air Quality monitors in each classroom, and they now demonstrate continuously the very low particulate matter levels (95–98% reduction of the ambient levels).



Simultaneous indoor and outdoor air PM2.5 measurement result one year after the refurbishment.

Introduction

Millions of people die each year due to air pollution and indoor air pollution is the second highest killer in India. Respirable Suspended Particulate Matter (RSPM) is the main ambient and indoor air pollutant in India[1]. Between 2005 and 2010, the death rate rose by 4% worldwide and by 12% in India. Cost of air pollution to society in 2010 was estimated at US$ 0.5 trillion in India according to a study by the Organization for Economic Co-Operation and Development (OECD)[2]. According Central Pollution Control Board's (CPCB) database[3] that includes RSPM data of 124 Indian

[1] UNEP Year Book, 2014. Air Pollution: World's Worst Environmental Health Risk.

[2] OECD Report, 2014. The Cost of Air Pollution: Health impacts of road transport.

[3] CPCB, Environmental Data Bank, Central Pollution Control Board, Government of India.

cities, 123 cities have the PM2.5 annual average level above WHO Air Quality Guideline level (10 µg/m³)[4]. Delhi annual average PM2.5 value was 122 µg/m³. The International Agency for Research on Cancer (IARC) and WHO concluded in 2013 that ultra-fine particulate matter is carcinogenic to humans[5].

In this project, we focused on the indoor air quality improvement in a one of the largest international school campuses in Delhi.

The school campus consists of 10 school buildings and 3 residential buildings. Each building has a mechanical ventilation system with cooling. The typical system consists of an air handling unit (AHU) located inside an air handling unit room. The air handling unit is supplying the cooled air into the classrooms or apartments via ducts. The return air path is a ceiling void and corridors. Fresh air intake is via a duct from the façade into the air handling unit room. Outdoor air volume is controlled by a damper at the end of the duct. Some of the classrooms and apartments have e additional fan coil units for local cooling. All air handling units had either EU2 or EU4 filters.

School campus in Delhi.

The school wanted to address increased concerns with indoor air quality (IAQ) as it is related to staff and student health. But it was not clear for the school what all need to be done to ensure good air quality inside the buildings. Room air purifiers had been tested but the air quality results were not good and, also, the high maintenance was an issue. Lots of plants had already been located in school premises to purify air, but mechanical ventilation system had not been addressed.

4 WHO, 2005, Air Quality Guidelines.

5 IARC and WHO, 2013. Outdoor air pollution a leading environmental cause of cancer deaths, press release no. 221.

User satisfaction results before refurbishment.

Indoor Air Quality was studied thoroughly in School Campus

To improve indoor air quality (IAQ) in school campus, we first had to understand the current performance of ventilation systems in each building, the current maintenance practices and the current IAQ & user satisfaction. In the second phase the recommended solution was designed and piloted in one of the buildings and then later the same concept with some improvements were executed in all buildings at the campus.

During the 'Indoor Air Quality and Ventilation System Performance Study' we reviewed all buildings in the school campus. We studied the maintenance practices, we conducted the user satisfaction survey, we measured the indoor air quality (IAQ) parameters in various locations in each building and we studied the ventilation system operation.

The User Satisfaction Survey consisted on three major elements: perceived indoor environmental quality (based on the CBE Berkeley questionnaire), users' awareness of air quality problems in Delhi and user's Building Related Health Symptoms (based on the Orebro MM40 questionnaire). We covered the following areas: Thermal comfort, Indoor air quality, Lighting and daylight, Acoustic conditions and Cleanliness. Survey results shows that the Indoor Air Quality (60% dissatisfied) and Thermal Comfort (40% dissatisfied) are the two major areas creating dissatisfaction among the users.

The only symptom that stands out is coughing which may be due to the high level of particulates and irritants in the respiratory system.

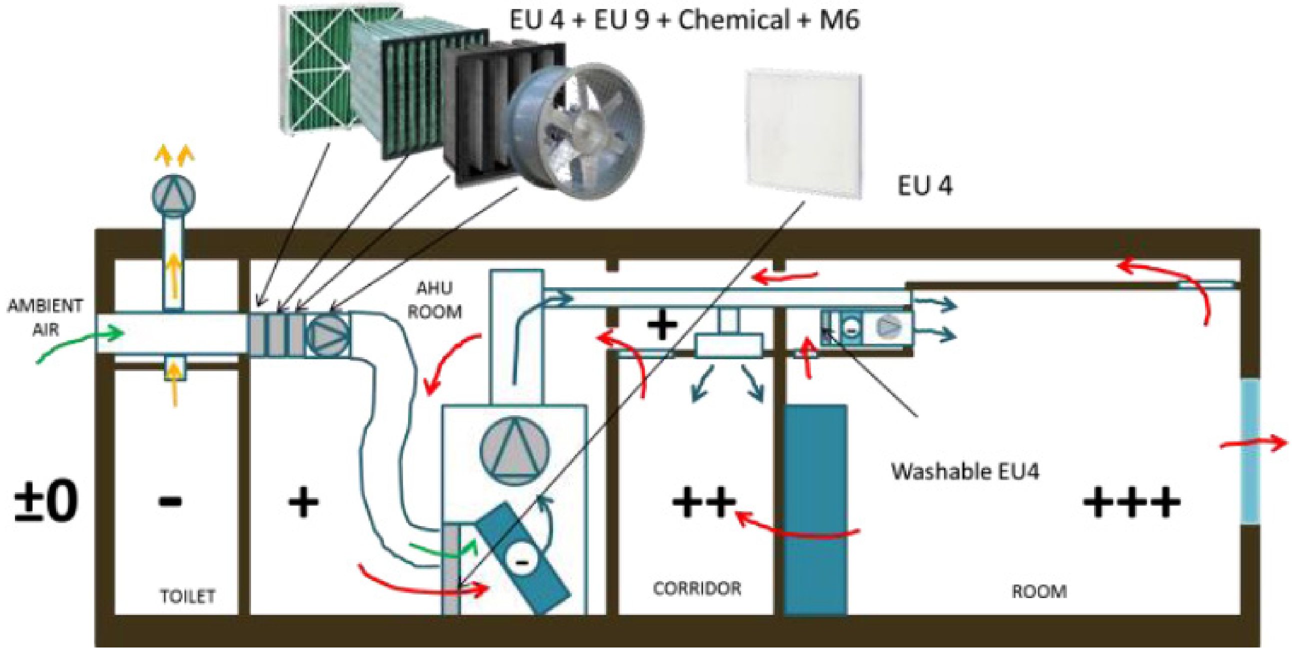
We measured temperature, relative humidity, CO_2 and particulate matter in several locations in each building. Temperature was mainly comfortable in all those spaces, where either fan coil units were operating or ventilation was properly functioning. High temperature and CO_2 were problems in the rooms where there was no sufficient ventilation. Relative humidity was mainly below 65%, however during the measurements the outdoor air was very dry. The biggest IAQ problem were the high ultra-fine particulate matter (PM2.5) levels. They were very high everywhere, sometimes even higher than in the outdoor air, especially near the doors and in the spaces with several printers and copy machines. The PM5 levels were between 100 and 200 µg/m³ during the measurement both in indoor air and outdoor air.

Ventilation System Performance Audit

During the ventilation system performance review, we measured air flow rates in each air handling unit and pressure loss across each component (filters, cooling coil and fan). Air flow rates in all air handling units were below design value. The current filtration G3+G4 was not sufficient to remove RSPM. The pressure loss across the filter section was very low, about 40–100 Pa only, indicating the poor quality of current G4 filters. This was confirmed with visual inspection – there were lots of damaged filters and due to the regular washing, the filter media had worn out.

Recommendations to improve IAQ

To improve air quality, ambient air and AHU filtration needs to be improved, buildings needs to be properly over-pressurized to avoid ambient air from entering indoors via windows and doors and each room to have the sufficient amount of supply air. Maintenance and operation of ventilation system needs to be improved. HVAC-system components (including AHU rooms) need to be maintained at a high standard. Operation and maintenance personnel need additional training



Proposed Ambient Air Purifier solution to clean the outdoor air before it is supplied to the AHU room.

to better manage the operation of ventilation and air conditioning system in each building. Regular 3rd party inspection of indoor air quality and HVAC-system operation is required.

Ambient Air Purifier is the core of the IAQ solution

The main target was to reduce indoor air particulate matter PM2.5 level to be 70% below ambient air level. Simultaneously, traffic emissions (NO_2, SO_2, O_3) shall be removed from the supply air and cooling capacity needs to be improved in classrooms by ensuring correct ventilation rates and balancing the ductwork properly.

The selected solution consists of retrofitting an ambient air purifier into each AHU room, repairing and cleaning the ventilation system, balancing the ductwork and improving the system maintenance. Ambient Air Purifier (AAP) is a fan-filter unit that cleans the outdoor air before it is supplied into the AHU room. The fresh air supply of each unit was designed at 1.5 l/s,m² (which equals 15% of the total air handling unit air volume), which gives the air exchange efficiency of 2 air changes per hour. Each unit has a place for five filters: washable G4 filter, M5 coarse filter, F9 fine filter, chemical filter and M6 post-chemical filter. This unit shall give the filtration efficiency that is more than 99% for PM2.5, 100% for PM10 and remove gases from outdoor air.

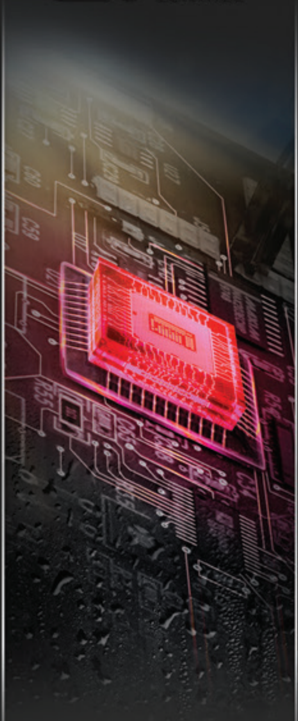
The ventilation system required lots of small repairs and maintenance activities. All air handling unit rooms were cleaned and sealed properly. New G4 filters were installed to all air handling units. Some ductwork modifications were done. All loose mineral wool surfaces were covered inside the air handling units and ducts. Ducts and diffusers were cleaned. After installing the Ambient Air Purifier units, some new balancing dampers were installed and all ductworks were balanced in order to have sufficient ventilation and to maintain positive pressure in all classrooms against outdoor air and other spaces.

Independent third-party validation proved the results

After the pilot project the indoor air quality was measured and compared with ambient air quality as the target was set relative to that. During the measurement period, the ambient air PM2.5 level was 142 µg/m³ and in the classrooms 7 µg/m³. This is 95% less than ambient air level. Also, SO_2, NOx and O_3 levels were below detectable limit.

This case study shows that indoor air quality can be improved a lot even in the most polluted cities in the world by designing and maintaining the ventilation system properly and that standalone, high maintenance requiring room air purifiers are not necessary. In this case, the ambient air purifiers were installed, but the same result in terms of IAQ could have been achieved by retrofitting existing air handling units with similar set of filters and new EC fans. However, this would have meant higher filtration and energy cost, as the improved filtration would have been needed for the total air volume. Now the higher-pressure loss impacts only 15% of the air and also the number of filters to be changed annually is less. This case study proves, that as long as the main pollution source is the outdoor air, good IAQ can be achieved by just properly cleaning the outdoor air before supplying it into a building. ■

DUAL SENSING CONTROL



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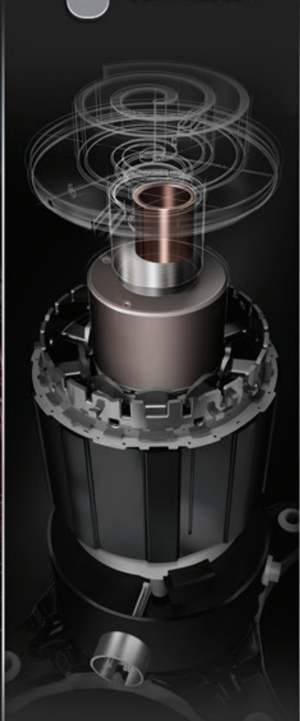

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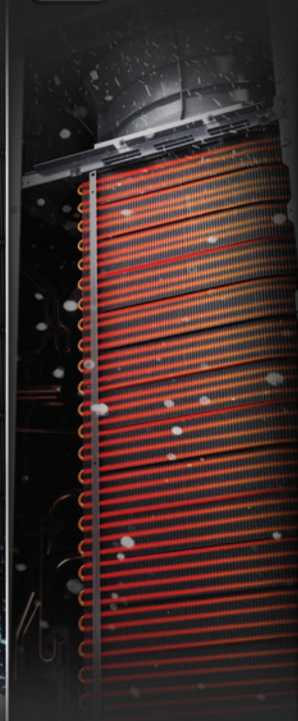

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3D printing of HVAC systems

3D-Printing (additive manufacturing) has been a paradigm change for the manufacturing industry especially on the last decade. It is expected that it will be used in the enterprise within the following 2-5 years. We predict that additive manufacturing will be the primary method for the production of HVAC systems; firstly, components such as heat exchangers (3D-CM), followed by the Equipment Manufacturing (3D-EM), and finally the technology will be adopted to the integrated design and 3D building construction (3D-BC).

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Introduction

3D-Printing (additive manufacturing) has been a paradigm change for the manufacturing industry especially on the last decade. It has basically been used as a hobby tool and for the production of non-functional parts to aesthetically control the design, it is also being used for manufacturing functional parts in the prototyping phase in a very wide range of industrial fields. As the technology has been developed, additive manufacturing has also been used for production of fully functional parts, even in the aerospace industry. There are many organizations and collaborations to study the technology and environmental impact of additive manufacturing and build the industrial standards. It is expected that additive manufacturing will take the place of today's industrial production methods and affect value chains to a significant extent within the next decades, along with the development of relevant design theory and tools. Especially, the future of industry shaped upon "cloud manufacturing" and "mass customization", relies on additive manufacturing the most. The Hype Cycle of Gartner on emerging Technologies reports that enterprise 3D printing is to be used in the main stream industry in the following 2–5 years.

One of the areas that additive manufacturing will have a significant impact will be the Architecture, Engineering and Construction (AEC) industry. The hot topic about building technology is integrated design that includes the overall design of a building including all of its components in harmony. This was also a hot topic in the old times. Two examples of integrated design solutions of the past are Ondol and Hypocaust systems. Ondol system is an example from the eastern world that was used in the traditional houses of Korea for cooking and underfloor heating simultaneously. Hypocaust is an example of integrated design of Greco-Roman World, which is a kind of central heating system in a building that produces and circulates hot air below the floor of a room, and may also warm the walls with a series of pipes through which the hot air passes. The hot air carried by the pipes can warm the upper floors as well [1].

The hypocaust system was built by bricks, which is a kind of additive manufacturing process (**Figure 1**). Therefore the Hypocaust system can be assumed as the ancestor of the near future's buildings, which will be constructed in a holistic approach. The buildings of the future will be constructed at once by additive manufacturing with all of their architectural elements, HVAC systems, and sanitary systems, as their ancestors were built.

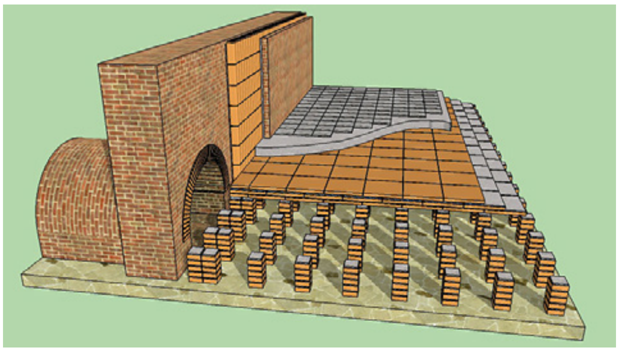


Figure 1. A Hypocaust system construction. [2]

An early example on additive manufacturing of buildings is by the group of Khoshnevisk [2] in 2004. They named the method as "Countour Crafting" which is an additive manufacturing application for building construction. The method is said to be most useful for emergency reconstruction by disaster and relief agencies working in third world nations devastated by earthquakes, floods, other natural disasters and war. However, they worked on developing technologies on this subject including a project (together with NASA) on using the additive manufacturing for building space colonies. They also mention about the integrated design needs and the possibility of manufacturing HVAC equipment together with the building itself.

More recently, in 2015, World's first 3D printed apartment building was constructed in China. In 2016, world's first 3D-Printed and fully functional office building was constructed in Dubai. All of the furniture of the office were also printed. There are many other examples of 3D printed houses and structures around the world. Some are modest to utopian shelters and the other are fully functional buildings for different purposes. There are also many interesting and/or functional designs waiting to be built [3]. What is more, some of those are designed to be constructed in a modular way which is a very efficient method of using additive manufacturing. Factories having a number of 3D printers for this purpose may be set up and manufacture the modules in the construction site. The modules then will be used to build up the building. The integrated design of a module will probably include some or all of the HVAC and sanitary components and we can imagine that they will be produced during the additive manufacturing phase.

Is the HVAC industry ready for the change?

There are some signs of awareness on the topic, but not being discussed widely. Additive manufacturing is being used in the prototyping phase of HVAC components and equipment, especially by the fan manufacturers. Some researchers has focused on the heat exchanger technology. A team from University of Maryland used direct metal printing (DMP) to manufacture the miniaturized heat exchanger as a single, continuous piece using titanium [4]. Another example is the design, fabrication, and test of a plastic heat exchanger [5]. However, there is not any information about these research and development studies that they have resulted to mass production by additive manufacturing.

Two important studies on the possible status of additive manufacturing and integrated design are reported by Tibaut et al. [6] and Joplin [7]. Tibaut et al. [6] introduced the concept "Digital Fabricated Buildings" and reports that additive manufacturing has potential to be "the next big step forward" for the AECO (Architecture, Engineering, Construction and Owner-operated) industry. Although application of large-scale additive manufacturing systems in this industry is in early research phase, it is expected that are further parameterization of the interoperability demand function, BIM maturity, automation of workflow models, and new approaches for engineering of embedded building elements will be the important research and application topics of the near future [6]. New approaches for engineering includes freeform constructions inspired by the nature for the building construction elements and HVAC, sanitary, electrical etc. components. Joplin [7] reported the Innovations That Will Change HVAC Forever including 3-D Printed Air Conditioners as an expected consumer product of the future.

We predict that additive manufacturing will be the primary method for the production of; firstly components such as heat exchangers (3D-CM), followed by the Equipment Manufacturing (3D-EM), and finally the technology will be adopted to the integrated design and 3D building construction (3D-BC).

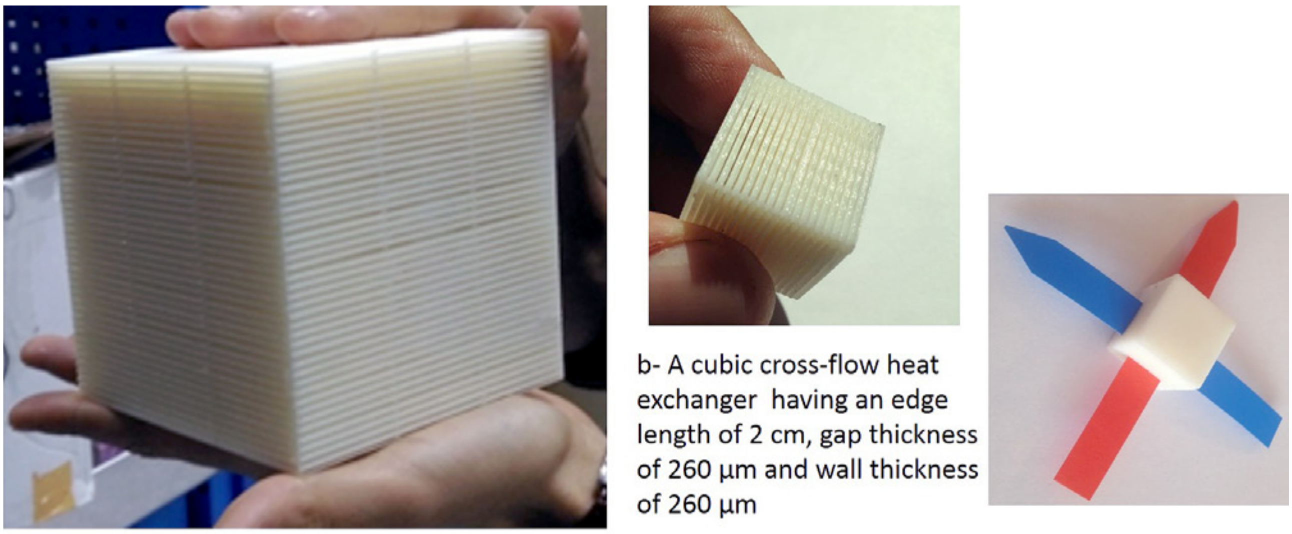
Preliminary R&D studies

A task force has been established to work on a project about implementation of additive manufacturing technology to HRV (Heat Recovery Ventilation) systems including all three phases of the progress as 3D component manufacturing, equipment manufacturing, and building construction in İzmir (Turkey). The first step is component manufacturing and we have started with the heat exchangers. Cellulose, pet, or aluminum heat exchangers are mostly used in HRV systems. A wide range of materials are available for additive manufacturing but ABS (Acrylonitrile Butadiene Styrene) was used to produce the air-to-air cross-flow plate heat exchanger material. As this is a conceptual study the material is not the primary matter of interest, instead producibility is the main concern.

The main parameter that effect the producibility is geometry. A new approach to geometric design needed. Different than the conventional manufacturing methods, adding material in a discrete manner totally changes the dimensioning and tolerancing strategies during design. The critical geometric parameters are layer thickness, single wall thickness, and nozzle diameter while using the additive manufacturing method. There are a wide range of 3D printers in the market and the technology is in a very fast progress. Therefore, supply and demand balance will be ruled by the demand side in the near future.

In our case, heat exchangers always have gaps. Another question is question is how can we build gaps by adding material? Support materials or supporting structures are used during manufacturing. After the manufacturing process, cleaning starts either mechanically or chemically. However in tiny gaps mechanical cleaning is very hard. More time, material and money is used when supports are used. A more logical solution is constructing a self-supported geometry that can be manufactured without using any supports. Topology optimization is the keyword while determining the most efficient way of manufacturing process, and also having an optimized performance of heat exchanger by means of heat transfer and pressure drop. There many other problems waiting ahead. But the opportunities of the additive manufacturing by means of free form or non-linear geometric designs will certainly produce more efficient components. Same examples of the heat exchangers produced by additive manufacturing are given in **Figure 2**.

The next level is equipment manufacturing. An ordinary commercial HRV unit which is manufactured and designed for conventional production. Many processes exist during manufacturing of this unit. A hybrid approach is to produce the casing by additive manufacturing, which can be manufactured as a single continuous piece, and other components (heat exchanger, fans, filters, and electronic equipment) are assembled afterwards (**Figure 3-a**). A more **additive** approach would be to produce the body and the heat exchanger as a single continuous piece and assemble the other components afterwards (**Figure 3-b**). When you are free about the production method and supply procedures, you can free your mind and focus on the main problem, engineering. The second design (**Figure 3-b**) has a heat exchanger volume of almost twice the first one (**Figure 3-a**), when the outer dimensions are kept constant. Engineering and integrated design will be



a- A cubic cross-flow heat exchanger having an edge length of 10 cm

b- A cubic cross-flow heat exchanger having an edge length of 2 cm, gap thickness of 260 µm and wall thickness of 260 µm

Figure 2. Same examples of the heat exchangers produced by additive manufacturing.

more important than ever when the method is fully available for the industry. We are on our way.

The last level of our future perspective is the building construction. By conventional methods we can calculate the loads and select a system from any manufacturer. Latest technology enables us to embed (immerse) the ducts into the building, while we are constructing the building. But when we go a step forward, together with the ducts embedded into the building elements, we will be able to embed units also into the walls or facade of the building. **Figure 4** shows the integrated design of an apartment for which we have calculated the loads, prepared a CAM model for additive manufacturing and the HRV unit embedded into a wall together with the ducts. It is ready for construction.

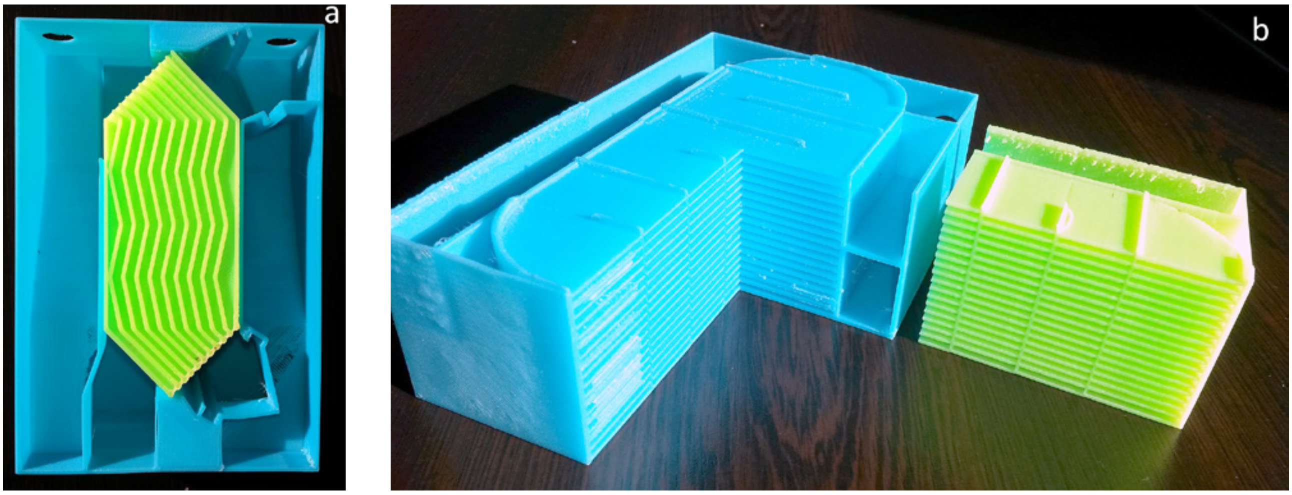


Figure 3. Samples of HRV units produced by additive manufacturing.

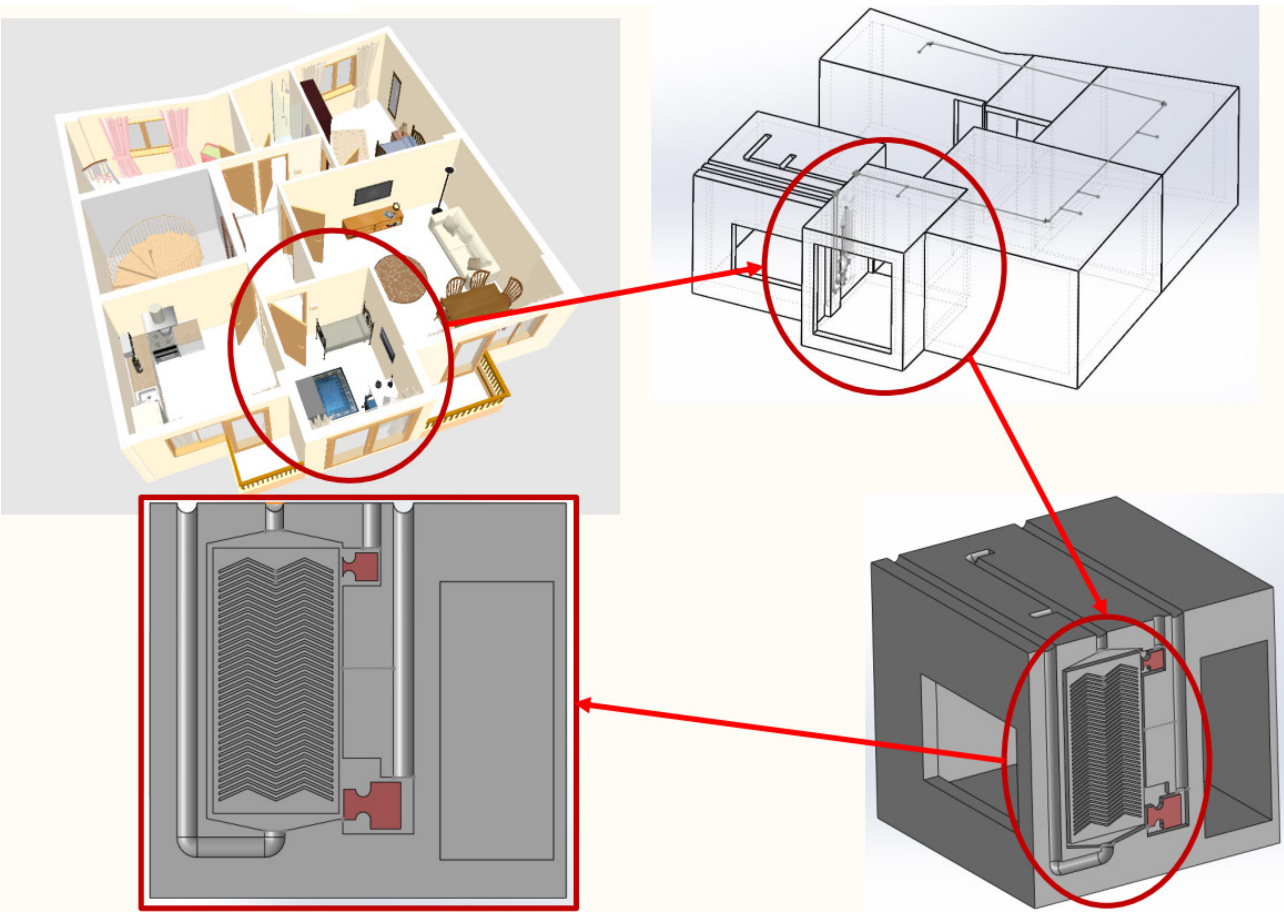


Figure 4. Integrated design of an apartment for additive manufacturing.

Conclusion

Our Perspective is:

1. Additive manufacturing will be an **alternative tool** for manufacturing firstly the HVAC components, then the units (HRVU, AHU, etc.) **in the near future**.
2. The days that additive manufacturing will be used for **production of all of the components** (walls, roof, ducts) of a building on site in a holistic approach is **not so far**.
3. Additive manufacturing will change the World from Cartesian design to **non-Cartesian (freeform, nonlinear)**. This will enable more compact unit designs with higher performance while keeping the capacity the same.
4. Additive manufacturing will **enforce** designers of **different disciplines** to cooperate for integrated design.
5. Integrated building design for additive manufacturing will arise **a new sector that will be developing software for 3D printed components** designed for both Cartesian and non-Cartesian geometries. ■

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Personal control over indoor climate disentangled, Part 1

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Most non-residential buildings that were built or retrofitted in the last 20 years use a Building Automation System (BAS). BASs are installed to efficiently operating buildings and reducing their energy usage and operating costs. At the same time BASs allow to tightly control the indoor climate in line with requirements as defined in guidelines, standards and building decrees. But this tight control does not necessarily lead to higher occupant satisfaction or lower complaint rates.

Keywords: Perceived Control, Occupant Behaviour, Indoor Environment Quality (IEQ), Integrated Design, Energy Efficiency, Smart Buildings, Building Automation System (BAS), Building Management System (BMS).

Introduction

Recent research shows that too much centralized control has drawbacks. Depriving building occupants of options to adjust their indoor climate in line with momentary needs is contra-productive. Personal control in indoor environments has been identified as playing a major role in the perception of the indoor environment. Leaman & Bordass (1999), for good reason, talk about personal control as one of the *'killer variables'* that determine a building's performance. This implies that HVAC system engineers, facade designers and facility managers should take personal control needs of building occupants into account when designing and operating buildings and their service systems. In this article we present answers to 10 frequently-asked-questions about control over the thermal environment and indoor air quality. The focus in this Part 1 article is on importance of control, effects of control and mechanisms involved. In a follow-up article (Part 2) additional control-related questions will be answered. The answers presented in this article are based upon our own research (as described in e.g. Boerstra, 2016, Hellwig, 2005 & Hellwig, 2015), the work of other researchers and the feedback from participants during workshops at Clima 2013 and Indoor Air 2016 conferences (reported in: Boerstra & Simone, 2013 and Hellwig & Boerstra, 2016).

Q1: What do we mean with personal control?

Personal control means that in the case of suddenly occurring discomfort an occupant has the opportunity to adjust their indoor climate according to his preference and momentary needs. Also in the case of comfort: the knowledge about the opportunity to be able to change the indoor climate if discomfort would occur gives occupants more confidence in the comfort potential of their workplaces (Hellwig, 2015). Building occupants can exercise control by adjusting their physical environment (e.g. by adjusting a wall thermostat) or by adjusting themselves (e.g. by changing one's clothing insulation). Note that in the context of this article we look at personal control for all aspects affecting heat exchange of the body with the environment as well as control over the air quality in one's breathing zone. The latter implies that also adjustability of local fresh air supply is addressed (e.g. via an operable window).


Photo: J van Berkum

Q2: Is control over indoor climate really an issue for the modern office worker?

International data, collected using identical methodology are not available. But a study conducted in 2011 and 2012 amongst 236 occupants working in a total of 9 modern office buildings in the Netherlands (Boerstra, 2016) revealed that only 31% of the Dutch respondents was satisfied with the amount of control that they had over their indoor climate. This shows that there is clearly room for improvement. One could argue in this context that maybe not every building occupant wants to be in control over his/her indoor climate at work. The results of a German field study (ProKlimA) contradict that view: this study revealed that 85% of German office workers (in total 4596 respondents) wish to have control over their indoor climate (Bischof et al. 2003).

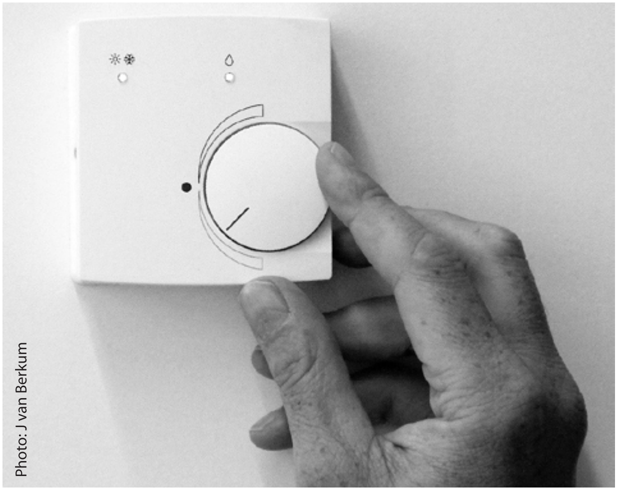
Photo: J van Berkum

Q3: What are the main problems with control over indoor climate in existing buildings?

This question was asked during a personal control workshop organized by the authors at the Indoor Air 2016 conference (Hellwig & Boerstra, 2016). One conclusion there was that one can distinguish between problems due to limited control options and problems due to mal-performing building service systems. Both can result in a perception of low personal control. More specific control problems reported by the workshop participants were the lack of openable windows and missing temperature knobs. The lack of information about control devices' functioning and lack of 'intrinsic logic' of interfaces were also reported as prevalent problems. A majority of workshop participants agreed that occupants often do not understand (or are not informed well on) how technical systems work and therefore do not know how to operate them. One example in this context are 'autonomously' operating sun blind systems, activating or deactivating venetian blinds at random (at least in the perception of building occupants).

Q4: How does control over indoor climate affect comfort and satisfaction in offices?

A number of studies have shown that personal control level is positively associated with wellbeing and occupant satisfaction (e.g. Leaman & Bordass 1999 and Ackerly, Brager & Arens 2012). An analysis of a database that consisted of data from 1612 respondents working in 21 Dutch buildings (Boerstra, 2016) revealed that those with adequate options for control over temperature and fresh air supply were significantly more comfortable. The previously mentioned Dutch field study (also described in Boerstra, 2016) revealed that high control respondents (those that perceive to be more in control over temperature and fresh air supply) are significantly more comfortable (about 1 scale unit on the 7 point scale used) than low control respondents. These results are in line with the outcomes from the EU HOPE study (Roulet et al. 2006). This field study, conducted in a total of 64 office buildings from 8 different European countries, found that a high degree of perceived control was positively associated with occupants' satisfaction with their environment.

Q5: Is there an impact of installation type?

Installation type seems to be a factor of importance. The above mentioned German field study ProKlimA revealed the following: In window ventilated offices with radiators, openable windows and light switch, 87% of the respondents feel they have control over temperature and air movement; meaning their office environment confirms their expectation towards control and hence they express satisfaction (Hellwig 2005). In the same study, offices with sealed facades and central air-conditioning lead to only 7% respondents saying they have control over the air-movement. For them, expectation towards control was not met and therefore they expressed more often dissatisfaction. Personal control and satisfaction with temperature showed a strong significant interrelation. A meta-analysis by Mendell & Smith (1990) too concluded that building related symptoms are more prevalent in buildings without operable windows and with more complicated HVAC systems. Mendell & Smith suggest that the more limited possibilities for personal control in more 'advanced' buildings explain this relation.

Q6: How about the effect of control on Sick Building Symptoms?

A study amongst 4596 German office workers in 14 buildings showed that a high perception of personal control is related to a lower prevalence of the Sick Building symptoms (Bischof et al. 2003). This result is in line with the outcomes of the Dutch database analysis (Boerstra, 2016) described before: the analysis revealed that occupants that perceive to have little or no control over their indoor climate are a factor 2,5 times more likely to have Sick Building symptoms than occupants that report optimal control over temperature and fresh air supply. A field study in 24 Danish office buildings (Toftum, 2010) lead to the conclusion that Sick Building Symptom prevalence was strongly correlated with occupants' satisfaction with control options.

Q7: How does control over indoor climate affect productivity?

Office workers that have access to adequate controls are more productive. Leaman & Bordass (2001) conducted a field study in 11 English office buildings and found that self-assessed productivity was significantly and positively associated with perceptions of control. Wyon (2000) re-analysed data of several lab and field experiments and determined that personal control over room temperature (with a ± 3 K bandwith) impacts objectively measured task performance of office workers positively. Also Boerstra (2016) found that high control occupants estimate themselves to be more productive than low control respondents.

Q8: How about sick leave effects?

The Netherlands database analysis described in Boerstra (2016) indicates that also self-reported sick leave is related to personal control: only 2% of the respondents that said to have access to (effective) operable windows and (effective) adjustable thermostats reported one or more days of sickness absence during the previous 12 months 'due to an adverse indoor climate'; for those that said not to have access to operable windows and not to have access to temperature controls this was 14%. Compare this to Zweers et al. (1992): they found that office workers that indicate to be in control over their indoor climate on average were 34% fewer days sick at home.

Q9: What do we know about the mechanism involved?

The core assumption is that it is not just the objective indoor climate (e.g. momentary temperature or indoor air quality in the breathing zone) that determines whether people feel warm or cold, or are satisfied or dissatisfied with the air quality. Instead, the hypothesis is (Hellwig, 2015 & Boerstra, 2016) that personal control also has an impact and in fact acts as a moderator in the indoor climate > comfort/health/performance relation that is depicted in **Figure 1**. The idea is that human responses to sensory stimuli are modified when those exposed have control over these stimuli (after Brager & de Dear, 1998).

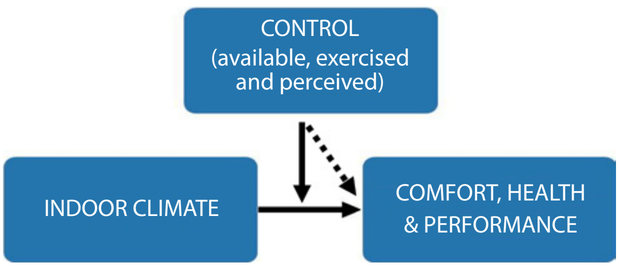

Figure 1. Conceptual model that describes how control acts as a moderator.

Q10: How about the difference between available, exercised and perceived control?

Personal control has been defined as the combination of available, exercised and perceived control as it is available to individual building occupants (Paciuk, 1990). Available control refers to the presence and effectiveness of building controls like operable windows, adjustable thermostats, fans and blinds. Organisational aspects play a role too: available control is partly defined by e.g. dress codes and bans (if any) on control use. Exercised control refers to the use of controls and the relative frequency with which occupants engage in indoor climate related behaviour in order to regain comfort. Perceived control is defined as the degree to which building occupants perceive that they can change their local indoor climate. It refers to the confidence that individuals have in their ability to effectively influence their environment, in a desired direction (Boerstra, 2016 and Hellwig, 2015). ■

This is the end of part 1. In another issue of REHVA journal, the second and last part will be published. In this 2nd article we will explain more about the psychological factors involved. And we will focus on the design implications of the latest personal control findings. The 2nd article will end with some suggestions for future indoor climate guidelines and some general thoughts on further control studies.

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Green Air Conditioning

– Using indoor living wall systems as a climate control method

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

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

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

Figure 1. Living Wall System, Quito, Ecuador.

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

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

Evaporative coolers

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

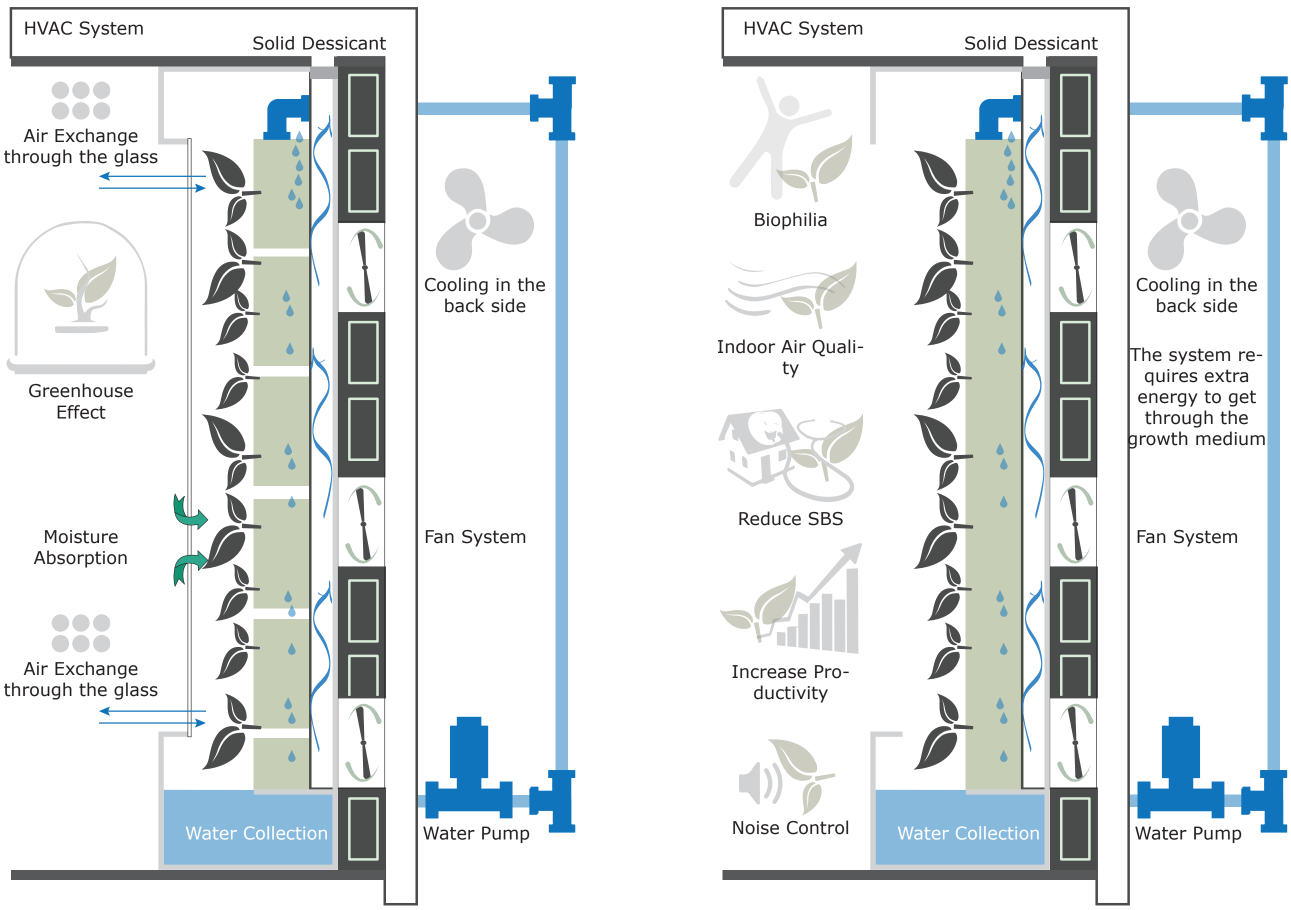
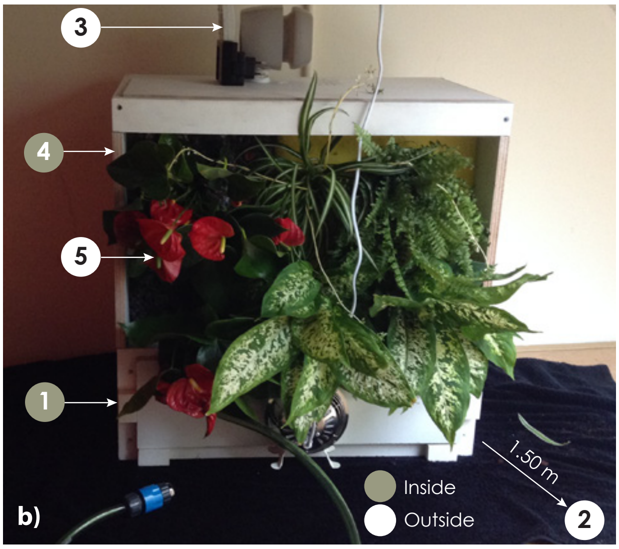


Figure 2. Diagrams of the alternatives for LWS. (Armijos Moya, 2016)

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

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



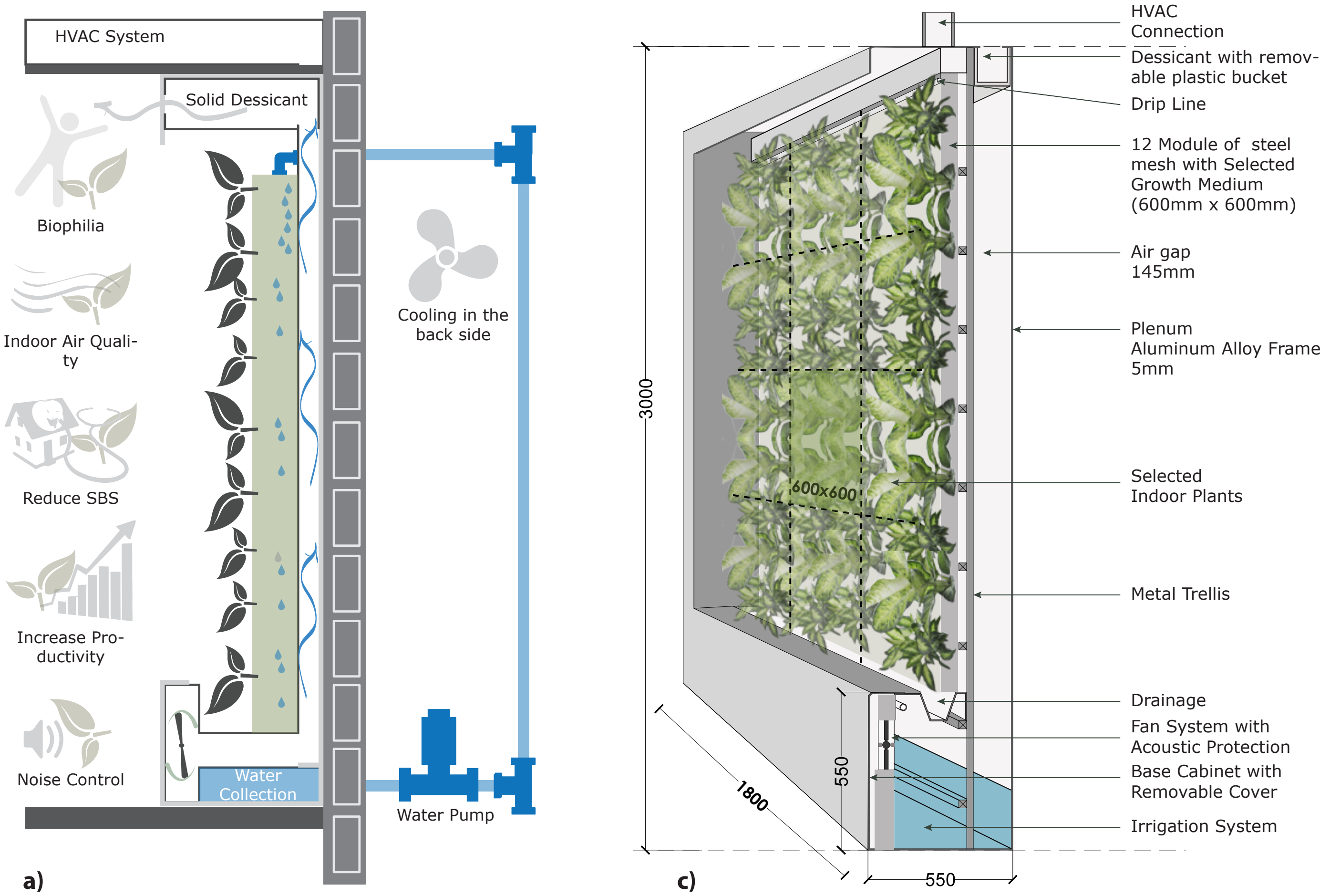


Figure 3. Prototype. **a)** Diagram of the LWS Design, **b)** LWS scaled Prototype and Data logger location, **c)** Section. (Armijos Moya, 2016)

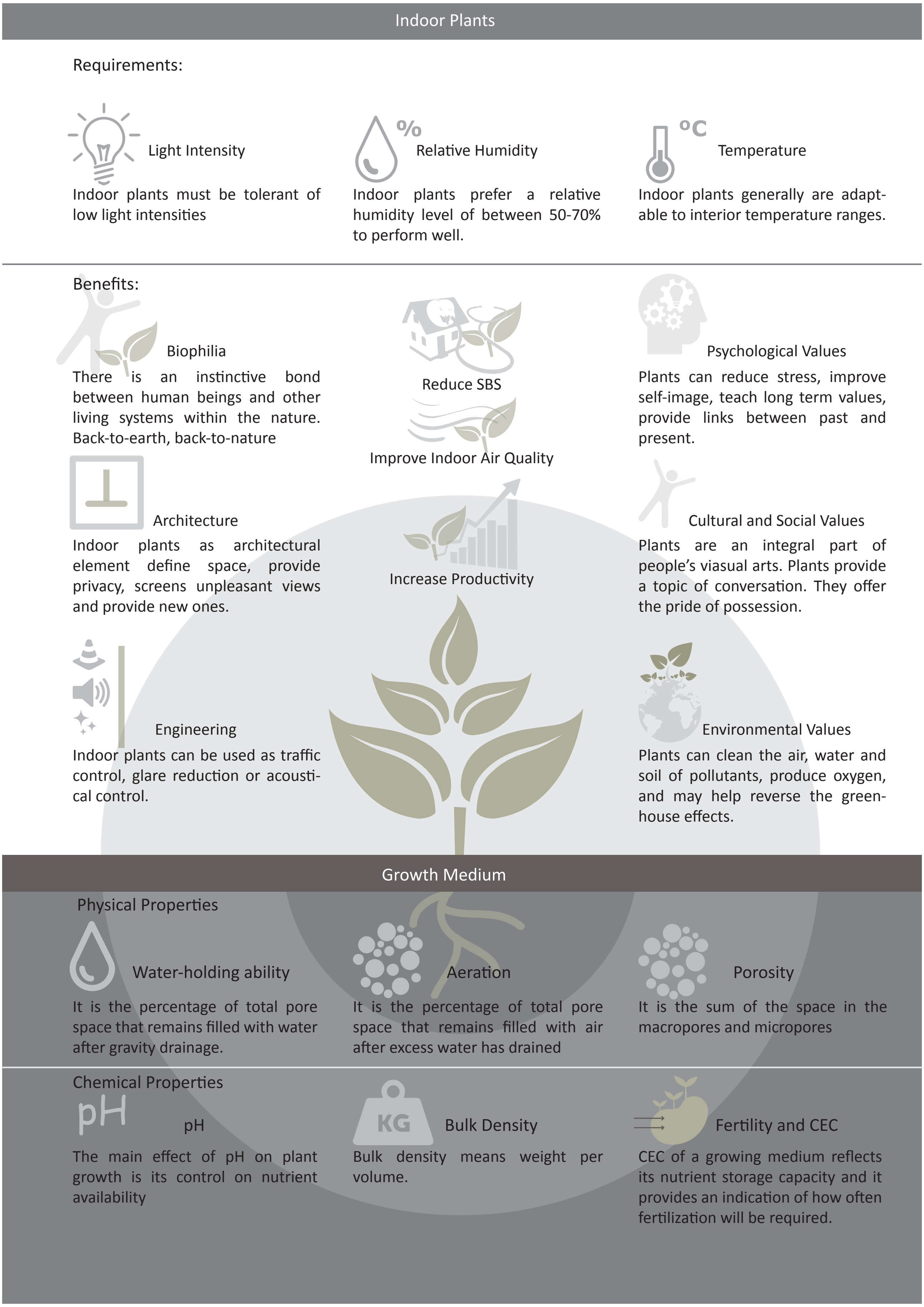


Figure 4. Indoor Plants: Benefits and Requirements.

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

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

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

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

Conclusions and recommendations for further research

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

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

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

Phytoremediation

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

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

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Indoor Air Quality Monitoring 2.0 – Seeing the invisible

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

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

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Practitioner's perspective

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

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

Why monitor?

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

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

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

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

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

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

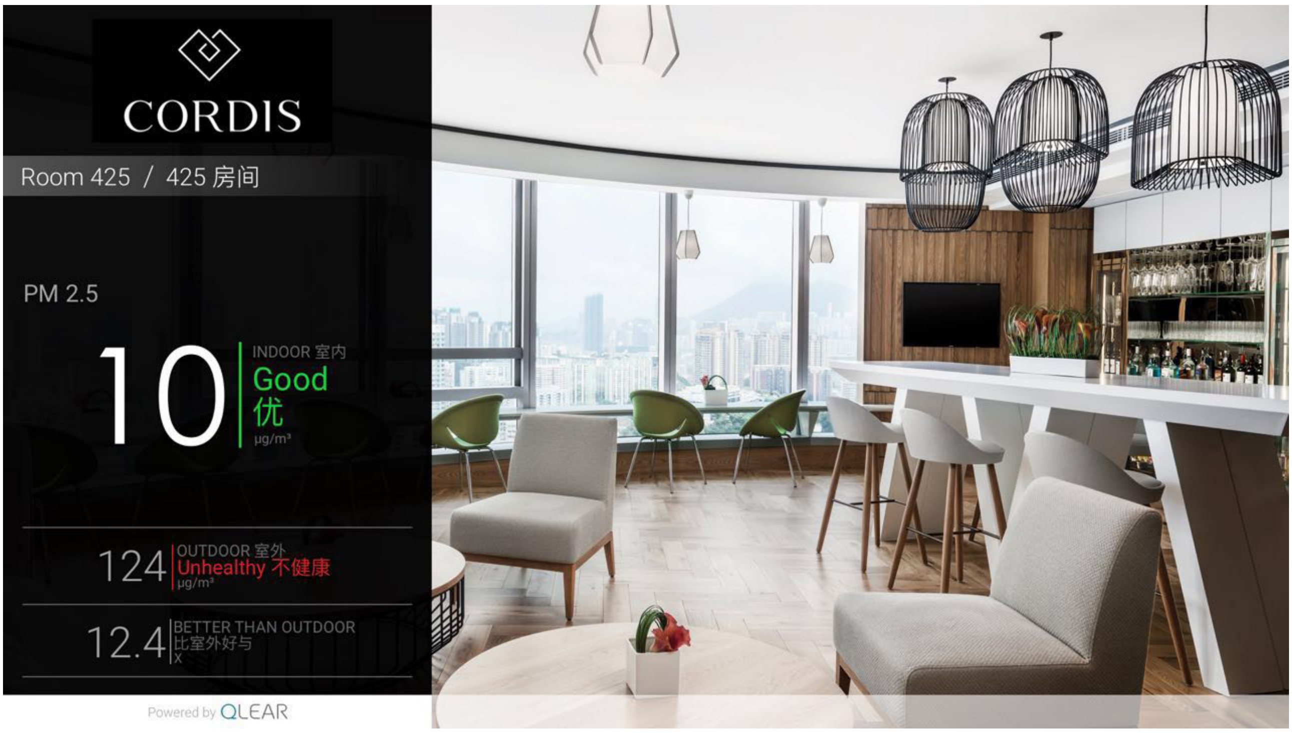

Figure 1. Indoor air quality monitoring data screenshots as displayed in a hotel public spaces.

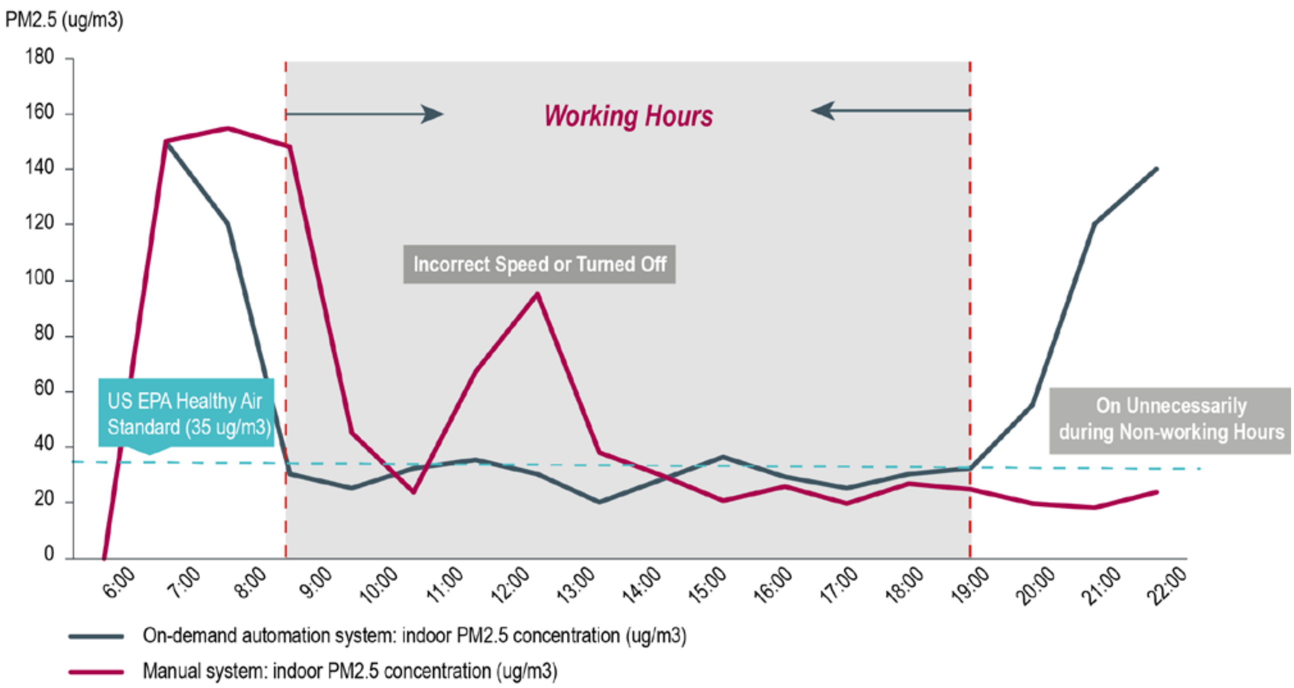

Figure 2. On-demand Automation vs. Manual Operation (µg/m^3 equals µg/m^3). [Source: "Every breath we take–transforming the health of China's office space," JLL & PureLiving Research Report, December 2015.]

All sensors are not created equal

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

Figure 3. Various types of continuous monitoring equipment.

Typically, we guide monitor selection with a few considerations:

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

Table 1. The most important parameters in IAQ monitoring.

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

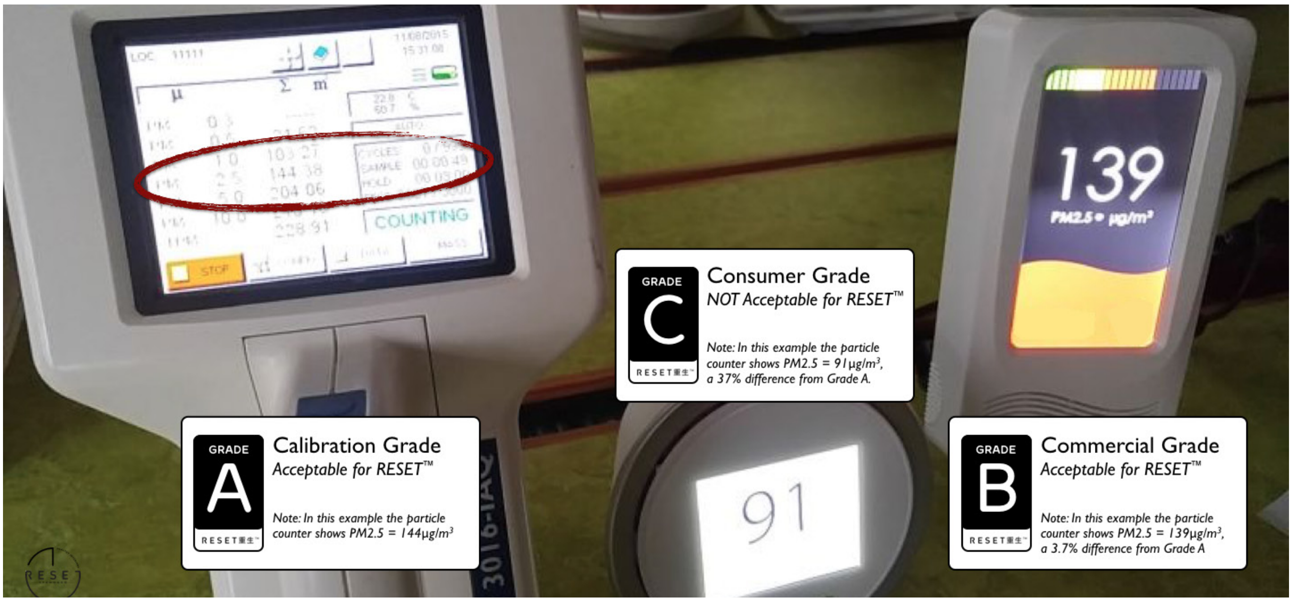

Figure 4. Varying accuracy of three monitors show the difference between monitor quality grades. General rule: if you can't calibrate it, don't buy it. Only Grade A and Grade B monitors are accepted for RESET™. Latest RESET™ standards are here: http://reset.build/resources/RESET_Accredited_Air_Monitor_Requirements

5. Costs

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

Deployment Tips:

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

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

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

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

Cloud-ware and analysis

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

Conclusions & takeaways

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

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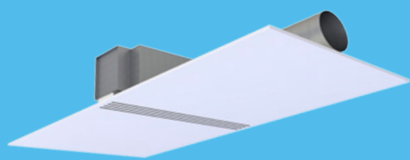

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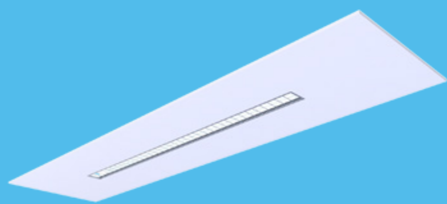

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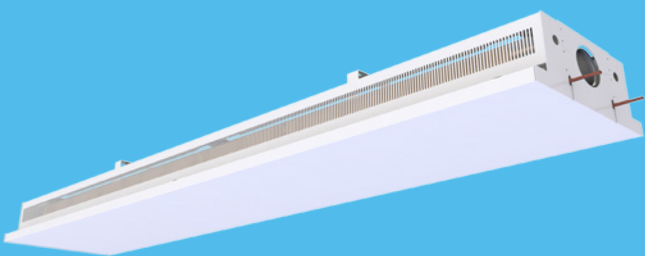

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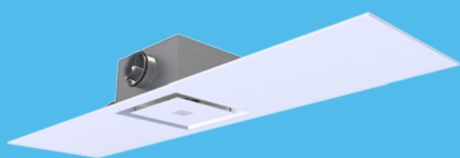

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Metrics of Health Risks from Indoor Air

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

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

Problems

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

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

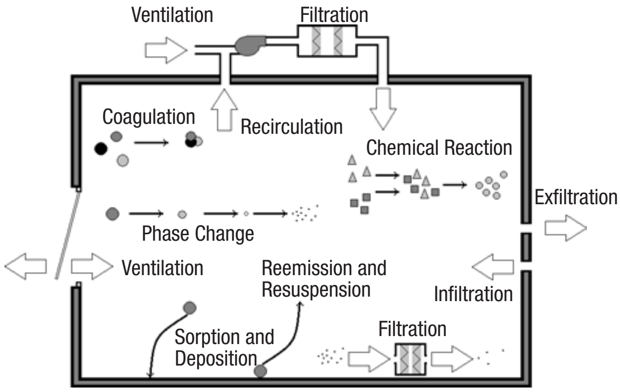
However, existing measurements of contaminants, whose type and toxicity are known, still give cause for concern (Logue *et al.*, 2011). They could negatively affect the health of occupants of any building they were found in and, when extrapolated to larger building stocks, could adversely affect healthcare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

What do we think we know about IAQ?

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

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

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

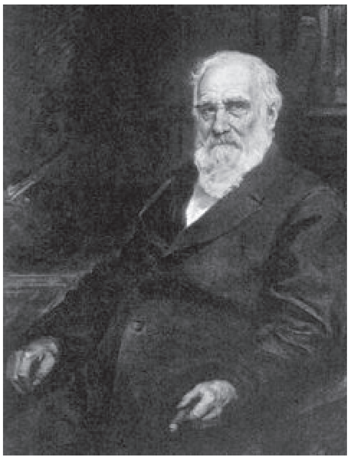


Ventilation Mechanisms and Pollutant Behaviours Indoors.

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

Practical solutions

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



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

Attributed to
Max Von Pettenkofer

Source Control (Fanger, 2006).

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

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

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

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

IAQ metrics

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

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

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

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

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

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

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

Next steps

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

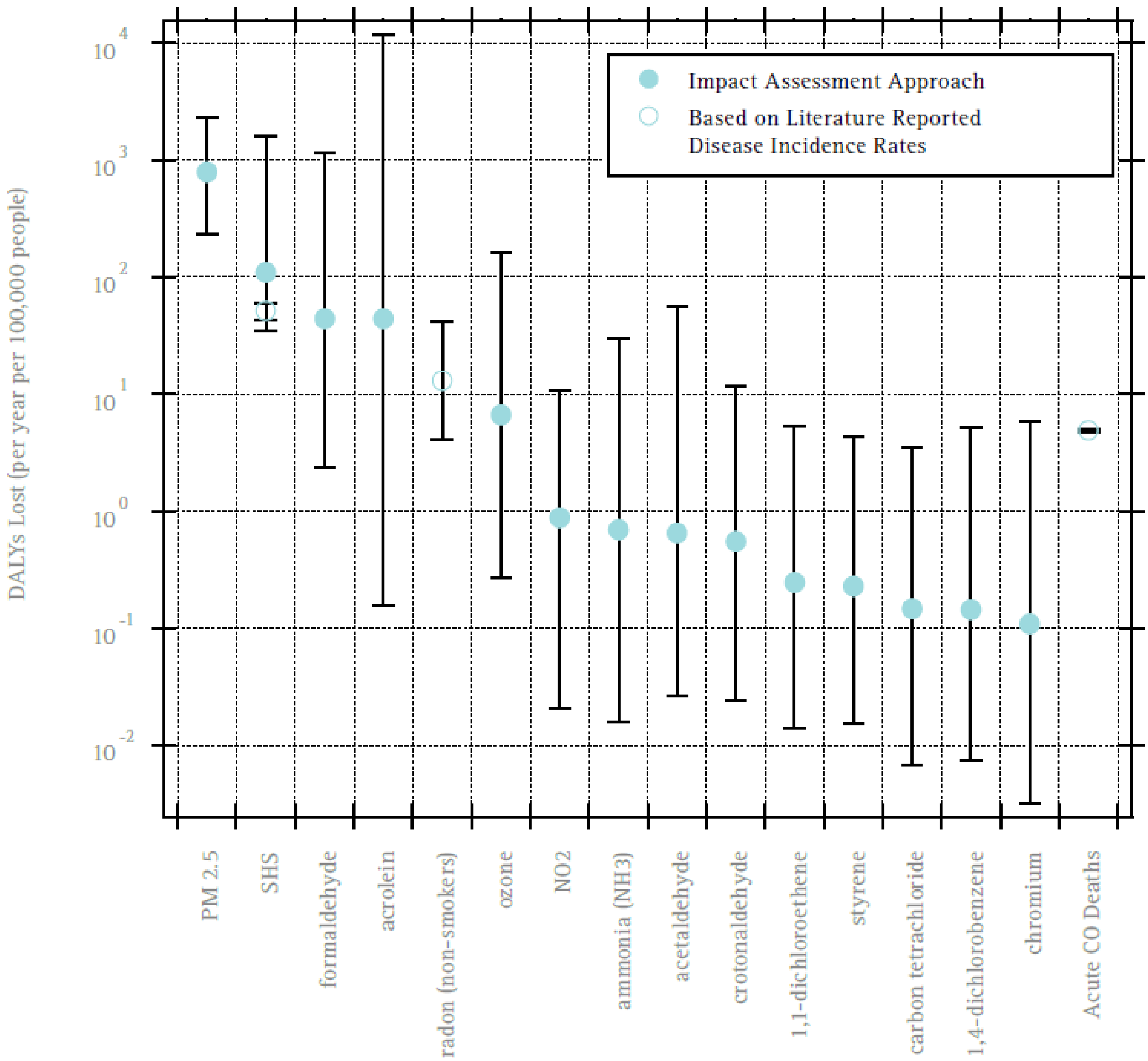


Figure 4. Estimated population averaged annual cost, in DALYs, of chronic air contaminant inhalation in U.S. residences (AIVC, 2016).

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

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

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

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

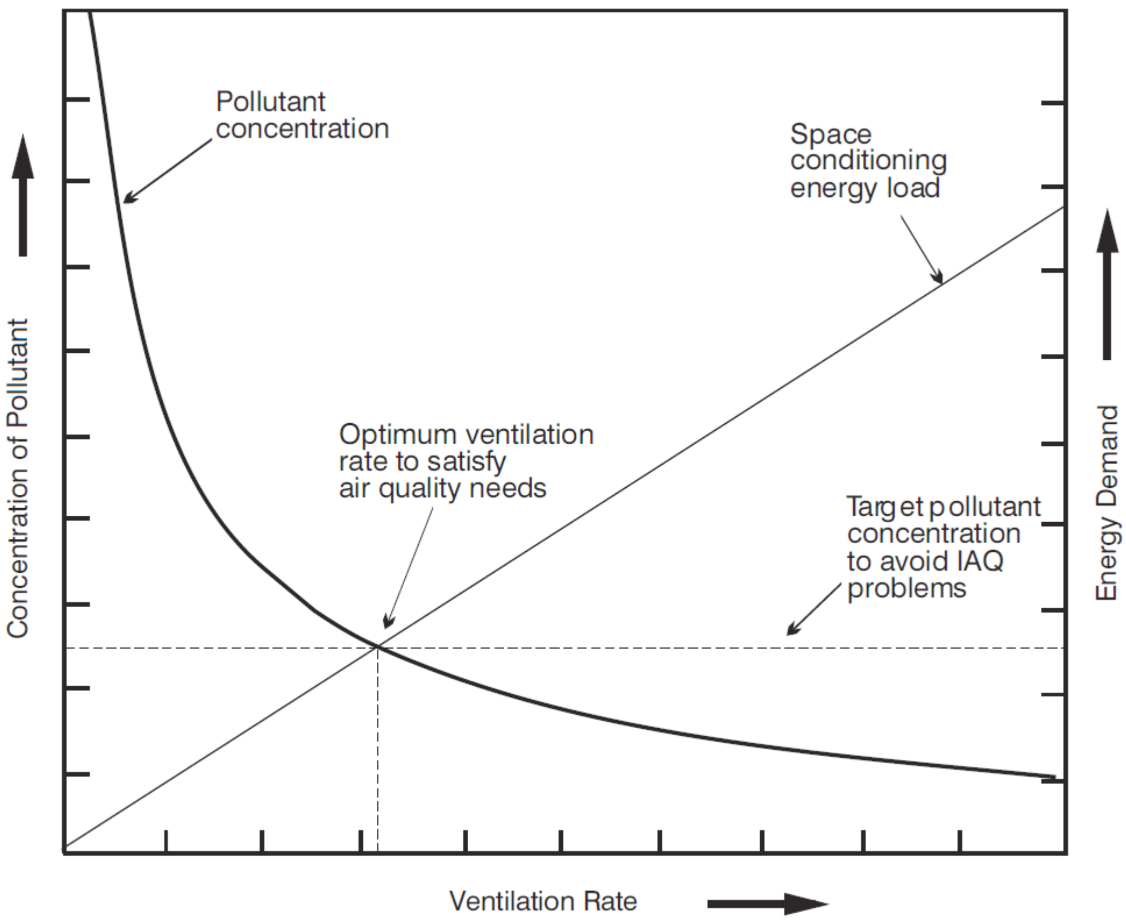


Figure 5. Controlling the Dominant Pollutant (AIVC, 1996).

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

Acknowledgements

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The UK is putting IAQ and health on the agenda again

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This article presents an overview of current UK developments in the field of indoor air quality and health, in particular the outcomes of the AHRC funded HEMAC (Health Effects of Modern Airtight Construction) Network and the UK Indoor Environments Group 2017 Conference (26th April 2017, held in Glasgow, Scotland).

Keywords: IAQ, health, UK, UKIEG, HEMAC, Conference

It is apparent that there is an increasing awareness of the potential health effects of indoor air pollution in the UK. Links between health and outdoor air pollution have been understood by the medical community, and this was well publicised last year following the launch of a report on *Every breath we take: the lifelong impact of air pollution,* by the Royal College of Physicians (RCP) and the Royal College of Paediatrics and Child Health (RCPCH). Importantly, the report also identified the risks of indoor air quality and acknowledged that some aspects are not fully understood and more evidence is needed. As a result, RCPCH and RCP have joined with the Building Research Establishment (BRE) and the Adaption and Resilience in the Context of Change (ARCC) network to establish a new *working party* to tackle indoor air quality in homes. This shift coincides with the recent announcement of the development of *indoor air quality guidelines* by the National Institute for Health and Care Excellence (NICE) in collaboration with Public Health England (PHE).

At the same time, initiatives from indoor and built environment communities are raising the agenda of IAQ and health in UK homes. A recent review entitled *Each Home Counts* published in December 2016 on consumer advice, protection, standards and enforcement of energy efficiency and renewable energy, calls for measures to tackle problems with inadequate ventilation, poor quality installations and moisture problems in buildings. A workshop report launched by the UK Indoor Environments Group on *Healthy Indoor Environments: Challenges and Opportunities for Policy Makers,* calls for collaborative action across UK government departments to develop an effective, coordinated strategy to improve indoor environmental quality in buildings. A campaign launched by the BEAMA group on *My Health, My Home* aims to raise awareness among the general public of the dangers of poor indoor air quality in the home environment and there is also an All Party Parliamentary Group (APPG) set up last year called *Healthy Homes and Buildings*.

There have been increasing reports in the media raising awareness of the dangers of poor indoor air quality in airtight homes, including BBC coverage of a report funded by the Scottish Government on *Occupier Influence on Indoor Air Quality in Dwellings*. A recent report published by *Which?* (the largest consumer body in the UK) reveals potential exposure to high levels of pollutants in the home, following everyday activities.

Two recent events hosted by the Mackintosh Environmental Architecture Research Unit (MEARU) at the Mackintosh School of Architecture, Glasgow School of Art, aimed to accelerate and strengthen this expansion of the IAQ and health agenda within the UK. The first was a sandpit event, organised by the Health Effects of Modern Airtight Construction (HEMAC) network (25^{th} April, 2017), followed by the 14^{th} annual UKIEG Conference (26^{th} April, 2017). These events marked the bringing together of researchers and practitioners from across the UK and beyond, to deliberate ways of addressing the challenge of improving the quality of the UK indoor built environment.

HEMAC Network

The HEMAC network (*Health Effects of Modern Airtight Construction*) was established to bring together researchers and practitioners from the fields of indoor air quality (IAQ), health and the built environment to develop shared research agendas and identify ways of addressing these. The network has a particular focus on challenges concerning IAQ in new-build and/or retrofitted airtight dwellings. The HEMAC network is made up of a steering committee of researchers and practitioners from medicine, indoor air science, microbiology, engineering, architecture and ventilation; including participants from the UK, Ireland, the Netherlands, Denmark, Belgium and China.

Participants attending sandpit session on: The Changing Nature of Pollutant Exposure in the Home Environment.

Participants attending sandpit session on: Ventilation Noise Levels and Occupant Perception in Airtight Homes.

Attendees at UKIEG 2017 Conference. (photo credits: Vivian Carvalho)

Lunch and poster viewing at UKIEG 2017.

The network was funded by the Arts and Humanities Research Council (AHRC) and has supported a series of events, including a symposium (21st September 2016), a workshop event (30th November 2016) and most recently a sandpit, held at the Glasgow School of Art in Scotland (25th April 2017). The symposium provided a platform for members to present recent findings, and put forward ideas regarding gaps in the knowledge and possible research questions; which were deliberated during a discussion session at the end of the day. This was followed by an online survey, which collated opinions of symposium participants concerning key problems and challenges in the field.

This information, together with the outcomes of the symposium, was used to develop a series of workshop sessions to discuss the state of knowledge in the field and stimulate ideas for multidisciplinary projects, to address the challenges of designing healthy, energy efficient homes. Some sessions explored the need for practical guidance for design and construction professionals on ventilation and source control and the challenges of ensuring effective ventilation in airtight homes. Others addressed specific gaps in knowledge, such as the role of dwelling ventilation and IAQ on the health of susceptible groups, or the influence of housing ventilation on the indoor microbiome. Nine workshop sessions were held throughout the day, which culminated with a sequence of presentation pitches from the workshop chairs on proposed multidisciplinary projects, to an audience of invited participants.

The purpose of the sandpit event was to take these ideas further and develop them as funding proposals for collaborative projects between academia and industry. Six proposals were developed in total. Some of these were focused specifically on addressing the evidence gap between IAQ and health, whilst others proposed mapping studies of chemical emissions in the home. Several proposals addressed specific concerns regarding ventilation performance standards, in particular the need for improved ventilation noise characterisation and ventilation control metrics. The event concluded with a networking dinner.

UK Indoor Environments Group

The UK Indoor Environments Group (UKIEG) is a multidisciplinary network committed to the development, synthesis, dissemination and application of evidence concerned with UK policy and practice on the indoor built environment. Set up in 2003 to co-ordinate UK activity relating to the improvement of indoor environments for people, the group organises annual conferences to provide a platform for members to discuss areas of common interest. The UKIEG Committee also organises and promotes expert workshops and reports.

This year's UKIEG conference was supported by the HEMAC network and MEARU, at the Glasgow School of Art in Scotland. The theme of UKIEG 2017 was *Indoor Environments and Health in Buildings*. The conference kicked off with a keynote presentation by Prof Jan Sundell, who presented evidence on the relationship between ventilation and health in homes, including interesting new findings from China on risk factors for asthma and allergies. The conference included 10 oral and 10 quick-fire / poster presentations, on topics including indoor air quality, occupant control, comfort and perception, ventilation performance and green infrastructure.

Visitors at industry stand at UKIEG 2017.
(photo credits: Vivian Carvalho)

Several challenges regarding ventilation performance were highlighted, with presentations dealing with the relationship between ventilation noise (and associated occupant behaviour) and overheating in homes, issues regarding passive ventilation provision in retrofitted Irish homes, and the influence of design decisions on the performance of MVHR systems in practice. Challenges of setting appropriate ventilation standards in homes were discussed, following a presentation on the introduction of a new Belgium workplace ventilation requirement, which stipulates an ambitious carbon dioxide concentration threshold limit of 800 ppm. Evidence was also provided on the importance of control (whether available, implemented or perceived) on the stimulus-response relationship between indoor environmental parameters and occupant comfort, productivity and health. The conference concluded with a presentation by Allergy UK, which provided details of a number of initiatives to help improve knowledge and awareness of allergic diseases among health care professionals and reduce allergens in the indoor environment, through endorsement schemes with product manufacturers.

Remarks

The two events held side-by-side provided a meeting point for UK researchers and practitioners to share ideas and insights on how to improve the quality of the indoor environment for people. The HEMAC sandpit brought together a diverse group of people to facilitate the development of cross-disciplinary collaborations, whilst the UKIEG conference provided a platform for researchers to present new findings and promote knowledge exchange. It is hoped that the outcomes of the HEMAC sandpit might lead to some large-scale multidisciplinary UK projects or initiatives to improve IAQ and ventilation provision in contemporary dwellings. ■

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For more information on the HEMAC network and related events, see: www.hemacnetwork.com

Particulate matter reduction in Eindhoven

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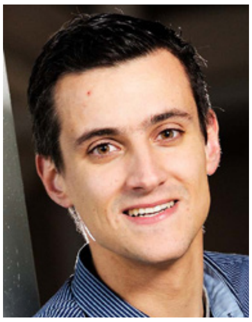

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High traffic intensities in cities are a cause of high particulate matter (PM) concentrations due to tailpipe emissions and tire and brake wear. The objective of this study, is to assess whether PM removal in parking garages by implementation of electrostatic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

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

The effects of particulate matter exposure

The collection of all solid and liquid particles suspended in the atmosphere, known as particulate matter (PM), is currently one of the most dangerous forms of air pollution. According to the World Health Organization (WHO), daily and long-term exposure to PM is strongly related to human morbidity and mortality [1]. Health effects are closely related to the size of the inhaled particles [1]; large particles can be filtered by the nose and throat, however, particles smaller than 10 μm (PM_{10}) can enter the bronchi and lungs. Particles smaller than 0.1 μm

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

Air pollution in the city

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

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

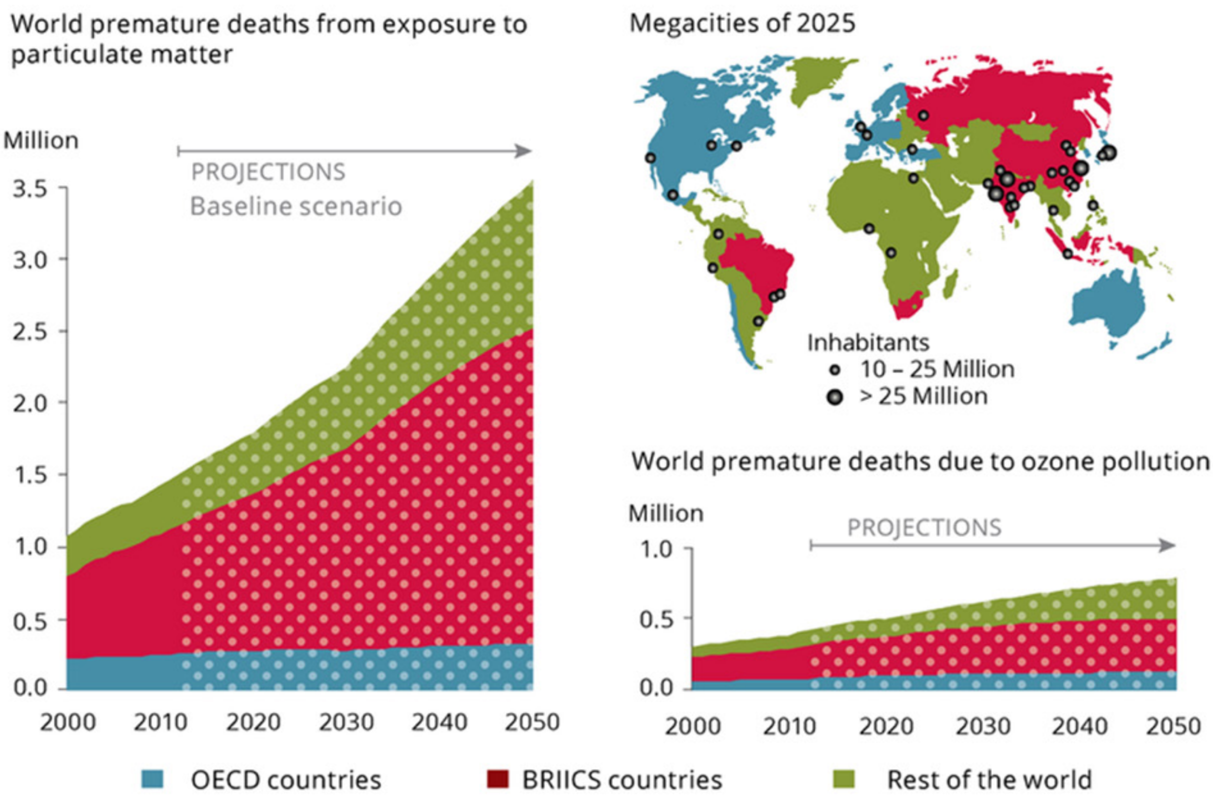

Figure 1. Projected premature deaths due to PM and ground-level ozone [7].

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

Air purification in garages

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

CFD model Eindhoven city center

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

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

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

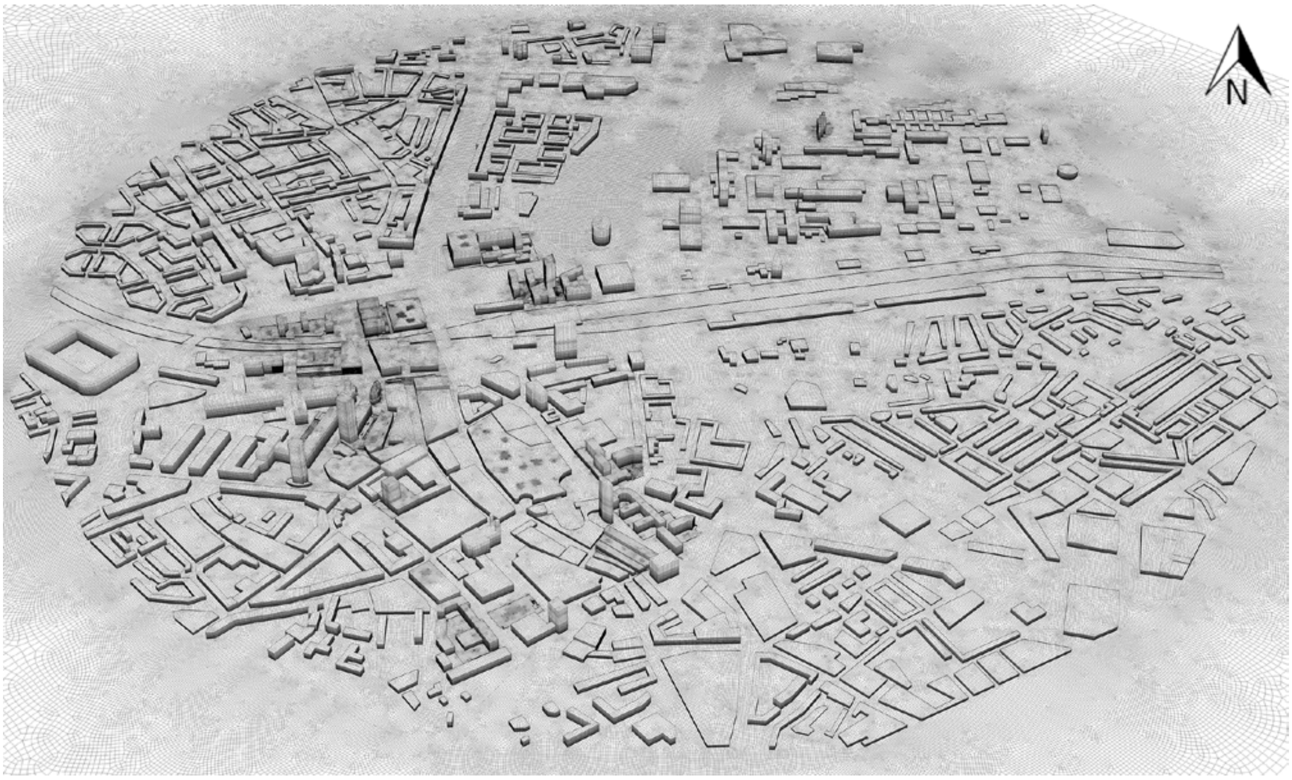

Figure 2. Overview of the computational grid of the city center of Eindhoven (65.7 million cells) [3].

[16]. Three different cases are modeled: a reference case without ESP units, a case including 99 units (one unit per 65 parking spots) and a case including 594 units (six units per 65 parking spots) spread over the 16 parking garages. Garage ventilation is imposed based on the Dutch building regulations (10.8 m^3/m^2h).

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

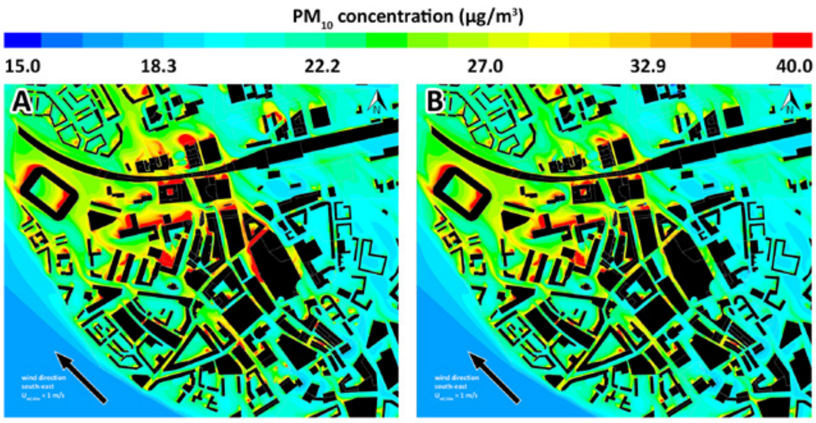

Figure 3. Contours of PM_{10} concentrations (µg/m^3) in a horizontal plane at 1.75 m height without units (a) and including 594 units (b) installed over 16 parking garages in the city center of Eindhoven. Wind direction South-East $U_{ref,10m}$ = 1 m/s.

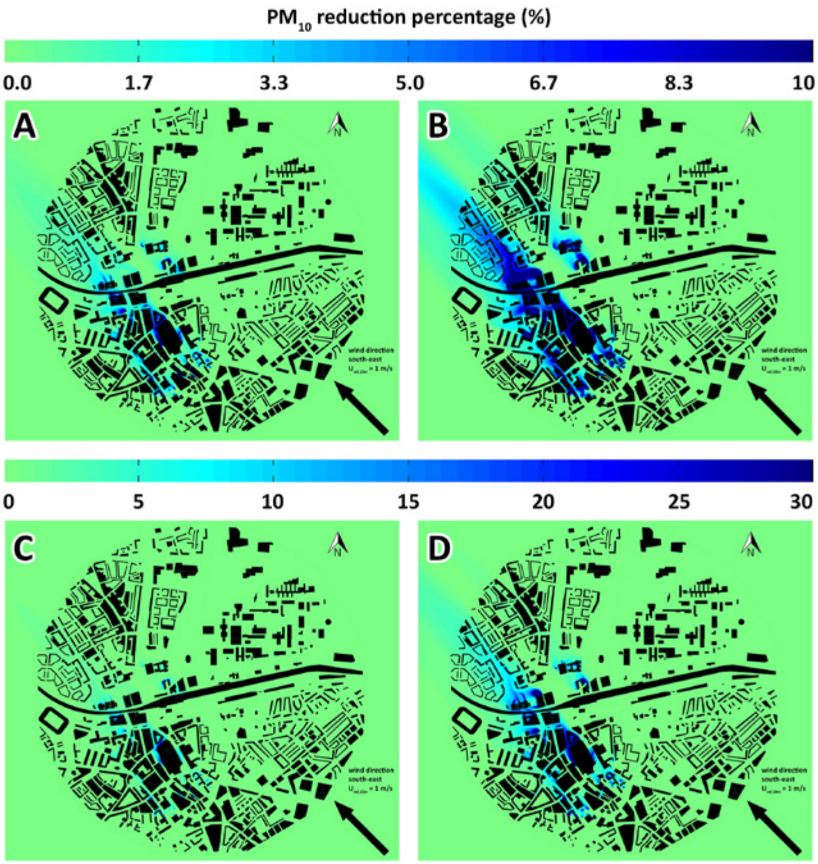

Figure 4. Contours of PM_{10} concentration reduction percentage at a height of 1.75 m for the case with 99 units (a, c) and 594 units (b, d) relative to the reference case without units. Wind direction South-East $U_{ref,10m}$ = 1 m/s. [3]

Case study results

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

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

Discussion and conclusion

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

Acknowledgements

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Infosys EC-53 building, Bengaluru.

An efficiency benchmark for the building industry

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About the Author: Guruprakash Sastry is a building industry professional with over 12 years of experience. Currently, as Regional Head – Infrastructure at Infosys, he is responsible for driving sustainability initiatives across Infosys campuses. These include energy efficient facades, efficient HVAC systems and efficient water and waste water treatment systems. He has been instrumental in implementing several innovative HVAC technologies in buildings including the first radiant cooled building in India.

Buildings account for over one third of global energy consumption and are responsible for an equally significant amount of carbon dioxide (CO_2) emissions. In the Indian context, with rapid urbanization and growing energy demand, it is essential to make sure that the upcoming building stock is built in the most efficient way. The fact that 70% of the India of 2030 is still to be built, provides a great opportunity for the building industry fraternity to transform the way buildings are designed and to adopt a sustainable approach. Though renewable energy sources like solar photovoltaic (PV) are getting cheaper and are witnessing tremendous growth, it is important to understand that the first step to being sustainable is to bring down the demand (energy, water, materials, etc.) through resource efficiency measures, and the second step is to meet the demand through renewables, recycling, etc.

While the building industry embarks on the path of efficiency, it helps to have a building efficiency benchmark to guide design and operations. The benchmark should be unreasonable and challenging, but at the same time practically achievable. One such benchmark is the Infosys EC-53 building, which was inducted into the *ACREX Hall of Fame* in 2017.

Building Features

The Infosys EC-53 building, located in Electronics City, Bengaluru, is a combination of innovation and excellence in building design and operation. Sustainability measures were an integral part of the design right from the concept stage, and included the building envelope, innovative cooling system, energy metering, automation and continuous performance monitoring. The salient features of the building are described below.

Pushing the Envelope

Building envelope is the most important aspect of an efficient building design and can impact up to 50% of cooling demand. While most critics would vote against insulation in a moderate climate like Bengaluru, the EC-53 building has a fully insulated high performance envelope. This includes insulated walls (U value: 0.4 W/m²K), insulated roof (U value: 0.3 W/m²K) and a high-performance glass and shading for windows. What this has resulted in is an exceptionally low cooling requirement of about 160 TR* (563 kW or 37,5 W/m²) at peak for a building area of about 15,000 m² (160,000 ft²). High performance spectrally selective glass (light transmission of 42%, solar factor of 0.22 and U value of 1.05 W/m²K) and shading on windows has ensured that there is ample natural light inside the building and at the same time occupants feel comfortable without glare or heat radiation from the windows.

Selecting the Right Systems and Efficient Equipment

The second most important step for achieving a high-performance building is to select the most efficient system. LED lighting is used throughout the building to ensure low energy consumption and low maintenance due to long life of LED lamps. All the rest of the rooms are equipped with motion sensors that ensure switched off lights when there is no occupancy.

Efficient LED lighting in the building.

The EC-53 building was the first in India to implement a radiant panel based cooling system. The radiant panels (supplied by Uponor) are in the form of ceiling tiles and have small pipes within them through which cold water at 16°C circulates to take care of the sensible load in

Natural day-lighting inside the building.

* 1 TR (Tons of Refrigeration) = 3,517 kW

the building. One floor of the building uses radiant panels developed by the Infosys team to achieve cost effectiveness and higher cooling efficiency. Air handling units take care of the latent load in the building and are equipped with two cooling coils – one with 16°C chilled water and the other with 7°C chilled water.

Uponor radiant panel system.

Radiflux radiant panels developed by Infosys team.

Other important features of the HVAC system include:

- All equipment with variable speed drives (chillers, pumps, cooling towers, AHUs).
- Magnetic bearing chillers for high efficiency and low maintenance.
- Automatic tube cleaning system to ensure chiller efficiency.
- Dual source units (DX + chilled water) for critical areas like server rooms.

With all these interventions in HVAC, the annual average efficiency of the chiller plant (chiller, pumps and cooling tower) was measured to be 0.42 kW/TR.

Performance Monitoring

An efficient design does not always translate into efficient operation if the right metering and performance measurement is not carried out. The EC-53 building is equipped with a Building Management System (BMS) with accurate sensors that enable efficient operation of the building systems including proper scheduling and control of different equipment remotely. The role of the BMS does not end here. Smart algorithms defined in the BMS make sure the systems ramp up or down based on the building requirement. The efficiency of various equipment like chillers and pumps is continuously tracked with respect to their design curves, and any deviation is highlighted to enable the operations personnel to take appropriate action. Any critical parameter going out of range triggers an alarm and notification to the operations personnel so that any equipment failure can be foreseen and preventive action taken. Effective use of BMS for control as well as continuous performance monitoring of the building is a distinguishing feature of the EC-53 building and several other buildings of Infosys.

Floor Energy Summary
Lighting, Fans, UPS & Rawpower

	Lighting			RAW Power		Fans			UPS Work-station		
Floor	Inst.kW	Target kW Unocc Mode	No. of Lights ON	Inst. kW	Target kW Unocc Mode	Inst. kW	Target kW Unocc Mode	No. of Fans ON	Inst. kW	Target kW Unocc Mode	No. of PCs ON
Ground floor	0.0	0.2	0	1.9	0.1	0.0	0.0	0	11.3	5.2	141
First floor	1.6	0.0	41	0.1	0.0	0.0	0.0	0	9.6	3.3	120
Second floor	3.6	0.1	89	0.6	0.1	0.0	0.0	0	12.3	0.9	154
Third floor	3.5	0.2	87	1.8	0.1	0.0	0.0	0	15.0	3.1	187
Fourth floor	0.6	0.1	14	1.1	0.1	0.0	0.0	0	11.3	3.1	141
Fifth floor	2.1	0.1	52	0.7	0.1	0.0	0.0	0	7.7	2.4	96
Sixth floor	1.6	0.1	41	--	0.1						
Total	13.0	0.1	324	6.1	0.2	0.0		0	67.2	16.0	839

Screenshot of floor wise energy consumption.

Granular metering in the building enables study of energy patterns among different systems in the building, and helps in focusing action on the right system to minimize energy consumption. Separate energy meters for lighting, computers, ceiling fans and other plug loads at the floor level give an accurate account of the energy consumption and identify opportunities for savings.

Central Command Center for monitoring performance.

Solar Energy

The EC-53 building has an installed capacity of 90 kWp solar PV plant on the rooftop. A unique feature of the plant is that it consists of 5 different solar technologies of equal capacity on the same roof. This makes for a very accurate comparison between different technologies for the same weather parameters including temperature, humidity, dust, etc. The technologies installed are monocrystalline, polycrystalline, HIT, CIS thin film and Cd-Te thin film. The plant is able to meet about 10% of the energy requirement of the building on an annual basis.

Water Wise

Water is a precious resource, the value of which is inadequately understood by the society today. Water scarcity is a serious problem that is increasing every day. When a significant population of the country does not have access to clean water, it is more imperative to use the available water most judiciously and harvest every drop of rainwater.

The Infosys EC-53 building has a very low water demand of 25 liters per person per day in all (15 liters fresh water and 10 liters recycled water), owing to low flow fixtures, dual flush toilets, waterless urinals, etc. Hundred percent of the wastewater is recycled in the Sewage Treatment Plant (STP), and the recycled water is used for flushing, irrigation and cooling tower makeup requirements. Rooftop rainwater is harvested in a dedicated tank and used for potable purposes. Last year, about 42% of the fresh water requirement in monsoon months was met through rainwater.

Benchmarking Parameters

- Energy Performance index (EPI): 84 kWh/m² per annum (includes all the energy consumed in the building) for 100% daytime occupancy and 50% night time occupancy.
- Building peak electrical load: 2.85 W/ft² (0.26 W/m²) (peak observed at building incomer in a year).
- Light Power Density (LPD): 0.5W/ft² (0,05 W/m²)
- Peak cooling capacity: 1000 ft² per TR (37,5 W/m²)
- Chiller plant efficiency: 0.42 kW/TR (annual average).
- Solar PV plant capacity: 90 kWp (meets about 10% of annual energy requirement).
- Water requirement: 25 liters per person per day.

Conclusion

All the above strategies are replicable for other buildings as well. The cost of the building is not higher than a regular building. At Infosys, we have consistently observed that efficient buildings are less expensive than regular buildings when there is a focus right from the initial design stage. It only requires a small additional effort at the design stages and setting the expectations right with the entire design team. It requires questioning every assumption and frugal engineering. It requires rejecting thumb rules and adopting a data driven approach. Most importantly, it requires will from the entire design team including the owner to achieve a sustainable high performance building. ■

Different solar PV technologies on the roof of EC-53 building.

Building Simulation 2017 Conference Open for Registration

SAN FRANCISCO, California (March 1, 2017) – For the first time since 1995, the international Building Simulation conference will be held in the United States this year. Registration is now open for Building Simulation 2017, which will take place in downtown San Francisco, California August 7–9.

Building Simulation 2017 will include presentations on leading-edge research and on best practices. Sessions will cover all types of simulation – airflow, light, moisture, acoustics, egress, and energy – at scales from components to buildings to cities. Other activities will include pre-conference software training workshops, optional tours of Lawrence Berkeley National Laboratory and Stanford University, and an exhibition of simulation software vendors.

The conference will bring together simulation practitioners, building designers, researchers, software developers, and policy makers from around the world. Practitioners will be able to learn how firms around the world use simulation for building design and code compliance and will find out which tools they are using. Researchers, software developers, and practitioners will have the opportunity to exchange ideas about the future of simulation and building science. Conference chair Philip Haves of Lawrence Berkeley National Laboratory says, "I'm excited about the blend of research and practice coming together at this conference, and I hope that everyone involved in building performance analysis takes advantage of this special learning opportunity."

The downtown waterfront conference venue is the Hyatt Regency Embarcadero hotel, which offers walking access to shops, restaurants, and attractions and is conveniently accessed by public transportation. Registration is open for discounted rooms via the conference website.

BUILDING SIMULATION 2017
AUGUST 7-9 • SAN FRANCISCO
www.buildingsimulation2017.org

Building performance simulation is gaining a unique position at the center of the push for high performance buildings, zero-energy buildings, and smart cities. Simulation plays a central and increasingly vital role in integrated design and optimized operation. As a design tool, simulation allows practitioners to make informed decisions when they seek to optimize building performance, in areas such as energy efficiency, comfort, and health and safety. As a research tool, simulation is used in development of new building technologies and techniques. Simulation is also widely used to develop and evaluate policy options, such as building energy codes.

According to keynote speaker Anica Landreneau, Director of Sustainable Design at the architecture firm HOK, "Energy modelling is a no-brainer for HOK, and we believe for our clients. It's like reading the MPG (miles per gallon) rating before you buy a car. It's basic performance information every building investor should know."

The International Building Performance Simulation Association (IBPSA) is a nonprofit organization devoted to advancing and promoting the science of building simulation in order to improve the design, construction, operation, and maintenance of new and existing buildings and urban developments.

IBPSA-USA, the U. S. regional affiliate of IBPSA, is the host of Building Simulation 2017. ■

More information:

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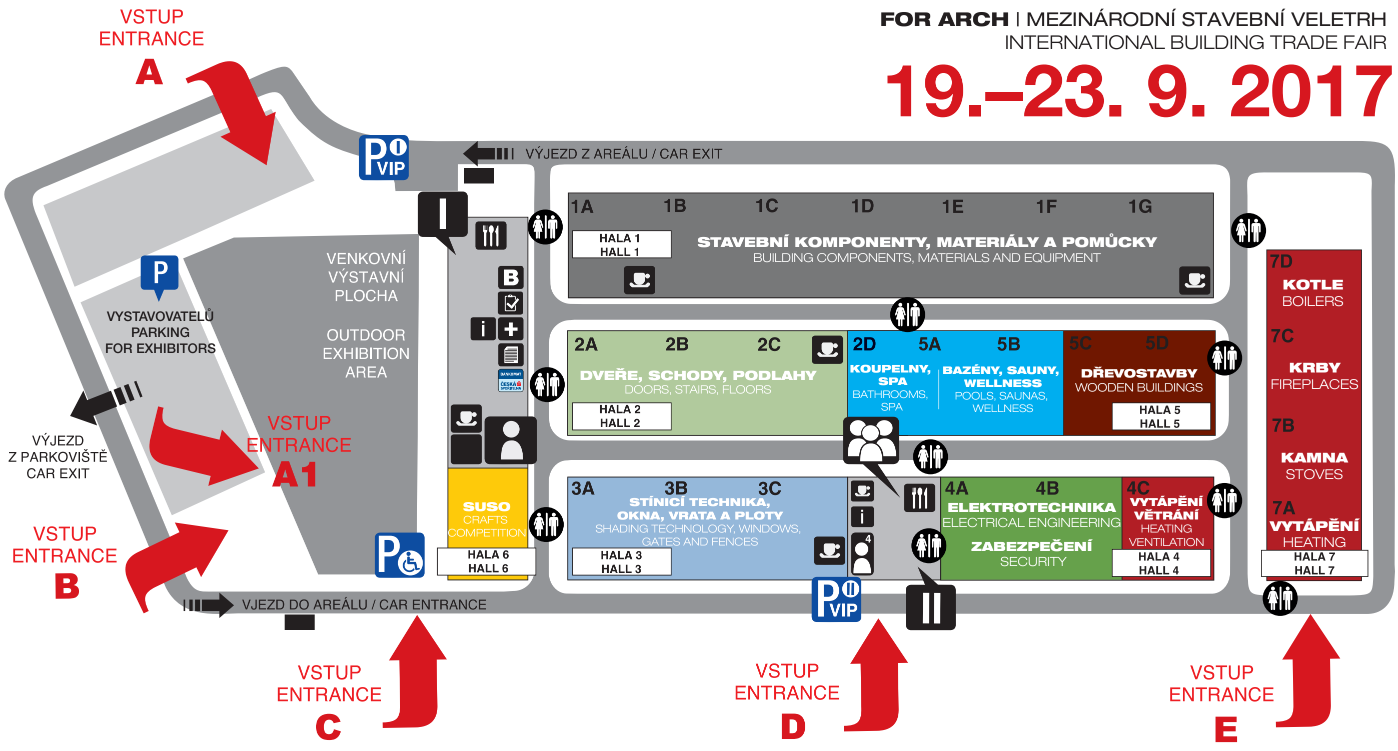
28th FOR ARCH

No. 1 building trade fair in the Czech Republic, will offer all imaginable construction solutions in one place this September

In September this year, the FOR ARCH international building trade fair, one of the most important construction exhibitions in Europe, will be held already for the twenty-eighth time in Prague, Czech Republic. The interest of exhibitors is record-breaking already now. The number of visitors is likely to grow as well, thanks to their will to invest and spend money, and the number will approach eighty thousand. This year's edition will not be divided into several simultaneously held trade fairs, but conversely, it will be merged into one whole roofing all the existing topics under one name.

This means that visitors can look forward not only to various news, like every year, but also to the best products and services from the area of building elements and materials, HVAC solutions, wooden buildings, swimming pools, saunas and spa facilities. A new branch focused on current trends and technologies in the field of security technology, building protection



Vstupní hala I / Entrance Hall I

Vstupní hala II / Entrance Hall II

informace / information

Kongresový sál (1. patro Vstupní haly II)
Congress Hall (1st floor in the Entrance Hall II)

konferenční centrum (sály 1, 2, 3)
conference centre (conference rooms 1, 2, 3)

přednáškový sál 4
conference room 4

press centrum / press centre

business centrum / business centre

registrace / registration

první pomoc / first aid

bankomat / ATM machine

kavárna / café

restaurant / restaurant

parkoviště / parking area

WC

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PVA EXPO PRAHA

systems, security services and cybernetic protection will be presented this year for the first time. One entire hall will be dedicated to heating. Dozens of expositions will offer to visitors various equipment which is not seen at first sight in houses and flats, but which makes the building a comfortable place for living. Boilers, heat pumps, solar panels, fireplace inserts, electric as well as gas boilers, specific fuels and many other things will be presented at the exhibition.

The last year's twenty-seventh edition of the FOR ARCH Trade Fair was visited by more than 71,000 visitors. The trade fair, held in Prague's largest exhibition venue PVA EXPO PRAGUE, showcased 841 exhibitors from 15 different countries on the gross exhibition area of 39,203 m². As the importance of Prague as a cultural and business metropolis of Europe continues to rise, the organisers expect that the interest in FOR ARCH will continue to grow also among foreign exhibitors and visitors.

The PVA EXPO PRAGUE exhibition centre is the largest trade fair centre in the capital city of the Czech Republic. This multifunction venue underwent extensive renovations in several last years and has become a unique and modern centre which is able to host even the most technically demanding events. The PVA EXPO PRAGUE exhibition centre now offers 105,000 m² of surface area, excellent traffic accessibility, state-of-the-art equipment and all necessary background services for both organisers and exhibitors. ■

ACREX India 2017

BY RAKESH KUMAR
MANAGING EDITOR, ISHRAE JOURNAL

ACREX India is an annual celebration of the achievements of HVAC&R industry, showcasing its innovations, technical expertise and manufacturing prowess. It is also a platform for networking between the industry players from India and abroad. Recognised as the largest exhibition of air conditioning, ventilation, refrigeration and building services in South Asia and the sixth largest in the world, it is more than an exhibition. It is an array of events that flow seamlessly across each other, leaving you breathless yet rejuvenated. And it is a valuable brand that epitomizes the spirit of the industry.

This year, ISHRAE was instrumental in bringing together all the major associations in the field of building solutions under the umbrella of Build Fair Alliance (bfa), resulting in five major exhibitions being held simultaneously at one venue for the first time – ISH India powered by Indian Plumbing Association, glasspro INDIA, FensterbauFrontale India, FSIE (Fire and Security India Expo) and ACREX India.

There were several concurrent events like workshops, seminars and interactive panel discussions, meetings with domestic and international associations, signing of MoUs, meeting with industry captains and book releases. The evenings glittered with events like the Curtain Raiser, ACREX Awards Night and ACREX Hall of Fame Night. And there was the immensely popular student event aQuest.

Inauguration

The event was inaugurated on the morning of February 23 with the lighting of the traditional lamps of knowledge by dignitaries. In addition to ISHRAE President Sachin Maheshwari, National Steering Committee members and Host Committee members, there were celebrities who came from all over the world for the occasion: Timothy Wentz (ASHRAE President), Jeff Littleton (Vice President, ASHRAE), Didier Coulomb (Director General, IIF-IIR), Andy Ford (Past President, CIBSE), Frank Hovorka (Treasurer, REHVA), Jaap Hogeling (Editor-in-Chief, REHVA Journal), Prof. Okumiya (President, SHASE, Japan) and several others. Heads of many Indian associations also graced the occasion.

ASHRAE President Timothy Wentz and REHVA Treasurer Frank Hovorka at the inauguration.

ACREX Awards Night

ACREX Awards of Excellence are presented annually for products displayed in the exhibition for excellence in various categories. The awards function was in the evening of February 23 in the IEML lawns. Daikin was the Partner in Excellence, and Kanwal Jeet Jawa, MD and CEO, Daikin Air-conditioning India was the host of the evening.

Ashish Rakheja addresses the audience at ACREX Awards Night.

The Curtain Raiser

On the eve of inauguration of ACREX India 2017, a Curtain Raiser was held at Le Meridien, New Delhi on February 22 in the presence of a large number of distinguished professionals from the industry. The theme was 'Realonomics: New Direction for Real Estate in Changing Environment'. Carrier-Toshiba was the event partner.

Workshops and Seminars

Workshops conducted by domain experts are a regular feature of the ACREX program schedule. The inauguration of workshops was held in the forenoon of the first day of ACREX. Voltas was the Knowledge Partner this year.

The workshops were spread over 3 days, beginning February 23. The topics covered included Tall Buildings, Healthcare and Standards.

Concurrently, there were seminars on topics as diverse as Legionella Control to IEQ and Energy Analytics to Green Secondary Refrigerant, interspersed with interactive panel discussions.

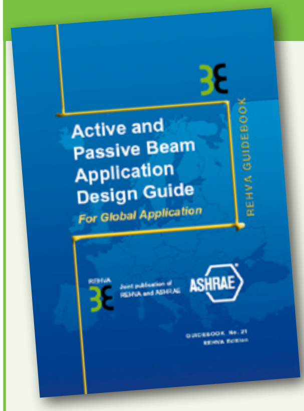
Sachin Maheshwari, Tim Wentz, M. Gopi Krishna and Frank Hovorka light the lamp to inaugurate the workshops.

aQuest – the Ultimate Engineering Face-off

The fourth edition of aQuest, an all-India student quiz competition in which a large number of ISHRAE student chapters across India participated, was a part of the bouquet of events that comprised ACREX India 2017. Johnson Controls-Hitachi was the Quiz Partner.

With the tagline 'The ultimate engineering face-off', its preliminary rounds were held by various ISHRAE chapters among student chapters across the country. The final round had a compelling format that held the participants as well as the house-full audience spellbound for a full three hours. It alternated between serious quizzing, questions to the audience and pure entertainment.

REHVA GUIDEBOOK



Active and Passive Beam Application Design Guide for global application

Active and Passive Beam Application Design Guide 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. The systems are simple to operate and maintain. This new guide 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.

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REHVA REPORT NO 6

Building and HVAC system performance in practice

REHVA Workshops at CLIMA 2016, Aalborg, Denmark, 22-25 May 2016

The "CLIMA World Congress" series, that includes the REHVA workshops, provides a highly prestigious showcase of REHVA network activities undertaken in order to fulfil our mission. The 6th REHVA Report deals with the outcomes of the 25 technical workshops organised during our triennial flagship event, the CLIMA World Congress. The workshops held during CLIMA 2016 presented advanced technologies and tools, European projects and the work of the REHVA Task Forces which developed new Guidebooks.

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ACREX Hall of Fame Night

ACREX Hall of Fame is a recognition instituted by Danfoss India and ISHRAE to celebrate the excellence achieved in conserving energy by commercial buildings in the Indian subcontinent. The Hall of Fame was introduced at ACREX 2016 for the first time. In its second edition in 2017, a sub-committee of ISHRAE headed by Sushil Choudhury (Chair, ISHRAE Technical Committee) shortlisted the entries, which were then evaluated by the Jury.

Rajesh Premchandran, Vice President – Danfoss, set the tone for the evening by speaking about sustainability, the energy scenario, urbanization and air and water quality. He emphasized that 70% of tomorrow's buildings are yet to be built. Technologies to achieve energy efficiency are already available. As much as 38% of the total reduction in emissions can come from energy savings.

He disclosed that this year there were about 50 nominations for the Hall of Fame, of which 10 were shortlisted by the Technical Committee. Most of the nominees were Platinum rated buildings, with one being a net zero energy building. He acknowledged the massive efforts made by the Technical Committee and the Jury to sift through the applications and data to select the ultimate inductee.

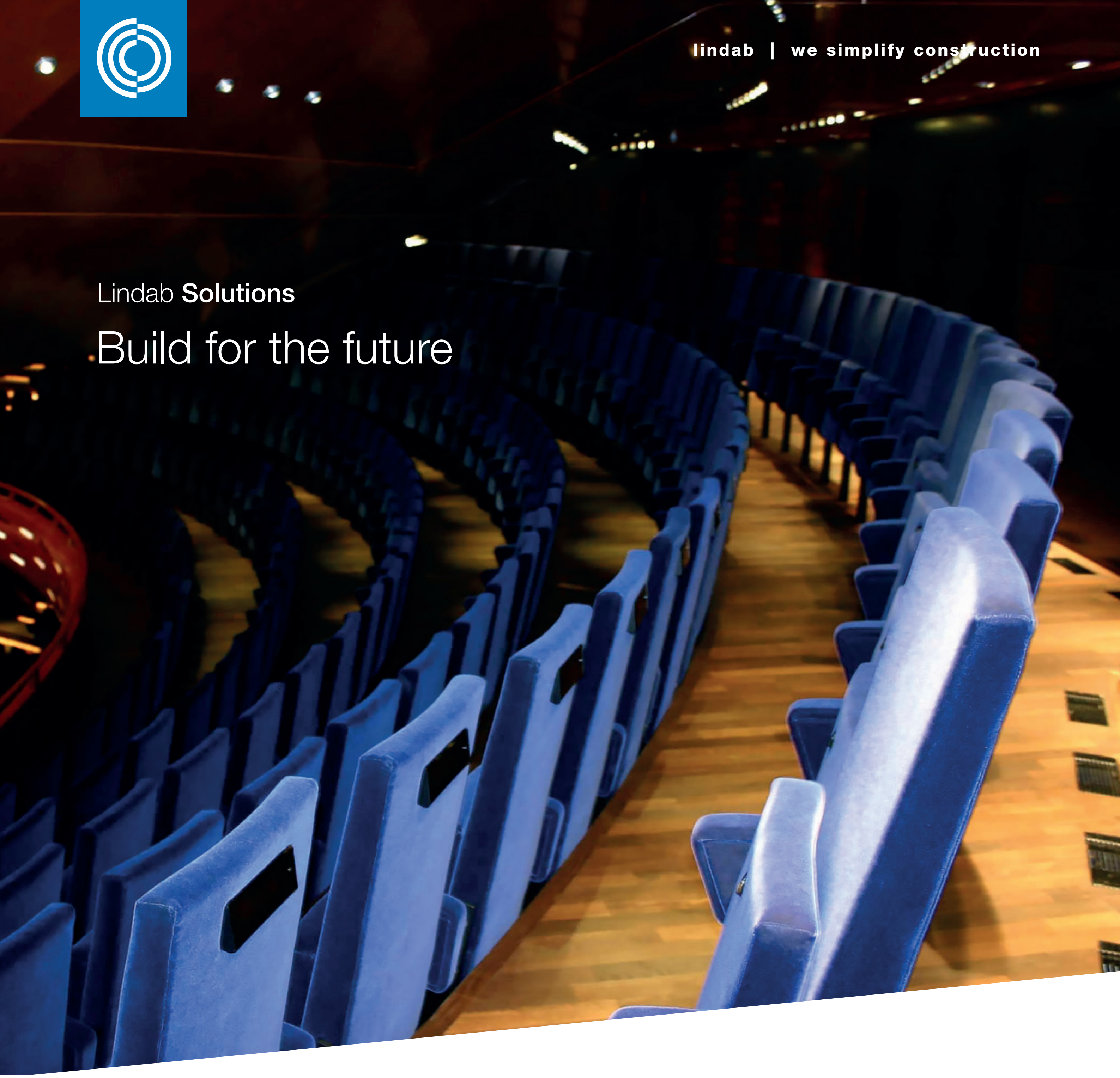
An audio-visual introducing the top 10 nominees was played for the audience.

A coffee table book featuring the top ten buildings, specially prepared for the occasion, was released by Dr. Prem C. Jain, Ravichandran Purushothaman and representatives of the 10 buildings.

A social media campaign was carried out to select a building for the Danfoss Popular Choice Award from among the top ten buildings. Indira Paryavaran Bhawan won this award. Excitement built up as the name of this year's inductee to the Hall of Fame was declared. Infosys EC-53 Campus at Bengaluru received this distinction.

The coveted recognition was awarded to Infosys for being a front-runner in promoting energy conservation and sustainable work environment. With an integrated approach to developing energy efficient buildings that include harnessing natural light, efficient LED lighting, intelligent sensors and controls and the implementation of a radiant panel based cooling system developed in-house, Infosys reaffirmed its commitment to develop and maintain a green infrastructure. ■

The team behind Infosys EC-53 Campus is all smiles while receiving their awards



Lindab **Solutions**

Build for the future

Customised indoor climate solutions that simplify the construction of sustainable buildings

Our customised indoor climate solutions comprise all the parts you need to efficiently execute a project. You receive a complete combination of ventilation systems, products, knowledge and support – all in one package.

As your partner, we put together a solution that is tailored to meet your needs, and those of the end user, while supporting you throughout the process. We help you to plan, dimension and optimise your project and provide complete documentation about your systems and products. And you can draw on the knowledge we have amassed over years of developing energy-efficient systems that meet future needs. This means you can carry out your project more efficiently, and offer your clients the perfect indoor climate.

REHVA 2017 General Assembly

The 61st REHVA General Assembly was held on Monday April 3rd, 2017 in London, UK.

About 73 were the participants from 23 countries. After a welcoming address by the host, CIBSE President, John Field, Professor Stefano Corgnati, REHVA President, opened the REHVA General Assembly with the presentation of the 2016 Annual Report.

During the meeting, President Corgnati thanked the members of the board having contributed to his first presidential year.

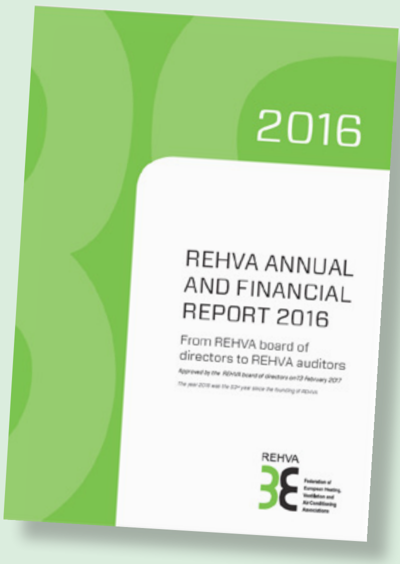
During the meeting, the REHVA Members delegates elected a new member of the REHVA Board, Catalin Lungu that replaced Egils Dzelzitis at the end of his mandate as Vice-President of REHVA.

The General Assembly also accepted as new REHVA Member the Polish association PZITS.

All REHVA Committees' Chairs presented their reports of activities, outcome and future goals.

After the General Assembly, the REHVA Dinner was organized in the Montague on the Gardens Hotel in London, during which the REHVA Professional Awards were assigned to:

Andris Kreslins (AHGWTEL – Latvia) received a REHVA professional award in education. ▶



Johnny Andersson

Andris Kreslins

Enno Abel

Peter Luscuere

▶ **Enno Abel** (SwedVAC – Sweden) received a REHVA professional award in education.

Peter Luscuere (TVVL – the Nederlands) received a REHVA professional award in design

Johnny Andersson (SwedVAC – Sweden) received a REHVA professional award in technology

Ongun Berk Kazanci (DANVAK - Denmark) received a REHVA Young Scientist Award. Ongun Berk Kazanci was not present at the REHVA Annual Meeting and the Award has been delivered to a DANKVAK representative.

The REHVA Gold Medal, the highest REHVA recognition, was handed to Prof **Michael Schmidt** in recognition of his outstanding services to REHVA and for his excellent contributions to science and engineering in heating, ventilation and air-conditioning.

New REHVA Board Member

REHVA installed a new board member at its Annual Meeting in London. Prof. Catalin Lungu was elected as Vice President of REHVA. His term began at this year Annual Meeting and will last till REHVA Annual Meeting in 2020.

One new board member for 2017-2020 has been elected during the REHVA General Assembly 2017 in London: Prof. Catalin Lungu was elected as Vice President from 2017 to 2020.

Q: Prof. Lungu, how has your background and experience prepared you to be effective as REHVA Vice-president?

— I am university teacher in HVAC field, since 1996. Since 1997, I was also involved in AIIR activities (AIIR-Romanian Association for Building Services Engineers) as member and, since 2012, as board member (vice-president). Since 2014, I am a full member of 3 technical committees of the national standardization body (ASRO). For the last 3 years (2014-2016), I was invited professor at ENSE3 (Ecole Nationale Supérieure de l'Energie, l'Eau et l'Environnement) from INP (Institut National Polytechnique) in Grenoble-France. I am also the general manager for RCEPB (Romanian Conference on the Energy Performance of Buildings), organizing, until now, 9 annually international editions. REHVA was introduced to me after 2010 when dr.eng. Ioan Dobosi, former REHVA vice-president and my close friend and adviser, invited me to attend several committees' meetings and the REHVA student competition as a scientific tutor. All these organizational, academic and professional skills which I acquired during more than 20 years of activity, will probably help the REHVA board to become more pragmatic, transparent and of course more effective.

Q: What are the main changes you would like to make within REHVA?

— REHVA is like a "living" body, getting stronger and stronger as long as all its "organs" (i.e. members) will keep strong. Strength means good communication, honesty and deep involvement for the promotion of the innovation in our technical fields. One single person could never change a big organization as REHVA. A united team (REHVA board), if one has the goal of changing something, will succeed. Me, as the newest vice-president, I will try to understand, to learn, to communicate and to help!

Q: How do you see REHVA in 3 years' time? Exactly when your mandate will end or you will be re-elected?

— My mandate will finish in 2020. Meanwhile, I will manage the organizing team for CLIMA 2019, the REHVA world congress, which will take place in Bucharest-Romania. A big challenge for us and simultaneously a greater responsibility for the new REHVA image related to CLIMA! Balancing the responsibilities between all REHVA members could be a more visible gain in the next few years. More REHVA members are involved in new EU technical and scientific projects with REHVA's help and more added value will get REHVA, finally, a larger budget could be used for competing successfully on all markets for building services. ■

REHVA Student Competition 2017

During the REHVA Annual Meeting 2017, on Tuesday April 4th, 2017 in the University College London, UCL, the REHVA Student Competition has been organized.

Under the leadership of Manuel Gameiro da Silva, REHVA Vice-President, twelve candidates representing eleven countries, competed for the Trophy Cup, the certificates and the financial prizes sponsored by Eurovent Certita Certification.

Romania has been represented by a team of two students. During the morning of April 4th, 2017, all the students' presentations have been shown to a crowded room that also included the REHVA jury represented by:

- Manuel Gmerio da Silva, ODE and REHVA Vice President
- Uwe Schulz, SWKI
- Murat Çakan, TTMD
- Dusan Petras, SSTP
- Juan Travesi, ATECYR

In the afternoon of the same day, during the REHVA Seminar on HVAC sector challenges ahead, the jury, the REHVA President and Mr. Erick Melquiond, Eurovent Certita Certification President handed out certificates of participation to each Students and financial prizes to the three students in the podium.

The third prize was awarded to the German student from the RWTH Aachen University, Aachen, Ben Krämer, while the second prize went to the Swedish student from the KTH, Royal Institute of Technology, Stockholm, Fanny Lindberg.

The winner, Rob Vervoort from Eindhoven University of Technology for his work "Lungs of the city of Eindhoven: Reduction of outdoor particulate matter concentrations by local removal in parking garages: a case study for Eindhoven", received the financial prize, the certificate and the Trophy Cup directly from the winner of 2016, Arash Rasooli from Delft University of Technology. ■

Thierry van Steenberghe in Memoriam

Backbone of increased visibility of REHVA in the 2000´s has been the participation in the projects financed by the European Union. Participation began around 2005 with some simple project but the REHVA activity rapidly increased when Thierry got involved in the REHVA projects, first as a consult and, after some years, as a REHVA employee. During the busiest times, REHVA participated close to ten projects simultaneously. Due to its good reputation REHVA became a popular partner in the projects.

Thierry´s contacts and understanding of the EU administration were invaluable to REHVA. Without Thierry´s active participation in the REHVA proposals and projects, REHVA would not be what it is now. Thierry´s work in REHVA was not limited to the EU projects, he also took care of all administrative issues when REHVA office was established in Brussels and when REHVA became a legal entity and employer in Belgium.

Thierry was a great person to work with, pleasant, dependable and accurate. The EU project teams benefitted his expertise and understanding of the practical issue related to dissemination of project results. For REHVA his work was priceless. The projects were always in budget, all reporting to the Commission were perfect and on time. The Commission did not have to do auditing of the projects when Thierry made the reports. He was really a perfect employee to work with.

We learned a lot from him about Belgian culture and Brussels during the times we worked together and had often lunch together. He always had his glass of red wine while having lunch, but only one. A custom which was new to us but part of the Belgium culture. His knowledge of cultures did not limit to Europe, he had travelled a lot and had enjoyed hiking in various environments and we often shared our experience from our hiking trips.

Thierry was an experienced expert when he joined REHVA and was willing to use his knowledge for the benefit of REHVA. He understood REHVA´s mission and objectives and worked for them. He left REHVA in the retirement age, and had, unfortunately, only a few years to enjoy with his loved ones.

We have been extremely lucky to know Thierry and work together for the benefit of REHVA during our time as president and secretary general for REHVA.

OLLI SEPPÄNEN and **FRANCIS ALLARD**

"I am sure we all, who have known Thierry for a long time, will remember him as our always friendly, reliable colleague. He has significantly contributed to our work and he has had quite an importance to REHVA`s wellbeing."

MICHAEL SCHMIDT

SCANVAC awarded Per Rasmussen

Scandinavian Federation of HVAC Associations, SCANVAC, awarded its former president Mr Per Rasmussen from Denmark with the honorary membership of the federation, the highest ranking award of SCANVAC. During his presidential term Mr. Rasmussen enhanced remarkable the cooperation between the Scandinavian and Baltic HVAC Associations. He also made SCANVAC better known internationally. He initiated the organisation of SCANVAC congresses RoomVent and HVAC in Cold Climate outside the Scandinavian countries such as Korea, China, Brazil and Canada.

The award was given to Per Rasmussen in Kongen´s Lyngy, Denmark, in the occasion of a jubilee seminar organised at International Centre for Indoor Environment and Energy at Danish technical University (DTU). The seminar was organised for celebrating the change of the leadership in the Centre. Prof. Bjarne Olesen retired and Ass. Prof Pawel Wargocki was nominated to his successor, both of them have long working relations with SCANVAC.

SCANVAC is well known all over the world through its famous conferences. RoomVent Conference has been organised regularly since 1987 in all Scandinavian countries and every second time outside Scandinavia. The next conference is in Finland June 2–5, 2018 (http://roomventilation2018.org/).

The first Cold Climate HVAC was organised in 1994. The next conference will be in Kiruna, Sweden (located far north from Arctic Circle), March 12–15, 2018 (http://www.cchvac2018.se/).

SCANVAC members are the HVAC Associations for Sweden, Finland, Norway, Denmark and Iceland, listed in the order of the number of members, totally about 20.000. More information on the SCANVAC activities can be found at www.scanvac.info.

The current president of SCANVAC is professor emeritus Olli Seppänen, and secretary general Ms Siru Lönnqvist, both from Finland. **OS**

Stay Tuned for the REHVA Brussels Summit 2017

REHVA Brussels Summit 2017 will be held on November 13th and 14th, 2017. SAVE THE DATE!

REHVA will organize Committee Meetings on November 13th and a Seminar on November 14th, 2017.

More information about the exact location and schedule will be upload on the REHVA Website in the next months.

REHVA Annual Meeting 2018

Announced to be held in April 2018 in Brussels, Belgium.

The next REHVA Annual Meeting will be held in Brussels by ATIC, the REHVA Member organizing it.

More information about the exact location and schedule will be upload on the REHVA Website in the next months.

REHVA World Congress CLIMA2019

May 26th to 29th, 2019, Bucharest, Romania

The next REHVA World Congress, CLIMA2019 was promoted during the last REHVA Annual Meeting by the new REHVA Board Member Catalin Lungu as vice – president of AIIR, the REHVA Member organizing it. The next CLIMA Congress will be held in the Romanian Parliament Palace in Bucharest between May 26th and May 29th, 2017.

More information: http://clima2019.org/

REHVA GUIDEBOOKS

REHVA Guidebook on 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.

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Product news

New sensor range from Belimo

The perfect complement to actuators and valves

Belimo is proud to announce the expansion of its product range with new and innovative HVAC sensors. The sensors are the ideal complement to actuators and valves from Belimo, optimising system performance and improving energy efficiency.

The new sensor range is the result of over four decades of experience, intensive research and focus on providing added value to customers.

The sensors can be seamlessly integrated into all major building automation and control systems (BACS) and are extremely reliable, guaranteeing high quality.

Belimo's expertise and ability to innovate are evident in the universal compact enclosure design, intuitive tool-less snap-on cover and detachable mounting plate which make installation and commissioning easy. BACnet and Modbus communication protocols provide superior application data access.

The highly resistant sensors also carry a five-year warranty, conform to NEMA 4X / IP65 requirements and are UL compliant. Belimo offers sensors for measuring temperature, humidity, pressure, CO_2, and VOC (volatile organic compounds) for pipe, duct and outdoor applications.

"Sensors from Belimo not only deliver reliable and accurate readings," states David Alliband, Product Manager, ***"but the sensor enclosure design also features a modular conduit fitting and a plug-in terminal that installers and technicians will love."***

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

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REHVA MEMBERS

Network of European HVAC associations

Association Royale de la Technique du chauffage, de la ventilation et de la climatisation—Belgium

Croatian Chamber of Mechanical Engineers—Croatia

Society of Environmental Engineering—Czech Republic

Danish Society of Heating, Ventilating and Air Conditioning Engineers -Denmark

The Estonian Society of Heating and Ventilation Engineers—Estonia

The Finnish Association of HVAC Societies—Finland

Association des Ingénieurs en Climatique, Ventilation et Froid—France

The Association of German Engineers—Germany

Scientific Society for Building—Hungary

Hungarian Coordinating Association of Building Engineering - Hungary

Associazione Italiana Condizionamento dell'aria, Riscaldamento Refrigerazione—Italy

Association of Heat, Gas and Water Technology Engineers of Latvia— Latvia

Lithuanian Thermotechnical Engineer's Society—Lithuanua

Installation Engineers Association from Moldova—Moldova

Dutch Society for Building Services— Netherlands

Norwegian Society of HVAC Engineers, NORVAC—Norway

Polskie Zrzeszenie Inżynierów i Techników Sanitarnych —Poland

Portuguese Association of Engineers—Portugal

Romanian Association for Installations Engineers—Romania

Romanian General Association for Refrigeration—Romania

Romanian Association for Refrigeration and Criogenics Engineers—Romania

Association of Engineers in Heating, Ventilation, Air-conditioning, Heat Supply & Building Thermal Physics—Russia

Serbia HVAC&R Society—Serbia

Slovak Society for Environmental Technology—Slovakia

Slovenian Society for Heating, Refrigerating and Air-conditioning Engineers — Slovenia

Asociación, Técnica Española de Climatización y Refrigeración—Spain

Swedish HVAC Society - Society of Energy and Environmental Technology - Sweden

Société suisse des ingénieurs en technique du bâtiment—Switzerland

Turkish Society of HVAC and Sanitary Engineers—Turkey

Chartered Institution of Building Services Engineers—United Kingdom

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

Events in 2017—2018

Conferences and seminars 2017

June 8-9	The Holistic Approach: From Building to Sustainable Urban Design	Faculty for Building Services Engineers, Bucharest, Romania	http://www.rcepb.ro/
June 19	Dutch National Congress of Sanitary Technologies	Theater De Flint, Coninckstraat 60, 3811 WK Amersfoort, The Netherland	https://www.tvvl.nl/bijeenkomsten/bijeenkomsten-detail/1550/nationaal-congres-sanitaire-technieken-2017/about#.WSVQiGiGPct
June 19-25	EU Sustainable Energy Week	Brussels, Belgium	http://eusew.eu/
August 7-9	Building Simulation 2017	San Francisco, California, USA	www.buildingsimulation2017.org
August 23-25	43rd International Symposium of CIB W062 Water Supply and Drainage for Buildings 2017	Haarlem, The Netherlands	http://www.tvvl.nl/cib-w062-2017
September 13-14	Ventilating healthy low-energy buildings	Nottingham, United Kingdom	http://www.aivc2017conference.org/
September 28-29	7th International Conference on Solar Air-Conditioning - PV Driven/Solar Thermal	Tarragona, Spain	http://www.solaircon.com/
October 24-25	European Heat Pump Summit 2017	Nuremberg, Germany	https://www.hp-summit.de/en
October 31	7th International Conference on Solar Air-Conditioning - PV Driven/Solar Thermal	Abu Dhabi, UAE	http://www.solaircon.com/
November 10-11	Second ASHRAE Developing Economies Conference	Delhi, India	https://ashraem.confex.com/ashraem/de17/cfp.cgi
November 13-14	REHVA Brussels Summit	Brussels, Belgium	http://www.rehva.eu/

Conferences and seminars 2018

January 22-24	2018 AHR Expo	Chicago, IL	www.ahrexpo.com
February 22-24	ACREX 2018	Bengaluru, India	http://www.acrex.in/home
March 12-15	Cold Climate HVAC Conference 2018	Kiruna, Sweden	http://www.cchvac2018.se
June 3-6	ROOMVENT & VENTILATION 2018	Espoo, Finland	http://www.roomventilation2018.org/

Exhibitions 2017

September 5-7	ISH Shanghai & CIHE 2017	Shanghai New International Expo Centre, Shanghai, China	www.ishs-cihe.hk.messefrankfurt.com
September 19-23	FOR ARCH	Prague, Czech Republic	www.forarch.cz/en/
October 10-12	HVAC 2017	NEC, Birmingham, UK	www.hvaclive.co.uk

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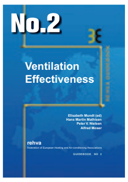
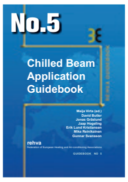
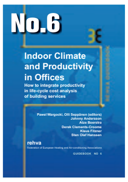
REHVA Guidebooks are written by teams of European experts



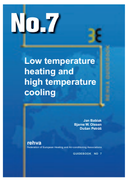
Ventilation Effectiveness. Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher costs and energy consumption associated with increasing the ventilation rates. This Guidebook 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.



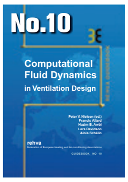
Chilled Beam Cooling. Chilled beam systems are primarily used for cooling and ventilation in spaces, which appreciate good indoor environmental quality and individual space control. Active chilled beams are connected to the ventilation ductwork, high temperature cold water, and when desired, low temperature 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.



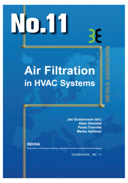
Indoor Climate and Productivity in Offices. This Guidebook shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available.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



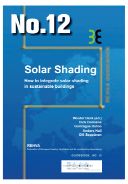
Low Temperature Heating And High Temperature Cooling. This Guidebook describes the systems that use water as heat-carrier and when the heat exchange within the conditioned space is more than 50% radiant. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in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



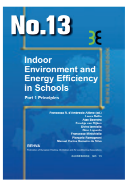
Computational Fluid Dynamics in Ventilation Design. CFD-calculations have been rapidly developed to a powerful tool for the analysis of air pollution distribution in various spaces. However, the user of CFD-calculation should be aware of the basic principles of calculations and specifically the boundary 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.



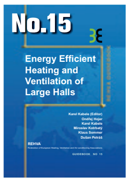
Air Filtration in HVAC Systems. This Guidebook will help the designer and user to understand the background and criteria for air filtration, how to select air filters and avoid problems associated with hygienic and other conditions at operation of air filters. The selection of air filters is based on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



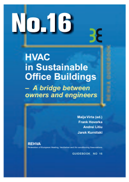
Solar Shading – ***How to integrate solar shading in sustainable buildings.*** Solar Shading Guidebook gives a solid background on the physics of solar radiation and its behaviour in window with solar shading systems. Major focus of the Guidebook is on the effect of solar shading in the use of energy 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.



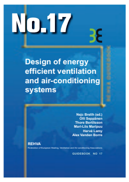
Indoor Environment and Energy Efficiency in Schools – ***Part 1 Principles.*** School buildings represent a significant part of the building stock and also a noteworthy part of the total energy use. Indoor and Energy Efficiency in Schools Guidebook describes the optimal design and operation of schools with respect to low energy cost and performance of the students. It focuses particularly on energy efficient systems for a healthy indoor environment.



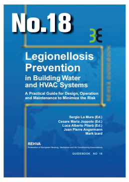
Energy Efficient Heating and Ventilation of Large Halls. This Guidebook is focused on modern methods for design, control and operation of energy efficient heating systems in large spaces and industrial halls. The book deals with thermal comfort, light and dark gas radiant heaters, panel radiant heating, 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.



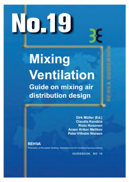
HVAC in Sustainable Office Buildings – ***A bridge between owners and engineers.*** This Guidebook discusses the interaction of sustainability and heating, ventilation and air–conditioning. HVAC technologies used in sustainable buildings are described. This book also provides a list of questions to be asked in various phrases of building's life time. Different case studies of sustainable office buildings are presented.



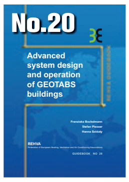
Design of energy efficient ventilation and air-conditioning systems. This Guidebook covers numerous system components of ventilation and air-conditioning systems and shows how they can be improved by applying the latest technology products. Special attention is paid to details, which are often overlooked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



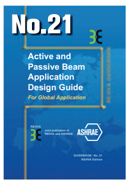
Legionellosis Prevention in Building Water and HVAC Systems. This Guidebook is a practical guide for design, operation and maintenance to minimize the risk of legionellosis in building water and HVAC systems. It is divided into several themes such as: Air conditioning of the air (by water – humidification),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



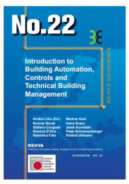
Mixing Ventilation. In this Guidebook most of the known and used in practice methods for achieving mixing air distribution are discussed. Mixing ventilation has been applied to many different spaces providing fresh air and thermal comfort to the occupants. Today, a design engineer can choose from large 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 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. The systems are simple to operate and maintain. This new guide 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 aims to provide 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 avoids reinventing the wheel and rather focuses on collecting and complementing existing resources on this topic in the attempt of offering a one-stop guide.

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