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Indoor air humidity Special

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Humidity of indoor air needs attention

This last issue of 2021 is focussing on one aspect of the IEQ which is not always at the forefront: humidity of the air indoors. Humidity became also visible in the context of COVID-19 measures, the first article "Relative humidity effects on viruses and human responses" reports that there are good reasons to maintain a RH of around 36%. When taking good care of our respiratory system, see article "The nose – our personal high-performance air conditioning system and mighty protector" the advice is to keep the RH in the range of 40–50%.

These advised rages are higher as the default values presented in the EN 16798-1. They seem conservative with the advised rage of 20 – 30%. These lower values are merely based on the fact that the evidence in many studies is not very strong and that the impact of humidification and de-humidification has a substantial influence on the energy use of buildings and that poor maintenance of humidification sections in AHU's can cause adverse effect on the IEQ in buildings.

However, we all know the complains about dry air during winter time. In the past this was mainly caused by too high ventilation rates due to leaky buildings. Nowadays more buildings are better insulated and weather stripped which leads to lower infiltration rates and better control of the required ventilation rate. For residential buildings which the low ventilation rate of 0.5 (lowest class according EN 16798-1) dry air complains may be minimal due to the internal water vapour production by persons and their activities. When ventilating according higher comfort and health expectations, dry air complaints during winter time are to be expected in the colder regions in Europe. For non-residential buildings where the internal latent load is much lower, dry air complaints when not humidifying are quite common.

In these cases, humidification control should be considered, the energy use impact can be limited by using latent energy recovery system, quite common in many non-residential buildings but also worth to be considered in residential buildings. About humidification: there are safe to use and maintain humidification system which capacity (and maintenance and running costs) can be limited when using latent heat recovery systems.

Revision of the Energy Performance Buildings Directive (EPBD:2018)

The Commission is currently preparing a revision of the EPBD. I expect the coming months of 2022 discussions at policy level to finalise this draft, hopefully before the summer 2022. We really need an update given all the EU policy targets. The EU Green Deal - Fit for 55 by 2030 etc. are the drivers for the EPBD revision in 2022. Some highlights: more attention to ventilation, a definition for Deep Renovation is proposed, the concept of NZEB (nearly zero energy buildings) is replaced by Nearly Zero Emission Buildings. EU MS's have to report National Renovation Action Plans by 2025 (and every 5 years to update). The concept of Minimum Energy Performance Requirements is introduced. A Building Renovation Passport to be assessed by certified accredited experts is expected to become in force by delegated act to be ready by 2023. New cost optimality procedure by 2026. Alle new buildings shall be zero carbon emission by 2030 (public buildings by 2027). IEQ parameters have to be include in EPCs for new buildings by 2030. Life-cycle GWP (EN15978) for all new buildings by 2030.

The REHVA board, RJ editorial board and REHVA staff wishes all our readers a healthy, prosperous and inspiring 2022. We thank all our readers, supporters and all authors that contributed to the success of this journal in 2021. ■

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Relative humidity effects on viruses and human responses

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Relative humidity effects have two important practical implications: it is not useful to humidify to moderate 40-60% RH in the context of COVID-19, but excessively low RH in cold winters of <20% remain a problem to be solved with humidity recovery or other technical means.

In the context of COVID-19, the effect of indoor relative humidity (RH) on infection risk has been extensively discussed. This has brought RH effects under the attention of researchers and practitioners and has resulted in new experimental evidence and awareness-raising. Before COVID-19, scientific discussion on RH effects has had decreasing trend, many positive and negative effects are listed, but no clear decisions concerning IEQ control have been drawn. RH has been addressed in EN 16798-1 and ISO 17772-1 standards with a recommendation that humidification and dehumidification in European climates are generally unnecessary. However, the discussions on RH concerning the COVID-19 deserve reiteration of what we know about RH and its effects on humans.

Generally, RH and temperature contribute to the infection risk by three main mechanisms:

- By affecting the virus viability, i.e., the length of inactivation time of the virus in the air;
- By impacting expelled droplets and aerosol desiccation and residence time in the air;
- By influencing the susceptibility of people through the sensitivity of nasal systems and mucous membranes.

Several studies have indicated that RH and temperature significantly influence the incidence of COVID-19 for a specific location (Mecenas et al. 2020, Tobías et al. 2021, Yuan et al. 2021), sharing common findings that colder and drier climates may increase the incidence of COVID-19. Although several recent experimental studies have been relating the survival of the SARS-CoV-2 virus in aerosols under various RH and temperature conditions (Dabisch et al. 2020, Schuit et al. 2020, Smither et al. 2020), the precise nature of the relationships is much less clear. On the contrary, the relationship between deposition loss by gravitational settling and RH is clear: the deposition loss of infectious particles is determined by the droplets settling or terminal velocity, which itself is dependent on the size of the droplet. When released from the respiratory tract (assumed to have ~99.5% RH), droplets experience rapid evaporation and shrinkage upon encountering the unsaturated ambient atmosphere. The ultimate size of a droplet depends on ambient humidity, and size determines aerodynamic behaviour and whether the droplet will settle to the ground quickly or remain suspended in the air long enough to possibly cause a secondary infection. It has been suspected that due to low RH, the droplets that will evaporate to a smaller size could lead to more airborne suspension time of viral droplets, and ultimately, they could be transported to farther distances depending on ventilation conditions. However, the droplet desiccation is a fast process, for instance, an original droplet size of 10 µm will evaporate in 0.1 seconds and RH effect on shrinking is quite limited, as shown in **Figure 1**.

The dependence of the equilibrium size of an aqueous droplet containing dry solutes on RH is described by one of the fundamental interpretations of equilibrium thermodynamics, also known as the Köhler theory (1936). Therefore, without incorporating the impact of RH, current modifications of the Wells-Riley model used to estimate infection risk are limited to only one specific RH assessment of the removal terms by inactivation and gravitational settling.

The wide ranges of RH values as defined by existing building regulations design criteria for humidity in both the U.S. (RH < 65% as per ASHRAE 2013) and Europe (20 < RH < 70% used for existing buildings as per EN 16798-1) together with the intensified sensitivity of nasal systems and **mucous membranes to infections at low RH of 10-20%** (Salah et al. 1988, Kudo et al. 2019) emphasizes the need for incorporating the variability of RH values in epidemiological models for a more accurate prediction of airborne transmission risks of SARS-CoV-2 in confined spaces. Consequently, by addressing these factors, a novel model for calculating the infection risk of airborne infectious transmission of SARS-CoV-2 as a function of RH was introduced in a recent paper (Aganovic et al., 2021). To advance a mechanistic understanding of the role of RH in aerosol transmission, the change in the size of respiratory droplets and aerosols and SARS-CoV-2 airborne decay at RHs ranging from 20% to 83.5% was modelled. Based on these results, the dynamics of droplets emitted from an infected person in an indoor environment were further modelled to simulate the airborne transmission of SARS-CoV-2 viral load, considering **removal by ventilation, deposition by gravitational settling, and biological decay** of the SARS-CoV-2 virus in aerosols. Such modelling can support public health experts, engineers, and epidemiologists in a more comprehensive understanding of the impact of RH on the infection risk in indoor spaces.

To characterize the impact of relative humidity on inactivation rate, experimental data on the survival time of SARS-CoV-2 in aerosols can be aggregated from measured values of k (min^{-1}) currently available at RH 20% to 83.5%, **Figure 2**.

A modified version of the Wells-Riley model was used in (Aganovic et al. 2021) to include the impact of RH on the volume emission of respiratory droplets from an infected individual and its removal mechanisms of deposition by gravitational settling and inactivation by biological decay. This study was thus able to determine and estimate the magnitude by which RH can affect the airborne transmission of SARS-CoV-2 and reduce the infection risk from one infected individual within public indoor spaces. In addition to the impact of RH, by

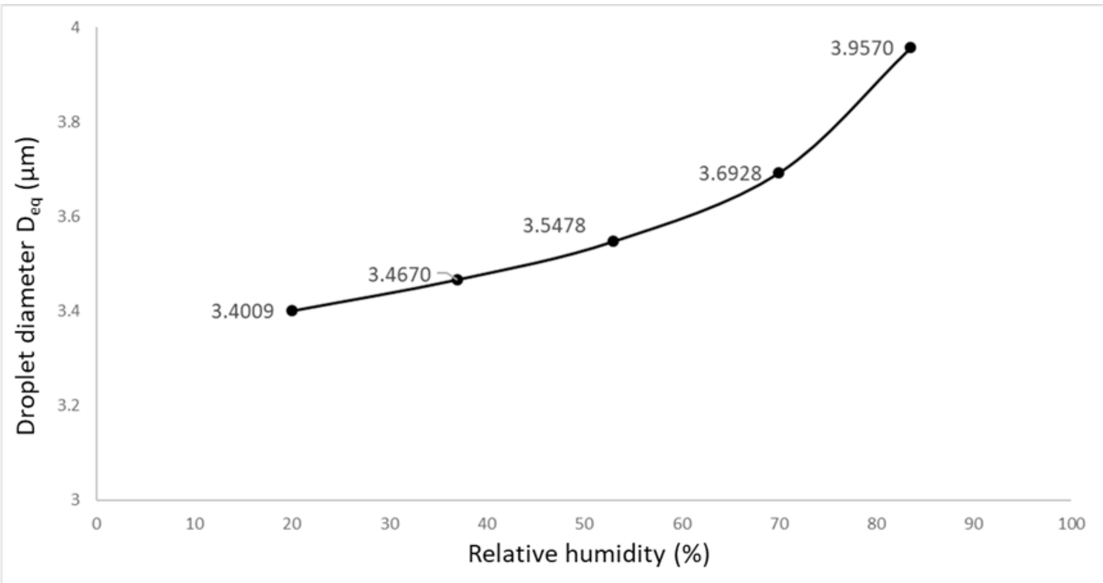


Figure 1. Equivalent dehydrated droplet diameter at five RH values (RH = 20%, 37%, 53%, 70% and 83.5%) for an original droplet size of 10 µm the indoor air temperature range 20-25°C (Aganovic et al. 2021).

using updated characteristics of the SARS-CoV-2 virus on estimated infection dose, theoretical calculations of the infection risk were possible to perform for different scenarios considering the viral load in the infected individual, different size ranges of dehydrated respiratory droplets, and different ventilation rates, **Figure 3**.

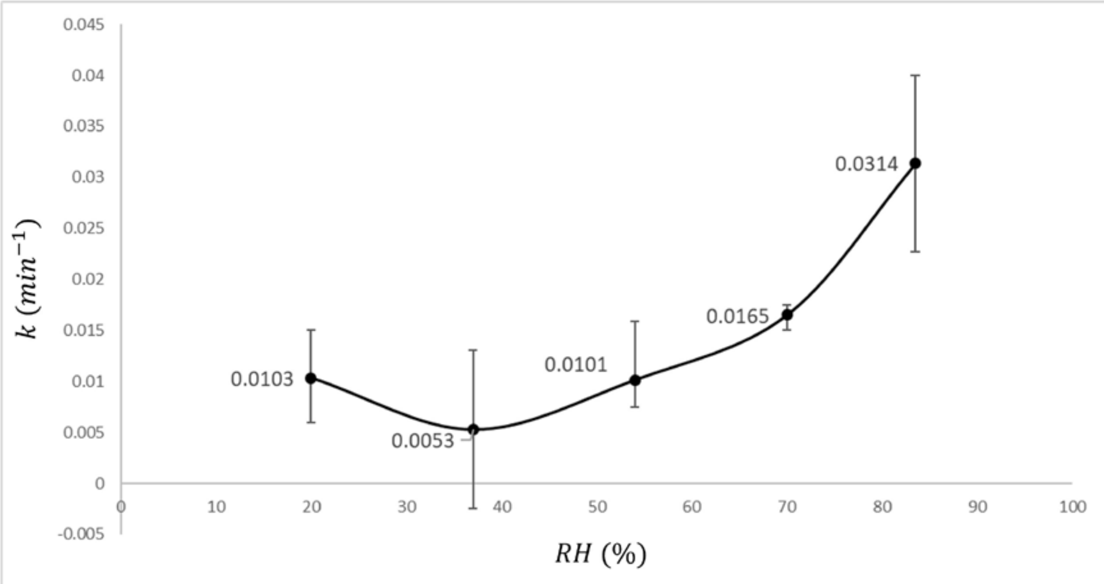


Figure 2. Mean, min, and max IAV inactivation rates (k) for each RH were derived based on experimental data adapted from Dabisch et al. (2020), Schuit et al. (2020), and Smither et al. (2020).

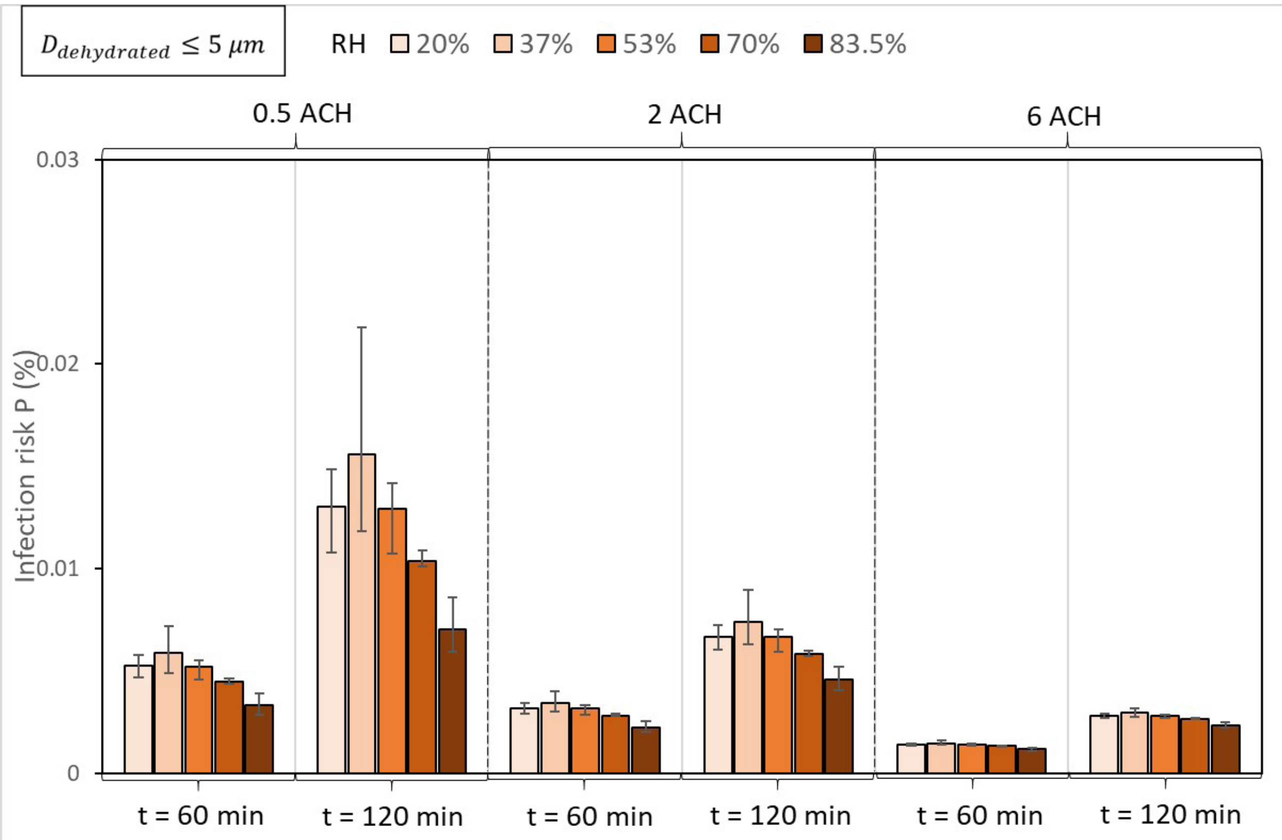


Figure 3. Impact of RH and ventilation on the infection risk probability P (%) when an infected person with a viral load of $c_v = 10^9$ RNA/ml is speaking continuously for 60 and 120 min. The columns depict mean P (%), and the error bars present min and max values (Aganovic et al., 2021).

The infection risk P (%) will decrease with decreasing RH to 20% or by increasing from 37% to 83.5%, but mainly for RH > 53%, given the same ventilation rate, droplet size range, and viral load considered. For smaller droplets considered ($D_{dehyd} \leq 5$ µm), the mean infection risk for 20% and 53% are approximately equal. The difference in infection risk for different RH values will increase with exposure time at a constant ventilation rate. The differences between infection risks for different RH values become relatively small for higher ventilation rates, and RH will have only a minor effect if any. Generally, increasing ventilation rate will provide a stronger effect in reducing infection compared to changing the relative humidity given the same exposure time and viral load considered. Changing RH in the range between 20% and 53% is ineffective plausibly due to the non-linearity of the relationship between RH and inactivation rates.

To explain the results in **Figure 3**, the removal efficiencies for all three mechanisms for different size ranges and ventilation rates are reported in **Figure 4**. Regardless of ventilation rate and droplet size considered, both the removal efficiency due to settling and inactivation increase at RH from 37% to 83.5%. The mean removal efficiency at RH = 20% will be higher than at RH = 53% for smaller droplets ($D_{dehyd} \leq 5$ µm). At this size range, the differences in inactivation rates for different RH values will determine the overall impact of RH on the removal efficiency, as the removal efficiency for ventilation is not influenced by RH. At the same time, the differences in removal efficiency for settling for different RH are too small to impact the overall removal efficiency. However, as larger droplets have greater settling velocities at higher RHs, the equilibrium droplet size will be relatively larger and will therefore accelerate the removal mechanism. Thus, with an increase in the considered droplet size range, the relative removal efficiency effect by settling will increase. Although the difference between the settling removal efficiencies at different RH will increase with an increase in droplet size range, these differences will have a small impact compared with the overall removal efficiency at higher ventilation rates, as the ventilation rate removal efficiency is independent of RH value.

The evaluation of the infection risk in **Figures 3 and 4** does not consider the human immune system's reaction to changes in RH. In this area, the evidence on RH effects is somewhat conflicting and not complete as studies provide an indication that the lower limit of RH could be 10%, 20%, or 30% RH. The sensitivity of nasal systems and mucous membranes has

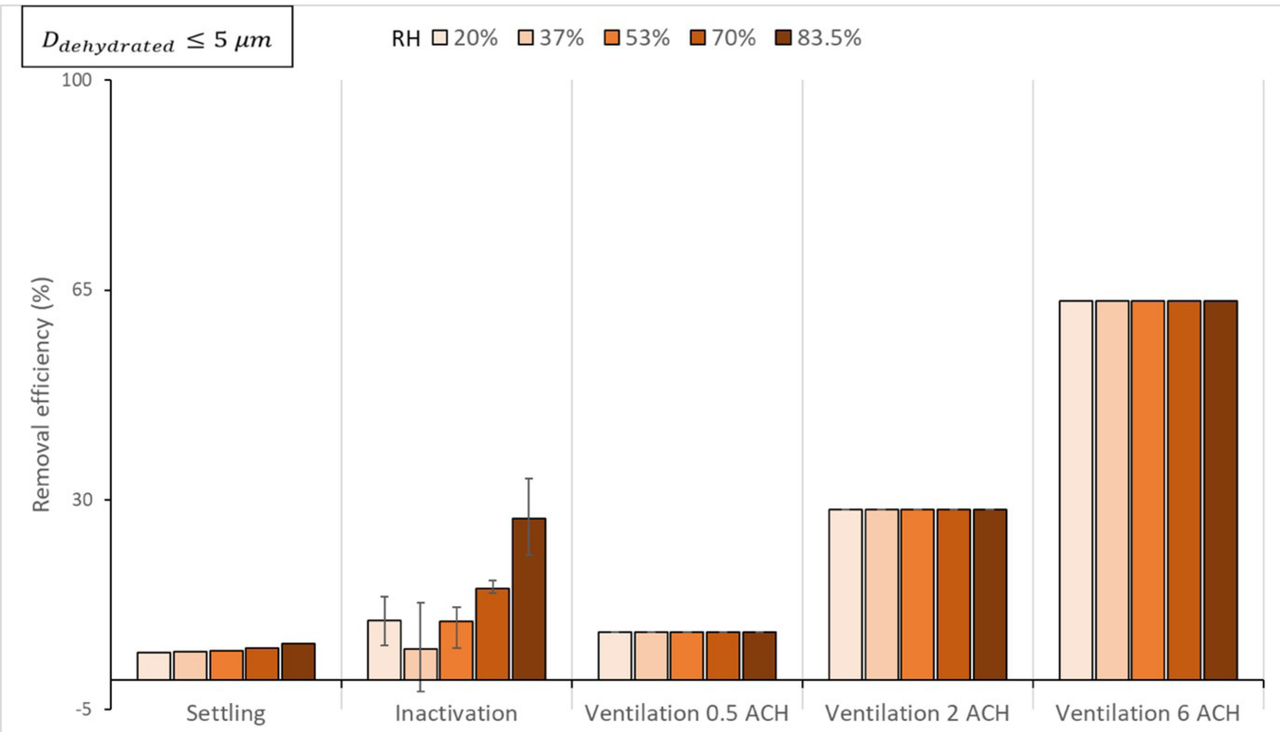


Figure 4. Removal efficiency when individual stopped speaking (source absent) due to gravitational settling, inactivation, and three different ventilation rates (0.5, 2, and 6 ACH) for small airborne infectious droplets (≤ 5 µm). The columns depict mean removal efficiency, and the error bars present min and max values (Aganovic et al., 2021).

been extensively studied. Andersen et al. (1974) did not observe changes in mucociliary clearance during 78 hours of exposure to dry unpolluted air at 9% compared to 50% RH. Other studies showed that nasal systems and mucous membranes are more sensitive to infections at RH of 10-20% (Salah et al. 1988, Kudo et al. 2019). It is well established that low RH aggravates the eye tear film leading to eye symptoms like dry eyes, for which Wyon et al. (2006) showed significant differences between 25% and 15% RH. The dry nose and throat sensation also occurs in the nose and throat after some latency and without pollution, which is more pronounced at RHs below 10% (Wolkoff 2018). Therefore, some humidification in winter may sometimes be useful to reach the levels of 20-30% recommended in ISO 17772-1:2017 to be used as a design criterion if humidification systems are installed.

On the other hand, the use of humidifiers is linked with increased short-term sick-leave rates due to infections (Milton et al. 2001). Humidification is an energy-intensive process that may lead to wet surfaces in air conditioning systems, known as one of the most significant IAQ risk factors. Adding humidification to reduce sensitivity to infections may not be as beneficial as claimed, although it must be admitted that sensitivity to dry air in polluted air is increased (Andersen et al., 1974). Consequently, improved ventilation may provide the benefits of removing and diluting the viruses and reducing sensitivity, especially when RH levels are low.


Photo by Anne Nygård on Unsplash

It should also be noted that high RH (over 40-50% RH) may be harmful, especially during the winter. High humidity levels can lead to risk of mold and allergic reactions related to house dust mite. Indoor air humidity may condense on cold surfaces and increase the risk of microbial growth on surfaces, and further in structures, and deteriorate indoor air quality. Condensation of moisture, particularly on window panes, has been related to the indoor air problems linked to inadequate ventilation or wrong pressure difference over the building envelope in many studies. Moisture damages due to high indoor air humidity are, however, not so common as damages caused by other sources of water.

Conclusions

Evidence on the RH effect can be summarized in the following key points:

- The relative importance of RH and the ventilation rate in reducing the infection risk of the COVID-19 is comprehensively studied, allowing informed decisions to be made for indoor environmental control;
- The evidence clearly shows that humidification to moderate levels of 40% to 60% RH should NOT be expected to provide significant effects in reducing infection risk;
- High humidity levels can lead to risk of mold and allergic reactions related to house dust mite;
- Hence, installing and running humidifiers may NOT be an efficient solution to combat the infection risk in indoor spaces;
- The results **emphasize the key role of ventilation** in controlling the virus concentration in the air;
- Nasal systems and mucous membranes are more sensitive to infections at **RH below 20%** leading to dry eyes, nose, and throat sensation that supports to avoid excessively low RH, especially in cold winters;
- Technical means to address very small humidification need to 20% RH limit do not need to be humidifiers, but humidity recovery by proper selection of enthalpy or other hygroscopic heat exchangers may also be considered. ■

References

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

ISO 17772-1:2017 Energy performance of buildings — Indoor environmental quality — Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings.

Mecenas P., Bastos R., Vallinoto A.C.R., Normando D. Effects of temperature and humidity on the spread of COVID-19: A systematic review. *PLoS One*. 2020;15(9) (e0238339. PubMed PMID: 32946453. PMCID: PMC7500589. Epub 2020/09/19).

Tobías A, Molina T, Rodrigo M, Saez M. Meteorological factors and incidence of COVID-19 during the first wave of the pandemic in Catalonia (Spain): A multi-county study. One Health. 2021 Jun;12:100239. DOI: https://doi.org/10.1016/j.onehlt.2021.100239. Epub 2021 Mar 29. PMID: 33816746; PMCID: PMC8007195.

Yuan J, Wu Y, Jing W, et al. Association between meteorological factors and daily new cases of COVID-19 in 188 countries: A time series analysis. *Sci Total Environ*. 2021;780:146538. doi: https://doi.org/10.1016/j.scitotenv.2021.146538.

Dabisch P, Schuit M, Herzog A, Beck K, Wood S, Krause M, Miller D, Weaver W, Freeburger D, Hooper I. 2020. The influence of temperature, humidity, and simulated sunlight on the infectivity of SARS-CoV-2 in aerosols. Aerosol Science and Technology 55(2):1–15.

Schuit M, Ratnesar-Shumate S, Yolitz J, Williams G, Weaver W, Green B, Miller D, Krause M, Beck K, Wood S. 2020. Airborne SARS-CoV-2 is rapidly inactivated by simulated sunlight. Journal of Infectious Diseases 222(4):564–571 DOI https://doi.org/10.1093/infdis/jiaa334.

Smither SJ, Eastaugh LS, Findlay JS, Lever MS. 2020. Experimental aerosol survival of SARS-CoV- 2 in artificial saliva and tissue culture media at medium and high humidity. Emerging Microbes & Infections 9(1):1–9.

Aganovic A, Bi Y, Cao G, Drangsholt F, Kurnitski J, Wargocki P. Estimating the impact of indoor relative humidity on SARS-CoV-2 airborne transmission risk using a new modification of the Wells-Riley model. Building and Environment 205 (2021) 108278. https://doi.org/10.1016/j.buildenv.2021.108278.

Köhler, H., "The nucleus in and the growth of hygroscopic droplets," Trans. Faraday Soc. 32, 1152–1161 (1936).

ANSI/ASHRAE, 2013b. ANSI/ASHRAE Standard 169-2013, Climatic Data for Building Design Standards 8400, 104.

Salah et al., 1988. Nasal mucociliary transport in healthy subjects is slower when breathing dry air. European Respiratory Journal 1(9): 852-855.

Kudo et al., 2019. Low ambient humidity impairs barrier function and innate resistance against influenza infection. PNAS: 1-6.

Andersen, I. B., Lundqvist, G. R., Jensen, P. L., & Proctor, D. F. (1974). Human response to 78-hour exposure to dry air. Archives of Environmental Health: An International Journal, 29(6), 319-324.

Wolkoff P, 2018. Indoor air humidity, air quality, and health – An overview. International Journal of Hygiene and Environmental Health 221 (2018) 376–390.

Wyon, D.P., Fang, L., Lagercrantz, L., Fanger, P.O., 2006. Experimental determination of the limiting criteria for human exposure to low winter humidity indoors (RP-1160). HVAC&R Res. 12, 201–213.

Milton et al., 2001. Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints. Indoor Air 2001. https://doi.org/10.1034/j.1600-0668.2000.010004212.x.

The nose – our personal high-performance air conditioning system and mighty protector

Fascinating analogy, isn't it? Let me introduce you to your own nose. It can do so much more than just help you breathe and smell! There are ventilation and air-conditioning functions performed by this crucially important, yet underappreciated part of the human body.

WALTER HUGENTOBLER
MD, family doctor, medical consultant, and indoor climate expert

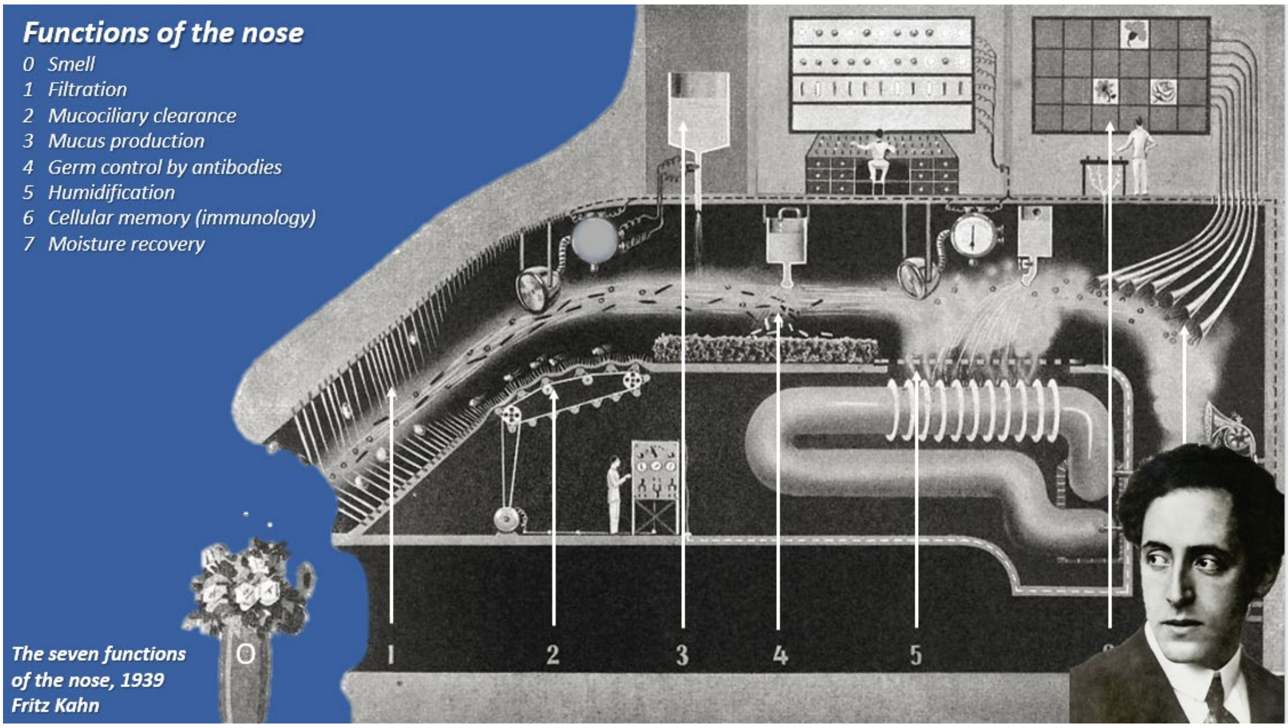
See also: https://www.condair.de/fachartikel/aerztemeinung-zum-thema-luftbefeuchtung
https://www.humidification.com/medical-advisors
https://40to60rh.com/

Let's have a look: the description of this fascinating "device" in technical terminology should read:

The Nose is a bidirectional, cyclic, two-part mini-combined device for air conditioning, heat and moisture recovery, air filtration with integrated disposal, odour sensor, direct access to the brain (known as the "nose-brain axis") and for infection defence!

With the last aspect becoming more understood, we realize what tremendous performance healthy noses can deliver, with every breath we take. And therefore, how important is the conditioning of the indoor air by the buildings' HVAC systems, as this factually represents the first stage in ensuring gas exchange in our lungs and in enabling our efficient immune response. How exactly does this functional dependence work?

One key capability of our nose is to protect us from viral infections and consequences of air pollution. With a functioning respiratory mucosa, a series of obstacles are put-up against viruses and other pathogens. First, a mechanical removal through the moving mucus carpet, swallowing and coughing. An effective disposal prevents the viruses from reaching the target, the receptors of the epithelial cells, quickly enough to start an infection.



The seven functions of the nose, 1939 Fritz Kahn

Processed illustration: © Fritz Kahn, Das Leben des Menschen III, Franckh/Kosmos, Stuttgart 1926

www.fritz-kahn.com

This is called the mucociliary clearance. Second, the viruses cannot penetrate critical mucus layers and get us sick, if these layers are intact. A third obstacle subjects viruses to chemical attacks by antibodies and enzymes, while a fourth sees the local immune cells creating a toxic environment for viruses and also call upon the acquired immunity cells for help via messenger substances and stimulate antibody production, as a fifth and final step.

Nevertheless, all these defence mechanisms can only function optimally, if the water content of the mucus layer is between exactly 96 and 98 percent and the temperature is around 37 degrees Celsius.

Especially the capability of viruses' removal is severely impaired by dry air, leading to the water content of the mucus to fall below 96%.

Our wonderfully designed nose must prepare the inhaled air – provided to it in any given initial condition – in such a way, that it supports optimal hydration levels of the mucus so that the air reaches the alveoli at 100% relative humidity and 37°C. This is an absolute must, by physiological design. Consequently, the respiratory tract must add-on every percent of moisture that is not provided by the air conditioning technology: if the inhaled air is too dry, the nose, mouth, throat and bronchi get in competition with the mercilessly "thirsty air", which strives for saturation, i.e. 100% moisture. The air fetches the moisture wherever it is present, in whatever form – and in dry indoors, the human being is often the only source of moisture – thus the person becomes one's own humidifier, leading to discomfort and illness. So, if the indoors relative humidity does not rise above 20 to 30% – like most commonly during wintertime – then the nose, throat and bronchi of any occupants are challenged until possible decompensation.

Depending on the outdoor climate region, in winter, as the cold outside air contains very little water, heating often leads to very dry indoor air. In about a half (!) of the population, the nose is not able to provide the humidification required without desiccation of the respiratory mucus. Particularly at risk are seniors, babies, allergy sufferers, asthmatics, bronchitis sufferers, smokers, and COPD patients, all overwhelmed as a result of the extreme dryness of heated indoor air. Dehydration symptoms appear and the mucous membranes of their respiratory tract are damaged. The result: more frequent infectious diseases, nasal, and paranasal sinus problems as well as worsening of allergic and chronic respiratory diseases.

Dryness and dust exposure belong together

The drier the air, the more dust-laden it is. Therefore, during the heating season, both the air dryness and the dust strain the air conditioning and cleaning function of the respiratory tract to its performance limit and beyond. These factors represent a double burden and are mutually dependent. Our indoor climate presents the respiratory tract with days and weeks of challenges that it never faces outdoors in this form!

So now you see the connection: the quality of the provided indoor air, especially the often-overseen relative humidity levels of indoor air, are key for keeping us healthy and striving. Because not only the respiratory tract's performance is affected, but also the eyes and skin, brain, kidneys and blood. Changes under air dryness stress are measurable in all these organs, without exception. The effects on the eyes and skin are best known. So are the negative effects on the brain performance, also well documented e.g., the scientific aviation literature presents numerous papers on the dangerous consequences of excessive dehydration on pilots' vision, responsiveness, and decision-making processes. The negative effects of air dryness on the intellectual performance of office staff and students are well documented.

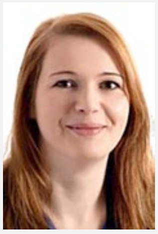
Fact: air humidification during winter is a necessity and the nose physiology request the ideal minimum of 40% RH

Modern building's physics, building equipment and services are exclusively determining the indoor air quality, so these should be designed based on the latest knowledge, making indoor air conductive to health and performance.

The described processes have every day, practical consequences: the air humidification opens up a large, previously untapped prevention potential – and we all should use it! Because in the planning and building stage of public spaces, offices, homes, shops, etc. there is still freedom of choice – which is later not granted to the building's occupants, to the organ systems in their bodies. Hence the functions of the HVAC system – especially the humidification performance – are fundamental in the process of keeping us all healthy and performant, enabling our respiratory system, our own portable A/C system, to function efficiently and to keep us safe and vivacious throughout the cold season. ■

Dry indoor climate

– Why and how to prepare for the next cold season?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It's easy to forget, what you can't see – if we live in the Nordic region or other colder areas, we could acknowledge that the air feels dry and the indoor climate is less comfortable during wintertime, i.e. we experience cold, dry spells. In addition to impaired indoor comfort, research shows that a dry indoor environment is also one of the causes of seasonal illnesses such as influenza. In this article, we will introduce the reasons behind a dry indoor environment and how it affects us and a few simple tips on what we can do to make the indoor climate more comfortable in the winter. We can have the systems/controls for handling humidity indoors in place for the next cold season if we start planning straight away!

Keywords: relative humidity (RH), cold climate, health, indoor air quality

Today, we live for a few months a year in a desert climate!

In the winter months and till late in spring, in modern private households, offices and public spaces the relative humidity could drop to just 15 to 20 percent – comparable to the conditions in the bone-dry desert! Indeed, such climate of 20-26°C and 10-40% RH exists in nature only in winter time in the desert! And in our temperate climate zones, you can find it in buildings only.

The problem of dry indoor air has increased dramatically over the last 50 years partly because of:

- The average indoor temperature has increased by 5°C (remember, for example, grandparents who only heated the living room and only to 18°C).
- The living space per inhabitant increased from 25 m²/p. to 45 m²/p. between 1970 and 2013 (thus less natural moisture input through cooking, washing, showering).

- Loss of healthy practices: recall the wise grandmothers placing wet towels or small ceramic pots onto the heating elements or ovens during the winter season, in order to keep a pleasant air quality, or humidifying especially when children were sick with respiratory diseases, to naturally ease the cough and aid recovery. They knew it, empirically!

How do we notice dry air?

High humidity may cause problems indoors, leading to moisture and damage in case of water condensating onto cold walls– which can be easily avoided, primarily through good wall insulation in combination with sufficient ventilation. However, in winter, when it's cold and freezing, in many parts of the world, we experience the opposite – that the indoor air feels uncomfortably dry. We notice it when our bodies start to itch, our hair feels electric, our hands and lips get chapped, our throats and eyes feel dry, and we easily get an irritating cough. People with asthma, allergies, or other respiratory disorders often have more trouble during the cold season, particularly noticeable symptoms. In addition, a dry indoor climate also affects the building, as laminate flooring cracks and parquet flooring starts to separate or warp. So, what is the reason behind all of this?

The laws of nature rule - How does it work technically?

Dry air in winter is mainly due to our natural laws and the fact that cold air cannot physically contain as much moisture as warm air. In the humidity diagram (**Figure 1**), the blue line shows the maximum "absolute humidity" of the air (g/m³), i.e. the maximum amount of moisture the air can contain at a given temperature (°C). In simpler terms, the blue line shows when the relative humidity (RH-) is 100% at different temperatures.

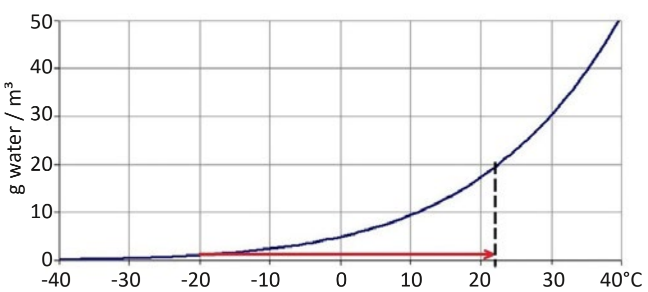

Figure 1. Relative humidity – moisture content in the air at a given temperature.

Example: At minus 20°C, the air's absolute humidity at most is approximately 1 gram moisture per cubic metre of air. If the air is heated to 22°C (red arrow), the air can contain 15 times more moisture without condensation, i.e. a maximum of about 20 g/m³ of water. However, since no moisture is added during the increase in temperature, the relative humidity (RH) will instead drop from RH = 100% to only about RH = 7-8%. This means that cold air dries when it is heated and we often experience a poor indoor climate in winter.

Humidity and water in your body

The human body is composed of 60-80% of water, which is why people have such an adverse bodily reaction to extremely dry air, see **Figure 2**. Therefore, to function properly, people need to be in an environment with ample moisture levels in the air.

Did you know that the brain and heart are composed of 73% water, and the lungs are about 83% water? And that the skin contains 64% water, muscles and kidneys are 79%, and even the bones are watery 31%? (Source: H.H. Mitchell, Journal of Biological Chemistry 158).

Humidity and the feeling of cold

In winter, drier air assists evaporation and thus the cooling of the people's skin. The most immediate effect of this phenomenon is that for the same temperature, the drier the air – the colder we feel.

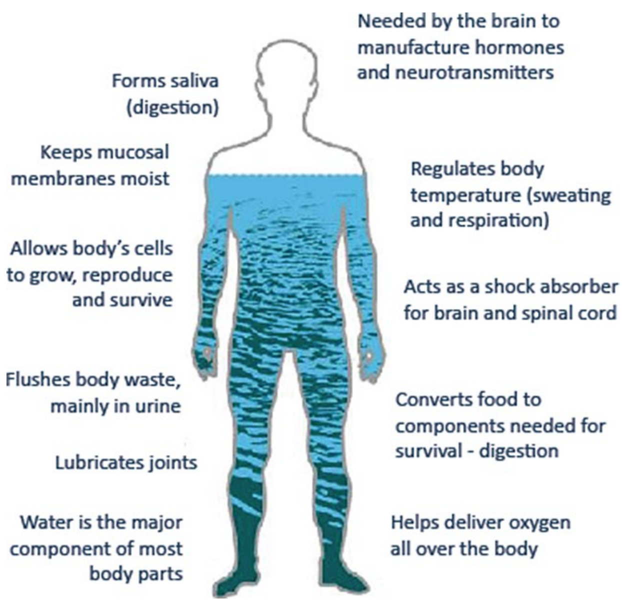

Figure 2. Water in the human body, i.e. what water does for you – just a few examples.

The impact of humidity on indoor climate and health

As stated in the beginning, in homes, but also in other premises such as offices and schools, the relative humidity is often 20-40%, but at times during the winter it can be as low as 10%. The recommended level is often given as between 30% and 60% depending on the season, but there is no set limit for this. At higher levels, the indoor environment can be perceived as damp, close and sticky, while lower levels can be perceived as dry and dusty, and you experience problems with static electricity and itching on the body.

The common problems associated with severely dry air

The effects of low humidity can be expressed in two areas – the skin and respiratory problems.

- Chapped lips, dry and irritated eyes, and dry skin with itching, tiny cracks and even bleeding (cracked skin opens the body up to greater exposure to microbes and illness). Also, dry nasal passages cause nosebleeds. Similarly causing sore or scratchy throat. And in the long-term, it can cause or worsen skin – irritation, inflamed eczema and allergy.
- As your body's ability to trap and filter out the viruses and microbes decreases – it can cause discomfort and also make you more susceptible to sickness. And prolonged stay in low humidity can cause developing respiratory problems such as asthma, bronchitis, sinusitis, etc.

What can be done to counteract dry indoor air in your home and at your workplace?

There is no one-size-fits-all solution, but it's possible to influence the indoor climate to some extent by simple means to reduce the dryness of the air in offices or other premises in winter.

- During periods when humidity is low, you should take care of yourself – drink more fluids, especially water, and surely moisturize your skin and lips. Also make sure that you humidify the air around you, so it does not dry you out!
- The traditional way of increasing the humidity indoors relies on placing large bowls of water in various places in the room, especially near the heat source, to accelerate the evaporation process. And the more modern approach is to use mobile humidifier.
- Living plants increase the sense of well-being and release humidity into the environment through evaporation. The more and larger the plants, the better (for example green living walls). Also, you may want to close the door to the office in your workplace and at home to preserve the higher humidity level, both during the working day but also overnight. An aquarium can also be an excellent complement in common areas.
- A small humidifier can help to add moisture, but often only works on a room-by-room basis, and this can be a less ideal option in open-plan offices and large classrooms. There are also larger mobile humidifiers, suitable for these setups. Remember that there are different humidifiers and that some of them emit noise, so it's important to choose a model with a low noise level. All humidifiers also need some form of maintenance, such as cleaning, in order not to pose a health risk.
- Control and improve your indoor air quality, you can monitor the overall conditions of the room using either a simple humidistat/hygrometer or use more complex monitoring equipment provided in your office connected to a more advanced building system.
- Invest in your indoor climate system by adding controls and functions for humidity recovery as well as the potential of adding humidity, in order to offer effective and safe protection, via a permanent solution. to achieve a both pleasant and healthy indoor climate.

In conclusion…

Nature is always looking for balance. In the case of relative humidity, this means 100% saturation. The air will therefore always remove moisture wherever it finds it until it is saturated. The scientific evidence [**1**] is there, controlled and increased relative humidity during our dry season will increase wellbeing and health and levels up to 60 percent relative humidity in central Europe is ideal – this corresponds approximately to the conditions prevailing in the nature. It is considered ideal both for value preservation and more importantly, for the immune system of our respiratory tract. So, let's keep our surrounding air well hydrated over this winter, for us all to keep healthy, merry and radiant as we enter a very good 2022! ■

References

[1] Indirect health effects of relative humidity in indoor environments. A V Arundel, E M Sterling, J H Biggin, and T D Sterling. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474709/pdf/envhper00436-0331.pdf

Clearing up a few myths in humidity recovery

There are many assumptions and opinions circulating around humidity recovery in the European HVAC industry and among HVAC engineers. Some of them are based on bad experiences, some of studies or claims presented with a certain partiality. I will try to clarify some these myths based on my experience in this industry.

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Keywords: Rotary heat exchangers, Humidity recovery, Carry-over, Internal leakages, Sorption rotors

Myth #1: Mould and bacteria can grow on the surfaces of the humidity recovery rotor or sorption rotor

It is often claimed that humidity recovery rotors would allow the growth of mould and bacteria on the wet surfaces of the rotor matrix. In humidity recovery the moisture does not condensate on the surface of sorption rotor foils. Water molecules are adsorbed as molecules in the sorption coating. So, there is usually no wet surface on the coating of the rotor matrix. However, humidity will condensate on Aluminium rotor (condensation rotor) if the outdoor temperature is low and extract air humidity is high enough.

Many sorption rotor suppliers have performed a hygiene test in which the rotor foil is placed in a humid test chamber, and the growth of mould and bacteria is observed. The results from these tests show an extremely low risk of mould or bacterial growth. To get this confirmed by your supplier, ask for the result of such a test. Even the used sorption foils in residential buildings have been tested by some suppliers with similar results.

Myth #2: Humidity recovery will transfer odours/smells and VOC gases to the supply air

The risk of unpleasant odours and volatile organic compound (VOC) gases transmission depends on three aspects. Generally, aspects (a) and (b) are covered by the exhaust air transfer ratio (EATR), which describes the amount of exhaust air in the supply air. And the aspect (c) is dependent on the active material in humidity recovery.

Note that there are also air leakages from the supply air to the exhaust air, which are not included in this paper, as these air leakages have no impact on smell.

a. Internal leakages of extract air to the supply air due to the pressure relationships inside the air handling unit

Internal leakage is a function of the pressure relationship between the outdoor/supply and extract/exhaust airflows around the rotor and other leakage sources in the air handling unit (AHU), such as recirculation dampers.

Depending on the position of the fans, the required pressures in the ducts and the AHU design, these internal leakages can range from 0% up to 20-30% in the worst scenario. The best way to determine internal leakage is to ask from air handling unit supplier for the EATR value calculation based on the actual design pressure conditions and to clarify how the pressure relation is kept correct under different operating conditions. During the site inspection, the best way to ensure the correct pressure relationship is to measure the pressure difference between the supply and extract air on the building side of the rotor. There should always be a small overpressure (at least 0-20 Pa) on the supply airside. If so, this problem is resolved.

b. Rotary heat exchanger carries extract air over to the supply air due to its rotation

It is commonly known that the purge sector will clean up the rotor from the remains of extract air (**Figure 1**). However, it is often not understood that certain requirements are needed for the purge sector to work correctly.

The purge sector must be available, properly adjusted and well designed. For purge sector to work correctly the pressure relationship between airflows must be over-pressured on the supply air side, as mentioned in the above section (a) about the internal leakages.

There are however many markets where purge sector is not commonly used, then it will become inevitable that the extract air will be carried over to the supply air. Typical extract air carry-over values due rotation will be 2-5% extract air in supply air (EATR). With a low airflow and a high rotation speed, it can be even higher.

c. Possible carry over of odour and VOC gases in the sorption matrix

This so-called Matrix Borne Carry Over (MBCO) is a very much discussed but less studied topic. Therefore, special attention needs to be paid to the selection of suitable sorption materials.

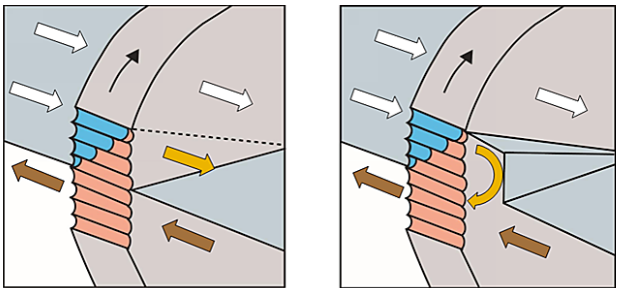

Figure 1. The purge sector. [image by Swegon]

Until the beginning of the 2010´s, the European market was not very clear about the specification of the active coating material for humidity recovery. Silica gel was commonly used for humidity recovery rotors. The problem with silica gel is that it is not specific what gases it adsorbs. Due to the wide variation of pore sizes, which plays critical part in the adsorption process, silica gel can adsorb a large variety of VOC gases. If the sorption material can adsorb the VOC gases in the extract air, it can also release it in the supply air. That's why it is used also in cat sand and electronic or leather product packings airside. Silica gel is used also in so called VOC gas concentrators/filters where VOC gases are adsorbed from air and concentrated on other air flow.

MBCO rates can be up to 20-40% of the VOC gases concentrations in the rotors with the silica gel. If the extract air contains very foul-smelling gases, even 1% can be too much. Some applications with silica gel rotors have had problems with so-called 'wet basement' odour. This occurs when the humidity levels are high on both air flows, and the matrix material starts to heat up and it releases odour gases.

For the past 10 years in European and for the last 20-30 years in the Asian and American markets, many suppliers have offered different types of adsorbent coatings. Zeolites (**Figure 2**) are widely used in industries and processes to adsorb a specific gas from liquids or gas mixtures. Different pore sizes can be artificially designed to adsorb specific types of gases. (The pore sizes are measured in Ångström (Å), which is a metric unit of length equal to 10^{-10} metres, and it is used to measure the molecule size.) Water vapour molecules

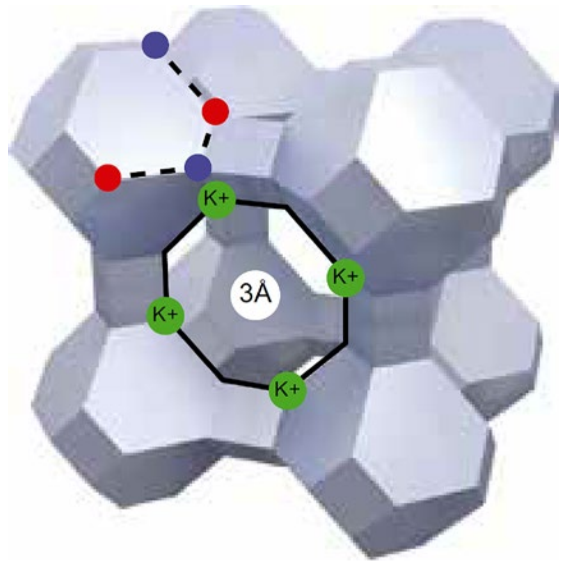

Figure 2. Zeolite 3Å molecule. [Östberg AB documentation]

are one of the smallest molecules, with a molecular size of 2.7Å. Therefore, 3Å molecular sieves are very well suited to adsorb water molecules, as it is used in various industrial applications. Other molecular sieves are also used in ventilation applications, for example, 4Å.

The selection of adsorbent is an optimization between costs, capacity and the risk of VOC carry over. In order to fix the coating on the surface and in order to increase the surface area on the foil some other materials might be used and act differently as the primary sorption material. Therefore, the testing of the foil material/rotors for MBCO would be very important.

Some suppliers have performed different kinds of the MBCO tests. The results show variations between different coating materials, especially 3Å molecular sieve has shown low MBCO values. Unfortunately, there is no standard available to measure this carryover. Some research projects are ongoing in both the US and Europe to develop such test method.

Today, the 3Å molecular sieves and other zeolites are widely available in the sorption recovery wheels. Just ask your supplier about this specification. Otherwise, there is a risk to get the silica gel coated rotors (and thus have problems with carryover of smell and VOC gases).

Myth #3: Humidity recovery will transfer aerosols from the extract air to the supply air

During the Covid-19 pandemic, it is often discussed and claimed that rotary heat exchangers, especially sorption rotors, would carry over aerosols containing viruses and bacteria, i.e., there would be a risk of spreading infectious diseases in ventilation systems with rotary heat exchangers.

Only recently, in September 2021, company Hoval AG has presented a study [**1**] done at the HSLU HVAC test laboratory in Luzern, where the carryover of aerosols in rotary heat exchangers was studied. The results showed no evidence that the aerosols would be carried from the extract air to the supply air in the rotor matrix. The results were similar for both aluminium and sorption rotors.

Of course, the results do not exclude a possible internal air leakage in AHU; due to wrong pressure relations between air flows, absence of purge sector, or the lack of proper functioning purge sector.

Myth #4: One cannot regulate the efficiency of humidity recovery

The temperature and humidity efficiency are regulated by reducing the rotor speed (revolutions per minute, rpm). The dependency of the temperature and humidity efficiency on the rpm is often characterized by the following type of a chart (**Figure 3**).

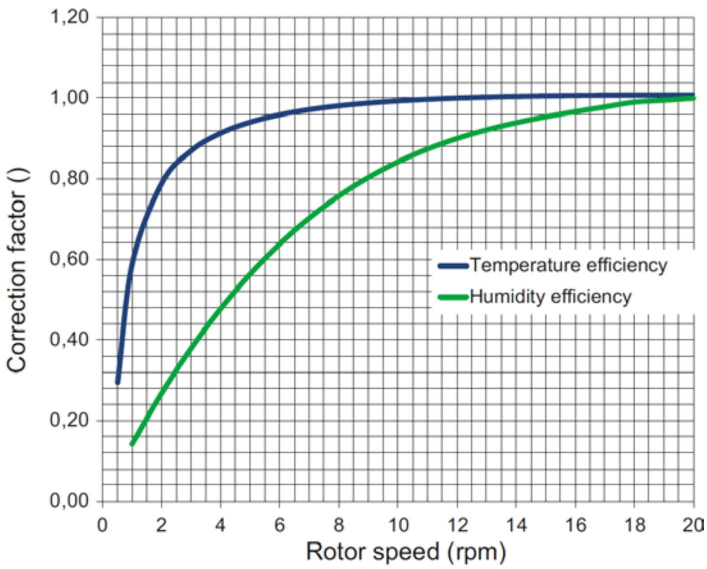

Figure 3. Temperature and humidity efficiency depending on rotor speed. [Hoval AG documentation]

The blue line characterizes the relative change of temperature efficiency and green line of humidity efficiency as the function of rotor rpm. Important in this diagram is that the humidity efficiency (green line) has different characteristics. This difference can be used to control the humidity recovery rate without affecting the temperature efficiency too much. It is worth emphasizing that these characteristics are generic, each rotor design, sorption coating and air flow rate will have its specific characteristics.

Temperature and humidity recovery efficiency control of plate heat exchangers are possible only by using the bypass, and therefore humidity efficiency will have similar control characteristics than temperature efficiency.

Myth #5: Humidity recovery will cause too high humidity levels in a building

Humidity recovery is often claimed to cause too high humidity levels, especially in residential buildings in cold climates (condensation on windows etc.).

This may sometimes be the case. Likely reason for too high humidity levels is that ventilation unit had no control routine to avoid too high humidity levels. Unfortunately, there are still very few, if any, residential ventilation units that would have such functionality. So, it is a question of control function. Hopefully, progressive suppliers will find a business opportunity in this area.

In the Central European climate, the risk of too high humidity levels is lower as the outdoor temperature does not drop much below 0°C.

With enthalpy plate heat exchangers, the control of humidity recovery rate is not possible without bypassing the airflow. On the other hand, the humidity recovery efficiency of these products is also usually lower, typically around 55-65%.

In non-residential buildings, too high humidity levels are rarely a problem, but more advanced control systems can handle possible problem situations.

Myth #6: Humidity recovery works only in the coldest wintertime and with low recovery efficiency

Especially in the European market, we often see that the specification for humidity recovery is not adequate. Often specification is only requesting for the hygroscopic recovery wheels. Unfortunately, this frequent specification allows almost any kind of humidity recovery and any coating quality. With hygroscopic rotor specification humidity efficiency levels are low from 10-40% in winter and hardly any in summer conditions. Eurovent Certification program for energy recovery wheels (AARE) classifies energy recovery wheels with high humidity recovery efficiencies to sorption wheels. These products need to have a humidity recovery rate of at least 70% of the temperature efficiency. This means, if the temperature efficiency is 80%, the humidity recovery rate in summer testing conditions needs to be a minimum of 70% * 80% = 56%. The same range of humidity recovery efficiency will also be gained in wintertime.

Looking at the certification data from the Eurovent Certification home page of the AARE program, we can see that with airflows at 1 m/s (air speed over the rotor), we can get more than 90% recovery efficiency, and at 2 m/s we find many products and more suppliers achieving humidity recovery efficiency up to 80-90%. So, for energy cost calculations of 50% humidity recovery rate we have massive potential for improvement.

From a humidity recovery perspective, the ventilation could be much lower consumer of humidification. Modern energy recovery components can recover most of the humidity back to the building and therewith decrease humidification costs dramatically.

Discussion

I have tried to cover here some of the most common myths circulating around in our industry. It is often forgotten that sorption rotors have some very good benefits for the installation and energy economy of the building:

- Decrease cooling capacity and cooling energy need.
- The dry cooling systems (chilled ceilings and chilled beams) can work longer with maximum capacity in extreme humid weather conditions.
- Decrease defrosting limit in coldest wintertime down by 5-8°C.
- Buildings with humidification will gain remarkable energy cost savings.
- In old installations chillers and heat pumps will have better energy economy if dehumidification load is reduced with humidity/cool recovery.

In USA, middle East and Asia humidity recovery is commonly used (some countries even mandatory) due to cooling capacity savings. In Europe we can profit the same and many other points. Humidity recovery can have a major role to play in countries (in south Europe) where electric network peak load situation takes place in warm summer days.

It is worth to take a close look on facts, what humidity recovery can offer in improving IAQ and energy efficiency of buildings. ■

References

[1] Hoval presentation in Swiss Hygiene confrens 10.09.2021 in Baden "Interne Leckagen bei Energierückgewinnung in Luftaufbereitungsgeräten".

Key Considerations when Planning Humidification Systems

On one hand, humidification is indispensable in air conditioning in buildings and, on the other, fundamental hygiene concerns come to mind. Rules and regulations such as VDI 6022 give useful information about design, planning, building and system operation in order to effectively mitigate risks and provide healthy air and safe operation of the systems.

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40 to 60% relative humidity for health protection, comfort and value preservation

Modern buildings, with their tight building envelopes, are designed to save energy and thus prevent the natural air exchange by infiltration. Mechanical air ventilation systems are designed to create completely different indoor air conditions versus the outside and generate comfortable temperatures in the range of 20-26°C. Yet especially in winter, this indoors warm air is also very dry, at 10-30% relative humidity (RH) – such climate exists in nature only in the desert, while in temperate climate zones, one can find this in buildings only!

This excessively dry indoor air is often perceived as uncomfortable: effects such as itchy skin, irritated eyes, scratchy feeling in the throat are the telling signs, besides the reduced performance and fatigue, both also directly caused by insufficient humidity. However, the less known phenomenon is the drying out of the mucous membranes in the respiratory tract, which weakens our defense mechanism against airborne infection. If the air we are breathing in is below 40%RH over a prolonged period, this mucous membrane layer dries out, causing damage to the cilia - tiny hair-shaped structures acting as pollutants and germs filter from the air we breathe in. This can lead to respiratory diseases – from the common colds, bronchitis, sinusitis to influenza, as several epidemiological studies reveal. [**1**]

Medical evidence [**2**] shows that the optimal indoor air parameters for comfort and health protection lie in the range of 21-22°C and a relative humidity between 40-60%.

Adequate humidification during the heating period is not only beneficial to health but also essential for valuables preservation – whether in homes or in museums and churches: objects made out of wood and paintings crack as they release their material moisture into the dry environment. Same for paper, leather and other hygroscopic materials. In several processing industries, manufacturing or storage of certain commodities, as well as for electronic data processing equipment the humidification control is mandatory, whether to increase productivity, preserve goods or to prevent electrical discharges: one spark can cause material damage and the production stops.

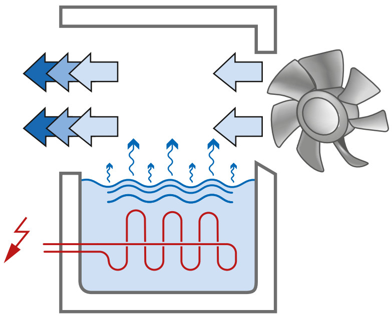
Yet for most consultants, humidification projects do not occur frequently, so it's difficult to build-up the expertise needed to avoid the many potential design errors that can occur. Additionally, when considering humidification in air conditioning, besides many factors impacting the correct humidifier specification – some obvious, such as the available energy source, and some not so, such as water quality or the cost of maintenance – there seems to be a main reluctance deriving from hygiene concerns and anticipated potential project issues with clients and contractors. They don't need be!

So, let's look first at the main systems and then at the layout and considerations for a hygienic and efficient operation.

Humidification methods

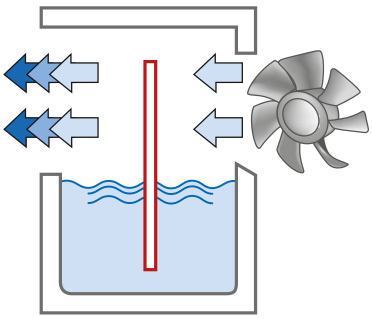
Humidification is provided based on the three physical methods of vaporization, atomization or evaporation. From the hygienic standpoint, the three methods have different requirements for the humidification equipment.

Vaporization



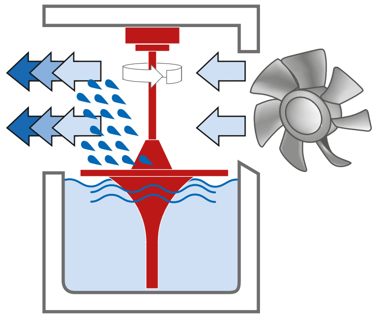
Steam humidification provides least concerns in terms of hygiene because of the high temperature level. The steam distributors are to be correctly placed and humidification distance correctly determined. The humidification distance is the distance required for optimum absorption of steam by the air. Essentially, it comprises the mist zone and the expansion and mixing zone. If existing humidification distances are very short, i.e. from 0.5 to 1 m, multiple steam distribution systems are the preferred choice.

Evaporation



The humidification distance in evaporation humidifiers is pre-determined by humidifier design. Preventive measures to avoid biofilm growth on the evaporation media are to be taken.

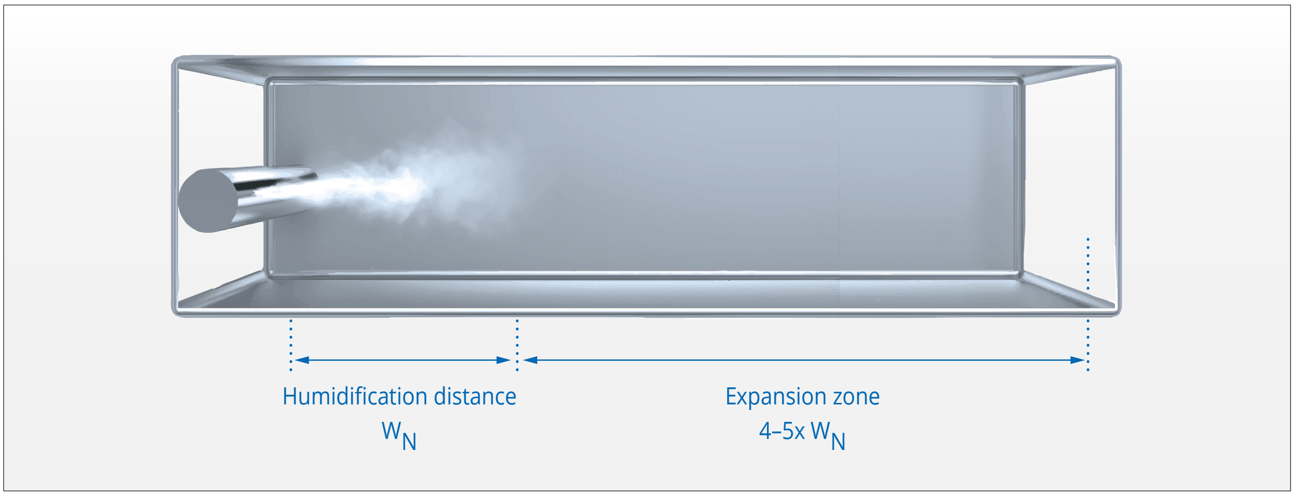
Atomization



Atomization humidifiers represent the greatest challenge from the hygiene point of view. Water aerosols must not enter the air ducts downstream of the humidification system as they can form hygienically hazardous damp surfaces in there.

The key importance of humidification distances

The overall humidification distance, consists of two zones: the mist zone and the subsequent expansion and mixing zone. The mist zone is the section downstream of the humidification system –from the water droplets respectively steam injection to the complete absorption of the steam by the air. In the following expansion and mixing zone humidity mixes evenly with the air stream. To prevent condensation inside the air duct the humidity sensor needs to be placed after the expansion and mixing zone. See the **figure** (Diagram of a humidification distance) below.



The humidification distance in adiabatic humidification systems such as hybrid humidifiers or surface evaporators is provided by design. A hybrid humidifier uses two adiabatic humidification methods. An atomizer unit and an evaporator unit are used in parallel to achieve the most efficient humidification result and an outstanding level of hygiene quality.

It is significantly more difficult to specify the humidification distance in high-pressure and ultrasonic atomizers. The key parameters are: humidity increase, air temperature, air speed, flow profile and the aerosols size.

Hygiene Considerations

A small number of microorganisms may settle in
- Humidifier water supply lines
- Water lines inside humidification systems
- Evaporation bodies
- Droplet separators (to remove unevaporated water droplets from the air stream, ensuring droplet-free humidification - for optimal hygiene.)
- Water basins
- Humidifier chambers

and can form a biofilm there. Over the course of a few days to months, the biofilm will grow to a certain thickness and reaches its stationary phase. From this time onwards, the biofilm continuously releases germs, and the uncontrolled contamination of the humidifying water and system air follows.

Germ-reducing hygiene measures

Biofilms may settle on all humid surfaces and often remain unnoticed in humidification systems for a long period. The supply water for humidifiers should have the same microbiological quality as potable water i.e. maximum value of 100 CFU/mL.

The formation of biofilms can be prevented only by a combination of relevant measures:
- Hygienic humidification water
- No water stagnation in the water lines
- Efficient measures for microbial reduction
- Periodic and strict cleaning and disinfection

Did you know how quickly microorganisms can spread?

- After 2 hours: 8 germs
- After 6 hours: 512 germs
- After 12 hours: 262,144 germs
- After 18 hours: 53,667,776 germs
- After 24 hours: 68,719,476,736 germs

Control Concepts for Hygienic Humidification

From a hygiene standpoint, the proper control of humidification systems is of great importance. Falling below the dew point must be avoided so no condensation gets deposited in the air duct system.

Steam humidification is in principle an isothermal process: Only a small increase in air temperature occurs due to the humidification process. For this reason, only the system and room humidity values need to be controlled.

Yet, when atomizing or evaporating water, the humidified air cools down considerably. Therefore, in these cases, temperature control is also crucial for humidity control.

Hygiene proofs

Reliable hygiene proofs include all hygiene-related aspects: microbiological long-term stability, preventive hygiene measures and periodic and strict maintenance and service. Only meeting the technical and structural compliance of devices and components according to specific guidelines do not constitute evidence of hygienic operation.

The humidification system hygiene is provided only if all aspects are covered:
- Correct sizing of humidification distances
- Prevention of biofilm formation
- Prevention water aerosols spread
- Provide system-compatible humidity control
- Provision of hygiene proofs ■

Relevant standards and directives

EN 16798 Part 3 "Energy performance of buildings – Ventilation of buildings – Ventilation of non-residential buildings – Performance requirements for ventilation and air-conditioning systems and room cooling systems".

Drinking Water Ordinance (TrinkwV, Appendix 1 "Microbiological parameters", Part II "Requirements for drinking water intended for delivery in sealed containers").

VDI 6022 sheet 1 — "Ventilation technology, indoor air quality – Hygiene requirements for ventilation and air-conditioning systems and devices".

References

[1] e.g. Noti et al 2013, Lester W. 1948, Casanova et al 2010, Lowen et al 2007, Yang W., Marr L. 2011, Yang W., Marr L. 2012, Myatt T.A. et al 2010, etc.

[2] Criteria for human exposure to humidity in occupied buildings Author: Sterling EM et al, 1985;
Study: High humidity leads to loss of infectious influenza virus from simulated coughs Author: Noti JD et al, 2013;
Study: Dynamics of airborne influenza A viruses indoors and dependence on humidity Author: Yang W, Marr LC.

Cooling energy recovery

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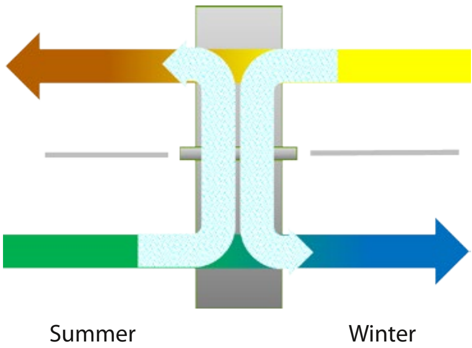
Rotary heat exchangers with a sorption coating bring significant opportunity for energy and carbon emission reductions while also improving the indoor environment.

Sorption

The material of the sorption coating has the ability to absorb moisture from the air when the humidity is high and to release it when the humidity is low. This means moisture is recovered; which means we get latent energy recovery as well as sensible energy recovery.

In the summer time when the outdoor air is humid, moisture is removed from the outdoor air and released to the exhaust air. In the winter time the outdoor air has a low moisture content so the sorption coating can recover moisture in the extract air and release it to the supply air. This brings two benefits in cold outdoor conditions. Firstly, the raised humidity in the supply air is beneficial for the indoor environment quality and secondly, because the moisture is removed from the rotor there will be much less risk of frost and the need for defrosting is more or less avoided. This means that the sorption rotor saves some heating power during the winter.



In summer, when the humidity is higher, moisture is removed from the outdoor air and transferred to the exhaust air. In winter, moisture is transferred from extract to supply.

Humidity transfer happens when there is a difference in specific humidity between the extract air and the outdoor air. The amount transferred is given by the latent efficiency performance of the rotor.

$$\text{Latent efficiency} = \frac{x_{22} - x_{21}}{x_{11} - x_{21}} \%$$

Where
x_{11} = specific humidity in the extract air g/kg
x_{21} = specific humidity in the outdoor air g/kg
x_{22} = specific humidity in the supply air g/kg

Cooling Power reduction

Because of the latent energy recovery in the rotor, we significantly reduced the cooling power demand in the cooling system. Even with a plain aluminium heat exchanger we get sensible cooling recovery

Figure 1 illustrates how much more cooling recovery we get with the sorption rotor compared with a normal aluminium rotor. The example is based on 30°C outdoor air and a supply temperature of 12°C. The sensible rotor provides about 20% of the cooling while the sorption rotor is able to provide about half of the cooling power. This will vary depending on the conditions but shows that the cooling power reduction is very significant with the sorption rotor.

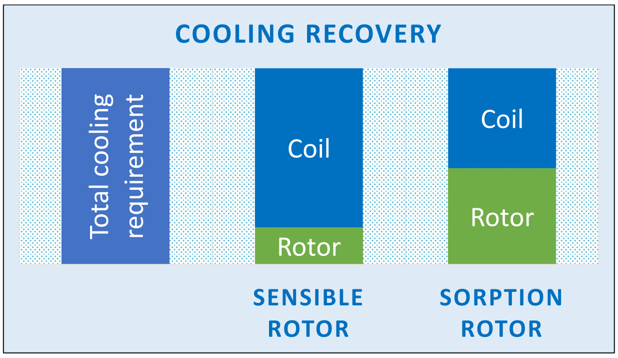


Figure 1. Reducing the capacity of the cooling coil due to the use of sensible and sorption rotors.

This latent cooling recovery means that we can radically reduce the size of the cooling plant. This means the chiller capacity and the cold-water distribution system made much smaller; which means significantly lower installation cost, smaller space requirement and a smaller refrigerant charge.

Cooling Energy reduction

The cooling energy reduction will, of course depend on the duration of warm weather.

The following example has been calculated with the following conditions:

- Airflow rate: 2 m^3/s
- Supply air temperature 16°C
- Extract air temperature 22°C
- The sorption rotor has a temperature efficiency of 82% and a humidity efficiency of 74% in the summer.
- The aluminium rotor has a temperature efficiency of 82% in the summer.
- The pressure drop of the sorption rotor is about 10Pa more than that of the aluminium rotor so the difference in fan energy is small.

Figure 2 shows the cooling recovery using the aluminium rotor and the second diagram shows the recovered cooling recovery using the sorption rotor.

Figure 3 illustrates the reduction in cooling energy consumption is near 50% in the warmer climates of Milan and Frankfurt while in the cooler places it is near 20%

Compared with cooling equipment, sorption rotors are relatively simple machines, so we have the additional benefit that the maintenance cost is much lower per kWh.

Power peak reduction

Occasionally the weather brings higher temperatures and humidity levels that that of the design. This will, of course, lead to an increase in the temperature indoors. The recovered cooling power of the heat exchanger is proportional to the temperature and humidity difference so when the outdoor condition rises and the difference between extract and outdoor condition increases, we get more recovered power.

Humidity recovery

In cold weather outdoor air that is heated will have a low humidity so the indoor air will become dry. In these conditions, the sorption rotor recovers moisture in the extract air and returns it to the supply air; which means the indoor air is kept more moist and more comfortable and hygienic. It may be necessary to add moisture using humidification and then the sorption rotor brings the benefit of a lower humidification load so the installation will be cheaper and the running costs lower.

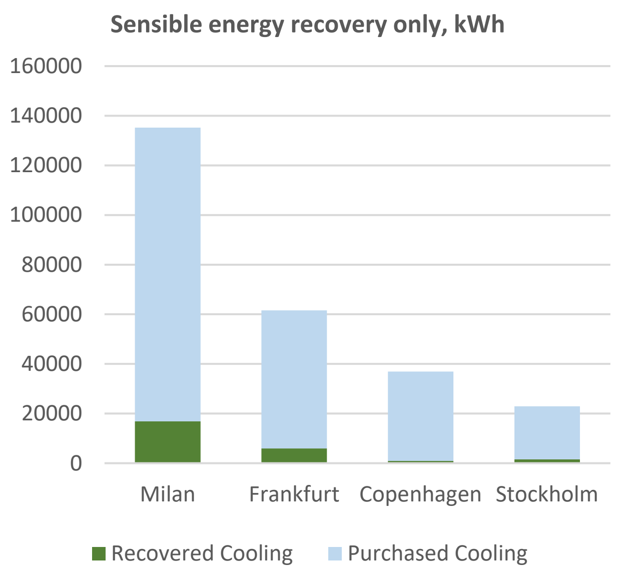


Figure 2. Sensible and latent energy recovery with a aluminium rotor.

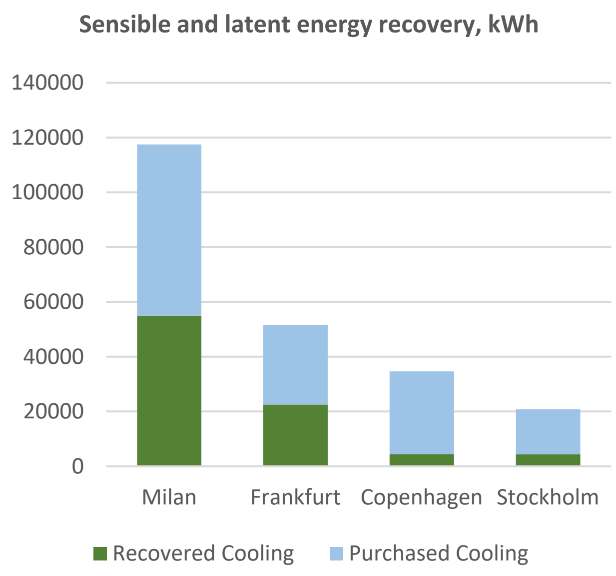


Figure 3. Sensible and latent energy recovery with a sorption rotor.

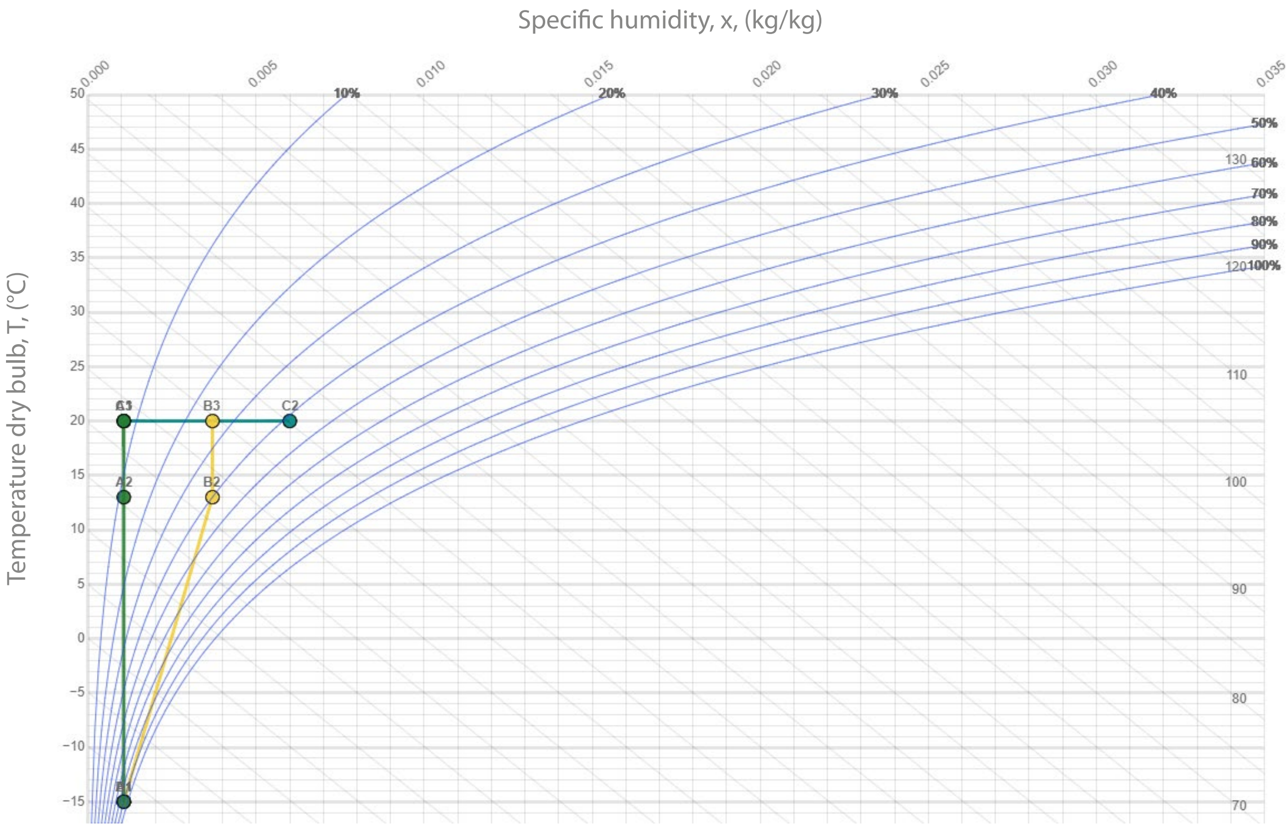


Figure 4. H-x diagram for humid air, x-axis: x (g/kg), y-axis: Celsius temperature.

In this example cold air is heated by the rotor to 13°C and is then reheated to 20°C.

With the aluminium rotor the resulting supply air has a relative humidity of just 10% while with the sorption rotor it is over 25%.

Reduction of humidification power

We can see from the diagram that the cost of humidification is significantly reduced.

The green line represents the heat recovered in a rotor with only sensible recovery. The yellow line is that for a sorption rotor. The rotor heats the air to 13°C and it is then reheated to 20°C.

If we assume the supply air condition needs to be 30% to 40% relative humidity then instead of needing to add about 5-6 g moisture per kg of air, we will only need to add 2-3 g moisture so the cost of humidification will be halved by using the sorption rotor.

If using an adiabatic humidifier, then the sorption rotor can offer the benefit of reduced reheat power and reduced water consumption.

Leakage

The disadvantage with rotary heat exchangers is the problem of leakage. If properly designed and installed, the leakage can be reduced to less than 1%. The rotor needs to be fitted with effective seals, a purging sector and the system needs to be set up with the correct pressure balance.

To get the correct pressure balance, the fans need to be correctly positioned. Both the supply and the extract fans are best placed upstream of the rotor in their respective air streams. It will often be necessary to introduce a pressure reducing device in the extract air.

This has been described in more detail in an earlier article (see REHVA Journal 5/2020 pages 65-68) and is also well documented in Eurovent REC 6/15

The ability of the sorption rotor to recover both sensible and latent cooling has profound impact on both the cooling power demand and the cooling energy consumption. The cooling system is made much smaller saving space and cost. A smaller chiller also means a reduced amount of refrigerant. ■

Relative humidity in the indoor air

– impact on indoor air quality and means of control

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Keywords: relative humidity (RH), indoor air quality (IAQ), well-being, thermal comfort, humidity recovery

Abstract

The relative humidity in the indoor air in buildings is often associated with various problems and sick building syndromes. In addition, humidification is associated with high operating and service costs. Indoor air humidity control is often related to removing humidity from the building, not controlling it. In some specific building applications, it is necessary to maintain the humidity at a certain level defined by requirements for the use of the building, such as museums, archives, laboratories or diverse processes.

But what about us — people — and the indoor air humidity? We, engineers and indoor air quality scientists, tend to conclude that humidity has a small impact on human well-being and perceived indoor air quality (IAQ). Research communities rarely focus on indoor air humidity. Humidity is even considered only as an aspect of thermal comfort in IAQ ratings. Humidity indeed has some effects on thermal comfort, but its importance in the overall IAQ is more significant than just as a part of thermal comfort. In fact, indoor air humidity has its own dimension in indoor air quality.

This article proposes to use of a balanced approach to humidity, weighing the concerns of the building construction, the economic aspects and human well-being into consideration.

Low humidity levels

Diverse research studies about the spreading of aerosols through tests and modelling (bacteria and viruses) show some effects of indoor air humidity. The lower limits in these studies are often around RH 20-25%. But what happens when the indoor air humidity drops below RH 20%, or even under RH 10%? Could our annual winter flu season have something to do with indoor air humidity? What about dry skin and dry eyes? Mortality is also higher in the cold season. If we spend 80-90% of our time indoors, maybe it is not just the low outdoor temperatures, but the problem might be in the dry air that comes with the cold outdoor air.

When the outdoor temperature drops below 0°C, we get around RH 20% when the air is heated to 20-22°C. In the climates of northern, central and continental Europe, as well as at higher altitudes, the outdoor air temperature can remain under 0°C for longer periods. If the outdoor temperature drops under -10°C, we will get indoor relative humidity around RH 10% in well ventilated spaces, if no additional humidity is available. This can be confirmed by monitoring humidity levels in non-residential installations around northern Europe.

On the other end of the scale, we have energy and investment costs, and the fact that most humidity related problems in building envelopes could be avoided, if humidity levels are kept low.

Addressing building envelope issues, humidification costs and impact on humans is an optimization problem. So far, the optimization is mainly done, with a few exceptions, by optimizing energy costs and the risk of possible damage to building envelopes. We – people and building users – play a minor role in this humidity equation.

What can be done to improve the indoor relative humidity levels?

Adjusting the room temperature to increase relative humidity levels

It is often said that relative humidity in a room can be increased when dropping the room temperature.

Unfortunately, this has only a marginal impact when the air is dry. With RH 15%, changing room air temperature from 20°C by ±2°C will impact the RH level by less than ±2%. Even with RH 20%, the impact is less than ±3% RH. Remember that dropping the humidity too much will compromise the thermal comfort of the building occupants.

Humidity recovery in ventilation systems

In theory, plain aluminium rotors (condensation rotors) could also recover humidity by condensation during in the coldest wintertime. However, if the extract air is dry, no condensation and therewith no humidity recovery will take place. In the design phase, it is often assumed that the humidity of the extract air would be RH 30%. With this humidity level, condensation could occur, and some humidity will be recovered, but the humidity level of extract air is usually much lower in wintertime.

Humidity recovery with sorption rotors (high-performance humidity recovery rotor) has a 60-90% humidity recovery efficiency. Humidity recovery efficiency remains quite constant in all conditions. Humidity can be recovered even at small humidity level differences between outdoor air and extract air. Mostly sorption wheels are used in hot and humid environment for cooling recovery, but it would have major advantages also in cold climate.

Humidity recovery can dramatically reduce the operating costs for humidification, and humidification capacity and investments. With efficient humidity recovery, the moisture will be reused 3-10 times before it is lost in the exhaust air. We should look humidity as asset in wintertime and act accordingly.

Humidity recovery is also possible with the cross-flow and counterflow plate heat exchangers. In some markets, enthalpy plate heat exchangers are well established in residential applications. In non-residential applications, humidity recovery with membrane foil plate heat exchangers is also available. Humidity recovery efficiency rate remains under 60-65%. However, there is a limited offer (suppliers and sizes) for such products on the European market.

Adding humidity to the indoor air

In residential buildings we have some natural humidity sources (cooking, laundry and showers, etc.) that increase the indoor humidity. And these often solve the problem of extreme dryness of the indoor air. Depending on the outside temperature and peak production, like in bath rooms, it is even necessary to ventilate the humidity out from the building.

In non-residential buildings the only sources of humidity are humans, plants, and possible moisture accumulated in the interior and in building materials. These humidity sources help to some extent but are usually not enough to make a real difference.

There is also the possibility of increasing the humidity with plants and vegetation. The required quantity of plants is high to achieve any meaningful increase in humidity levels in the building. However, plant walls are a good improvement in indoor air humidity, and they are being installed more and more frequently in high end buildings.

Further development of plant walls are units where the air is circulated through the roots of plants. One plant wall of 1 m width and 2.3 m height can evaporate up to 400 g/h of water with 72 plants and forced ventilation through the roots. It is worth mentioning that some plants are better suited to humidification purposes than others, as humidity generation and day- versus night-time activity may vary. For a bedroom, a plant active in the night fits the purpose, and for offices, a plant active in the daytime.

The most common way to increase the humidity level in the building would be fixed installed or portable humidifiers with steam or adiabatic technology. These solutions are not discussed in this paper, as other articles cover these technologies.

Controls strategy and target settings

It is often stated that RH 40% should be the minimum humidity level for human health. In more moderate climates, the target setting of RH 40% or even higher is not that difficult to reach and can be well motivated. Humidification costs increase rapidly with the increase of humidity levels, and in the coldest climates, the risks to building envelopes are increasing too. For climates with cold winter, the target setting is crucial for the operating costs and risk management.

In comfort humidification, the cost impact of the required humidification levels is often underestimated. Could it be reasonable to avoid the very driest periods in winter, e.g. indoor humidity levels below under RH 20-25%? If we limit our requirements to RH 25-35% indoors in the coldest and driest periods, we would save quite some costs.

One may ask whether it is necessary to keep the humidity level strictly at a certain level? What seasonal or daily variations are acceptable? Does the RH level need to be always kept constant, as it is practised for museums and processes? Could we take more flexible approaches in comfort humidification and try to optimize energy cost and avoid risks for the building envelope?

Field test in Sweden

During winter and spring of 2021, Swegon performed a series of tests in its offices in Malmö, Umeå and Luleå. While Malmö is in the south of Sweden, the latter two cities are located in the northern part of Sweden. The offices have floor areas from 120-500 m². The smaller office buildings are made of light wood construction. The larger office in Malmö has the building envelope made of wooden construction with concrete floor structure and exterior cladded with bricks.

The purpose of the test series was not to carry out a scientific academic study, but rather more practical testing of some hypotheses about the dynamic of humidification and some control strategies.

Methodology for testing

The method for testing was based on the “minimizing water usage principle”, i.e. use humidification only when needed, minimize water consumption and use the best possible humidity recovery.

The ventilation system was set to a constant airflow of 1-1.2 exchange per hour. Humidity recovery was optimized, and new control loops were installed. Ventilation was running for 12-13 hours per day during weekdays. Different humidification levels were tested, and the water consumption of portable humidifiers was registered manually. Humidification was controlled with the hygrostat that was placed on the wall in an open place in the offices.

Data was recorded every minute by an air handling unit using standard data collection routines and integrated room automation system [**1**]. In addition, the measurements could be followed up online with a remote connection system. This allowed to check the testing conditions in real time and identify any problems during the measurements.

The occupancy rates in the offices were relatively low due to Covid-19 restrictions during the months of February-April in 2021.

Some additional humidification methods were also tested, such as plants and wet towels in the rooms.

The data was analysed using Excel statistical functions.

The daily water consumption model was developed with regression analyses based on daily water consumption and absolute humidity surplus (x_{in}–x_{out}). Later, the model was used to estimate the annual humidification requirements based on actual local weather data.

Weather conditions in northern Sweden were continuously sub-zero temperatures during the testing period. On cold days, the temperature would drop down to −16-18°C, and even under −24°C.

Indoor temperatures were set by users to 21-22°C. Various indoor air humidity set-points (RH 25%, RH 30%, RH 40%) were tested. As the capacity of humidification was limited, the required levels of indoor humidity were not always reached. Especially during very cold weeks, RH 40% was not reached.

Results of modelling the consumption

The ability to model the humidification requirement based on the daily average absolutely humidity surplus (x_{in}–x_{out}) gave no statistically significant correlation. The coefficient of determination (R2 values) was less than 0.5.

However, when the data for weekly average values was used, the R2 increased to 0.7-0.9 (see **Figure 1**). This significant improvement can be explained by less data points, the fact that the dynamics of humidity transfer and the accuracy of the measurement arrangement have less impact on the data.

Follow-up test weeks confirmed the accuracy of the model. Prediction for a given control week was in the range of ±10-20%, depending on the RH setpoints, weather and the office locations. This is adequate to estimate the annual humidification requirements with the used control strategy. The results will give an indication of how the humidification requirements would vary dependent on the RH setpoints and locations.

With the model and with local weather data, annual water consumption could be calculated.

For example, to maintain 30% relative humidity in the Luleå office (120 m²), we would need 1,200 litres of water per year. This corresponds to 850 kWh of evaporation energy in the form of electricity or heating. The electricity cost in Sweden is approximately 1 SEK/kWh = 0.1 €/kWh, which means the additional annual energy costs (for evaporation) are only 850 SEK/a or 85 €/a. In a workplace for 3-5 people, the cost would be 20-30 €/a/person. These costs are much lower than the cost of a single sick day. In Malmö, we could keep about the same cost per m² for 40% relative humidity.

Figure 2 illustrates the impact of location and the RH setpoints on annual water consumption requirements per m². To reach 35% RH indoor air humidity level the impact on the water consumption of location between Luleå and Malmö is 3-fold (5 vs 15 ℓ/m²/a). The increase in water consumption doubles in Luleå when changing the target humidity level from RH 30% to RH 40%. The variations of the RH setpoints have huge impact on water consumption and operation cost, even when we have excellent humidity recovery, as in these sites.

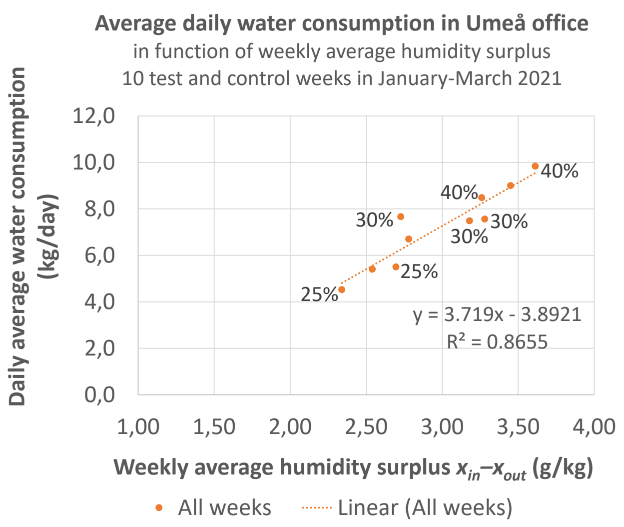

Figure 1. Average daily water consumption as a function of weekly average humidity surplus in Umeå. The % value in data points refers to set point for humidity level.

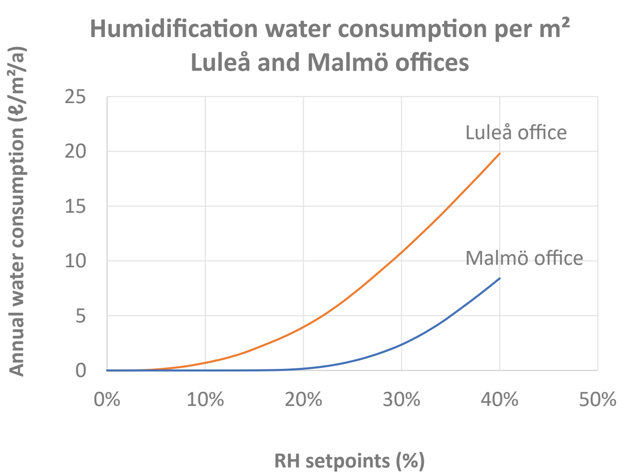

Figure 2. Annual water consumption in Luleå and Malmö.

Discussion and conclusion

The surprisingly low humidification requirements at the tested sites with the help of highly efficient humidity recovery and innovative control strategies will raise the question of whether the humidity control should become more widely used in planning, execution, refurbishing and upgrading of ventilation systems.

It is indisputable that the very low indoor air humidity of 10-20% is too dry — both for our health and comfort. It seems that even in the coldest weather conditions, we can increase the humidity level up to 30% with very limited costs. Raising the humidity level to RH 30-40% in Central and Southern Europe should not be beyond reasonable costs.

We would like to emphasize that this was a preliminary field study. These field tests will continue in winter 2021-2022 to ensure that our assumptions are correct and that the control routines work in full scale.

The scientific community in Northern Europe should take a deeper look into the health effects of extreme dry indoor air (RH <20%) in the coming years. Especially in the USA and Canada, there seems to be quite some research on-going in this field.

From economic point of view, it will not make sense to humidify the air without very good humidity recovery and good control systems to minimize costs and risks for the building envelope. In this aspect, we need to improve the indoor air quality with careful actions. On the other end of the scale is however human health, our sensitivity to bacterial and virus diseases in the dry wintertime, and our well-being indoors, both at home and in the workplace. The cost per person of humidity control can be covered by avoiding a single sick day per year. Maybe it is time to raise the discussion of people´s needs to the same level of indoor air humidity requirements as paintings, music instruments, printing machines and laboratory rats. ■

References

[1] Swegon Gold Air Handling Unit, WISE room automation system was used for data logging.

Numerical simulation of thermal environment at different relative humidity levels in one operating room of St. Olav's hospital

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This study investigated the influence of three different levels of relative humidity, 20%, 40%, and 60% on the thermal comfort of surgical patient and staff in one operating room of St. Olav's hospital with mixing ventilation. The results of computational fluid dynamics (CFD) are used to calculate the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) values in order to evaluate the thermal comfort levels of surgical patient and staff. The calculated values of PMV and PPD indicate the thermal environment may be acceptable for the patient with different relative humidity levels, while surgical staffs feel always warm in all three scenarios.

Keywords: Thermal comfort, ventilation, operating room, CFD simulation, air velocity

Introduction

Human beings spend approximately 90% of their time indoors [1]. [2]. [2]. Indoor air quality and thermal comfort are two important aspects that need to be taken into account when design the indoor environment. Indoor environments like healthcare facilities and hospitals, where the work performed could be potentially life-saving, it is especially important to ensure desired indoor environment quality. Bad indoor environment quality many increase the risk of life-threatening diseases and infections for the patient, such as Surgical Site Infection (SSI) [2]. The thermal comfort can be expressed as an indicator that shows how people may be satisfied with the thermal environment [3]. If thermal discomfort is experienced it can lead to less productive working conditions as the employees may be feeling too warm or too cold. An uncomfortable indoor environment may in turn cause health symptoms, like headaches, dizziness, concentration problems, apathy, and tiredness [4]. The work performed by the surgical staff is very important, and will potentially improve the life quality of people. Desired indoor environment should be achieved to ensure improved thermal comfort level for all the members of the surgical staff without compromising the patient thermal comfort.

In an ideal case, the indoor environment should satisfy all human beings that would feel thermally comfortable all the time, but according to Ole Fanger [5], that is not physically possible. This study will investigate, the thermal comfort level of surgical staff and patients under different relative humidity level in an OR at St. Olav's hospital by using computational fluid dynamics simulation (CFD). CFD simulations are performed to analyze important thermal environmental factors such as air temperature, relative humidity, air velocity, heat distribution, and airflow patterns in an operating room.

Computational Fluid Dynamics

CFD is an engineering tool derived from different disciplines of fluid mechanics and heat transfer [6]. Computational Fluid Dynamics (CFD) offers the same flexibility as the analytical methods and a lot of the detailed accuracy of the experimental methods [7]. Renormalized Group (RNG) k-ε model, which is used in this study, gives better predictions due to the lower amount of entrained air, compared to the standard model. The idea of the RNG k-ε is to filter out the smallest eddies [8].

Simulation conditions

The study is composed of three scenarios. Scenario 1 is also referred to as the base, whose values are validated by measurement. Scenarios 2 and 3 use different relative humidity levels. This is based on the fact that the operating room ventilation standards indicate that the relative humidity should range from 30 to 60%. However, the investigated operating room at St. Olavs has a low relative humidity of 20% within a period of the year. Supply air velocity, relative humidity, and supply air temperature are presented in **Table 1**.

Geometry

The geometrical model is made based on the real geometry of operating room 1 in the AHL department at St. Olavs Hospital with some simplification of medical equipment. The model is illustrated in **Figure 1**. The dimensions of the room are given in **Table 2**.

Table 1. *Simulation scenarios.*

Case No.	Supply air temperature [°C]	Relative humidity [%]	Supply air velocity [m/s]
Scenario 1	23	20	2.86
Scenario 2	23	40	2.86
Scenario 3	23	60	2.86

Table 2. *Room dimensions of the simulation model.*

Geometry	Value
Room length	7.9 m
Room width	7.2 m
Room height	2.9 m
Area inlet	0.6 m^2
Area lower outlet	0.16 m^2
Area upper outlet	0.078 m^2

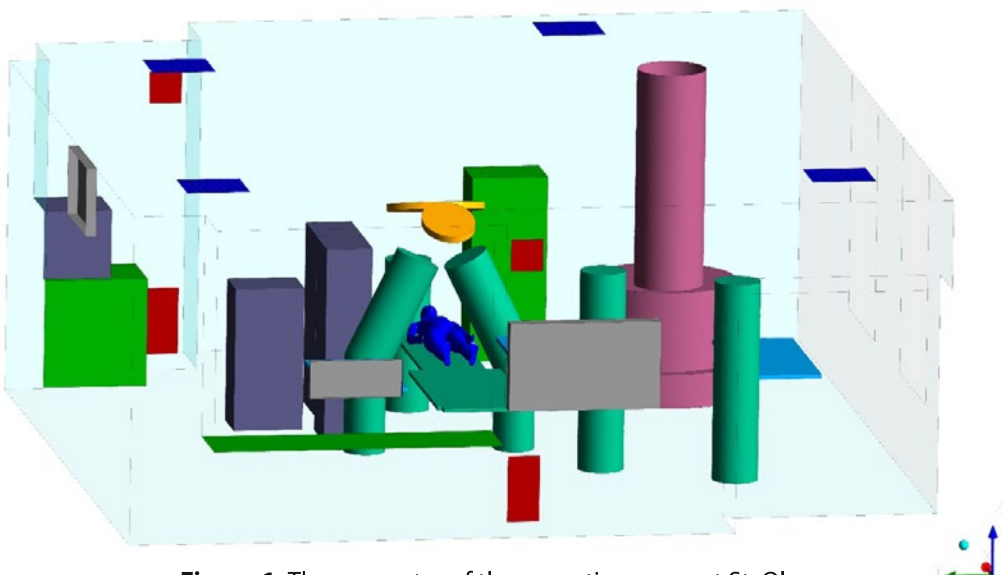

Figure 1. The geometry of the operating room at St. Olavs.

Results

Air velocity

One earlier study states that the acceptable measurements of air velocity in relation to thermal comfort should be down to below 0.1 m/s [9]. According to the operating room ventilation standards, VDI, a German standard, it requires that the air velocity in an operating room should be a minimum of 0.2 m/s. In this study, the simulated results show the air velocity is lower than 0.1 m/s in most of the room (see **Figure 2**). While at some specific locations, like close to the diffuser and above the surgical wound area, the air velocity is higher than 0.1 m/s. The average air velocity in all scenarios is approximately 0.09 m/s, which is within the thermal comfort guideline. None of the air velocity magnitudes are above 0.2 m/s, as required by VDI. The air velocities for each scenario are presented in **Table 3**.

Air temperature

One study [10] states that the air temperature must never drop below 21°C for the patient. This is to prevent discomfort and health risks for the patient. Simulation results observed in table 4 it can be observed that the air temperature surrounding the patient is ranging between 22.7°C to 27.5°C. For each scenario, it can be observed that the surgeon and assistant surgeon are always experiencing the highest air temperature. This could be because they are located right below the surgical lamps and due to their high metabolic rate. The highest increase of temperature is for the anesthesia, where the air temperature increases by 0.5°C, from 24.4°C in Scenario 1 to 24.9°C in Scenario 3. **Figure 3** shows that surgical lamps significantly heat of surgical site of patient for all three scenarios.

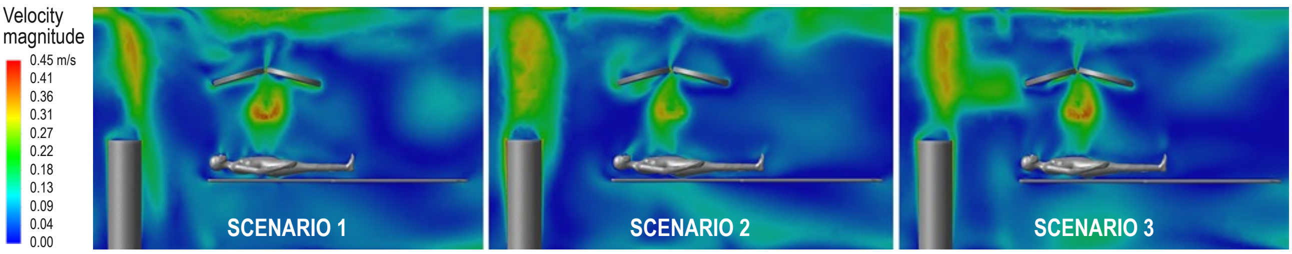

Figure 2. Air velocity of the cross-section plan of patient and anesthesia.

Table 3. *Summary of the air velocities.*

Role	Scenario 1	Scenario 4	Scenario 5
Surgeon	10 m/s	10 m/s	0.10 m/s
Assistant surgeon	0.10 m/s	0.10 m/s	0.10 m/s
Sterile nurse	0.08 m/s	0.08 m/s	0.08 m/s
Non-sterile nurse	0.10 m/s	0.11 m/s	0.11 m/s
Anesthesia	0.09 m/s	0.08 m/s	0.08 m/s
Patient	0.09 m/s	0.08 m/s	0.07 m/s

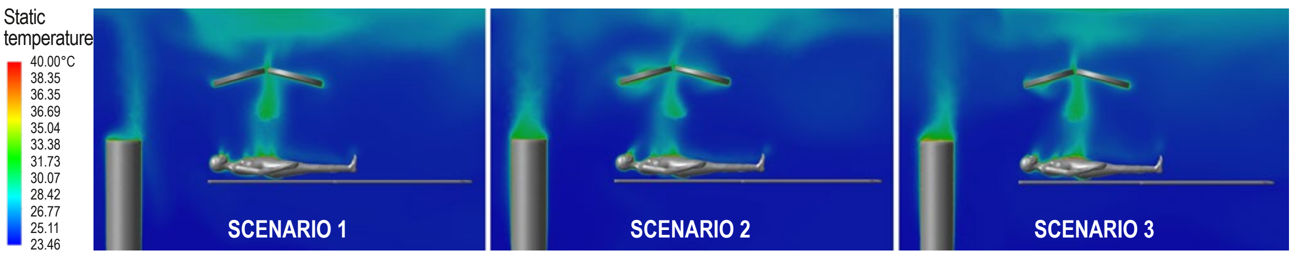

Figure 3. Air temperature of the cross-section plan of patient and anesthesia.

Table 4. *Summary of the air temperatures close to patient and staff.*

Role	Scenario 1	Scenario 2	Scenario 3
Surgeon	25.6°C	25.4°C	25.6°C
Assistant surgeon	25.6°C	25.4°C	25.6°C
Sterile nurse	24.8°C	25.1°C	25.2°C
Non-sterile nurse	24.8°C	25.0°C	25.1°C
Anesthesia	24.4°C	24.7°C	24.9°C
Patient	25.0°C	25.3°C	25.2°C

Relative humidity

Table 5 show the simulated results of three scenarios of relative humidity. The variations in the relative humidity within each scenario are relatively small. The maximum difference between the highest and lowest value is found in Scenario 3. The surgeons have a surrounding relative humidity of 59.1% while the anesthesia has a surrounding relative humidity of 60.2%. For all cases except scenario 1, the surgeons, patient, and the anesthesia in scenarios 2 and 3, the surrounding relative humidity is lower than the supplied relative humidity. **Figure 4** show the relative humidity distribution is to similar for all scenarios. The relative humidity is decreasing with increasing height which also occurs with temperature while the stratifies. This corresponds well with findings from a study conducted by Liu et al. [6]. In that study, it was found that for the surgical staff, the head experienced a relative humidity was lower while the rest of the body experienced a relative humidity was higher.

PMV and PPD

The result observed in **Table 6**, none of the people present in the operating room experienced a PMV in the range 0.31-0.35, which Liu et al. found in their study, while the relative humidity was between 59-60% and the air temperature ranged from 24.5 to 27°C. Another study, conducted by Van Gaever et al. [11], found that the optimal value of PMV for the surgeon, assistant surgeon, nurses, and anesthesia in

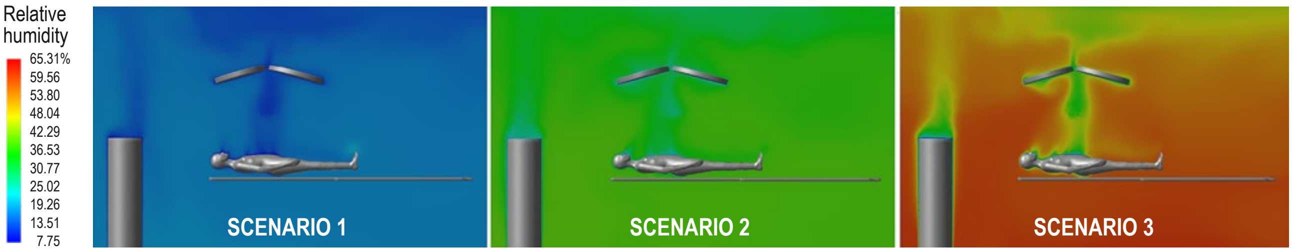

Figure 4. Relative humidity of the cross-section plan of patient and anesthesia.

Table 5. *Summary of the relative humidity close to patient and staff.*

Role	Scenario 1	Scenario 2	Scenario 3
Surgeon	21.0%	39.4%	59.1%
Assistant surgeon	21.0%	39.4%	59.1%
Sterile nurse	20.8%	39.3%	59.8%
Non-sterile nurse	20.8%	39.3%	59.8%
Anesthesia	20.9%	39.9%	60.2%
Patient	20.2%	39.4%	59.5%

Table 6. *Calculated PMV and PPD based on simulated results.*

		1	2	3
PMV [-]	Surgeon	1.39	1.39	1.41
	Assistant surgeon	1.39	1.39	1.41
	Sterile nurse	1.08	1.11	1.14
	Non-sterile nurse	0.99	1.02	1.04
	Anesthesia	0.91	0.95	0.99
	Patient	–0.43	–0.33	–0.27

		1	2	3
PPD [%]	Surgeon	29.3	29.3	29.7
	Assistant surgeon	29.3	29.3	29.7
	Sterile nurse	23.0	23.7	24.2
	Non-sterile nurse	21.0	21.5	22.0
	Anesthesia	18.8	19.9	20.6
	Patient	8.7	7.1	6.5

the operating room is 0.21, −0.30, −0.46, and −0.5, respectively. None of the members of the surgical staff in this study obtained a PMV close to the optimal value found by Van Gaever et al. According to ASHRAE, an acceptable thermal environment for general thermal comfort is achieved when the PMV lies within the range of −0.5 < PMV < +0.5 [1]. Based on this guideline, it is just the patient that has obtained general thermal comfort in scenarios 1, 2, and 3. All the members of the surgical staff have values of PMV that are outside the range given by ASHRAE.

Conclusion

This study investigated the effect of relative humidity on thermal comfort by increasing the relative humidity to 40 and 60%. By comparing the results of the three scenarios, it was found that the thermal comfort level of the surgical staff is always between neutral and warm for all three scenarios. The surgeon and assistant surgeon have the same value for PMV in both Scenario 1 and Scenario 2. The difference between these two scenarios is that the relative humidity is changed from 20% in Scenario 1 to 40% in Scenario 2. For the rest of the surgical staff, the PMV is slightly increased from scenarios 1 to 3, while the patient experiences a better thermal comfort level when the relative humidity is increased. These results would indicate that it is possible to increase the relative humidity to 40% while the thermal comfort level stays warm for surgical staff. Relative humidity of 40% is also in compliance with what Oslo Universitetssykehus recommends for their operating rooms. ■

References

[1] Neil E. Kleieis, William C. Nelson, Wayne R. Ott, John P. Robinson, Andy M. Tsang, Paul Switzer, Joseph V. Behar, Stephen C. Hern, and William H. Engelmann. The national human activity pattern survey (nhaps). https://doi.org/10.1038/sj.jea.7500165, 2001.

[2] Zohaib Akhtar, Brian D Hesler, Alexa N Fiffick, Edward J Mascha, Daniel I Sessler, Andrea Kurz, Sabry Ayad, and Leif Saager. A randomized trial of prewarming on patient satisfaction and thermal comfort in outpatient surgery. Journal of Clinical Anesthesia, 33:376–385, 2016.

[3] Thermal environmental conditions for human occupancy. ANSI/ASHRAE standard, 55-2013, 2013.

[4] L. Lan, P. Wargocki, D. P. Wyon, and Z. Lian. Effects of thermal discomfort in an office on perceived air quality, sbs symptoms, physiological responses, and human performance. Indoor Air, 21(5):376–390, 2011.

[5] Povl Ole Fanger. Thermal comfort: Analysis and applications in environmental engineering. McGraw-Hill, New York.

[6] Jiyuan Tu, Guan Heng Yeoh, and Chaoqun Liu. Computational Fluid Dynamics - A practical approach. Butterworth-Heinemann, Burlington.

[7] Datawave Marine Solutions. What is cfd: Introduction to computational fluid dynamics. https://www.youtube.com/watch?v=jQHp49OyPn8, 2019.

[8] Tollef Hjermann. CFD simulation of active displacement ventilation. Master thesis. Norwegian University of Technology and Science (NTNU), 2017.

[9] Per Erik Nilsson. Achieving the desired indoor climate: Energy efficiency aspects of system design, 2003.

[10] J Khodakarami and N Nasrollahi. Thermal comfort in hospitals - a literature review. Renewable Sustainable Energy Reviews, 16(6):4071–4077, 2012.

[11] R Van Gaever, V.A Jacobs, M Diltoer, L Peeters, and S Vanlanduit. Thermal comfort of the surgical staff in the operating room. Building and Environment, 81:37–41, 2014.

Indoor humidity of dwellings in a northern climate




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Keywords: Relative humidity, Indoor air quality, Residential building, Dry air, Symptom, Complaint, Disturbance, Ventilation, Building system, Apartment

Introduction

Dry air in buildings is prevalent in the Scandinavian countries, including Sweden, throughout the winter (heating season). In contrast to other types of buildings such as museums, residential buildings do not require indoor humidity assessment and control [1]. Nonetheless, relative humidity analysis is performed in northern climates primarily aiming at preventing moisture damage (e.g., in the crawl spaces and attics). Moisture damage is the primary source of building structural deterioration, but also cause "poor" indoor environmental quality, such as perception of "dampness", especially in high-occupancy spaces [2]. The level of humidity inside a dwelling can be consequently considered as a critical quality component that affects satisfaction, health, stress level, learning and sleep quality [3].

In general, there is no commonly acknowledged limit for a low relative humidity value in conjunction with a tolerable exposure time [3-4]. Guidelines recommend a minimum relative humidity of about 30-40% as a comfort-related limit value (mainly for the thermal environment), whereas other research recommends a minimum relative humidity of about 20-30%, if health is taken into account [1-3]. Several respiratory problems, including asthma and allergies, dryness of the airways, dry hands and eye irritations have been linked to a low relative humidity level [3, 5].

Present paper describes the study aiming to: a) correlate relative humidity levels with the characteristics of residential buildings and occupancy; and b) associate low relative humidity levels with health symptoms and complaints. Both aims are achieved by analyzing a comprehensive and broad dataset from a national survey performed in Sweden.

Materials and methods

Present analyses are based on the results obtained during BETSI project. This project was commissioned in 2006 by the Swedish National Board of Housing, Building, and Planning. The project's objective was to collect data on the indoor environmental conditions, energy use, and technical quality of the Swedish residential building stock, as well as on the users' comfort, satisfaction and health status. References [4, 6, 7] provide more information about the survey and the properties of the buildings and systems.

Between October 2007 and April 2008 (heating season), 678 residential buildings, 520 single-family dwellings, and 158 multi-family buildings were monitored for this study (measurements in living rooms). For the investigated dwellings, a list of 22 parameters, 13 categorical and 9 numerical, have been used to investigate possible correlations and associations with different relative humidity levels.

The dwellings were classified according to type of housing (detached single-family houses or apartments in multi-family houses), year of construction (<1960, 1961-1975, 1976-1985, 1986-1995, and 1996-2005), location (city center, suburb, residential neighborhood, and sparsely populated area), climate zone, ventilation system (return only, supply and return, supply and return with heat recovery, exhaust air heat pump, and natural ventilation), and heating system (wood stove, directly produced electricity, own combustion boiler, electric boiler, electric resistances, electric radiator, district heating, stove, local produced district heating, fireplace, pellet stove, heat pump, and other systems).

Indoor air temperature, ventilation air change rate, volume of the dwelling, indoor moisture supply, total U-value, number of occupants, and other numerical parameters were included (**Figure 1-3**). A list of 20 symptoms and complaints were listed as health-related criteria (**Table 1**; [4]).

Table 1. *Examined 6health symptoms and complaints (last 3 months) and frequency of yes-responses for the "best" and "worst" assessment categories of relative humidity.*

a/a	Symptoms	Cat. I-II (yes %)	Cat. III-IV (yes %)
1	Asthma+	9.0	**9.6**
2	Cough	33.9	27.8
3	Difficulty to concentrate	22.6	20.3
4	Dry air	23.1	**24.0**
5	Dry or flushed facial skin	18.4	13.1
6	Dry, itching, red skin on hands	19.5*	13.5
7	Dust and dirt	34.8	33.1
8	Eye sensitivity++	25.8	24.7
9	Headache	51.2	46.9
10	Heavy head	46.4	41.6
11	Hoarse, dry throat	25.6	23.8
12	Irritated, stuffy or runny nose	41.9	37.4
13	Itching, burning, irritation of the eyes	23.1	**28.1**
14	Scaling, itching scalp or ears	19.8*	13.2
15	Nausea, dizziness	16.3	16.1
16	Respiratory infection	51.9*	44.0
17	Static electricity	4.9	**9.1***
18	Stuffy air	25.6*	16.4
19	Stuffy smell++	24.3*	12.8
20	Fatigue	71.1	70.6

+12 months, ++ In general, * Statistically significant

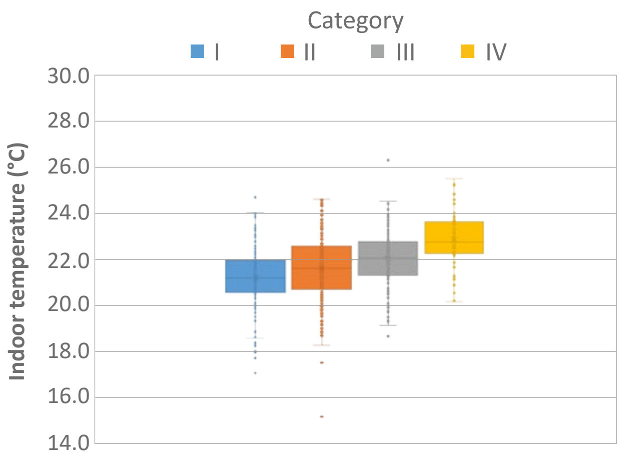

Figure 1. Boxplot of average indoor air temperature (°C) for the four relative humidity assessment categories.

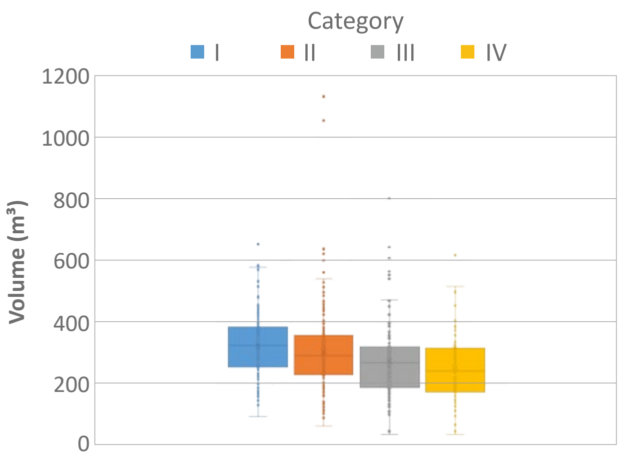

Figure 2. Boxplot of total heated building volume (m^3) for the four relative humidity assessment categories.

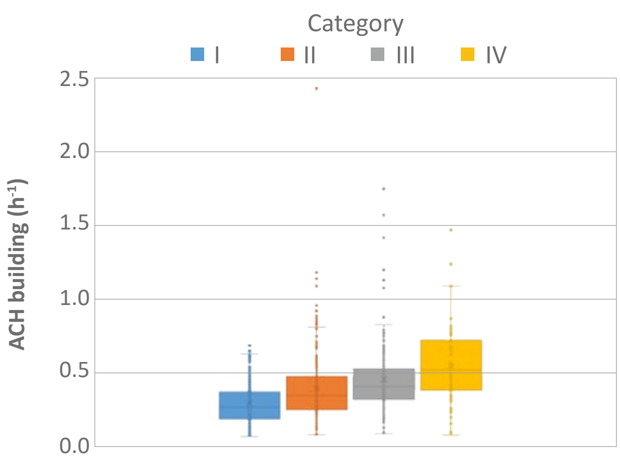

Figure 3. Boxplot of building level ventilation air change rate (h^{-1}) for the four relative humidity assessment categories.

To classify dwellings according to their monitored relative humidity levels, the research team used a classification system based on suggestions in the European Standard EN 16798:2019 [1, 8], which been adapted to fit the study's focus on low relative humidity levels (**Table 2**). The categories' lower limits are based on EN 16798:2019. This upper value is normal for indoor relative humidity (heating season), for these climatic conditions (no issues to human health or the construction elements [1]). The deviation percentage is set at 3% for each group [1]. Category IV is the lowest relative humidity category (followed by Cat. III), with the majority of monitored occurrences appearing at a relative humidity of less than 20% (**Table 2**).

Results and discussion

Our analyses show that about 37% of dwellings fall into Categories III and IV. For apartments, the biggest proportion belongs to Category III (36%), whereas for single-family houses, the highest proportion belongs to Category I (38%). Indoor low relative humidity appears to be more prevalent in dwellings with a higher temperature, a smaller volume, a higher ventilation rate and frequent airing practices, a lower inhabitant and pet count, and were primarily developed after 1985 in city suburbs and the northern part of the country (**Figures 1-3**). In Swedish buildings, ventilation without energy recovery appears to be a crucial role in controlling and optimizing indoor humidity levels. Over 70% of investigated cases had an average ventilation air change rate of less than 0.5 h^{-1} during the examined period. Reduced ventilation rates maintain acceptable relative humidity levels throughout the heating season but may create unsanitary and polluting conditions.

District heating is the primary method of heating apartments in Sweden. In terms of relative humidity, analyses show that district heating systems perform better in single-family houses than in apartments.

Table 2. *Relative humidity category boundaries (%).*

Category	Lower and upper levels of relative humidity (%)
I	30-60
II	25-60
III	20-60
IV	<60

Heat pumps, district heating, and directly produced electricity are the systems with the highest percentages in single-family homes. In terms of relative humidity levels, heat pumps appear to be a reliable solution in houses. Additionally, directly generated electricity systems provide a sustainable and very effective method of controlling relative humidity levels. The systems with the least optimal performance are those that utilize simply return air. According to the data, installing automated fans in bathrooms enhances the likelihood of the dwelling having an adequate moisture level. Indoor activities such as cooking and drying clothing significantly improve the indoor environment's relative humidity. Furthermore, for various residential building types, moisture supply values are suggested for optimum levels to minimize dry air [4].

Research team also analyzed the low relative humidity in connection with the prevalence of health symptoms and complaints including asthma, dry air sensation, itching-burning-irritation of the eyes and static electricity. Health problems such as fatigue, respiratory infections, and headaches had the highest ratio of yes-responses (**Table 1**).

Conclusions

Low indoor relative humidity has been shown to be an issue in Swedish dwellings and mostly apartments, during the heating season. Present analysis adds to the scientific literature by demonstrating a possible association between low relative humidity and particular health symptoms and complaints. ■

Acknowledgement

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References

1) ÖNORM EN 16798-1, Energy Performance of Buildings. Ventilation for Buildings. Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Module M1-6, Austrian Standards, International Standardization and Innovation, Wien, 2019.

2) T. Alsmo, C. Alsmo, Ventilation and relative humidity in Swedish buildings, Environ. Protect. 5 (2014) 1022-1036.

3) M.M. Derby, M. Hamehkasi, S. Eckels, G.M. Hwang, B. Jones, R. Maghirang, D. Shulan, Update of the scientific evidence for specifying lower limit relative humidity levels for comfort, health, and indoor environmental quality in occupied spaces, Science and Technology for the Built Environment 23 (1) (2017) 30-45.

4) T. Psomas, D. Teli, S. Langer, P. Wahlgren, P. Wargocki, Indoor humidity of dwellings and association with building characteristics, behaviors and health in a northern climate, Build. Environ. 198 (2021) 107885.

5) A.V. Arundel, E.M. Sterling, J.H. Biggin, T.D. Sterling, Indirect health effects of relative humidity in indoor environments, Environ. Health Perspect. 65 (1986) 351-356.

6) S. Langer, T. Psomas, D. Teli, "I-CUB: 'Indoor Climate-Users-Buildings': Relationship between measured and perceived indoor air quality in dwellings." 8 International Building Physics conference (proceedings), Copenhagen, Denmark, 2021.

7) D. Teli, T. Psomas, S. Langer, A. Trüschel J.O. Dalenbäck, "Drivers of winter indoor temperatures in Swedish dwellings: Investigating the tails of the distribution." Building and Environment 202 (2021) 108018.

8) P. Wargocki, W. Wei, J. Bendžalová, C. Espigares-Correa, C. Gerard, O. Greslou, M. Rivallain, M.M. Sesana, B. Olesen, J. Zirngibl, C. Mandin, TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project), Energy and Buildings 244 (2021) 111029.

Optimising thermostat settings in school and office buildings for thermal comfort, cognitive performance and energy efficiency

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Keywords: Energy conservation; HVAC; Schools; Offices; Cognitive performance; Thermal comfort

Abstract

The Jevons Paradox predicts that any increase in energy efficiency will lead to an increase in energy use. This occurred recently in Denmark when the energy efficiency of domestic heating was increased by improving the thermal insulation of dwellings – there was a "Jevons rebound" in the energy used for heating as increased energy efficiency made it affordable to raise indoor temperatures. Raised temperatures and correspondingly lighter clothing mean that activity levels can vary more between occasions without the need to adjust clothing insulation to maintain thermal comfort. This article suggests that a Jevons rebound need not occur when the energy efficiency of heating or cooling in school or office buildings is increased. Research published in recent months has shown that cognitive performance is reduced as the indoor temperature is increased **even if subjective thermal comfort is maintained**. Thermostats should therefore be set at the lower bound of the thermal comfort range: this will save energy when heating and improve performance when either heating or cooling. Additionally, the thicker clothing that will be required means that even the small adaptive variations in activity level that occur while sedentary will be sufficient to maintain thermal comfort. These recommendations apply also to dwellings in which office work is being performed.

Introduction

Energy efficiency in space heating

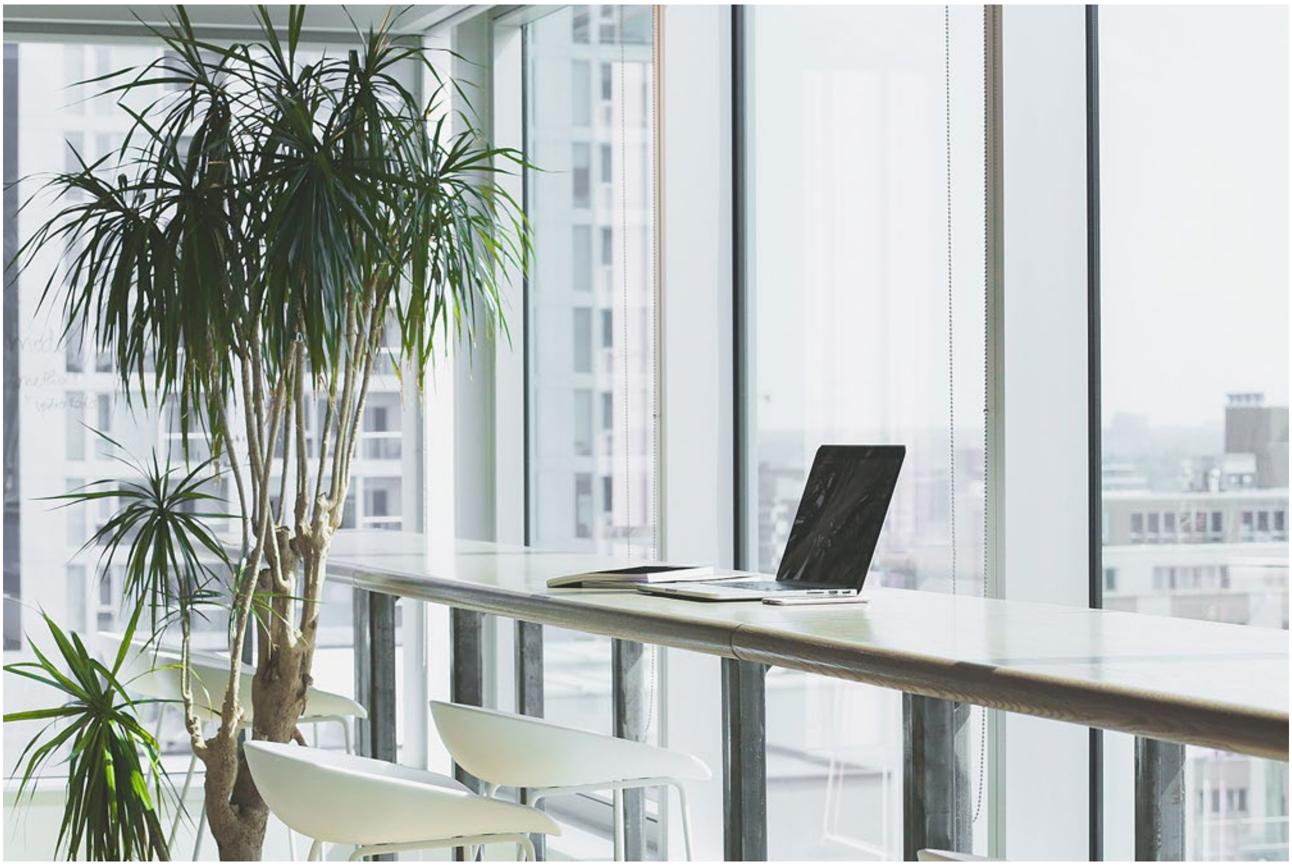
A recent survey examined energy use for heating in 230 000 newly-built Danish dwellings (Gram-Hanssen & Hansen 2016) whose energy-efficiency categories ranged from Category A, the most energy-efficient, to G, the least energy-efficient. In Category A, the actual energy use was 80% **more** than expected, while in Category G, it was 48% **less** than expected. Engineering calculations for both categories had assumed that user behaviour would be the same in all energy-efficiency categories and on this basis had predicted that households living in Category A dwellings would use 84% less energy than households living in Category G. In fact, they used only 45% less – a return on the investment in energy efficiency, certainly, but much less than would be expected if user behaviour had remained the same. As some households were found to use 2 or 3 times as much energy as other households, even in identical buildings, the conclusion was that household behaviour determines energy use and that energy use will increase when the energy and economic cost of space heating is reduced.

The Jevons Paradox may increase indoor temperatures

The authors of the report did not measure indoor temperatures, but they concluded that households living in energy-efficient buildings may have raised indoor temperatures, heated more rooms, or opened windows more often to improve indoor air quality. The result was that as much as half of the expected saving in space heating costs had been used to improve occupant comfort. This is an example of the Jevons Paradox (Freire-Gonzalez & Puig-Ventosa, 2015), which was formulated in 1865 when it was found that increasing the efficiency of steam engines led to more coal being used, not less as engineers had expected. What had happened was that as the cost of whatever benefit was obtained from steam energy decreased, it became economically possible to use more of it. Since that time, this "Jevons rebound" in energy use has been found to hold quite widely in the industrial and transport sectors, e.g., when more efficient airplane engines lead to more air travel, more efficient cars are driven further, and LED lighting is left switched on for longer. In a recent review, Brockway et al. (2021) showed that the economy-wide rebound in energy use following an increase in energy efficiency has been close to the 50% found in Danish dwellings. There is therefore a real risk that energy efficiency improvements in school and office buildings might result in a similar rebound, so if this is to be prevented, it is important to understand the mechanisms involved.

Activity levels and thermal comfort

The authors of the Danish report concluded that the reason thermostat settings had been raised in the more energy-efficient buildings was "so that the occupants could wear summer clothing all year round". It is worth noting that this is not a fashion fad that can be "nudged" (influenced subconsciously), because it provides a real advantage in dwellings: when wearing light clothing, the range of activity levels that is possible without experiencing hot or cold discomfort is much wider than it is for thick, better-insulating clothing. Calculations made with ISO 7730/ASHRAE Standard 55 assumptions indicate that an increase in activity level from 70 to 100 W/m² (1.2 to 1.7 MET)



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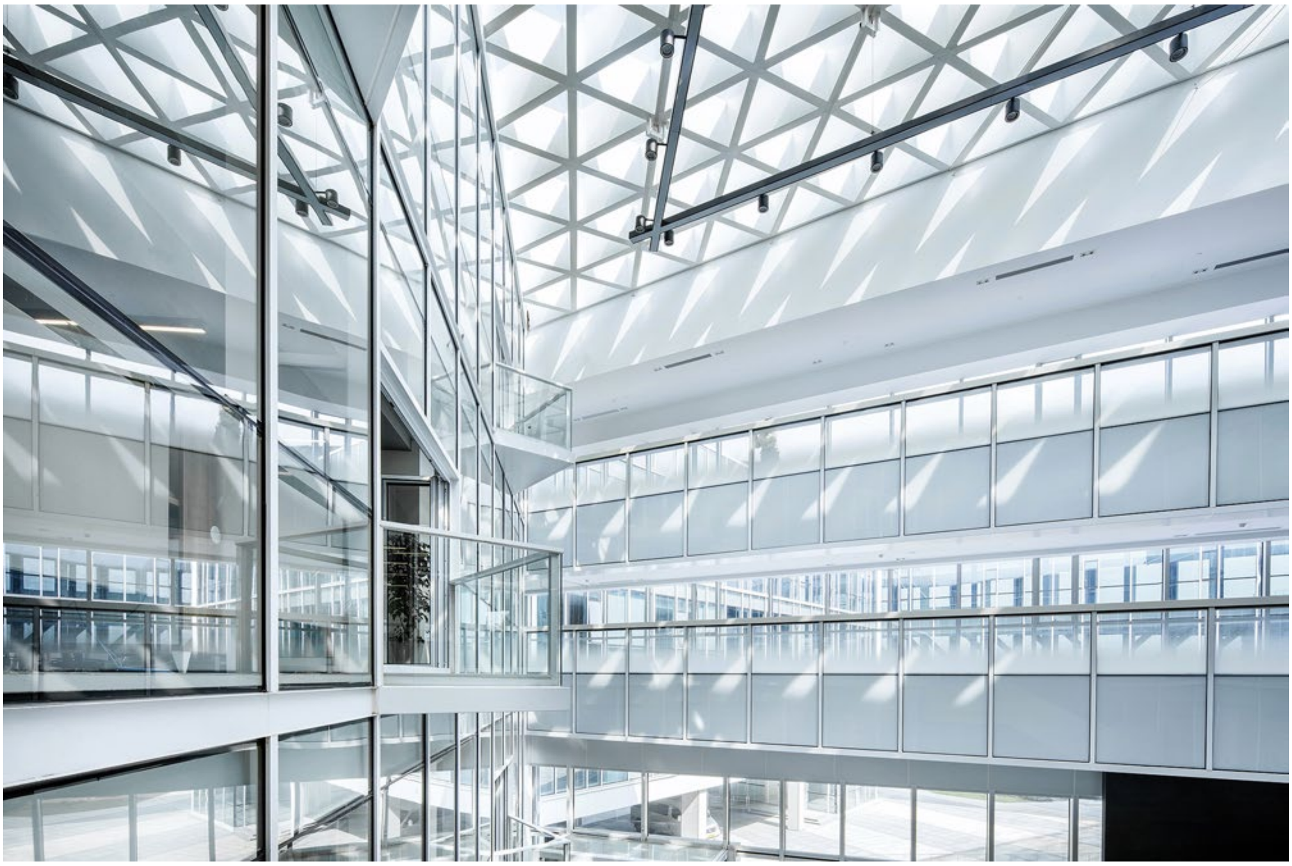
at the operative temperature that is neutral at the lower (sedentary) level of activity would increase the percentage dissatisfied with the thermal environment (i.e., PPD) from 5% to 26% if occupants were wearing thick clothing (1.0 clo), but to only 9% if they were wearing thin clothing (0.5 clo). Additionally, if sweating becomes necessary for heat balance to be maintained at raised activity levels, thin clothing ensembles intended for use in summer weather will usually have a lower vapour diffusion resistance than thick clothing does, allowing sweat to evaporate and provide additional cooling, which would then extend the comfortable range of activity levels still further upwards. The rebound in energy use for space heating is caused by the understandable wish for this additional freedom of action without constantly having to adjust clothing insulation levels to match leisure activity levels, in which the rate of metabolic heat production varies more widely than during the standardized activities that take place in schools and offices. The primary purpose of a dwelling is to provide comfort and convenience for leisure activities, and it appears that householders in Denmark are prepared to re-invest about half of the cost and energy savings provided by energy-efficient buildings to achieve these goals. However, it is worth noting that in an increasing proportion of dwellings, one or more occupants now work from home. This trend was accelerated by the social isolation and lockdowns required to control infection rates during the 2020-2021 Covid-19 pandemic but may continue beyond it. These dwellings must be able to provide an indoor environment that is optimal for office work, which as will be seen below may reduce the above-mentioned Jevons rebound.

Discussion

Offices and schools

If the occupants of offices and schools were as free to adjust their thermostats as householders are at home, the same mechanisms would probably increase indoor temperatures over time, especially as they would not have to pay for the rebound in energy costs in the way that householders do. However, the primary purpose of office and school buildings is not to provide comfort and convenience – it is to make office work, teaching and schoolwork as productive as possible. The indoor environmental conditions should therefore be optimised for cognition because it is the monetary value of the cognitive activities performed in these buildings that pays for the space heating and cooling. Maximising the comfort and convenience of the occupants of these buildings are secondary goals. Thermostats must be set with this in mind.



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Comfort and cognition

It is widely assumed that thermal conditions for cognitive performance will be optimised if subjective thermal comfort is achieved. This is the economic justification for the energy conservation made possible by adopting the Adaptive Thermal Comfort (ATC) rules of thumb that predict acceptable indoor temperatures from a knowledge of outdoor temperature alone. They have been proposed in many current Standards as an alternative to rational models of physiological heat balance and they suggest that higher indoor temperatures are acceptable when it is warm outdoors. A climate-chamber experiment reported by Wyon et al. (1975) exposed subjects to operative temperatures of 18° and 23°C, adjusting the insulation value of their clothing between conditions so that they did not report thermal discomfort in either condition. It was found that their cognitive performance did not differ significantly between the two conditions. For the next 45 years, this finding was taken to support the proposition that cognitive performance must be optimal if no subjective thermal discomfort is experienced. It was assumed without proof that this finding can be extrapolated to temperatures above 23°C. The present authors pointed out that in view of the physiological changes that take place at raised temperatures, this was unlikely to be the case (Wyon and Wargocki, 2014), a reservation that was immediately discounted by the thermal comfort researchers from 6 countries on 3 continents (de Dear et al., 2014) who stated that "we firmly believe (that the evidence supports) the notion that optimal comfort and performance temperatures are broadly aligned" even though their review of 20 years of research on ATC and thermal comfort had found no proof of the assumption.. Two recent climate chamber experiments have now provided evidence that disproves that assumption. First, Lan et al. (2020) showed in a pilot experiment that was carried out in Denmark that the cognitive performance and perceived indoor air quality of 12 subjects were significantly worse at an operative temperature of 27°C than they were at 23°C even though the subjects reported no thermal discomfort at either temperature. Lan et al. (2021) then exposed 36 subjects for 4.5 h to 24, 26 or 28°C in Shanghai in

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hot and humid summer weather in which the average maximum daily temperature was 33°C during the exposures. These subjects remained thermally neutral at all 3 temperatures by adjusting clothing insulation and air velocity. Their self-estimated performance did not change but their objectively measured performance decreased significantly with increasing temperature, by 10 and 6% respectively. The conclusion must be that the absence of thermal discomfort is not a sufficient condition for optimal performance and that the lower the temperature at which thermal neutrality is achieved, the better the resulting cognitive performance will be.

This finding will have to be validated in different seasons, climates and cultures but it seems likely that setting space heating thermostats at the lower bound of the thermal comfort range – which may be well below 23°C if thick clothing is worn and well above this temperature in hot and hot humid areas where clothing is light and sweating is an acceptable and necessary means of maintaining heat balance – will minimise the use of energy for heating and also optimise cognitive performance. The new results cited in the present analysis suggest that in heating mode, thermostats should be set at or below 23°C, or even to as low as 20-21°C in Danish school classrooms in winter (Vorre et al. 2021). A meta-analysis of published experimental results shows that this will improve the performance of schoolwork by up to 20% (Wargocki et al. 2019) and an analysis of ten million end-of-year national examination results in the USA has now confirmed that reducing the mean classroom temperature over a school year will increase learning (Goodman et al. 2018). A recently published experiment that is discussed below in the context of space cooling (Fan et al. 2019) indicates that when maintaining cognitive performance is the goal, thermostats should not be set to above 26°C even in hot and humid areas where still warmer temperatures are traditionally and subjectively regarded as acceptable. If these rules of thumb are followed, no Jevons rebound in energy use will occur following future increases in the energy efficiency of space heating, and no downward trend in clothing insulation values will occur. Using productivity as the criterion for optimising thermostat settings in this way need not result in thermal discomfort: Yamamoto et al. (2010) pointed out that until 1965, the summer thermal comfort zone recommended by the ASHVE Guide that preceded ASHRAE Standard 55 was 24-27°C while the winter thermal comfort zone was 17-22°C. It was always assumed that clothing would be adjusted according to outdoor conditions and that local air

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velocity would be raised when appropriate, e.g., by ceiling fans or table fans, as is assumed when the ATC rules of thumb are applied to optimise thermostat settings for thermal comfort rather than cognitive performance.

Clothing insulation for non-sweating sedentary work

Thick clothing reduces the range of metabolic rates compatible with thermal comfort. It was argued above that it is for this reason that thin clothing is preferred for leisure activities in the home. However, wearing thick clothing during sedentary work can be an advantage, because it ensures that the quite small variations in metabolic rate that can be achieved while sedentary, such as sitting straight or slumping in a chair, are better able to adjust metabolic rate, making it easier to remain in thermal comfort. This is another reason for setting thermostats in schools and offices (and in dwellings where office work is being performed) to temperatures low enough to encourage the wearing of thick clothing. This appears to be the case even at operative temperatures well below 20°C: Jiang et al. (2018) showed that a Mean Thermal Vote (MTV) of -1.4, between cool and slightly cool, was ideal for cognitive performance in some poorly heated classrooms in China, in which unusually thick clothing was being worn – the children's performance was found to be optimal at 14°C. However, while this extreme example supports the general conclusions set out above, WHO guidelines (2018) recommend that to reduce respiratory infections, indoor temperatures should not be lower than 18°C.

Implications for space cooling

Cognitive performance will be maximised if space cooling is operated to ensure that office or classroom temperatures are close to the lower bound of the thermal comfort range, while energy conservation in space cooling will be maximised if temperatures are close to the upper bound. In resolving this conflict between two important facility-management goals it should be recalled once again that investment in the building and operation of schools and offices is justified by how well they contribute to ensuring that office work, teaching and schoolwork are as productive as possible, not by how much energy can be saved while keeping the occupants thermally comfortable. The total cost of heating, cooling and air conditioning per unit of floor area is usually at least two orders of magnitude (100 times) less than that of the recruitment, training, equipment, salary, health insurance, sick leave, vacation and pensions of those occupying the floor space (Woods 1989, Wargocki et al. 2006), and there are many ways of reducing daytime temperatures that do not require active cooling, such as night-time cooling, cross-ventilation, drapes, blinds and window opening when appropriate. However, if active cooling is used, additional energy is required for keeping indoor temperatures closer to the lower bound of the thermal comfort zone than to the upper bound. The lower bound of operative temperature will not be as low as 23°C if clothing insulation values are very low, as they usually are when outdoor temperatures are very high, if activity levels are low and both clothing and skin are damp with sweat following exercise or exposure to hot outdoor conditions, or if air velocity is increased. The measured cognitive performance (accuracy in a Tsai-Partington test) of heat-acclimatised subjects in the hot-humid region of Changsha in China was much better at 26°C than at 30°, 33° or 37°C, even though they found 33°C thermally acceptable and did not report feeling hot below 37°C (Fan et al. 2019). The Jevons Paradox predicts that some of the cost savings due to improvements in the energy efficiency of active space cooling will be used to reduce room temperatures still further and that this will increase energy use. In residential buildings, this would increase total costs, but in school and office buildings, investing some of these cost savings in reducing temperatures to increase productivity is economically justified from a national economic standpoint, as any increase in the energy used for space cooling in school and office buildings will pay for itself.

Conclusions

- The absence of subjective thermal discomfort does not ensure that cognitive performance will be optimal.
- The physiological changes that allow subjective thermal comfort to be achieved above thermal neutrality have the effect of reducing group average cognitive performance.
- The full economic benefit of improving the energy-efficiency of space heating and cooling in school and office buildings will only be achieved if thermostats are set at the lower end of the range of temperatures at which thermal comfort can be achieved.
- This will optimize group average cognitive performance while ensuring that there will then be no "Jevons rebound" in the energy used for heating.
- Any Jevons rebound in the energy used for cooling will be cost-effective because it will improve group average cognitive performance. ■

Acknowledgements

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References

Brockway, P.E., Sorrel, S., Semiuniuk, G., Heun, M.K. and Court (2021) Energy efficiency and economy-wide rebound effects: A review of the evidence. Renewable and Sustainable Energy Reviews, 141, May 2021, 110781.

de Dear, R., Arens, E.A., Candido, C., Brager, G., Zhang, H., Toftum, J., Zhu, Y., Kurvers, S., Leyten, J., Sekhar, C. and Cheong, D.K.W. (2014) Indoor temperatures for optimum thermal comfort and human performance – Reply to the letter by Wyon and Wargocki. Indoor Air, 24, 554–555.

Fan, X., Liu, W. and Wargocki, P. (2019) Physiological and psychological reactions of sub-tropically acclimatized subjects exposed to different indoor temperatures at a relative humidity of 70%. Indoor Air, 29, 215-230.

Goodman, J., Hurwitz, M., Park, J. and Smith J. (2018) Heat and Learning. Working Paper 24639 (http://www.nber.org/papers/w24639) National Bureau of Economic Research, Cambridge, MA, USA.

Gram-Hanssen K. and Hansen, A.R. (2016) The difference between measured and calculated energy use for heating in dwellings (In Danish). Report SBI 2016:09, Aalborg University, Denmark: Danish Building Research Institute (SBI).

Jiang, J., Wang, D., Liu, Y., Xu, Y. and Liu, J. (2018) A study on pupils' learning performance and thermal comfort of primary schools in China. Building and Environment, 134, 102-113.

Lan, L., Tang, J., Wargocki, P., Wyon, D.P., and Lian, Z. (2021) Cognitive performance was reduced by higher air temperature even when thermal comfort was maintained over the 24-28°C range. Indoor Air (DOI: 10.1111/ina.12916).

Lan, L., Xia, L., Hejjo, R., Wyon, D.P. and Wargocki, P. (2020) Perceived air quality and cognitive performance decrease at moderately raised indoor temperatures even when clothed for comfort. Indoor Air, 30, 841-859 (DOI: 10.1111/ina.12685).

Freire-Gonzalez, J. and Puig-Ventosa, I. (2015) Energy efficiency policies and the Jevons Paradox. International Journal of Energy Economics and Policy, 5(1), 69-79.

Vorre, M.H., Noyé, P., Maagaard, S.E., Johannsen, K.B., Østergaard, T., Sørensen, M.K. and Andersen, M.D.A. (2021) Branchevejledning for indeklima i skoler (Indoor environmental guidelines for Danish schools, in Danish), 103p. Teknologisk Institut (Danish Technological Institute), Taastrup, Denmark.

Wargocki, P., Porras-Salazar, J.A. and Contreras-Espinoza, S. (2019) The relationship between classroom temperature and children's performance in school. Building and Environment, 157, 197–204.

Wargocki, P., Seppänen, O., Andersson, J., Clements-Croome, D., Fitzner, K. and Hanssen, S.O. (2006) Indoor climate and productivity in offices. REHVA guidebook, 6p.

Woods, J.E. (1989) Cost avoidance and productivity in owning and operating buildings. Occupational Medicine (Philadelphia, Pa.), 4(4), 753-770.

World Health Organization (2018) WHO housing and health guidelines.

Wyon, D. P., P. O., Olesen, B. W., and Pederson, C. J. K. (1975). The mental performance of subjects clothed for comfort at two different air temperatures. Ergonomics, 18(4), 359-374.

Wyon, D.P. and Wargocki, P. (2014) The Adaptive Thermal Comfort model may not always predict thermal effects on performance. Indoor Air. 24, 552–553 (Letter to the Editor).

Yamamoto, M., Nishihara, N., Kawaguchi, G., Harigaya, J. and Tanabe, S-I (2010) Comparison of the transition of thermal environment in office between Japan and the US, Paper to the CLIMA 2010 conference (10th REHVA conference), May 9-12, 2010, Antalya, Turkey.

Influence of building typology on Indoor humidity regulation

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This article presents a case study to explain the influence of building typologies in regulating indoor humidity, thereby impacting Indoor Environment Quality. Results from Vernacular (adobe) and conventional (brick/concrete) building typologies in the composite climate zone of India have been presented.

Keywords: Indoor Environmental Quality, humidity exposure, comfort, indoor air quality, vernacular building materials, moisture regulation, moisture buffering, hygroscopic materials

Moisture and Indoor Environment Quality

Indoor environment quality (IEQ) is considered an essential determinant of an individual's health, comfort, and productivity [1]. Comfort parameters can be thermal, visual, acoustic, and hygiene. Health includes the ailments and illnesses that an individual might develop as a result of the IEQ. Moisture in the air is an essential determinant of Indoor air quality and affects thermal, visual, and acoustic comfort parameters.

Building Functional Performance (BFP) constitutes a set of functionalities derived by the occupants from the building, e.g., structural integrity, comfort, illumination, etc. Moisture is often attributed to detrimental effects on BFP. **Figure 1** illustrates the aspects of BFP as impacted by moisture in the air.

Occupant health

Moisture in the building leading to surface condensation, mold growth, etc., especially in air-conditioned buildings, is often associated with Sick Building Syndrome (SBS). A set of health outcomes like asthma, respiratory infections, cough, wheeze, etc., is observed in occupants of such buildings. Apart from this, increased relative humidity levels in the indoor air are associated with increased heat stress in warmer climates. Moisture in the air impacts respiratory, olfactory, cardiovascular, and tactile response causing infections, itching, and allergies. It can also cause neurotoxic symptoms like headache, nausea, lethargy, dizziness, drowsiness, and mental fatigue.

Water vapor in the air acts as a solvent for chemical compounds and carrier of biological contaminants, as evident in the COVID-19 pandemic. Recommendations by WHO [2] highlight the importance of proper moisture management for ensuring occupant health and productivity from natural ventilation.

Shifts between extreme environmental conditions (heat stress) can affect the blood vessels, impacting cardiovascular functioning. It disturbs the immunological response causing infections, allergies, and respiratory distresses. With sudden changes in heat stress, natural body reflexes get affected, which leads to the hampering of the protective layer of the brain [3].

The vital link between any Building typology and Occupant is **indoor air**. Moisture unifies all parameters of the indoor air, yet strangely remains the least explored. Building typology (materials) regulate indoor air, determining the Indoor Air Quality (IAQ) to which occupants are exposed. IAQ of an indoor space is an essential determinant of occupant comfort, productivity, and health conditions; hence, it must be understood.

Study Overview

The objectives of the study were as follows:

- To understand moisture variations in naturally ventilated: Conventional (Brick / Concrete) and Vernacular (Adobe) dwellings.
- To understand the perceived discomfort due to moisture in the air.

Results obtained by monitoring temperature and relative humidity in a building cluster (details are shown in **Figure 2**) in India's Jamgoria village situated in composite climate zone for a year are presented.

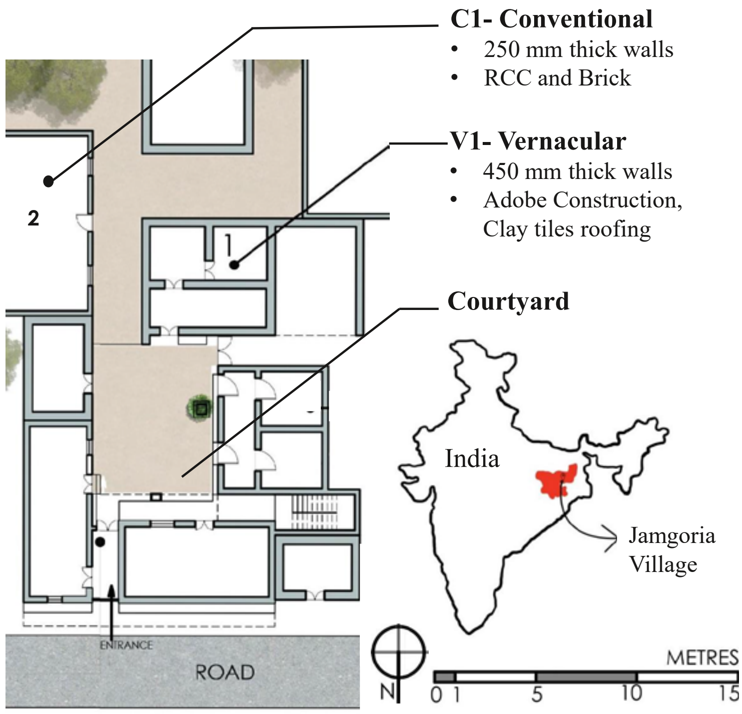

Figure 2. Location and details of the Jamgoria Cluster.

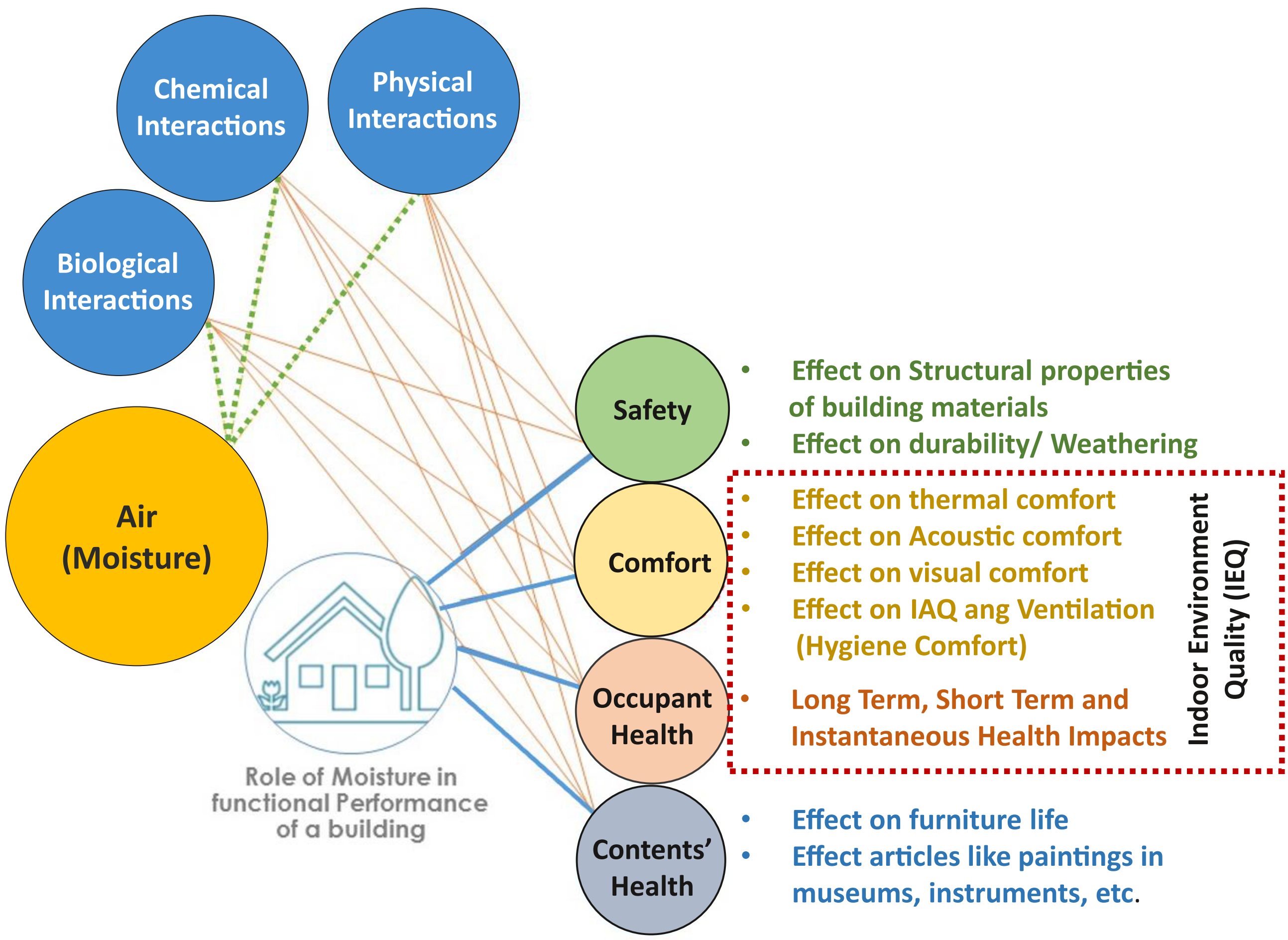

Figure 1. Impact of moisture on Indoor Environment Quality.

On-field occupant survey based on an aggregate comfort approach [4] was conducted to understand the perception of thermal, respiratory, and sensory comfort due to air moisture. 50 occupants (33 Males and 17 Females, 13 vernacular and 27 conventional dwelling residents) living in the community were interviewed.

The models [5], [6] are used to calculate discomfort for respiration reported as Warm Respiratory Comfort (WRC) and discomfort for skin contact reported as Indoor Air Quality (IAQ). Survey results were compared to the results obtained from these models to understand their applicability.

Vernacular vs. Conventional building typology

Humidity ratio in kilograms of water vapor per kilogram of dry air (kg-wv/kg-da) was based on psychrometric computation concurrent with measured temperature and relative humidity in different rooms.

The adobe (vernacular) buildings moderate and dampen the peaks of the diurnal trends of humidity ratio. This effect is seen more in the colder seasons of the year. The dropping of humidity ratio values in conventional buildings even below the outdoors (courtyard) indicates the possibility of interstitial accumulation or condensation. The maximum limits of humidity ratio for occupant comfort are 0.012 kg-wv/kg-da suggested by ASHRAE [7]. In a study from China, revised value [8] 0.0188 kg-wv/kg-da, was proposed, and was further revised [9] to 0.017 kg-wv/kg-da.

As shown in **Figure 3**, during the summer and monsoon months, the average humidity ratio remains much above the recommended values and lowers as the winter approaches. However, the winter month of November remains in close consonance with ASHRAE recommendations. This observation suggests the need to revisit the optimum humidity exposure recommendations in warm and humid climates.

Earth/Adobe is hygroscopic and regulates the indoor environment by moderating the change in conditions indoors. It can moderate exposure variations during the transition from outdoor to indoor environments and diurnal exposure indoors, thereby inhibiting sudden changes in heat stress.

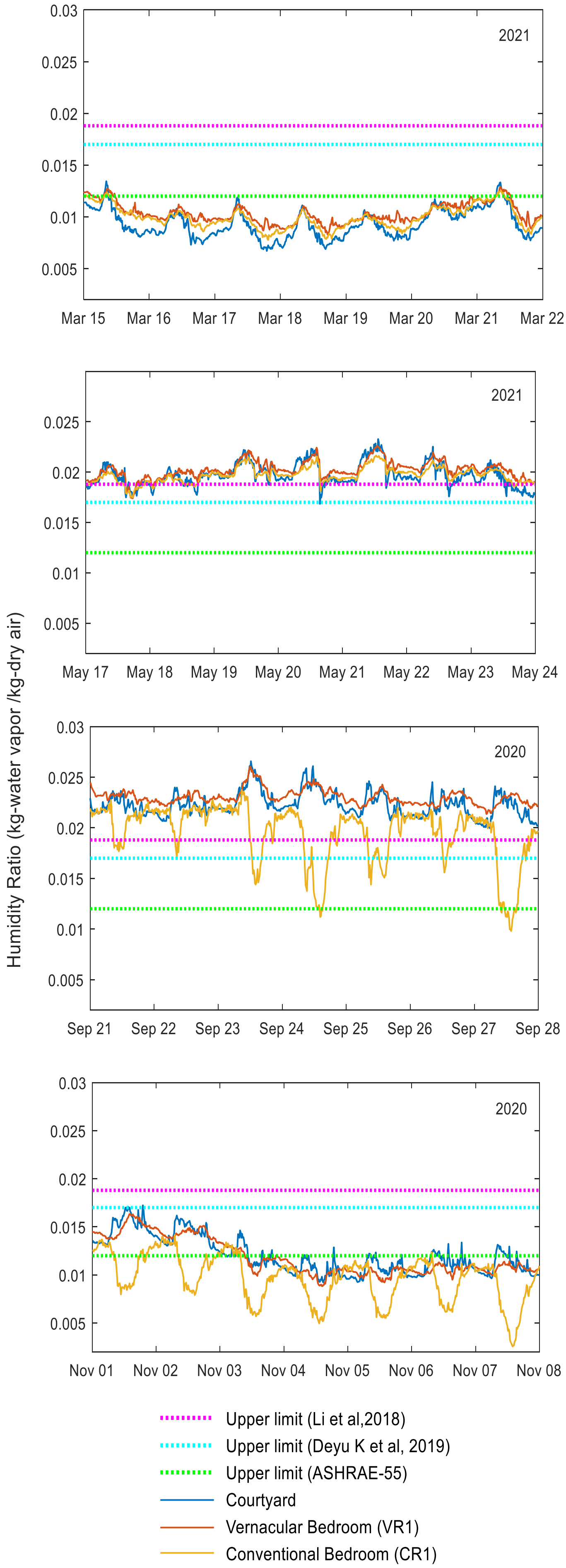

Figure 3. Trends of humidity ratio in different months.

Indoor air quality and respiratory comfort in different moisture exposure conditions

Survey results have been summarized in **Figure 4**, **Figure 5**, show the variation of Thermal Sensation Response, Warm Respiratory Comfort votes. Occupants have reported dry skin and respiratory problems due to dry air in the colder months. Responses indicate perception of humid air for respiration more in the vernacular room compared to conventional room.

Response for IAQ (skin) perception in vernacular show coherence with the change in outdoor humidity conditions unlike in conventional room. Cultural practices of the community reflect adaptation strategies to cope with changing humidity conditions. For example, "oil bath" during Diwali festival in November (low humidity, beginning of winter) for skin hydration, and bath with "ubtan" (Scrub paste made of natural ingredients) to remove excess oil and dirt during Holi festival in March (high humidity, beginning of summer).

Calculations using the models [5], [6] show that humidity parameters in all rooms appear conducive for respiratory comfort (5-10 % dissatisfied) during all seasons. IAQ in all rooms is dissatisfactory (nearly 100% dissatisfied) during the rainy months.

Dissatisfaction for IAQ decreases during the winter months as the outdoors get colder and drier. However, the occupant survey shows disparity with these results. **Figure 6**, and **Figure 7** show the comparison between observed and model-based computed values.

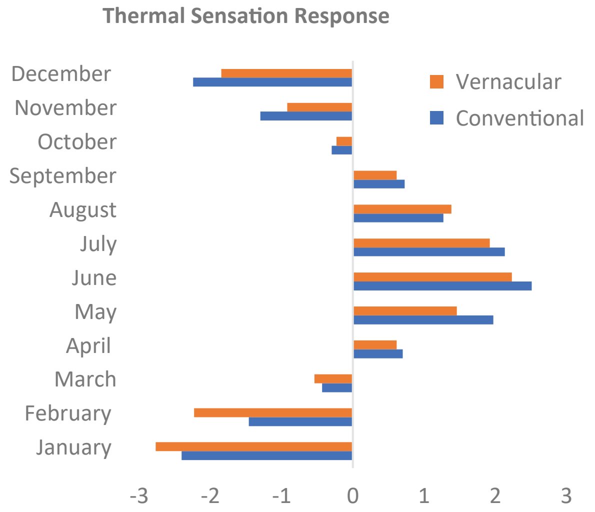

Figure 4. Monthly aggregated Thermal Sensation Response (-3 Very Cold to +3 Very hot Scale).

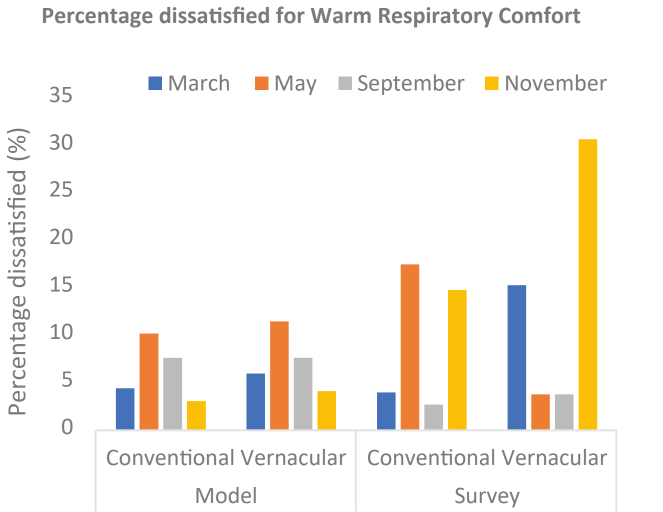

Figure 6. Comparison between observed and model-based computed values of percentage dissatisfied for WRC.

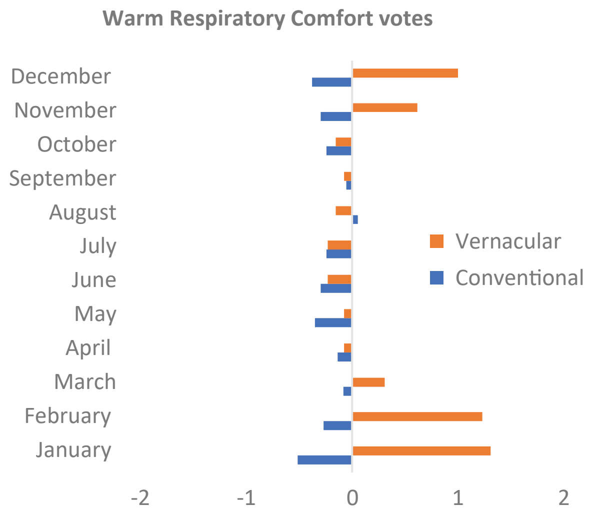

Figure 5. Monthly aggregated Warm Respiratory Comfort Votes (-2 Very dry to +2 Very Humid Scale).

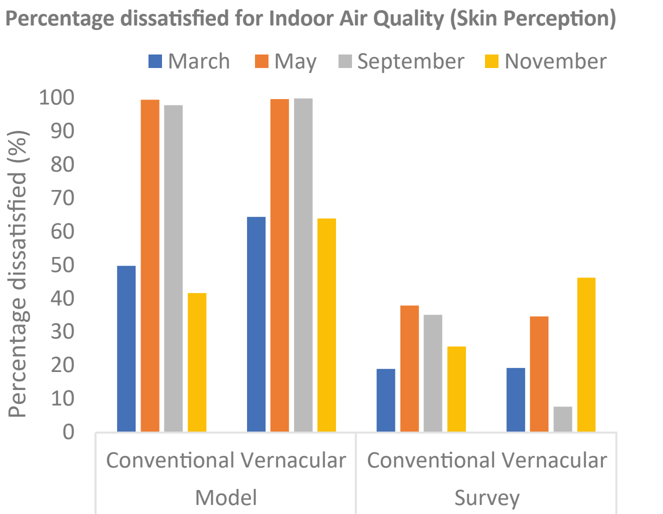

Figure 7. Comparison between observed and model-based computed values of percentage dissatisfied for IAQ.

Major findings

- Vernacular construction, in comparison with conventional construction, maintains indoor conditions close to outdoors and may contribute to improved occupant wellbeing
- The disparity observed between occupant responses received and the computed results advocates examining the applicability of the WRC and IAQ models for different climatic contexts and building typologies.

Conclusion

Moisture is a vital parameter associated with occupant health. Occupants are subject to sudden variation in moisture exposure in conventional buildings, especially during cold weather conditions. This highlights the need to adopt construction materials that can moderate exposure variations and help maintain a healthy indoor environment. Earth-based materials can be explored for their adoption due to their low cost, durability, lower carbon footprint, and thermal properties. The less understood vernacular building typologies need to be understood well for their benefits towards improved indoor environments. The study results highlight the need for scrutiny of building material based on environmental (climatic zone, microclimate, etc.) and personal factors (acclimatization, age, gender, etc.). ■

Acknowledgment

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References

[1] Y. al Horr, M. Arif, A. Kaushik, A. Mazroei, M. Katafygiotou, and E. Elsarrag, "Occupant productivity and office indoor environment quality: A review of the literature," *Building and Environment*, vol. 105, pp. 369–389, 2016, doi: 10.1016/j.buildenv.2016.06.001.

[2] O. Seppänen and J. Kurnitski, "Moisture control and ventilation," *WHO Guidelines for Indoor Air Quality: Dampness and Mould*, pp. 31–61, 2009.

[3] P. Tiwari, "Alert! Sudden change from hot to cold can be harmful to your health," 2019. https://timesofindia.indiatimes.com/life-style/health-fitness/health-news/alert-sudden-change-from-hot-to-cold-can-be-harmful-to-your-health/articleshow/69354918.cms (accessed Nov. 11, 2021).

[4] V. Shastry, M. Mani, and R. Tenorio, "Evaluating thermal comfort and building climatic response in warm-humid climates for vernacular dwellings in Suggenhalli (India)," *Architectural Science Review*, vol. 59, no. 1, pp. 12–26, 2016, doi: 10.1080/00038628.2014.971701.

[5] J. Toftum, A. S. Jørgensen, and P. O. Fanger, "Upper limits of air humidity for preventing warm respiratory discomfort," *Energy and Buildings*, vol. 28, no. 1, pp. 15–23, 1998, doi: 10.1016/S0378-7788(97)00018-2.

[6] J. Toftum, A. S. Jørgensen, and P. O. Fanger, "Upper limits for indoor air humidity to avoid uncomfortably humid skin," *Energy and Buildings*, vol. 28, no. 1, pp. 1–13, 1998, doi: 10.1016/S0378-7788(97)00017-0.

[7] ASHRAE, "Standard 55-Thermal Environmental Conditions for Human Occupancy," 2004.

[8] C. Li, H. Liu, B. Li, and A. Sheng, "Seasonal effect of humidity on human comfort in a hot summer/cold winter zone in China," *Indoor and Built Environment*, vol. 28, no. 2, pp. 264–277, 2019, doi: 10.1177/1420326X17751594.

[9] D. Kong, H. Liu, Y. Wu, B. Li, S. Wei, and M. Yuan, "Effects of indoor humidity on building occupants' thermal comfort and evidence in terms of climate adaptation," *Building and Environment*, vol. 155, no. March, pp. 298–307, 2019, doi: 10.1016/j.buildenv.2019.02.039.

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This article is follow-up part of the article published in REHVA Journal 2018-02 "Natural air conditioning: What are we waiting for?"

Naturally air-conditioned nearly zero-energy housing: The Earth, Wind & Fire Case Study

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Dutch housing built before the 1990s consumes the highest percentage of primary energy for heating and generally exhibits poor comfort. With the government targeting to convert 300,000 existing homes to become more energy-efficient every year, a renovation wave has started. How do we achieve this? This paper proposes a natural air-conditioning refurbishment strategy which not only provides energy savings but also contributes towards renewable energy harvesting to address the goal of a zero-energy built environment.

Keywords: Earth, Wind & Fire system, energy neutrality, housing refurbishment, nearly energy neutral design, indoor comfort, energy efficient buildings, Netherlands

Earth, Wind & Fire (EWF) System at a glance

The EWF (Bronsema, 2013) is a natural air-conditioning ventilation system which utilizes the environmental energy of earth mass and water through Climate Cascade, wind through Ventec roof and sun through Solar Chimney to air-condition the building in a mainly natural way. The Climate cascade is the heart of the EWF system which utilizes gravity and water for cooling, heating, drying and humidifying the ventilation air. This treated air is supplied to the building. The used air from the building is extracted by a shunt/exhaust shaft which is connected to the solar chimney at the bottom. The Ventec roof is used for creating sufficient pressure for the natural flow of ventilation air.

The system is initially designed for the office buildings in the Western European climate. However, integrating this system in dwellings is complex since the occupants like to regulate their environment and the occupant behaviour greatly affects the performance of the system. In order to investigate the potential of the system for dwellings in terms of its energy-efficiency and thermal comfort potential, a case study building Arthur Van Schendelplein, Delft- is selected. It is a multi-family social housing block consisting of 198 apartments and built in the year 1969.

Figure 1. Arthur Van Schendelplein, Delft.

EWF integration design concept

Figure 2 describes the integration of EWF in the design concept. The air enters at the top of the climate cascade and passes through water nozzles which pre-warm or pre-cool the air temperature thereby also humidifying it. During summers, the air is dried and cooled to 18°C. Whereas in winter, air is pre-heated via heat recovery by the twin coil system, after which it is humidified in the cascade and re-heated to 18°C at the foot of the supply shaft. The treated air is finally supplied to the apartments through supply ducts placed at each level of the building. When the pressure generated at the base of the Climate Cascade is less than the pressure loss, auxiliary fans are activated to generate the necessary pressure. For the exhaust, the exhaust ducts from the apartments bring the air to the shunt channel. The air is then pulled up in the Solar chimney due to the effect of thermal draft. The auxiliary fans are activated when the thermal draft is insufficient to pull the air to the top. The Solar Chimney has a heat recovery system at the top to reclaim the heat from the exhaust air before finally exhausting the air from the top of the chimney. The Cascade and the Chimney are both connected through an air to water heat exchanger to an ATES system for restoring the heat from the Chimney during summers and for cooling/heating the water to 13°C before pumping it to the nozzles in the Cascade.

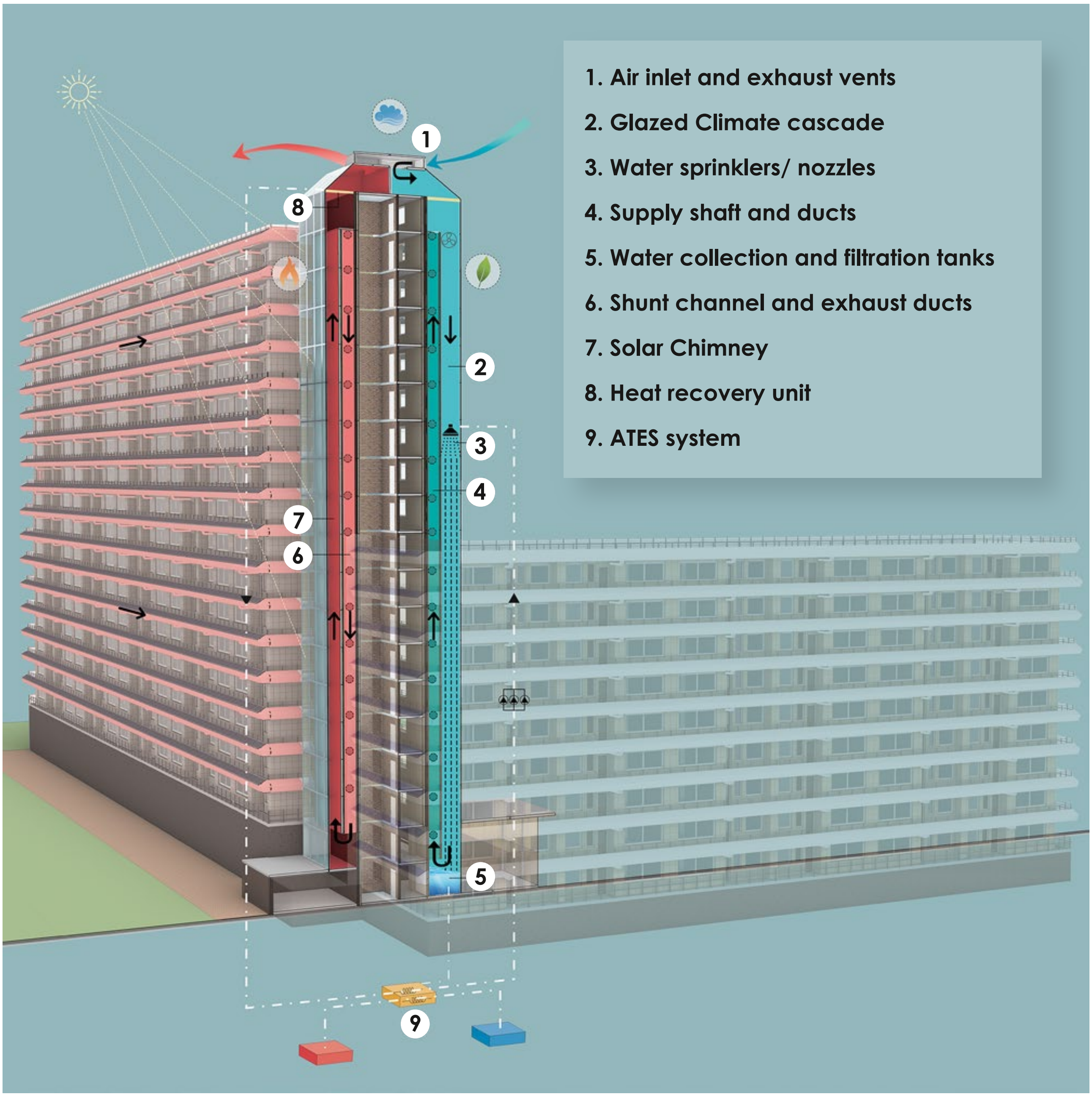

Figure 2. Vertical section through the building showing the integration of the EWF system.

The horizontal supply and exhaust ducts at every floor from the Climate Cascade and Solar Chimney are integrated into the building on the outside of the galleries at opposite sides as shown in **Figure 3**. The secondary supply ducts to each apartment are provided to living room and bedrooms whereas the secondary exhaust ducts are connected to kitchen, toilet and bathroom.

Design principles

Based on the integrated design concept, design principles are established and the annual energy consumed by the system for its operation is calculated. For a three-bedroom apartment, the minimum fresh air is taken to be 200 m³/h. For the entire building consisting of 198 apartments, the total ventilation rate is thus 39,600 m³/h. The system is designed for demand-controlled ventilation based on an occupancy profile such that the maximum ventilation is provided at night and less during the day for extra energy saving.

Climate Cascade

Size of the Cascade

For the calculated ventilation rate of 39,600 m³/h and an air velocity of 3.5 m/s, a shaft of dimensions 1.7 × 1.7 m is required. The height of the cascade is 54 m.

Number of water nozzles and pump energy

10 spray nozzles are provided at a height of 36 m instead of the building height of 54 m. The lower placement of the nozzles reduces the pump energy needed to elevate the water till the nozzles.

Air temperature and heating energy

The air temperature achieved at the base of the Climate Cascade should be close to 18°C after passing through the water of 13°C. During winters, the air temperature at the base is around 10-11°C which needs further heating using a reheating coil at the foot of the supply shaft, see **Figure 4**.

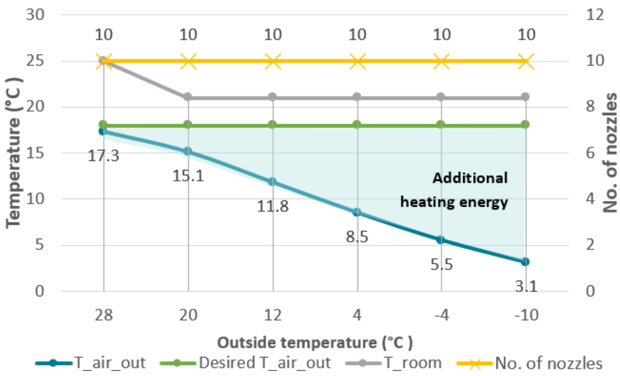

Figure 4. Graph showing the no. of nozzles and air temperature achieved at different outside temperatures.

Pressure build-up and fan energy

The pressure loss of the air supply system is estimated as 150 Pa. Using 10 spray nozzles throughout the year, the pressure achieved at the base of the Climate Cascade is less than 150 Pa during the winter months. This results in some amount of fan energy consumption in order to generate sufficient pressure. (See **Figure 5**)

Solar Chimney

Size of the Chimney

For the calculated ventilation rate of 39,600 m³/h and an air velocity of 1 m/s, a shaft of dimensions 1 × 11 m

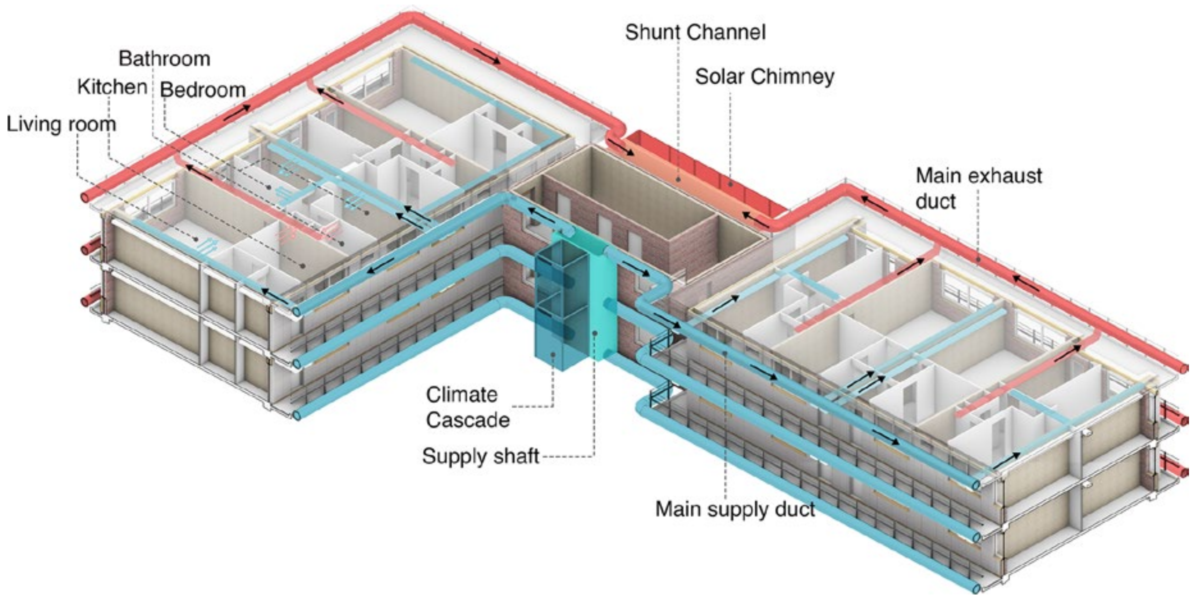

Figure 3. 3d section showing the EWF integration and air flow through the building.

is required. To avoid any daylight hindrance to the apartments, the chimney is placed at the central core behind the staircase.

Thermal draft and fan energy

The pressure loss of the air exhaust system is estimated as 50 Pa. When, the thermal draft generated in the chimney is less than the pressure loss, a fan is needed for the exhaust of the air, see **Figure 6**.

The total ventilation energy consumed by EWF system is the summation of the pump energy, heating energy, and fan energy for supply and exhaust. For the case study building this is calculated as roughly 14 kWh/m² which is considerably less than the traditional HVAC systems which consume more than 25 kWh/m².

Energy & Comfort performance

Having calculated the energy consumption for the EWF system, its effect on the total energy consumption of the building is studied by performing dynamic simulations using the Design Builder software. Since the EWF is a novel ventilation technique, certain simplifications are required to mimic the system in the software. With the goal to assess the effect of EWF on the energy consumption, it is assumed that a constant air temperature of 18°C is supplied in the different rooms.

For achieving the goal of a nearly energy neutral building, integration of EWF in isolation is not a complete solution. Thus, a four-step refurbishment strategy is adopted and calculations for energy and comfort are provided for each stage, see **Figure 7**.

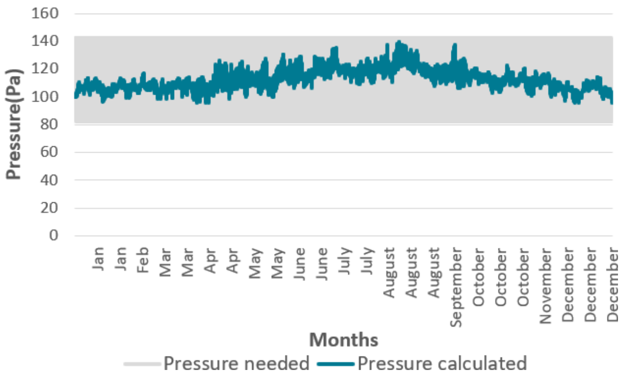

Figure 5. Graph showing the pressure calculated and pressure generated at the base.

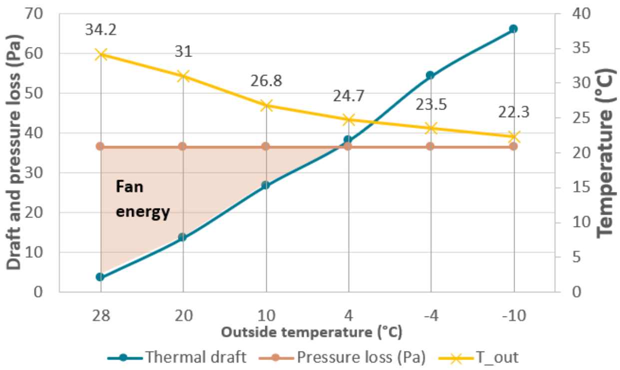

Figure 6. Graph showing the pressure loss and thermal draft generated at different outside temperatures.

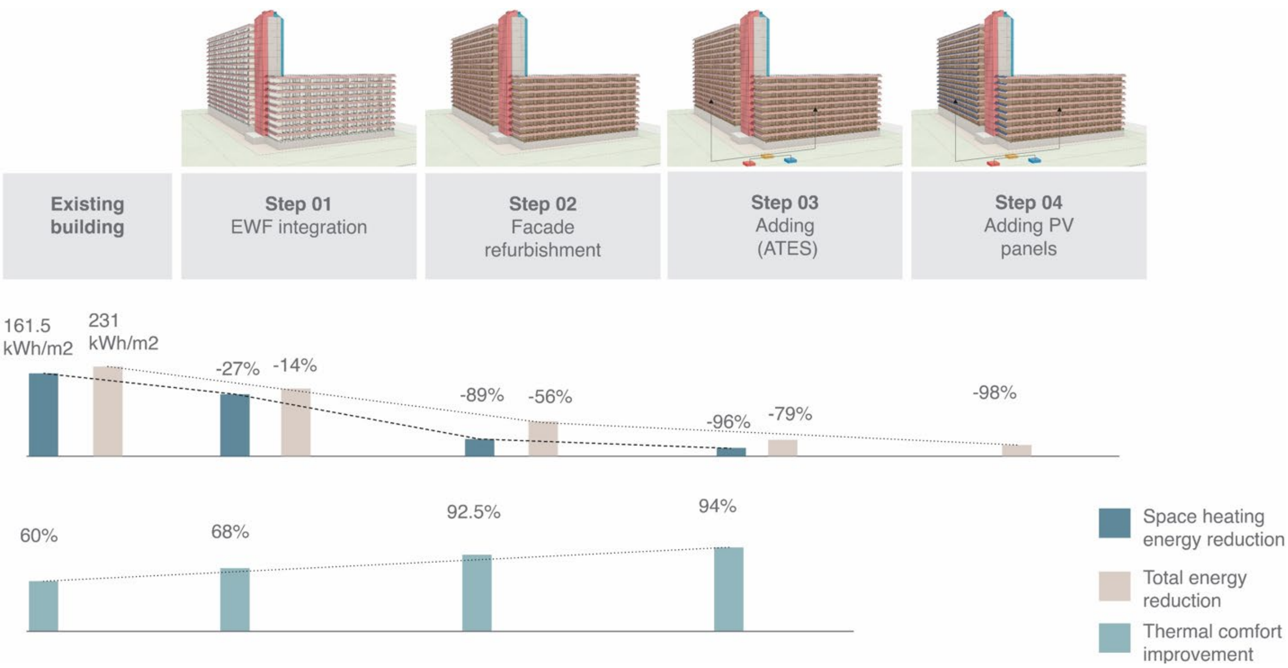

Figure 7. Step-by-step refurbishment strategy with energy savings and comfort performance.

Replacing the existing ventilation by EWF system

The Climate cascade and Solar chimney are integrated into the building based on the design parameters. Supplying the ventilation air of 18°C through the supply duct reduces the energy consumed for space heating by 27%. The ventilation energy, however, increases for the EWF system since it is a summation of fan, pump and additional heating energy to heat the air till 18°C as compared to the existing case which only has exhaust fans. The total energy consumption of the building with EWF system thus reduces by 14%.

The thermal comfort also greatly improves with a total of 68% hours satisfying the comfort criteria as per the ATG adaptive comfort method. There is a considerable improvement in the summer comfort with EWF ventilation due to the cooling effect of the 18°C air supply With the EWF system, roughly 60 hours exceed the 26°C as compared to the existing building where 95 hours exceed the 26°C comfort criteria.

Building envelope refurbishment

To achieve the goal of nearly energy neutral refurbishment, the poorly performing parts/system of the building needs to be refurbished. The old Dutch dwellings usually have a poorly insulated building envelope resulting in high heat losses and gains, higher energy consumption and poor thermal comfort. The case study building has a cavity brick wall without insulation, R-value of 0.706 m^2K/W and single glazed windows with a U-value of 6 W/m^2k. The building envelope thus does not satisfy the present-day Dutch regulations.

For an improvement in the performance, an external insulation layer is added to the building envelope and existing glazing is replaced by double glazing. With a combination of the EWF system with building envelope refurbishment, the space heating load drastically reduces by 89% due to lower heat losses from the renovated building envelope during winter. The total energy consumption reduces by 56%.

The thermal comfort shows a big improvement with around 92% of total hours falling inside the comfort criteria.

Replacing the existing boiler heating with an Aquifer thermal energy storage system

Adding an ATES system increases the share of renewable energy, getting us a step closer to achieve the goal of nearly energy neutral housing. This also aligns with the Dutch government's plan to make the Netherlands natural gas-free. Since an ATES system is more energy-efficient than boilers, the total energy consumption is further reduced.

As a part of this step, it is made sure that natural ventilation is possible in summer through operable windows in addition to the EWF system. This improves the summer comfort by reducing the overheating effect caused due to the insulated building envelope.

Adding solar panels

Solar panels for on-site energy production in combination with the previous three steps, reduces the total energy consumption of the building by 98%. The solar panels are provided as a part of the prefabricated module covering the supply and exhaust ducts attached to the galleries, see **Figure 8**.

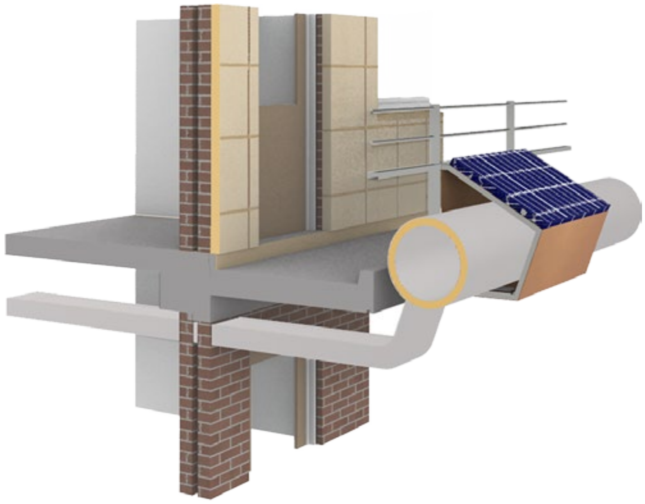

Figure 8. Prefabricated duct cover with solar panel attached to the top.

The final refurbished design is evaluated for BENG criteria to derive whether the building achieves the goal of a nearly zero energy building design as shown in **Table 1**. Since the building satisfies all the three BENG criteria, the refurbishment strategy transforms the building into a **nearly zero energy** dwelling. The EWF system has an effective contribution in reaching this goal.

How does the future of the built environment look like?

With a promising technology and sensible refurbishment strategy, we as architects and engineers can highly contribute towards the sustainability of the built environment. The refurbishment of the apartments with the EWF system results in a major transformation in the energy and comfort performance as well as the architectural aesthetics of the building. The social housing associations could perceive this as an opportunity to showcase the energy-efficiency of their building renovation by integrating the Climate Cascade and the Solar Chimney components. A refurbishment strategy that improves comfort, reduces energy consumption, adds to architectural aesthetics and contributes towards a sustainable zero-energy built environment; What are we waiting for? ■

Table 1. *BENG criteria assessment.*

Usable Floor area (UFA)(m^2)	17,820 m^2			
BENG category	**Requirement** (kWh/m^2.yr)	**Formula**	**Results** (kWh/m^2.yr)	
BENG 1	< 65	Total energy need	57.9	**Satisfied**
BENG 2	< 50	(E_total-Lighting)/UFA	40.14	**Satisfied**
BENG 3	> 40	E_ren/ (E_total + E_ren)	51.28%	**Satisfied**

BENG (A Dutch abbreviation meaning "Nearly Energy Neutral Building") is an energy performance indicator for nearly energy-neutral construction, and serves as the legal requirement in the Netherlands from January 1, 2021. BENG is a three-step approach for the energy concept.

- BENG 1 stands for the total energy need of a building in kWh/m²/year
- BENG 2 stands for the primary non-renewable energy use of a building in kWh/m²/year
- BENG 3 stands for the share of renewable energy expressed in percentage which is determined by dividing the amount of renewable energy use by the total energy use

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References

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

Patidar, Y. 2021- TU Delft Repository Housing Refurbishment using the Earth, Wind & Fire System: Towards a nearly energy-neutral housing in the Netherlands.

Indoor Environmental Quality Analysis of 3D Printed House

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Will we be printing our houses soon? Will this technology affect the quality of the indoor environment and the well-being of the occupants? The paper presents the results of a holistic assessment of the indoor environmental quality in a 3D printed building used as an accommodation unit.

Keywords: 3D printed building, indoor environmental quality, IEQ assessment method, measured data evaluation, holistic IEQ assessment, intelligent building, ventilation, cooling, heating

Introduction

In 2020, the Scoolpt art studio came up with an idea to create a residential sculpture, realised by 3D printing from a concrete mix. The authors, Michal Trpák, Ladislava Trpák, Jiří Vele and Kateřina Nováková, managed to find sponsorship support for this idea and thus the first Czech 3D printed house called PRVOK (=Protozoa) was created (**Figure 1**). After the installation of all technical equipment together with an intelligent control system, the object was put into operation in summer 2020 [1]. Since spring 2021 it has been used for short-term accommodation for (up to) 2 persons in a holiday resort on the shore of a South Bohemian pond.

The use of 3D printing technology for the printing of the whole house is a major challenge and innovation in the building process. It brings new issues not only in

Figure 1. Residential sculpture PRVOK.

the field of actual production, the static and the thermal properties of building structures, energy consumption in operation and production, durability and environmental impact, but also in the quality of the indoor environment. Thanks to the authors' helpfulness, the building besides acting as an interesting functional art object, awarded in many competitions, is working also as a living laboratory for testing and research. Therefore in 2021, a comprehensive assessment of the quality of the indoor environment was carried out in PRVOK using the HAIEQ (Holistic Assessment of Indoor Environmental Quality) certified methodology developed by the team of the Department of Indoor Environmental and Building Services Engineering at Faculty of Civil Engineering of CTU in Prague [2][5]. The HAIEQ assessment helps to identify the problem areas in terms of IEQ (Indoor Environmental Quality) and to propose measures. In this case it also works as a metric to find the gaps and express the benefits of the implementation of new intelligent management services in the field of indoor environmental quality management and building management in general within the TRIO research project, focused on identification and development of new services for intelligent buildings [3].

HAIEQ assessment methodology

The indoor environment of buildings consists of a set of physical, chemical, and social reactions between users and the building, which includes phenomena affecting the technical, natural, and medical sciences [4]. To describe and quantify the parameters of the indoor environment of buildings, we commonly use a simplified model, describing and evaluating the individual components of the environment separately – thermal comfort, air quality, acoustics, lighting, electromagnetic and other fields that co-create the final state of the environment.

The aim of this methodology is to create a complex holistic view of the assessed object in terms of all factors of the indoor environment. The HAIEQ methodology is based on a holistic approach to the integration of information about the building-technical design and interior, heating, cooling, ventilation, lighting, acoustics and electromagnetic, -ionic, -static fields and ionizing radiation, information about the real operation of the assessed building, based on data from measurements, mathematical model, and questionnaire survey. The output is a set of information expressing whether the object under assessment, in terms of each criterion, is solved at the level of the current state of knowledge or has the potential to improve the quality of the indoor environment, or whether there are significant deficiencies in terms of the quality of the indoor environment. The advantage of the methodology is the assessed method, which is not only intended to classify IEQ in buildings but primarily to indicate bottlenecks. In addition, a holistic approach helps to identify the causes of the problems and to better find ways to possible remedies. The information obtained can also be used to evaluate SRI (Smart Readiness Indicator [6]).

The methodology contains four basic parts (**Figure 2**). The first part summarizes the basic data about the

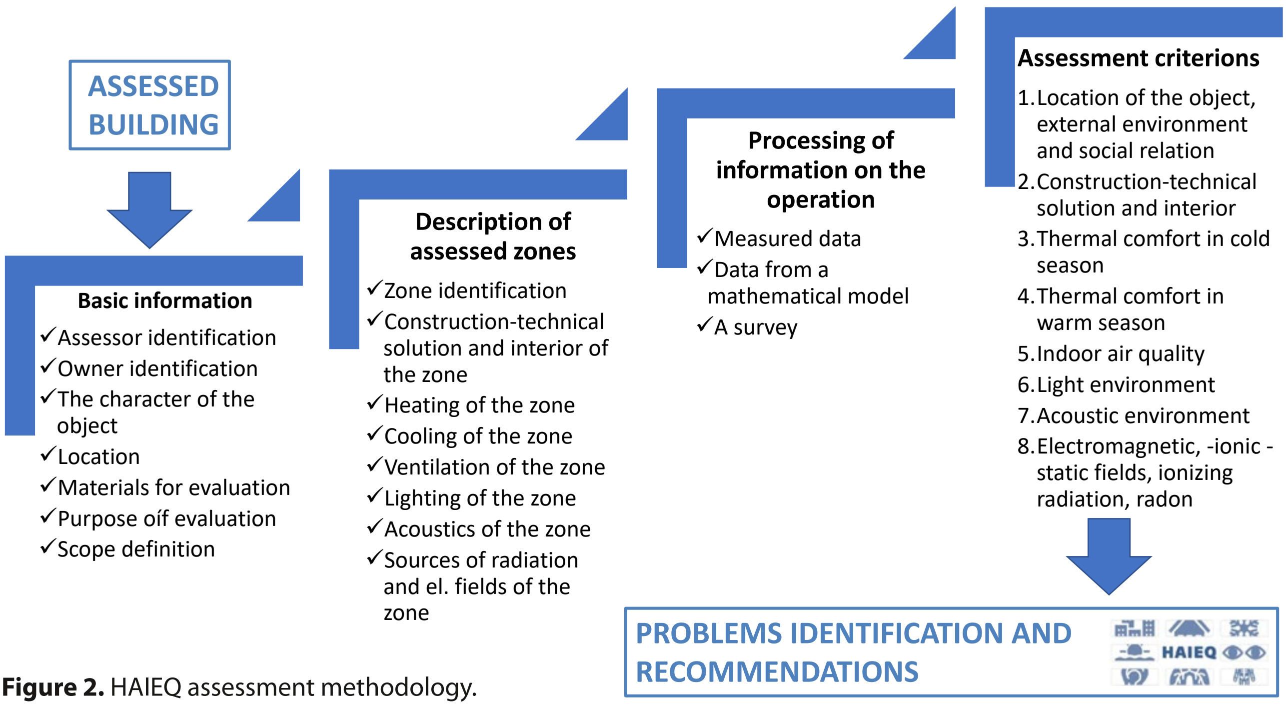

Figure 2. HAIEQ assessment methodology.

assessed object and the assessor and the scope of the assessed parts of the object is defined, including materials for assessment (project documentation, local investigation, measurement and regulation records, own measurements, questionnaire survey). Data about the assessed zone with a focus on building technical solutions and interior, heating, cooling, ventilation, lighting, acoustics and electro-magnetic, -ionic, -static fields and ionizing radiation are processed in the second part. Information about the real operation of the assessed object, based on data from measurements, mathematical model, and questionnaire survey is processed in the third part. The fourth final part contains an assessment of the above-described state of the building solution in terms of the eight criteria.

Each of the eight criteria contains 3-10 sub-criteria, where each is scored with grade 0 to 3. Grades are awarded based on the subjective assessment of the assessor, who has information about the object, measured data and, if possible, the result of a questionnaire survey. The evaluation is intended to express the state of the assessed criterion. If there is not enough data for the assessment of the given criterion or its assessment is not relevant for the given object, this is evaluated as “0”. If there is sufficient data to assess the criterion and the analysis of the criterion, considering user’s feedback, does not provide any recommendations for improving the current situation, this is evaluated as “1”. If the assessor suggests a measure leading to the improvement of the indoor environment, he evaluates criterion “2” or “3”. A rating of “3” indicates a serious problem in a given criterion that must be addressed immediately (e.g. violation of binding regulations, emergency state, malfunction or malfunctioning equipment). A rating of “2” indicates a condition that is acceptable but can be improved and it is desirable to do it. The proposed measure must be feasible for the given object and substantiated by justification (e.g. technical-economic analysis, expression of the benefit of the given measure, etc.). This assessment can to some extent, especially when deciding between 1 and 2, be influenced by both the knowledge and experience of the assessor and the feedback from the users. Thus, for these criteria, the evaluation of some objects may be satisfactory (i.e. rating “1”, without comment), while for other similar ones objects these criteria are commented and measures leading to an increase in the quality of the indoor environment are proposed (a rating “2”). The result of the questionnaire survey will play a role in this decision, which will express, for example, the user’s satisfaction with the current situation, even if it does not correspond to the current best state of knowledge (best practice).

The output of the methodology is a set of information expressing whether the assessed object is solved in terms of individual criteria at the level of the current state of knowledge or has the potential to improve or there are serious shortcomings in terms of indoor environmental quality.

HAIEQ Assessment of PRVOK

The assessment of IEQ using the HAIEQ methodology is based on the assessment of data describing the architectural and construction design, the design of technical systems and the operation.

Description of the building

PRVOK is a ground floor building, where on the floor plan of 43 m² of open space there is a bedroom, a toilet with a bathroom and a living area with kitchenette (**Figure 3**).

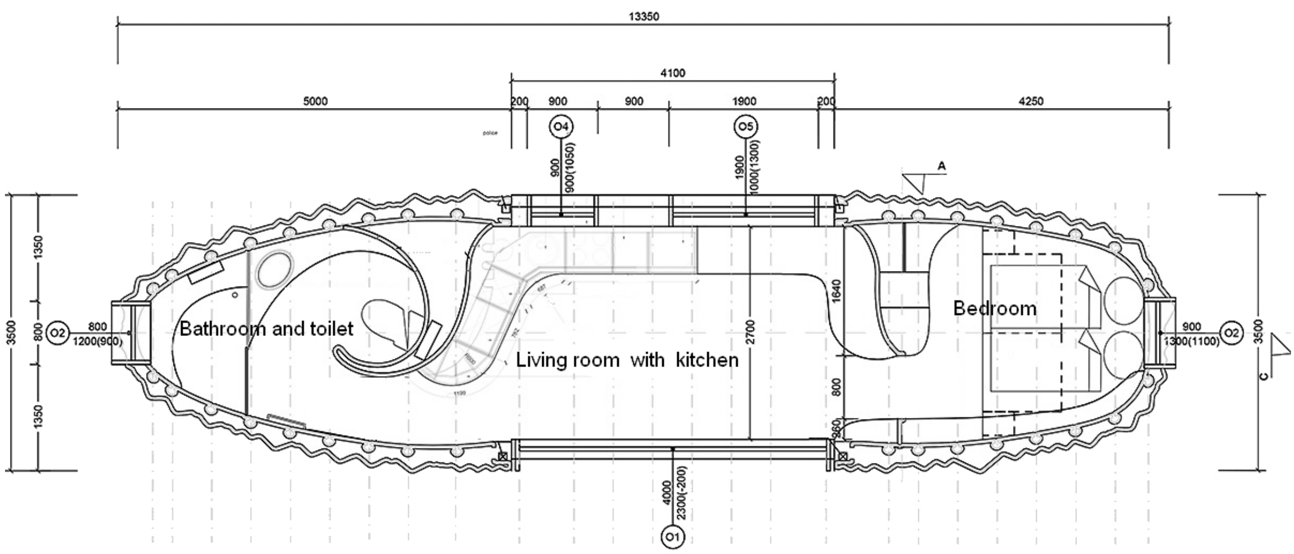

Figure 3. Floor plan of PRVOK.

The building is without foundations, respectively the supporting bottom frame is metal, the perimeter structures (walls) are made of 3D printed concrete (bedroom and bathroom) in combination with a wooden structure (living area). The windows of the building are wooden frames with double glazing, the roof is flat green and in the central part of the building vertical green walls are implemented in the exterior. The interior surfaces are made of 3D printed concrete, ceramic mosaic tiles, plaster, and wooden cladding.

The building has electric underfloor heating, ceiling split air conditioning cassette unit with heating output 3.2 kW and cooling output 2.5 kW and ventilation unit 150 m³/h (up to 500 m³/h) with heat recovery exchanger providing equal pressure ventilation with air supply to the bedroom, living area and shower and with air exhaust from the bedroom, kitchen area and toilet.

The bathroom is equipped with a unique recirculation shower unit, smart toilet with automatic operation and an electric storage water heater is installed for hot water generation. The building is connected to a grey water tank, with water recovery for toilet flushing, and a black water tank with the possibility of pumping and removal of sewage. Rainwater is used for automatic irrigation of the green roof and facades. The object is connected to a mains water supply.

As part of the research project [3], in cooperation with industrial partner a master control system was installed in the building, which allows to integrate all control functions of the building operation, monitor individual parameters, automate control and, thanks to remote access, perform service interventions. At the same time, the user has information about the current thermal comfort (air temperature and relative humidity) and the history of air temperatures in the bathroom, living area and bedroom. Information about the operating mode of the air conditioning and air handling unit (% of power), information about the use of lighting (in the living area including the intensity of lighting and colour) and information about the current and total electricity consumption for a certain season is available. The user is also able to change the desired temperature in the interior of the bathroom, bedroom and living area, the setting of the power of the airhandling unit and the air conditioning unit and the desired temperature of the air supplied by the air conditioning unit. There is the possibility to switch the lighting on/off, and in the living area to change the intensity and colour of the light.

Measurements

For the PRVOK building, we had the design documentation, supplemented, and verified by the actual condition during a detailed survey of the building (**Figure 4**) and data from the installed intelligent control system. As it has been found in previous surveys, the data from the building control system needs to be validated – the industrial sensors used to control different technical systems are not always calibrated with each other and so the data on the same quantity from different sensors varies within the tolerance of the sensor accuracy and the location of the sensor also has an influence. Therefore, the data from the control system were supplemented with several measurements of selected indoor environmental parameters.

The monitoring process started with one-off indicative measurements of selected parameters (VOC, CO_2, Formaldehyde, negative ions) to get an overall picture of the state of the environment. Hand-held instruments were used for this purpose. At the same time, measurements of illuminance and analysis of the light spectrum of the artificial lighting system were carried out. These measurements were complemented by thermographic images of the envelope and floor heating to identify areas with thermal bridges. Then additional medium-term (approx. 1 week) measurements of flow velocity, the resultant and the air temperature, relative humidity and CO_2 concentration were carried out with a datalogger measurement set under different operating modes of the air handling equipment and with different occupancy. Installation of long-term online monitoring

Figure 4. Verification of air flow at the exhaust of ventilation system.

of air temperature and relative humidity, CO_2 concentration, sound and barometric pressure levels followed. The results from the monitoring were processed and evaluated in the VISIEQ graphical output (**Figure 5**). All the data obtained formed a picture of the object, which was assessed and evaluated in the next step.

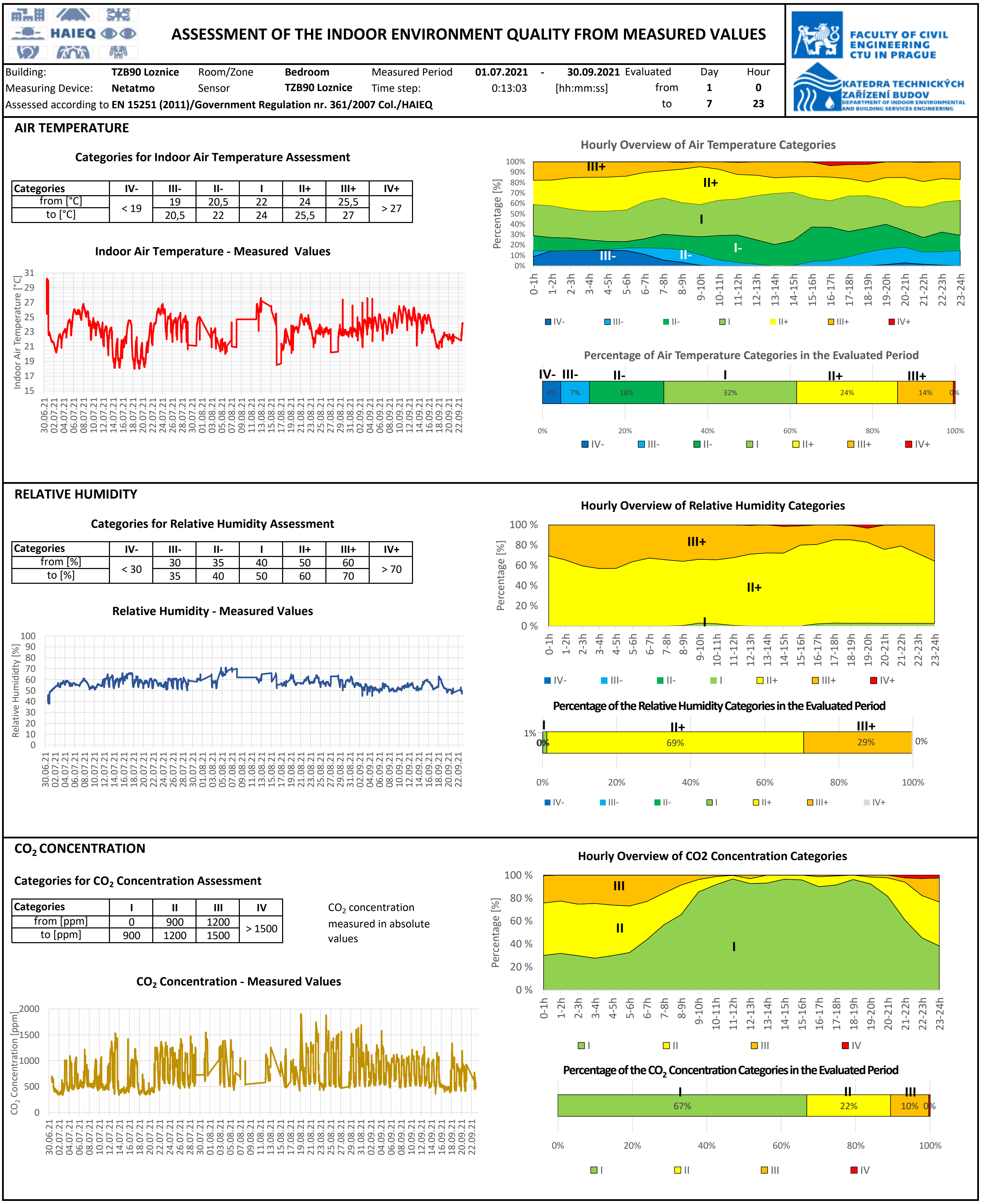

Figure 5. Evaluation of measured values in VISIEQ format.

Evaluation

The principle of the HAIEQ methodology, based on a 0/1/2/3 rating of a total of 48 sub-criteria grouped into 8 areas, provides a holistic view of the indoor environmental quality. The following tables summarise the results of the evaluation of each criterion and comment on the criteria rated 2 or 3.

Table 1. *LS Evaluation of the locality and the location of an object in terms of the external environment and social relations.*

Criterion		Grade
LS1	Air quality (pollution)	1
LS2	Wind region	1
LS3	Noise from the surroundings	1
LS4	Orientation to cardinal points	1
LS5	Influence of heat island	1
LS6	Psychic perception of surroundings, interpersonal relationships	1
LS7	Risk of energy poverty	0
LS	**Average of non-zero values LS1 to LS7**	**1**
No comments		

Table 2. *STI Evaluation of building -construction and technical solution and interior.*

Criterion		Grade
STI1	Use of hazardous materials in building structures (asbestos, etc.)	2
STI2	Risk of water vapor condensation on structures (thermal bridges)	2
STI3	Use of hazardous materials for equipment (formaldehyde etc.)	2
STI4	Use of daylight	1
STI5	Active shielding and its control	2
STI6	Greenery in the interior	1
STI7	Visible defects and disorders (mold, leakage, cracks, poor surfaces, etc.)	2
STI8	Color space solution	2
STI9	Layout solution, occupancy of the zone	2
STI10	Maintenance	2
STI	**Average of non-zero values STI1 to STI10**	**1.8**

Comments

ST1: 3D printing from concrete is a new technology, and given the composition of the concrete mix, we recommend to monitor the indoor air quality.

ST2: The details at the floor-wall interface show anomalies in terms of temperature field distribution and are potential areas of condensation.

ST3: The use of non-traditional materials (table made from subfossil oak 6000 years old, mined in Ostrava + resin, in the kitchen there are on the shelves 220000 strips of veneer).

ST5: External shading is not installed; internal shading is in the form of a roller shutter on the eastern window in the bedroom.

ST7: Cracks in the structure caused by the transport of the building. The rough surface of the 3D printed wall with no surface treatment can increase the risk of dust deposition and mechanical cleaning systems should be used to clean it.

ST8: The colour scheme of the space is avant-garde, matching the character of the building. It may have a psychological impact on more conservative individuals.

ST9: The layout of the social facilities without door does not provide privacy.

ST10: The technical design of building services systems (recirculating shower, ventilation unit with heat recovery, air conditioning, rainwater irrigation, intelligent control system programming) requires qualified operators.

Table 3. TCW Evaluation of thermal comfort in the cold season.

Criterion		Grade
TCW1	Choice of the heating system	1
TCW2	The ability of the heating system to adapt its operating mode in response to the users' needs with due regard to user-friendliness, maintaining a healthy indoor environment – e.g. individual temperature control, user feedback – subjective environmental quality assessment	1
TCW3	The ability of the heating system to report energy usage to the user	2
TCW4	The ability of the heating system to report the quality of the indoor environment in terms of thermal comfort in cold to the user	2
TCW5	Summary of thermal comfort assessment results for the cold season from the measurement/simulation (e.g. risk of overheating of the zone in cold due to heat gains, under-heating, etc.)	3
TCW6	Summary of thermal comfort assessment results for the cold season from the questionnaire survey (if performed)	0
TCW	**Average of non-zero values TCW1 to TCW6**	**1,8**

Comments

TCW3: The control system of the building is providing the total energy use for all the systems, there is not any separate information about the energy use of the heating system.

TCW4: There is only the air temperature reported, not the resulting temperature, which is insufficient in the case of radiant heating systems.

TCW5: There were large temperature fluctuations during the measurements, probably caused by the ON/OFF control of the electric underfloor heating located and the storage layer of the floor. As a result, higher floor surface temperatures were also experienced.

Table 4. TCS Evaluation of thermal comfort in the warm season.

Criterion		Grade
TCS1	Choice of the cooling system	2
TCS2	The ability of the cooling system to adapt its operating mode in response to the users' needs with due regard to user-friendliness, maintaining a healthy indoor environment – e.g. individual temperature control, user feedback – subjective environmental quality assessment	1
TCS3	The ability of the cooling system to report energy usage to the user	2
TCS4	The ability of the cooling system to report the quality of the indoor environment in terms of thermal comfort in cold season to the user	1
TCS5	Summary of thermal comfort assessment results for the warm season from measurement/simulation (e.g. risk of overheating of the zone in cold due to heat gains, under-heating, etc.) (if performed)	1
TCS6	Summary of thermal comfort assessment results for the warm season from the questionnaire survey (if performed)	0
TCS	**Average of non-zero values TCS1 to TCS6**	**1,4**

Comments

TCS1: Regarding the object design, the whole object is cooled in case of cooling requirement, it cannot be "zoned", the object behaves as 1 zone (including the bathroom).

TCS3: The control system of the building is providing the total energy use for all the systems, there isn't any separate information about the energy consumption of the cooling system.

Table 5. IAQ Evaluation of indoor air quality.

Criterion		Grade
IAQ1	Choice of the ventilation system	1
IAQ2	The ability of the ventilation system to adapt its operating mode in response to the users' needs with due regard to user-friendliness, maintaining a healthy indoor environment – e.g. user feedback – subjective environmental quality assessment	3
IAQ3	The ability of the ventilation system to report energy use to the user	2
IAQ4	The ability of the ventilation system to report the quality of the indoor environment in terms of indoor air quality	3
IAQ5	Summary of indoor air quality assessment results from measurement/simulation (if performed)	3
IAQ6	Summary of indoor air quality assessment results from the questionnaire survey (if performed)	0
IAQ	**Average of non-zero values IAQ1 to IAQ6**	**2,4**

Comments

IAQ2: Ventilation system is working in four modes with different air change rates depending on the chosen operation situation (0 %,30 %,60%, 100% of the total output of the AHU) without any monitoring of IAQ parameters. No automatic control of the ventilation system output.

IAQ3: There is available just the information about the total energy use of the whole building not only for the ventilation system itself.

IAQ4: No measurements of IAQ parameters are taken, so they aren't available to the users.

IAQ5: Based on the seven days measurement of CO_2 concentration it can be stated that 80% -90% of the time the IAQ is in category II (according to EN 16798-1). There were several rare episodes when the CO_2 concentration reached values above 1500 ppm and even above 4000 ppm. But it can be due to more people present in the building then it is designed to.

An orientation measurement of formaldehyde performed within one hour detected its concentration. Averaged measured concentration was 0.2 ppm and this concentration is four times bigger than the limit concentration for residence rooms coming from the Czech standard (Decree No. 6/2003 Coll.). This situation can be due to the new and unconventional equipment of the building and it is supposed to decrease in time. Nevertheless, increased air change rate may help.

Table 6. LC Evaluation of light comfort.

Criterion		Grade
LC1	Choice of the lighting system	1
LC2	The ability of the lighting system to adapt its operating mode in response to the users' needs with due regard to user-friendliness, maintaining a healthy indoor environment – e.g. regulation of intensity and spectrum of light sources in the workplace, user feedback – subjective environmental quality assessment	2
LC3	The ability of the lighting system to report energy usage to the user	2
LC4	The ability of the lighting system to report the quality of the indoor environment in terms of light comfort	2
LC5	Summary of light comfort assessment results from measurement/simulation (if performed)	1
LC6	Summary of light comfort assessment results from the questionnaire survey (if performed)	0
LC	**Average of non-zero values LC1 to LC6**	**1.6**

Comments

LC2: Although the system of LED luminaires and strips offers and allows great variability in colour and intensity, the creation of lighting scenes and their control requires user effort and is not intuitive.

LC3: The control system of the building is providing the total energy use for all the systems, there isn't any separate information about the energy consumption of the lighting system.

LC4: There is no information about the quality of the light environment in the building provided to the user.

Table 7. *AC – Evaluation of acoustic comfort.*

Criterion		Grade
AC1	Sources of noise and measures to eliminate them	2
AC2	The ability of the system to report the quality of the indoor environment in terms of acoustic comfort	2
AC3	Summary of acoustic comfort assessment results from measurement/simulation (if performed)	1
AC4	Summary of acoustic comfort assessment results from the questionnaire survey (if performed)	0
AC	**Average of non-zero values AC1 to AC4**	**1,67**

Comments

AC1: Due to the open space, sounds spread throughout the space (e.g. sounds from the toilet and kitchen area). Door between living room and bathroom may help to solve this problem.

AC2: There is no information about the quality of the acoustic environment in the building provided to the user.

Table 8. *EC Evaluation of electro-magnetic, -ionic,- static fields, ionizing radiation.*

Criterion		Grade
EC1	Sources of Electro-magnetic, -ionic,- static fields, ionizing radiation and measures to eliminate their negative effects	0
EC2	Summary of assessment results from measurement/simulation (if performed)	0
EC3	Summary of assessment results from the questionnaire survey (if performed)	0
EC	**Average of non-zero values EC1 to EC3**	**0**

Comments

Not enough information for assessment. Despite the fact that electric devices installed in the building individually meet the limits for electromagnetic fields (kitchen appliances, hot water tank, air conditioning unit, LED light stripes, electric underfloor heating, smart toilet, shower, intelligent control with wireless data transmission), it is recommended to provide measurement and analysis of the electromagnetic fields and determine whether there is an increase in their intensity above the permissible limits.

Table 9. *Summary evaluation and potential for improvement.*

Zone:			"PRVOK"	
Evaluation criteria			Evaluation	Potential for improvement
	LS	Locality and place of the object in terms of the external environment and social relations	1,000	0%
	STI	Building - construction and technical solution and interior of the evaluated zone	1,800	40%
	TCW	Thermal comfort for the cold period	1,800	40%
	TCS	Thermal comfort for the warm period	1,400	20%
	IAQ	Indoor air quality	2,400	70%
	LC	Light comfort	1,600	30%
	AC	Acoustic comfort	1,667	33%
	EC	Electro-magnetic, -ionic,- static fields, ionizing radiation	0	N/A

Conclusion

The HAIEQ assessment methodology allows a comprehensive holistic view of the assessed building in terms of the individual factors of the indoor environmental quality and its assessment. The method helped to identify the problems and showed potential areas for improvement.

Summarizing the findings obtained from the analysis of the investigated object, we can say that 3D printing technology brings new opportunities, especially in the freedom of the building shape and enables the realization of buildings with a distinctive architectural expression. The only problem area related to the structure was revealed by the thermal imaging camera, which identified potential condensation points in the detail at the floor-wall interface.

In terms of the quality of the indoor environment, the greatest potential for improvement was in the area of air quality. Due to the small volume of the building and the specific layout, taking into account measured values, it became clear that it would be advisable to control the HVAC according to CO_2 concentration, humidity and to consider control according to VOC.

In addition, repeated measurements of formaldehyde, which may be produced by the new equipment and can be expected to decrease in concentration during operation, should be made. The rough internal surface of the 3D printed structure requires more intensive maintenance and if neglected, increased airborne dust concentrations can be expected. The specific layout also causes acoustic problems between the different functional areas - bedroom, living area and sanitary facilities.

Our main objective was to test and evaluate a master control system that, in its basic configuration, enables the required functions and provides most of the necessary information. The subject of our further research and development is now the creation and testing of an advanced user interface that allows the user to modify the environment in a user-friendly way to a comfortable form, while getting feedback on its actual quality and energy performance.

The IEQ rating of this 3D object is not different from that of a conventionally constructed building. Most of the critical areas are not directly related to the 3D printing technology, but rather to the architectural design and operational management of the building. ■

Acknowledgment

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References

[1] https://www.scoolpt.com/pribeh-prvoka/

[2] KABELE, K., Z. VEVERKOVÁ, and M. URBAN. Metodika hodnocení kvality vnitřního prostředí v budovách s téměř nulovou spotřebou energie. [Applied Certified Methodology] 2019.

[3] KABELE, K., et al. Výroční zpráva projektu TRIO – FV40183 Rozšíření systému řízení produktu inteligentní dům. [Annual Report] Brand-Tech, 2019. Report no.1BLUYSSEN, P., M., 2009. The Indoor Environment Handbook How to Make Buildings Healthy and Comfortable United Kingdom: Earthscan ltd, ISBN: 13: 9781844077878.

[4] KABELE, K., Z. VEVERKOVÁ, and M. URBAN. Methodology of IEQ assessment in energy efficient buildings. In: *Windsor 2020 Resilient Comfort*. Windsor, 2020-04-16/2020-04-19. Witney: Ecohouse Initiative Ltd., 2020. p. 861-876. ISBN 978-1-9161876-3-4. Available from: https://windsorconference.com/proceedings/.

[5] VERBEKE S., WAIDE P., BETTGENHÄUSER K., USLAR M.; BOGAERT S. Et al., 2018. Support for setting up a Smart Readiness Indicator for buildings and related impact assessment - final report; August 2018; Brussels.

Indoor Environmental Quality – Global Alliance (IEQ-GA):

Working Together for Improvements in the Indoor Environment

For the past two years, it has been my great honour to be the President of the Indoor Environmental Quality – Global Alliance (IEQ-GA). It has been a great start to the IEQ-GA, and I firmly believe that it will get even better as more professional organizations join us to help improve IEQ worldwide.

DONALD WEEKES
President of IEQ-GA
www.ieq-ga.net

The vision 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 and places of work around the world. The mission of IEQ-GA is to provide an acceptable indoor environmental quality (thermal environment-indoor air quality-lighting-acoustic) to occupants in buildings and places of work around the world and to make sure that the knowledge from research on IEQ is implemented in practice. One example of IEQ-GA's leadership role in the IEQ field was our Position Statement on 'The Airborne Transmission of COVID-19', which was issued in April, 2020. IEQ-GA lead the way on this critical issue, and it (and its member organizations) continues to monitor the pandemic in a science-based and evidence-based approach.

The objective of IEQ-GA is to collaborate with the professional societies organizations to think together, work together and speak with the same voice. The alliance is formed as an interdisciplinary, international working group of societies interested in indoor air quality, thermal comfort, lighting and acoustic science, and technology. IEQ-GA is also interested in applications to simulate indoor activities that will help in a significant way to improve the actual, delivered indoor environmental quality in buildings. The members of IEQ-GA's membership organizations work every day to enhance the IEQ of the built environment, IEQ-GA stands ready to work with the members in distributing this work and research to the world.

Prior to the formation of IEQ-GA, a few national and international societies or professional organizations were dealing fully or partly with the indoor environment, but their voice was often neglected or not heard at the policy making stage. It should be noted that the indoor environmental quality field is a multidisciplinary issue involving architects, engineers, health specialists, occupational health specialists, and other professionals. With the advent of the pandemic, it was soon apparent that there was a need for one professional organization to speak for all of these IEQ professionals when talking to policy makers, other IEQ scientists and researchers, and those in the medical field. The creation of the IEQ-GA ensured that there was one society or professional organization (IEQ-GA) which in a significant way can make sure that all interested parties can be a part of the value chain to improve the indoor environment in all buildings.

It has been a long nineteen months since the advent of the Age of COVID in March, 2020 in North America, Europe, Asia, and elsewhere. Many of us are finally able to enjoy a 'new normal' life with vaccine passports, booster shots, the continuation of mask wearing, and social distancing. However, the pandemic is certainly not over in many parts of the world, and it is quite possible that there will be more waves or surges of COVID in areas that are starting to recover. We all must remain vigilant and careful, especially as international travel begins again. As IEQ scientists and engineers, we must continue to offer science-based and evidence-based papers, recommendations and interviews. The amount of misinformation and non-scientific posts and tweets can be overwhelming, but this must be countered by the scientists and engineers who have carefully reviewed (and peer-reviewed) the data and information about the pandemic.

In the last few months, IEQ-GA has been in touch with representatives of the World Health Organization (WHO). It has been an excellent dialogue, primarily about COVID-19, and related subjects. As a result of this dialogue, IEQ-GA has been invited to submit the names and credentials of qualified representatives to participate in the WHO's Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19. In response to this invitation, IEQ-GA's Board of Directors have submitted four candidates to date, and these individuals have been accepted by WHO to serve on the ECAP for COVID-19. We are hopeful that this will be the start of a favourable long-term relationship between WHO and IEQ-GA.

In coordination with ISIAQ and our MOU, we are now completed program #4 of the Indoor Environments webcasts. Indoor Environments is a new online program that includes a video show and audio podcast series coordinated by Healthy Indoors, a webcast company based in Syracuse, NY. The fifth program will be streamed on Friday, November 19th, 2021 at 11 am EST. The topic will be Indoor exposure to chemicals and microbes via dust and resuspension. This topic will be discussed with Doctors Karen Dannemiller and Brandon Boor. They were selected by ISIAQ as guest speakers on this jointly owned and managed webcast. I am sure that it will be a lively and insightful discussion with the professors and the co-hosts, Bob Krell from Healthy Indoors and myself. The steaming of the webcast will be will be available at: https://global.healthyindoors.com/c/indoor-environments/episode-5

Please note that a sixth webcast is planned for December, 2021. It is hoped, since the webcasts have been successful to date, that there will be additional programs in the future. For the future, it is also hoped that the two organizations (IEQ-GA and ISIAQ) will look for other opportunities to collaborate under the terms of the MOU.

Throughout the pandemic, the Indoor Environmental Quality – Global Alliance (IEQ-GA), its member organizations, and the professional members of these organizations will continue to work together as a worldwide alliance of scientists, indoor environmental practitioners and researchers. In addition, as shown by our MOU with ISIAQ, we plan to work with other professional organizations on collaborative efforts, such as webinars, podcasts and publications, in order to provide to all of the world's population effective and pertinent scientific information about indoor environmental quality (IEQ).

I would like to conclude with a reminder that IEQ-GA has set up a webpage specifically dedicated to addressing concerns about COVID-19. This webpage includes a series of Questions & Answers (Q&A) that are intended to provide information to anyone that wants to know more about COVID-19 transmission in buildings. This webpage can be found here: https://ieq-ga.net/covid-19/faqs/ ■

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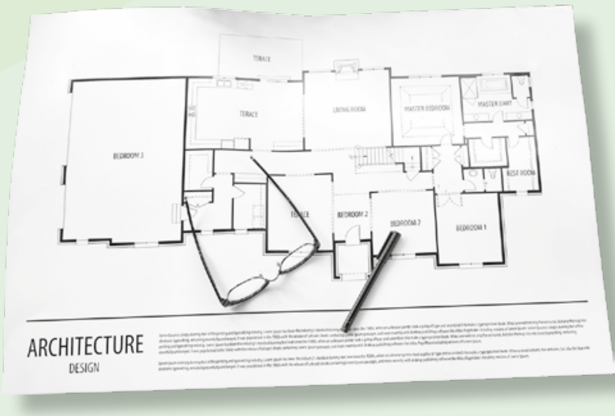
OAER – Romanian Chamber of Energy Auditors
SIE – Society for Indoor Environment



REHVA Healthy Homes Design Competition

Urban population in our major cities is rapidly growing, increasing the demand for dwellings and thus, the prices. This will likely lead to the "urbanization" of the suburbs, where many people will be willing to move to get affordable housing, areas with suboptimal outdoor air quality. Apart from that there is a need of designing new houses and redesigning existing ones in a new way to meet the demand of different type of users, to comply with the necessity for comfortable, sustainable and resilient buildings and not least, to provide the users with quality of life and enhanced wellbeing.

Reducing the environmental impact buildings have on our planet is a well-recognized issue among both practitioners and researchers. It has a large influence on the way buildings are designed today and will certainly continue to inform future developments in efforts to mitigate climate change. An equally important issue lies in understanding how buildings affect people's health and wellbeing.

With this design ideas competition, we want to stimulate the minds of young and future building designers and engineers to identify innovative solutions that help create good indoor air quality, adequate thermal comfort and stimulating light and acoustic environments in dwellings also taking into account energy efficiency and e.g. climate resilience. ■

Register
Download the Brief and register

Design
Create a healthy home design 2022

Submit
Submit your project by 1 March 2022

Jury
Our international jury panel will evaluate

Awards
Winners will be awarded prize

SHARE THE WORD, REGISTER AND WIN!

The EU Sustainable Energy Week (EUSEW) 2021: Overview of Sessions

EUSEW 2021 took place between 25 and 29 October, preceded by an extended programme which included sessions earlier in October, under the title "***Towards 2030: Reshaping the EU Energy System***". For one week, high-level stakeholders from different fields were brought together to present and discuss the latest developments on the sustainability of the EU's energy system. REHVA actively followed the sessions and here we provide an overview of some them that are related to the sustainable built environment.

SPYRIDON PANTELIS
Project & Technical Officer at REHVA

JASPER VERMAUT
EU Policy & Project Officer at REHVA

EUSEW 2021 Opening Session

The EU Sustainable Energy Week 2021 was officially opened on the 25th of October with a keynote speech by the President of the European Commission, **Ursula von der Leyen**, who emphasized the EU's leading role during the COP26 negotiations:

"The European Green Deal is the calling card for Europe at the global stage, with many of the major economies following the example of the EU on setting climate targets for carbon neutrality by 2050 or shortly after."

Kadri Simson, Commissioner for Energy, confirmed that the second act of Fit for 55 is still planned to be published by the end of 2021, including the revision of the Energy Performance of Buildings Directive (EPBD).

The contrast in opinions on the ongoing Fit for 55 negotiations between the European Parliament and some Member States became clear during this opening session. Niels Fuglsang, rapporteur of the European Parliament on the Energy Efficiency Directive (EED), stated that the European Parliament is looking at how the ambitions & targets in the Fit for 55 negotiations can be raised even higher than what the Commission has proposed.

In contrast, **Jernej Vrtovec**, the Slovenian minister of infrastructure who spoke at the opening session on behalf of the Presidency of the EU Council, had a more cautious tone on the targets. Mr. Vrtovec stated that most Member States oppose the proposal by the Commission to increase the annual savings of final energy consumption to 1.5% in the EED, and that more flexibility was needed regarding the targets on heating & cooling.

Building renovation: Riding the wave

The session "*Building renovation: Riding the wave*" brought together different stakeholders to discuss the latest developments of the Renovation Wave and the review of the Energy Performance of Buildings Directive (EPBD). **Kadri Simson**, European Commissioner for Energy, put the focus on three components to make the Renovation Wave a success: *funds* to enable research & innovations; *upskilling* the workforce to enable digitalisation; and setting the right *regulations* to have the right combination of performance requirements on buildings, which is what the ongoing revision of the EPBD aims to do.

In the following panel discussion, **Adrien Joyce** (EuroACE) noted that the definition of Nearly-Zero Energy Buildings (NZEB) in some Member States is quite weak and that not all buildings are being constructed at NZEB level, which is a key aspect to be tackled within the EPBD revision alongside the integration of a whole-life carbon approach for new buildings.

Digital Building Logbooks are mentioned as a key tool for information on the performance of buildings to enable more renovations, as they can act as a single repository where data from other tools (e.g. Building Renovations Passports, EPC, Smart Readiness indicators…) can be lodged and made accessible through a single interface. By simplifying the information process to the end-users, we can create more incentives for renovation.

When discussing the affordability of renovations, **Peter Sweatman** (Climate Strategy) mentioned that the Renovation Wave wants to renovate 35 million buildings by 2030 and this would require 275 billion euros of additional annual investments. The current Recovery & Resilience Plans setup by the Member State fall short in this as the total planned sum to invest in the "Renovate Flagship" is targeted at 50 billion euros. Mr. Sweatman noted that Europe needs a leverage of at least 20 times this sum to reach the investment levels that are required to meet the targets and unlock the needed private finance.

Towards Zero-Impact Buildings: Making Life-Cycle Thinking the Norm

How can the life-cycle approach be practically integrated within the building industry? Policy Officer at the European Commission (DG ENV), **Josefina Lindblom**, presented the Level(s) framework which aims to set a common language with different criterion on what sustainable buildings are. The strength of the framework is in its flexibility, it's not a certification scheme, but a set of indicators that different actors can use to varying degrees to assess the sustainability of buildings. Slowly we are seeing an integration of Level(s) into other policy initiatives, such as Life-Cycle Assessment within the EPBD that is supported by the framework.

Oliver Rapf, Executive Director at the Buildings Performance Institute (BPIE), reinforced the need for the integration of a whole-life carbon approach within the existing EU policy framework. Mr. Rapf demonstrated, see **Figure 1**, that Level(s) currently is the only EU policy instrument which fully covers whole-life carbon and it's only a voluntary framework. The EPBD, EED and Taxonomy currently only cover the operational use of buildings. If we want to make life-cycle thinking the norm, we need to start integrating this across policy instruments.

CURRENT STATE OF WHOLE-LIFE CARBON REGULATIONS

Lifecycle stages	Modules	EU policy instruments							
		EPBD	EED	CPR[6]	Ecodesign	WFD[7]	ETS[8]	Level(s)[9]	Taxonomy[10]
PRODUCTION	A1 Raw material supply	-	-	(*)	•	-	•	••	(*)
	A2 Transport	-	-	-	-	-	(*)	••	(*)
	A3 Manufacturing	-	-	(*)	-	-	•	••	(*)
CONSTRUCTION	A4 Transport	-	-	-	-	-	(*)	••	(*)
	A5 Construction installation process	-	-	(*)	-	-	-	••	(*)
USE	B2 Maintenance	-	-	(*)	-	-	-	••	(*)
	B3 Repair	-	-	(*)	-	-	-	••	(*)
	B4 Replacement	-	-	(*)	-	-	-	••	(*)
	B5 Refurbishment	-	-	(*)	-	-	-	••	(*)
	B6 Operational energy use	••	••	-	•	-	(*)	••	••
END-OF-LIFE	C1 Deconstruction	-	-	(*)	-	•	-	••	(*)
	C2 Transport	-	-	-	-	-	(*)	••	(*)
	C3 Waste processing	-	-	-	-	••	-	••	(*)
	C4 Disposal	-	-	-	•	••	-	••	(*)
BEYOND LIFE	D Reuse/recycle	-	-	(*)	•	•	-	••	(*)

Partially covered   Fully covered   Under revision

BPIE

Figure 1. Slide presented by Oliver Rapf (BPIE) on inclusion of whole-life carbon criterion in EU Policy Instruments.

The Next Generation of Energy Performance Certificates: Making Buildings fit for the Energy Transition

In the extended programme of EUSEW 2021 on 14 October, REHVA co-organised a session to present the latest evolutions on how EPCs can be innovated to become a more reliable and widespread instrument to increase building renovations. In his keynote speech, REHVA President – **Frank Hovorka** – stressed the importance of including an indicator on Indoor Environmental Quality (IEQ) within the current EPC framework to ensure that the health of people are at the centre of renovations. Within this context the ALDREN-TAIL indicator is mentioned as a best practice example on how it can be integrated.

Pau Audi Garcia, Policy Officer at the Commission (DG ENER), stated that the main focus of the EPBD revision is on boosting renovations. Here lays an important role for strengthening EPCs where the upcoming EPBD proposal aims to improve their quality & comparability, as well as enhance their information role by increasing indicators within EPCs besides the strict indicator on energy use.

Energy efficiency first: From principle to reality

In the proposed revision of the Energy Efficiency Directive (EED), the mandatory application of the "Energy Efficiency First" (EE1st) principle was introduced for planning and investment decisions. This overarching principle should be taken into account across all sectors, including the financial sector. **Maciej Grzeszczyk**, Policy Officer at the European Commission (DG ENER), provided a brief overview of the "Energy Efficiency First" principle guidelines and underlined that a cost-benefit analysis should take into account a system approach and adopt a wider societal perspective, counting also the wider benefits of energy saved.

Fergus Sharkey, Head of Business and Public Sector of the Sustainable Energy Authority of Ireland (SEAI), presented the Irish Energy Performance Certificate (i.e. Building Energy Rating). He underlined that it is equipped with an algorithm that provides an energy efficiency roadmap for homeowners. The roadmap recommends interventions to increase the energy efficiency of a building, prioritising those that target improvements on the building envelope and insulation; while mechanical or electrical building service systems such as heat pumps and solar panels are recommended as a later step of an energy efficiency improvement.

At energy system level, **Michael Villa**, executive director at SmartEn stated that the volatility of renewables constitutes an opportunity for new business models. He reminded that the potential of demand-side flexibility should first be activated to enable end-users to flexibly adapt to this variability and contribute on the

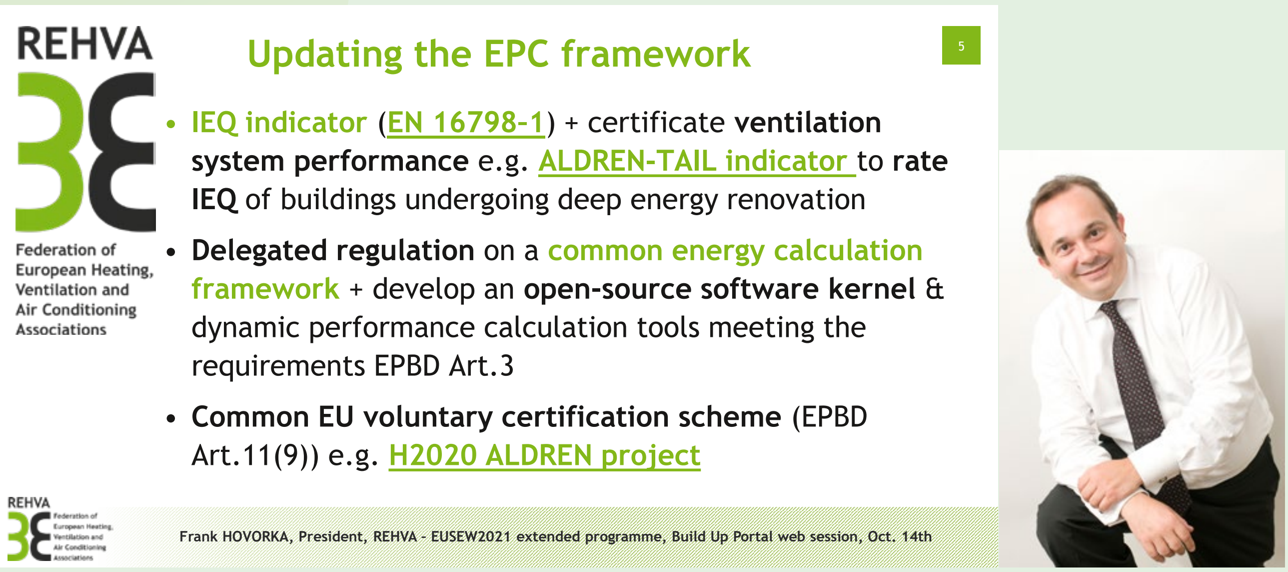


Figure 2. REHVA President Frank Hovorka delivering the keynote speech at the EUSEW 2021 on next generation EPCs.

integration of renewable energy. As a closing remark, he highlighted that demand-side flexibility will also bring benefits to industry and will boost digitalisation and automation of industrial processes.

Striving for decarbonisation in the Energy Community with renewable district heating

District heating based on renewable energy technologies has significant potential to boost the energy transition and help reach climate and energy goals for 2030 and beyond. Though, this transition in the Western Balkan countries and Ukraine will be particularly challenging due to their overwhelming reliance on coal-based power plants.

Violeta Kogalniceanu, Head of Energy Efficiency at Energy Community Secretariat stated that the Clean Energy package is planned to be adopted by the Energy Community Ministerial Council by November 2021, highlighting that there is a need for legislative and structural reforms. A platform on renewable heating and cooling network has been established to bring together technical experts and policy makers to support the deployment of renewables and waste heat in district heating networks and facilitate the exchange of good practices among the participating countries.

Greg Gebrail, Energy Specialist at the European Bank for Reconstruction and Development (EBRD) stated that markets with less political regulations will have easier access to financing for environmental and efficiency improvements. Financial institutions are focusing on 6 key aspects in order to aid and de-risk investments in district heating networks: business models, the level of private sector participation, regulatory certainty, funding costs, legacy infrastructure and available subsidies/grants.

Renewable heat was put on the spotlight in the presentation of **Christian Holter**, Founding Manager at SOLID, who provided an overview of current technologies for decarbonizing district heating networks. He highlighted that we should explore the synergetic potential of different technologies for renewable heating, and most importantly the combination of solar heat with thermal storage, presenting successful applications from Serbia, China, Canada and Denmark. ■

Bibliography

EUSEW 2021 Opening Session: https://eusew.app.swapcard.com/event/eu-sustainable-energy-week/planning/UGxhbm5pbmdfNjUxOTc5.

Building renovation: Riding the wave: https://eusew.app.swapcard.com/event/eu-sustainable-energy-week/planning/UGxhbm5pbmdfNjk5NDg5.

Towards Zero-Impact Buildings: Making Life-Cycle Thinking the Norm: https://eusew.app.swapcard.com/event/eu-sustainable-energy-week/planning/UGxhbm5pbmdfNzAwNzg2.

The Next Generation of Energy Performance Certificates: Making Buildings fit for the Energy Transition: https://epc-recast.eu/recording-workshop-next-gen-epcerts-making-buildings-fit-for-the-energy-transition-eusew-2021/.

Energy efficiency first: From principle to reality: https://eusew.app.swapcard.com/event/eu-sustainable-energy-week/planning/UGxhbm5pbmdfNjk5NDgz.

Striving for decarbonisation in the Energy Community with renewable district heating: https://eusew.app.swapcard.com/event/eu-sustainable-energy-week/planning/UGxhbm5pbmdfNzAwNzg1.

Every drop counts

The importance of humidity control

Humidity is a key parameter for optimal indoor air quality. Swegon GOLD air handling units now offer a new sorption rotor with a 3Å foil coating that, combined with updated control functions, optimize the indoor humidity in all seasons.

Key benefits include:

- Maximised humidity recovery
- Decreased need for cooling capacity
- Reduced energy use if combined with active humidification
- Reduced odour transfer
- Controlled humidity levels

All in all, this provides lower investment and running costs as well as a more comfortable and healthier indoor climate that makes you feel good inside.

GOLD

Swegon

WISE received an award in Finland

Photo: Jyri Laitinen

Swegon's WISE-system was awarded "**Energy Solution of the Year**" at the Building Energy Seminar in Finland on November 9. The energy seminar for buildings 2021 was the first one of its kind and organized by FINVAC.

Companies and communities that participated in the building energy seminar exhibition had the opportunity to participate in the "Energy Solution of the Year" competition. The competition sought a solution that could provide a cost-effective solution for the energy use and carbon footprint of a building. The solution must be applicable to new or renovation construction and must be available in the market. Innovation and scalability of the solution was also emphasized in the selection.

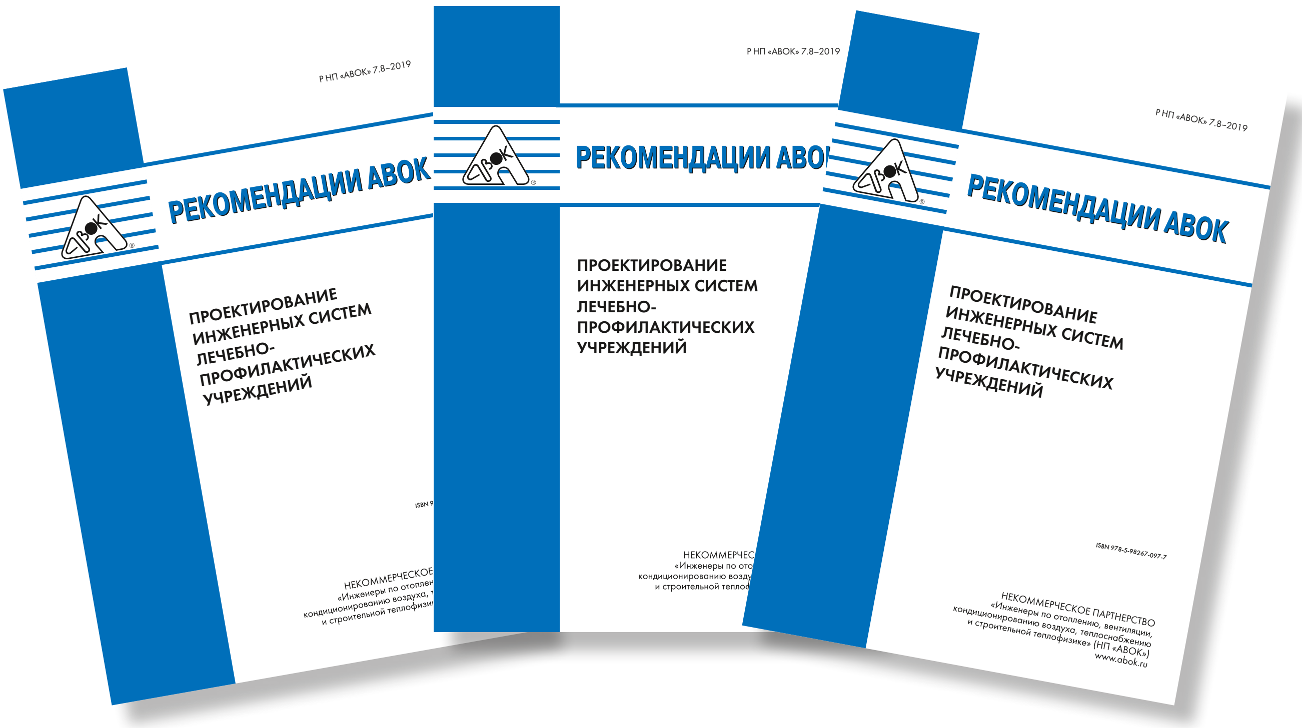
The competition jury was impressed by Swegon's solution for the novelty, concreteness and ease of productization it offers. WISE offers a complete system for managing room conditions that is hardly available on the market. WISE is a turnkey product that replaces many devices and functions, and offers a more cost-effective solution for the builder. It also offers great potential for energy savings through pressure optimization. WISE combines optimization of indoor air quality, energy efficiency and a functional whole. ■

ABOK

A series of ABOK standards:

Recommendations on the design of engineering systems of medical organizations

The author's team of the Russian HVAC society "ABOK" for the first time attempted to generalize the accumulated experience in the field of creating and providing air exchange and ventilation in medical organizations for various purposes, as a result of which a series of regulatory documents, each with a volume of more than 100 pages, was created and published.



The series includes three interrelated regulatory documents developed in the period from 2019 to 2021: Standards R NP "ABOK" 7.8-2019 "Design of engineering systems of medical and preventive institutions", R NP "ABOK" 7.8.1-2020 "Design of engineering systems of infectious hospitals", R NP "ABOK" 7.8.2-2021 "Design of engineering systems of maternity hospitals".

The documents formulate requirements for the effective prevention of the spread of infection by engineering methods while ensuring reliable isolation of the patient, technological requirements for the premises of medical organizations, sanitary and hygienic and anti-epidemic requirements for planning solutions and organization of air exchange and ventilation, architectural and planning requirements for design, requirements for the organization of heat supply, heating, automation, water treatment and water treatment, ventilation and air conditioning, requirements for the organization of air exchange in the main structural units. The practical appendices to the recommendations provide examples of new innovative technologies and equipment.

Standard R NP "ABOK" 7.8-2019 "Design of engineering systems of medical and preventive institutions" is a regulatory document that opens the entire series. It contains the most general requirements and provisions for the design of engineering systems in medical and preventive institutions, reference materials on the calculated temperature, the multiplicity of air exchange and the sanitary norm of outdoor air supply for rooms of different cleanliness classes. The rdocument contain methods for selecting a radiant heating and cooling system, calculating the multiplicity of air exchange in the operating room, variants of supply and exhaust ventilation schemes for operating rooms with a laminar ceiling air distribution device and equipment for air recirculation in particularly clean rooms, as well as testing air disinfection systems for inactivation of microorganisms on filter elements.

Standard R NP "ABOK" 7.8.1-2020 "Design of engineering systems of infectious hospitals" were created during the beginning of the COVID-19 pandemic, when the engineering community was faced with the urgent question of implementing engineering methods in the fight against COVID-19. In the recommendations, special attention is paid to architectural and planning solutions and the organization of air exchange, including ways of distributing air inside the departments of the infectious diseases hospital and the organization of the direction of air movement. Modern requirements for automation of ventilation systems, cleaning and disinfection of air in buildings of infectious diseases hospitals are given, which is especially important during the fight against the spread of a new coronavirus infection. The recommendations are supplemented by the design features of TB hospitals (departments).

Standard R NP "ABOK" 7.8.2-2021 "Design of engineering systems of maternity hospitals" logically continue the topic of combating COVID-19 in medical institutions of maternity care: in maternity hospitals and perinatal centers. For the first time in regulatory practice, materials on the composition and regulatory areas of premises for each department of the maternity hospital and perinatal center are summarized, detailed standard schemes of medical and technical specifications for the design of engineering equipment in maternity and operating rooms of maternity hospitals are provided - an invaluable guide for designers. The technologies recommended for the construction of a drinking water purification system and variants of schemes for the organization of water treatment systems are given.

A series of regulatory documents created by the creative team of ABOK is a serious work that deserves the close attention and recognition of professionals in the field of HVAC. www.abok.ru, brodatch@abok.ru. ■

Mastering the Flow

Years of expansion at the Ludmillenstift Hospital resulted in an HVAC system that just could not cope. The introduction of Belimo Energy Valves™ significantly reduced the water flow rate of the heating network, resulting in smart, transparent, and energy-efficient load-dependent heating and cooling systems – while improving comfort and keeping energy consumption stable.

The Ludmillenstift Hospital is located in the city of Meppen in Lower Saxony (Germany). This large multidiscipline hospital forms the main pillar of a comprehensive health network and can boast more than 160 years of providing healthcare to the Emsland region. It prides itself on exceptional levels of care for its patients, backed by modern infrastructure and state-of-the-art medical technology, including advanced diagnostic and therapeutic expertise and other specialized services.

Ludmillenstift Hospital

- Opened: 1851
- Location: Meppen, Lower Saxony (Germany)
- Inpatients: 20,000 a year
- Outpatients: 150,000 a year
- Beds: 420 beds

Bold Attempts

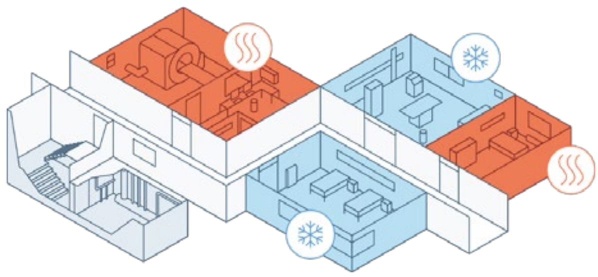
Technology also plays a crucial role in ensuring the functionality, comfort, safety and efficiency of the buildings that make up the hospital's infrastructure. However, patient demand and specialist facilities have grown beyond capacity over the years, and repeated expansion and renovation programs have resulted in major challenges related to controlling and maintaining the hydronic distribution system.

Maintaining a well-balanced HVAC system can be challenging in multiple-building complexes like hospitals. This was certainly the case when the situation came to a head, with many complaints from staff about cold rooms and zones in the winter months. The facilities management team at the Ludmillenstift was aware that certain parts of the site were regularly undersupplied with adequate hot water and recognized that the heating system's hydronics was struggling to manage and monitor comfort levels.

The team made bold attempts to improve the situation by dramatically raising the boiler temperature, with all pumps set to full load. However, this met with very limited success; the complaints continued and the excessive pumping and generation of additional steam energy led to a huge increase in cost, which heavily stretched the hospital's budget. At this point, the Ludmillenstift decided to call in experts – in the form of the company G.U.T. August Brötje KG – to find out the root cause of the issue and decide on an adequate solution.

Oscillating Heat Supply

The engineers from August Brötje KG looked over pre-existing system drawings of the heating supply and decided that only a central balancing of the sub-manifolds would solve the hydronics problems. They then carried out an extensive survey of the building's HVAC system, which disclosed various weaknesses and bottlenecks. For example, the temperatures measured at the hydronic switch were 90/86°C (194/187°F), and the heat supply of the individual sub stations was oscillating, which made the heat supply come and go randomly. The lack of hot water reaching the heating coils also repeatedly triggered the frost protection system to shut down the ventilation system in winter, which was especially problematic in the operating theatres. Overall, the heating supply simply had not been modernized at the same rate as the rest of the hospital.

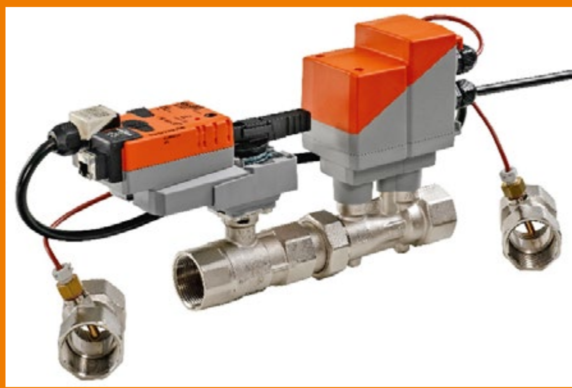


To address the enormously high boiler flow and system return temperatures throughout the year, Peter Meier, the controls expert from August Brötje KG, had to define the longterm scope of the improvement project, which included the following specifications:

- All heating manifolds should be adjusted to their nominal flow volume to ensure that only the exact amount of water needed for hydronic balancing is supplied;
- The currently required thermal energy should be recorded and quantified at the respective distribution feeds;
- The system's return temperature should be reduced to improve the energy conversion efficiency of heat recovery towards the boiler (and prepare for the later planned use of a combined heat and power unit);
- The flow volume through the entire facility should be load dependent to make sure that the system can be operated efficiently, and that the maximum amount of water is not permanently pumped through the buildings.

About the Belimo Energy Valve™

The Belimo Energy Valve™ is an IoT cloud-connected, pressure-independent valve that monitors coil performance and energy consumption while maintaining high delta T. It also has an exclusive glycol monitoring feature, providing accurate, repeatable flow measurement, and ensuring that the glycol concentration meets design requirements.



The patented Power Control and Delta T Manager™ built-in logic software enables power monitoring and control and optimizes the energy supplied to the coil by maintaining the designated delta T.

In addition to the analog control and feedback signal, the Energy Valve™ communicates data to Building Management Systems (BMS) via BACnet MS/TP or BACnet IP, as well as Modbus RTU and Modbus TCP/IP.

The integral webserver enables clear visualization of the valves' operation in real time. Performance data is stored remotely on the Belimo Energy Valve™ for 13 months and cloud data provides lifetime data access.

The functionality of the Belimo Energy Valve™ precisely matched what Peter Meier was looking for to address both the current and future challenges of controlling the hospital's hydronics system. He particularly liked the performance reporting of current and historical data – such as flow rates and energy usage – as well as BACnet IP communication between each Belimo Energy Valve™, the August Brötje KG on-site control and regulation technology, and the hospital's building management system.

Innovation to the Rescue

Belimo had already introduced Peter Meier to its latest innovation – the Belimo Energy Valve™ – and this seemed the ideal solution for the Ludmillenstift Hospital site.

This electronic, characterized control valve combines pressure-independent control, flow and energy measurement, automatic hydronics balancing and data monitoring, all in one device. By continuously measuring water flow and temperature of the supply and return (delta T), the Belimo Energy Valve™ determines the thermal energy being consumed. The automatic flow control function then makes sure that only the required amount of energy is supplied, regardless of any differential pressure fluctuations.

Cautious Start – Instant Results

The first installation was chosen at manifold 1, which supplied a ward block, a residential building for staff, and a hotel for patients' families. A total of eight Belimo Energy Valves™ were installed in several zones and linked to the hospital's existing Building Management System (BMS) via the BACnet/IP interface. A test phase was first carried out in a transparent manner to identify and mitigate any potential risks before they became problems, which led to a win-win situation for all parties.

"It was astonishing to see how the true flow rates of the heating supply became visible in the BMS for the first time. Together with the facilities management team at the Ludmillenstift, we were able to identify the weak points in the hydronics system and take appropriate countermeasures."

Peter Meier, controls expert from August Brötje KG

The Belimo Energy Valves™ were put to the test from February to March and proved a complete success in the prevailing weather conditions of temperatures as low as −12°C (10°F). They dynamically controlled and monitored all hydronic manifold circuits by continuously measuring the flow and water temperatures, from the very first moment they were commissioned – problems with the heating supply had finally been localized and solved. From then on, all rooms and zones connected to manifold circuit 1 were supplied with precisely the right volume and correct flow of water actually needed for heating purposes, which considerably reduced the amount of water the hospital had to supply. The data the Belimo Energy Valves™ measured and recorded also provided an in-depth view of what was really happening in the system, leading to recommendations for further potential improvements for energy efficiency.

Next Steps for More Savings

The energy reports automatically generated from the Belimo Energy Valves™ are much appreciated by the Ludmillenstift because they provide a transparent view of the flow, temperature and overall coil performance. As an additional benefit, the hospital now uses the data from the hot water preparation for regulatory reporting to the health authority.

"Now the heat and cold generated is distributed sensibly and according to demand. In the heating circuit, for example, we have now been able to reduce the supply temperature to below 70°C (158°F), which saves a lot of money."

Matthias Jungedeitering, facility manager at Ludmillenstift

The Belimo Energy Valves™ provided performance data that led to additional measures, including the following improvements:

- The feeder pump of ward block B (Bettenhaus B) became obsolete and was removed;
- The two feeder lines of the medical center had already become obsolete and were removed;
- The hot water preparation in section E was reduced from 2 200 liters (581 gallons) to supply 700 liters (185 gallons);
- The hot water preparation for the Konvikt compound was reduced from 1 100 liters (291 gallons) to supply 350 liters (92 gallons).

The successful completion, informative results and data transparency of the test phase showed that the Belimo Energy Valves™ would be a perfect fit for the complete HVAC system in the hospital, including other application areas where thermal energy and volumetric flow had to be monitored and recorded.

The Ludmillenstift Hospital maintained comfort and energy consumption in 2020 at 2013/2014-levels despite having expanded floor space by 40 percent in the meantime.

Keeping Warm

On the heating side, the Ludmillenstift implemented further modernization projects, renovating manifolds 2 and 3 in the same way as manifold 1. The system operates at a seasonally dependent flow temperature of between 72 and 75°C (162 and 167°F), to supply the main heating and ventilation system, as well as 17 other hot water heating systems. The return temperature of the heating systems is set to 48°C (118°F) in winter and 60°C (140°F) in summer; the higher temperature in summer is due to the hot water preparation. As a result, all hydronic adjustments of the heating system were made in preparation to initiate the planning and integration of the cogeneration unit (BHKW) with 8 551 operating hours per annum into the network.

Staying Cool

The renewal of the HVAC system continued with the cooling system. All chillers are now connected to form a common system, enabling load-dependent cooling and making optimal use of available capacity by transporting excess cooling energy to other buildings. The Belimo Energy Valves™ use the monitored flow and temperature data to reliably control the flow volumes and cooling demand of the entire network. For example, when external temperatures are below 12°C (54°F) and the cooling circuit used for ventilation does not require any cooling capacity, the Belimo Energy Valves™ stay closed and the water is pumped to another area that has a cooling demand. The Belimo Energy Valves™ are also used in the cooling systems of large medical equipment such as MRI and CT systems, where they monitor and record the flow volume for reporting purposes.

Partnership for Energy Efficiency

Today, the HVAC system at the Ludmillenstift Hospital reliably supplies the entire site with the right amount of cooling and heating all year round, in an energy-efficient way. Between February 2013 to February 2014, the hospital used approximately one million kWh (1 GWh) less input energy in the form of natural gas than in previous years – equivalent to 202 tons of CO_2. The technological advances of the Belimo Energy Valve™ have allowed the Ludmillenstift to maintain comfort and energy consumption at the same levels in 2020 as it achieved between February 2013 and February 2014, despite the site expanding by 40 percent. At the same time, the data from the Belimo Energy Valves™ gives the facilities management team total transparency, allowing them to analyze potential problems far more easily and solve glitches independently, keep running costs low, and make easier, sound decisions on further investment into the system.

"Our work is easier now. If a problem occurs somewhere in a building, we can see straightaway on the BMS what is going on and react accordingly, even if we are on call and working from home. And now, when any expansions or new buildings are planned, we can provide concrete information as to whether, for example, additional cold or heat generators are required, or whether our existing resources are sufficient."

"We have collaborated many times with August Brötje KG and recently our work with them at the Ludmillenstift was recognized as best practice. It is now being used as a blueprint for how to deliver similar projects in the future."
Matthias Jungedeitering, facility manager at Ludmillenstift

Watch the video:

Expertise, partnership and smart valve control has once again proven to be a winning combination for reaching new heights of energy efficiency and savings. ■

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www.ekvy.ee

FINVAC – Finland
www.finvac.org

AICVF – France
www.aicvf.org

VDI–e.V. – Germany
www.vdi.de

ÉTÉ – Hungary
www.eptud.org

MMK – Hungary
www.mmk.hu

AiCARR – Italy
www.aicarr.org

AHGWTEL/LATVAC – Latvia
www.lsgutis.lv

LITES – Lithuania
www.listia.lt

AIIRM – Republic of Moldova
www.aiirm.md

TVVL – The Netherlands
www.tvvl.nl

NEMITEK – Norway
www.nemitek.no

PZITS – Poland
www.pzits.pl

ORDEM DOS ENGENHEIROS – Portugal
www.ordemengenheiros.pt

AIIR – Romania
www.aiiro.ro

AFCR – Romania
www.criofrig.ro

AGFR – Romania
www.agfro.ro

ABOK – Russia
www.abok.ru

KGH c/o SMEITS – Serbia
www.smeits.rs

SSTP – Slovakia
www.sstp.sk

SITHOK – Slovenia
https://web.fs.uni-lj.si/sithok/

ATECYR – Spain
www.atecyr.org

SWEDVAC – Sweden
www.energi-miljo.se

DIE PLANER – Switzerland
www.die-planer.ch

TTMD – Turkey
www.ttmd.org.tr

CIBSE – United Kingdom
www.cibse.org

Network of 26 European HVAC Associations joining 120 000 professionals

REHVA Office: Rue Washington 40, 1050 Brussels - Belgium • Tel: + 32 2 514 11 71 - info@rehva.eu - www.rehva.eu

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

Exhibitions, Conferences and Seminars in 2021

Conferences and seminars 2021

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

01-03 Dec	52nd International HVAC&R Congress and Exhibition	Belgrade, Serbia	http://www.kgh-kongres.rs/index.php/en/
08 -10 Dec	Driftskonferansen 2021	Oslo, Norway	https://www.driftskonferansen.no/
17-18 Dec	REFCOLD INDIA 2021	Online	https://www.refcoldindia.com/

Conferences and seminars 2022

29 Jan - 02 Feb	2022 Winter Conference and AHR Expo	Las Vegas, USA	https://www.ashrae.org/conferences/2022-winter-conference-las-vegas
17-19 Feb	ACREX 2022	Bangalore, India	https://www.acrex.in/
08-11 Mar	Mostra Convegno Expocomfort 2022	Milano, Italy	https://www.mcexpocomfort.it/en-gb.html
13-18 Mar	Light + Building	Frankfurt am Main, Germany	https://light-building.messefrankfurt.com/frankfurt/en.html
01 Apr	CIBSE Technical Symposium 2022	London, United Kingdom	https://www.cibse.org/technical-symposium/about
06-08 Apr	World Sustainable Energy Days 2022	Wels, Austria	https://www.wsed.at/
04-06 May	CIAR Lisboa 2022	Lisbon, Portugal	http://www.ciar2022.com/
04-06 May	IAQ 2020: Indoor Environmental Quality Performance Approaches	Athens, Greece	https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches
20-22 May	REHVA Annual Meeting 2022	Rotterdam, the Netherlands	https://clima2022.nl/
22-25 May	CLIMA 2022	Rotterdam, the Netherlands	https://clima2022.nl/
12-16 Jun	Indoor Air 2022	Kuopio, Finland	https://indoorair2022.org/
22–24 Jun	Ventilation 2022: 13th International Industrial Ventilation Conference For Contaminant Control	Toronto, Canada	https://www.ashrae.org/conferences/topical-conferences/ventilation-2022
22-23 Aug	BuildSim Nordic 2022	Copenhagen, Denmark	https://ibpsa-nordic.org/
16-19 Sep	ROOMVENT 2022	Xi'an, China	https://www.roomvent2022.com/
5-6 Oct	42 AIVC Conference	Rotterdam, the Netherlands	https://www.aivc.org/news/42-aivc-conference-october-2022-netherlands
20–21 Oct	The Fifth International Conference on Efficient Building Design	Beirut, Lebanon	https://www.ashrae.org/conferences/topical-conferences/the-fifth-international-conference-on-efficient-building-design

ASHRAE Celebrates Grand Opening of New Global Headquarters Building

Focus on the economic viability of transforming existing buildings into sustainable, resilient & healthy operations

On 18 November 2021 ASHRAE formally opened its new global headquarters building, following a ribbon cutting ceremony, attended by its board of directors, top building campaign donors, elected officials and local guests. The Society completed a $20 million building renovation project intended to prove the economic viability of a fully net-zero-energy (NZE) operation.

"The completion of this project is an important milestone for ASHRAE as a professional society and for the built environment worldwide," said 2021-22 ASHRAE President **Mick Schwedler**, P.E., Fellow ASHRAE, LEED AP. "Our investments in energy efficiency and sustainability will boost innovation within the built environment and inspire others to replicate our headquarters' project model. Our Society reimagined a pathway forward for existing building stock and is pleased to provide an example of the future of high-performance buildings."

The renovated, 6 200 m² building, situated on 44 500 m² of land at 180 Technology Parkway in Peachtree Corners, Georgia, is the culmination of a 10-month project, completed in October 2020, during the height of the COVID-19 pandemic.

"One could make the assertion that constructing a new net-zero-energy building from the ground up would have been much easier than renovating an existing building," said 2021-22 ASHRAE Treasurer and Former Building Ad Hoc Committee Chair Ginger Scoggins P.E., Fellow ASHRAE, CEM, CxA. "We decided that ASHRAE could make the greatest impact by showing others how to renovate an existing building with net-zero-energy as the focus, using our own standards and guidelines. ASHRAE is making net-zero-energy the 'new norm' in sustainable design and construction. It has been an honor to lead this historic project."

The building's grand opening comes at the conclusion of highly successful building campaign that raised more than $10.3 million in monetary donations and contributions of equipment and services from multiple ASHRAE members and thirty-three corporate donors. Top corporate building donors NIBE and Cisco were represented at the ceremony.

In addition to the 332 kW PV system, other innovative approaches incorporated in the building include:

- 18 new skylights and reconfigured window/wall ratio.
- Radiant ceiling panel system: This is used for heating and cooling & dedicated outdoor air system for outdoor air ventilation with enthalpy heat recovery.
- Overhead fresh air distribution system augmented with reversible ceiling fans in the open office areas and displacement distribution in the learning center.
- Six water source-heat pumps.
- A robust Building Automation System with remote access.
- Demand Control Ventilation (DCV): This will be used for high occupancy spaces in the meeting and learning center.

For more information about ASHRAE's global headquarters, please visit https://www.ashrae.org/about/ashrae-s-global-headquarters where you'll find photos, videos, case studies, project concepts, plans, etc. ■

EU BIM BUILDING RENOVATION COMPETITION
A BIM-SPEED initiative

BIM-SPEED Competition:

“EU BIM for Building Renovation” for design and construction professionals and students!

The partners of the Horizon 2020 project BIM-SPEED are pleased to announce the launch of their “EU BIM for Building Renovation Competition” which will take place from 21 June 2021 to 21 February 2022, bringing together multidisciplinary teams composed of professionals and students active in the design and construction sector.

The participants will present **building renovation design projects** that apply at least one of the BIM tools and methodologies developed by the BIM-SPEED partners (exclusively or in combination with other tools available on the market) and that deliver energy savings for the occupants, improve their comfort while at the same time reduce the duration and cost of the overall renovation process.

An independent jury will anonymously evaluate all projects submitted by the participants, with **final prizes to be awarded to the top 3 finalists in each category:** Professionals and Students.

The project and the competition concept

The EU-funded **project** “***BIM-SPEED – Harmonised Building Information Speedway for Energy-Efficient Renovation***” gathers 21 construction stakeholders from 9 different European countries, under the lead of the Technical University of Berlin.

BIM-Speed has developed a **set of BIM methodologies and tools aimed at facilitating the deep**

The BIM-SPEED project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 820553.

building renovation process for all actors in the design and construction chain. All integrated into a single platform, the BIM-SPEED solutions are designed to reduce the cost and duration of the renovation process while improving the energy performance of the building.

The organisation of the EU-wide BIM competition involving all disciplines (architects, HVAC engineers and construction firms) is considered a key moment of the project, to trigger the **first market replication of BIM-SPEED innovations in BIM-based building renovation projects**.

Who can participate?

The EU BIM for Building Renovation Competition is a **free-of-charge competition** split in two categories, one for design and construction professionals and another for students.

- The participation is open to **multi-disciplinary teams** consisting of at least two members from different professional/educational backgrounds (e.g., civil engineer, architect, HVAC engineer, contractor, etc.).
- The competition is open to **all nationalities.**
- **There is no limitation on the number** of members in each team, nor on the number of disciplines represented in each team.
- Each team must use at least **one of the BIM-SPEED tools** that can be found in the **BIM-SPEED platform**.
- **For the professionals**, the team will have to work on the renovation design of a residential building project. The project should be in the design phase.
- **For the students**, the team will have to use a renovation design project from one the BIM-SPEED demonstration sites to be provided by the competition team after the registration. At the time of the registration, the participants must be enrolled in an academic programme of an accredited educational institution.

YouTube introductory video

Timeline

Registration for the competition was launched on 21 June 2021 and remains open until **14 February 2022**.

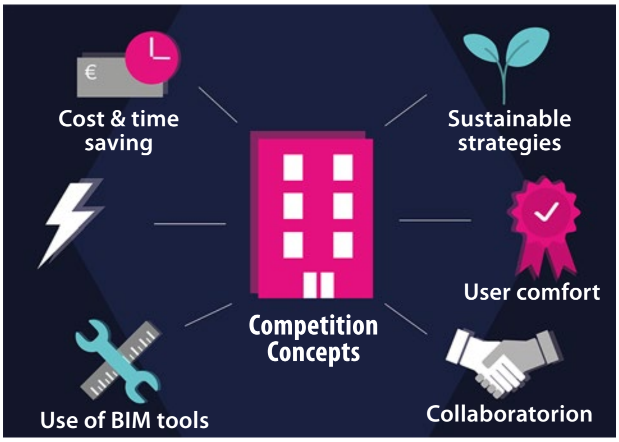
Evaluation process and the BIM-SPEED Jury

All projects submitted correctly by the participants will be **judged in anonymity by an independent Jury**, composed of top-notch experts from the fields of engineering, architecture, and construction:

- András Rónai (Mechanical Engineer, M.Sc. HVAC+R and BIM – Óbuda Group, MMK - Hungary)
- Chiara Dipasquale (Expert in Innovation and Sustainability, Volksbank - Italy)
- Olga Venetsianou (Architect PhD, MA in Digital Arts ASFA - Greece) delegate from the Greek Association of Architects Diplomés SADAS-PEA to the Architects' Council of Europe BIM Working Group.
- Tomi Henttinen (CIO, Architect SAFA - Finland) delegate from the Finnish Association of Architects SAFA to the Architects' Council of Europe BIM Working Group.
- Filippo Lodi (Head of Innovation and Knowledge Management, UNStudio – The Netherlands)

All valid entries will be assessed by the jury members based on the following evaluation criteria:

- Proven time and cost savings resulting using the BIM-SPEED platform
- Application of sustainable strategies in the renovation project
- Addressing issues and strategies related to user comfort and health
- The use of participants' own BIM tools and software in combination with the BIM-SPEED tools and BIM-SPEED platform
- Level of team collaboration within the BIM-SPEED platform



Prizes and awards

For both the professional and student categories, the following prizes will be awarded to the top 3 finalists in each category:

Professionals:

- Free licenses to use BIM-SPEED platform and BIM tools
- EU wide exposure through BIM-SPEED dissemination channels and umbrella organisations networks covering the widest professional coverage
- Possibility to present the winning project to the Architects' Council of Europe and its Member Organisations
- Presentation of their project during the European Sustainable Energy Week 2022 and/or Sustainable Places 2022
- Participation and contribution to the REHVA's BIM task force of the Technology and Research Committee
- Featuring an article/interview on mainstream academic media, such as BIM Today or Build UP

Students:

- EU wide exposure through BIM-SPEED dissemination channels and umbrella organisations networks covering the widest professional coverage
- Presentation of their project during the European Sustainable Energy Week 2022 and/or Sustainable Places 2022.
- Mentorship on student's thesis with UNStudio's BIM experts (suitable for architects)
- Presentation of their project at UN Studio
- Presentation of their project at REHVA Brussels Summit 2022

The prizes may be exchanged with another prize of the same value / similar characteristics if circumstances demand it. ■

Contacts

For all detailed information on the competition terms and conditions, please visit the BIM-SPEED website: https://www.bim-speed.eu/en/competition

For any enquires and questions about the competition, reach out to the BIM-SPEED competition team at competition@bim-speed.eu

IAQ 2020 CONFERENCE

4-6 May 2022 | Wyndham Grand Athens

Organized by ASHRAE and AIVC
Indoor Environmental Quality Performance Approaches Transitioning from IAQ to IEQ

The pandemic has given us a new understanding of what indoor environmental quality is, and we now have an opportunity to discuss these important issues in person.

"As the world recovers from COVID, there is no better time to focus on indoor environmental quality writ large" said conference co-chair Max Sherman. "It is an opportune time to discuss a paradigm shift to built environments that mitigate the transmission of epidemic diseases and more broadly support the wellbeing of occupants."

– Bill Bahnfleth, co-chair

Keynote Speakers

- **Philomena Bluyssen, PhD**, Professor of Indoor Environment, TU Delft
- **Richard de Dear, PhD**, Director, Indoor Environmental University of Sydney
- **Mariana Figuiero, PhD**, Rensselaer Polytechnic Institute
- **Benjamin Jones, Dr**, University of Nottingham
- **Cath Noakes, PhD**, University of Leeds
- **Stephanie Taylor, MD**, Taylor Healthcare Consulting

Interactive Sessions, Global Networking

The conference features six renowned, international Keynote Speakers. Topical and timely Workshops (see examples below) comprised of hand-picked experts make for can't-miss sessions. Papers, Workshops and Keynotes and other sessions are presented live, and one-third of the sessions are livestreamed, connecting virtual and in-person attendees for a worldwide discussion on topics.

Workshops (Partial List)

- CO_2, Human Bioeffluents, VOCs, Ventilation and Human Performance
- Ventilative Cooling: New Design Approaches, Cases and Lessons Learned
- Addressing IEQ: Developing an Integrated Management Framework Together
- Impact of Building and Ductwork Airtightness on IEQ
- Crucial Role of Well-Performing Ventilation Systems in Pandemic Control
- Knowns and Unknowns: Ventilation, Air Distribution and COVID-19

Vaccinated and looking for a great place to talk with your IEQ peers?
Mark your calendar for IAQ 2020 in Athens and participate in the vanguard event on IEQ.

ashrae.org/iaq2020

The congress venue: Rotterdam Ahoy Convention Centre.

CLIMA 2022 UPDATE: REHVA's 14th HVAC World Congress is ready to go

From 22 until 25 May 2022, TVVL (Dutch Society for Building Services and Technology), and the Technical Universities of Delft and Eindhoven are organising the 14th REHVA HVAC World Congress CLIMA 2022 in Rotterdam. "Although times are still uncertain due to the Covid-19 pandemic, all the conditions have been met to make the congress a great success. We have put together a wonderful preliminary programme. In terms of content, we are working on a line-up of top speakers, innovative workshops and high-profile presentations. In addition, we will provide an unparalleled social and cultural programme."

Atze Boerstra, congress president and **Lada Hensen Centnerová**, one of the two vice presidents, exude confidence in their update on the organisation: "Both the programme and organisational matters for welcoming all the guests are well on track. Our core objective is to make CLIMA 2022 the most versatile and diverse congress ever organised for REHVA. Those that attend the congress will notice this in its content, form and also in the supporting programme of social events and activities. Apart from that, it goes without saying that we take all the Covid-19 measures we deem necessary - and that is more than our government prescribes - to ensure the safety and health of all the guests", says Atze Boerstra.

Opening keynote speech

During the interview, in November 2021, Boerstra and Hensen Centnerová reveal that the programme is shaping up. It will be highly engaging for academics specialized in building technology as well as for

First three CLIMA 2022 keynote speakers to be announced: Prof. Lidia Morawska, Prof. Arsen Melikov and Marjan Minnesma.

representatives of manufacturers, installers, consulting engineers, HVAC system designers, property developers and facility managers. The 14th HVAC World Congress starts on Sunday with special excursions in Rotterdam and an exciting opening event in the afternoon. To this end, **Marjan Minnesma** will give a stimulating opening keynote speech. Marjan is director of the Dutch Urgenda Foundation, an organisation that successfully took legal action to force the Dutch government to take faster and more drastic measures to combat climate change. She is the most influential person in the Netherlands when it comes to putting and keeping energy transition on the agenda.

Five congress themes

"The three main congress days each have one or two themes. This does not mean that on these days we only schedule sessions and meetings around that specific theme, but they are the main part. The keynote speeches are also related to the themes of that day," says Lada Hensen Centnerová. On Monday, the central theme is Health & Comfort, on Tuesday it is Energy and Learning & Education, and on the last day, Wednesday, Digitisation and Circularity are the main focus.

COVID & ventilation

Many speakers have been approached and some have already been booked. This is especially true for the health & comfort day. Boerstra feels very enthusiastic about monday-keynote speaker professor **Lidia Morawska**. She is the director of the International Laboratory for Air Quality and Health at Queensland University of Technology (QUT). She was recently named one of the 100 most influential people worldwide by TIME Magazine for her publications and activities on air quality and the transmission of infectious diseases. Lidia Morawska will give a keynote speech on Monday 23rd May about the airborne route transmission of the Coronavirus and the importance of ventilation in the issue at hand. In her presentation she will explain, among other things, how she, in cooperation with colleagues, managed to convince the World Health Organisation (WHO) to include ventilation as a standard Covid measure," Boerstra says. "After Lidia, Professor **Arsen Melikov** of the Danish Technical University will advocate a ventilation paradigm shift; he will explain how he thinks the COVID pandemic will change the way we ventilate our buildings in the future. Arsen is a specialist in fluid mechanics, air distribution, indoor climate and heat- transfer. In the past he has been involved with several REHVA projects and he for example is co-author of REHVA Guidebook 19 on "mixing ventilation" and Guidebook 23 on "displacement ventilation". As for the other keynote speakers, they will be announced through the congress website in the coming period; periodically check out www.clima2022.org or subscribe to our newsletter via the website."

Many abstracts for a diverse programme

Lada Hensen Centnerová: "So far, we have received around 600 abstracts from authors in 44 countries. These abstracts and the papers resulting from them form the basis for the very diverse scientific programme at our congress. Also, quite a few people sent in ideas for workshop subjects. We received the most abstracts for the theme Energy. It is obvious that the energy transition is generating a huge amount of research internationally, which in turn results in much zest for presentations and workshops on this topic." "On Tuesday, we deliberately linked the Energy theme to Learning & Education, precisely because the energy transition and decarbonisation poses enormous challenges for the installation sector. There is hardly a country to be found that is not dealing with a shortage of skilled workers. Therefore, to us, it is vital to come up with inventive ways to train enough new people (quickly), especially through innovative learning pathways. We want to explicitly discuss this with everyone at the congress," says Atze Boerstra. "But we also consider a theme such as circularity crucial because this topic will have decisive influence on the future of our profession. Fortunately, we have received some nice abstracts thereto as well. Apart from that, we will in any case organise a dedicated workshop on 'circular building technology'." He underlines that the definitive programme will be compiled by the Executive Scientific Committee led by **Laure Itard** and Lada Hensen Centnerová, the two vice presidents. Further we have The International Advisory Board (IAB) which plays an essential role as a sounding board. The IAB consists of several European experts who have experience in organising large-scale, international scientific events.

Digitisation, Health & Comfort

Not all abstracts relate to the Energy topic. "As pointed out, Energy, with 240 abstracts, is the front runner. But a topic like Digitisation is also quite popular with almost 100 abstracts. The theme Health & Comfort generated almost 200 abstracts," says Hensen Centnerová. "The experts who submitted the abstracts are now preparing their papers. On 3rd January, all papers should be in, after which we will start to review the submitted papers mid-January with a group of about 200 reviewers. Around mid-February, we will let the submitters know whether we accept their paper "as is" or whether a revision is necessary." Atze Boerstra adds: "But of course the congress is not just for these submitters of abstracts and papers. We believe that this event is also very worthwhile if you do not make

CLIMA 2022

REHVA ANNUAL MEETING*

	FRIDAY 20 May	SATURDAY 21 May	SUNDAY 22 May
7:30			
8:00			
8:30			
9:00			
9:30			
10:00		COMMITTEE MEETINGS*	EXCURSION ROTTERDAM
10:30			
11:00			
11:30			
12:00		LUNCH	
12:30			
13:00		COMMITTEE MEETINGS*	REHVA GENERAL ASSEMBLY* & REHVA COURSES
13:30			
14:00			
14:30			
15:00	COP MEETING*		REGISTRATION
15:30		BREAK	
16:00	REHVA BOARD MEETING*	COMMITTEE MEETINGS*	CLIMA OPENING EVENT KEYNOTE
16:30			
17:00			
17:30			
18:00			WALKING DINNER
18:30			
19:00			
19:30			
20:00		REHVA DINNER AND PROFESSIONAL AWARDS*	
20:30			
21:00			
21:30			
22:00			
22:30			

Times and order of items might be changed at a later stage if necessary.

a presentation yourself. If you come to Rotterdam in May 2022, there will be plenty of room for interaction between practitioners and academics, for instance. The congress offers a unique opportunity - after two years of contact via Zoom, Teams and other digital ways - to finally share knowledge in the field of building technology in real live; I think we are all very much ready for that, to finally meet face to face again."

PRELIMINARY PROGRAM

CLIMA 2022 14TH HVAC WORLD CONGRESS		
THEME HEALTH & COMFORT	THEME ENERGY | LEARNING & EDUCATION	THEME DIGITIZATION | CIRCULARITY
Halton	DAIKIN	
MONDAY 23 May	TUESDAY 24 May	WEDNESDAY 25 May
MORNING SPORT	MORNING SPORT	MORNING SPORT
REGISTRATION	REGISTRATION	REGISTRATION
KEYNOTE	KEYNOTE	KEYNOTE
	PARALLEL SESSIONS WORKSHOPS	PARALLEL SESSIONS WORKSHOPS
BREAK	BREAK	BREAK
PARALLEL SESSIONS WORKSHOPS	PARALLEL SESSIONS WORKSHOPS	PARALLEL SESSIONS WORKSHOPS
LUNCH	LUNCH	LUNCH
KEYNOTE	KEYNOTE	PARALLEL SESSIONS WORKSHOPS
PARALLEL SESSIONS WORKSHOPS	PARALLEL SESSIONS WORKSHOPS	KEYNOTE
		CLIMA CLOSING EVENT
BREAK	BREAK	
PARALLEL SESSIONS WORKSHOPS	PARALLEL SESSIONS WORKSHOPS	
EXHIBITION	EXHIBITION	EXHIBITION
REHVA PRESIDENTS DINNER* AND STUDENT EVENT	CONFERENCE DINNER**	

* upon invitation only ** tickets possible to buy during registration

Brand new congress centre

The congress is being held in the brand-new, Rotterdam Ahoy Convention Centre (RACC), a contemporary and sustainably designed congress centre in the south of Rotterdam. "The beauty of it is that this accommodation offers many varied rooms and locations where we can organise presentations as well as workshops or other interactive sessions. Furthermore, the floor plans are such that we can create a perfect place for sponsors to present themselves and for visitors to meet each other between sessions."

"Also, very important to me," Boerstra continues, "is that the rooms are already quite "COVID-proof", with high ceilings and well-designed ventilation systems. Moreover, we will be monitoring air quality, specifically the CO_2 concentration, during the congress anyway. We will have to wait and see what the government requirements will be next spring, for instance regarding individual COVID entry pass checks. Nevertheless, we do expect that in May there won't be any super strict COVID restrictions anymore."

Excursions, dinners and sports

In addition to all the sessions in the RACC, the organisation also arranges for various social and cultural events. "On Sunday, we will start with a couple of excursions in Rotterdam. It is a city with a lot of impressive architecture, which we will definitely incorporate. But Rotterdam is also known as a leading international port, which also makes for a fascinating excursion. We believe that this will provide a wonderful opportunity for the visitors arriving during the weekend to get acquainted with the city in a pleasant way. By the way, the REHVA Annual Meeting will be held on Saturday and Sunday prior to the congress. In principle, this is only open to invited guests and REHVA committee members. But they are also invited to join the Rotterdam excursions on Sunday morning.

In addition to the excursions, the organisation chooses to offer sports activities in the morning before the programme starts each regular congress day. Participants should therefore also bring their sportswear. "A healthy mind in a healthy body makes sure you get through the knowledge-intensive days. In the evenings there are several dinners for which one can register separately, with a gala dinner on Tuesday 24th May. Together with ISSO (the Netherlands Building and Building Services knowledge organisation), we also organise technical excursions to special projects in the area. On top of that, Young REHVA also organises a specific social activity for young congress participants on Monday night," says **Hensen Centnerová**.

Early bird discount until 16th January

In order to give as many people as possible the chance to attend the congress, an early bird discount applies until 16th January, which means that everyone can buy a ticket at a 200 euro discount. And exclusively for bachelor and master students, there is a student ticket that can be purchased at a huge discount also until 16th January. All prices can be found on the website (www.clima2022.org). Furthermore, the organisation advises potential visitors - if they attend several days - not to wait too long with booking a hotel. There are several international events in Rotterdam around the same time, so there may be a tight supply of hotel rooms, especially when May approaches. On the website, the organisation recommends specific, comfortable hotels in the city with special congress arrangements.

First hybrid event

The organisation is confident that REHVA's 14th HVAC World Congress will be a great success. The signs are promising. Several renowned international companies, including Carrier, have now officially signed on as sponsors. "Everything indicates that this congress can develop into a very attractive and, above all, very diverse event. For instance, this congress will also be the first real hybrid CLIMA Congress. This means that we will also make part of the sessions available online and share presentations via a digital, dedicated congress platform. Part of it can be watched live from anywhere in the world and part of it can be watched later," Boerstra says. "We will announce more on which sessions will be broadcast and how we will provide digital access next spring. But bear in mind that this method will never beat actually attending the sessions, with old-school interaction and networking moments with colleagues and all. So, don't delay and register today via the website. Don't miss this unique opportunity to attend, May 22th - 25th, the CLIMA 2022 congress in our beautiful city of Rotterdam." ■

More information on the programme, tickets & other facilities can be found on www.clima2022.org. If you have any questions about the congress, please send an email to info@clima2022.org.

CLIMA 2022

EYE ON 2030 | Towards digitalized, healthy, circular and energy efficient HVAC

REHVA 14th HVAC World Congress

22nd - 25th May, Rotterdam, The Netherlands

CLIMA 2022:
Digitization of the installation sector: Towards predictive smart buildings!

JAN KERDÈL
Senior consultant,
Kerdèl Business Development

PIETER PAUWELS
dr. Ir.-arch,
TU Eindhoven

The installation sector is digitalising! As in the rest of the building industry, systems digitization and innovation have an increasing impact on the HVAC and installation sector. Far-reaching evolutions towards 'digital twins' and 'smart buildings', including predictive maintenance strategies and centrally linked systems, mean that the installation sector faces the next wave of digitization, or rather an AI (r)evolution.

Partly for this reason, 'digitization' is an important topic at the upcoming REHVA World Congress CLIMA 2022, the leading international scientific congress in the field of heating, ventilation and air conditioning (HVAC). The congress is organised every three years by one of the member associations of REHVA. The upcoming edition will be organised by TVVL in the Netherlands, in cooperation with Delft University of Technology and Eindhoven University of Technology. In addition to Digitization, CLIMA 2022 also covers the topics of Energy, Circularity, Health & Comfort, and Education.

How will current demands and influences evolve until 2030? What insights will we gain? How do the topics relate to each other? Will they reinforce each other or slow each other down? And how does the impact of climate systems relate to the building process and other influencing factors? What kind of teaching and learning is needed? With these questions in mind, CLIMA 2022 will have its BYE ON 2030.

Digitization is, therefore, an important topic at CLIMA 2022. However, typically digitization is not a stand-alone topic: it is often part of larger issues. No doubt other conference topics will use digitization to carry out complex research or solve certain issues. Digitization also plays an undeniable role in the design and operation of installations. And here, too, it typically serves specific purposes (e.g. system optimisation). In the following we provide a brief overview of the most important developments of this form of digitization for the HVAC sector.

Digitization

Digital solutions that stimulate the energy transition in the built environment are a crucial topic. In many companies and organisations, solutions in the field of (predictive) digital twinning, data-driven smart buildings, data management, and continuous commissioning are high on the agenda.

Nowadays, digital solutions must be able to handle a wide range of HVAC systems and be self-learning in detecting trends and process deviations. While current systems often concentrate on monitoring, it is becoming clear that the future lies in predictive planning of interventions based on recommendations from an AI system.

It is expected that in an actual, physical building (physical twin in **Figure 1**), several sensors and actuators will actively monitor data. In this environment, monitoring and surveillance are therefore carried out in a data-driven manner. On the other hand, the digital side means a virtual model (digital twin) that is usually strongly model-based. An information model and/or prediction model (e.g. neural network) is digitally available, including a number of simulated scenarios. These are compared to the input from the data-driven physical twin. Such comparisons make it possible to work on prediction, fault detection and self-learning (**Figure 1**). In this way, model-based and data-driven approaches are combined, making for a powerful potential resource and important AI research topic, that can also be employed for HVAC systems.

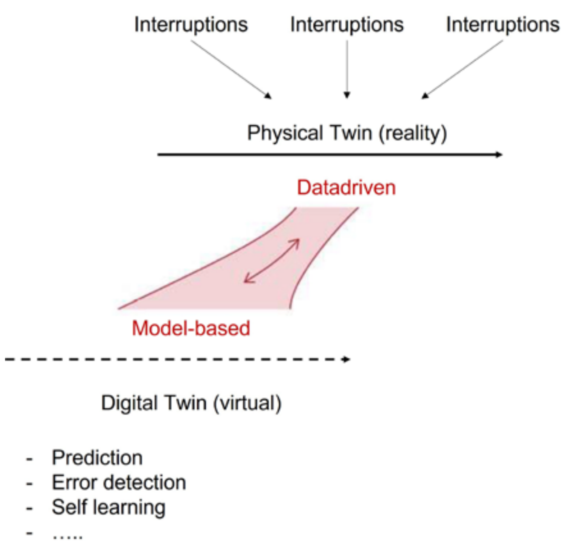


Figure 1. CLIMA theme Digitization.

The above-mentioned ambitions put the evolution towards dynamic HVAC systems under digitization pressure. Stand-alone or integrated solutions are possible, and a system and environment as shown in **Figure 1** is certainly achievable and already a reality in several places. However, there are some important preconditions or even obstacles for placing such systems on the market in a scalable way (performance, cost, speed):

- System architectures must be able to cope with large-scale implementation with various hardware (wired and wireless solutions, IoT, cloud solutions, blockchain technologies), and at the same time, they must be flexible to continuously accommodate change (additional sensors, new users, change of provider, etc.).
- In addition to these large-scale and flexible infrastructures, the world of smart buildings also requires monitoring strategies that bridge the gap between building automation and control systems (BACS) and building information modelling (BIM) tools.
- Also, the recent COVID pandemic has led to research into digital-oriented design, monitoring and control of ventilation systems related to general comfort and health. This includes machine learning (ML) algorithms for fault detection and diagnosis, pattern recognition and anomaly detection: training a model based on sensor data; model-based prediction; intervention in the building system.

With the above evolutions in the HVAC field, the lifecycle costs of a building are expected to be easier to control, the comfort of the occupant or user will improve, and the system will be easier to monitor and maintain.

Building management systems for energy performance innovations are a prerequisite for better performing buildings. These are buildings that adapt to the changing climate, provide optimum comfort in an intelligent manner and, ideally, also produce energy (net positive buildings). The innovations are primarily expected from the building management system (BMS), which maintains a central reference point for a specific building (model-based and data-driven - **Figure 1**). Based on this, a building management system can actively carry out interventions in the building.

Positive energy should also become possible in the field of energy management for buildings. Solutions in this direction are expected in the areas of (predictive) digital twinning and data-driven smart buildings, in which building performance is monitored and displayed in real time through dashboards that relate building data and measured values (time series). Recent developments link this to information models and metadata standards for data management such as the Industry Foundation Classes (IFC), Linked Building Data (LBD), Brick, and Haystack.

The latest developments are:

- Energy transition measures for existing buildings
- Net positive building developments
- Building performance monitoring with digital twins
- Data-driven smart buildings: monitoring based on time series data
- Linked building data for digital twinning (LBD, Brick, Haystack, etc.)

Design for automation: from SIM models to BACS

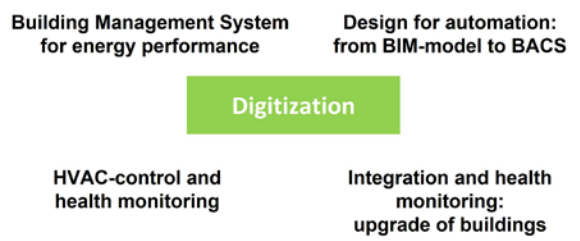
Typically, there is a Building Information Model or BIM model available for modern buildings. Such a semantic 3D model allows architects, engineers and building professionals to plan, design, build and manage a building better and more efficiently. However, the BIM model is usually limited to the design and construction phase. This means that valuable information in the operational phase is either collected by another dedicated management system or (not infrequently) lost.

Research and development are trying to close the gap that still exists between BIM and Building Automation and Control Systems (BACS). The information available in the BIM design model could form an excellent basis for the start-up and design of the control technology in a BACS. Since the orientation of the building, the use of space, the intended use and the desired comfort classes are known, SIM routines could be developed to suggest BACS solutions and control strategies. Monitoring strategies should follow to maintain quality and control costs throughout the lifecycle. Hereby, information from SIM models can become a basic reference for cost control over the lifecycle of a building.

The latest developments:

- BIM for indoor climate control design
- Building automation design from BIM environments (BIM & BACS)
- Automation of maintenance and monitoring: self-sufficient buildings
- From data to decision-making: standards and best practices
- Facility management design
- Digitization of design and engineering of HVAC installations

HVAC control and health monitoring



Particularly after the outbreak of the COVID-19 pandemic, much research has focused on rethinking ventilation strategies and their design, monitoring and control. This leads to an intensive research project on the role of ventilation in comfort and health monitoring in a building. Within CLIMA 2022, several contributions are expected around the digitization-focused research on the design, monitoring and control of ventilation in a building in case of a pandemic.

Furthermore, the use of AI techniques for this purpose is encouraged, in particular the use of AI algorithms for fault detection and diagnosis, but also pattern recognition and anomaly detection in building use and HVAC systems. It is important to use these digital technologies for critical control and risk mitigation strategies, rather than signalling every minimal error or deviation within tolerances.

Rather than displaying all available information, the key question is how these techniques can be used to proactively predict where and how systems will fail and how this risk can be mitigated.

The latest developments are:

- Ventilation strategies in pandemics (design, monitoring, control)
- Health and comfort monitoring
- Pattern recognition and anomaly detection in building use
- Algorithms for fault detection and diagnosis
- AI for critical control and risk mitigation strategies (proactive vs. reactive)

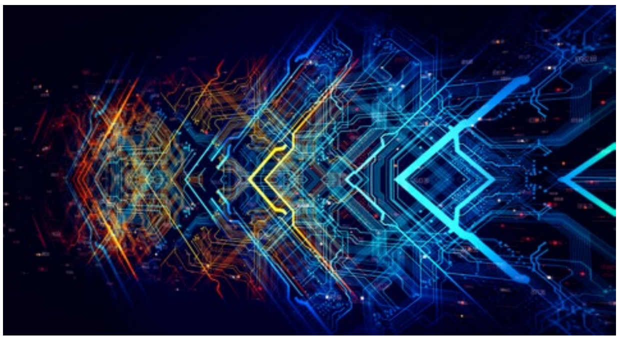
Integration in existing buildings: Upgrade of buildings

Buildings and the energy infrastructure are undergoing a transition to a carbon-free society by the year 2050 (Paris Agreement 2015). The approach differs from country to country: in countries with a temperate climate, the building envelope is often of insufficient quality and requires renovation or upgrading. In addition, low temperature (LT) heating and cooling solutions are often implemented, even though they are more sensitive to failures. In order to deploy these systems appropriately and make renovation possible, large-scale monitoring at an affordable cost must be developed to continuously monitor commercial buildings.

Research on this topic typically focuses on the process of building improvement and poses new challenges for building management; this topic is thus also expected to be discussed at CLIMA 2022. Solutions must be able to handle a wide range of HVAC systems and be self-learning in detecting trends and process deviations. In renovating and implementing systems, system architectures must include large-scale implementation. Both wired and wireless solutions are possible, and in the case of implementing loT in a renovated building, a professional approach to loT (loT as a quality standard) is recommended (lowest risk level).

The latest developments are:

- loT and industrial loT
- Cloud solutions for building management (e.g. Kubernetes, MS Azure)
- Security, control and authorisation in cloud-based BMS systems
- Edge computing: on-device computing for building automation
- LoRa and LoRaWAN: training connected and loT devices
- Local area networks, WiFi networks and 5G networks in embedded infrastructure



Terminology:

- Digitization: Converting information into a format (usable by a computer system)
- Digital Twin: Digital representation of the actual control process of an installation or system. It is developed simultaneously with the actual model. Differences in the process may indicate errors in design, construction and use (operation). The model can also be used to simulate an extension or modification.
- Building Energy Management System (BEMS): Energy registration and management system. A minimum implementation is prescribed by law for gas consumption >25.000 m3 and/or an annual electricity consumption of 50,000 kWh.
- Building Automation & Control System (BACS): A system for the automation (regulation and control) and technical management of installations in a building also called building management system (BMS).
- Building Information Modelling (BIM): A system for setting up and managing information for a construction project.
- Smart Building: A building that meets the requirements by means of independent intelligent control of the technical installations. Systems take into account both internal and external factors. Self-learning and cooperating systems form the basis. Control mechanisms monitor efficiency, operation, safety, energy and energy grids. For the user, specific user requirements are (explicitly) met.
- Brick and Haystack: Data analysis in buildings in relation to energy consumption and/or maintenance costs plays a major role in optimisation. Brick and Haystack form a semantic bridge between the HVAC designs and the data analyst.
- Linked Building Data: Method to make building data available on the web as semantically meaningful linked data.
- Fault Detection and Diagnosis (FDD): A method (originally from the chemical industry) to identify abnormal situations.
- The coincidence of several (sometimes many) circumstances can approach, or lead to, a situation that results in process deviation, risk or cost overrun. The system diagnoses and advises.
- Machine Learning (ML): A technology that combines data analysis and the use of algorithms. An ML system learns from the results of prior decisions or calculated values. ML is part of Al technologies.
- Artificial intelligence (Al): An imitation of human intelligence. ■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