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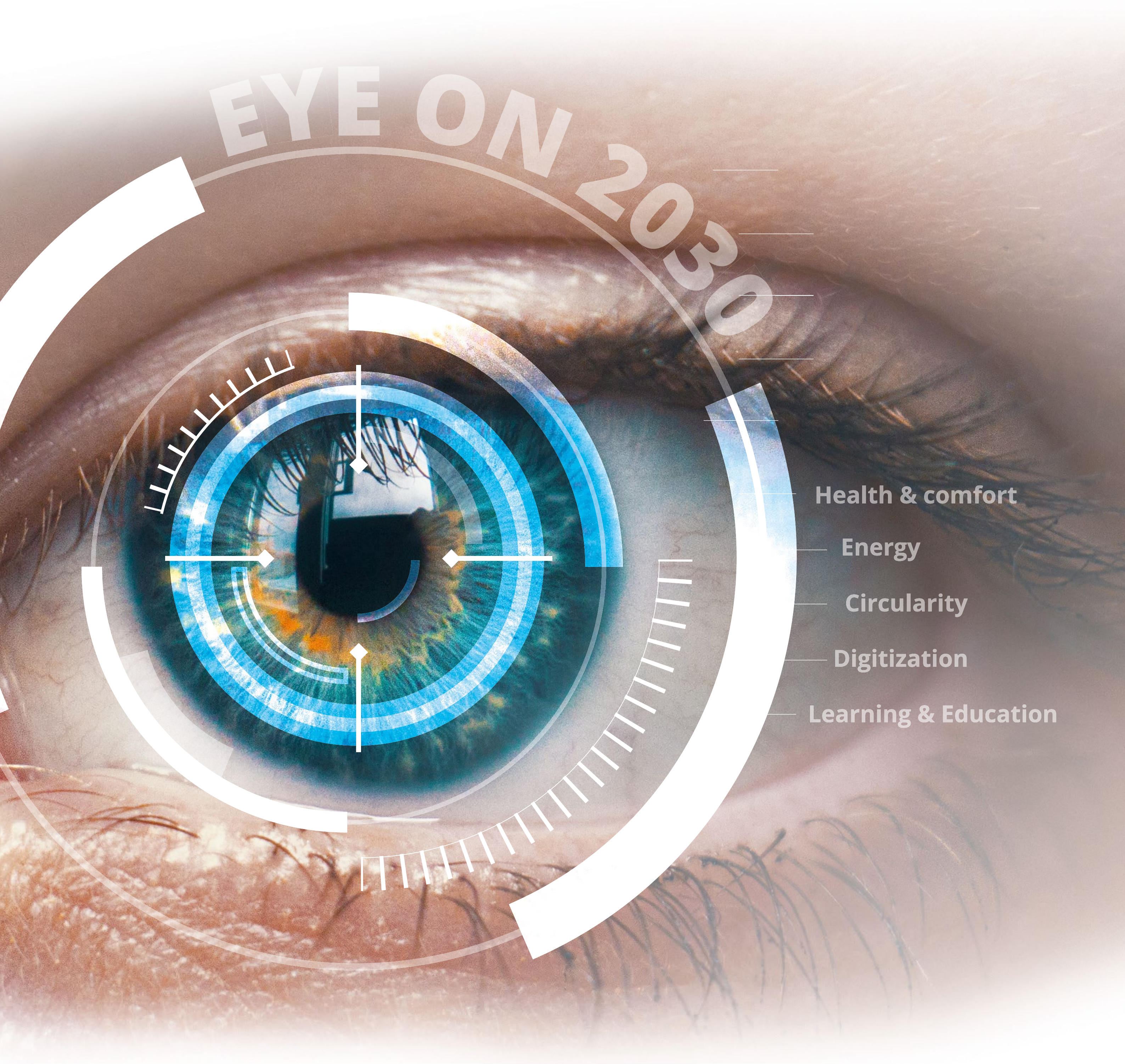

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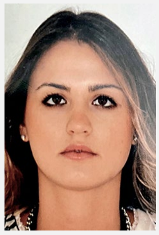
EU trajectories and opportunities for HVAC sector



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The achievement of a future post-carbon society asks for a careful management of a series of transitions, topic that is of fundamental importance today. Such transitions are not only energy- and environmental-related, but involve also economic and social domains, engaging all sectors in a process that will lead the world towards a green future.

The European direction is clear and well defined in two documents of vision - the Energy Roadmap 2050 and the European Green Deal – which allow to define the prospects for the sustainable development of our European Union, also to recover from the COVID-19 emergency period. Among the pillars of the future transition, in which it is interesting to mention hydrogen and renewables, the fundamental role of buildings and of their renovation is well-recognized. Specifically, the rationalisation of energy consumption and the introduction of technological innovation to increase the energy efficiency of buildings represent key factors for the implementation of community policies, always keeping in mind the need to guarantee high-quality comfort and health conditions within occupied spaces. The technological innovation in the building sector is exploited on three levels: the reduction of buildings energy demands required by the energy metabolism of the buildings, the use of efficient technological solutions to improve the overall buildings energy efficiency, and the integration of renewable sources.

In this scenario, the HVAC sector plays a key role in defining effective research and development roadmaps for the industrial sector, as well as in rendering such innovative and promising technologies market-ready. The industrial sector, nowadays, is able to provide high-quality and efficient products, which can drive the sustainable transition of the building sector. Moreover, new approaches are needed to value investment decisions and technological solutions. In this sense, it is interesting to mention that we started from a design approach that encouraged the introduction of the cost-optimal concept to move to the cost-benefit approach, which allows to include into projects evaluation also the related externalities and their effects on society, well-being and people's health. This approach can be considered as more in line with the transition we are living, allowing to consider the effects that our choices will have on a new society, the post-carbon one. ■

Evaluation tools: cost-optimal and cost-benefit analysis

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Starting with a review of the current implementation state of the cost-optimal methodology in European Member States, this paper offers an outline of the cost-benefit analysis and future developments. It shows how the overall goal of a zero-carbon building stock by 2050 can be accomplished by synergic efforts involving a multi-dimensional approach.

Keywords: Energy Performance of Buildings Directive (EPBD), cost-optimal methodology, cost-benefit analysis, energy efficiency, energy performance requirements, human-centric approach, zero-carbon society

The recently revision of the Energy Performance of Buildings Directive (EPBD) of 2018 [1] is an essential component of the European strategy to achieve a zero-emission and fully decarbonised building stock by 2050. The new proposal reiterates the key role of the cost-optimal methodology introduced in the EPBD [2] and, at the same time, stresses the importance to improve the quality of life, health and performance of building occupant, and introduced the Smart Readiness Indicator, the calculation of which is based on eight impact criteria. Two of these criteria, indeed, are comfort and health. In this scenario, resulted essential to take into account not only the improvement of building energy efficiency, but also the indoor environmental quality and the interaction between the building, its systems and the occupant. Consequently, concerning the analysis of the built environment the new subject of the investigation is the building-systems-occupant complex. In this framework, the challenge in renovation planning is the definition of proper metrics and tools able to take in consideration the multiple benefits related to the renovation itself. If the cost-optimal methodology is built on two indicators (an energy one and a financial one), considering the occupant-centred investigation, energy, financial, environmental and socio-economic impacts are needed to be taken into account in the decision-making process at the foundation of energy planning. Cost-Benefit Analysis (CBA) is an analytical tool that can be used in energy projects decision-making process in order to assess design alternatives from a social point of view. In theoretical terms, the CBA introduces the economic dimension in the financial analysis, allowing positive and negative externalities to be examined in the assessment. This paper offers a review of the current state of the cost-optimal methodology implementation and outlines the CBA as a possible development.

Cost-optimal methodology

Despite wide debated topics arisen around the cost-optimal approach [3], it is not questionable that its introduction signed an important milestone towards the renovation of the existing building stock and a substantial transformation towards a zero-carbon society.

Cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle (i.e. 20–30 years), where the lowest cost is determined taking into account the building use and category, energy-related investment costs, maintenance and energy, and operating costs. Member States set minimum requirements for the energy performance of buildings and building elements with a view to achieving the cost-optimal balance between the investments involved and the energy costs saved throughout the building lifecycle. Member States use that framework to compare the results with the minimum energy performance requirements in force and, in case of significant discrepancies higher than 15%, justify the difference or plan appropriate steps to reduce the gap.

According with the latest cost-optimal reports provided by Member States in 2018–2020, the average cost-optimal level is 80 kWh/(m²·year) for new residential sector, 140 kWh/(m²·year) for the new non-residential, 130 kWh/(m²·year) for existing residential and 180 kWh/(m²·year) for existing non-residential. About the gaps with current energy performance requirements, few Member States provided gaps greater than 15%, and the picture is more critical for new multi-family buildings.

Reaching cost-optimal levels of minimum energy performance requirements challenged Member States [4] also in the light of the heterogeneity of European countries in relation to the variability of building types and climates [5]. However, the analysis of the first reported cost-optimal calculations to the Commission revealed an overall rather positive picture regarding both the conformity to the official requirements and the plausibility of the final outputs [6]. Regardless of the progress achieved through European legislations [7], the envisaged match between cost-optimal and nearly zero-energy building (NZEBs) energy performance level remains questioned. The link with NZEBs is also reiterated in the EPBD revision: it cannot be lower than the cost-optimal level that will be reported in 2023 by Member States in accordance with Article 6(2).

Figures 1 and 2 show cost-optimal and NZEBs levels for new and existing buildings, respectively, as assessed by the JRC in 2020 [8]. The area of an acceptable gap is the green, where the NZEB net primary energy is lower than the cost-optimal.

Figures 1 and 2 allow depicting a quite positive picture. A good number of Member States are introducing NZEB requirements substantially lower (about –50%) compared to cost-optimal levels. Only in 20% cases the NZEBs and cost-optimal gap overcame 15%

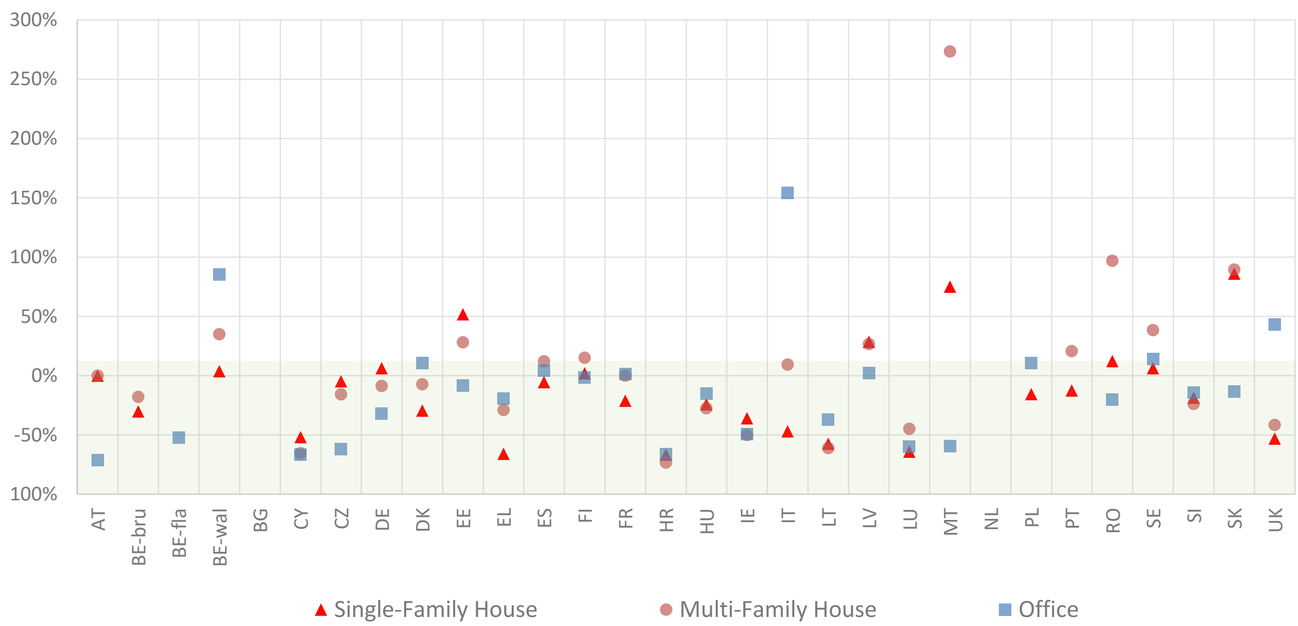

Figure 1. Cost-optimal and NZEB net primary energy levels for new buildings.

for new buildings, in 18% of cases for existing. A good number of Member States referred to the cost-optimal approach to define the NZEBs requirements.

Especially at retrofit level, studies investigating the possible energy/financial performance gaps between the two levels can inform policy-makers about how demanding the forthcoming market transition towards an energy efficient building stock will be [9]. Important novelties will be revealed with the review of the cost-optimal framework, expected by the Commission by 30 June 2026, to enable the calculation of both energy and emission performance taking into account environmental and health externalities, as well as the emissions trading system (ETS) extension and carbon prices [1].

The update of NZEB definitions for new buildings (and major renovations), the introduction of energy requirements and incentive mechanisms for renovation, in line with the Renovation Wave Strategy [10], and the environmental targets for the building sector as a whole require an update of the methodology. In compliance with Article 6 of reference [1] (ex-Article 5 of the EPBD), the calculation of cost-optimal levels will be more aligned to the Green Deal [11], as costs of greenhouse gas allowances as well as environmental and health aspects of energy use will have to be considered to derive the lowest costs. The cost-optimal level shall lie within the range of performance levels where the cost benefit analysis calculated over the estimated economic lifecycle is positive.

Cost-benefit analysis

After the revision of EPBD, the recent focus has been on incorporating co-benefits into decision frameworks to take into account the full range of stakeholders involved in energy investments such as citizens, owners, users and so. Indeed, contemplating not only the costs but also the benefits and, in particular, the co-benefits make it possible to highlight how investments in energy efficiency can provide many different benefits to various stakeholders, for example, reductions in local air pollution associated with the reduction of fossil fuels, employment creation, fuel security, improvement in productivity, illness reduction, indoor comfort increase [12].

The CBA analysis includes five successive steps: identification of costs and benefits of the project, estimation of the monetary values, distribution of the estimated costs and benefits over the time and construction of the cash flow, definition of the discount rate, calculation of the performance indicators such as Net Present Value (NPV) and benefit/cost ratio (B/C). This tool can be exploited at different scale of analysis: at technological component level, at the building level and at district/city level.

Innovative technologies that can be deployed in the renovation process should be evaluated taking into account their impacts not only in terms of energy efficiency, but also on the matters mentioned in the updated regulation panorama (i.e. indoor air quality, comfort, health, etc.). The CBA can demonstrate how higher investment costs of innovative technologies can

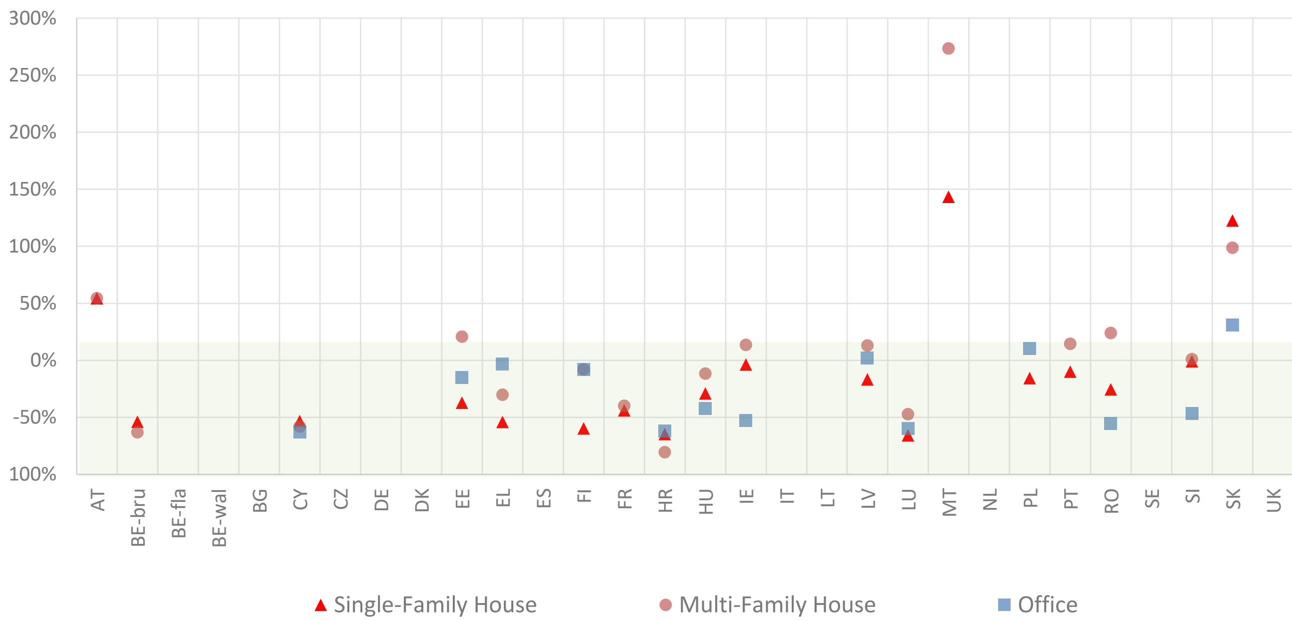

Figure 2. Cost-optimal and NZEB net primary energy levels for existing buildings.

be repaid by socio-economic benefits. In reference [13] the CBA underlines that regarding the use of an innovative antibacterial filter for air handling units in office building, the investment and replacement costs are higher than reference filter ones but they are totally repaid by the improvement of workers' productivity and by the decreasing in respiratory diseases.

At the building level, the CBA can be exploited for evaluating and comparing different energy scenarios for new or existing buildings in terms of energy consumptions, water consumptions, productivity, IEQ improvement, GHG emissions, PM emissions, health (headache cases), as done for the pilots of MOBISTYLE EU project (financed by European Community, grant agreement No. 723032) [14]. The aim of the project was to motivate behavioural change by raising consumer awareness through a provision of attractive personalized information on user's energy use, indoor environment and health, through information and communication technology-based services. The multi-dimensional approach of the CBA (**Figure 3**) was use to assess the effectiveness of consumer awareness in each case study evaluating the impacts above mentioned.

At district scale, there are some examples of utilization of CBA for evaluates alternative retrofit scenarios with respect to energy, environmental and social criteria. In reference [15] after the assessment of the energy status of the district, the second step of the analysis consists in establishing the alternative retrofit scenarios for enhancing the energy efficiency. The third phase involves the identification of costs and benefits for each hypothetical scenario, and the related translation in monetary terms (investment costs, running costs, energy consumption, GHG emissions, green jobs, asset value). The step four aggregates the impacts within a framework based on CBA and evaluates the indicators of profitability, in particular the Social Return On Investment (SROI). The final steps consist in the development of some sensitivity analyses in order to test the stability of the obtained results.

Conclusions

To summarize the paper proposes a review of the current state of the implementation of cost-optimal methodology that represents a solid evaluation tool

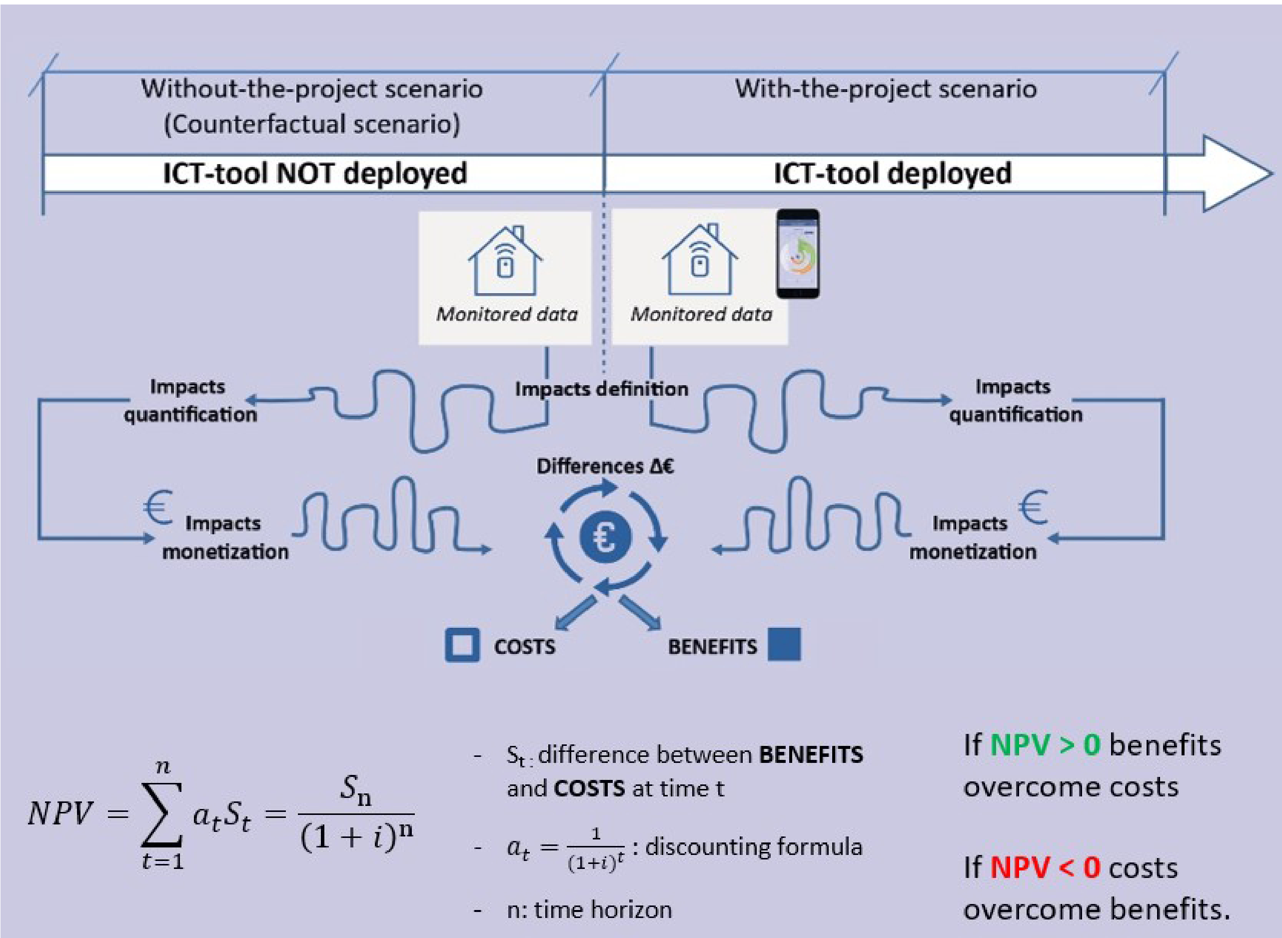

Figure 3. Cost-benefit analysis applied in MOBISTYLE EU Project.

for managing the existing building stock renovation. Moreover, it outlines the CBA as a possible evolution underlining its potentialities with some examples of applications at different scales. In a season characterized by the human-centric approach, exploiting new multi-dimensional evaluation metrics that consider not only the costs of the renovation project but also the multiple benefits for the multiple involved stakeholders becomes indispensable. ■

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Multi-energy systems as enablers of the flexible energy transition

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The growing deployment of renewable sources is having a relevant impact on the whole energy chain, and much more flexibility is required to continuously ensure the power balance between generation and demand. In line with this, the paper focuses on the analysis of Multi-Energy Systems, recognized as a key solution to efficiently match final users' needs by exploiting flexible interactions between different energy vectors.

Keywords: Multi-Energy Systems, Flexibility, Energy Transition, Multi-Generation Technologies, Energy Models, Simulation.

Overview Of Multi-Energy Systems

The current energy transition is having a huge impact on the whole energy chain and the progression towards carbon neutrality is affecting supply, transmission, conversion, and demand sides. In particular, the increasing diffusion of controllable distributed generation technologies enables to better exploit renewable energy sources (RESs), transforming consumers from passive to active actors (i.e., the so-called prosumers). The shifting in the way energy is produced and consumed clearly represents a challenge for transmission and distribution networks, leading the concept of power flexibility to play a crucial role in future power systems [1], [2]. According to [2], flexibility is defined as "the ability to adjust generation or consumption in the presence of network constraints to maintain a secure system operation for reliable service to consumers". This means that the availability of an adequate power flexibility becomes a prerequisite to foster the effective integration of RESs, enabling to tackle their volatility and uncertainty strongly dependent on weather conditions. In this framework, the necessity of more flexible energy players puts the attention on the efficient exploitation of the interaction between different energy vectors, converging towards the so-called Multi-Energy Systems (MESs). According to [3], MESs are defined as systems "whereby electricity, heat, cooling, fuels, transport, and so on optimally interact with each other at various levels for instance, within a district, or a city, or at a country level". In other words, the main idea of MESs is to manage different energy vectors as a whole, exploiting the synergies between them. An example of MES can be an electric network coupled with a thermal network, or a building where electrical, thermal and gas utilities are jointly regulated to improve the overall energy efficiency. MESs can perform better than traditional separate energy systems in terms of technical, financial, and environmental performances, allowing higher conversion efficiencies, efficient exploitation of local energy sources, reduction of greenhouse gases emissions and opening to new business and market opportunities [3], [4]. Nevertheless, MESs ask for the effective and optimal management of different energy sources and power interfaces; this is challenging since it increases the complexity of the systems and involves different dynamics [5; the same holds for design, modelling and simulation tasks concerning MESs [4], [6], [7]. For the above reasons, MESs and their provided flexibility are a current and trending research field, with significant interest both from the academic and in the industrial sector, in order to foster their integration in the energy system [3], [7]. In this context, a European project named MAGNITUDE has been recently carried out, with the objective of developing market mechanisms and tools to enhance MESs providing flexibility to the European power system, exploiting and optimizing the synergies among different energy vectors (i.e., electricity, heating and gas) [8]. Fitting into the context, this paper aims to provide a complete overview of the main features and modelling issues of MESs, proposing also a dynamic simulation approach, allowing a quick evaluation of a MES performances and suitable for testing control/optimization algorithms.

Multi-energy technologies and systems

A key role in enabling and practically allowing interactions between energy commodities is played by conversion technologies. In MESs, there exist several possibilities to transform one energy vector into another [7], each with related efficiency, technical features, emissions and costs. In line with the growing electrification of final uses [9], power-to-X technologies are increasing their relevance and diffusion, being able to exploit electricity coming from local RES. Nevertheless, gas technologies are still the most widespread and affirmed on the market and are improving their efficiency to reduce their environmental impact. In this regard, Guelpa et al. [7] offered a complete review on the conversion technologies suitable for MESs applications, classifying them into the following classes: *(i)* gas-to-heat, cooling and power (e.g. condensing gas boilers, chillers or trigeneration systems), *(ii)* power-to-gas (e.g. electrolysers), *(iii)* power-to-heat (e.g. electric boilers, heat pumps or polyvalent heat pumps), and *(iv)* power-to-commodities (e.g. mobility or desalination), with a final focus on storages considered fundamental to decouple supply and demand phases. Witkowski et al., [1], using a similar classification, added information about technical features of technologies (e.g., operating temperature level, efficiencies, partial load conditions, etc.), financial data and information about ramp rates and response time in case of flexibility demand. Concerning the technological sphere, the presence of multiple energy technologies in a single system can be challenging. Indeed, complexity comes from *(i)* the different sources of energy that can be used, from fossil to renewable sources; *(ii)* the level of maturity and readiness of technologies (e.g. gas vs hydrogen) with related financial and environmental implications; *(iii)* the different networks they need to use (i.e. power, gas or district heating and cooling networks) and finally *(iv)* the necessity to satisfy several types of energy demand simultaneously (i.e., heating, cooling and electricity) [4].

Modelling and simulation challenges

While technologies seem to be ready for their implementation into multi-energy systems, the design and operation phases ask for new approaches, models, and simulation tools to properly describe the operation of MESs and to optimally manage the interaction between energy vectors. Such tools are fundamental to provide science-based support to decision-makers, to effectively plan the development and optimization of MESs at different scales of analysis. Building an energy model is firstly a goal-driven process; indeed, all models are developed for a very specific purpose, which in turn determines the diverse characteristics of the models, from the level of abstraction and simplification to the spatial and temporal scale and resolution [10]. According to [11], models "could be categorized according to their purpose, methodology, assessment criteria, and structural and technological detail. They also take different analytical and mathematical approaches and vary according to their reusability.". In addition, diverse models' classifications are present in literature, depending on several factors, among which geographical coverage, spatial and temporal resolutions, as well as time horizon [11].

Focusing on the complex framework of MESs, the most challenging issue is that the different energy vectors involved may require the application of different time scales, resolutions and approaches to be addressed in the right way, in particular when dealing with modelling of networks or renewables [6]. According to [10], models can be defined as integrated or integral; the former are built assembling already existing models, the latter are usually built as a whole from scratch, giving more interest on the dynamics of the overall system, while devoting less attention to the detailed analysis of single components. The selection of proper modelling techniques for MESs is not an easy task, since it is not trivial to synthetize complex and bigger systems from small pieces and deduce or extend the properties of the MES from the features of the components. Considering that technologies and networks involved in MESs operations are well known and already modelled in separate environment, it could be easier to build an integrated model, using already existing models and adding links between them. Nevertheless, it has to be considered that the link between existing models, if not properly implemented, can increase the overall complexity [10]. This aspect, coupled with the challenge of mixing models with different requirements in terms of temporal and spatial granularity, could make it more beneficial to use an integral approach, building the entire MESs model from scratch; in this way, the management of a unique model with different energy vectors and their synergies in the same simulation environment could be easier. Several recent review papers facing the problem of modelling and simulating an MES are present in literature. Drivers, requirements, opportunities and drawbacks of modelling the interactions between energy vectors under the MES framework were discussed in [6]. The paper also reported examples of existing models and tools. Mavromatidis et al. tried to address the challenges of modelling Distributed-MES by answering ten questions on the most relevant topics [4]. The importance of choosing the proper level of detail when describing components of complex systems was stressed, to reach a good trade-off between model accuracy and computational time. In [7], a review on the state-of-the-art of modelling aspects and trends concerning the integration of gas, heat and electricity was conducted, with a focus on networks infrastructures; starting from a separate and detailed analysis of energy networks, highlighting differences and similarities between them, authors addressed the issue of optimizing and designing an MES as a whole. Finally, [11] presented a review on energy models and existing tools to optimize MESs in mixed-use districts, concluding that few already existing tools are able to answer the research question.

A "quick and dirty" simulation method for multi-energy systems

In line with the above, this section presents a proposal of a new simulator well suited for the efficient and dynamic simulation of MESs. The main objective of the tool is to give a quick answer about the performances of a MESs, which is a crucial feature when testing energy optimization and control algorithms. For this reason, the developed simulator is defined as "quick and dirty", giving outcomes in reasonable time and therefore requiring less detailed systems' modelling. The simulation methodology is here presented considering the case study of a small district heating network, named AROMA network [12], connected to the electrical utility through a CHP plant. In detail, this benchmark system is composed of a central power station (with a gas boiler and a CHP system), five residential users and several supply and return pipes to link demand and supply sides. As said before, the choice of the proper simulation tool is crucial for a good quality analysis [11]. According to the model purpose, the Simscape environment from MATLAB®

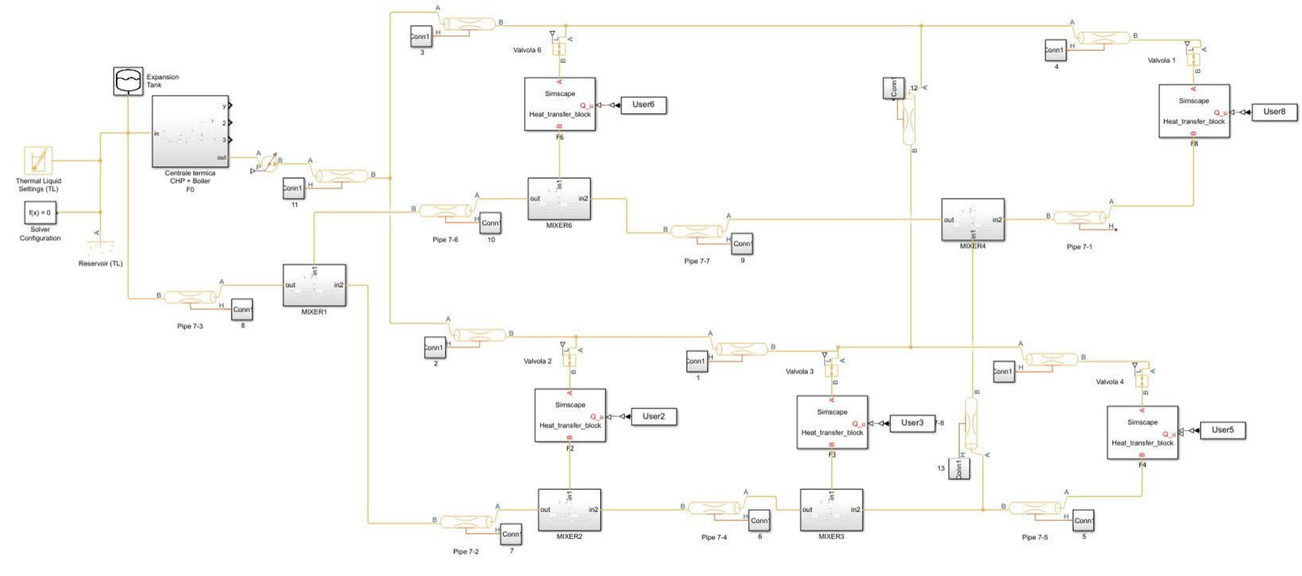

Figure 1. AROMA network scheme on Simscape.

was selected [13]. Simscape enables building models of physical components based on physical links that integrate directly with block diagrams and other modelling paradigms. Moreover, thanks to its several libraries, it allows to cover all the physical domains involved in MES analysis (electricity, thermal fluids, gas and eventually hydrogen).

Figure 1 shows the global architecture of the designed simulation model for the district heating network, developed using the thermal liquid domain of Simscape.

In detail (**Figure 1**), the following components were used:

- a central power station, composed by a CHP plant, power-regulated, and a gas boiler in series; the boiler outlet water temperature is regulated by properly designed controllers tracking an imposed reference temperature, in this case 90 °C. CHP and gas boiler blocks are manually designed as heat exchangers.
- a water-pump (derived from the Simscape foundation library), to impose a desired pressure difference;
- supply and return pipes (taken from the Simscape foundation library), able to simulate temperature and pressure dynamics, as well as to account for the thermal losses through the pipe walls. Data concerning pipe lengths and diameters were selected according to [12];
- users' valves, regulating the water flow entering the users' substation to maintain the return temperature as close as possible to a reference (here 65°C), through a properly designed control system;
- users' substations, modelled as heat exchangers, in which the water supply network deliver to users the required amount of power; thermal loads are distributed on the five users following [12] distribution, while the users' power profiles come from the real experimental data provided by RSE;
- adiabatic water mixers (self-made components), which mix mass flowrates at different pressure and temperature conditions;
- an expansion vessel, giving the reference for the regulation of water pressure in the circuit.

For the sake of exemplification, a simulation for one day with a resolution of one second is carried out and the simulation time is around one minute. Supposing variable load profiles, **Figure 2**(a) shows the total water mass flowrate, while **Figure 2**(b) depicts thermal powers exiting from the central power station. The total flowrate circulating in pipes is the result of the valve regulation at the users' substations in order to keep the return temperature at 65°C, as previously reported. Therefore, the flowrate is set so that all users, even the furthest from the supply plant, can receive the desired amount of heat at the proper temperature. Concerning thermal powers, looking at **Figure 2**(b), it is possible to notice that the profile of the CHP heating power is almost constant during the day as it is controlled to track a predefined power reference. On the other hand, the boiler integrates the heat delivered by the CHP to satisfy the users' demand. Its power profile recalls the flowrate one, since both are imposed by the users' cumulated heating request.

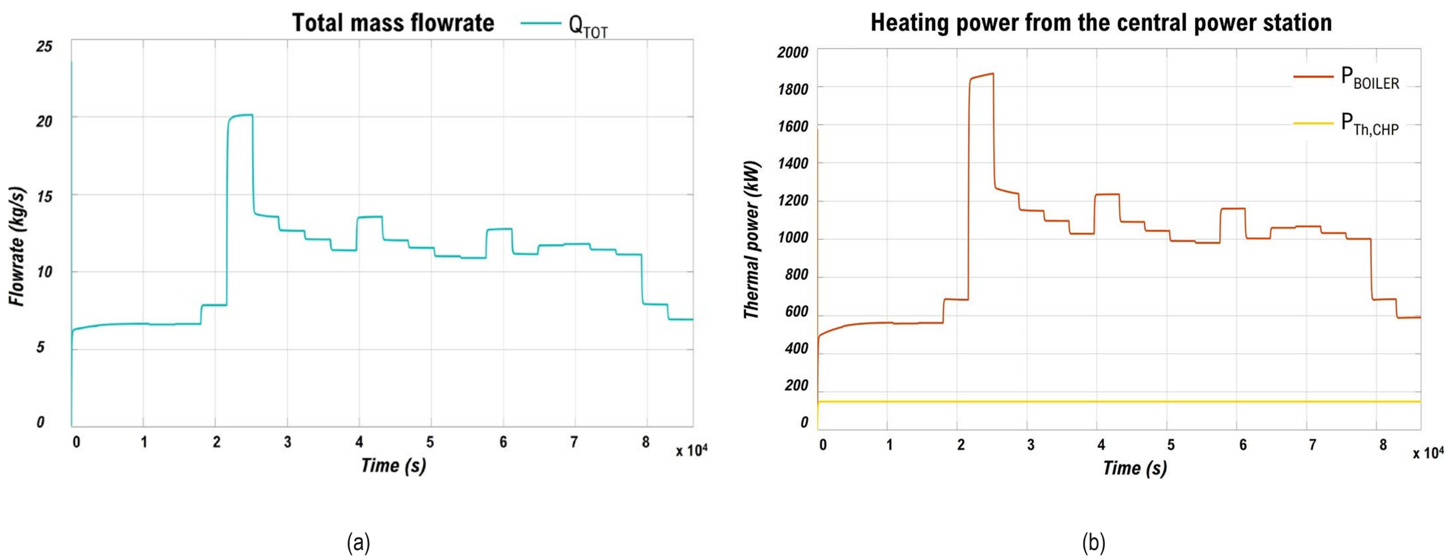

Figure 2. Total mass flowrate of the district heating network (a) and thermal powers exiting from the central power station (b).

Conclusions

The need for more flexible energy systems in response to the volatility and uncertainties coming from the deployment of local renewable energy sources opens the way to the so-called Multi-Energy Systems in which different energy vectors optimally interact with each other. The paper investigates some fundamental aspects concerning MESs, from technological readiness, to modelling and simulation opportunities and challenges. It emerged how from a technological point of view, even if with different levels of maturity, technologies are ready to be implemented in MESs, while the same cannot be stated for models and simulation tools, needed to support the development of such systems from operation and management standpoints. As witnessed by the literature, MES modelling is a current and open research topic, still difficult to solve. In line with this, a proposal of a "quick and dirty" MES simulator has been presented, with promising results in properly simulating the dynamics of the system. The first step has been the development of a base district heating system, with the perspective of integrating it with electric power and gas networks. ■

Acknowledgements

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Contemporary and unbalanced loads in buildings: *new performance indicators*





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Giving the promising benefits potentially offered by polyvalent heat pumps, either used alone or coupled with other HVAC systems, for meeting contemporary and unbalanced loads, the paper aims to define new performance indicators able to assess the potentialities of these HVAC configurations, surpassing the existing literature and standard gaps.

Keywords: Polyvalent heat pumps, Key Performance Indicators, contemporary and unbalanced heating and cooling loads, HVAC systems

Introduction

The polyvalent heat pump (PHP) is currently recognized as a promising HVAC technological solution for buildings, thanks to its capability to provide heating and cooling services simultaneously and independently, and not only seasonally (as traditional reversible heat pumps) [1, 2]. In particular, the use of PHPs, alone or in conjunction with other HVAC systems (e.g., chillers, heat pumps, etc.), can provide several benefits in terms of reduced fuel expenditure, environmental impacts, and costs [2]. However, despite the potentialities of PHPs, little literature is present regarding their modelling and valorisation; in this regard, there is a gap in literature on the possible metrics or key performance indicators (KPIs) to be used to value PHPs operations and benefits, also when compared with other widespread systems [2]. So far, indeed, PHPs performances have been evaluated in terms of the well-known seasonal indexes SCOP (Seasonal Coefficient of Performance) and SEER (Seasonal Energy Efficiency Ratio), compliant with the EN 14825 standard [3]. If these metrics are particularly useful to express the potentialities of traditional heat pumps (HPs), which provide one service at once (cooling or heating, exploiting a seasonal changeover), SEER and SCOP are not suitable enough for the PHPs performance assessment [2]. According to EN 14825, indeed, the seasonal indexes are computed using linear loads and defining the number of hours of heating and cooling seasons and the reference temperature bands for their calculations, according to diverse climatic conditions (i.e., warmer, average, and colder climates) [3]. Aiming to estimate the PHPs performances, some criticalities arise from this approach. It is limiting to consider fixed temperature ranges for the loads definition, as well as to define two separate and independent heating and cooling seasons; indeed, using this approach, it is not possible to account for possible contemporary heating and cooling requests, or to consider the number of contemporaneity hours, and these aspects are the main advantages of PHPs. In the light of the above, the work aims to develop new KPIs able to include the assessment of the hours of contemporary heating and cooling demands, to quantify and valorise the benefits that the use of PHPs can offer. Furthermore, thanks to the recent spreading of effective management and control systems, diverse technological solutions can be efficiently integrated to properly serve building loads. Especially in case of unbalanced heating and cooling loads over the year, it is interesting to consider the possibility of coupling more units with lower nominal capacities (among which also PHPs), rather than oversizing single units to meet the highest load. In support to this, there is the necessity to define proper annual indicators, able to include in a single metric all the specific performances of the units when working according to specific operation modes. Starting from an applicative study, the paper wants to discuss the potentialities arising from the coupling of PHPs with other systems thanks to efficient management and control systems able to strategically optimize the use of the two technologies in an effective way in case of unbalanced loads.

Method

The methodological approach is composed of two main parts: *i)* numerical experimentation, needed to model the coupling between load profiles and units operation dynamics; and *ii)* KPIs definition, aimed to define a set of metrics able to express the technical performances of the analyzed technological solutions [1, 2]. The numerical modelling phase is developed around three methodological steps, which allow to: *i)* create the load profiles; *ii)* define the units operation modes; and *iii)* model the load-unit coupling, considering partial loads and external air temperature as influencing parameters [1, 2]. In order to generalize the methodological framework and disengage it from specific case studies, cooling (P_C) and heating (P_H) load profiles are distributed along the hours of the year according to theoretical normalized Gaussian curves [1, 2, 4], assuming the possibility to have contemporary requests and fixing a specific percentage of contemporaneity. During non-contemporaneity hours, only cooling and heating loads are present, while contemporaneity hours are characterized by simultaneous heating and cooling requests. Thanks to the technical characteristics of the PHP, the unit works according to three main operation modes: A1 or cooling only (the PHP works as a traditional chiller); A3 or heating only (the PHP works as a traditional heat pump); and A2 or combined heating and cooling. In this latter mode, the PHP allows the recovery of heat from the evaporating process that otherwise would be wasted [1, 2, 4]. Knowing that for the PHP, only two modes can be activated in each hour, it is possible to identify five combinations of operation modes: $A1_{NCont}$ (cooling only load in non-contemporaneity hours), $A3_{NCont}$ (heating only load in non-contemporaneity hours), A2 (combined heating and cooling request), $A2+A1_{Cont}$ (when A2 mode requires an integration in A1 mode to meet the cooling demand during contemporaneity hours) and $A2+A3_{Cont}$ (when A2 mode requires an integration in A3 mode to meet the heating demand during contemporaneity hours). In the model, $P_C(i)$ and $P_H(i)$ loads were associated to the correspondent functioning modes for each hour. The performances of air-cooled units, of interest for this paper, are influenced by external air temperatures; moreover, also partial load condition reflects on the performances of heat pumps. Therefore, to consider both influencing parameters, an ad-hoc numerical model was developed to create the capacity curves of the units, based on real commercial units data from technical documentation [5] (i.e., heating and cooling capacities, absorbed electric powers, COPs, EERs) and to couple load and supply sides with an hourly time-step, considering the combined effect of partial load conditions and external air temperatures. More details on the numerical model can be found in [1, 2, 4].

Due to the current lack of appropriate KPIs for assessing the technical performances of PHPs, with a specific attention on contemporary operation modes, the model supports the definition of proper performance metrics. Specifically, in line with the existing performance coefficients for heat pumps [3], five indexes were developed to evaluate the performances in different operation modes. Each metric is calculated as the ratio between the total requested energies (E) and the relative absorbed electric energies (E_{el}) for a specific operation mode, as shown in eq. 1-5. The eventual integration of an electric back-up system (with a unitary efficiency) for heating peak demands is included into the

KPIs computation. Even though some of the metrics ($SCOPnc_{mode}$, $SCOPc_{mode}$, $SEERnc_{mode}$, $SEERc_{mode}$) can partly recall the standard-based and commercially diffused SCOP and SEER, it is important to note that there are differences in their definition.

$$SCOPnc_{mode} = \frac{E_{A3,NCont}}{E_{el,A3,NCont}} \quad (1)$$

$$SEERnc_{mode} = \frac{E_{A1,NCont}}{E_{el,A1,NCont}} \quad (2)$$

$$S\text{-}EXP_{mode} = \frac{E_{A2}}{E_{el,A2}} \quad (3)$$

$$SCOPc_{mod} = \frac{E_{A3,Cont}}{E_{el,A3,Cont}} \quad (4)$$

$$SEERc_{mod} = \frac{E_{A1,Cont}}{E_{el,A1,Cont}} \quad (5)$$

Furthermore, to define a single annual indicator able to express the whole annual performances of the considered units, including possible multi-unit configurations, the Annual Performance Indicator (API) was developed. API is calculated as the sum of the five previously mentioned KPIs, each weighted on the operation hours of the unit in each operation mode. In detail, by defining w_1, w_2, w_3, w_4, and w_5 as the fractions of annual hours in which the PHP operates in $A3_{NCont}$, $A1_{NCont}$, A2, $A3_{Cont}$ and $A1_{Cont}$, respectively, the API metric is computed as expressed in eq. 6 below:

A summary of the five developed KPIs, with the indication of the hourly weighting coefficients used for the API calculation, is provided in **Figure 1**.

Application

The developed methodological approach was tested for comparing two air-cooled HVAC configurations to satisfy the same load curves. In line with the current air conditioning trends, according to which cooling requests are surpassing heating ones (because of the recent increment of external air temperatures [6]), unbalanced loads were considered; specifically, maximum heating and cooling loads were set equal to 350 kW and 630 kW, respectively.

As shown in **Figure 2**, load profiles were built based on Gaussian-shaped profiles, considering an average percentage of contemporaneity, equal to 52% [1, 2, 4]. All calculations are developed considering the climate of Strasbourg (i.e., "average" climate, according to [3]).

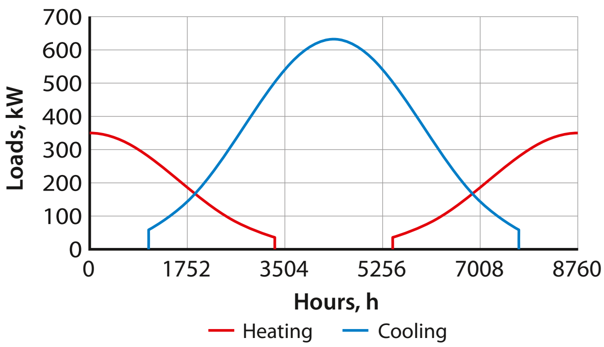

Figure 2. Gaussian-shaped unbalanced load profiles: 52% percentage of contemporaneity.

$$API = w_1 \cdot SCOPnc_{mode} + w_2 \cdot SEERnc_{mode} + w_3 \cdot S\text{-}EXP_{mode} + w_4 \cdot SCOPc_{mode} + w_5 \cdot SEERc_{mode} \quad (6)$$

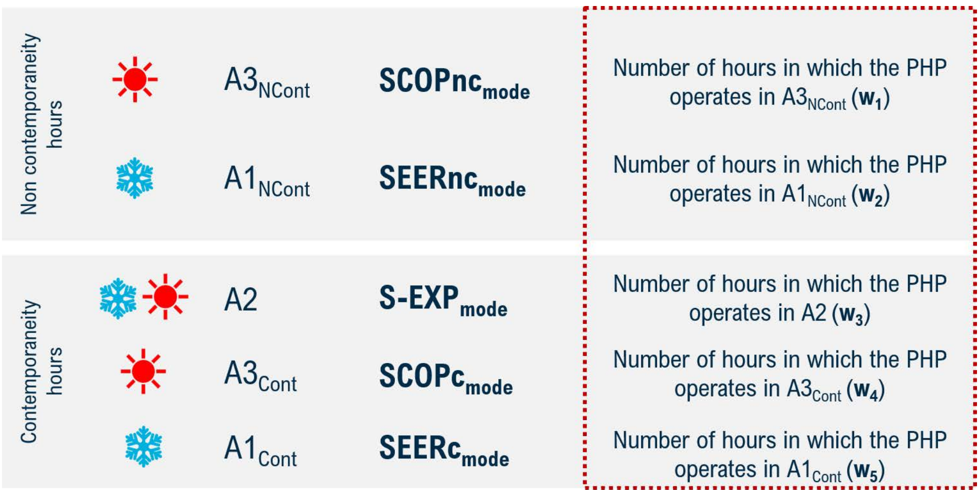

Figure 1. Definition of performance metrics for each operation mode and identification of hourly weighting coefficients.

Two 4-pipes HVAC configurations were considered and compared in terms of the defined KPIs:

1. A single polyvalent heat pump (660 kW, 6 scroll compressors) sized to meet the cooling request. This configuration considers the use of a single unit to satisfy all loads.
2. A polyvalent heat pump (370 kW, 4 scroll compressors) sized to meet the heating request, coupled with a chiller (330 kW, 4 scroll compressors), the latter used as integration unit to match the remaining cooling load. In this case, being the PHP alone not able to satisfy all loads, an efficient multi-technology management system is required to combine the integrated solutions and to define and apply their start-up and operation strategies in an efficient way.

Results and discussion

The two configurations were compared in terms of the defined KPIs, using the same numerical model. Based on the load distribution among the considered operation modes, both configurations are characterized by the same weighting coefficients, depending only on the load curves, and not on the considered units. Specifically, w_1 and w_2 are equal to 24%, while the remaining percentage (i.e., 52%, percentage of contemporaneity) is distributed among the other coefficients (28%, 5% and 19% for w_3, w_4 and w_5 respectively).

It is worth mentioning that, if the PHP works in all operation modes in both configurations, the chiller of the multi-unit configuration works only in $A1_{NCont}$ and $A1_{Cont}$, to integrate the PHP in meeting the cooling loads. To compute the API index for the multi-unit configuration, therefore, there is the need to couple the performances of the two units in both $A1_{NCont}$ and $A1_{Cont}$ in a single coefficient. As a result, $SEERnc_{mode,SYSTEM}$ and $SEERc_{mode,SYSTEM}$ were defined, calculated as the ratio between the cooling requests served by both units and the total electricity consumption of both units, in $A1_{NCont}$ and $A1_{Cont}$ respectively. For the multi-unit configuration, thus, the API formula is updated as in eq. 7, where the chiller contribution is included only in the new-defined indicators, while, for this application, $SCOPnc_{mode}$, $SCOPc_{mode}$ and $S\text{-}EXP_{mode}$ are characteristic of the sole PHP (pls. see eq below):

Table 1 summarizes the results obtained for the two compared HVAC configurations in terms of the five developed metrics. Based on its definition, $S\text{-}EXP_{mode}$ values for both configurations are higher than other metrics, since the A2-related index considers the capability of the unit to provide a double service with a single electricity consumption. Values are comparable between the two configurations; it is worth mentioning that the results are strongly dependent on the partial load conditions of the considered units.

Table 1. *KPIs results for the two compared configurations.*

Configuration 1: PHP		Configuration 2: PHP +chiller	
$SCOPnc_{mode}$	3.0	$SCOPnc_{mode}$	3.0
$SEERnc_{mode}$	4.5	$SEERnc_{mode,SYSTEM}$	5.0
$S\text{-}EXP_{mode}$	8.0	$S\text{-}EXP_{mode}$	8.5
$SCOPc_{mode}$	2.5	$SCOPc_{mode}$	3.0
$SEERc_{mode}$	4.5	$SEERnc_{mode,SYSTEM}$	5.0

The presented application allowed to assess the higher technical convenience of the multi-unit configuration, compared to the use of the sole PHP. Indeed, the API of the PHP+CHILLER configuration (approximately 5.5) results higher than the other solution (approximately 5), and thus can be used as a metric to numerically express how it would be more beneficial to use two units with a lower nominal capacity for matching the considered unbalanced loads, rather than using a single unit with a higher nominal capacity. It is worth mentioning that the obtained results are related to the fixed boundary conditions of the specific application presented in this work. However, the methodological approach can be extended to other profiles, characterized by diverse contemporaneity levels and peak loads; starting from the development of diverse profiles, the multi-unit configuration can achieve higher benefits in terms of the API metric, and its deviation with respect to the PHP alone can increase up to 15-20%.

The considered systems were compared also in environmental and financial terms. Investment costs were computed considering real units costs, while energy costs were calculated considering 2019 Italian electricity prices (only variable quota considered) [7].

$$API = w_1 \cdot SCOPnc_{mode} + w_2 \cdot SEERnc_{mode,SYSTEM} + w_3 \cdot S\text{-}EXP_{mode} + w_4 \cdot SCOPc_{mode} + w_5 \cdot SEERc_{mode,SYSTEM} \quad (7)$$

As reported in **Table 2**, indeed, the multi-unit configuration appears to be more attractive, thanks to its lower investment and energy costs, as well as its lower environmental impact, in terms of generated CO_2 emissions (electricity emission factor was taken from [8]).

Conclusions

Polyvalent heat pumps are becoming important actors of the transition of the building sector, thanks to the several benefits arising from their capability of providing heating and cooling services simultaneously and independently. However, still few methodological approaches and metrics are present to express the potentialities of this technology, used alone or in combination with other units, thanks to the use of proper management and control systems. The work aimed to develop new metrics to assess the performances of HVAC systems (both single- or multi-unit) in presence of contemporary and unbalanced heating and cooling loads in buildings. Based on these newly developed KPIs, and mainly on API, the work allowed the comparison of two configurations (PHP vs. PHP+CHILLER). The integration of PHP and chiller, using units with lower nominal capacities, has appeared to be more beneficial in technical terms (i.e., API), as well as from financial and environmental standpoints, with respect to the sole PHP with higher capacity. Future works will be developed to refine the numerical approach, to test the defined KPIs with other HVAC configurations and diverse contemporary load profiles, as well as to enlarge the set of metrics, always aiming to valorize the technologies capabilities of meeting contemporary loads. ■

Table 2. *Environmental and financial outcomes for the two compared configurations.*

	Configuration 1: PHP	Configuration 2: PHP +chiller
Investment cost [€]	88,027	87,172
Energy cost [€/y]	143,393	141,267
CO_2 emissions [t/y]	337.5	332.5

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Energy savings of "tailored-to-occupant" dynamic indoor temperature setpoints

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A dynamic thermal environment that temporarily exceeds the boundaries of the thermal comfort zone can be an approach to reduce energy use in buildings while providing occupants with instances of thermal delight and positive stimulation. This work presents "tailored-to-occupant" dynamic heating profiles based on in-situ-measured occupancy in a Swiss case study office and compares resulting heating energy demand with rather static setpoints used in practice and established by current standards.

Keywords: occupant-centric buildings, energy reduction, heating demand, dynamic temperature setpoint, open space office

Introduction

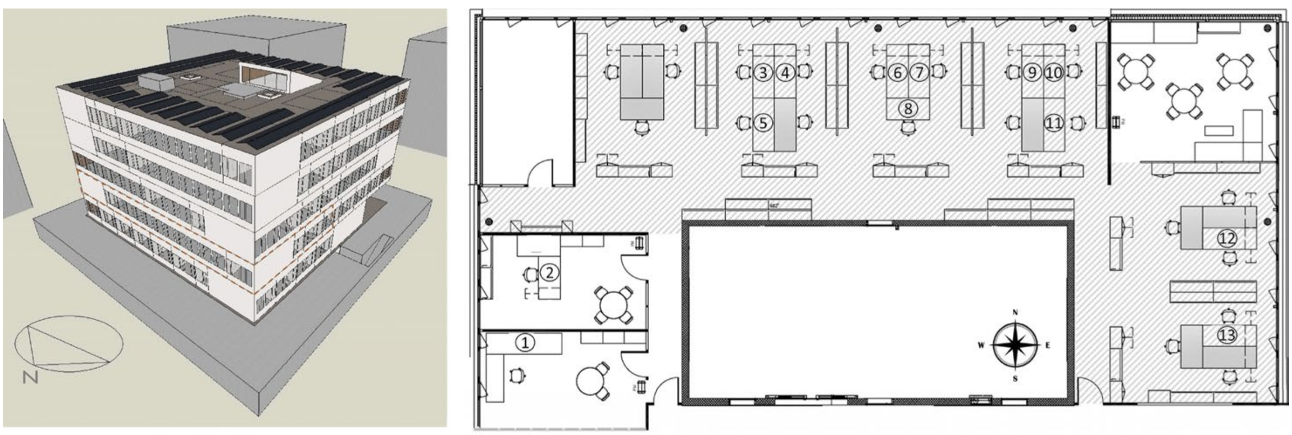
Indoor temperatures setpoints in buildings are typically fixed and set according to standardized regulations on indoor thermal comfort such as ISO 7730 [1] and ASHRAE 55 [2]. Thus, the common way for operating HVAC systems in buildings is to avoid deviations of the indoor temperature from the steady-state, most often the indoor temperature is kept within 2 K around the set point [3]. However, such a practice of tight indoor temperature settings has resulted in significant operational energy use in buildings [4]. Alternatively, energy-expensive *static indoor temperature setpoints* can be challenged by *dynamic occupant-aware setpoints*. Such profiles can be developed by considering recent physiological research, such as [5-7], showing that mild cold exposure could positively affect the body's energy metabolism and glucose metabolism. The studies also demonstrated that people could well adapt to a variation in the indoor temperature, including mild cold. In other words, short exposure of people to indoor temperatures beyond the typical thermoneutral range during the day could be acceptable for occupants and beneficial from a health perspective. Thus, if temperature profiles introducing short-term beyond neutral thermal exposure can be adapted by considering the daily routines of people, *less stringent* requirements for temperature control can directly contribute towards operational *energy* reduction in buildings [22]. Therefore, we explored dynamic heating approaches with more easing heating setpoints with respect to the practice and permitted under the current standard setpoints during heating months (November-February) for a specific open space office located in Lausanne, Switzerland. The objective of this work is to present novel "*tailored-to-occupant*" heating approaches and how these, with respect to actual operational heating settings and standardized profiles according to the Swiss national standard SIA 2024:2015 [9], can affect the building energy performance.

Case study office monitoring and energy simulation

For developing tailored dynamic heating profiles in the specific case study, it is crucial to firstly gain insights into the real occupancy of the space, as well as understanding typical indoor temperature profiles. For that reason, the 224 m² open space Swiss office was monitored as part of the eCOMBINE project described in [10]. The overview of the building is shown in **Figure 1**a, and the floor plan of the open space office located on the first floor of the building and occupied by a maximum of 22 employees is provided in **Figure 1**b. In particular, for this work, we refer to measured operative temperature values based on data collected for two weeks in Fall (28.10. – 09.11.2019) and Winter (27.01. – 07.02.2020) at the desk level of the occupants and occupancy measurements taken under 13 employees' work desks. The actual heating setpoint profile was rather static, varying in the range of 22.5-24°C with no nocturnal setpoint. It serves as a *baseline* for further analysis of simulated energy use. Building energy simulations were performed in DesignBuilder using an Ideal Air Loads System by modeling the open space as a single thermal zone. The hourly simulation was run for the period from the start of November to the end of February, accounting for the winter months in Switzerland, using Typical Meteorological Year (TMY) based on historical weather data (2002). As the *standard-based scenario*, 21°C during working hours and 16°C of nighttime setback is considered per Swiss standard SIA 2024:2015 [13].

Dynamic heating setpoint profiles

To adapt the setpoint profiles to the specific occupancy of the space, the daily average, minimum, and maximum occupancy rates are profiled, as shown in **Figure 3**. This allowed for defining 9 different types of occupancy patterns: an *early* arriver (6 am),



(a) (b)

Figure 1. Case study open space office: (a) overview of the building (studied office façade is highlighted), (b) floor plan of the selected open space office (shaded in grey) with the numbering of monitored desks.

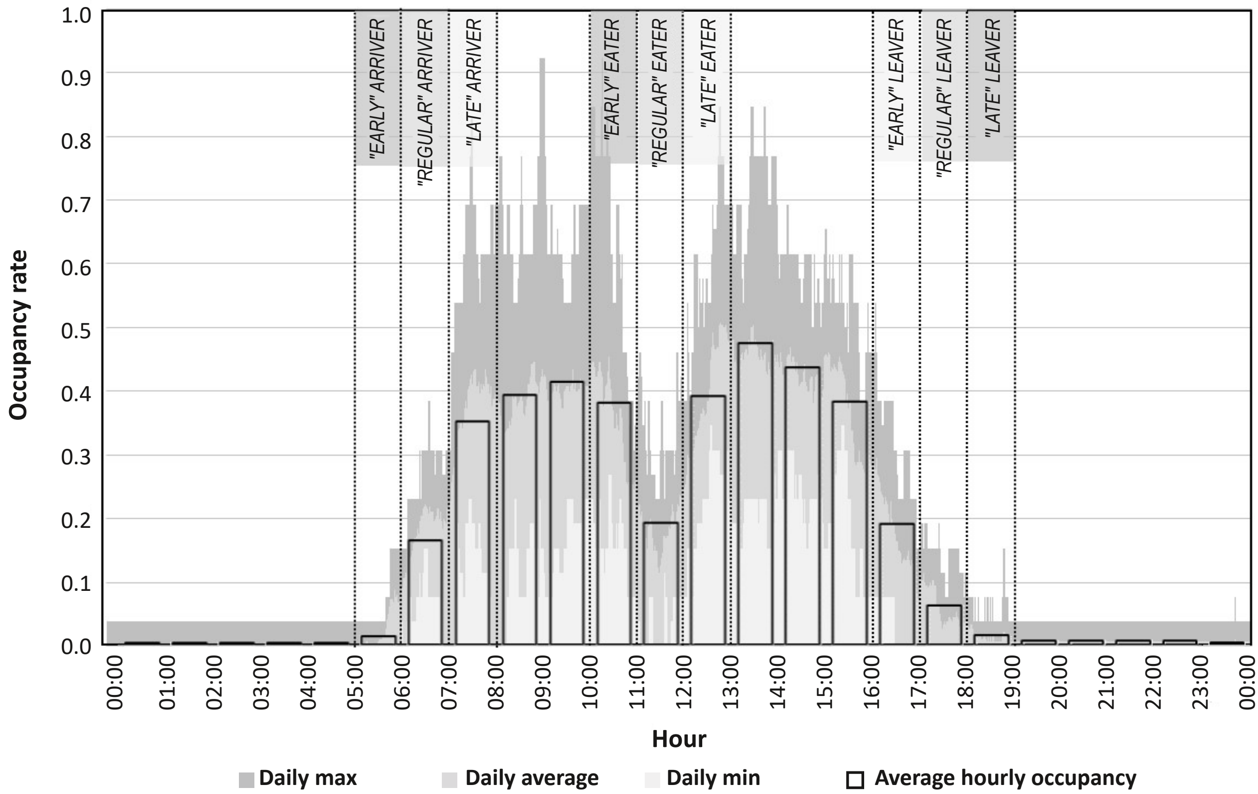


Figure 2. Real occupancy in the case study building: average, minimum, and maximum daily profiles (minutely) and hourly occupancy rates.

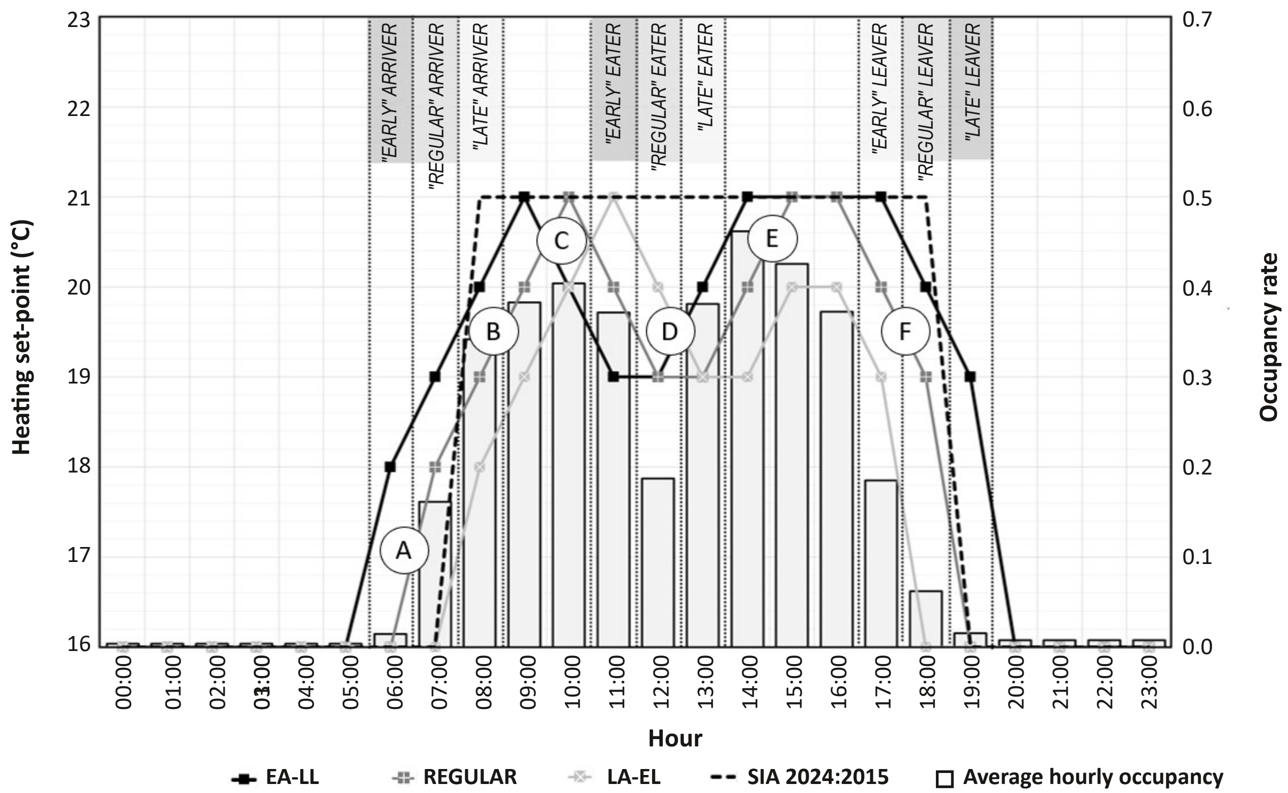


Figure 3. Heating set-point profiles for (i) early arriver (EA) - late leaver (LL), (ii) regular, (iii) late arriver (LA) - early leaver (EL), and (iv) based on SIA 2024:2015. The heating setpoint profiles are plotted against hourly occupancy rates (averaged over the previous hour).

regular arriver (7 am), and *late* arriver (8 am); an *early* eater (11 am), *regular* eater (12 pm), and *late* eater (1 pm); and, finally, an *early* leaver (5 pm), *regular* leaver (6 pm) and *late* leaver (7 pm). Based on these patterns, horizontal variations/shifts of alternative heating profile designs are introduced to evaluate their impact on the energy demand for space heating. In particular, the concept behind the design of the alternative heating profiles, shown in **Figure 4**, follows the following assumptions:

A. *At arrival*, the temperature setpoint is set at 18°C since the employees arrive from outdoors and likely have higher acceptability towards lower indoor thermal conditions (prior walking/biking to get to work results in elevated metabolic rate, and a person entering an indoor warmer space from cold outdoors is expected to feel the pleasure of a rising temperature).
B. *After arrival*, to stimulate the thermal pleasure of the employees typically performing sedentary work, the temperature will constantly rise for three consecutive hours, reaching a peak of 21°C (ΔT=3°C);
C. *During mid-morning*, due to increasing occupancy and heat gains from occupants and electric equipment, the temperature setpoint will start to drop, allowing for stimulating employees' alertness after a few continuous sedentary working hours;
D. *During lunch*, when occupants are usually not sitting at their desk, the temperature setpoint is reduced down to 19°C;
E. *After lunch*, due to elevated metabolic rates after the meal intake, the heating setpoint will first remain low and then rise in the afternoon hours (ΔT=1-2°C) to compensate for continuous sedentary work at a low metabolic rate;
F. *In the afternoon*, the setpoint will drop to 19°C to avoid potential drowsiness at prolonged exposure to a constant and warm environment, and then further drop towards the end of the working day as people start departing from the office until reaching the nocturnal setback of 16°C.

The definition of extreme patterns such as "*early arriver-late leaver*" (EA-LL), and "*late arriver-early leave*r" (LA-EL) allowed for exploring different energy-saving scenarios, assuming that the "*early arriver - late leaver*" (EA-LL) profile represents the highest consumer scenario, while the "*late arriver - early leaver*" (LA-EL) profile represents the lowest consumer scenario.

Heating energy demand reduction

The results of the heating demand of different setpoint profiles are presented in **Figure 4**. The comparative analysis shows the reduction in the heating demand with respect to the *baseline* scenario. The *standard-based* scenario (SIA 2024:2015) allows for reducing the demand by –51%, while the dynamic heating setpoint profiles allow for further reducing the demand by –53% ("*early arriver-late leaver*"), by –56% ("*regular*"), and up to –59% ("*late arriver-early leaver*"), respectively.

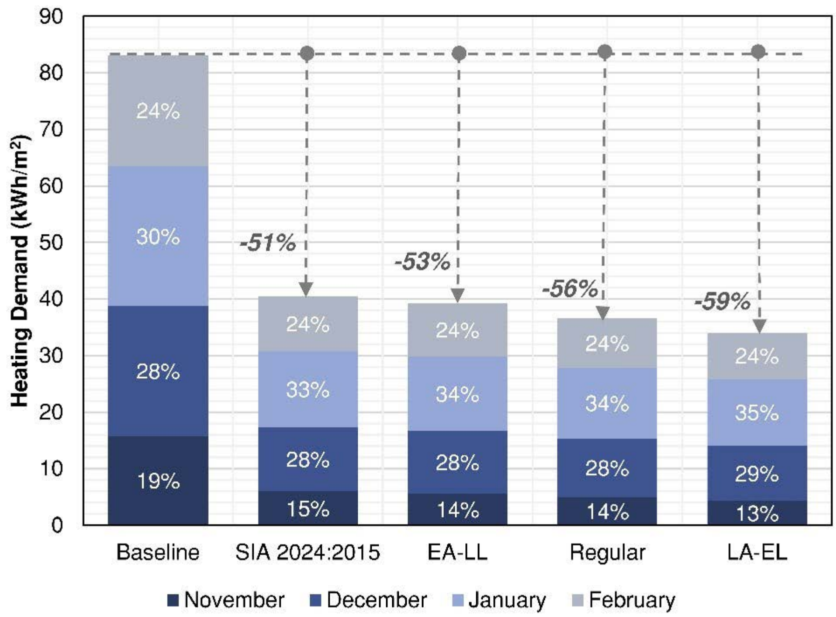


Figure 4. Energy demand for space heating according to different heating setpoint profiles.

The most impacting months on the heating demand in all scenarios are December (28-29%) and January (30-35%). As expected, the profile LA-EL resulted in the lowest heating demand among all three dynamic profiles due to the shortest working hours (8 hours/day), while EA-LL resulted in 6% more heating demand due to the longest working hours (12 hours/working day). Notably, EA-LL heating demand was 2% less than the standardized scenario at a constant 21°C during working hours. These results highlight that there is a potential improving building energy performance by modifying the thermostat operation of the case study office.

Conclusions

The advantage of existing buildings is the possibility to know more about occupants compared to the design stage. Thus, by considering the daily routines of employees and the corresponding occupancy profiles, *tailored-to-occupant* heating approaches can be defined rather than using standard ones. As a concrete example, occupancy of the case study open space office in Switzerland is analyzed, and three setpoint profiles **EA-LL** ("*early arriver-late leaver*"), **regular**, and **LA-EL** ("*late arriver-early leaver*") are identified, based on the hours of individuals coming to work, having lunch, and departing from work. Dynamic daily temperature profiles are drawn in the range of 18-21°C with a 1K/h drift rate by aiming to introduce more moments of positive alliesthesia, and slightly more exposure to a cooler environment to keep employees potentially alert during prolonged sedentary work and avoid potential drowsiness. All in all, this work demonstrated that by implementing customized heating profiles, heating energy demand could be reduced up to 60% compared to the existing practice. Obviously, this can be achieved by going to a certain extent beyond the comfortable range of temperatures. While such thermal environments are not very acceptable in the current practice, there is a great chance that this would change in the future as more attention to human well-being in buildings is paid. ■

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Requirements for health-promoting and resilient HVAC and IEQ control

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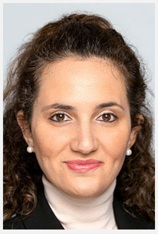

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Concepts for HVAC and IEQ control are challenged by a multitude of traditional and new requirements. This article aligns these frontiers within the human-building resilience framework and discusses resulting performance needs and advancements for HVAC and IEQ control together with existing research gaps from the users' comfort and health perspective.

Keywords: Resilience; health; comfort; adaptation; alliesthesia; IEQ control; energy

Historical requirements

Traditionally, the design of HVAC systems and IEQ controls requires an optimization of user safety and comfort, together with resource efficiency among others. Both requirements are regulated by existing standards and technical guidelines, aiming at high user comfort and safety through low resource usage. First requirements were derived from occupational safety and health perspectives dating back to 1700 and before [1]. Since the two oil crises in the 1970's, energy efficiency not only became a market advantage, but more and more turned into a requirement, and regulations constantly got stricter.

For a long period, both types of requirements were embedded in rather stable, steady state contexts. Recent developments with respect to the COVID-19 pandemic, climate change, and human comfort and health aspects, however, challenge these existing approaches and emphasize simultaneous considerations of the demands for robustness, dynamics, flexibility and individualization. While these needs partly appear contradictory to each other, their consideration offers new trajectories and perspectives for technological advancements as outlined in the following.

Contemporary and future challenges and opportunities

The last two decades can be characterized by an explosion of new requirements for and challenges to traditional views on HVAC and IEQ control (**Figure 1**), of which a few will be highlighted in the following.

Climate change and the COVID-19 pandemic have emphasized the importance of IEQ and *flexibility*. Climate change decreases predictability of future conditions under which HVAC and IEQ controls implemented today will have to operate. As far as predictions tell, heat waves and floods will be more frequent and severe, summer nights warmer and pollen periods longer than today, among others [2]. On the one hand, these extreme weather events pose new challenges to IEQ control concepts characterized by a lower predictability and slower adaptability. On the other hand, consequences of climate change are predicted to increase negative consequences for the populations' mental (e.g., elevated risk for depression, anxiety and post-traumatic stress disorder, which will be maintained even years after exposure) and physical (e.g., increases in total, cardiovascular and respiratory mortality and morbidity) health [3]. The ongoing COVID-19 pandemic gave a glance at the importance of the indoor environment for the future – though such 'discovery' did not come as a surprise for those involved in this area for many years. In addition, the pandemic accelerated the move towards home office and mobile working. Especially the former raises questions on the provision of IEQ in residential places previously meant for relaxation, recharging, and social life, now becoming simultaneously work places and as such building the foundation for the height of ones' earnings, and potentially affecting career opportunities. These challenges of climate change and COVID-19 pandemic highlight the need for providing *safe* indoor conditions with *robust,* but *flexible* concepts.

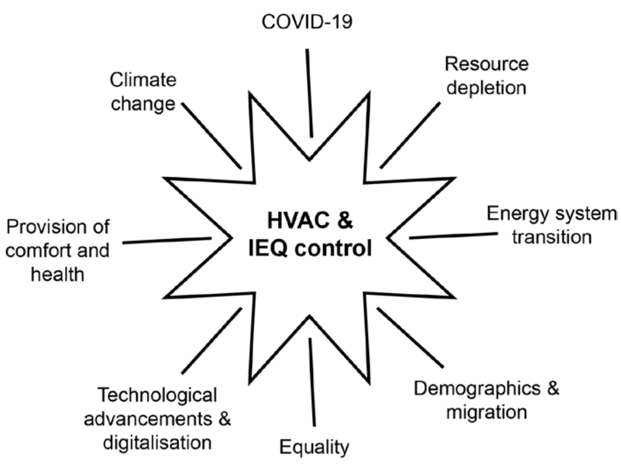

Figure 1. Traditional and new challenges for HVAC and IEQ control.

Energy resource depletion and energy system transition require an intensified search for the most *efficient* solutions together with new, partly *dynamic* concepts to deal with a higher share of fluctuating renewable energies. In addition, increasing costs for energy usage and materials raise questions regarding equality of access and *affordability* (see also next point). Such effect is emphasized – unless countermeasures such as additional payments are implemented – in the context of the move towards increased home office hours, since some energy costs will shift from the employing organizations to the employed individuals.

Demographic factors, migration and equality will add additional variance to required conditions, ideas on comfort requirements, and cultural practices in the interaction between occupant and building – overall requiring a high degree of *flexibility* and *robustness*. HVAC and IEQ control concepts need to consider a partly more vulnerable society and increasing injustice in access to required resources to avoid long-standing challenges due to energy insecurity and inequality [4]. For example, local split-type air-to-air air-conditioning units permit those able to afford them cooling in summer, while increasing urban heat island and noise pollution effects for others in the immediate surroundings and thereby reducing their potential for natural ventilation concepts.

Technological advancements and digitalisation have led to numerous innovations, efficiency improvements and will lead to further opportunities. At the same time, potential risks in relation to ecological, economic, and social dimensions need to be put into perspective [5]. One example is related to adaptive control opportunities, i.e. an individual occupants' control over window state, set points, among others. Some of the first automation systems completely removed the control options for the occupants. Such misconception was reduced only after an increased understanding that **actual adaptive control opportunities** are a pre-requisite for occupants' satisfaction [6]. Therefore, especially more complex HVAC and IEQ controls (if they really need to be that complex) require understandable interfaces and need to provide adaptive control opportunities. At the same time, it is not clear to what extend control is required, because too much control and the need to constantly hassle with IEQ settings has been reported as a source of stress and dissatisfaction itself [7].

At last, a **changing approach towards the provision of comfort and health** is one of the most, if not the most important aspect related to changed requirements. Through efficiency thinking and the neutrality paradigm, comfort has been for long, and largely still is, defined as a provision of conditions, which are leading to a maximum relief from potential thermal, visual, IAQ, and acoustic stressors. Recent discussions promote to change the view from relief (i.e. maintaining neutrality) at all times, towards relief where necessary, in combination with encouragement (i.e. increasing adaptive opportunities) and enjoyment (i.e. potential for perception of alliesthesia) [8, 9]. While, for example, the provision of thermally neutral conditions is still standard in practice, research highlights the benefits of IEQ control applying more varied conditions or naturally occurring dynamics for resource efficiency [10], satisfaction [11], and also health-related parameters [12, 13]. The provision of visual conditions changed from considerations of minimum illuminance levels alone to considerations of circadian effects and the quality of lighting [14]. Such approach is in line with the trend in medicine from a focus on risk assessment, which was dominant in the 1970's, towards risk management including well-being and salutogenesis from 2000 onwards [1]. These upcoming paradigm shifts, towards a more holistic view on comfortable *and* health-promoting conditions, add further requirements to HVAC and IEQ control in terms of *flexibility* and opportunities for *individualization*. At the same time, basic requirements such as the avoidance of toxins in the air or other harmful conditions, should stay in place and be developed further according to the newest level of information and evidence. Furthermore, multi-sensory thoughts are required [15]: for example, having large windows for maximum daylight exposure is not helpful by itself in case the overall building design requires day-long shading (e.g. to avoid overheating), as this may lead to the reverse or rebound effect of reducing the potential for such daylight exposures.

Resilience thinking from human perspective and required approaches

Above described challenges lead to new requirements for future HVAC and IEQ control, including parameters such as *flexibility*, *robustness*, *dynamics*, *individualized solutions*, *adaptive controls opportunities*, *encouraging*, *health-promoting*, and *equality*. At first sight, those parameters could seem to contradict themselves, like robustness and dynamics (**Figure 2**). At the same time, these requirements can complement each together, when extending the definition of resilience beyond the robustness of buildings by two means: the first mean is to extend the definition of a resilient system from the human perspective, towards a combined human *and* building resilience (**Figure 3**). This approach does not start with the focus on certain room temperatures or energy efficiency levels as questioned earlier [14], but with requirements for relief, encouragement and enjoyment. Guiding questions will be, for example, when and how to keep warm or cool, when and how to offer physiological, behavioural, and psychological adaptive opportunities, and when and how to offer enjoyment as stress relief or motivational driver. The second mean is to consider a resilient system that is not only able to flexibly react to a potential shock or stressor, and restore itself afterwards, but that can also

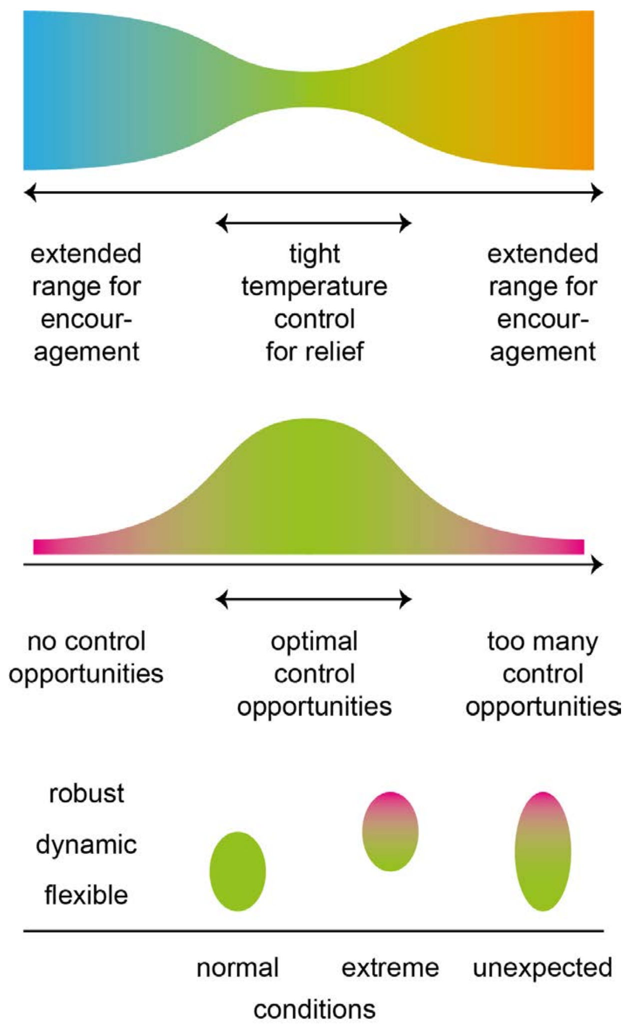

Figure 2. Three areas of tension of future HVAC and IEQ control.

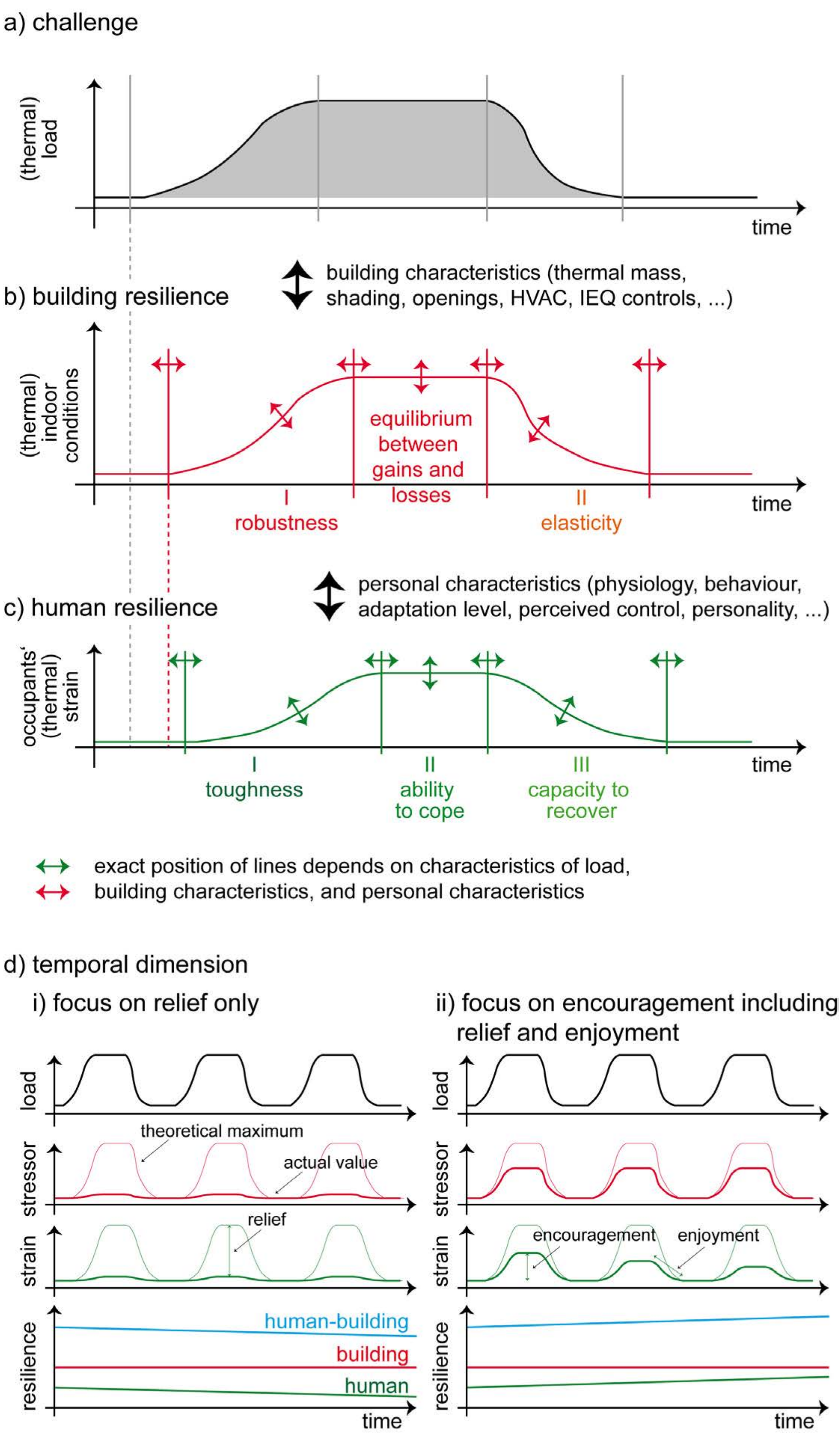

Figure 3. Simplified version of the human-building resilience framework (a-c) including hypothetical temporal evolution of human building resilience (d). Robustness and toughness describes the buildings' and human ability to withstand a load or stressor. Elasticity and capacity to recover describe the ability to return to initial state after removal of load and stressor (adapted from [8,9]).

evolve further in order to increase its capacity before the next shock or stressor occurs [8, 9].

Following the above, resilient and health-promoting built environments are envisioned to provide sufficient relief (prevention), the right dose of encouragement (salutogenesis), and potential for enjoyment for all. Hence, future HVAC and IEQ control trajectories need to provide energy efficient solutions for this balance, while considering the dynamics of multiple environmental stressors and their interactions, the psychological load and potential interactions with the built context, the physical load, and the individuals' characteristics and needs. Such vision may appear utopic and unreachable and will definitely require further research, as several aspects are lacking full evidence. However, we argue that similar to the WHO definition of health from 1946, which defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity", and has been denoted as utopic by some, it is crucial to make a first step by establishing such vision.

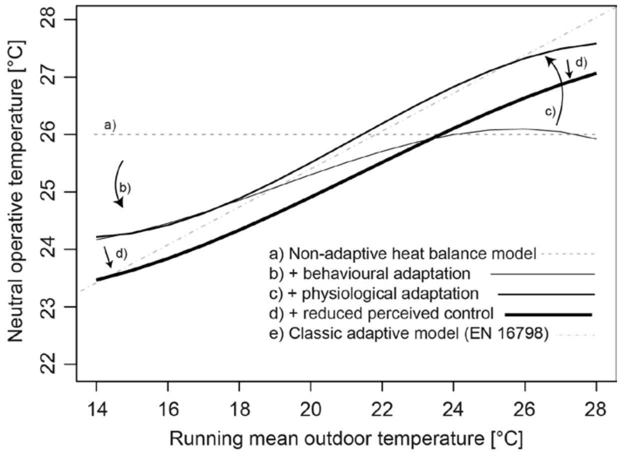

Figure 4. The adaptive heat balance framework enables the prediction of the effect of individual adaptive mechanisms on thermal perception in combination with the six classical influences on human heat balance (adapted from [16]).

Accordingly, concrete steps can be:

(1) Considering resilience by emphasising the need to increase human resilience in the long term. This requires HVAC and IEQ control approaches to support opportunities for adaptation and alliesthesia, and to not only strive for an elimination of even mild stressors. In contrast, evaluating solutions on existing (thermal) adaptation levels, but with future climatic conditions, may prescribe specific cooling solutions. This, however may ignore the adaptation potential when designing for encouragement and lead to rebound effects. Still, further advancements in the prediction of individual aspects of human adaptation are necessary (**Figure 4**) [16].

(2) Approaching resilience of the human-building system including the human, by passive measures (e.g. within the building envelope), and active measures (e.g. through elements of the HVAC system), and not through individual components. This point emphasizes the need for multi-disciplinary, multi-dimensional, and multi-sensory approaches. From the human perspective, flexibility in adaptive controls and measures to fulfil individual needs are relevant. In contrast, focusing on single aspects rather than a holistic approach may lead to unintended energetic and non-energetic side-effects or rebound.

(3) Supporting capacity building of the human-building system, including HVAC and IEQ control under normal operation modes, while being designed for certain robustness to extreme conditions. The robustness then allows occupants sufficient time and opportunity for behavioural and physiological adaptation – something achieved with a high thermal, visual, and ventilation autonomy. For example, rising temperatures in an acute heat wave need to be buffered first, and even with power shortages, the indoor environment needs to keep acceptable conditions.

(4) Considering resilience beyond the individual building towards the neighbourhood or urban scale. Take, for example, above example of decentralized air-to-air air-conditioning units, which reduce (as long as power is available) the thermal strain for the occupants, while increasing the load for adjacent buildings [17].

(5) Creating easily understandable building, HVAC and IEQ concepts in normal and in crisis mode. Best solutions do not require special information such as guidebooks, which will likely be lost soon after operation starts, but are self-explanatory like a window handle or fan switch.

Overall, we are living in an exciting period with dynamic changes at several levels, asking for innovative and creative solutions to improve life indoors. ■

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Achieving decarbonization: challenges and opportunities of green hydrogen




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Identified among the key pillars to achieve decarbonization, hydrogen, specifically the green one, will play a strategic role against climate change. Assessing the opportunities and challenges of its adoption, this work outlines the hydrogen (r)evolution in the transition agenda towards 2050, shifting from the global scale to the European one.

Keywords: energy transition; green hydrogen; long-term strategies; decarbonization.

Introduction

Several interventions, aiming to achieve the ambitious and urgent targets needed to actively and rapidly fight against climate change issues, are at the centre of worldwide policies and long-term strategies. Deepened by the recent COP26 at Glasgow [1], the goal of 1.5°C as limit for global temperature rising seems to require greater efforts, starting from energy systems and involving all other sectors. This desired changeover will affect both energy production and consumption, specifically concerning the diffusion of climate-neutral solutions and the development of new energy infrastructures, in parallel with the substitution of well-established sources like fossil fuels [2]. A transition away from fossils to climate-neutral solutions will play a crucial role, considering that energy-related carbon dioxide (CO_2) emissions represent three-quarters of the global greenhouse gases (GHG) emissions today [3]; in particular, the robust electrification of end uses and the decarbonization process are the two major developments that energy systems are experiencing [4]. This shift is not limited to energy aspects but involves transformations of "the broader social and economic assemblages that are built around energy production and consumption" [5]. In this context, it is of primary importance to identify the appropriate long-term strategies towards a carbon-neutral 2050, through the identification of the key pillars driving the decarbonization process. Specifically, renewable energy deployment, energy efficiency interventions, electrification of end uses, clean hydrogen adoption and sustainable bioenergy represent promising candidates to make the transition happen [6]. Among the key pillars of the transition, this paper concentrates on hydrogen exploitation. Identified as valuable energy carrier and chemical feedstock, hydrogen represents one of the irreplaceable drivers of the transition to tackle climate change issues, specifically if produced from renewable energy [7,8,9]. Hydrogen is experiencing "an innovation turning point", concerning its potentiality to decarbonize challenging sectors, specifically those that are harder to electrify (i.e., shipping, aviation, heavy industry, long-haul transport) [6,10]. One of the biggest opportunities, in terms of innovation concerns hydrogen electrolysers, which represent a technological option that can contribute to the CO_2 emissions reductions between 2030 and 2050 according to the net zero pathway [3]. In the light of the above, studying hydrogen, in the attempt of deepening its opportunities and criticalities, perfectly fits within the mentioned carbon-neutral view. Therefore, recognizing the crucial role of hydrogen in the complex energy transition framework, this work seeks to deepen the potentialities of this vector and to assess its main challenges, focusing on how countries worldwide are paving the way to its adoption. The paper underlines how the role of policy makers can become crucial for spreading innovative measures and technologies, through the development of informed interventions and strategic actions. Ad-hoc long-term strategies are required to drive the transition towards 2050, considering that now, reversing from the past, political systems have become a determinant of energy transitions [11].

Hydrogen through its main drivers and main barriers

This section aims to describe the different ways of hydrogen production that are already used, available or under study. Around 120 million tonnes of hydrogen are produced yearly, two-thirds of which are of pure hydrogen, while the remaining part is a mixture of other gases [12]. When analysing the commodity, it is important to distinguish the possible production modes; specifically, diverse colours (i.e., grey, brown, black, green, blue, pink) are used in literature, aiming to create a common language for hydrogen and to effectively select real carbon-neutral solutions. About 95% of hydrogen used worldwide (the same percentage is valid if considering the sole European Union) is produced using fossil fuels, generally classified as grey type [7]. Mostly exploiting the steam methane reforming process, grey hydrogen production causes an increase of CO_2 emissions, slowing down the pace of transition; similar considerations are valid for the so-called brown (or black) hydrogen, produced using coal, and representing 19% of the total hydrogen production [13]. Specifically, the term green hydrogen is used to indicate the commodity produced by water electrolysis exploiting renewable energy, which represent less than 1% of the global hydrogen production [6]. This typology is gaining interest, since, due to the negative environmental impacts that the production of grey and brown hydrogen has, it is widely recognized the

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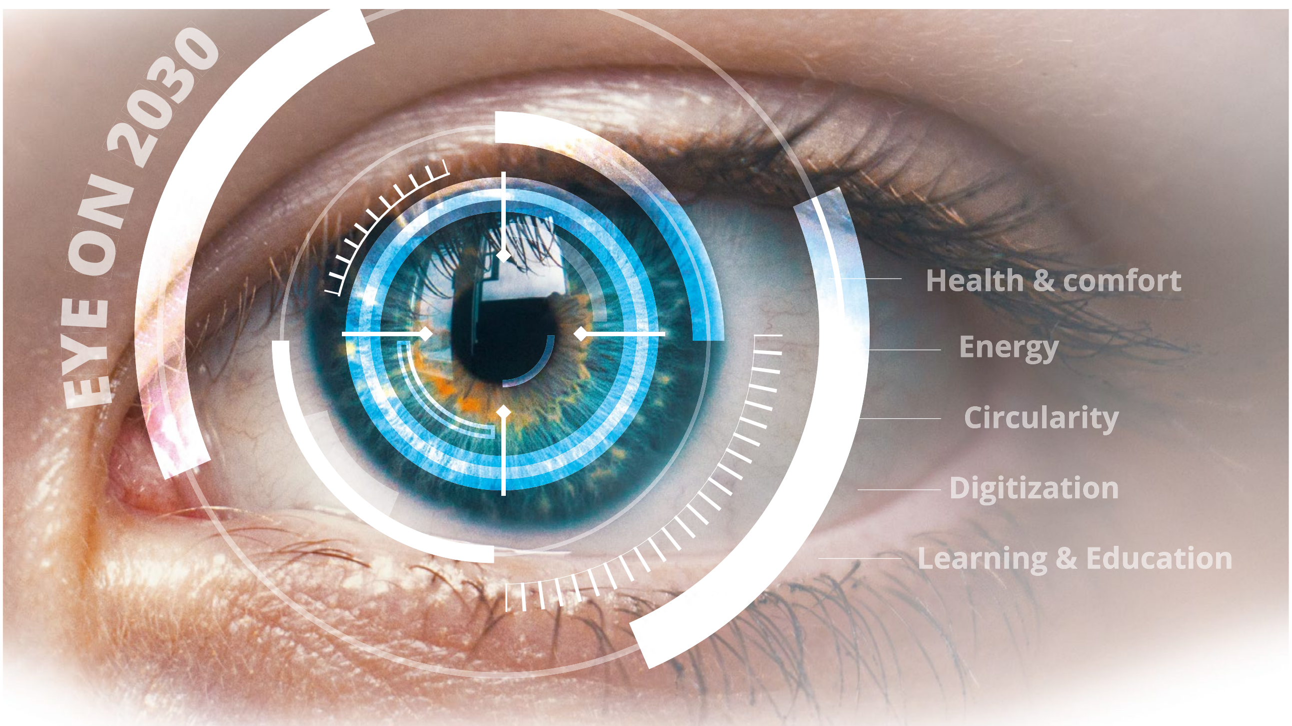

need to convert all the hydrogen based on fossil fuels to the green type. Moreover, attention is also devoted to the blue hydrogen; produced from natural gas as the grey one, the main difference relies on the possibility for the CO_2 emitted by the production process to be compressed and liquefied, then transported and stored (Carbon Capture and Storage, CCS) or also supplied to a process, reusing CO_2 in new products (Carbon Capture and Use, CCU) [14]. According to the net zero pathway [3], the role of blue hydrogen will be crucial to get the long-term targets, with a coverage of 40% of the total production of the energy carrier, while the remaining percentage will rely on renewable energy (i.e., green hydrogen) [3]. However, it is worth mentioning that, at present, the required CCS and CCU technologies for the blue hydrogen exploitation are still not technologically ready and economically competitive [13,15]. For the sake of completeness, also pink hydrogen is discussed in literature, which is associated to the exploitation of nuclear energy for the water electrolysis process. Recognizing the need to put strong effort in green hydrogen technological advancement, the most evident factor slowing down its adoption is of economic nature; specifically, at present, the price of grey hydrogen ranges from 0.5 to 1.7 USD/kg, while the adoption of CCUS technologies (blue type) increases the levelized cost of production up to around 1 to 2 USD/kg [16]. The use of renewable electricity to produce hydrogen costs from 3 to 8 USD/kg [16], clearly constituting a key barrier to its scaling up with respect to the hydrogen produced by fossil fuels, which is responsible of around 900 million of tonnes of CO_2 emissions each year [16]. However, the economic barrier is not the only one to be addressed; in detail, **Table 1** reports the main drivers and barriers concerning green hydrogen, adapted from [17].

Having set with undisputable certainty that the green option is the most effective choice among the alternative ways of hydrogen production, how to effectively use this clean hydrogen is still a remarkable challenge to be addressed. Today hydrogen is mostly exploited in industrial applications (i.e., oil refining, ammonia production, methanol production, steel production), with an increase of methanol and ammonia demand expected for the medium-term, while in the long-term steel and high temperature production can determine a huge growth for green hydrogen demand [18]. Specifically, hydrogen can give a contribution to the hard-to-decarbonize sectors, for which the direct electrification and use of renewable energy is not a viable solution as it is for other sectors [19]. Thanks to the possibility to shortly reach very high temperature levels, green hydrogen can substitute coke, leading to the decarbonization of the sector of iron and steel production, which currently determines 7.2% of the global CO_2 emissions [20]. For what concerns transport, hydrogen is a promising solution for decarbonizing railway, aviation and shipping sectors, even if an open debate is ongoing in relation to real opportunities and challenges [13]; moreover, according to the International Renewable Energy Agency (IRENA), in 2050, a request of about 46 million of tonnes of green hydrogen will come from the naval sector [21]. Finally, looking at the building sector and its potentialities to be decarbonized through end uses electrification, some promoters of hydrogen argues that the actual gas pipelines could be exploited for transporting blending hydrogen [13], while its percentage in the mix with natural gas is at the centre of debates and technological studies and advancements are ongoing.

The role of hydrogen in the long-term strategies: global and national insights

Hydrogen effectively contributes to the definition of energy transition scenarios; specifically, "the more ambitious the GHG reduction target, the greater is the amount of green hydrogen expected in the system" [17]. In fact, the first key recommendation from the International Energy Agency (IEA) to scale up hydrogen refers to the need to establish the role hydrogen must play in the long-term energy strategies

Table 1. Green hydrogen: main drivers and barriers, adapted from [17].

DRIVERS	BARRIERS
Low variable renewable electricity costs	High production costs
Technologies ready to scale up	Lack of dedicated infrastructure
Benefits for the power system	Energy losses
Government objectives for net-zero energy systems	Lack of value recognition
Broader use of hydrogen	Need to ensure sustainability
Interest of multiple stakeholders	High production costs

[18]. In particular, it in envisioned that the share of green hydrogen will be significant in the future energy mix if no fossil fuels subsidies will be guaranteed in the long-run; moreover, assumed that the variety of cost assumptions could lead to a wide range of different green hydrogen deployments, its spread will rely on economic challenges, but will be also strongly affected by political, social and environmental priorities [17]. Having set this, it is crucial to understand that geographical constraints and cross-border dynamics play a strategic role in defining the adequate hydrogen pathway, being tailored on several government priorities, opportunities, and strategies. In fact, the term "transition" in its common meaning must be able to capture also more widely changes in the spatial organisation of energy systems and economic activities, being dependent also on the relationships between one country/region and others [22]. Among the policy interventions proposed by IRENA [19], aiming to scale up the green hydrogen adoption with respect to different contexts of actions, four measures are highlighted: (i) acceleration of manufacturing capacity, tackling of high investment costs of electrolysers and enabling of infrastructure; (ii) reduction of renewable electricity costs; (iii) advancement in sustainability; (iv) enabling of demand and market entry for hydrogen [19]. Specifically, effective policy measures should concern capacity targets, fiscal incentives, auctions, green gas targets, international agreements, financing, planning, creation of standards, guaranteeing of origins, research and development [17]. The adoption of ad-hoc policies depends on how advanced each country hydrogen market is and on how governments intend to address the climate change issues and react to the related challenges with respect also to their possibilities. Pflugmann and De Blasio [23], taking care of (i) RES endowment, (ii) renewable freshwater resource endowment, and (iii) infrastructure potential, proposed five groups to classify countries according to their possibility to produce green hydrogen, grouped among "export champions", "renewable-rich but water-constrained with high infrastructure potential", "renewable-constrained with a high infrastructure potential", "resource-rich with high infrastructure potential", "resource-rich with low infrastructure potential" [23]. Despite the possible geographical constraints and barriers, the reaction of different countries to the "call for hydrogen" is encouraging. In fact, at the date of publication of the IEA report "The future of hydrogen" in 2019 [18], only Japan and Korea had developed national hydrogen strategies and France had announced an ad-hoc hydrogen plan. After that, Australia, Canada, Chile, the Czech Republic, France, Germany, Hungary, the Netherlands, Norway, Portugal, Russia, Spain, the United Kingdom, Colombia, together with the European Commission, had published their own strategies referred to hydrogen exploitation, while Italy and Poland had released their strategy for public consultation; meanwhile 20 other countries worldwide are developing their own plans [16]. Besides the specific proprieties of single countries, it is important to mention that there are also geopolitical implications that cannot be left behind: the creation of new dependencies between states in case of large-scale imports; (ii) the change in the interest and actors of the energy transition if hydrogen throws a lifeline to fossil fuels market; and (iii) the possible escalation of rivalry between countries [24]. In line with this, potential and established co-operation among countries is ongoing; specifically, not only bilateral coordination between governments but also international co-operation agreements have been established among governments and private entities [16]. The development of multilateral initiatives and projects can be a key enabler of knowledge-sharing, also promoting the elaboration of best practices to connect a wider group of stakeholders [16]. Focusing on European Union, the European Commission adopted its Hydrogen Strategy on July 2020 [25], aiming to study and strategically define the contribution of green hydrogen to a climate-neutral Europe for 2050 [26]. Covering the entire hydrogen value chain, the European Strategy explores how this vector can unlock investments supporting economic growth and job creation, which is a critical point to be addressed, mostly to encourage a faster recovery from the Covid-19 crisis [26,27]. Recognizing the need of developing an ad-hoc investment agenda, through the European Clean Hydrogen Alliance and proper recovery plans, other key actions aim to scale up demand and production, promoting hydrogen adoption in transport sector, introducing certifications, common standards and effective planning of infrastructure and adequate market rules, boosting research and development and strengthening the EU international leadership through new missions, cooperation and agreements [25]. It is widely recognized that hydrogen can represent a win-win option for the whole Mediterranean region; specifically, the well-established RES sector and the hydrogen production in the Northern shore of the Sea could support the installation of production sites in the Southern and Eastern coasts and promote a share of knowledge and activities among the interested countries [28]. Moreover, reinforcing hydrogen and its role as key pillar to achieve carbon neutrality, in the Fit for 55 Package, the European Commission has set the

objective of including a 50% of renewable hydrogen consumption in industry by 2030 [29]. As a result, Member States are planning to use for hydrogen on average 7% of the funds regarding the green transition pillar of their Recovery and Resilience Plans (RRP); in line with national priorities, it is interesting to note that the percentage increases up to 24% according to German plans, while the Italian percentage falls to 3% [30]. Despite the national peculiarities, hydrogen clearly represents a strong candidate to guide the energy transition process, identified as "an investment priority to boost economic growth and resilience, create local jobs and consolidate the EU's global leadership" [31]. **Figure** below summarises the overview conducted on green hydrogen, specifically fixing why, where [19], and how [17] to use it.

Conclusions

In the attempt to achieve the climate neutrality target for 2050, governments worldwide have planned and adopted strategic interventions involving hydrogen. Specifically, the exploitation of renewable energy for water electrolysis makes green hydrogen a perfect candidate to speed up the transition process, primarily allowing the decarbonization of hard-to-abate sectors.

The paper investigated the hydrogen (r)evolution, analysing the main drivers and barriers to the green hydrogen diffusion. It is undoubted that the role of hydrogen in the energy transition and the speed of technological advancements in this sector is dependent on the different long-term strategies adopted by single countries, in line with their priorities and potentialities, as well as on the possibility to exploit bilateral and multilateral agreements between countries and on the research and development progresses. The green hydrogen adoption must be a key priority in the next years, to favour its spread worldwide and to make the long-term pathways traced to achieve decarbonization more effective. ■

Acknowledgments

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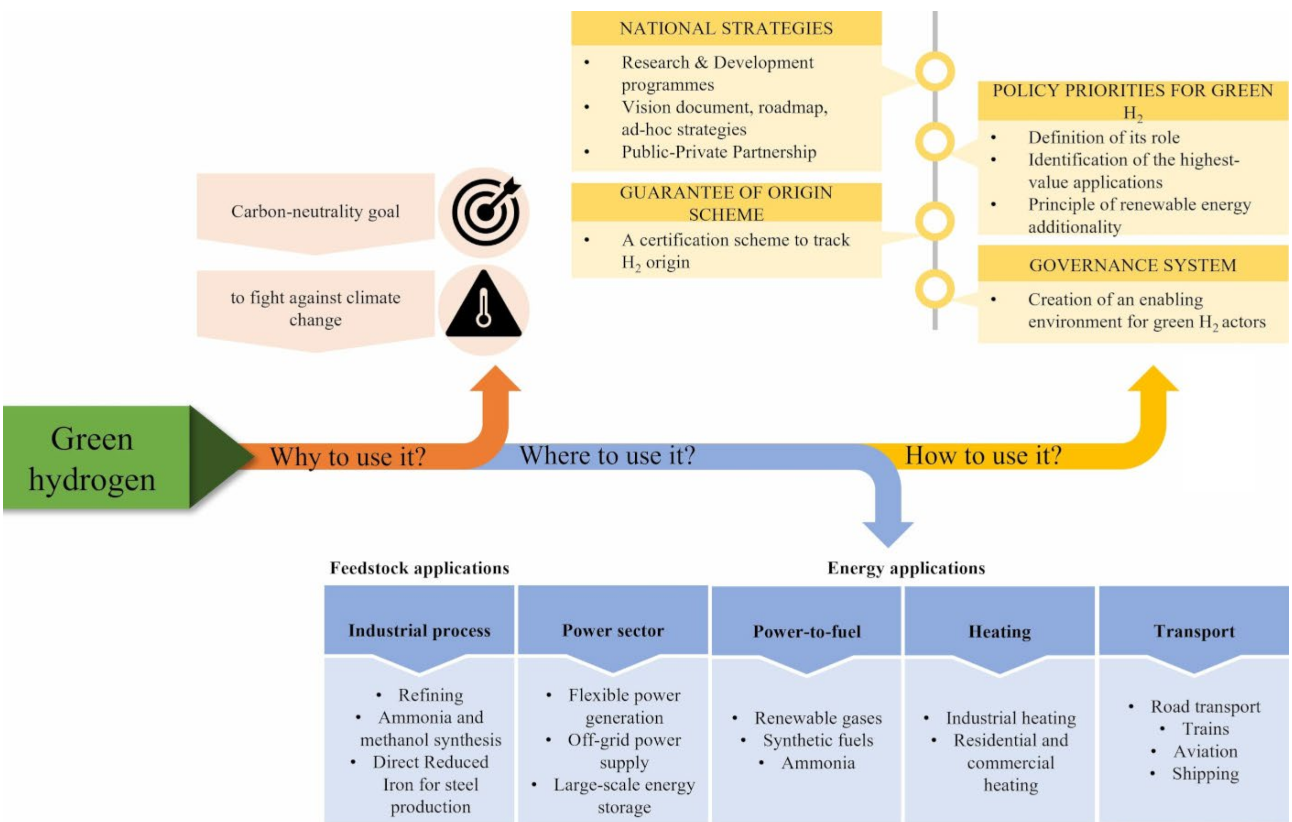

Overview on why, where, how to use green H_2.

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Articles

Analysis of design solutions for overpressure systems in accordance with EN 12101-6

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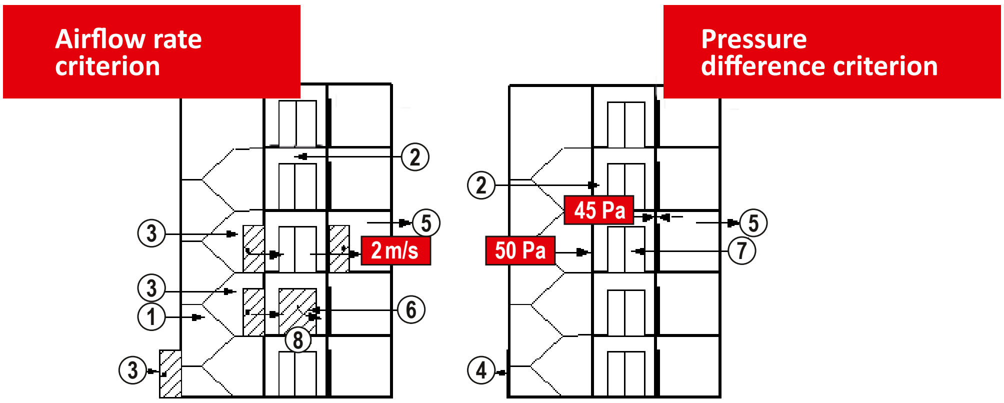
The EN 12101-6 standard defines six classes of pressure differential systems: A, B, C, D, E and F. A designer working with an expert should establish which class to use in a given building. Depending on the choice, certain system design criteria introduced by the standard must be met.

In this article, we will focus on the class B pressure differential system and the airflow rate criterion, that is the air supplied to a zone engulfed in fire, which is 2 m/s (**Figure 1**). The airflow rate must be ensured at an open door in a baffle between the zone engulfed in fire and protected space (an entrance hall or a lift foyer).



LEGEND

1. Staircase
2. Fire lift lobby
3. Open door
4. Closed door
5. Air exhaust
6. Fire lift door open
7. Fire lift door closed
8. Lift shaft air exhaust

Figure 1. Requirements for positive pressure differential system Class B.

This criterion can be met by supplying an adequate quantity of air to the stairwell, and then forcing it through an open door to the entrance hall and the zone engulfed in fire, or by first supplying air directly to the entrance hall, and then to the zone engulfed in fire. Before we decide on a place to supply air in order to meet the airflow rate criterion of 2 m/s, we should conduct an architectural building analysis and an airflow dynamics analysis between the place where air is supplied and the place where it is extracted.

Let's assume that the doorway, for which the airflow rate is measured, has an area of 2 m². The quantity of air that should be supplied is then 2 m² × 2 m/s × 3 600 = 14 400 m³/h. It is important to know that the air will only flow from the overpressure zone if the room engulfed in fire has an appropriate exhaust located outside the building. If there is no exhaust, the pressure between the zones will be equalized, resulting in a dynamic migration of smoky air to the protected zone (i.e. the staircase /lift foyer /entrance hall).

Let's first agree with the architect on a solution to extract hot smoke from the zone engulfed in fire (mechanical or gravitational). The extraction value must be equal or greater than 14 400 m³/h.

Today, we are going to discuss solutions using gravitational extraction of hot smoke from a zone engulfed in fire.

Gravitational exhaust ventilation

When using this solution, we need to ensure the lowest possible calculated airflow resistance as the resistance value directly impacts the entire pressure differential system output. In the class B pressure differential systems, with an airflow rate of 2 m/s at the staircase the door is open not only at the storey engulfed in fire, but also below this storey and at the storey where evacuation from the building takes place (usually the ground floor).

a) Let's assume that the entire air is supplied to the staircase (**Figure 2**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the staircase and entrance hall, and then through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is pushed out of the building through the provided exhaust. Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). We have two doorways. The total resistance equals 12 Pa. Next, let's assume that the air will be extracted through a smoke exhaust window. It has an area of 2 m². The total resistance thus amounts to 18 Pa. We can therefore state that all the other openings in the staircase require a resistance of at least 18 Pa so that the air passes through an open door in the direction of the smoke exhaust window.

Table 1. *The rate of air flowing through gaps or bigger openings.*

Pressure difference (Pa)	Airflow rate (Pa)
4	1,7
6	2
8,5	2,4
10	2,6
25	4,2
50	5,9

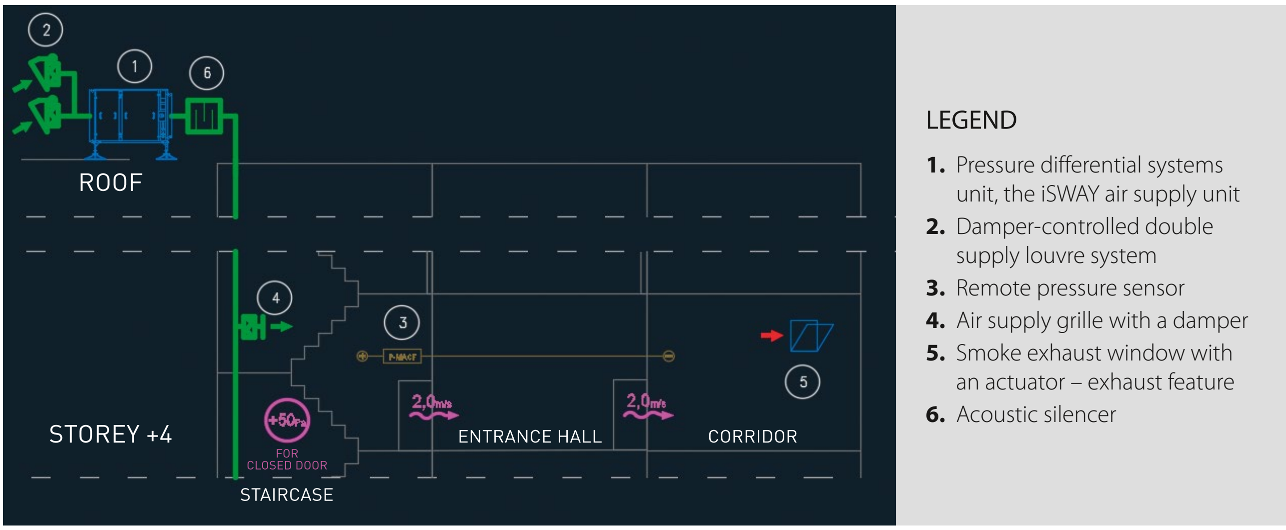


Figure 2. Air inflow into the stairwell.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 18 Pa, the airflow rate must equal 3.5 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply additional 25 200 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow rate criterion with such a gravitational exhaust is 14 400 m³/h + 25 200 m³/h = 39 600 m³/h.

Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N.

ATTENTION! In case of the pressure difference criterion leaks in the staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Only devices with valid certificates stating fan working ranges and system response times should be used.

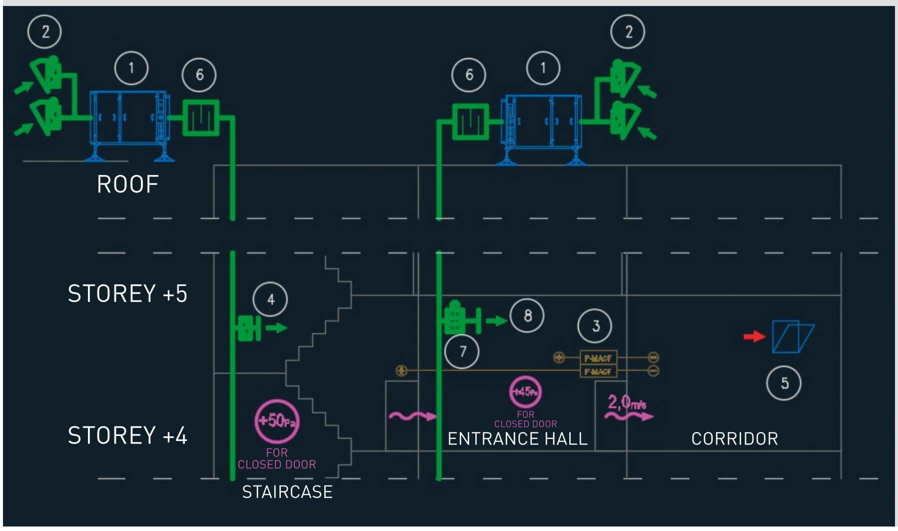
b) Let's assume that the entire air is supplied to the entrance hall (**Figure 3**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is pushed out of the building through the provided exhaust. Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). We only have one doorway, so the total resistance is 6 Pa. Next, let's assume that the air will be extracted through a smoke exhaust window. It has an area of 2 m².

The total resistance thus amounts to 12 Pa. We can therefore state that all the openings in the staircase require a resistance of at least 12 Pa so that the air passes through an open door in the direction of the smoke exhaust window.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 12 Pa, the airflow rate must equal 2.9 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 20 880 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow criterion with such gravitational exhaust ventilation is: 14 400 m³/h + 20 880 m³/h = 35 280 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N. This also applies to the door in the entrance hall to the zone engulfed in fire. Air is supplied to the entrance hall and staircase by two independent devices.

ATTENTION! In case of the pressure difference criterion leaks in the entrance hall and staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Only devices with valid certificates stating fan working ranges and system response times should be used.



LEGEND

1. Pressure differential systems unit, the iSWAY air supply unit
2. Damper-controlled double supply louvre system
3. P-MACF remote pressure sensor
4. STW/GA air supply grille with a damper
5. Smoke exhaust window with an actuator – exhaust feature
6. TAP rectangular acoustic silencer
7. KWP-P-E fire ventilation damper with an actuator
8. STW air supply grille

Figure 3. Air flowing through a doorway.

The above analyses indicate that the choice of a design solution impacts the total quantity of air supplied to protected zones. In accordance with the EN 12101-6 standard additional 15% should be provided due to uncontrollable leaks. Consequently, the number of devices supplying air, electric motor power, power cable cross-section and I&C cabinets may significantly differ. In SMAY's experience, the choice of a solution significantly impacts the total cost of a pressure differential system.

The EN 12101-6 standard defines six classes of pressure differential systems: A, B, C, D, E and F. A designer working with an expert should establish which class to use in a given building. Depending on the choice, certain system design criteria introduced by the standard must be met. In total, we can distinguish five versions of the system based on the mechanical exhaust ventilation. Today, we will discuss three of them while the subsequent two will be described in the next article.

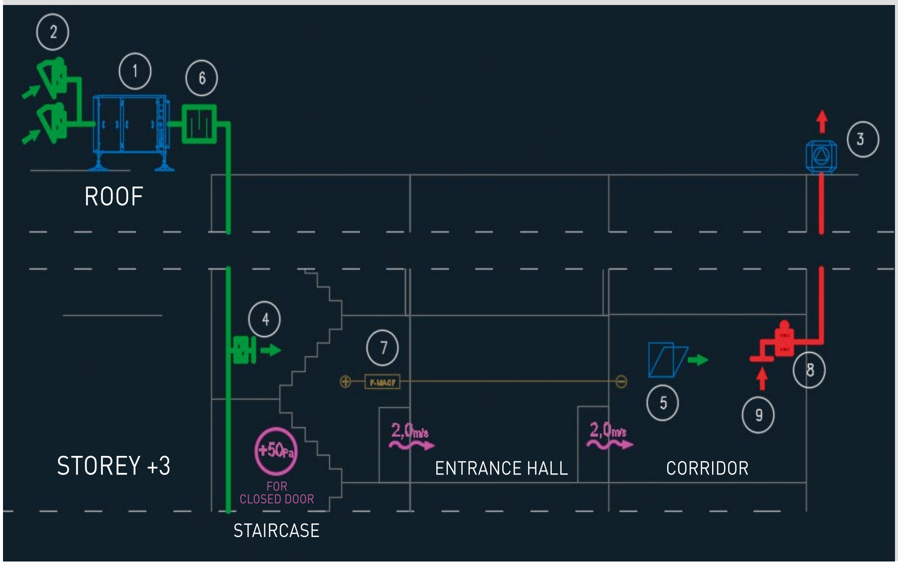
Mechanical Exhaust Ventilation

With this solution we need to seek the lowest possible underpressure in the zone engulfed in fire when the door to the entrance hall is closed, because the underpressure value directly affects the door opening force, which cannot exceed 100 N.

a) Let's assume that the entire air is supplied to the staircase (**Figure 4**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the staircase and entrance hall, and then through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is being transported out of the building by the provided smoke ventilation system. An automatic opening window of 2 m² effective area is planned for smoke exhaust compensation when the door is closed. Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). Since we have two doorways, the total resistance equals 12 Pa. We use mechanical exhaust ventilation. Therefore, no additional resistance is present in this case. The total resistance thus amounts to 12 Pa. We can state that all other openings in the staircase require the resistance of at least 12 Pa so that the air passes through an open door in the direction of the exhaust grille of the smoke ventilation system.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 12 Pa, the airflow rate must equal 2.9 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 20 880 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow rate criterion with such a mechanical exhaust is 14 400 m³/h + 20 880 m³/h = 35 280 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N.



LEGEND

1. Pressure differential systems unit, the iSWAY air supply unit
2. Damper-controlled double supply louvre system
3. SEFL/REF smoke exhaust fan
4. STW/GA air supply grille with a damper
5. Automatic opening window with an actuator – smoke exhaust compensation feature
6. TAP rectangular acoustic silencer
7. P-MACF remote pressure sensor
8. KWP-P-E fire ventilation damper with an actuator
9. SDS-STW smoke exhaust grille

Figure 4. Air flowing through the doorway from one area to another.

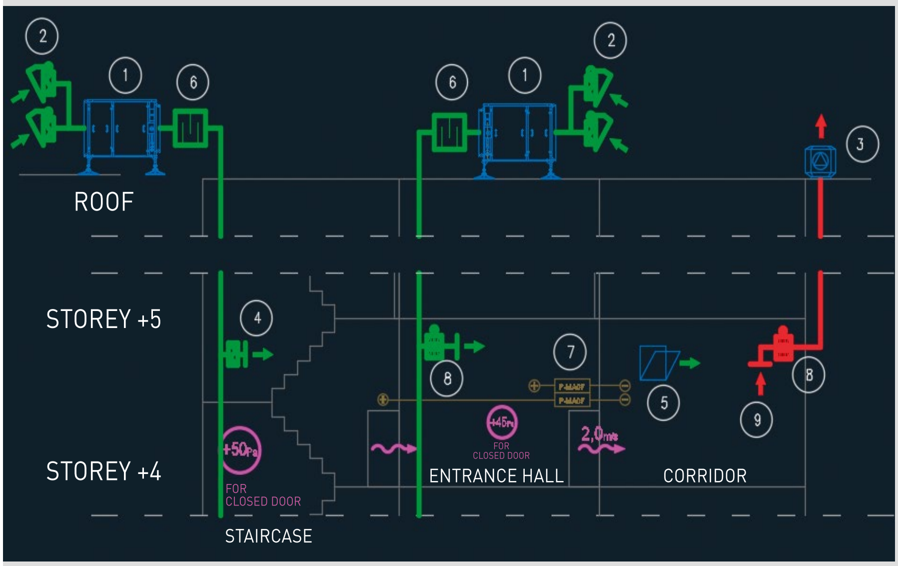
ATTENTION! In case of the pressure difference criterion leaks in the staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Only devices with valid certificates stating fan working ranges and system response times should be used. Additionally, the smoke ventilation system for the zone engulfed in fire shall be designed for the output rate of 14 400 m³/h.

c) Let's assume that the entire air is being supplied to the entrance hall (**Figure 5 and 6**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is being transported out of the building by the provided smoke ventilation system. A hole in the wall between the zone engulfed in fire and the entrance hall with an effective area of 1 m² is planned for smoke exhaust compensation when the door is closed. In order to maintain the 2 m/s velocity of air flowing through the door, we need to supply additional 7 200 m³/h of air to the entrance hall. In total, we supply 14 400 m³/h + 7 200 m³/h = 21 600 m³/h of air to the entrance hall. Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). As we have a single doorway, the total resistance equals 6 Pa. We use mechanical exhaust ventilation, so no additional resistance is present in this case. The total resistance thus amounts to 6 Pa. We can state that all openings in the staircase require a resistance of at least 6 Pa so that the air passes through an open door in the direction of the exhaust grille of the smoke ventilation system.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 6 Pa, the airflow rate must equal 2.0 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 14 400 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow rate criterion with such a mechanical exhaust is 14 400 m³/h + 14 400 m³/h = 28 800 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N. This also applies to the door in the entrance hall to the zone engulfed in fire. Air is supplied to the entrance hall and staircase by two independent devices.

ATTENTION! In case of the pressure difference criterion leaks in the entrance hall and staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Only devices with valid certificates stating fan working ranges and system response times should be used. Additionally, the smoke ventilation system for the zone engulfed in fire shall be designed for the output rate of 14 400 m³/h.



LEGEND

1. Pressure differential systems unit, the iSWAY air supply unit
2. Damper-controlled double supply louvre system
3. SEFL/REF smoke exhaust fan
4. STW/GA air supply grille with a damper
5. Automatic opening window with an actuator – smoke exhaust compensation feature
6. TAP rectangular acoustic silencer
7. P-MACF remote pressure sensor
8. KWP-P-E fire ventilation damper with an actuator
9. SDS-STW smoke exhaust grille

Figure 5. Air flowing through the doorway from one area to another.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). As we have a single doorway, the total resistance equals 6 Pa. We use mechanical exhaust ventilation, so no additional resistance is present in this case. The total resistance thus amounts to 6 Pa. We can state that all openings in the staircase require a resistance of at least 6 Pa so that the air passes through an open door in the direction of the exhaust grille of the smoke ventilation system.

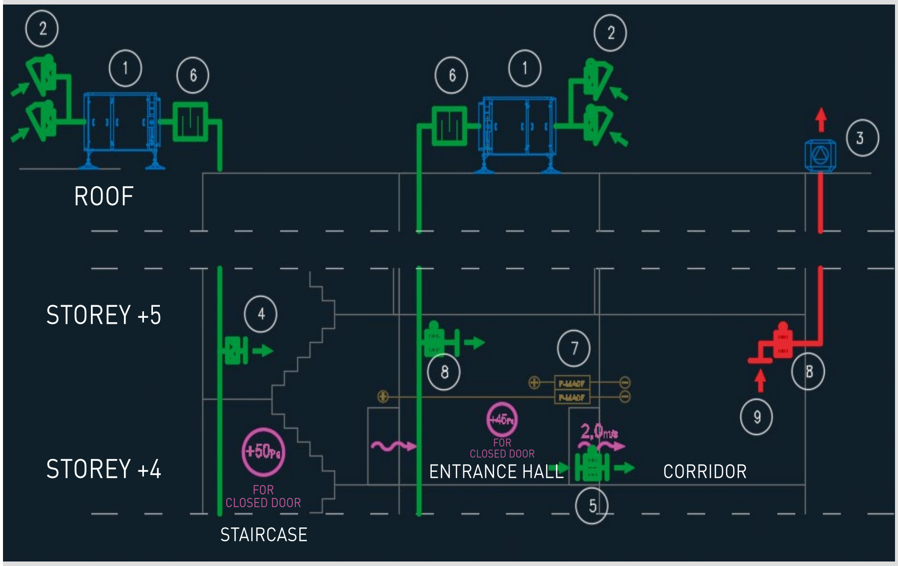
The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 6 Pa, the airflow rate must equal 2.0 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 14 400 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow criterion with such a mechanical exhaust ventilation is: 14 400 m³/h + 21 600 m³/h = 36 000 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N. This also applies to the door in the entrance hall to the zone engulfed in fire. Air is supplied to the entrance hall and staircase by two independent devices.

ATTENTION! In case of the pressure difference criterion leaks in the staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Since the smoke exhaust compensation is carried out by the air supplied to the entrance hall, in case of the pressure difference criterion (**Figure 1**) the output rate is 21 600 m³/h. The air supply device supplies the constant amount of air at all times – when the door is both closed and open. Only devices with valid certificates stating fan working ranges and system response times should be used. Additionally, the smoke ventilation system for the zone engulfed in fire shall be designed for the output rate of 21 600 m³/h.

In the second case, the entire air is also supplied to the entrance hall. The air flowing at a rate of 14 400 m³/h passes through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is being transported out of the building by the provided smoke ventilation system. Smoke exhaust compensation with the door closed is ensured by an independent device that supplies air to the zone engulfed in fire.

First case, continued

d) Let's assume that the entire air is being supplied to the entrance hall (**Figure 7**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is being transported out of the building by the provided smoke ventilation system. Smoke exhaust compensation with the door closed is ensured by an air supply system controlled by a pressure difference sensor equipped with a set of



LEGEND

1. Pressure differential systems unit, the iSWAY air supply unit
2. Damper-controlled double supply louvre system
3. SEFL/REF smoke exhaust fan
4. STW/GA air supply grille with a damper
5. WKP-O-E-T transfer damper with an actuator
6. TAP rectangular acoustic silencer
7. P-MACF remote pressure sensor
8. KWP-P-E fire ventilation damper with an actuator
9. SDS-STW smoke exhaust grille

Figure 6. Air flowing through the doorway from one area to another.

dampers and quick-acting actuators. When the door is open, the air is being supplied to the entrance hall in order to ensure that the rate criterion of 2 m/s is met. However, when the door is closed, the air is being supplied directly to the zone engulfed in fire. Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). As we have a single doorway, the total resistance equals 6 Pa. We use mechanical exhaust ventilation. Therefore, no additional resistance is present in this case. The total resistance thus amounts to 6 Pa. We can state that all openings in the staircase require a resistance of at least 6 Pa so that the air passes through an open door in the direction of the exhaust grille of the smoke ventilation system.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 6 Pa, the airflow rate must equal 2.0 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 14 400 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow rate criterion with such a mechanical exhaust is 14 400 m³/h + 14 400 m³/h = 28 800 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N. This also applies to the door in the entrance hall to the zone engulfed in fire. Air is supplied to the entrance hall and staircase by two independent devices.

ATTENTION! In case of the pressure difference criterion leaks in the staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Smoke exhaust compensation and entrance hall air supply are carried out by a single device. Its output rate is thus always 14 400 m³/h, regardless of whether the door is open or closed. Only devices with valid certificates stating fan working ranges and system response times should be used. Additionally, the smoke ventilation system for the zone engulfed in fire shall be designed for the output rate of 14 400 m³/h.

e). Let's assume that the entire air is being supplied to the entrance hall (**Figure 8**). The air flowing at a rate of 14 400 m³/h passes through the doorway between the entrance hall and the zone engulfed in fire. Subsequently, the air is being transported out of the building by the provided smoke ventilation system. Smoke exhaust compensation with the door closed is ensured by an independent device that supplies air to the zone engulfed in fire. Air supply systems (both for the entrance hall and the zone engulfed in fire) have the same output rate, but they alternate and are regulated by a pressure difference sensor. When the door is open, the device supplies air to the entrance hall, ensuring that the rate criterion of 2 m/s is met, while when the door is closed, the amount of air is drastically lowered in order to meet the pressure difference criterion

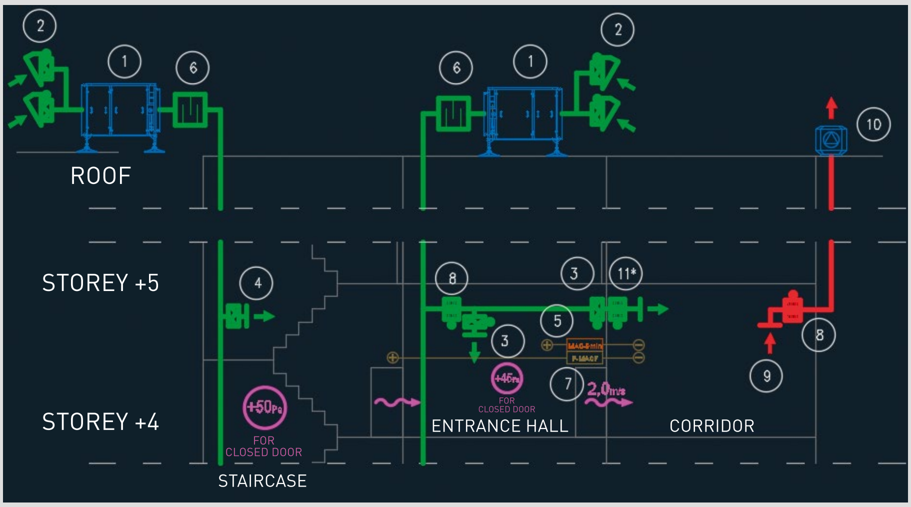


Figure 7. Air flowing through the doorway from one area to another.

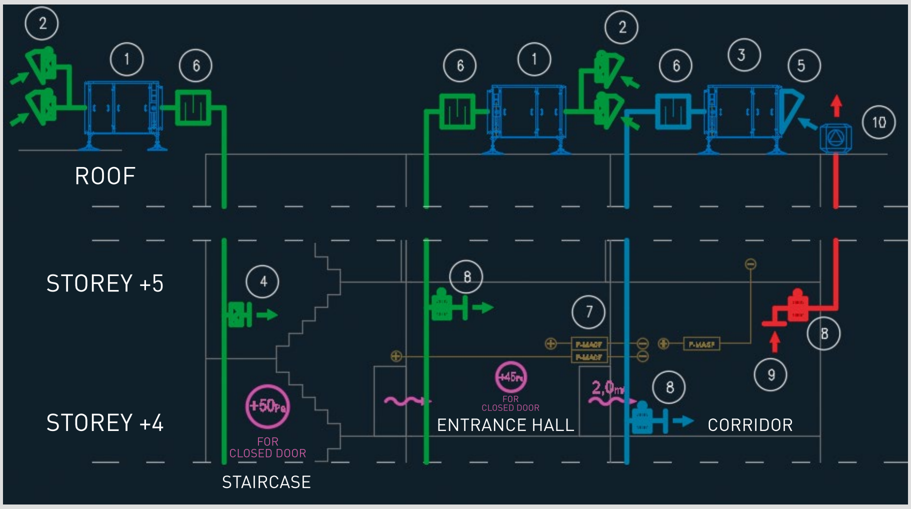


Figure 8. Air flowing through the doorway from one area to another.

(**Figure 1**). At the same time, the device that supplies air for the purposes of smoke exhaust compensation provides the absolute minimum amount of air (door open) in order to drastically increase it to 14 400 m³/h (door closed). Let's analyse the resistance and system output generated with this airflow criterion.

The air flowing through the doorway from one zone to the other at a rate of 2 m/s generates a resistance of 6 Pa (**Table 1**). As we have a single doorway, the total resistance equals 6 Pa. We use mechanical exhaust ventilation. Therefore, no additional resistance is present in this case. The total resistance thus amounts to 6 Pa. We can state that all openings in the staircase require a resistance of at least 6 Pa so that the air passes through an open door in the direction of the exhaust grille of the smoke ventilation system.

The biggest opening in the staircase is an open emergency exit door outside the building. Let's assume that its area is 2 m². In order to ensure a flow resistance of 6 Pa, the airflow rate must equal 2.0 m/s. It seems that – considering that the air should flow to the staircase at a rate of 2 m/s – we must supply 14 400 m³/h (we shall not include any other leaks in the staircase in this analysis). Therefore, the total amount of air required to meet the airflow rate criterion with such a mechanical supply and exhaust is 14 400 m³/h + 14 400 m³/h + 14 400 m³/h = 43 200 m³/h. Now, we should consider a proper placement of air supply points in the staircase in order not to exceed door opening force at any storey, i.e. 100 N. This also applies to the door in the entrance hall to the zone engulfed in fire. Air is supplied to the entrance hall and staircase by two independent devices.

ATTENTION! In case of the pressure difference criterion leaks in the staircase may be significantly lower (**Figure 1**). The fan must therefore supply extremely different quantities of air depending on the number of open and closed doors. Only devices with valid certificates stating fan working ranges and system response times should be used. Additionally, the smoke ventilation system for the zone engulfed in fire shall be designed for the output rate of 14 400 m³/h.

Conclusion

In order to ensure the rate criterion of 2 m/s by means of gravitational exhaust ventilation, the following should be taken into consideration: the bigger the resistance of air flowing from the stairwell/entrance hall in the direction of the exhaust located outside the building, the bigger the output rate of devices that supply air.

In order to ensure the rate criterion of 2 m/s by means of mechanical exhaust ventilation, the following rule should be followed: the underpressure in the zone engulfed in fire should be as low as possible due to the fact that the force vectors applied to the closed door between the underpressure and overpressure zones add up. As the door surface, closer setpoint and door handle location may differ, we suggest making calculations that would confirm the door opening force of not more than 100 N. ■

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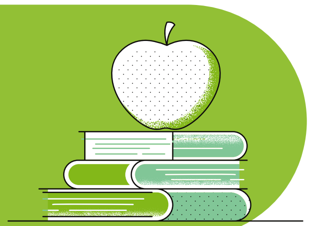

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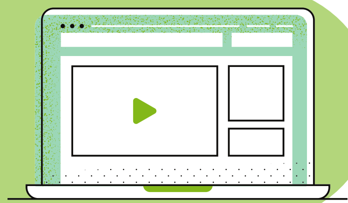

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Perspectives on IEQ control and HVAC sector in relation to the COVID-19 emergency

The point of view of Professor
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How has the perception of the need for high indoor environmental quality changed during the COVID-19 emergency?

— My guess is that there have been very few changes, at least in Italy. Unfortunately, the attitude of the World Health Organization (WHO), which has denied for more than one year the airborne transmission of the virus (despite all the appeals from scientists worldwide and the efforts of REHVA and ASHRAE), has led to insufficient attention to the issue of Indoor Air Quality (IAQ). Nowadays, as WHO has accepted that the virus is airborne, IAQ has come to the fore. In any case, in my country, still very little has been said about the other aspects of IAQ, except in the context of researchers.

What are the key trends for the technological innovation in the field of indoor environmental quality control? What are the sectors in which you think there will be a greater push towards this technological transition?

— The COVID-19 pandemic emergency has brutally highlighted the need to equip air conditioning plants with abatement systems able to reduce the risk of infection from viruses and bacteria. In Italy, most of existing buildings is not equipped with ventilation or air conditioning systems; moreover, the existing structures are such that it may be not possible to install new systems. This is a serious problem, especially in schools and in many public offices, where only specific actions are possible; some companies are already investing in this sense, proposing easy-to-install solutions, mainly for school buildings. Nowadays, a challenge for existing buildings is to realize systems for "non-typical" situations, characterised by low energy consumptions and costs comparable to those of standard systems.

In the field of indoor environmental quality (IEQ) control, two key pillars are filtration and recirculation, which are closely linked to each other if we consider that filtering recirculated air can reduce energy consumptions and guarantee good IAQ levels, as well as can reduce the risk of infection. In this context, given the sensitivity of the situation, the filtration and recirculation effectiveness of the existing systems must be checked (even though few of such systems are currently present in Italy).

It is worth mentioning that the concept of IEQ also concerns thermal, visual, and acoustic comfort. Companies should invest in products able to guarantee a good IEQ, and mainly an excellent IAQ, with minimum energy consumptions and to be easily installable in existing buildings, where several architectural constraints (e.g., inter-floor height) can exist. It is also important to consider the interaction between thermal comfort and visual comfort, which, if properly applied, can bring to energy consumptions reductions.

Finally, another important topic is decarbonisation, which comes through the realisation of Nearly Zero Energy Buildings (NZEBs), the energy renovation of existing buildings (with great attention to historic ones) and the use of renewable electricity. For the scope of pushing towards the decarbonisation of the building sector and the improvement of the air quality of the indoor spaces, it is important to also cite the field of management and control systems, which is in great expansion in recent years.

So, to sum up, several actions can be implemented by researchers and industrial partners, to take forward to guarantee to future generations a better world than the one we are offering today.

Nowadays, there is a strong attention towards the topic of global comfort, also in relation to the occupants' expectations; in your opinion, which will the main research trajectories be?

— As an ergonomist, I can only express my full satisfaction concerning the diffusion of an anthropocentric perspective for the research on the field of indoor environmental quality. However, I should point out that very often it is not possible to compare the diverse published results, because unfortunately researchers use protocols that differ from the international standards in force.

Anyway, as far as the subjective aspects of acoustic, thermal, and visual comfort are concerned, besides the widespread research, which is traditionally carried out using specific questionnaires, I think that it would be important to continue the path of virtual reality (no immediate for IAQ studies). ■

The point of view of Professor

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How has the perception of the need for high indoor environmental quality changed during the COVID-19 emergency?

— No doubt, it changed really a lot. Nowadays, very much on account of the discussions that were carried out about the role of the different transmission modes on the contagious of COVID-19, most of people is well aware about the importance of indoor environmental quality, with a particular emphasis on indoor air quality. The role of the scientific community in the area of Indoor Air Quality and of the HVAC technical associations should be highlighted by the enormous contribution that was made to the clarification of public opinion worldwide and to the change in the recommendations of the World Health Organization, which started to consider in a different way the aerosol transmission mode. On account of that, the importance of aspects like the performance of ventilation systems, air cleaning and filtering, air distribution, became like a topic of discussion of everybody.

What are the key trends for the technological innovation in the field of indoor environmental quality control? What are the sectors in which you think there will be a greater push towards this technological transition?

— This one is always a difficult question to answer in a complete way because the reality of scientific and technological evolution often exceeds our predictions, and the emergence of innovative methods and technologies allows the exploration of completely new and disruptive solutions.

We can say that there has been a certain revolution in the way of defining the performance requirements of HVAC systems, which, before the pandemic crisis, was mainly dominated by chemical pollutants. I think that, once we may have more exact and precise answers in aspects such as the emissions of contaminants by infected people, the conditions of persistence of bio contaminants in ambient air, the effectiveness of protective devices and the infectiousness thresholds of the population, refinements will emerge in the current models of forecasting the risk of contagion.

We began to notice an increasing use of the indoor CO_2 concentration as an indicator of indoor air quality, which is justified by the difficulty in having, in an easy and economical way, a real-time indication of the viral load in the air. I think there will be a great effort to develop methods that will allow this type of monitoring of the viral load itself in the near future.

The market will certainly be more receptive to innovative air purification, cleaning and filtration products and the effectiveness of ventilation systems in removing contaminants will be very much taken into account in the equipment specification phases.

We can have different understandings of the word "sectors" that appears in the question. If we consider that these are different types of buildings intended for human occupation, one of the lessons we have learned from the pandemic crisis is that it is really very important to put into practice the spirit of the European Standard EN 16798-1 regarding the categorization that is proposed for the indoor environment in buildings in the various aspects in which it is evaluated (thermal, acoustic, and visual environments and air quality). It is defined in this standard that environments occupied by more susceptible people must provide a better indoor environmental quality in order to guarantee health conditions for people for whom the risk of disease is greater. If this spirit were really followed in its fullness in the European space, probably the high mortality rates that occurred in nursing homes would not have happened. Another sector that should also deserve special attention is that of school buildings because their particular characteristics, with high occupancy rates per unit of volume and surface, mean that the risk of transmitting an infectious disease is higher.

Deconstructing in some way the answer given so far, it is important to have the notion that what is critical in risk assessment, more than a given space being considered as belonging to sector A or sector B, are the particular circumstances of each case in terms of a set of variables related, for example, to the intensity of polluting sources, the efficiency of the ventilation system and the flow of fresh air in the space. In summary, we can say that, contrary to what is often reported in the media, there are no sectors that can be considered safe and in relation to which there will be no significant need for improvement.

Nowadays, there is a strong attention towards the topic of global comfort, also in relation to the occupants' expectations; in your opinion, which will the main research trajectories be?

— I think that control systems based on the collection of information on the perception of occupants, whether with subjective or objective data, collected in practically real time and processed in order to be integrated into decision support models, will deserve particular attention. Also, the refinement of the human behaviour models will be an area with special relevance.

Thus, I expect a stronger integration of the internet of things, artificial intelligence and machine learning in monitoring and management of global comfort. However, an aspect that will be very important for the success of the new solutions is multidisciplinary, because we will always have a better perception of the object of our study if we have more points of view on it, and this is an area where there are many advantages in having greater interaction between the exact sciences and the social sciences.

Would you like to add anything else?

— Yes, a reminder of the need for a greater investment to be able to have a correct diagnosis of what the indoor environmental conditions really are in the park of buildings built in different sectors in different countries. There is a certain tendency to simplify this type of assessment by recurring to what is defined in the requirements published in the national regulations in force in the various countries. However, in many cases, when a new recommendation is published, its effects will be felt mainly in future buildings and other indoor spaces and has little influence on existing ones. In addition, what is built or installed does not always correspond completely to what was specified in the project and also, over time, a degradation of the performance of HVAC systems may occur, mainly due to maintenance and commissioning deficiencies. Thus, so that political decisions can be taken in a conscious and informed way, this effort has to be made to know what really exists on the ground. ■

Perspectives on technological advancement in the HVAC sector

The point of view of Professor
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What are the most significant and recent technological innovations within the HVAC sector?

— What I noted is not a specific new emerging technology innovation in the HVAC field but instead a significant route change in approaching HVAC system design and components production. Two main "innovations" can be identified: the sustainable HVAC system design and production/construction and smart technologies applied to HVAC systems to improve their operation efficiency while improving comfort and health. The first improvement regards not only the design for minimizing energy needs and use and maximizing fossil fuel replacement with renewable energy sources but also the circular economy approach both in HVAC design and components construction (several firms have already started to follow such approach) to minimize any resource use. The second "innovation" covers a much broader field and makes a wide use of electronic, artificial intelligence, robotics and so on. Merging informatics and automation with mechanical systems, new "smart" HVAC components are available on the market that, embedding fault detection and diagnosis procedures, can simplify and make more efficient an HVAC system design and management.

What is the role of the energy and buildings sector in the energy transition process?

— Focusing on the building sector, which uses for its operation about 40% of the final energy use in the European Union, corresponding to about 23% of the total greenhouse gas (GHG) emissions, it is evident that an energy transition process cannot avoid modifying and improving the energy use in buildings. A switching from fuel-based heating systems to electric-based ones is a needed transition to reduce both air pollution in terms of GHG and PM1&10 and fossil fuel use. Exploitation of renewable energy use as fossil fuel replacement is much easier and flexible if all building thermal processes are electricity-driven using on site or off-site electricity production from sun or wind or hydro. Direct use of thermal solar systems is also possible, but it is constrained to specific applications as domestic hot water (DHW) production and, in some case, to heating or cooling systems, where is possible and economically convenient. Of course, electricity use can be covered only by an electric energy carrier and thus by a renewable energy carrier as well.

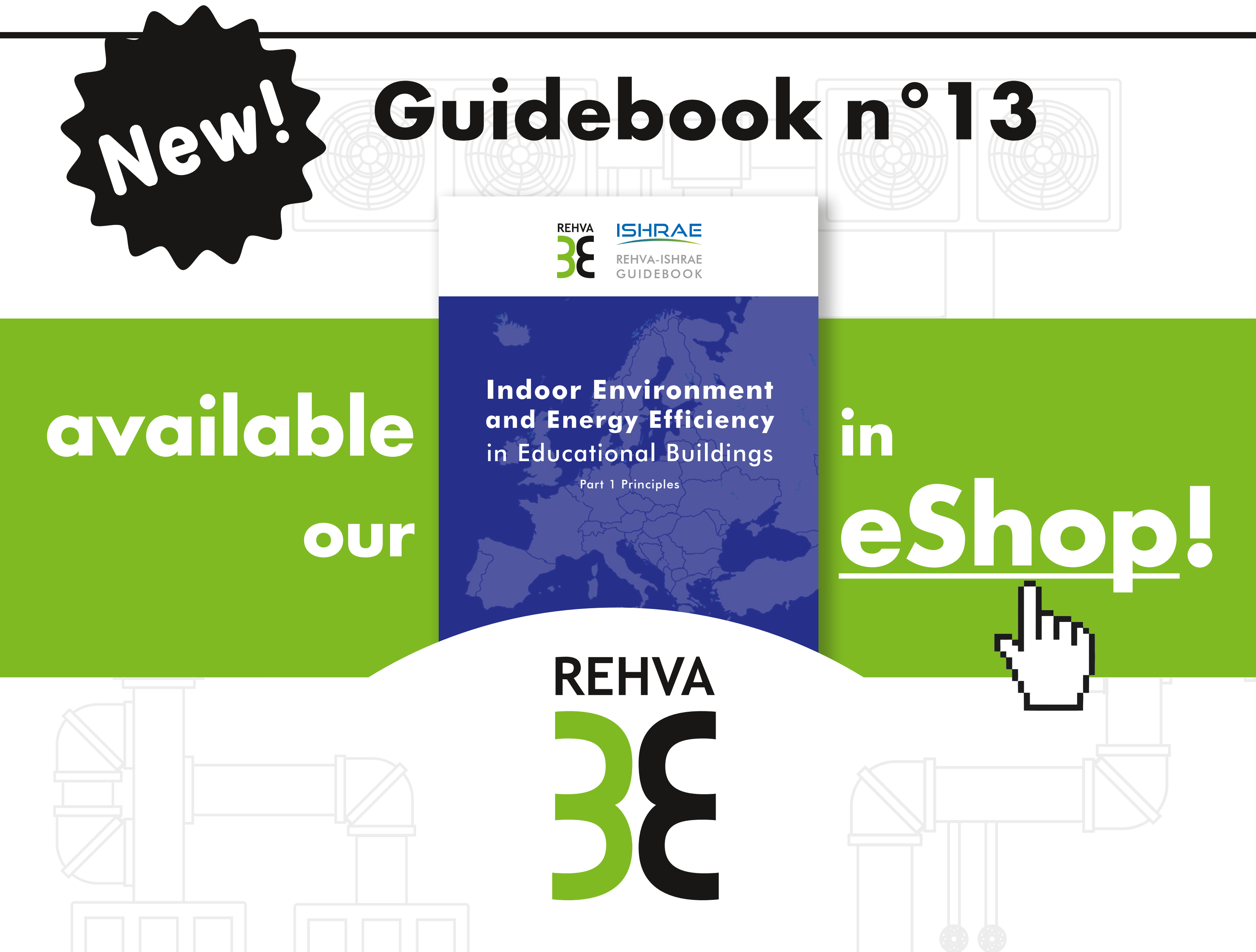
Nowadays, there is an increasing push towards "all electric buildings"; in your opinion, which are the main pros and cons of this electrification process?

— A building using only electric energy carrier for its energy need is the only possible solution for the future. Already today a lot of new buildings are fully electric, using for their heating system and DHW production heat pumps, which are thermodynamically much better than boilers. Thus, today we are already experiencing a transition from fuel-driven heating systems to electric-driven ones. The main pros are the avoided air pollution banning fuel boilers and cooking burners together with the easiest exploitation of renewable energy sources through the use of green electricity (on site and/or off-site produced). The main cons are just the extra cost and required transition time related to the needs of repowering the electric distribution lines to be able to support the increasing electricity request.

The only possible alternative is to extensively use district heating and cooling networks, where this is possible and economical convenient. In this case, we just move out from the building the heat and cold generation to central heating and cooling station where may have a direct use of some renewable energy source or waste heat from industrial process or recovered heat from sewer water using heat pumps. But such approach is not even possible and economical feasible.

Could you please give a comment on the penetration of hydrogen technologies in the building sector?

— To massively introduce hydrogen as energy carrier for buildings systems green fuel, even if it has been produced using renewable energy source, is not a winning long-term strategy. From the energetic point of view, for buildings heating and cooling it is more efficient to use reversible vapour compression heat pumps than hydrogen boilers and chillers. Green hydrogen, if imported, can be used in power station to produce green electricity or directly PV and wind power systems can feed the electric grid instead of producing green hydrogen. The use of green hydrogen in the building sector can be seen as transition strategy in using existing natural gas distribution pipelines as long as the repowering of the electric network (mainly at low voltage in towns distribution) is not completed and able to satisfy the increasing electric power request. Even in this case, pure hydrogen cannot feed the natural gas pipelines, but a mixture has to be used due to possible leaks in the gas network that was built not to carry hydrogen. Also, similar safety issues arise in house gas equipment (boilers, burners, in-house-gas distribution) and an important adaptation cost has to be considered for each owner. Finally, in cooking electric induction technique has very high efficiency (up to 90%) that no one fire burner can reach even in terms of primary energy. ■



The point of view of Professor
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What are the most significant and recent technological innovations within the HVAC sector?

— HVAC sector innovations greatly depend on the market demand. We have seen many innovative components and assemblies which haven't been taken into use for various reasons. This is why we should look more on trends providing a possibility for HVAC sector to offer innovative products. I would like to highlight four important megatrends which probably will affect the development in coming years:

1. User satisfaction, well-being and high-quality indoor environment is more and more required by clients and developers of non-residential buildings. Real performance and high quality IEQ can be seen as a warranty for investors against uncertainty in the future. For instance, popularity of WELL certification for advancing health and well-being in buildings is one reflection of this development. HVAC products are the most important components of a general energy and indoor climate concept, but only the demand can put the developers to order and designers to design high performance and high-quality systems which can result in increased well-being, productivity, learning performance and user satisfaction.

2. Nearly zero energy buildings were a big issue, but even bigger will be zero-emission buildings proposed by the first draft of EPBD recast. HVAC product offering is generally ready for this development. In residential buildings air-to-water heat pumps, which efficiencies have been greatly improved during recent years, are ready to take large market shares and the same applies for the heat recovery ventilation units offering high energy efficiencies at low specific fan power. There are also other heat pumps, for instance exhaust air heat pumps are almost not known in Central Europe, offering a perfect renovation solution for apartment buildings together with mechanical exhaust ventilation system using ventilation radiators as air intakes. Ground source heat pumps will remain superior in Nordic climate. There is also a new issue to be solved – how to implement feasible cooling that would suit to renovation of apartment buildings and would avoid overheating – there are no good common concepts and product offering in this sector.

3. COVID-19 initiated a development trend on improved ventilation, especially in public spaces, workplaces and schools, aiming to reduce and control the infection risk. This consideration gives attention to flexible, on demand high capacity ventilation and air conditioning systems which should operate at wider range than commonly, and also on effective and low velocity air distribution solutions, which is a challenge when we speak about operation say at 20-100% airflow range. Moreover, there is a clear need to make indoor air quality visible, so all larger rooms should have CO_2 readings easy to follow by occupants. REHVA recommendation of 800 ppm CO_2 has been widely followed and helps to improve ventilation.

4. Finally, flexibility, utilisation of renewable energy sources and controlling grid load caused by electricity use of HVAC systems starts to be an issue in conditions of clean but variable grid electricity. Current regulatory efforts have been focused on energy only, but buildings' peak powers and load shifting to lower electricity price period can be useful both for energy system development as well as for building owners. Addressing interaction

of buildings and electricity grids has been challenging, but the Smart Readiness Indicator (SRI) can be seen as a first step in this direction and perhaps could develop in future to performance-based load reduction at high price hours.

What is the role of the building sector in the energy transition process?

— We are used to speak that buildings account for 40% of the final and primary energy use. Recent Estonian values show much higher impact when we speak about electricity use: Estonian buildings account for about 60% of the total electricity use and 85% of the peak electricity power. Especially the peak power value is so high that it well demonstrates the need to consider the renovation of existing buildings and the construction of new buildings much more seriously as a part of energy system development. Renovation strategies and regulation can have crucial effect on energy transition because electric loads can either be considerably decreased or increased depending on HVAC and renewable energy system solutions applied.

Currently we aim to double the deep renovation rates of existing buildings for achieving the long-term renovation strategies targets, so, it would be wise to pay attention not only to energy savings but also to electric loads of HVAC systems. This question will need European and national level attention, because there seems to be consensus that future prices of clean but variable electricity will be more volatile and buildings should be prepared for this development.

Nowadays, there is an increasing push towards "all electric buildings"; in your opinion, which are the main pros and cons of this electrification process?

— To phase out fossil fuels we simply need to replace all gas and oil boilers with heat pumps and district heating. There is no alternative to achieve climate neutrality by 2050. Instead of burning gas in buildings it should be left to be used in power plants and in cogeneration district heating plants as a top-up fuel. To be accurate we speak about electrification with heat pumps and wider use of effective district heating and district cooling which enable to use renewable energy and waste heat. Indeed, this process will need time, in some countries it is possible by 2030 but in some countries by 2050 until the long-term renovation strategies (LTRS) are fully executed. This process will increase electricity use and peak powers in residential buildings, but non-residential buildings offer so good energy saving possibilities that on the level of the building stock it is possible to keep electricity use and power constant. However, keeping electricity at the same level is not obvious, it is important to model LTRS-based national building renovation plan scenarios together with new-build scenarios in every country and to decide proper technical and financial conditions for renovation grants and other incentives which will orchestrate this process in practice.

Could you please give a comment on the penetration of hydrogen technologies in the building sector?

— Hydrogen solutions are mostly for energy storage that needs enough large-scale to be effective. For this reason, it is still far to be used in single buildings. Hydrogen applications are currently in the heavy transport and in industry sectors. In the future, in the surplus of renewable electricity generation, green hydrogen production should enable large-scale electricity storage. This could be a solution to phase out fossil fuels in power generation. Therefore, we can expect that green hydrogen will be a part of clean energy system and buildings still can directly use the grid electricity. I don't believe that transporting biogas and hydrogen in existing gas networks to be burned in buildings would be a solution, because there are much higher demands for these renewable fuels in other sectors.

Would you like to add anything else?

— HVAC plays a fundamental role in the transition of buildings together with photovoltaic, building automation and electric car battery charging systems. In the context of 75% of existing EU building stock to be deeply renovated in 30 years, we really need affordable and cost-effective HVAC solutions to be applied in the existing buildings, to improve poor energy and indoor climate performance, to increase the use of renewable energy and to avoid high electricity loads. Only way to be successful is to develop a good set of common renovation concepts and apply these massively as standard solutions. This is something that industry cannot do alone, but strong cooperation with universities, renovation grant authorities and regulators are needed. The quality of these concepts and model solutions could resolve the success of the full transition process in practice. ■

Key trends in HVAC sector and the role of AiCARR: insights on the next Mostra Convegno Expocomfort

The point of view of
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Which are the key topics of the 2022 edition of MCE (28th June – 1st July 2022)?

In recent years, Italy has resorted to various measures with the scope of achieving environmental protection, energy security and affordability to reach the European Union (EU) targets in the field of Energy and Environment. Among other things, considering the environment as the economic engine of the country, Italy shared the orientation aimed at strengthening the commitment to the decarbonisation of the economy and at supporting the New Green Deal among businesses and citizens. Last July, these efforts were further stressed by the adoption at community level of a series of proposals, known as the "Fit for 55" package, which intended to accelerate the definition of EU policies on climate, energy, transport, and financial support, with the final goal of reducing the net greenhouse gas emissions of at least 55% by 2030, compared to 1990 levels. Based on the above, concerning the 2022 edition of *Mostra Convegno Expocomfort* (MCE), which has been postponed next summer (28th June – 1st July 2022), AiCARR decided to propose in the next months, as an accompanying path to MCE, three half-day seminars on the following topics: "Indoor air quality issues for future buildings", "Decarbonisation and energy carriers: a new roadmap for 2050" and "Technological innovation for sustainable refrigeration equipment".

Furthermore, AICARR is considering the possibility of holding the next National Conference, entitled "Buildings and HVAC systems for future climate" at the Mostra Convegno Expocomfort.

How has COVID-19 influenced these topics? And what are the main insights emerging from the COVID-19 pandemic emergency?

The current COVID-19 pandemic has highlighted how ventilation (i.e., introduction of outdoor air in confined environments) is a fundamental therapy for the prevention and reduction of the risk of airborne infection, including also the "normal" seasonal flu. Therefore, the COVID-19 emergency contributed to reinforce the need of proper systems able to guarantee and maintain good indoor air quality (IAQ) conditions in confined spaces, which was previously intended as a sole perception rather than a physiological need. These considerations open to a new vision on the future role of ventilation and especially of mechanical ventilation in buildings, which has been already exploited to combine IAQ requirements with those of energy consumptions reductions.

In all shared environments with many people, from offices to schools, from theatres to gyms, from sports halls to worship places, as well as in public transportation, ventilation should become an obligation, no longer remaining an optional plus. At the same time, it is necessary to ensure a comfortable environment for occupants since thermo-hygrometric well-being is not only a "whim" but has direct implications both on health (just think of the carriers of cardiopathic diseases) and on occupants' productivity. Consequently, all buildings not exclusively intended for residential use should mandatorily install mechanical ventilation systems, since natural ventilation is not sufficient enough to ensure the required outdoor air quantity and quality and to effectively filter any dust or pollutants present in the outside air. Meanwhile, such systems must respond to the need of containing energy consumption and of decarbonising the building stock.

In recent years, the pandemic has increased people awareness on environmental issues, as well as on the importance of living in secure and healthy spaces. Driven by a new paradigm, built around the main priorities of health, well-being, energy savings and environmental sustainability, it is necessary to rethink the design of buildings systems, to sustainably balance these needs. A change in how the building-plant system is designed is needed, to improve its energy performance and security, also guaranteeing a reduction of energy management costs. To this purpose, five strategies can be defined: ventilation efficiency (meaning the optimization and control of air diffusion in indoor spaces, especially in variable flow systems); sealing of aeraulic networks; adoption of selective systems for the abatement of specific contaminants; heat recovery systems; and free-cooling.

What do you think about the role of HVAC systems in the ecological transition promoted by Italy and Europe?

According to the latest energy efficiency report from ENEA (2021), in 2019, Italian final energy consumption reduced by 1.1% compared to the previous year, attesting to about 120 Mtoe in the last 3 years. The building sector remains the most energy-intensive sector, consuming 41.1% of total final energy (the sector has experienced a 44% increment of final energy consumptions from 1990 to 2019, corresponding to an average +1.3% annual increase), followed by transport (29.8%) and industry (20.7%) sectors, both characterized by a decreasing trend in the last years. Given the above, if we want to achieve the decarbonisation objectives at both European and Italian level, the building sector is in the spotlight and the greatest challenge lies in the renovation of the existing building stock, with a particular attention on existing historical heritage.

HVAC&R systems play a fundamental role in the building transition, especially in this last period, characterized by a strong attention on their capacity of guaranteeing healthier indoor conditions. To support this, there is the need to develop a holistic design approach for energy systems and buildings, having ventilation as their core element and adopting all the technical and technological arrangements able to minimize their energy and environmental impacts. For the sake of exemplification, in all existing buildings equipped with heating systems but without any primary air systems installed, it is necessary to introduce suitable ventilation systems with heat/enthalpy recovery units (double duct systems with heat exchangers); even though such technologies are already present in the market, the recovery systems should be further optimized, in terms of efficiency and safety related to the separation of air flows, not allowing contamination. Moreover, another consideration for current and future air systems is related to need of developing and adopting selective systems for the abatement of specific contaminants.

As previously mentioned, heat recovery, ventilation efficiency, aeraulic networks sealing and free cooling can be identified as important strategies for air systems. Indeed, these solutions are recognized as those having the greatest rooms for optimization, which can further increase in case these strategies are implemented simultaneously. Moreover, they can lead to the re-use of recirculation air as a means for reducing energy costs in competition with the use of recovery units. To conclude, it is important to specify that only the development of accurate and specialized feasibility studies, targeted on buildings uses and energy systems typologies, can give proper indications on the most efficient and sustainable solutions to be exploited.

How does AiCARR fit into this scenario?

AiCARR is an association that for over 60 years has been addressing these topics with competence and method, ensuring a highly scientific standpoint, but above all neutral and independent, being a non-profit association. We create and promote culture and method for sustainable well-being, contributing to the technological advancement of energy systems and to the definition of regulations on thermal energy production, distribution, and use.

Being present in all academic and institutional places where the energy future of our country is planned, AiCARR is recognized as an essential reference point for the definition of energy strategies and policies, as well as an irreplaceable interlocutor for anyone who deals with energy efficiency, environmental quality, renewable sources, and rationale energy use. AiCARR is also active at international level, thanks to the collaborations with other Associations or Federations, such as REHVA, ASHRAE, CIBSE and IEQ-Global Alliance. ■

EU Policy

EU Green taxonomy and nuclear power
– a technical, economic and political struggle

JOHANN ZIRNGIBL
Johann Zirngibl is an engineer, expert in decentralized energy systems. He was head of division in a French public research organization. He works for the European Commission and European banks on the transposition of European directives. He is responsible in European (CEN) and international (ISO) standardization groups and contributes to the work of the EPB Center.

To be able to finance new very capital intensive French nuclear powerplants under advantageous financial conditions, France wants to include nuclear energy in the European green taxonomy. The financial stake is considerable. A 3% difference in the cost of capital between nuclear and renewables represents 11 billion Euros per year (full costs ~400 billion Euros until 2060) [1].

The taxonomy has been set up to direct financial investments towards environmentally sustainable and resource-efficient projects and activities. It was to protect investors and savers from greenwashing. The Taxonomy Regulation was published on 22 June 2020 [2]. The Commission then establishes the list of sustainable activities by defining technical screening criteria for each environmental objective by delegated acts. A first delegated act on sustainable activities concerning climate change adaptation and mitigation was adopted on 4 June 2021 [3]. He passed the Parliament. The vote in the Council is scheduled for no later than 7 December 2021.

Nuclear was not included in the initial versions of the taxonomy. The Joint Research Center (JRC), the Commission's research centre, published in 2021 a technical report studying whether nuclear complies with the taxonomy [4].

The regulation [2] lays down the criteria for establishing whether an economic activity qualifies a financial investment as ecological and sustainable.

An economic activity can be qualified as ecological when that activity:

- contributes substantially to one or more of the environmental objectives,
- does not significantly harm (DNSH) any of the environmental objectives,
- is carried out in compliance with the thresholds of minimum guarantees,
- complies with the technical selection criteria.

The taxonomy defines six environmental objectives:

- climate change mitigation (energy efficiency),
- climate change adaptation,
- the sustainable use and protection of water and marine resources,
- the transition to a circular economy,
- pollution prevention and control, protection and restoration of biodiversity and ecosystems.

The taxonomy is a global approach, with several environmental objectives, none of which should be degraded.

How does nuclear power stand in relation to environmental objectives?

Nuclear power industry forwards the argument of being among carbon-free energies and being a controllable energy. But how does nuclear comply to other environmental objectives of the taxonomy as energy efficiency, sustainable development, pollution? If nuclear is not green, can it be at least be considered as an enabling or transition solution?

Climate change mitigation (energy efficiency), sustainable use and protection of water resources

Energy efficiency and the development of renewable energies are key elements of European policy.

Nuclear power is not a renewable energy, because it is depleting the source by extraction, and therefore not sustainable. France imports between 8,000 and 9,000 tons of uranium annually.

Nuclear has a low energy efficiency (efficiency <33%) compared to other electricity producing solutions such as a combined cycle gas power plant (efficiency ~ 60%) or cogeneration (efficiency >80%).

Therefore, nuclear power generates a high thermal pollution that potentially degrades biodiversity (warming of rivers). The JRC report highlights the thermal pollution of freshwater "*Large inland nuclear power plants using single-pass cooling systems take a large amount of water from rivers as a heat sink from the nuclear power plant. When heated cooling water is returned to the river, it represents a significant thermal pollution potential (warming of rivers) that must be handled appropriately.*" It should be recalled that the thermal losses of French nuclear power plants amount to about 800 TWh/a corresponding to the final consumption of the French residential sector and industry.

Pollution prevention and control

The JRC report concludes that there is no scientific evidence that nuclear power is more harmful to human health or the environment than other power generation technologies.

The storage of high-level radioactive nuclear waste in deep geological formations is considered "appropriate and safe". But no long-term operational experience is currently available. The technologies are still in the testing phase and this 50 years after the construction of the first power plants.

Less radioactive waste is stored near the surface and protected by technical and natural barriers for a period of about 300 years. The JRC report considers that even for such a long period the behaviour of technical barriers is well known and predictable and can be considered as sufficiently reliable.

For the risk assessment, the JRC report considers as a basic assumption that "*the protection of people and the environment in countries with nuclear installations depends on the existence of a sound regulatory framework that oversees the safety and impact of these installations*". This basic hypothesis of the JRC report questions the relevance of the conclusion concerning the risks, having in mind the instabilities (wars, natural disasters, change of political regimes, etc.) that the world and Europe have faced since the year 1700 to today.

Relying mainly on "a **strong regulatory framework**" to ensure nuclear safety at such a long period is astonishing. No private company is able to guarantee the storage of waste over such a period. If the final management of waste were included in the obligations of nuclear companies, one wonders which company would be able to take such risks.

Only nuclear power has such long temporality and loads that impact future generations as strong.

A fundamental ethical requirement should be that today's activities must avoid imposing excessive burdens and risks on future generations.

Nuclear power, a transitional energy?

Article 10 (2) [2] indicates that an economic activity, for which there is no low-carbon alternative, may be considered as a green activity when it promotes the transition to a climate-neutral economy. Transitional energies shall not hinder the development and deployment of low-carbon solutions.

Renewable energies are a low-carbon, reliable, technically and economically credible alternative, as shown in the 100% renewable scenarios of the RTE report [1].

Renewables positively meet all the criteria of the taxonomy. Nuclear power hinders their development, unlike as gas, because gas can run as a back-up (security) of renewable energies and therefore accelerate their development.

Nuclear cannot be a back-up of renewable energies because:

- it is less flexible than gas (nuclear needs 30 minutes to significantly change its power),
- it is a technology that is very capital intensive (high investment) that needs to produce high quantity of electricity to be profitable (must run as base load in the merit order of electricity production plants).

Thus, nuclear power competes and hinders the development of renewable energies because renewable energies also operate at base load. The energy produced by wind or solar must be consumed in priority if it cannot be stored.

Nuclear power plants are designed for a lifespan of 40 to 60 years. Therefore, they lock the development of renewable energies for a long time. It is also recalled that the European Commission has defined binding and ambitious objectives for 2030 and 2050. France's new nuclear power plants will produce electricity essentially between 2050 and 2100 and leave nuclear waste for thousands of years. This is contrary to the definition of a transition energy in the taxonomy.

Political struggle

"It's a **political** fight", said **Bruno Le Maire**, France's economy minister, determined to get a green label for nuclear power in taxonomy.

12 EU countries, led by France and Finland, want nuclear energy to be included in the taxonomy, arguing that it is a low-carbon energy source, and that radioactive waste can be treated safely.

A 6-country alliance of Denmark, Germany, Luxembourg, Portugal, Spain and led by Austria aims to prevent the inclusion of nuclear energy in green finance.

How will the decision be made?

Once the Commission has proposed its new supplementary delegated act, only a qualified majority in the Council (15 of 27 Member States and at least 65% of the total EU population) can reject it. The Commission's proposal can also be annulled by the European Court of Justice.

Each national state has the sovereign right to decide for or against nuclear energy... and to finance it from its own national means. But if there is no European consensus, trying to get national nuclear energy be financed by using the European Green Taxonomy will permanently discredit its integrity, credibility and therefore its usefulness. An EU green taxonomy, that includes nuclear power, will disqualify it among a large part of the European population. Many savers and investors may turn away from it. ■

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Smart Readiness Indicator – Updates and next steps

Back in 2020, the SRI Topical Group C published the 1st recommendations report. [1] Given that the scope of this group is focusing in the future implementation of the SRI, it will continue its work under the umbrella of the SmartBuilt4EU project [2], contributing to the relevant task group that is working on a White Paper to detect Research and Innovation gaps to be addressed in the coming years.

In December 2021 the new Concerted Action EPBD status report on Smart Buildings has been published with a focus on the roll-out of SRI in Members States and new requirements on Technical Building Systems. [3] Follow the REHVA's Knowledge Hub for continuous updates on the latest developments and implementation of the SRI. [4]

Commission adopted Delegated Regulation on Renewable Cooling

On 14 December 2021 the Commission adopted the Delegated Regulation on a method for calculating the quantity of renewables in cooling and district cooling. [1] This Regulation has the aim to strengthen the harmonisation between Member States on the calculation methodology and how much of it contributes to their overall renewable targets. Follow the REHVA Knowledge Hub for more information on the new Renewable Cooling calculation methodology. [2]

Taxonomy Climate Change Mitigation & Adaptation entered into force

Since 1 January 2022 the EU Taxonomy chapters on Climate Change Mitigation & Adaptation have entered into force. [1] The Taxonomy is a classification system that defines for investors, companies and policymakers which economic activities can be considered as environmentally sustainable.

The sectors currently covered within the Taxonomy represent over 80% of GHG, including the building sector. One important point within these two chapters that was widely discussed were the criteria for sustainable investments in new buildings. In the final document it states that they have to have an EPC class A to be considered as a sustainable investment or be within the top 15% of the national or regional building stock in terms of performance (p. 134 under climate change mitigation in the Taxonomy Delegated Regulation [2]).

French Presidency of the Council: Opportunity for Energy Efficiency?

France has taken over the Presidency of the Council of the EU since 1 January 2022. During this time the French government will coordinate the Council's work on EU legislation until 30 June 2022, when the Czech Republic will take over. The Presidency Council Program [1] that has been released by France sets an important role for the ongoing Fit for 55 negotiations and possible opportunities for energy efficiency.

The French Presidency comes at a crucial moment with the inter-institutional dialogues that have started between the Council and Parliament on the first package of Fit for 55, which includes the Energy Efficiency and Renewable Energy Directives (EED & RED III). In addition, the dialogue on the Energy Performance of Buildings Directive (EPBD) commence under the French Presidency as well. In early March 2022 a ministerial conference will be organised in Nice that will focus on energy efficiency in buildings and energy poverty.

Please see the online version for references and links: https://www.rehva.eu/rehva-journal

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Proposal of the EPBD Recast: Can it get the EU's building stock ready for 2030 and after?

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December 2021 marked an important month for the EU's attempts to decarbonise its building stock with the release of the proposal for a new revision of the Energy Performance of Buildings Directive (EPBD) by the European Commission.[1] A broad range of provisions within the EPBD have been changed and added, which finalised its previous revision in 2018, with the aim to steer the EU's decarbonisation efforts in a more ambitious direction within the Fit for 55-package. In this article we'll set the context for this new proposal for a revision, the key novelties that are introduced and what the next steps will be.

Policy context of the proposal

In October 2020 the Commission released the Renovation Wave strategy which set the ambition to, at minimum, double the annual renovation rate in Europe by 2030 and increase the share of *deep* renovations. The Commission assessed that the EPBD needed a new overhaul to accomplish these objectives. Worst-performing buildings have been made a priority as these have the largest potential for cost-effective improvements and are most urgent for protecting the most vulnerable households. In addition, the proposal aims to increase the quality of the renovations that take place and ensure that they have an impact in terms of energy performance and decarbonisation. Both priorities have been addressed within the proposal for a new revision of the EPBD with the introduction minimum energy performance standards (please see "NEW Article 9: Minimum energy performance standards (MEPS) for existing buildings" on page 63) and a definition on zero-emission building (please see "Article 2: Definitions" on page 63).

To accomplish the ambitions set under the Green Deal the Commission released the Fit for 55-package in two parts to get the EU's policy environment ready to reach the reduction target on greenhouse gases (GHG) of 55% by 2030. A mammoth package of 13 proposals was released in July 2021, among which there were the revisions of the Renewable Energy & Energy Efficiency Directives and the extension of the EU ETS to the transport and building sectors. [2] The EPBD proposal was part of the winter package released in December, together with proposals to reform the gas market.

The Commission states that the revision of the EPBD goes hand-in-hand with the extension of the EU ETS to the building sectors, where the latter aims to create more economic incentives for building decarbonisation by putting an extra cost on CO_2 emitted in buildings, while the EPBD recast aims to address the non-economic barriers, such as building standards and information tools.[3] It needs to be noted here that Article 15 still addresses multiple market incentives & barriers (please see "NEW Article 15: Financial barriers" on page 64).

Key novelties of the EPBD recast proposal

Below you can find a summary of key additions & changes made into the EPBD recast proposal. This list in non-exhaustive, follow the REHVA Knowledge Hub to access a more detailed overview.[4]

Article 2: Definitions

- Art. 2(2): '**Zero-Emission Building' (ZEB)** is introduced as a new definition where a building with very high energy performance any energy needs are covered by renewable sources generated on-site. **Requirements regarding total annual primary energy use for ZEBs are laid down in Annex III** (please see "Annex III: Zero-Emission Building Requirements" on page 64 for more information).
- Art. 2(3): '**Nearly Zero Energy Building' (NZEB)** remains the standard for new buildings until the application of the ZEB standard in 2030, which then replaces NZEB.
- Art. 2(19): '**Deep Renovation'** means a renovation that transforms a building or building unit into an NZEB before 2030 and into a ZEB starting from that year onwards.

Article 3: Long-term Renovation Strategies renamed to National Building Renovation Plans (NBRP)

One of the key updates in the requirements is a national roadmap where Member States have to set targets for 2030, 2040 & 2050 on different indicators such as annual energy renovation rate, primary and final energy consumption of the national building stock and its operational GHG reductions. For 2050 the objective for the transformation of the existing building stock is raised from NZEB to ZEB.

Article 6: Calculation of cost optimal minimum energy performance requirements

6(1): By 30 June 2026, the EC shall revise the comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements in existing buildings undergoing major renovation. The first Member State reports that are in accordance with the new methodology have to be submitted in 2028.

Article 7: New Buildings

7(1): All **new public buildings** shall be **zero-emission buildings from 2027**, and **all other new buildings from 2030**. **Life-cycle Global Warming Potential (GWP)** for all new buildings shall be calculated as numeric indicator in the EPC-s with the same timeline. Calculation of GWP for new buildings is **laid down in Annex III and is in accordance with EN 15978 and the LEVELs framework**.

7(4): New requirement for new buildings: MS **shall address healthy indoor climate conditions**, adaptation to climate change, fire safety and risks related to intense seismic activity.

NEW Article 9: Minimum energy performance standards (MEPS) for existing buildings

9(1): With the goal to transform the national building stock to zero-emission by 2050 a progressive MEPS timeline has been set for different types of buildings to be achieved in the coming decade:

- Buildings & building units owned by public bodies to achieve at least EP class F by 2027 and class E by 2030.
- Non-residential buildings & building units to achieve at least class F by 2027 and class E by 2030.
- Residential buildings & building units to achieve at least class F by 2030 and class E by 2033.

NEW Article 10: Renovation Passport

A new article introduces the **Renovation Passport** as a document that provides a tailored roadmap for the renovation of a specific building in several steps. By 2023, the EC shall establish a common European framework in a delegated act. MS to introduce the national schemes according to the EU framework by end of 2024. The passport should contain expected benefits in terms of energy savings, savings on bills and operational GHG reductions, as well as benefits related to health and comfort.

Article 11: Technical building systems

11(1): MS shall ensure that the set requirements for technical building systems reach at least the latest cost-optimal levels. They may also set requirements related to GHG emissions to the type of fuel used by heat generators, provided that such requirements do not become unjustifiable market barriers.

11(3): MS shall require the **installation of IAQ monitoring devices** in new zero emission buildings and where technically & economically feasible, in existing buildings undergoing deep renovation as well.

Article 13: Smart readiness of buildings

13(2) + 13(4): By the end of 2025, EC shall publish a delegated and an implementing act on a common Union scheme for rating the smart readiness of non-residential buildings above 290 kW effective rated output.

NEW Article 15: Financial barriers

15(10): From **2027**, MS **shall not** provide any **financial incentives for the installation of fossil fuel boilers**.

Articles 16-18: Energy Performance Certificates

16(1): EPCs shall include a primary energy use indicator for energy efficiency (not specified if total or non-renewable), reference values for minimum energy performance standards (Art. 9) and for NZEB & ZEB requirements.

16.2: Performance class A shall be a zero-emission building, class G correspond to the 15% worst-performing in the national building stock.

16.6: EPCs recommendations shall include an assessment whether heating or air-conditioning systems can be adapted to operate in more efficient temperature settings.

17.1: Buildings undergoing major renovations need to have EPCs, as well as all public buildings (owned or occupied by public authority).

NEW Article 19 Databases for energy performance of buildings

Member States shall to set up **integrated and interoperable national databases** on building energy performance with data to be gathered related to EPCs, inspections, building renovation passport, SRI and the calculated or metered energy consumption of the buildings covered. These databases shall be made publicly accessible.

Articles 20-21: Inspections & reporting on heating, ventilation, and air-conditioning systems

- Articles on inspection of heating & air-conditioning have been merged and extended with ventilation system in every aspect with updated requirements: separate inspection schemes for residential and non-residential buildings, different frequencies with a maximum 5 year, systems with an effective rated output of more than 290 kW every 2 years.
- **BACs and continuous monitoring**: from 2025 new residential buildings and residential buildings undergoing major renovation must be equipped with continuous electronic monitoring and effective control functionalities.

Annex III: Zero-Emission Building Requirements

The first part of Annex III lays down the requirements for ZEBs, both new and renovated. Maximum thresholds are laid down, expressed in **total annual primary energy use**, per climatic zone and per different building types. In addition, ZEBs shall not cause on-site carbon emissions from fossil fuels.

Annex V: New EPC Template to be used by the end of 2025

Key elements mentioned in Annex V to be included on the new EPCs:

- New mandatory elements on the EPC template include operational GHG & GHG emission class.
- Among the voluntary elements, EPCs may include an indication of the presence of fixed IAQ sensors & presence of fixed IAQ controls.

Next Steps

Stakeholders have until 21 March 2022 to provide feedback on the proposal, at time of writing REHVA is still putting together recommendations & comments with its members for this round. After this feedback round, the proposal will enter into inter-institutional dialogue between the Council of the EU and the European Parliament to amend the proposal. During the previous revision of the EPBD this process lasted around 18 months. The French Presidency has planned a ministerial conference, in Nice, in March 2022 to discuss energy efficiency in buildings and energy poverty.[5] It is expected that the Council will take a first position for the EPBD negotiations during the conference. ■

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Eurovent Market Intelligence has launched its 29th annual data collections

| Deadline: 14 February 2022 |

On 4 January, Eurovent Market Intelligence (EMI), the European statistics office for the HVAC&R market, has launched its new annual data collections for 2022 (see box). The aim is to collect sales data from manufacturers in the sector in order to provide them with a reliable and precise map of the HVAC&R market in Europe, Middle East, and Africa (EMEA).

Last year, around 400 manufacturers had joined EMI (so an increase of +20%), providing the most comprehensive and reliable overview of the market, and thus remaining the largest collection of data on the HVAC&R market in terms of the number of market players. The 3 new collections launched last year, Domestic Heat Pumps, Refrigerated Display Cabinets and Water Fan Heaters, met a great success and are thus be confirmed in 2022.

Big news for this 29th annual data collections: EMI is launching a new collection about Cooling Components (covering components like valves, filters driers, pressure switches, oil level regulators, etc.) already supported by the main players of this market, such as Danfoss, Emerson, Parker, and Castel.

Besides, the old collection on Heat Recovery Systems (heat exchangers installed in AHUs, such as plate, rotary or run-around-coils) suspended in 2016 has restarted as well after the decision of Klingenburg to join the programme.

EMI has also extended the programme on Pool Dehumidifiers to the Pool Heat Pumps and changed the name for Pool Application. The collection format has also been structured to be more in adequation with the market.

A new extension is also available for the IT Cooling: this programme covering already the CRAC units, RACK units, TLC and Evaporative Cooling, is covering now also the Fan Walls, with a split by capacity (in kW) and technology (CW, DX, Dual).

Regarding the Adiabatic Coolers, this market intelligence programme has been renamed in “Adiabatic and hybrid heat rejection” and now offers now much more details with a first split by type of product (Dry coolers/Condensers) then by the adiabatic system (pad, hybrid, simple spray).

EMI will also continue to give priority to the deadlines (fixed on 14 February this year) in order to ensure the freshness of the information and deliver the results during the month of March for all the regular annual programmes.

For additional information or to receive these reports:

https://www.eurovent-marketintelligence.eu / statistics@eurovent-marketintelligence.eu ■

EMI data collections - 18 products

- Adiabatic and hybrid heat rejection
- Air curtains
- Air filters
- Air handling units
- Chilled beams
- Chillers
- Cooling Components (new)
- Cooling towers
- Domestic heat pumps
- Fan coil units
- Heat exchangers
- Heat Recovery Systems (new)
- IT cooling (extended)
- Pool applications (extended)
- Refrigerated Display Cabinets (Quarterly)
- Rooftop units
- VRF Systems
- Water fan heaters


EUROVENT 4/23 - 2022

SELECTION OF EN ISO 16890 RATED AIR FILTER CLASSES FOR GENERAL VENTILATION APPLICATIONS

FOURTH EDITION

Published on 14 January 2022 by
Eurovent, 80 Bd A. Reyers Ln, 1030 Brussels, Belgium
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Eurovent publishes updated Recommendation 4/23

BRUSSELS, 18 JANUARY 2022. The Eurovent Product Group 'Air Filters' has published an updated version of the Recommendation 4/23 'Selection of EN ISO 16890 rated air filter classes for general ventilation applications'. It aligns with the 2021 WHO global air quality guidelines.

Based on the latest evidence on the health effects of exposure to airborne pollutants, the World Health Organization (WHO) has significantly reduced the recommended levels of PM2,5 and PM10 concentrations. Dr. Marc Schmidt, Chairman of PG-FIL stated: "The current update of the widely recognised Eurovent 4/23 aims to align guidelines for ISO 16980 rated filter selection with the latest WHO recommendations in order to increase the level of human health protection."

The Recommendation includes a comprehensive set of guidelines on the selection of air filters for general ventilation applications, which makes full use of potential EN ISO 16890 offers in terms of Indoor Air Quality. The document, which was jointly developed by the participants of the Eurovent Product Group 'Air Filters' (PG-FIL), is based on a deep technical understanding of filtration and the experience of global air filter manufacturers. It is addressed to all HVAC professionals dealing with ventilation systems, particularly designers, facility managers and manufacturers of equipment incorporating air filters.

The document can be downloaded free of charge in the Eurovent Document Library. A printed version can be requested by all filter manufacturers that are members of Eurovent. ■

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

Exhibitions, Conferences and Seminars in 2022

April			
6-8	World Sustainable Energy Days 2022	Wels, Austria	https://www.wsed.at/
21-22	CIBSE Technical Symposium 2022	London, United Kingdom	https://www.cibse.org/technical-symposium/about
May			
4-6	CIAR Lisboa 2022	Lisbon, Portugal	http://www.ciar2022.com./
4-6	IAQ 2020: Indoor Environmental Quality Performance Approaches	Athens, Greece	https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches
20-23	REHVA Annual Meeting 2022	Rotterdam, the Netherlands	https://www.rehva.eu/events/details/rehva-annual-meeting-2022
22-25	CLIMA 2022	Rotterdam, the Netherlands	https://clima2022.org/
June-July			
12-16	Indoor Air 2022	Kuopio, Finland	https://indoorair2022.org/
22-24	Ventilation 2022: 13th International Industrial Ventilation Conference For Contaminant Control	Toronto, Canada	https://www.ashrae.org/conferences/topical-conferences/ventilation-2022
25-29	2022 ASHRAE Annual Conference	Toronto, Canada	https://www.ashrae.org/conferences/2022-annual-conference-toronto
28-1 Jul	Mostra Convegno Expocomfort 2022	Milano, Italy	https://www.mcexpocomfort.it
August			
22-23	BuildSim Nordic 2022	Copenhagen, Denmark	https://ibpsa-nordic.org/
September			
16-19	ROOMVENT 2022	Xi'an, China	https://www.roomvent2022.com/
October			
2-6	Light + Building	Frankfurt am Main, Germany	https://light-building.messefrankfurt.com/frankfurt/en.html
5-6	42 AIVC Conference	Rotterdam, the Netherlands	https://www.aivc.org/news/42-aivc-conference-october-2022-netherlands
20-21	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

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

REHVA
Annual Meeting
2022
Woerden, 20-23 May
Hosted by TVVL

REHVA is pleased to invite its Members and Supporters to the 2022 REHVA Annual Meeting on Friday 20 – Monday 23 May 2022. This year, the Annual Meeting will be hosted by this edition's CLIMA organiser, TVVL in Rotterdam.

Program:

May 20-21 ...... Standing Committee Meetings
May 22 .... General Assembly
May 23 .... Supporters Lunch & Committee Meeting

After the Annual Meeting, REHVA welcomes all its members to participate in the CLIMA congress. For any questions or additional information, please contact info@rehva.eu

CLIMA WORKSHOPS

CLIMA World Congress is the flagship event series of REHVA in the field of building services and indoor climate quality. It attracts around 1 000 participants from around the world every 3 years.

CLIMA is the perfect meeting point of industry and academia, a unique mixture of a scientific congress, practice oriented sessions and exhibition to share knowledge, showcase technological trends and spur discussion about the challenges and trends ahead our sector among researchers, HVAC engineers, and industry representatives.

The 14th edition will be a hybrid event, offering on-site and on-line visibility for sponsors. The venue is the brand new AHOY congress center Rotterdam, the event is hosted by our Dutch Member Association, TVVL. We expect up to 700 attendees on-site (in-line with COVID-19 safety restrictions) and minimum 1 000 online participants.

TVVL TUDelft TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

Health & Comfort

COVID-19 implications on ventilation criteria and design

Sponsor(s) .... REHVA
Organiser(s) .. REHVA COVID-19 Task Force: Jarek Kurnitski and Atze Boerstra
Speakers ...... Bjarne Olesen, Jarek Kurnitski, Pawel Wargocki, Amar Aganovic

EN 16798-1 serves as a major indoor climate standard with the aim to specify IEQ design criteria for buildings with human occupancy. COVID-19 pandemic has initiated discussion and research to assess of what ratio of infections could have been prevented if buildings had been prepared with better ventilation systems that would reduce the risks associated with the aerosol-based transmission of infections. In the current standard, IAQ is dealt through perceived air quality and some specific pollutants. Ventilation sizing criteria is based on perceived air quality by the visitors (not adapted) in non-residential and occupants (adapted persons) in residential buildings that depend on the emissions from humans and building materials. Revision of the standard provides an opportunity to include infection risk-based ventilation (and filtering) criteria as well as productivity and learning performance which effects have been known for a long time but have not been addressed in standards.

The objective of the workshop is to discuss how new evidence on aerosol transmission should affect ventilation design methods/criteria and propose directions how to develop input to the revision of the standard. The following questions will be discussed:

- Bases for existing IAQ and ventilation criteria
- Relative humidity effect on the virus spread in indoor spaces
- Infection risk and event reproduction number-based ventilation (and filtration) design method
- Ventilation effectiveness importance in the design, including air distribution and room partitions/zoning

This workshop will facilitate the dialogue between researchers, HVAC professionals, consultants, manufacturers, building and occupational health authorities to find a path forward to solve a paradigm change in ventilation design.

TVVL
TU Delft
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

Advanced airflow distribution methods for reducing exposure to indoor pollution and cross infection

Sponsor(s) .... REHVA Technology and Research Committee & SCANVAC
Organiser(s) .. REHVA Task Force on Occupant Targeted Ventilation
Speakers ...... Prof. Arsen Melikov, Guangyu Cao, Bin Yang, Angui Li, Xianting Li, John Zhang Lin

A wide range of pollutants has been found indoors, and the adverse effect of various indoor pollutants on occupants' health has been recognized as well. In addition, both gaseous pollutants and particulate matter pollutants may spread indoors from one zone to another through an improperly designed airflow distribution system. Also, using traditional ventilation methods, influenza viruses may spread from person to person through coughing or sneezing by people in public spaces. And the COVID-19 pandemic shows clear evidence that advanced airflow distribution methods are urgently needed to reduce cross-infection and exposure to indoor pollution. Occupants' increasing exposure shows an urgent need to develop advanced airflow distribution methods to reduce exposure to various indoor pollutants.

However, the increase of the ventilation rate leads to an increase in energy consumption and the need for large and costly ventilation systems with possible penalties in thermal comfort. Instead, proper design and control of air distribution in spaces can be a better alternative. This is the focus of a new REHVA Guidebook on Occupant Targeted Ventilation. The present and future activities in guidebook preparation will be presented and discussed. Several working group members will report the details of the work on the guidebook. The goal is to inform the community, discuss the work performed on the guidebook and collect rational suggestions for improving the work on the guidebook.

Energy

Deep energy renovation of buildings for HVAC professionals

Sponsor(s) .... REHVA
Organiser(s) .. TECHNOLOGY AND RESEARCH COMMITTEE
Speakers ...... Tomasz Cholewa, PhD, DSc, CEng (PE), Ilinca Nastase, Jarek Kurnitski, Marija S. Todorovic

The decarbonisation of the buildings sector is vital to deliver on the EU's 2030 and 2050 climate and energy objectives, given that buildings are responsible for 40% of total energy consumption and 36% of energy-related greenhouse gas emissions in the EU. That is why, decarbonisation of the EU building stock requires energy renovation at a large scale: almost 75% of the EU's building stock is inefficient according to current building standards, and 85-95% of the buildings that exist today will still be standing in 2050. Across the EU, deep renovations that reduce energy consumption by at least 60% are carried out only in 0.2% of the building stock per year. Two thirds of the energy used for heating and cooling of buildings comes from fossil fuels.

However, numerous barriers stand in the way of higher renovation rates, such as:

- low awareness of the current energy and resource profile of buildings and the benefits of renovation,
- lack of trust in the energy savings that renovation will achieve.

Taking the above into account and the fact that the majority of energy in existing buildings is used by HVAC, it is crucial to addresses these topics.

For example, minimize loads and focus on the renovation of HVAC systems and the increase of energy efficiency of existing systems. The modernization of HVAC systems can play a very important role during deep renovations of existing buildings in order to achieve in practice the calculated energy savings by operating the existing HVAC.

The main objective of this workshop is to present:

1. Utilitary and widely applicable concepts for the renovation of existing buildings, underlining the critical role of HVAC professionals in the process;
2. Good practices that are widely applicable, have been validated and demonstrated with proven practices during field studies, that document the actual energy and cost savings, and/or realistic estimates from Life Cycle Analysis (LCA) that different renovations will achieve.
3. Practical guidelines applicable to different geographical locations and climate zones that have different priorities for heating/cooling during the renovation of existing buildings.

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Health & Comfort

Low relative humidity in indoor air — an important element of indoor air quality

Sponsor(s) .... Swegon
Organiser(s) .. Swegon
Speakers ...... Mikael Börjesson, Timo Schreck, Pawel Wargocki

In the recent years, indoor air quality research has been focused on air pollutants including VOCs and other species, Radon, particles, and dust etc. The aim was to define permissible levels of these pollutants to avoid the risks to comfort, health and other outcomes such as productivity and learning. Such information is important to equip buildings with technological solutions. There was less discussion on relative humidity and its importance as a modifier of the responses as well in the context of direct effects.

Relative humidity is usually discussed in the context of the thermal comfort criteria as well as perceived air quality because enthalpy of air modifies the perception of air quality. However, relative humidity seems to play much more important role in the context of IAQ and should be discussed on its own and consequently the methods allowing its control in the buildings.

The negative effects of high humidity (>70-80%) are well documented but these levels are rare and unusual. It is important to focus on low end and levels below 20-30% which are prevalent in a large population's occupying buildings, especially during cold winters and when the continuous ventilation with outdoor air is in place. Few studies looked at these levels, some documenting potential negative effects.

There is also a need to look at the effects of low RH for vulnerable populations as most of the work (if not all) is done with healthy people. What about the elderly and otherwise weak people? The discussion should also be potential adaptation to low RH.

Finally, the transmission of pathogens should be discussed in connection with low relative humidity especially that flu and common cold occur usually during winters with low RH indoors.

This workshop wants to initiate debate on the importance of low RH and which levels should create actionable decisions. We need more scientific studies of negative impact of dry indoor air in wellbeing and health.

One other reason for this debate is that the modern humidity recovery equipment in ventilation systems, control strategies and many humidity sources (mechanical and natural), gives new opportunities to minimize the energy costs and avoiding risks to have too high humidity levels in the buildings. Humidity control and humidity optimization is not so expensive as assumed if it is done.

BELIMO

Health & Comfort

7 Essentials of Healthy Indoor Air
Basic requirements for HVAC systems for healthy indoor air quality

Sponsor(s) .... BELIMO
Organiser(s) .. BELIMO
Speakers ...... M. George Hoekstra, Martyn Wyss, Mikko Gisin

Belimo has interviewed consulting engineers and experts in the ventilation sector around the world to identify the priorities when aspiring to create a healthy indoor air environment in a building. In the process, seven essential factors for ensuring healthy indoor air in non-residential buildings have emerged.

This workshop should help define the KPIs for each 7 essentials of healthy indoor air.

The Essentials of Healthy Indoor Air:

1. Continuous and reliable measurement, display and monitoring of indoor air quality
2. Accurate amount of air to the zone and controlled removal of contaminated air
3. Well-designed air dilution and airflow pattern
4. Active pressurisation of envelope and spaces
5. Correct temperature and humidity conditioning
6. Effective filtration
7. Proper amount of outdoor air

Energy

Deep Renovation Concepts

PURMO GROUP

Sponsor(s) .... PURMO GROUP Ltd
Organiser(s) .. Purmo Group
Speakers ...... Mikko Iivonen, Jarek Kurnitski, Clemens Felsmann, Michele De Carli

In the energy-efficient renovation of buildings, the thermal insulation and the airtightness of the building envelope, including windows and exterior doors, are improved to almost meet the requirements of new construction. Building services systems, such as heating, water and ventilation systems, as well as electrical and telecommunications systems, will also be modernized to be more functionally efficient and energy efficient.

This Workshop presents renovation concepts that can achieve the desired level of energy performance, which in many European countries is considered to have an EP value of less than 75 kWh / m² per year. The goal of deep renovation is to achieve at least 60% energy savings compared to the initial consumption.

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Digitization

The Future of HVAC as a Service

Sponsor(s) .... LG Electronics Air Solution Europe
Organiser(s) .. LG Electronics Air Solution Europe
Speakers ...... Pierre-Thomas Louis de Soultrait, Gianluca Figini

The digital transformation is nothing new, but it is still a transformation that is ongoing day-by-day in every facet of our world. Today, sustainability, the sharing economy and digitalization all work together to make our homes and our lives more efficient and user-friendly and the HVAC industry needs to continue to forge new paths toward innovation and integration.

We are the leaders of a transformation that has the power to shape the way we live our lives, the way we occupy spaces and the impact we can have on the future of this planet. Often considered a slow-moving industry, HVAC is now at the forefront of a major shift in both technology and mindset as we attempt to revolutionize the way both buildings consume energy and the way people consider energy as it applies to their day-to-day.

From climate change and COVID-19 to consumer expectations and evolving technologies, the task of our industry is more demanding than ever before. But, it's also more rewarding. If a house can work better for the people in it, while reducing its carbon footprint and overall cost, don't we want everyone to have access to that? What about an office space that inspires people to reinvent their routines and the way we work? Or consider a retail shop or restaurant that operates smoothly around its customer, as comfort is only something we notice when we don't have it. And that can make or break a business.

Sometimes it's easy to get caught up in the demands of our industry and we forget that we have an impact on the daily lives of real people. And what we also have to remember is that we are those people too. Buildings are an often overlooked aspect of our lives but our industry of smart, integrated solutions is paramount to a revolution that could change the way people engage with spaces the in which their lives take place.

So, let's take a collective step back together in order to reimagine a different future that works better for everyone.

This workshop will deep dive into the potential future of the HVAC industry when it comes to sustainable, shared and digitalized solutions and will allow participants to open our minds to what that future could look like through the unique, collected lens of experts from across the industry.

We will brainstorm, shake up the way we workshop and come together in a format where there is no wrong answer and all ideas are welcome to answer a few key questions: How can industry players collaborate to make HVAC a positive contributor to climate change while helping end-users enjoy more efficient spaces? How can HVAC technology be a key player in Europe's and the world's climate goals? What are our individual roles as industry players in shaping this change? How can governments go further in supporting the end-users' adoption of sustainable HVAC technologies? What can the industry do to empower end-customers about HVAC topic, trends, subsidies and more? What does HVAC as a service look like, what are the limitations and how far can we imagine taking it?

enerbrain
For an intelligent use of energy

Digitization + Energy

Efficiency beyond the building:
the leverage of advanced HVAC control systems in the management of Energy Communities

Sponsor(s) .... Enerbrain
Organiser(s) .. Enerbrain
Speakers ...... Tiziana Buso, Attilio Di Sabato

The workshop will introduce the principle of operation of Artificial Intelligence-based advanced BACS and focus on how these algorithms can be exploited to reach optimal performance of the HVAC systems with respect to different objective functions, ranging from occupants' comfort requests to community level energy self-sufficiency.

Specifically, the participants will exchange ideas on whether, how, and to which extent indoor environmental conditions and preferences - maintained through the remote management of the HVAC systems - can target flexible set-points, to be varied based on the energy use profiles and on the renewable energy production patterns both at the building level and at the community level as well as the needs of grid balancing. The discussion will thus explore the role of HVAC in Demand Side Management (DMS).

The Energy Communities introduced by the recast of the Renewable Energy Directive (RED II) and the Internal Electricity Market (IEM) represent an interesting new frontier for the application of advanced BACS in DMS services. In this framework, the possibility of cooperation with providers of energy flexibility services and the available business models to propose optimized HVAC-related management services will also be explored, opening up the discussion to the available opportunities from Country to Country.

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QUEST

Energy

Sustainable Finance in Building Projects: The EU Taxonomy & Financial Risks of the Performance Gap

Sponsor(s) .... QUEST project, H2020
Organiser(s) .. QUEST project https://project-quest.eu/
Speakers ...... Stefan Plesser, Frank Hovorka, Ole Teisen, Ivo Martinac, Cormac Ryan

The first part of the EU Taxonomy, on Climate Change Mitigation & Adaptation, entered into force on 1 January 2022 and aims to provide a common language on what economic activities can be labelled as 'sustainable'. Investments going into sustainable building projects are often perceived as a risk as financial actors are not always able to assess the technical risks involved in construction projects. This lack of understanding creates uncertainty if their investments will bring the impact on building performance they're looking for since building projects don't always deliver on the predicted performance during the operational phase, the so-called "Building Performance Gap". When building projects don't deliver on the expected sustainable impact, they're also not Taxonomy-aligned and can't be part of a "green portfolio".

This workshop will focus on bridging the gap between the financial community and technical expertise in building projects through the integration of Quality Management Services (e.g. Technical Monitoring, Building Commissioning, Green Building Certification). These services help to detect and mitigate the technical risks in the early-development stage of a building project and ensure that the "performance gap" between desired and actual energy performance is minimized. Within this context the Taxonomy will be discussed as this creates a common language for both investors, architects and building services engineers and aims to bridge the gap between all actors.

The workshop will be tailored towards building professionals on the topic of working with financial actors, the impact of the EU Taxonomy on these relations and how quality management can support. The session will start with a keynote speech by the outgoing REHVA President Frank Hovorka, on sustainable finance and impact of the Taxonomy. This will be followed by interactive presentations on quality management services, a practical methodology on how to integrate them in building projects and how they can support projects to be aligned with the Taxonomy. During and in-between the presentations questions will be asked to the audience to create discussions and exercises will be done to get their input.

This workshop will have 60 minutes of interactive presentations and 30 minutes of panel discussions with open inputs from the audience. During this open session both the panel and the audience can share their experiences to engage with financial actors and the impact of the EU Taxonomy.

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CLIMA WORKSHOPS
EU PROJECTS

Learning & Education + Energy

CEN-CE scheme roll-out: harmonised training and certification of experts on EPB standards

Sponsor(s) .... /
Organiser(s) .. EPB Center
Speakers ...... Andrei Lițiu (moderator), Johann Zirngibl, Laurent Socal, Cătălin Lungu

Learning and education is undergoing a shift in both terms of process and delivery channels. Buildings, in addition to the ongoing digital transformation, are now acknowledged as key areas to contribute to EU's energy and climate targets. This will result in a fast-paced evolution of the sector across the value chain and the need for continuous learning and education for keeping up both the pace of innovations with regards to building technology (retraining) and the scale of renovation activities (upskilling the additional workforce).

Maintaining a constant exchange of information will be needed between universities, manufacturers, policy makers and practitioners (designers, installers, operators, auditors) to guarantee the feedback loop is closed and all lessons learned captured, while taking into consideration the sector's language gap.

The set of EPB standards anchored in the EPBD and bringing added value to day-to-day activities of practitioners are the lynchpin between policy, standardization and practice. The EPB standards and related tools were however not enough, training was missing to create the needed communication bridges and overall community as described above.

CEN-CE scheme is now here! Join this workshop to understand the CEN-CE scheme's concept, how it's currently being rolled out, by REHVA and EPB Center, across Europe in cooperation with REHVA MAs (e.g. AIIR) and how to get involved and become a certified trainer in your country.

The 90 minutes shall be split into 45 minutes presentations and 45 minutes interaction with the audience (including live polls and specific topic selection).

Energy

Support, consultancy and services for the implementation and practical use of the set of Energy Performance of Buildings standards

Sponsor(s) .... /
Organiser(s) .. EPB Center
Speakers ...... Jaap Hogeling (moderator), Pau Garcia Audi, Xu Wei, Drake Erbe, Dick van Dijk

The set of EPB standards, stemming from the Energy Performance of Buildings Directive (EPBD), bring added value to day-to-day activities of practitioners thus represent the lynchpin between policy, standardization and practice with regards to building energy performance. Many EPB standards are already, in addition to CEN, included in the ISO 52000 series which will eventually integrate all EPB standards, making the set of EPB standards a global framework with the potential to bring together all actors in between policy makers and practitioners.

Experience has shown that having available just the standards and related spreadsheets is not enough to reap all the benefits they bring. An EPB platform creating the needed communication bridges and overall community is essential for the implementation and practical use of the set of Energy Performance of Buildings standards.

EPB Center aims to fill this gap! Join this workshop for getting an overview of the implementation of the EPB standards (EU, China and USA), learn about the publicly available resources provided by the EPB Center and how & which EPB Center tailored consultancy and services packages could ensure your organization unleashes the full potential of the set of EPB standards and becomes a front-runner in the race to net zero (positive) both energy and carbon buildings.

Energy

Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

Sponsor(s) .... TRI-HP project, H2020
Organiser(s) .. TRI-HP project
Speakers .... Daniel Cabronell, Maike Schubert, Alireza Zendehboudi, Xabier Peña Anton, Thibault Péan, Thomas Friedrich

TRI-HP project will develop and demonstrate flexible energy-efficient and affordable trigeneration systems. The systems will be based on electrically driven natural refrigerant heat pumps coupled with renewable electricity generators (PV), using cold (ice slurry), heat and electricity storages to provide heating, cooling and electricity to multi-family residential buildings with a self-consumed renewable share of 80%. The innovations proposed will reduce the system cost by at least 10-15% and decrease greenhouse gas emissions by 75% compared to gas boilers and air chillers.

This workshop will facilitate the dialogue between technology developers and HVAC designer experts to discuss the most prominent barriers and identify country-specific but also EU-wide innovation diffusion pathways, towards full market deployment of innovative, renewable heating and cooling applications.

The workshop will be split into three parts: In the first part, TRI-HP partners will briefly describe the innovations of the developed systems, while in the second part, they will answer targeted questions by "the jury" – made up by two HVAC designer experts from two different European countries. The third part of the workshop will be open for audience questions and be encouraged to participate in the discussion.

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Digitization

Digital transformation facilitating building performance convergence and enabling operational rating

Sponsor(s) .... U-CERT project, H2020
Organiser(s) .. U-CERT project
Speakers ...... Andrei Litiu (moderator), Peter op ‘t Veld, Jan Cromwijk, Dick van Dijk, Pablo Carnero

The main scope is to raise awareness/promote, collect feedback and explore use cases on the U-CERT digital tools while also presenting the overall contribution of U-CERT in the evolution process of Building Performance Assessment and Certification at both EU and national level.

The content will be tailored to building professionals illustrating the practical implementation of U-CERT digital tools on the U-CERT case studies and how this creates value to be swiftly captured in day-to-day activities by both designers and installers.

The U-CERT digital tools facilitate the convergence of building performance calculation methodologies leveraging the set of CEN/ISO EPB standards and enable the inclusion, next to asset rating only, of measured building performance and building operational rating (normalized measured building performance) creating complementing/new services that building professionals can swiftly include in their existing offering or expand it.

CLIMA 2022 Theme 4 Circularity

Circularity: narrowing, slowing and closing flows

Topic coordinators of Theme 4 Circularity:

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Due to a globally growing population and the need for comfortable and healthy indoor environments, a huge building challenge lies ahead of us, mainly related to the development of new building projects and the need to upgrade the existing building stock. To ensure a future-proof, sustainable economy for future generations, reducing the use of primary resources is essential. Therefore, there is a need for a shift from linear to circular systems. Circularity aims at narrowing, slowing and/or closing material, water, and energy flows (Boeken et al. 2015).

Strategies of circularity

Narrowing of cycles means a reduction in the use of raw materials. It prevents waste and is preventive in nature.

Slowing cycles focuses on extending the useful life of materials and products, for example, through proper management and maintenance and through applying value-preserving interventions such as repair, reuse and re-manufacturing (see the R-ladder, Kishna et al. 2019).

Closing cycles means that, at the end of their use or service life, materials are returned to the front end of the production chain. This can involve both recycling processes for technical materials and bio-cascades for the biological stream: from recycling to biodegradation.

In this respect, circularity cannot be viewed separately from **regenerative capacity**, so as not to end up in a negative spiral of ever-decreasing quality of products or the (built) environment, but to focus on increasing positive impact. This relates to 'purification', for example, such as the removal of toxic or other undesirable substances in materials, air or water flows.

Figure 1 visualises the previously mentioned strategies that can all facilitate a circular economy and are often combined.

The HVAC sector certainly has great potential to contribute to circularity. Cycles of energy, air and water flows form the core business. Service installations and components are often subject to maintenance or replacement. Here, the preservation

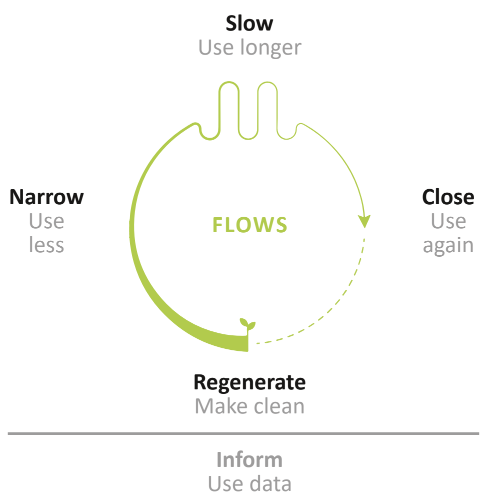

Figure 1. Circular Economy: narrow, slow, close and regenerate material and energy flows. [Konietzko et al. 2020]

Table 1. Matrix of functions, associated materialisation and some intervention and processing routes for circularity.
Based on Geldermans 2020

Function	Category	Section	Bio-cascades	Maintenance & Repair	Reuse & Redistribution	Refabrication	Recycling
HVAC	Ducting; Cables; Filters;	Product					
		Material					

and reuse of valuable components offer considerable opportunities, both from an environmental point of view and from a user comfort and business perspective. **Table 1** shows a simplified matrix, in which circular strategies are linked to earning models, such as maintenance contracts and take-back agreements.

The mentioned opportunities and benefits have, at least for the time being, not translated into a large-scale market breakthrough. The sector needs a clear vision on realising circularity targets, based on innovative strategies and an integrated approach in the area of **circular design, product technology, business models** and **administration & management**. Few examples of these four strategies, are as follows.

Examples of circular design: Design for disassembly; Product life cycle strategies; Product functionality; Building design; Environmental assessment of circular components

With the CSP Panel (particular PCM panel), PCM Technology has introduced a phase change material with Cradle to Cradle® Silver certification to the market (Source: CZCCertified.org). Phase change materials either store heat or release it, when their physical condition changes, allowing them to generate more consistent room temperatures. The panels are built into walls or ceiling surfaces.

To attain the CZC® Silver certification, the entire production process of the CSP Panel has been checked for health aspects and reusability of the material, as well as for (green) energy use, water use, and social justice. Circularity is therefore part of an integral methodology.

Examples of product technology: Biological, technical and critical materials; Reuse and remanufacturing of components; Circular maintenance; Product and material tracking; Standards and regulations

Since 2018, Carrier has been committed to setting up and tracking material passports for (a series of) air heat pumps. This venture immediately showed how complex the issue can be for installation components. The process took a considerable time, partly as a result of the long supply chain, the complexity of the products or the quantity and materials and origin.

Unlike a concrete shell or wooden frame, an installation component consists of a large variety of materials.

Figure 2. CSP Panels phase change material PCM Technology. [Source: C2CCertified.org]

Taking stock of these materials offers the possibility of generating a detailed LCA and thus providing products with better labels in the National Environmental Database (NMD). Most installation products in the NMD have a so-called generic category 3 label. This entails a conservative estimate of the LCA and an additional penalty of 30% to ensure that the results are not presented too positively. Within the framework of the MPG requirement, which has been tightened since 1 July 2021, improving data quality is therefore an attractive circular initiative and a basis for creating circular awareness.

A second example that contributes to increasing awareness and defining materials and raw materials, is Madaster (see www.madaster.com), the so-called registry for materials. Madaster offers a platform to record and store properties, quantities, locations and characteristics in a structured way.

Examples of business models: Value proposition; Total cost of ownership; Total benefits of ownership; Legal and safety aspects; New models of ownership; Strategies for product services

One of the best-known examples in the field of installation technology that is provided as 'As a Service' is 'Light as a Service', where Philips Lighting (now Signify) was the first party to offer light instead of lighting. Philips remains the owner of the LED lighting fixtures and lamps and charges an amount per quantity lux or burning hours delivered.

Also, the first 'Lift as a Service' concept was delivered in Circl, the ABN Amro pavilion on Zuidas in Amsterdam. Here, Mitsubishi launched its M-Use concept. It is a circular model for lifts, which charges for use rather than a traditional purchase and maintenance subscription.

This 'product as a service' model avoids high investment costs for the customer, and reuse and recycling are the priority at the end of the lift's service life. The handling of materials and effective lift maintenance can therefore lead to a longer service life compared to bought lifts, which in turn can contribute to the strategy of delay, according to **Figure 1.** The well-known principle of an Energy Service Company (ESCo) can also be described as a Heat AS A Service proposition. The big difference here, however, is that an ESCo is rarely, if ever, the producer of the products and thus differs from the regular As a Service proposition.

Examples of administration & Management: Supply chain management; Reverse logistics; Engagement of stakeholders; Responsibility of producer responsibility; Business operations, facilities and resources; Policy

In October 2018, Grundfos and Technische Unie took the initiative to collect old pumps for recycling. Collecting the pumps is a start to realising a circular production process. The take-back strategy that the parties have set up together has reduced the material impact, as materials taken from the pumps are no longer destroyed.

Old pumps were previously partially recycled at a traditional waste disposal facility. But here, not all the material from the pumps could be reused. By choosing to take back and reuse and/or recycle the pumps, the percentage of reused material from these old pumps is over 97%. That is 10% more than with a traditional waste management company. Wilo has also developed a similar programme, where they look at each pump to decide which parts can be reused or recycled. In 2020, for example, 23,000 magnets had been reused, according to the company. They do this, on the one hand, to avoid limiting the quantity of primary raw materials and, on the other hand, to ensure the quality of the supply of raw materials. Both are concrete examples of the closing and regeneration strategy, as shown in **Figure 1**. ■

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CLIMA 2022 Theme 3: Health & Comfort

Buildings and installations must show resilience in the long and short term

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The health and comfort of people in their built environment, at home, at work, at school, on the road or in leisure time is a complex subject involving physics, behaviour, physiology, energy use, climate change, architecture, engineering, and technology. The way people feel, experience, and behave is related to the quality of their environment, described by the thermal, air, light and sound qualities. In addition, the resilience of buildings and installations to changing demands and preferences and the ability of people to respond to new buildings and installations affect their perception and behaviour.

Studies worldwide show that relationships between the indoor environment (thermal aspects, indoor air quality, light and sound) and the well-being of occupants or users (health and comfort) in office buildings, schools, homes, and hospitals are complex [1], which makes it difficult to decipher them. Many indoor environmental stressors affect health and comfort either additively or through complex interactions. These include thermal aspects (e.g., draught, temperature), visual aspects (e.g., reflection, view, brightness differences), air quality (e.g., odours, moisture, mould, radioactive radiation, chemicals, particles), and acoustic aspects (e.g., noise and vibrations). Quite a few diseases and disorders are related to staying indoors, such as mental illness, obesity, cardiovascular disease, chronic respiratory diseases (such as asthma in children and COPD in adults), cancer, and COVID-19. The COVID pandemic has shown that buildings and installations must be able to provide a resilient environment not only in the long term (in connection with climate change) but also in the short term (during a pandemic, for example).

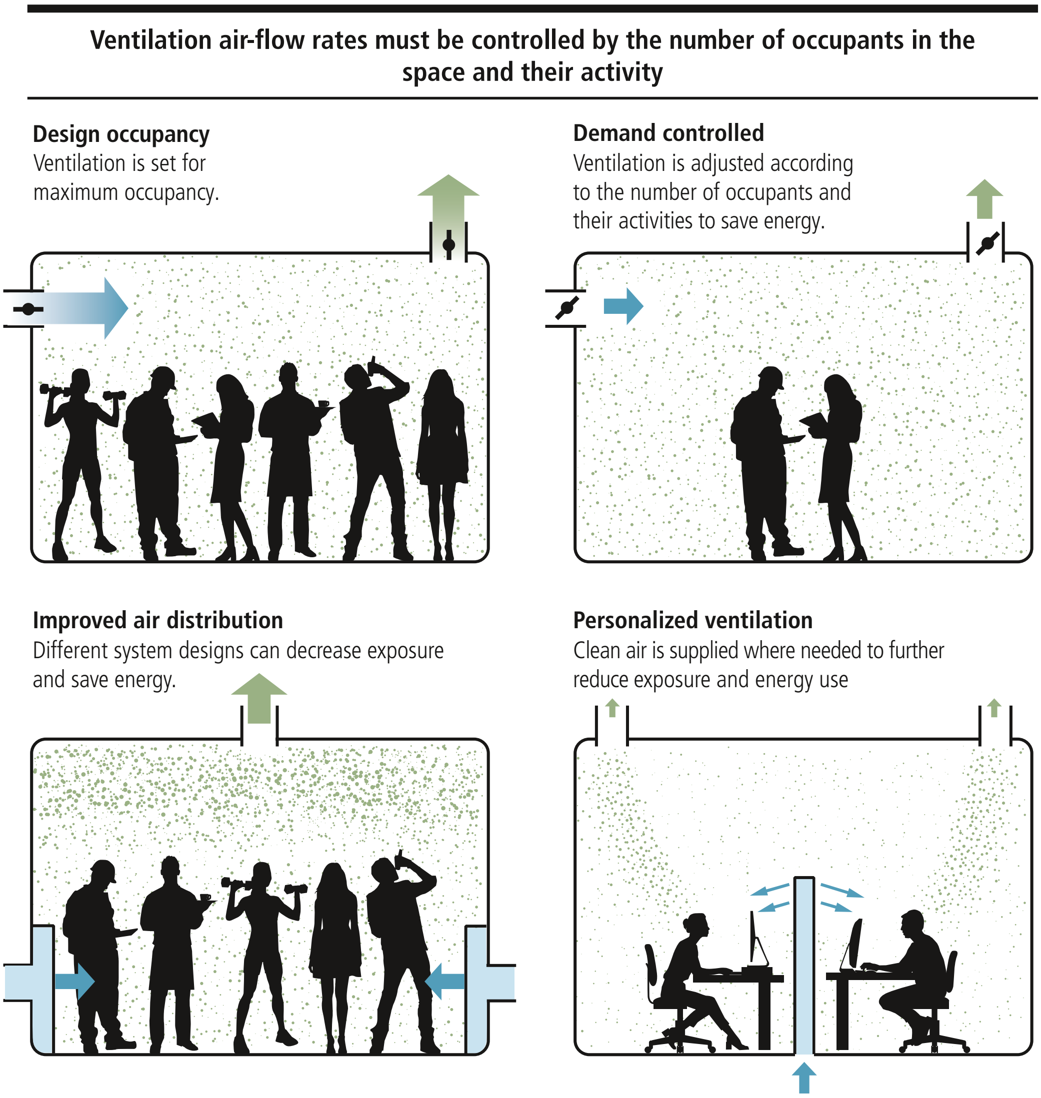
Ventilation to reduce infectious diseases

If we assume that aerogenic transmission of SARS-CoV-2 is a serious route of transmission, it is clear that not only the amount of required ventilation is relevant, but also the way of ventilating in different situations [2]. 'Good' or proper ventilation primarily means ensuring sufficient and effective ventilation. Ventilation that provides supply of 'clean' air and extraction of contaminated (infected) air in the breathing zone of each individual. Preferably, air extraction should take place without passing through the breathing zones of other persons and without recirculating (reusing) air. Air cleaning is an option when there is insufficient ventilation or when air recirculation cannot be avoided.

How much ventilation is needed? This is not an easy question to answer. Today's regulations for spaces occupied by multiple persons are based on the CO_2 concentration in the air. CO_2 is used as an indicator of the presence of people. With each breath, CO_2 is exhaled. However, it is not clear whether CO_2 is a good indicator for exhaled 'infectious' aerosols, because CO_2 is a gas, and exhaled droplets and aerosols are not. This raises many questions about the correct method for determining boundary values for the amount of ventilation. Do aerosols and exhaled droplets behave like gases or do they behave differently? Are there other models we can use if CO_2 is not a good approximation for exhaled infectious aerosols?

Indoor environmental quality in energy-efficient & refurbished buildings

In addition, we must not forget that 'infectious' aerosols are not the only possible contaminants present in a room. The debate about other sources of pollution than the presence of people in a room has



Flexible ventilation systems, dependent on the building purpose. [3]

been going on for a long time, such as emissions from building and furnishing materials, pollution from the outside air, or as a result of poorly maintained air-conditioning systems, as well as all those volatile organic substances and particles that are released during the activities that we carry out in our homes, offices or other buildings [4]. We must also consider the effects that measures taken to improve ventilation may have on other aspects of the indoor environment. Think about how opening a window introduces outside noise and allows cold air to flow inside. Last winter, many children at school sat in chilly classrooms with all the windows and doors open to get as much fresh air as possible. There were also more problems with noise, caused by the airflow in the supply piping, as the systems were running at their maximum. In addition, draughts can occur if the supply grilles are not properly adjusted.

In addition, research shows that buildings renovated to address climate change can pose a serious risk to the health and comfort of their occupants [5]. Respiratory, eye and skin problems can occur as a result of certain renovation measures. Insulating and making our buildings airtight can lead to moisture problems, build-up of air pollutants, lack of control, noise and/or overheating. Air-conditioning systems, although efficient, can cause air pollution, draughts, and noise.

Research also shows that such measures do not always yield the desired energy savings. This is partly due to the residents and their behaviour, and partly due to the technologies used and their feedback systems. When renovating energy-efficiently, it is therefore important to take into account the requirements and preferences of the occupants [4].

Flexible installations and climate-resistant buildings

It is important to reconsider the way we ventilate, especially in busy indoor areas where people stay for long periods of time, such as in classrooms, office landscapes, restaurants, nursing homes, theatres, sports clubs, etc. The new generation of ventilation systems should not just focus on ventilating a room but should offer a range of options so that the changing demands of occupants over time can be met, be it for health or comfort. Flexibility is therefore the key. The COVID pandemic has shown us that more knowledge is needed about the way potential pathogens spread in buildings, about the best conditions

and ways to fight infections, as well as ways to create affordable, flexible, energy-efficient, and effective ventilation. The need for related research is obvious. Collaboration between different disciplines, such as epidemiologists, virologists, aerosol experts, structural engineers, architects, psychologists, sociologists, and mechanical engineers is indispensable. The fight against future diseases will have to be taken up together with the challenges that climate change poses to the built environment. ■

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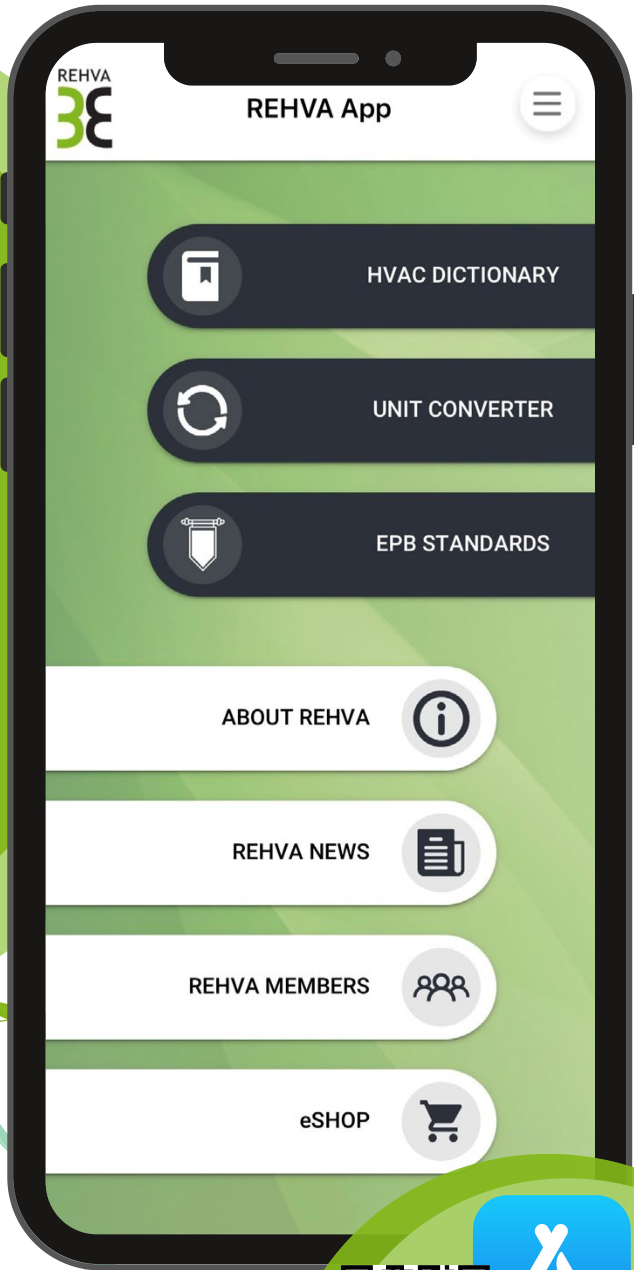

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