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Kitchen ventilation

Challenges and Needed remedies of Demand Controlled Ventilation

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IEQ and Ventilation to be integrated in recast Energy performance of Buildings Directive (EPBD)

The recast EPBD and the amendments as adopted by the European Parliament 14th March 2023 clearly includes Indoor Environmental Quality (IEQ) and ventilation requirements. The ongoing negotiation (the so-called triage) on the final text should result in a recast EPBD before the end of the summer. In this recast EPBD the IEQ will go alongside energy performance and decarbonisation requirements. It is a great step forward in securing healthy indoor environments in new and to renovate buildings. Clear statements on IEQ and ventilation control and inspection are included. The statement that the positive health effect of improved IEQ should be included in the cost optimal equation on energy efficiency and decarbonisation measures sounds very promising.

The focus on ventilation and IEQ in this RJ is most welcome. With thanks to our Scandinavian authors and coordinating support of Peter G. Schild. This RJ offers articles on ventilation in kitchens, the need for demand controlled ventilation, a survey on Swedish Covid guidance, position paper of the Nordic ventilation group. Also, on ventilation two articles from the last AIVC conference: one on inspection of ventilation systems and one on the role of indoor CO_2 in response on the pandemic.

The expected inclusion in the recast EPBD of waste water heat recovery (WWHR) as a well proven technical system to reduce the energy use of domestic hot water systems is the reason to include a first article to introduce shower drain heat recovery. In the context of reduced heating needs due to the increasing level of building insulation, the energy use for domestic hot water plays an increasing role. WWHR is a technology that allows to cover a significant part of the domestic hot water energy needs with heat recovered from the shower drain. In the next RJ issue, more will be published on a EPB WWHR system standard that is going to add the set of EPB standards.

In Annex I of the recast EPBD, it is stated that Member States shall define indicators on operational and embodied greenhouse gas emissions produced in $kgCO_2eq/(m^2 \cdot y)$ over the expected service life of the building. It is clear that the EPBD is restricted to ruling on carbon emission. In the near future the European Construction Product Regulation (CPR) will go much further to protect our environment. Step by step more elements will be required to include in the in the Environmental Product Declarations (EPDs). An article on EPDs for HVAC products illustrate the important role of EPDs in the coming years in Europe. The CPR is going to be the main driver for use of EPDs. ■

JAAP HOGELING
Editor-in-Chief
REHVA Journal

Evaluation of replacement air systems

– Avoiding negative pressure problems during cooker hood operation in airtight dwellings

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The present paper summarizes the results of a Swedish technology competition on ventilation in energy-efficient residential buildings. The first stage of the competition was conducted during 2019–2020 in collaboration between the trade organizations/networks Svensk Ventilation (svenskventilation.se) and BeBo (The Swedish Energy Agency´s network for residential property owners committed to energy efficiency bebostad.se) with the overall aim of stimulating new and innovative solutions to ventilation problems in energy efficient residential buildings. The problem addressed in this article is linked to the need to supply replacement air in conjunction with operation of the range hood to avoid disturbing under-pressure in the apartment.

Background

In the Nordic countries, high air tightness is sought in buildings in order to reduce the heat demand caused by air leakage due to wind. It is desired to maintain a small negative pressure indoors compared to outdoors (a few pascals) to reduce the risk of moist room air leaking into the climate screen (walls, roof, etc.) during the heating season and giving risk of moisture damage. Normally, 5 – 10% lower supply than exhaust air flow rate is sought for each apartment.

To avoid problems with negative pressure in dwelling projects, the requirement of a maximum negative pressure of 10 Pa is sometimes used. A negative pressure of more than 25 Pa can cause problems for people with reduced strength to open doors.

Very energy-efficient and airtight apartments can achieve a leakage air flow, Q_{50}, down to 10 l/s when tested with 50 Pa pressure differential. It has been shown that the negative apartment pressure becomes problematic if the difference between the total exhaust air flow and total supply air flow approaches half of the Q_{50} value. Thus, in airtight buildings, each apartment should have an exhaust -supply airflow rate difference less than 4 – 5 l/s (<0.5 Q_{50}). This places high demands on airflow measurement and balancing in such residential buildings. The higher the air tightness requirements, and the better the builder is at building airtight, the greater the demands on the ventilation to avoid problems with over- or under-pressure during basic or forced air flow. The need to increase the exhaust air flow rate in the cooker hood when cooking creates problems with replacement air.

One way to get replacement air has been window airing, but window airing can significantly increase heating demand if windows are left open. As a result, various solutions to control replacement air during cooker hood forcing have been tested by property owners, but good solutions have been missing, so far.

Problems with negative or positive pressure can occur if replacement air and the air flow of the cooker hood do not follow each other, so there is a need for monitoring and control, for example, built into the cooker hood, but this type of product is not yet available.

This is the background to Svensk Ventilation and BeBo initiating a technology competition on replacement air systems in 2019-20. The competition concerned energy efficient multifamily buildings, typically 3-8 stories high. The targeted building type typically have one centrally placed air handling unit per stairwell. On average, each apartment comprises a total floor area of about 70 m², distributed between three rooms and a kitchen. Typically, the airflow rate extracted from the kitchen cooker hood ranges from 10 l/s as the basic flow, up to a forced flow of about 40 l/s.

The tested solutions

Out of fifteen submitted solutions, the competition jury judged that three were particularly interesting for further consideration. These three were invited to be evaluated by laboratory testing with the purpose of verifying that the solutions maintain the required performance over time.

One of the chosen solutions were withdrawn, so, only two were tested in the laboratory at Chalmers University of Technology in Gothenburg, Sweden. Both these solutions are based on an electrically controlled damper opening for increased supply of replacement air when the range hood is activated. One solution is intended for use with mechanical supply and exhaust air, while the other is intended for buildings with mechanical exhaust air with supply of untreated outdoor air, e.g., through slot vents.

The test method

The tests were carried out in a test chamber with an internal volume of 30 m^3 and a total enclosure area of 59 m^2. The air leakage through its envelope was determined to 13 l/s at 50 Pa negative chamber pressure. The chamber dimensions are smaller than those of real apartments. The smaller size means that the pressure changes that occur in the chamber will be faster than they would be in a real apartment. Thus, the technology solutions have been tested under slightly stricter conditions than is normal in real buildings. **Figure 1** shows a sketch illustrating the principle of the test chamber when arranged to represent a dwelling with mechanical supply and exhaust ventilation.

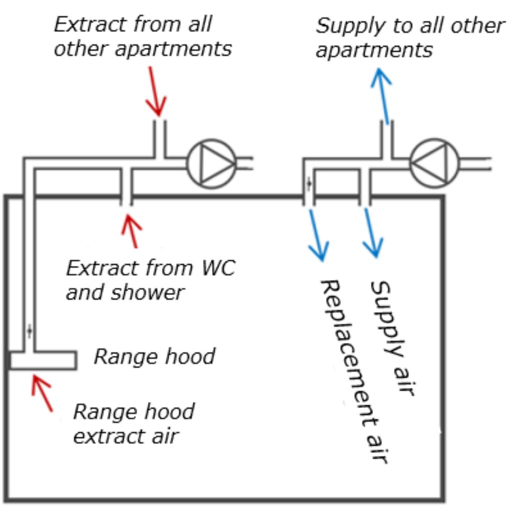

Figure 1. Sketch showing the principle of the test chamber when arranged to represent a dwelling with mechanical supply and exhaust ventilation.

The test chamber pressure was measured using a reference electronic micromanometer with a measurement uncertainty of ±0.3% of the reading plus ±0.3 Pa. The airflow rates were determined by measurement of pressure differentials over co-calibrated dampers. All micromanometers were co-calibrated and differed less than 0.6 Pa at the pressure levels measured in the test chamber, and less than 1.6% of the reading at the levels measured for air flow rate determination. To be able to follow the rapid flow and pressure changes, the readings were recorded typically using a time resolution of 1 value per second.

Results

The dampers for replacement air have different speed of position change. One takes 80 seconds between its end positions, while the other takes 22 seconds. Since the cooker hood's control is instantaneous, using a "flap" damper, there was a short-term pressure drop. In the case of the slower replacement air damper of *solution 1,* the test chamber pressure dropped towards –25 Pa during less than 1/2 minute. In the case of the faster damper of *solution 2*, the pressure rarely dropped below –10 Pa.

Figures 2 and 3 show examples of measurement results obtained for *solution 1,* i.e., when the test chamber was arranged to represent a dwelling with mechanical supply and exhaust ventilation. In **Figure 2** the range hood was inactive (both the range hood damper and

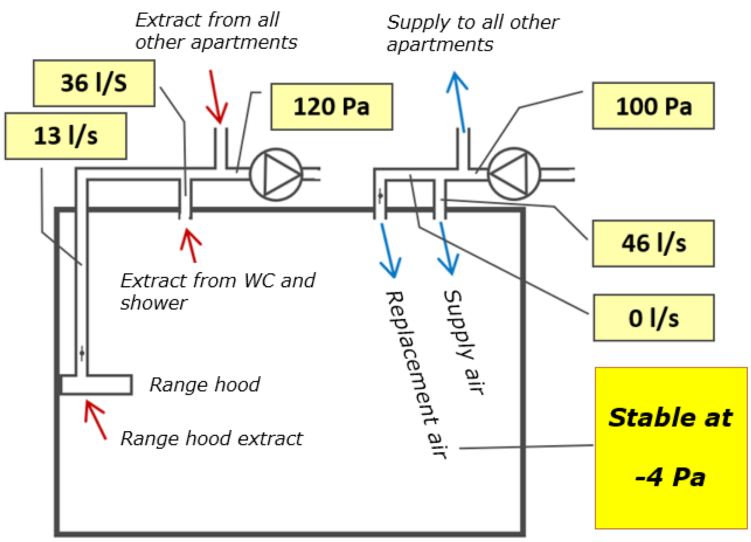

Figure 2. Example of measurement results obtained for *solution 1* when the range hood was inactive (with closed dampers). The test chamber was arranged to represent a dwelling with mechanical supply and exhaust ventilation.

the replacement air damper closed). The pressure in the extract and supply air ducts were maintained at 120 Pa and 100 Pa, respectively. The extract airflow rate from WC and shower room was measured to 36 l/s, and the basic extract airflow rate through the range hood was 13 l/s with the damper closed. Thus, the sum of the extract airflows rates was 49 l/s, which was slightly (3 l/s) higher than the supply airflow rate. At this airflow difference the test chamber pressure was −4 Pa.

In **Figure 3** the range hood was activated, which caused the extract airflow rate through the hood to increase to 34 l/s. In this case the total extract airflow rate was 68 l/s. The activated range hood caused the damper for replacement air to open. The replacement supply air flow rate was then measured to 34 l/s and the total supply airflow rate stabilized at 68 l/s. In this case the extract-supply airflow rate difference became too small to be able to be determined by measurement. The pressure in the test chamber briefly reached −24 Pa and then stabilized at −1 Pa.

The diagram in **Figure 4** shows an example of the total supply and extract airflow rates monitored together with the room pressure for *solution 1*. The diagram illustrates how the extract airflow rate increased instantly when the range hood was activated, and the supply airflow rate successively increased as the

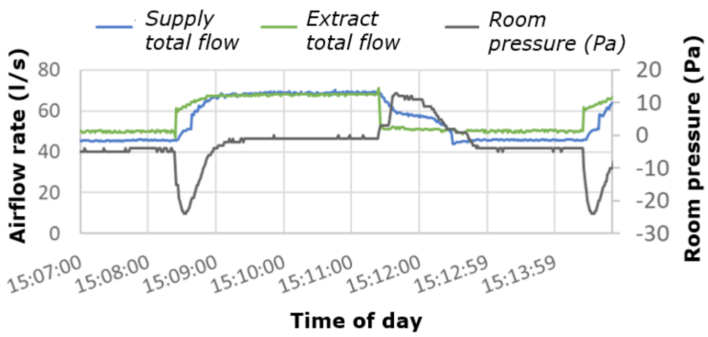

Figure 4. Diagram showing an example of a time series of measurement results obtained for *solution 1*. The test chamber was arranged to represent a dwelling with mechanical supply and exhaust ventilation.

replacement air damper opened. During this course the room pressure rapidly dropped towards −25 Pa before it was being restored. Later, when the range hood damper was closed, the room pressure became positive for a brief period before the replacement air damper reached its closed position.

Figure 5 shows an example of measurement results obtained for *solution 2* when the range hood was active (with open range hood damper). In this case the test chamber was arranged to represent a dwelling with mechanical exhaust ventilation and air supply through outdoor air vents, e.g., slot devices.

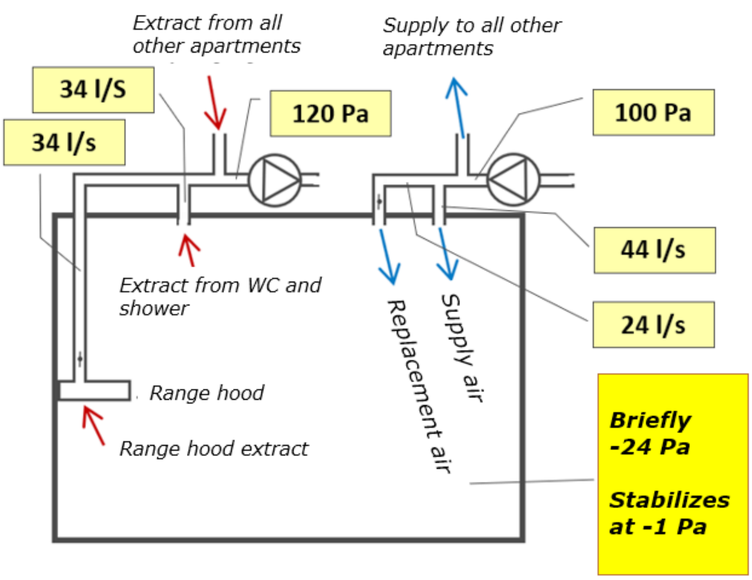

Figure 3. Example of measurement results obtained for *solution 1* when the range hood was active (with open dampers). The test chamber was arranged to represent a dwelling with mechanical supply and exhaust ventilation.

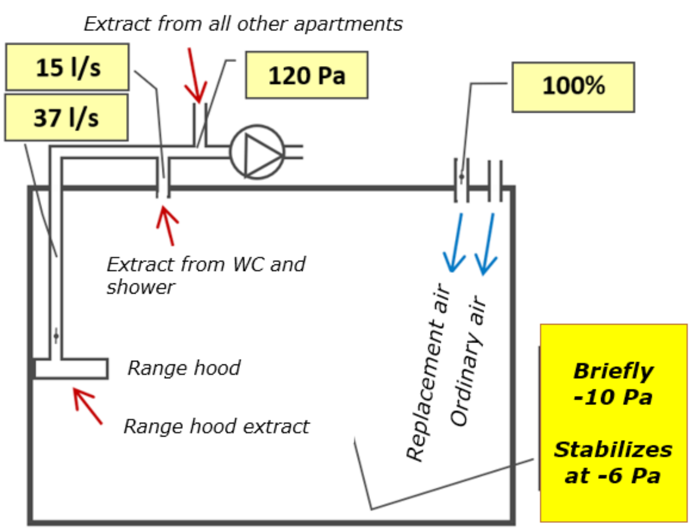

Figure 5. Example of measurement results obtained for *solution 2* when the range hood was active (with open damper). The test chamber was arranged to represent a dwelling with mechanical exhaust ventilation and air supply through outdoor air vents, e.g., slot devices.

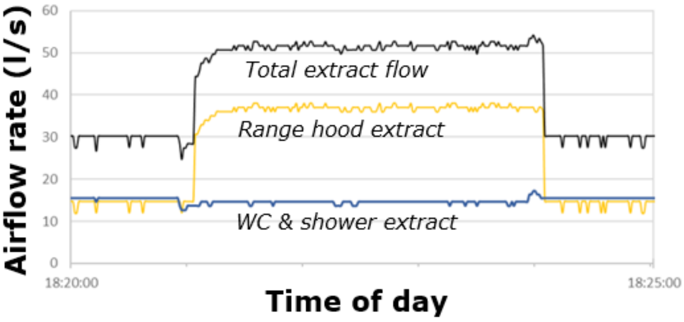

Figure 6. Diagram showing measured airflow rates for *solution 2*. The test chamber was arranged to represent a dwelling with mechanical exhaust ventilation.

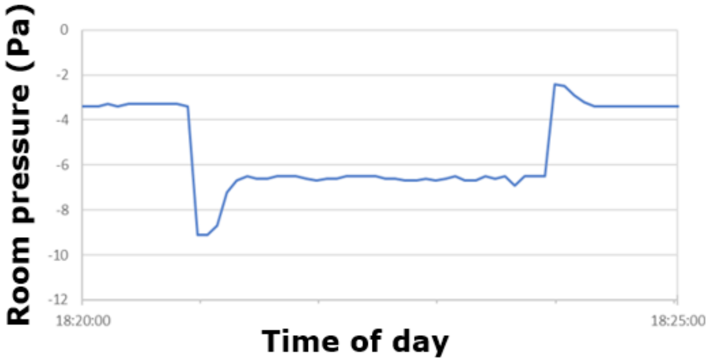

Figure 7. Diagram showing the measured room pressure for *solution 2*. The test chamber was arranged to represent a dwelling with mechanical exhaust ventilation.

Figures 6 and 7 illustrate examples om monitored test data for *solution 2*. **Figure 6** shows the measured airflow rates, while **Figure 7** shows the measured room pressure. When the range hood was activated the room pressure dropped from close to –4 Pa to about –9 Pa. As the replacement air damper opened the room pressure was restored to a value close to –6 Pa.

Summary and Conclusions

Both solutions met the technology competition requirement regarding limitation of room underpressure. The solutions are considered robust and long-term stable as they were tested for more than 200 cycles without any malfunction being observed.

Over time, however, dust will accumulate on the dampers, which could affect their functioning; that they get stuck and/or that they do not close tightly in the closed position. However, this has not been tested in the current project. Regular inspection and cleaning will be required, especially of the solution installed as an outdoor air valve/supply air radiator, as the damper in that case is exposed to unfiltered outdoor air. The rather slow change in the damper position contributes to the solutions being judged as robust.

Both solutions have the possibility to add an alarm function with an electric feedback signal in case the damper gets stuck in any position. However, none of the tested solutions had any such function available.

The tests conditions represent modern airtight buildings. In such buildings, very good air flow rate measurement and balancing is required. The air flow balance needs to be restored within 30 seconds. The solutions are ready to be adapted for full-scale tests in apartment buildings. ■

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Kitchen ventilation solutions in urban dwellings

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Kitchen extract hood design and volumetric flow rates have been discussed for years. The standard airflow rate once recommended for conventional volume hoods is outdated in the context of urban energy-efficient apartments. Can recirculating or downdraft-hoods be acceptable alternatives, and how should the overall ventilation solution then be for the apartment?

Keywords: Kitchen hoods, IAQ, urban apartments, recirculating solutions, downdraft, exposure, Particulate matter, VOC

Urban dwellings and challenges

Increased development of urban areas leaves new challenges for the indoor environment. Area-efficient dwellings with open-plan kitchens and living rooms are becoming the standard in most new Norwegian apartment buildings. At the same time, the design of the kitchen hood is evolving, and new designs such as the integrated downdraft cookers are gaining popularity as they release space above the cooktop.

The existing mandatory airflow rate in Norway of 108 m^3/h once recommended for volume hoods, often results in complaints of insufficient capture, while hoods with high airflow rates have capacity issues due to under-pressure in airtight buildings. Recirculation solutions can be a tempting alternative to ducted exhaust solutions, as the latter demands considerable space for shafts to the rooftop. However, the true performance of these alternative solutions is not well-documented. Existing test standards have their limitations, and the Norwegian building code demands documentation if pre-accepted solutions are not used.

Urban dwellings are generally getting smaller. Minimum exhaust rates for kitchens and bathrooms can result in high air change rates, and thus increase the risk of low humidity in winter. Taking all these aspects into consideration, what recommendations for ventilation rates can be given to achieve healthy and energy-efficient urban dwellings? The Norwegian research project *Health Energy-efficient Urban Home Ventilation* (2020–2024), coordinated by SINTEF, aims to answer this question.

Kitchen design and new products

The layout of urban apartments has changed, and this includes the kitchen. Design of kitchen hoods as well as introducing recirculating solutions reveal potential totally new concepts for kitchen design but need documentation. A team consisting of researchers, housing developers, main manufacturers of kitchen hoods and a ventilation system manufacturer, analysed architectural plans and project drawings to identify typical floor plans and appropriate HVAC solutions.

The analysis showed that separate kitchens as seen in the 1970–80s are now rare. Open-plan kitchen and living rooms are now standard. The kitchen furniture area is predominantly L-shaped (See **Figure 1**), followed by single-sided kitchens. None of the studied projects had kitchen islands or a kitchen hood in the middle of the room; the cooktop was normally placed next to a wall. In smaller apartments, the sofa may be located quite close to the cooktop. Generally, electric cooktops are used in Norway, and induction hobs (cooktops) have become the dominate solution in the marked. The study also revealed a slight variation in mounting height of the kitchen hood, related to variations in the standard set by the manufacturers of kitchen furniture.

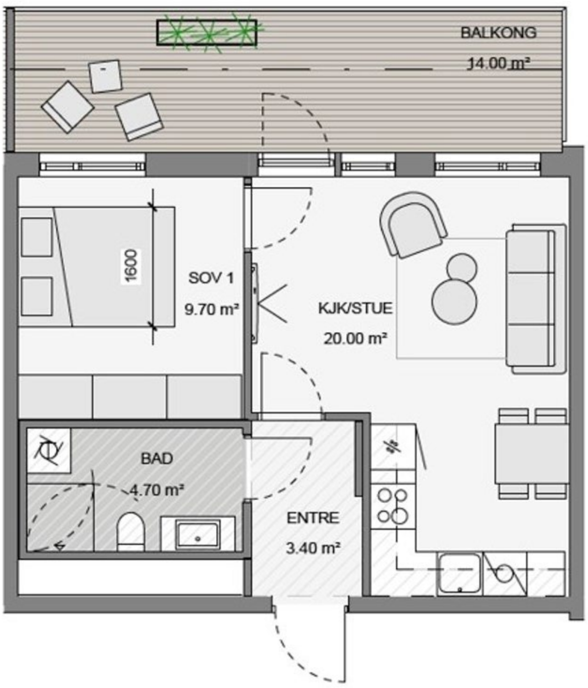

Figure 1. A typical 1-bedroom urban apartment in Oslo, Norway. Courtesy by: Selvaag Bolig.

Based on these findings and discussions with the four kitchen hood manufacturers, two different setups were chosen for testing:

- Standard wall-mounted kitchen hood fitted between wall-mounted cupboards
- Downdraft in the centre of an induction hob (cooktop) fitted in a countertop along the wall.

These two setups (**Figure 2**) are being tested for both ducted exhaust and recirculation configurations. The manufacturers selected products with known good performance from their product range, to be tested in the laboratory (**Figure 3**).

Typical Nordic cooking habits

The manufacturers of kitchen hoods strongly wanted realistic testing conditions for cooking meals. Nordic meals and cooking habits can be slightly different than ones found in the literature [1]. Two surveys were performed to find representative Norwegian cooking habits. Based on the responses and nutrition facts, procedures were developed for cooking three typical nutritious meals for two persons. These involved

Figure 2. Ducted standard setup (left) and downdraft recirculating solution (right).

frying of minced meat with taco spices, fried salmon with a vegetable and rice mix, and a vegetarian pasta Bolognese alternative [2]. Teflon-coated frying pan was used as it is the most common choice.

New methods and advanced studies

Based on the analysis of kitchen layouts in modern dwellings, and existing test standards, a test environment and test methods were developed to study both capture efficiency and exposure to persons in the room. The test room which emulates a typical open-plan living room and kitchen, as shown in **Figure 3**, is larger than the standard test room in EN 61591:2019 which more reflects older kitchens. Two different kitchen configurations were built: standard wall-mounted kitchen hood based on the standard setup, and a downdraft solution. The flexible setup of the test facilities allowed for recirculating and extraction solutions for both kitchen configurations. In addition, the height of the cupboards was adjustable. Diffuse supply air to the room is chosen, as balanced ventilation with supply air in bedrooms and living room is the standard solution in Norwegian dwellings.

As preparation for more advanced measurements, the first round of tests was performed for the three meals using the standard kitchen extraction configuration at different air flow rates and heights. Each experiment has a procedure of 13–16 minutes of cooking, followed by 45 minutes of continued logging of airborne particle concentrations.

Based on the results [3], frying salmon was selected to be explored further using more advanced instruments to perform real-time measurements of volatile organic compound (VOC) and particle (≤1 µm) concentrations.

The advanced experiments were done for two main setups – a standard wall-mounted hood and a down-draft kitchen hood. For each setup, both extraction and recirculation solutions were tested. Recirculation solutions were tested with retailed charcoal filters (activated carbon). The following airflow rates were tested for both setups: 108, 180, 250, 350 m³/h. In addition, the test room is ventilated with a basic ventilation rate of 36 m³/h. As there is no international standard for testing with real cooking, a new method was developed based on the international standard IEC 61591:2019 [4] and NORDTEST NT VVS 047 [5].

Indicative results can change the kitchen design and recommendations

The results of the VOC measurements are still being processed, but the preliminary results of the particle measurements can provide some indications:

- The Norwegian requirement of 108 m³/h is clearly insufficient in terms of reducing exposure to particles. Higher minimum rates will be recommended.
- The majority of the particles in the size range of ≤ 1 µm were difficult for the charcoal filter to

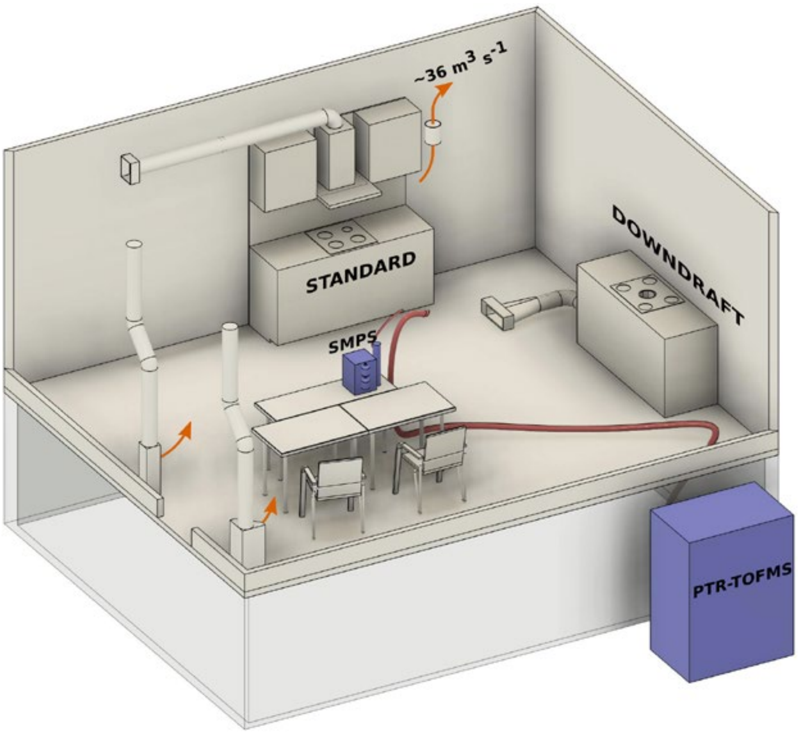

Figure 3. Testroom setup with advanced real-time measurements.

retain (**Figure 4**). The tested charcoal filers are not suitable as particle filters; recirculation solutions need further development.

- Recirculation solutions as today will then not perform as well as ducted solutions and cannot be an adequate solution.
- The capture efficiency of downdraft ducted solutions is better than expected, and downdraft solutions will have to be considered as a real alternative to standard wall-mounted solution. There are of course several considerations to be discussed, like type of downdraft and height of used frying pan/boiler.

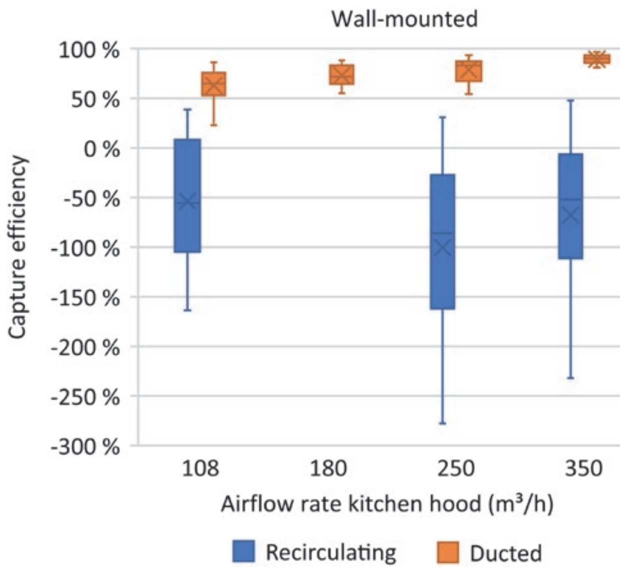

Figure 4. Capture efficiency of particles 0.3–2.5 µm, measured in the room's return air terminal, for wall-mounted kitchen setup with ducted and recirculation solution, preliminary results.

More results to come

In the next phase of the project, we will further assess the recirculation solutions, particularly the filter efficiency. A dedicated test chamber will be set up to investigate the effect of different types of filters (plasma versus charcoal) and the age of the filter on the concentration of volatile organic compounds.

Besides recommendations for kitchen ventilation rates and exposure assessment of cooking, the ventilation and resulting healthy indoor environment will be assessed in a holistic approach. These include extraction rates for the bathroom, moisture generation and removal [6], energy use and peak load. Recommendations for optimal future ventilation of urban dwellings will take into account also the fact of different needs for different size and use of apartments. Recommendations should be suitable for balanced ventilation systems for one apartment as well as several in a centralized system.

Read more: https://www.sintef.no/projectweb/healthy-energy-efficient-urban-home-ventilation/ ■

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Challenges and Needed remedies of Demand Controlled Ventilation

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Introduction

A recent position paper by the Nordic Ventilation Group (NVG) emphasizes the importance of demand controlled ventilation (DCV) systems in buildings and the necessity of addressing current challenges in these systems. The position paper is available on NVG web page at: https://www.vvsfinland.fi/foreningen/nvg/. It is based on the group´s collective experiences and the results of the Nordic Ventilation Forum on 21st September 2022, and some other relevant references. It applies to all building types with DCV systems with a main focus on commercial and public buildings.

1. Need for DCV systems in buildings and potential advantages

Sufficient ventilation must be ensured in buildings, which in many cases calls for increased airflow rates during times of occupancy. At the same time there is a strong demand for a substantially reduced use of energy, which creates an evident need for DCV systems in buildings [1]. Currently, close to 40% of the total energy consumption in Europe is used for buildings, and a substantial part of that is used by the ventilation system [2,4]. According to scientific studies, the energy consumption of heating, ventilation and air-conditioning (HVAC) systems can be reduced by 20-50% [1-3] with DCV compared to the systems with fixed ventilation airflow rates. This depends strongly for instance on the room usage/occupancy profiles in the buildings, which vary significantly in different spaces. Typical occupancy ratio is for instance 30%-40% in many office buildings [6].

2. Current systems and their principles

The main principle of the DCV system is to maintain good indoor climate conditions for occupants in buildings by dynamic control of the ventilation supply and exhaust airflow rates depending on occupancy, pollution load and thermal load. These systems are called also variable air volume (VAV) systems. Typically, also water-based heating and cooling room systems (for instance chilled beams, fan-coils or radiant panels) are linked to the DCV system. With these systems, the airflow rate is determined with respect to occupancy and excess cooling/heating demand is covered with water-based systems. HVAC systems based on fixed ventilation rates (CAV systems) need to be dimensioned for the most demanding situation which requires the maximum airflow rate and they are not able to reduce the ventilation fan energy consumption and cooling/ heating energy consumption, as opposed to the case with DCV systems.

Typically, in a DCV system, ventilation airflow rates are controlled based on schedule, occupancy detector, temperature sensor and indoor air quality sensors. The most commonly used indoor air quality sensors in DCV systems measure carbon dioxide (CO_2). Control of airflow rates in DCV systems can be designed for individual rooms, zones or specific modules in open areas like landscape offices.

DCV systems in apartment buildings can control ventilation airflow rates at the apartment level. This is typically done by switching to low airflow rate when the apartment is empty or by having a boost airflow mode when the kitchen hood is used. Additional kitchen hood exhaust air should be properly balanced by controlling the supply airflow rate in the DCV system. This should be done carefully when several apartments are boosting at the same time.

For maintaining the desired indoor climate conditions, the DCV system should control ventilation airflow rates at room level. Commonly the target for controlling ventilation airflow rates at room level is also to maintain the balance between supply and exhaust. Three most typical concepts for exhaust air flows are:

- Supply and exhaust airflow rates are balanced at room level.
- Constant room exhaust airflow, and when supply airflow is boosted, the room is over-pressurized, and the boosted fraction of the airflow is transferred from the room to central exhaust.
- Only supply air terminal units are installed in rooms and all the exhaust air is transferred from the room to centralized exhaust.

DCV systems can be defined as pressure-independent and pressure-dependent system categories related to the control of ventilation airflow rates.

- Pressure-independent systems require variable air volume (VAV) control dampers/units at all locations of ventilation ductwork where the ventilation airflow rate is measured and controlled to the desired level.
- Pressure-dependent systems use constant static pressure (CSP) control dampers to adjust each ventilation air ductwork zone to the desired level. CSP dampers include typically the measurement of airflow rate and static pressure at the specific location of the ductwork zone. It can be applied to supply air and the ductwork zone is needed to be designed for maintaining a constant static pressure level by utilizing the static regain principle after room branches.

3. Problems in the performance of current DCV systems

This section presents a summary of identified problems and challenges with DCV systems in buildings based on the Nordic Ventilation Forum presentations and discussions. These were based on experiences from real building cases as identified challenges for DCV system usage [4,5,8]. Technical problems may arise in any part of the processes of design, installation, commissioning, and operation. Any technical problem has a potential to become serious if it is not identified and properly corrected promptly. Obviously, the risk of serious problems increases if there is not a dedicated and adequate quality assurance system in place. Systematic quality assurance is really needed given that DCV systems are complex, they need more knowledge and they include more sensors and actuators than ventilation systems with constant airflow rate systems. As indicated above, problems appeared at all stages of the building process: design, installation, commissioning and operation. Some key findings are listed in the following according to the building process stages:

Design

- Too narrow and asymmetrical ductwork for proper DCV system operation
- Ventilation airflow rate range from minimum to maximum is typically very large (1:8) in commercial and public buildings causing measurement and control challenges for DCV system design and operation
- Level of DCV system documentation was not sufficient or based on general standard schemes
- Too low ventilation airflow rate in rooms due to undersized AHU or duct system caused by incorrect pressure loss calculations
- Noise problem due to system without zone dampers
- Imbalance (pressure difference between rooms) due to supply and exhaust covering different zones, with no air-transfer
- Unstable operation due to too low flow rate over VAV unit (VAV unit cannot measure flow rate)
- Mixing CAV and DCV in the same system, using the same supply air temperature to both system types. Either the CAV-rooms become too cold or the DCV-rooms too warm

Installation

- Actuators and control sensors were installed in the wrong places
- VAV dampers were installed in difficult locations regarding the maintenance
- VAV damper reports wrong air flow rate due to incorrect installation (wrong direction, too close to duct bend/t-branch, not proper safety distances used or found in drawings)
- Some electrical wires were not connected
- Loose, compressed or wrongly installed pressure tube in pressure measurement
- Too small or too high ventilation airflow rate in room due to wrong location of room CO_2 sensor
- Noise problem due to VAV-unit located too close to duct t-branch

Commissioning

- In the control of minimum-medium-maximum ventilation airflow rates in the room, the medium-maximum airflow rates were in the wrong order
- The ratio of supply and exhaust ventilation airflow rate was not correct
- The setpoint for the room air temperature was too low, leading to continuous unnecessary cooling with the maximum airflow rate
- Wrong k-factor for VAV flow-cross in VAV unit program parameters
- Too small ventilation airflow rate in room due to too low pressure setpoint in the duct
- Too small or too high ventilation airflow rate in room due to incorrect programming of the VAV unit
- Connections to building management system not correctly and clearly done

Operation

- Building management personnel did not know how to use automation systems and did not understand the overall operation

- HVAC and automation design documentation was not available in many cases
- VAV-pressure transducer blocked with dust or broken
- Exhaust airflow measurement devices were dirty and gave the wrong airflow rate leading to imbalance (pressure difference between rooms) or unstable operation of the system
- Noise problem in pressure-controlled systems due to pressure sensor damaged due to pressure or electrical spike
- Imbalance (pressure difference between rooms) due to zero pressure error in pressure transducer due to pressure/electrical spike
- Mechanical fault with VAV damper blade operation
- Too high supply air temperature due to lacking thermal insulation of supply air ducts installed in warm spaces (e.g. attics during summertime)
- Too high supply air temperature leading to open VAV dampers without adequate cooling power

4. What is needed and should be improved for reliable and well-performing DCV systems

Based on the Nordic Ventilation Forum presentations and discussions, the following improvements related to the design, installation and operation of DCV systems are suggested.

- Training of designers, contractors, and maintenance staff should be improved
- Proper design should focus on requirements that can be verified
- Documentation should be up-to-date and property/system-specific
- Commissioning tests before the building is occupied should include tests of all operating modes of the DCV system
- Commission and maintenance processes/contracts should be improved
- BMS for continuous monitoring should be utilized and need to be well-designed
- Maintenance staff appreciation and motivation should be improved
- Inspections and retro-commissioning should be performed regularly

Needed improvements related to the technology of DCV systems:

- Large and reliable measurement range of airflow rates in VAV measurement units
- Smart and robust control systems
- Utilization of IoT to monitor indoor climate conditions and systems operation

These reported improvements are suggested to be implemented with more detailed specifications for achieving reliable and well performing DCV systems in buildings with good indoor climate conditions and efficient use of energy during the entire building life cycle. ■

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COVID-19 guidance for the Swedish construction and real estate sectors – results from a survey study

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Buildings Post Corona is a Swedish collaborative research project between Chalmers, KTH Royal Institute of Technology, Lund, and Umeå Universities. The project intends to provide knowledge related to designing, maintaining and operating sustainable buildings with a healthy and good indoor environment. The project aims to contribute to the knowledge and processes needed for the construction and real-estate sectors to meet the needs of the post-pandemic era. The COVID-19 crisis has stressed the importance and urge of this research, which is financially supported by FORMAS (FORMAS is a Swedish Research Council for Sustainable Development, formas.se).

Covid 19 guidance and practice

One of the initial steps of the Buildings Post Corona project has been to collect experiences among various actors within the construction and real estate sectors during the recent COVID-19 pandemic. This step was conducted by developing and using a questionnaire survey study. The aim was to create a picture of how the COVID-19 pandemic influenced various stakeholders and entities.

One set of questions deemed especially important relates to the advice provided by authorities and trade organisations, e.g., to what extent such advice was utilized and if it led to any actions. In line with the overall objective of the research project, there was a special focus on indoor air quality and air handling measures.

The survey study in brief

The questionnaire is web-based, and can be accessed on the project homepage and via this link (https://www.kth.se/form/6268ff115f387cf0ec9ebf2e). As long as the link works, we are grateful for more answers.

The survey was widely disseminated and targeted respondents through multiple channels, including the reference group of the Buildings Post Corona project, the Swedish Energy Agency's network of non-residential real estate owners (BELOK belok.se), the exhibition Nordbygg (nordbygg.se) 2022 - directed to the building and construction industry in the Nordic countries. It was also announced via influential associations such as SWESIAQ (swesiaq.se) and the trade organization Svensk Ventilation (svenskventilation.se).

The questionnaire was initially published in Swedish, but an English translation was made available. The results will be published in a report available for download from the project homepage (buildingspost-corona.se).

Summary of results

The following is a summary of the survey study results obtained until end of 2022. The questionnaire was completed by 35 respondents, most of which represent building construction and management within the healthcare sector in Sweden. This may indicate a stronger motivation to utilize general information and specific guidance when working with buildings specifically targeting healthcare compared to other types of buildings, such as offices, schools and residential buildings. Most respondents work with entire property portfolios or premises with multiple buildings. Over one-third of the respondents represent management and decision-making; a category expected to be informed about any guidance from authorities and relevant trade organizations.

The respondents were mainly involved in the requirements specification, selection of technical solutions, construction, and operation. Real-estate owners were the major single professional category represented, followed by building operators, technical property managers, developers/procurers, contractors, and consultants.

The process towards taking action

- Over 90% of the respondents decided to implement – or not implement – changes or measures to respond to the pandemic based on risk analysis or dialogue.
- According to 20% of the respondents, the risk analysis/dialogue was initiated by the tenants.
- With one exception, the risk analysis/dialogue led to implementing one or more changes or measures.

The sources of guidance

- 70% of respondents based their actions on guidance from authorities.
- The use of guidance from the authorities in summary:
  - 94% of the respondents followed guidance from Swedish Public Health Authority.
  - According to about one-third of the respondents, Public Health Authority was the only source of guidance.
  - 49% of respondents used additional guidance provided by the Work Environment Authority.
  - 17% of the respondents used additional guidance from the Swedish National Board of Housing, Building, and Planning.
- 34% of the respondents used internal, already existing routines applied in the organization.
- 25% of the respondents stated that guidance from trade organizations was used.
- Information from technology suppliers resulted in action, according to one respondent only.
- The guidance from authorities was judged as clearer, more realistic, and more accessible compared to guidance from trade organizations.
- The guidance from authorities and trade organizations were judged as being, to a great extent, in harmony by 6% of the respondent only.

Implemented measures and their assumed effect

- 71% of the respondents reported that improved cleaning, hand hygiene, and limitation of the number of people in close contact were among the actions undertaken.
- 54% of the respondents implemented ventilation-related actions, and only 17% replied that ventilation was the only category of action undertaken.
- A list of ventilation-related measures has been extracted from the questionnaire results.
- 68% of the respondents assumed that the implemented measures had a good impact, at least partly, on reducing the risk of disease transmission.
- 79% of respondents assumed that the measures had a good impact, at least partly, on creating a sense of safety and security.

Reflections on the result: Identifying Imbalances in Guidance Provided during the Pandemic

Results from the survey study highlights an imbalance in the guidance provided during the pandemic, as illustrated by the diagrams in **Figure 1**. Specifically, guidance from the Public Health Authority dominated strongly over any other guidance, with daily press conferences emphasizing physical distance and hand hygiene, while overlooking the possible importance of ventilation and air cleanliness. In contrast, the Swedish Work Environment Authority provided guidance primarily via their web portal, highlighting ventilation as an essential factor for air quality and for reducing the risk of indoor disease transmission.

Other trade organizations, such as Svensk Ventilation and the Nordic Ventilation Group (NVG scanvac.eu/nordic-ventilation-group-nvg.html) also provided guidance in this regard, which mainly corresponded to guidance provided by the European Federation of Heating, Ventilation, and Air Conditioning Associations (REHVA rehva.eu).

The survey shows that although some respondents worked along the lines of the ventilation-related safety precautions provided by trade organizations, this was not the direction pointed out by the influential Public Health Authority. Therefore, different Swedish authorities and trade organizations provided partly different guidance on how to limit disease transmission in indoor environments.

A final remark is that it is crucial to harmonize guidance from all relevant sources, including authorities, trade organizations, industry, and academia, and efficiently distribute the message to all stakeholders to improve our ability to handle future pandemics or similar events efficiently.

In summary, the current setup with multiple sources for guidance and information appears to result in a low implementation rate of guidance not directly proposed by the Public Health Authority. Thus, it is crucial to establish a more coordinated approach to reduce imbalances in guidance and better protect public health.

The project continues

The findings of this survey study hold significant implications for building owners, planners, and contractors. Based on the results, updated guidelines and checklists are recommended to ensure better preparedness for similar pandemics in the future.

This effort is ongoing with a broad scope. The Building Post Corona team (buildingspostcorona.se/participants) invites all relevant networks and consortiums, including REHVA and its members, to join efforts, share ideas and explore collaboration opportunities. ■

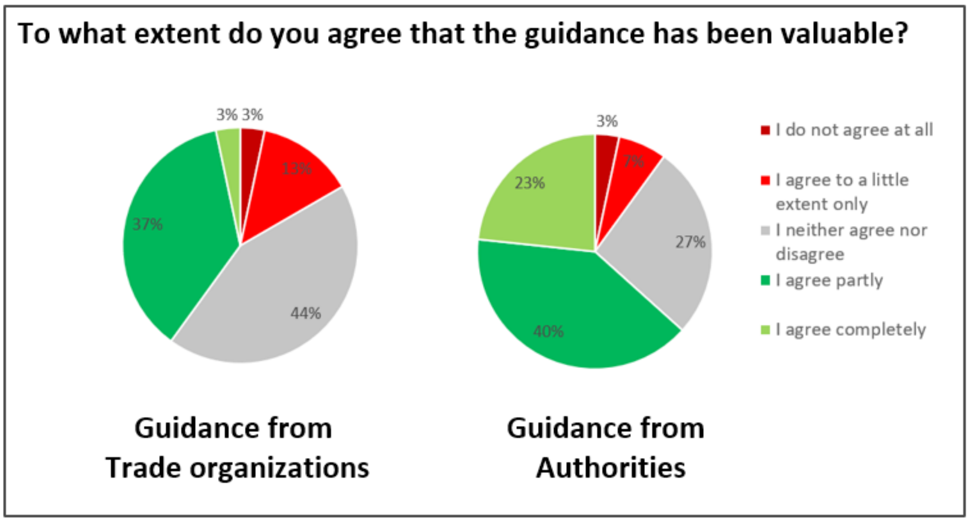

Figure 1. The replies regarding the perceived value of the guidance provided by trade organizations (left) and authorities (right).

Control of airborne infections with ventilation and air distribution in post COVID pandemic

POSITION PAPER BY NORDIC VENTILATION GROUP

Edited by **Guangyu Cao**, **Pawel Wargocki** and **Arsen Melikov**
based on presentations and discussions in the NVG meetings and presentations at the Nordic Ventilation Forum 2022

Nordic Ventilation Group is a group of academics sharing the same interest and concerns regarding the indoor climate and ventilation. The objective of the Nordic Ventilation Group (NVG) is to develop Nordic ventilation technologies and services for good and healthy indoor environment with an energy efficient and environmentally friendly way. The work is 100% voluntary and free from commercial interest. Possible outcomes of the work can be published through various channels with the common agreement of the group. Nordic Ventilation Group was very active in 80s and 90s when mechanical ventilation became more common in Nordic counties. The group published several guidelines for measuring air flow rates and evaluating of the performance of ventilation. The group is integrated with Scanvac activities. The history and objectives of the group are described in more details at www.scanvac.eu.

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The importance of airborne transmission of respiratory infectious pathogens has been widely recognized. The World Health Organization (WHO) acknowledged inhaling infectious aerosols as one of transmission modes for spreading COVID-19. Airborne transmission refers to inhaling virus-laden aerosols that can remain suspended in the air for extended periods and transported farther than a conversational distance away from the infected individual in a confined indoor space (WHO 2021). Transmission over distances beyond two meters has been documented and tends to be under preventable circumstances comparing short-range transmission, in which respiratory activities may play an important role (CDC, 2021, Amjadimanesh et al., 2022).

Moreover, the transmission of the infectious disease varies by pathogen infectivity, reservoirs, routes, secondary host susceptibility, environment conditions (like temperature and relative humidity in confined spaces), and ventilation performance, which includes both quantitative performance, like ventilation airflow rate, and qualitative performances, like indoor airflow pattern. Besides the social distance and personal hygiene-related guidelines recommended by WHO, increased ventilation and proper clean air distribution also contribute to reduction of airborne transmission. Furthermore, the latest studies advanced our understanding of transmission routes and the relative importance of various mitigation strategies for preventing transmission.

As engineering measures, ventilation solutions may be feasible for mitigating the spread of respiratory infection among occupants in both new buildings and existing buildings. However, different ventilation modes have different performances regarding infection control indoors. Generally speaking, mixing ventilation (MV) aims to dilute indoor contaminants by mixing supplied clean air with polluted room air. Displacement ventilation is based on moving clean air supplied near floor to the breathing zone of a person by the convective boundary layer existing around the body at comfortable room temperatures. Exposure in displacement ventilation (DV) may be rather sensitive to the location of the infected occupant in a room and to the movement of the exposed occupants as moving people will destroy their inhalation protection typical for DV (Bjørn and Nielsen, 2002; Halvonova and Melikov, 2010). The infection probability with DV seems lower than with MV, when people are in sitting still and keeping their distance (> 1.5 m in case of Covid-19) while DV will increase the infection probability when people are close to each other (< 1.5 m in case of Covid-19) (Nielsen and Xu, 2021). Recent studies show that the infection probability for several occupant- targeted ventilation methods can be lower than mixing ventilation (MV) in a classroom (Su et al., 2021). Compared to humidification at a constant ventilation rate, increasing the ventilation rate to moderate levels will have a more beneficial infection risk decrease for SARS-CoV-2, and the same trend is found for other airborne diseases like measles, human rhinovirus, and adenovirus (Aganovic et al., 2022). However, ventilation systems will not work economically under normal conditions (no pandemic) if the ventilation systems of the future are designed to supply large volumes of outdoor air during a pandemic. Rethinking airflow distribution in rooms is necessary to optimize system design and operation modes in normal and pandemic situations. With traditional methodology by dilution principle, this would be a very tough challenge, economically and technically, requiring much more power, energy, size of duct/space etc. The optimal solution should use the supplied air more rationally to create higher air quality around the people. Therefore, it must be considered timely to increase the focus on airflow distribution solutions that ensure a well-ventilated occupied zone and breathing zone, and provide occupants with an optimal climate where they live and work with a very low risk of transmission of respiratory diseases.

Nordic Ventilation Group of SCANVAC strongly supports actions to develop effective technical and non-technical solutions allowing sufficient protection against airborne transmission and the preparedness of buildings, other built environments, transportation means, and society against the future epidemic.

Conclusions

General statements regarding airborne transmission

- Respiratory pathogens are airborne and can be transmitted over long distances (more than two meters) within and between spaces in a building.
- The long-range transmission depends on indoor airflow patterns caused by ventilation, pressure (pressure difference over surrounding areas), occupants' activities and temperature differences, air distribution as well as buoyancy effects.
- The COVID-19 pandemic has made it clear that we need to pay special attention to reducing airborne transmission while ensuring effective ventilation.

Ventilation strategies

- The COVID-19 pandemic emphasized the importance of a healthy indoor environment for humans. It urged a radical change in our view of reconsidering ventilation design and implantation to promote a safe indoor environment.
- The construction sector is therefore facing a new challenge - a paradigm shift in the design of future ventilation in our buildings.
- Ventilation in more important in reducing infection risk due to exposure to respiratory pathogens than with other environmental conditions, like air temperature and relative humidity.
- Better ventilation solutions and indoor airflow distribution methods should be recognized as infection control measures in various building sectors, communities and societies.
- In healthcare facilities, patient rooms and isolation units should be negatively pressurized and avoid air recirculation. The same recommendations apply to temporary isolation rooms for infected patients.

Ventilation rate

- Increasing the ventilation rate from 0.5 ACH to 6 ACH may have a dominating effect on reducing the infection risk regardless of virus type.
- Increasing ventilation with outside air in existing buildings may not always be possible. In such cases, the effective ventilation rate per person can also be increased by limiting the number of people in the buildings.
- It is necessary to rethink ventilation solutions in order to achieve a high level of indoor air quality and to ensure the health and well-being of the occupants.

Indoor air distribution

- Air distribution is critical for lowering the infection probability in rooms with mechanical ventilation, air cleaner/purifier and natural ventilation.
- Dilution, removal, and deactivation of airborne respiratory pathogens will reduce the risks of infection indoors.
- Occupant target ventilation with an advanced airflow distribution method may significantly reduce the infection risk with relatively low energy consumption (Su et al. 2022).
- Personalized ventilation performed the best to prevent cross-infection, followed by displacement ventilation, impinging jet ventilation, stratum ventilation and wall attachment ventilation (with deflector) (Su et al. 2022).
- Personalized ventilation integrated with MV may provide clean air directly to the breathing zone of occupants while controlling the room air cleanliness with lower energy consumption.
- Protected occupied zone ventilation is able to separate a room into two zones with a different concentration level of contaminant (Aganovic et al. 2022).

Proposed actions in the post pandemic

- All regulations, building codes, standards, and guidelines should be revised to ensure the preparedness of buildings for periods with an elevated risk of airborne infection regarding the ventilation rates and air distribution.
- Action plans should be available for technical personnel and facility managers or anyone responsible for describing actions that need to be taken in case of the elevated risk of airborne transmission of respiratory pathogens in buildings both during epidemic and pandemic periods. These plans should describe activities during the non-pandemic period securing the maintenance and proper operation of the building systems, which should be able to monitor indoor air quality (IAQ) used when the risk of infection is increased.
- Special technical solutions for the pandemic period and proper operation of the existing systems should be certified by eligible personnel. ■

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Please find the list of references at
https://www.rehva.eu/rehva-journal

This article is based on a paper presented at the 42nd AIVC - 10th TightVent & 8th Venticool Conference "Ventilation Challenges in a Changing World" held on 5-6 October 2022 in Rotterdam

Existing protocols for the inspection of ventilation systems

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This paper aims at comparing the various national approaches on the inspection of ventilation systems to help provide guidelines. A general summary on 21 inspection protocols is first presented. Technical details collected through a survey are then given for 5 protocols implemented in Sweden, Belgium, Ireland, France and USA.

Keywords: Inspection; ventilation; protocols; national approaches; summary; technical survey

In a context of energy use reduction, low energy buildings are becoming more widespread. This kind of construction require a good envelop airtightness to prevent uncontrolled leakages of conditioned air leading to energy losses. As a result, more and more ventilation systems are installed to ensure a sufficient air change rate for a good indoor air quality.

However, in practice many issues are found with the installed ventilation systems not providing the expected flowrates. In France a study on 1287 dwellings showed that 68% do not meet the regulation (Jobert and Guyot, 2013). More and more countries have a mandatory inspection of ventilation systems, such as Sweden, Ireland, Germany and France.

This article aims at comparing the various approaches to help provide guidelines on the inspection of ventilation systems. It is based on an EPBD feasibility study detailing 20 protocols from 9 countries (Durier et al., 2019) with the addition of the new guide to comply with Irish regulations and a survey addressed to various countries for technical details. This article is based on a paper presented at the 42nd AIVC - 10th TightVent & 8th Venticool Conference "Ventilation Challenges in a Changing World" held on 5-6 October 2022 in Rotterdam, Netherlands (Hurel and Leprince, 2022), including in particular the list of the 21 protocols from 10 countries summarized below.

Summary of existing protocols for the inspection of ventilation systems

Types of protocols

Only six countries have a mandatory protocol (by legislation or regulation): Poland, Belgium (in Flanders only), Finland, Ireland, Sweden and Canada. The other 15 protocols are mostly non-mandatory guidelines (13) and two standards from France and the USA.

Countries

Some countries have several protocols, with a maximum of 7 in France, as illustrated in **Figure 1**.

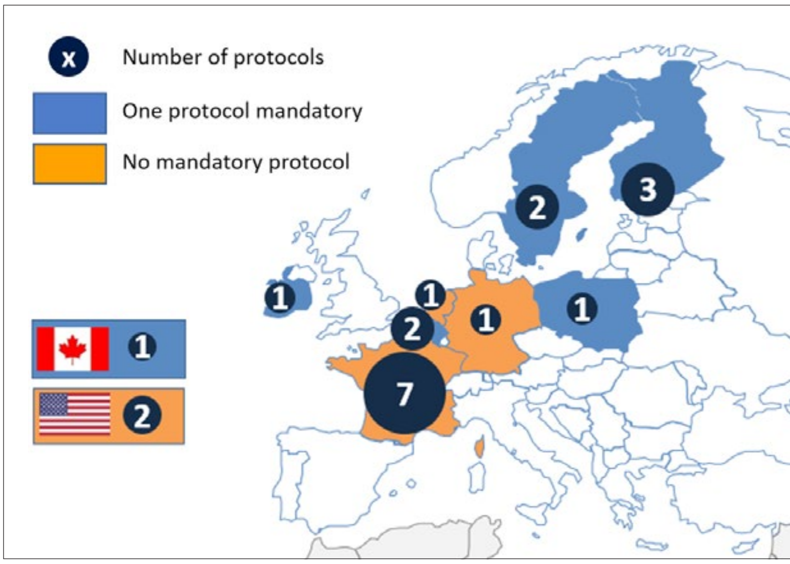

Figure 1

Type of buildings

Half of the mandatory protocols (3) and almost half of the non-mandatory ones (7) are dedicated to residential buildings only, while the other half is for both residential and non-residential buildings. There is only one protocol, in the USA, that does not include residential buildings and is dedicated to commercial and institutional buildings only. In this country, the other protocol applies to apartments only when each of them has its own/independent ventilation system.

The Canadian protocol is aimed for health care buildings only, that is to say hospitals, laboratories, psychiatric and mental health service facilities, long-term care homes and residences for persons with developmental or physical disabilities.

In Netherlands, the non-commercial buildings covered by the one protocol are only the educational ones (**Figure 2**).

Inspection

Who is allowed to perform the inspection?

Among the mandatory protocols, there is only in Poland that has no specification about who can operate the inspection. All other mandatory protocols allow or require (in Ireland and Sweden) an independent inspector.

Non-mandatory protocols are overall more flexible on who is performing the inspection, with in particular most of them (11 out of 15) allowing the installer to control (**Figure 3**).

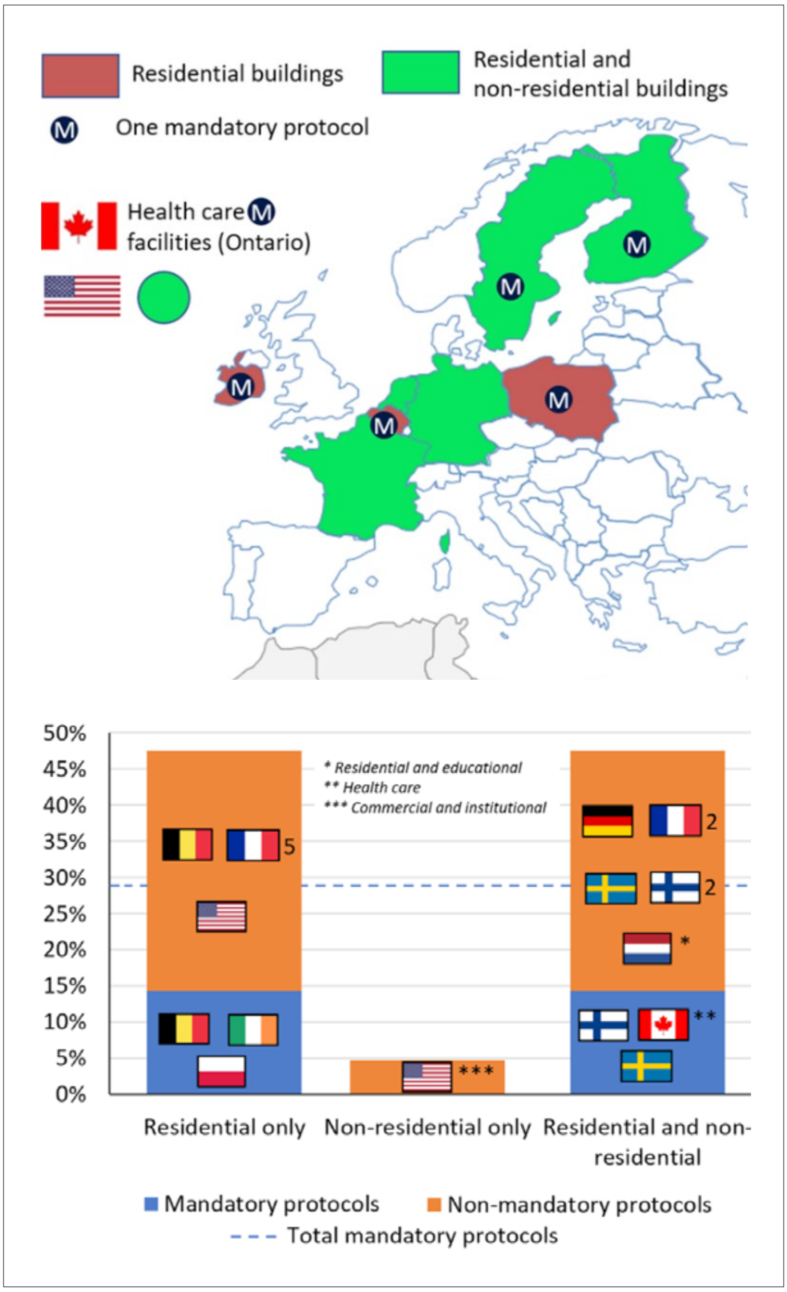

Figure 2

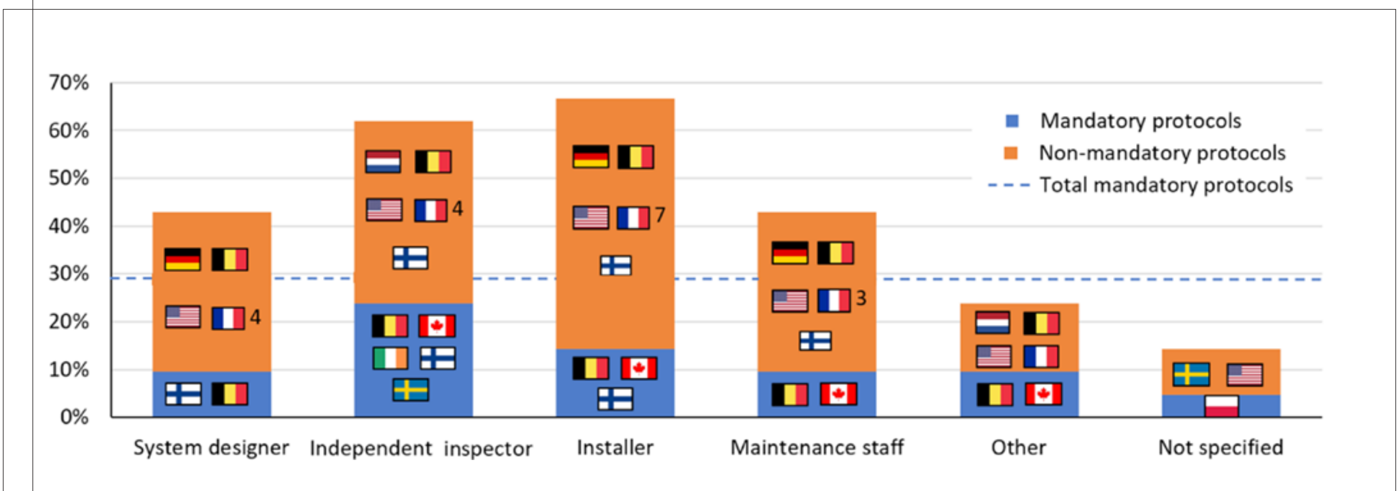

Figure 3

What types of control are performed?

All protocols cover the indoor air quality (IAQ) aspect, except one in Finland; less than half of them cover the energy performance and/or the acoustic performance, and a quarter only cover the thermal comfort aspect (**Figure 4**).

Aspects covered by the inspection

Most protocols cover a wide range of aspects as illustrated below. For example, all mandatory protocols cover the control of cleanliness, general state and good overall operation of the ventilation system (VS), and more than half of all protocols cover also the completeness of the VS, the adequacy between design and installation and a measurement or assessment of the air flow rates (**Figure 5**).

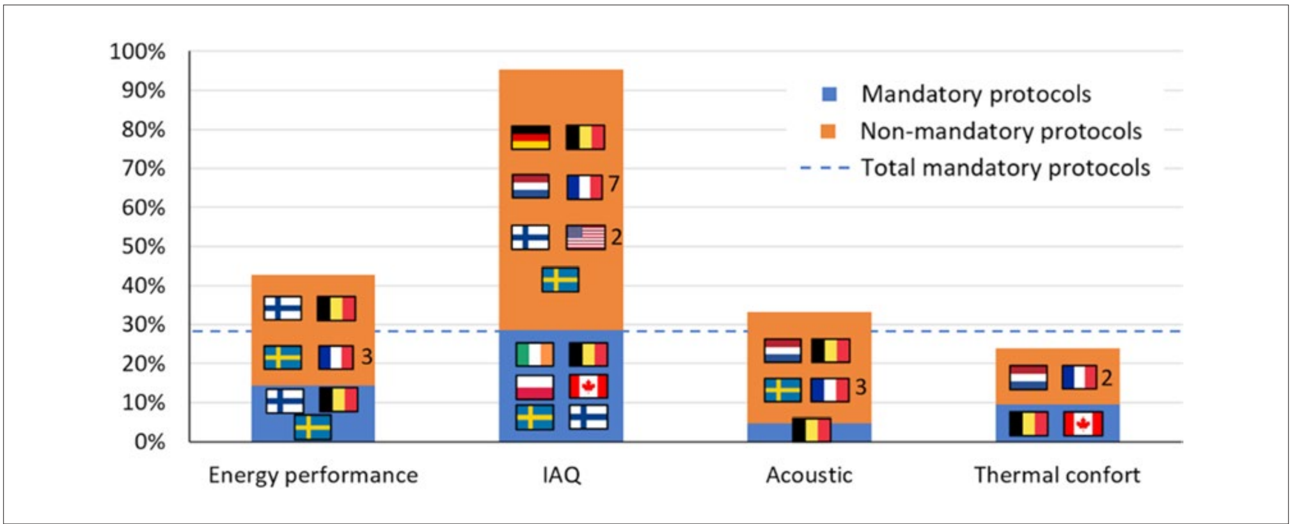

Figure 4

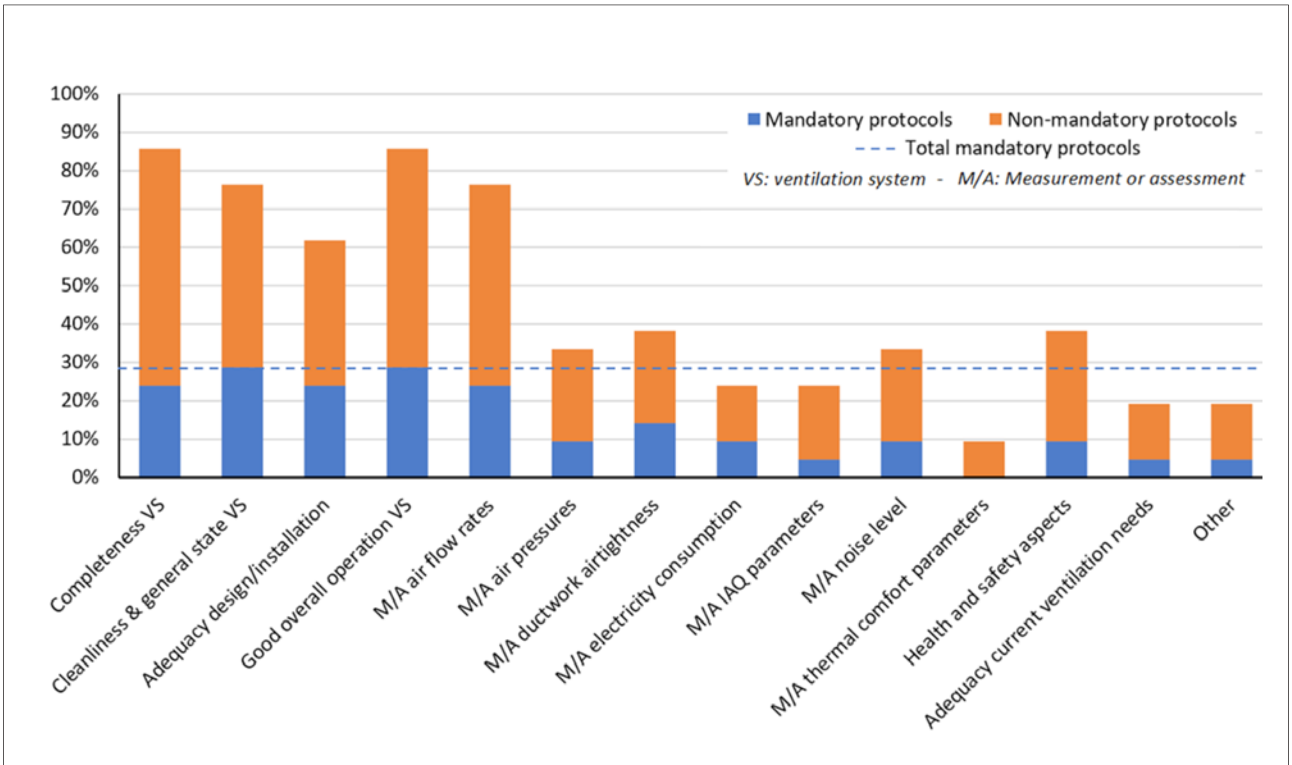

Figure 5

Periodicity of inspection

About half of the protocols (mandatory or not) are intended for a single inspection.

For the other half, concerning mandatory protocols:

- in Poland it is required to have an inspection at least every 5 years,
- in the Ontario State since the protocol is for health care facilities a periodicity of 6 months is required,
- in Sweden it depends on the type of buildings:
  - every 3 years for day-care centres, schools etc. with all types of ventilation; blocks of flats, office buildings etc. with balanced ventilation
  - every 6 years for blocks of flats, office buildings etc. with mechanical exhaust and natural ventilation;
  - single inspection for one and two-dwellings houses with mechanical exhaust with exchanger ventilation and balanced ventilation.

In Belgium, for the non-mandatory protocol the guide proposes different inspection frequencies from 1 month to 3 year-intervals depending on the type of components: 1 month for filters, 3 months for the natural openings, air intakes, exhaust devices, 1 year for heat exchangers and fans, 3 years for ducts (**Figure 6**).

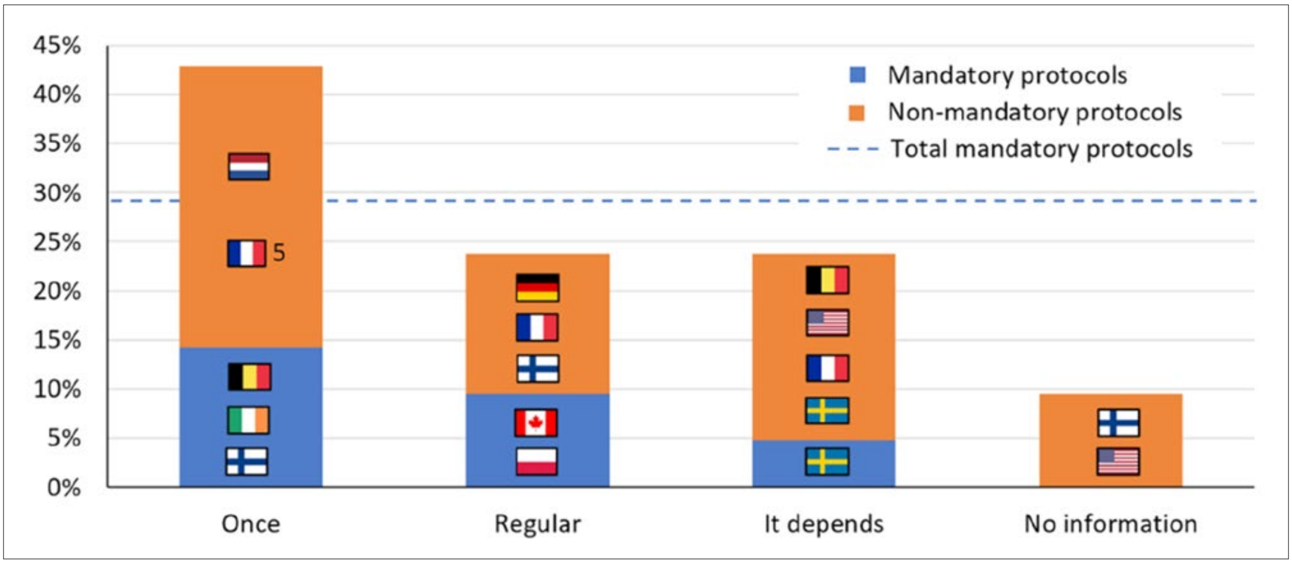

Figure 6

Technical questions - survey

Details of the 5 protocols

A survey of 21 technical questions was sent to get to know better how specific technical issues are handled for the inspection of ventilation systems according to the various protocols.

5 answers were collected from 5 countries: Belgium, Ireland and Sweden for their mandatory protocols, France for the non-mandatory protocol "Promevent" and USA for the non-mandatory protocol for residential buildings. Only a few of the 21 questions are addressed in this article, but they are all detailed in (Hurel and Leprince, 2022).

Note: In the illustrations of this survey, the flags have black edges for the countries with mandatory protocols and white edges for non-mandatory protocols.

Flowrate measurement protocol

What are the preparations for the building before the measurements?

Concerning the preparation of the building before the measurements, the respondent from Sweden did not specify about the opening of interior doors and sealing of ventilation openings in his answer. For the other protocols, the interior doors must be closed for all but the US one and all trickle-vents must stay open (in France they cannot be closable). Other specifications are required depending on the protocols (Hurel and Leprince, 2022).

Is there a minimum duration for the flowrate measurement or a constraint on the stability of the flow?

In the USA the constraint is 10 second averaging (except for bag filling). In France the flowrate measurement must last at least 10 seconds. In Belgium the minimum duration of the total measurement of the building is 20 minutes but there is no constraint on an individual ATD.

Is the flowrate measurement inside the ductwork an option?

The flowrate measurement inside the ductwork is an option for all protocols but the Irish one. In the USA, there are limitations on distances to upstream and downstream fittings as specified by the instrument manufacturer. In Belgium specific conditions for the ductwork measurement should be respected: e.g. minimum straight length of the duct before and after. In practice it is only performed if measurement of ATD is not possible. In Sweden, according to the regulations, flows must be measured in all branches of the systems.

Measurement at ATD (air terminal devices)

What is done when the ATD is installed in a way preventing from positioning airtightly the measuring device on the wall behind?

In the USA, the protocol does not address this issue directly, but it allows several alternative approaches including in-duct measurement. In Belgium they use ductwork measurement, or other solution from set of allowed solutions for measurement. Otherwise, they report "not measurable" (= 0 m³/h). In Ireland the issue is noted in report, not dealt with specifically. In Sweden measurements are then made in the duct or with a "hook" in the device. In France, airflow measurement is not possible in this case: measurement is not valid. If a pressure measurement can be done instead, this can be a solution: then one should make sure that the measuring device is adapted to the type of ATD.

Measuring devices

Are there requirements on measuring devices to be used according to the kind of ATD for exhaust systems?

There are requirements on measuring devices according to the kind of ATD for exhaust systems for all protocols but the Swedish one. In the USA, for an inlet terminal the airflow is permitted to be measured using a Powered Flow Hood, using an Airflow Resistance Device or using a Passive Flow Hood. In Belgium it is advised to always use stabilisation grid and largest hood, but the measurement is accepted without if the situation makes it not possible. In France, for humidity sensitive ATD, only pressure measuring devices must be used whereas for the other kinds of ATD, either pressure or airflow measuring devices can be used.

What is the calibration period for measuring devices?

A calibration period is defined in each protocol. In the USA, all equipment shall have their calibrations checked at the manufacturer's recommended interval and at least annually if no time is specified. In Belgium it is 2 years; for flow devices and 5 years for power meters; in Ireland and Sweden it is one year and in France it is 2 years for manometers and maximum 4 years for flow hoods.

Conformity / Non-conformity

How are non-conformities handled?

In Sweden every non-conformity should be corrected. In Ireland also, but it depends on flow rates. In the USA, the protocol is a method of test not a regulation and does not cover the consequences of not meeting target flows. In Belgium a table of non-conformities with sanction is available. Some should be corrected, some not. In France all of the non-conformities should be mentioned in the report or in the grid of inspection, differentiating those that relate to regulation or good practices.

For the dwelling to be conform:

There are two distinct approaches to consider a dwelling to be conform in terms of air flow rates. On one hand, in France and in Ireland it is the total flowrate that is required to be conform. On the other hand, for the other protocols (Sweden, USA and Belgium) every ATD shall be conform. In Sweden requirements for air flows are calculated by a consultant on information from the user and regulatory requirements.

For a non-residential building to be conform:

The Belgium and Swedish protocols are the only two covering also non-residential buildings and require that every room shall be conform. ■

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Application of Indoor CO_2 in Response to the Pandemic

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In response to the COVID-19 pandemic, there have been many recommendations to monitor indoor CO_2 concentrations. However, the technical basis for these recommendations and stated concentration limits are not always clear. This article discusses the application of indoor CO_2 during the pandemic and identifies opportunities for improvement.

Keywords: carbon dioxide, guidance, infectious disease, health, ventilation

The COVID-19 pandemic highlighted the importance of ventilation in mitigating the spread of airborne infectious diseases. As a result, many organizations have made recommendations for improved ventilation [1-2]. These include increased ventilation rates, higher efficiency filtration, and portable air cleaners. Real-time monitoring of indoor CO_2 concentrations is also recommended as an indicator of ventilation adequacy **[3-5]**. However, guidelines for CO_2 monitoring vary, and their technical bases are not fully described in all these recommendations. In addition, CO_2 has been used in modeling and experimental studies motivated by the pandemic.

The relationship of indoor CO_2 to ventilation and indoor air quality (IAQ) has a long history, dating back centuries. These discussions have evolved to include 1) the relationship between CO_2 and bioeffluent odors, 2) the impacts of CO_2 on building occupants, 3) the use of CO_2 as a tracer gas to measure air change rates and ventilation performance, and 4) outdoor air intake control using CO_2 concentrations. Recently, CO_2 has also been discussed in response to the pandemic in relation to the risks of airborne disease transmission. The ASHRAE Position Document on Indoor Carbon Dioxide **[5]** describes the relationship of CO_2 to ventilation and IAQ, documenting the solid knowledge base that exists to support the application of CO_2 monitoring and analysis. This article summarizes how CO_2 monitoring and simulation have been applied in response to the COVID-19 pandemic. Only limited references are provided, with a more complete list available in reference 6. The authors are pursuing a more comprehensive scoping review that will be published later this year.

CO_2 applications in studies of COVID

In response to COVID-19, there have been several research studies and guidance documents describing the use of indoor CO_2, which are all based on established concepts. However, the technical basis for the applications, recommendations, and supporting documents is not always clear. This review considered these applications, including tracer gas measurements of air change rates and ventilation performance, CO_2 as an indicator or proxy of infection risk, indoor CO_2 concentrations as indicators of ventilation or IAQ, and recommendations on the use of CO_2 monitoring.

As an indication of increased interest in CO_2, **Figure 1** plots the number of papers published by year, based on Web of Science searches, using the terms "carbon dioxide ventilation building" and the same terms with the addition of "disease" OR "infectious". The number of papers related to CO_2 and ventilation in buildings has been increasing since 2014, with another increase in 2021, presumably due to the COVID-19 pandemic. The number of papers that mention "disease" OR "infectious" increased even more dramatically in 2021.

Tracer gas measurements of air change rates and ventilation performance

Many field studies have measured air change rates using standard single-zone tracer gas decay or constant injection, with the latter assuming steady-state CO_2 concentration. These measurements have been conducted in various settings, such as schools, gyms, buses, and retail buildings, to evaluate transmission risk or IAQ. In addition, some measurements have been done using transient or integral mass balance analyses that are not standardized. Some studies have been conducted in naturally ventilated spaces, but applying tracer dilution methods to these spaces can be challenging due to the difficulty in achieving uniform tracer gas concentrations. A few studies used CO_2 as a tracer gas to measure air change rates in laboratory chambers for air cleaner performance testing. These environments are well-controlled, making measurements easier and the results more likely to be valid.

However, these studies involving air change rate estimation vary in their discussion of key assumptions and inputs. For example, some studies lack detail on the CO_2 generation rate, which varies based on occupancy. In addition, some use measured outdoor CO_2 concentrations, while others use an assumed value, which may not be reliable given variations in outdoor concentrations. Another critical assumption is that these tracer gas methods assume the space being studied behaves as a single zone, but most studies do not mention or justify this assumption. Finally, measurement uncertainty is not usually reported, making it difficult to interpret results.

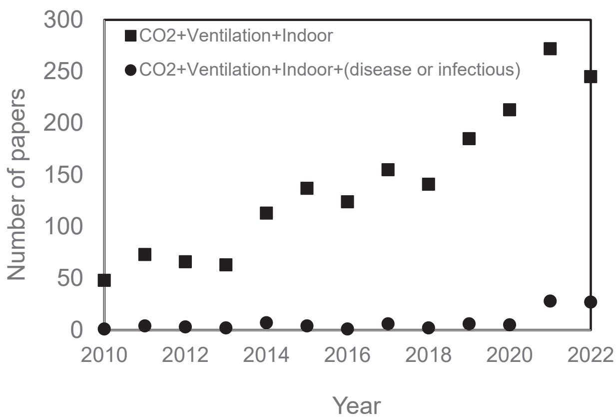

Figure 1. Number of papers related to indoor CO_2 as a function of year (as of 23 Feb 2023).

Indicator of exposure or infection risk

Several studies have used CO_2 as an indicator or proxy for exposure to infectious aerosols or infectious risk through measurements in the field of test chambers and simulations using computational fluid dynamics (CFD). Experimental studies have been conducted in various space types, including concert halls, healthcare facilities, and laboratory chambers. Some studies simultaneously measured CO_2 and airborne particle concentrations to study their relationship, while others used CO_2 concentration as an indicator of exposure or risk using the Wells-Riley equation. Others present CO_2 as a risk indicator without explaining the basis for the connection. Many studies employ the concept of rebreathed air, and some focus on the impact of specific activities like breathing, talking, or signing or features such as ventilation rates, physical partition, and filtration.

Several modeling studies have used CO_2 as an indicator of aerosol exposure and infection risk, using CFD to examine the impact of air distribution. Others used mass balance modeling to evaluate CO_2 variations in space and time as exposure or risk indicators, sometimes acknowledging that there is no direct evidence correlating CO_2 concentrations with virus-containing aerosol levels.

While CO_2 has been used as a surrogate for infectious aerosols, arguments exist for and against. Some reasons for using CO_2 as a surrogate include the ability to capture the fate and transport of fine droplets and simplicity. Reasons against include differences in particle dynamics from gases, two-phase airflow of infectious aerosols, and the inability to capture differences between particles with aerodynamic diameters relevant to virus transmission.

Measurement of indoor CO_2 as an indicator of ventilation and IAQ

Many field studies of infection risk or building performance during the pandemic have included measurements of CO_2 concentrations, generally as metrics of ventilation and IAQ. However, the links between CO_2, ventilation, and IAQ are not always explained. In many cases, ASHRAE Standard 62.1 **[8]** is cited as the source of concentration limits of 1000 ppm_v or 700 ppm_v above outdoors, despite the standard not containing either value. Other studies cite CO_2 limits in documents associated with the country where the measurements were conducted.

These studies include a survey of the indoor environments in taxis in Paris before and after the lockdown and an examination of the effectiveness of ventilation in buses in Spain. Other studies present assessments of ventilation and IAQ in a fitness club, a concert hall, and some mechanically ventilated buildings. Many of these studies simply report the measured CO_2 concentrations, sometimes compared to a local limit, but generally do not discuss the value of CO_2 as a ventilation or IAQ metric. As discussed in [6], indoor CO_2 concentrations are not good indicators of overall IAQ but can serve as a measure of ventilation using tracer gas concepts as discussed above.

CO_2 measurement for ventilation monitoring or control

Several studies using CO_2 measurement or analysis have been conducted to investigate strategies for monitoring or controlling building ventilation. While these studies generally do not quantify infection risk, they are motivated by the need to manage risk. For example, one proposed feedback control strategy uses CO_2 monitoring as a function of scheduled airing periods, class duration, and masking to manage infection risk in naturally ventilated classrooms. Another used metabolism-based ventilation control to reduce infection risk and energy use in gymnasiums. Others reviewed CO_2 monitoring and ventilation recommendations, noting the challenges in linking CO_2 concentration to infection rates and identifying concentration limits for different spaces.

Indoor CO_2 concentration monitoring

As noted in the ASHRAE Indoor CO_2 Position Document **[6]**, there are numerous recommendations, and in some cases requirements, to monitor indoor CO_2 concentrations to manage the risks of airborne infection, often with a reference concentration for comparison or compliance. These concentrations are based on CO_2 as an indicator of ventilation or as a direct or indirect indicator of infection risk, but the rationales presented are not always clear.

Indoor CO_2 limits have been established for decades for managing generic IAQ and sick building syndrome symptoms, usually around 1,000 to 1,500 ppm_v. During the pandemic, several organizations, and governments have recommended monitoring indoor CO_2 concentrations as an indicator of outdoor ventilation rates **[2-4]**. However, measured CO_2 concentrations are not considered reliable proxies for the risk of airborne exposure to the SARS-CoV-2 virus **[9]**.

Many of these indoor CO_2 limits are based on CO_2 as an indicator of the outdoor ventilation rates, which implicitly involves using CO_2 as a tracer gas requires a target ventilation rate. However, the bases for these limits are not always explained. CO_2 limits based can be estimated using the requirements of ventilation standards, e.g., CEN 16798 **[10]** or some other ventilation rate intended to control transmission. The CO_2 limits that have been issued generally do not differentiate between space types, occupant characteristics, or required ventilation rates, despite their impact on indoor concentrations. A space-specific CO_2 metric for ventilation has been developed that considers the space, occupants, and target ventilation rate **[11]**, which can be applied using an online tool called *QICO*$_2$ **[12]**.

Conclusions

This article summarized the application of indoor CO_2 in response to the COVID-19 pandemic. CO_2 has been used as a tracer gas to estimate air change rates and as an indicator of ventilation or IAQ, which are not new concepts. Some studies have focused on CO_2 as a proxy for airborne infectious aerosols. However, these applications do not always reflect a complete understanding of the relevant mass balance theory, building ventilation, and IAQ. The studies reviewed in this summary reinforce the need for better guidance on the use of indoor CO_2, including measurement protocols and research on CO_2 emissions by building occupants, indoor CO_2 concentrations, and the relationship between indoor CO_2 and airborne disease transmission. ■

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Shower drain heat recovery
– *an introduction*

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Keywords: EPBD, CEN, Standards, Domestic hot water, Heat recovery, Shower

Executive summary

In a context of reduced heating needs due to the increasing level of building insulation, the energy use for domestic hot water has an increasing role. Waste water heat recovery (WWHR in the following) is a technology that allows to cover a significant part of the domestic hot water energy needs with heat recovered from the shower drain.

The analysis of the technology shows the importance of the several factors that determine its efficiency in the daily operation:

- product related properties, like the heat exchanger efficiency as a function of the flow rates;
- installation related properties, like the type of connection of the WWHR device;
- operation properties, like the effects of transients when opening and closing the tap and the set-point temperature of the water heater (for type B and C connections see hereafter).

Introduction

The context

In the past decades, given the EU climate and building envelope technologies, space heating needs where the dominant factor in determining the energy use of buildings, with values ranging from about 50 kWh/m^2 year for residential buildings in Mediterranean countries to more than 200 kWh/m^2 year in cold climates. Currently, there is an ongoing effort to reduce space heating needs by insulating the buildings: the current design target values are in the range 10 to 50 kWh/m^2 year, depending on climate and building category.

Domestic hot water needs range around 10 to 25 kWh/m^2year for the residential sector and they are even much higher for hotels. They should be now under special attention because their relative value in the building energy balance has dramatically increased due to the reduction of energy needs and use for the other comfort services.

Domestic hot water needs do not depend on the building envelope. The possibilities to reduce the non-renewable primary energy use and carbon emissions are limited to:

- keeping a high efficiency of technical systems;
- using renewable and zero carbon energy as a source (renewables);
- and last but not least using heat recovery (recoverable).

An option to reduce the environmental impact of domestic hot water service is recovering heat from the hot water flowing in the drain to the sewer to pre-heat the incoming domestic cold water. Indeed, heat recovery should precede using renewable energy, which should be left only the final touch after having reduced the required output of the generation sub-system.

The basic idea

The basic idea is straightforward: to recover heat from the hot water flowing in the drain to pre-heat the incoming domestic cold water.

Heat recovery requires the simultaneity of the source and destination heat flows, otherwise heat must be stored. Simultaneity is guaranteed natively for showers, which are the main application of waste water heat recovery. Showering is becoming a major use of domestic hot water in buildings: showers are preferred to bathtubs in new houses and in renovations and where bathtubs are installed, they are often used to take showers, too.

There is no simultaneity of draw-off and drain when taking a bath. Some heat recovery is still possible using a heat storage device but it is not the topic of this article which is limited to instantaneous heat recovery.

The technology

Waste water heat recovery device types and properties

A WWHR device is a counterflow (sometimes crossflow because of installation constraints) heat exchanger where:

- the drain water of the shower flows through the primary side of the heat exchanger, which is the heating side. The flow through the primary side is normally guaranteed by gravity.
- The domestic cold-water flows through the secondary side of the heat exchanger, which is the heated side. The flow through the secondary side is guaranteed by the pressure of the domestic water distribution network.

The instantaneous type relies on the fact that the primary and secondary flows are simultaneous, except for an initial and final transient due to the water accumulated in the shower basin.

The construction can be vertical or horizontal, as shown in **Figure 1**.

The separation between primary and secondary side can be either single or double wall type, according to the required level of tightness, which in turn depends on the risk of contamination and/or uncontrolled losses of water. In case of double wall separation, the space between walls may be filled with an intermediate fluid to promptly identify any loss of tightness. There is ongoing discussion about this topic.

This article deals with:

- instantaneous waste water heat recovery heat exchangers;
- energy efficiency topics.

Functionality and safety requirements like e.g:

- head loss of the secondary side,
- maximum flow rate on both primary and secondary side,
- time constant for cooling,
- level of tightness (single versus double wall),

are assumed to be satisfied for the correct operation of the domestic hot water system.

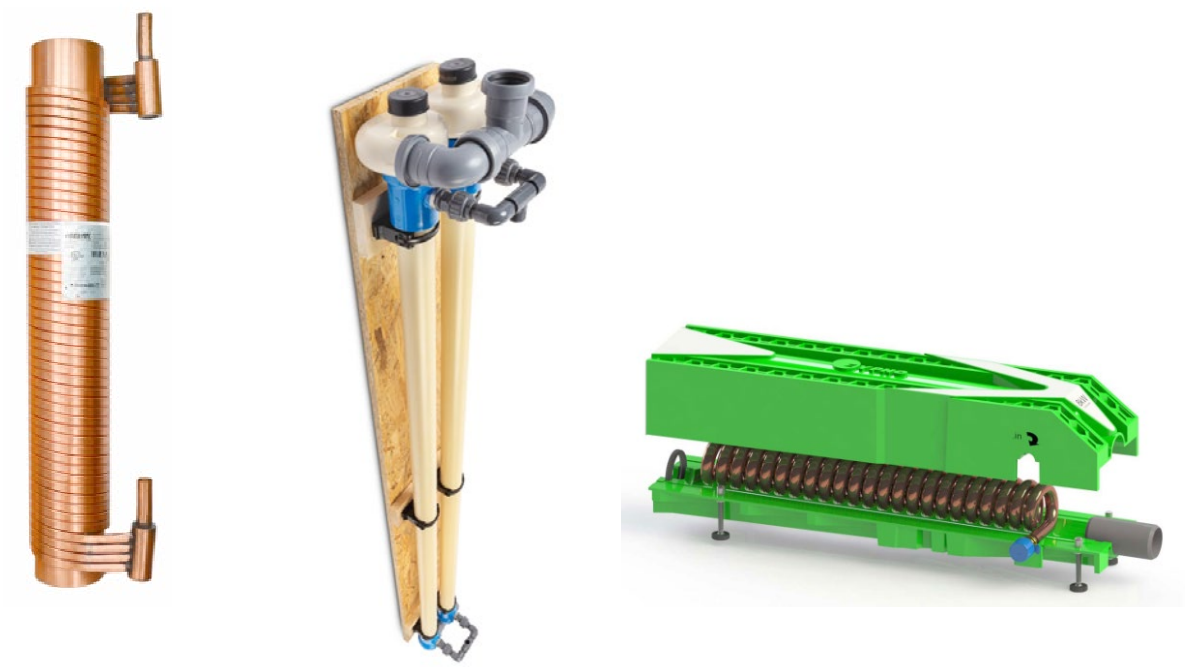

Figure 1. Example of waste water heat recovery exchanger construction, vertical and horizontal type.

Basic installation on a shower drain, type "A" connection

Basic connection and steady state operation

Figure 2 shows an example of the steady state operating conditions of a basic waste water heat recovery installation on a shower drain using type "A" connection (balanced operation).

The heat recovery device is installed nearby the shower drain. The device is heating:

- both the cold domestic water feed to the domestic water heater;
- and the cold domestic water to the shower mixer (cold water tap).

A bathtub and a sink are shown in **Figure 2** to support the discussion of the possible influence of other devices than showers.

The needs are represented by the 12.0 ℓ/min of domestic hot water flow rate $V'_{W;draw}$ at the draw-off temperature $\theta_{W,draw}$ = 40°C provided at the shower head. This can be turned into an needed power $\Phi_{W;nd}$ depending on the cold water temperature. The needed power is given by:

$$\Phi_{W;nd} = \dot{V}_{W;draw} \times (\theta_{W;draw} - \theta_{W;cold}) \times \rho_W \times C_w \qquad (1)$$

where r_W and C_w are the density and specific heat of water. The other symbols are shown in **Figure 2** and in the preceding text.

With 12°C cold water temperature, the power required to take a shower $\Phi_{W;nd}$ is around 24 kW. Assuming a shower duration of 5 minutes, the required volume of water at the tap is 60 litres and the energy need for each shower event is 1.95 kWh.

The recoverable heat

Not all the energy need is recoverable because the water cools down in the shower box and in the drain pipe from the shower outlet to the WWHR device inlet:

- the shower drain temperature $\theta_{w,drain}$ is assumed to be 35°C, according to an average user behaviour;

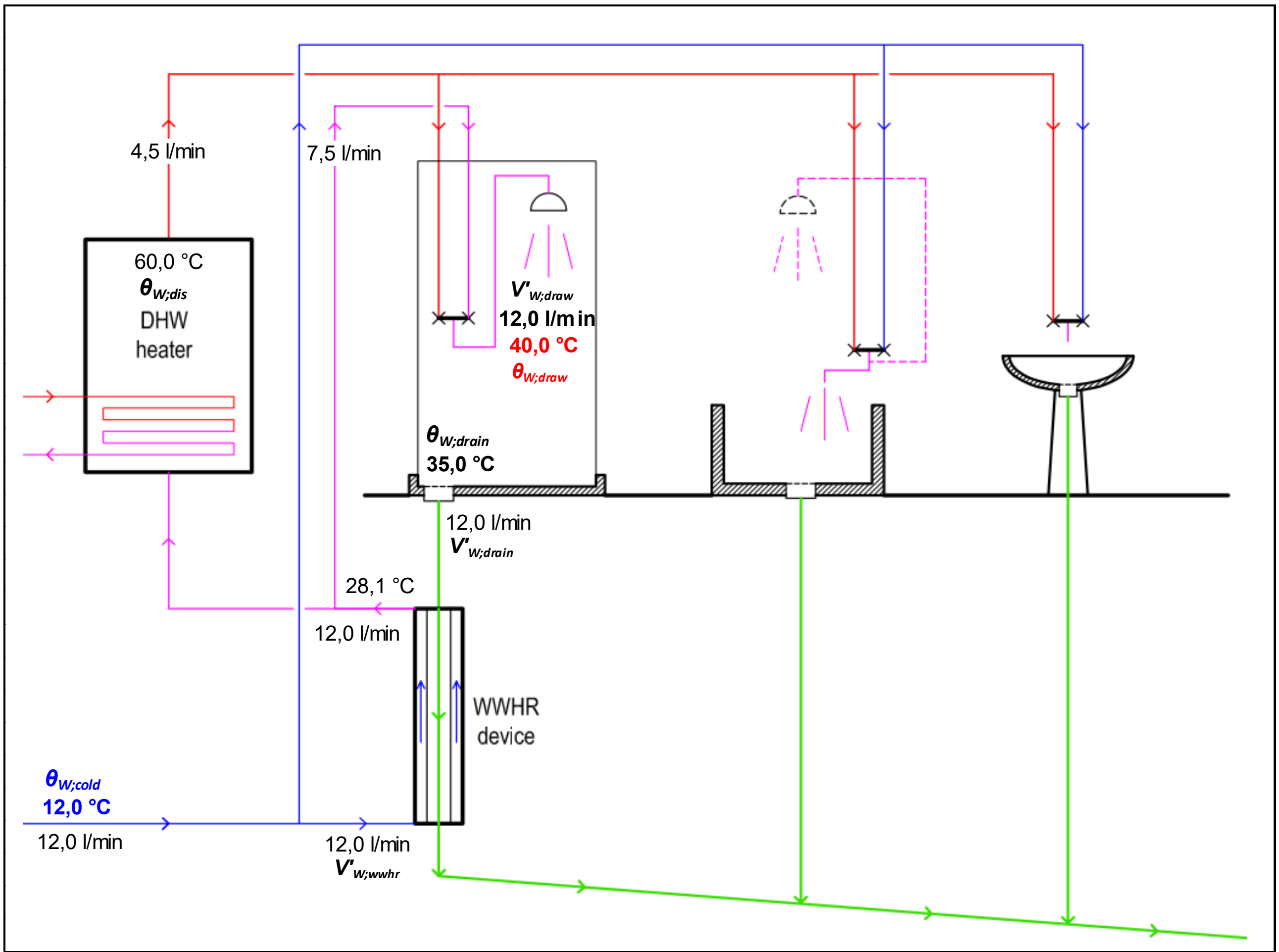

Figure 2. Basic installation – type A connection.

- the temperature drop in the connection from the shower drain to WWHR device is assumed to be negligible, unless there is a long connection pipe (several meters).

In principle there is also a loss of mass flow rate in the shower, because of evaporation and/or leaks. This is usually neglected and the flow rate at the drain $V'_{W;drain}$ is assumed to be equal to the draw-off flow rate.

Type A connection guarantees that the flow rates in the WWHR device are balanced ($V'_{W;wwhr} = V'_{W;drain} = V'_{W;draw}$), so the **recoverable** power $\Phi_{W;nd;rbl}$ is given by

$$\Phi_{W;nd;rbl} = \dot{V}_{W;draw} \times (\theta_{W;drain} - \theta_{W;cold}) \times \rho_W \times C_w \tag{2}$$

and the **recoverable fraction** of needs for type A connection $k_{wwhr,rbl;A}$ is given by:

$$k_{wwhr;rbl;A} = \frac{\theta_{W;drain} - \theta_{W;cold}}{\theta_{W;draw} - \theta_{W;cold}} \tag{3}$$

where all symbols have been already defined.

For the above example, as shown in **Figure 2**, the recoverable fraction is 82% of needs.

Since the recoverable heat is proportional to the difference between:

- the drain temperature, which is assumed to be constant;
- the cold-water temperature, which depends on the climate

then, the **recoverable** heat fraction for this configuration (type A connection):

- is not affected by the domestic hot water heater temperature;
- does not depend on the WWHR device efficiency;
- decreases with increased cold-water temperature;

and therefore, WWHR devices are more interesting in cold climates.

A long and uninsulated connection between the shower drain and the WWHR device inlet may cause a further reduction of recoverable heat. Usually, the device is installed next to the shower and this loss is negligible.

The heat exchanger efficiency and the recovered heat

Depending on the heat exchanger design and sizing, not all the recoverable heat will be **recovered**.

The recovered power during steady state operation $\Phi_{W;nd;rvd;ss}$ is given by:

$$\Phi_{W;nd;rvd;ss} = \Phi_{W;nd;rbl} \times \eta_{wwhr} \tag{4}$$

where η_{wwhr} is the heat exchanger efficiency.

The heat exchanger efficiency is defined as:

$$\eta_{wwhr} = \frac{\theta_{W;pre} - \theta_{W;cold}}{\theta_{W;drain} - \theta_{W;cold}} \tag{5}$$

The heat exchanger efficiency can be measured in reference conditions and then interpolated and/or corrected to actual operating conditions. More details are given in the following.

Depending on the heat exchanger design and sizing, only a fraction of the recoverable heat will be **recovered**. This fraction depends on the heat exchanger efficiency, which may be obtained by a test procedure.

The effect of the presence of other domestic hot water uses

The drains from bathtubs and sinks can also be collected to the WWHR device inlet, as shown in **Figure 3**. This will obviously increase the amount of recovered heat, especially if the bathtub is used for showers.

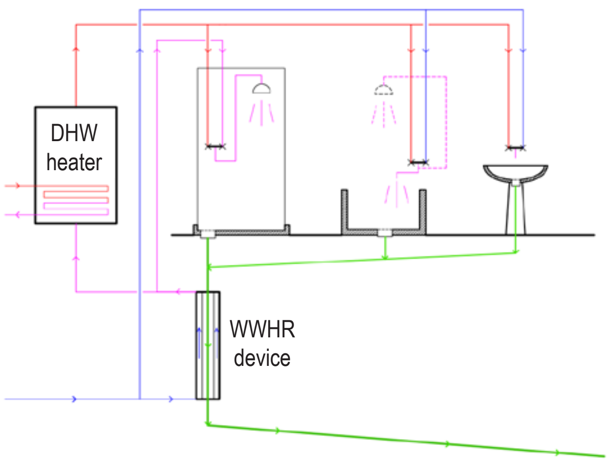

Figure 3. Collecting several drains to a WWHR device.

Effect of transient operation

The above is correct after that the flow rates and the temperatures in the drain and in the preheated water connections have reached a steady state operation regime. During transient operation:

- at the beginning of showering, the domestic cold water flowing through the WWHR device is not preheated until the warm water from the shower drain reaches the inlet and fills the WWHR device;
- at the end of the showering, the domestic hot water flow is suddenly interrupted and:
  - the warm water accumulated in the shower basin will flow through the drain when the incoming cold domestic water flow through the WWHR device is already interrupted and no more heat recovery may happen;
  - the preheated water will be trapped in the pipes and will cool down releasing its recovered heat contents in the environment;
  - the recovered heat accumulated in the pipe walls and heat exchanger material will be released in the environment as well.

The initial transient does not cause any loss in the heat recovery: as soon as the drain water reaches the WWHR device, there is an established cold domestic hot water flow and heat can be recovered.

The final transient causes the loss of the part of the previously recovered heat:

- contained in the water and pipe materials of the preheated water connections (from the WWHR device outlet to the shower tap and/or to the domestic hot water heater inlet);
- contained in the water accumulated in the shower basin and in the connection from the shower outlet to the WWHR device inlet;
- contained in the WWHR device itself, which includes both its water contents and the heat exchanger material.

The effect of the volume of hot water trapped in the hot water distribution pipe from the water heater to the shower tap is already covered by the final distribution losses.

The effect of transients is mostly depending on installation choices (shower basin size and shape, inner diameter and length of preheated water pipes). The heat capacity of the volume of water inside the WWHR device when closing the tap (steady state operation volume) and of the heat exchanger materials also contributes but only half of this heat capacity must be considered because domestic water and drain water are respectively preheated and cooled along the WWHR device.

Transient operation losses also depend on the use pattern. Since transient losses are a given amount of energy for each tapping event, their relative impact will be higher for small tapping events.

As a first approximation, the lost fraction of the recovered heat because of the transient operation $k_{wwhr;use;ls}$ is given by

$$k_{wwhr;use;ls} = \frac{V_{trans}}{V_{show}} \qquad (6)$$

where:

V_{trans} is the equivalent volume of water of the effective total heat capacity that has to cool down at each transient;

V_{show} is the volume of water drawn during a single shower event (the product of shower flow rate by the shower duration).

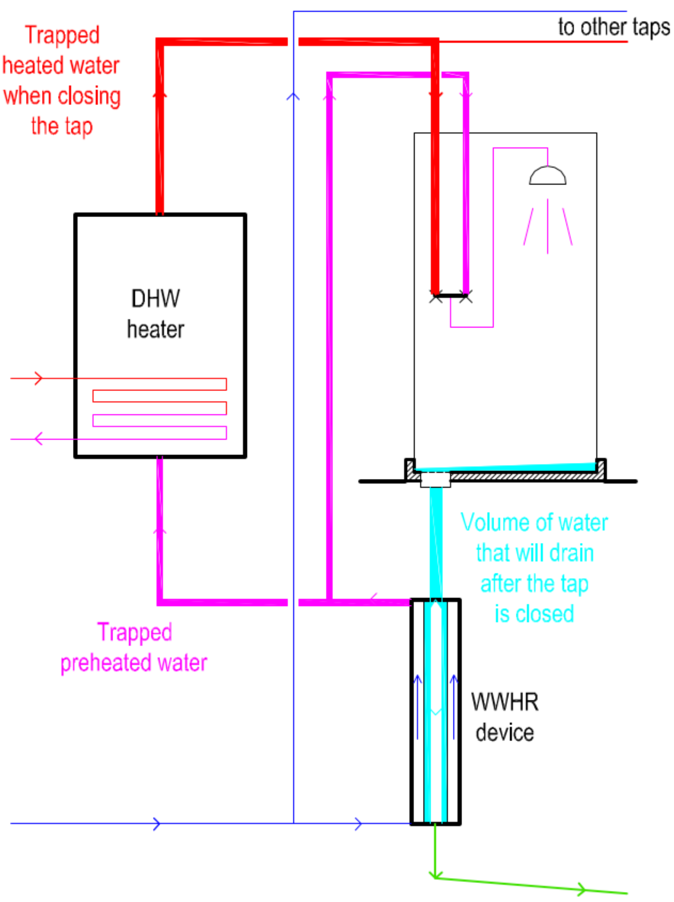

Figure 4. Volumes of water relevant for transient operation.

The complement to one of the lost fraction is called the utilisation factor of the WWHR device $k_{wwhr;use}$ and it is the fraction of the recovered heat during steady state operation which is actually recovered.

$$k_{wwhr;use} = 1 - k_{wwhr;use;ls} \quad (7)$$

As an example, with the following assumptions (on the safe side):

- volume of water in the shower box and drain connection: 2 litres (includes all the water from the shower head up to WWHR device inlet);
- volume of preheated water connections (15 m length with inner diameter 14 mm): 2.3 litres;
- volume of water inside the WWHR device (sum of primary and secondary): 2 litres, half to be considered;
- equivalent volume of water with the same heat capacity of the heat exchanger materials: 1 litre, half to be considered;
- total volume of domestic hot water drawn during the shower event: 60 litres (5 minutes @ 12 ℓ/min);

the resulting total equivalent trapped volume is 5.8 litres (2 + 2.3 + 2/2 + 1/2) and the value of the utilisation factor $k_{wwhr;use}$ is 1 – 5.8/60 = 0.90.

Other possible connections of a waste water heat recovery device to a single shower

Introduction

Figure 2 illustrates the theoretically optimal connection of the WWHR device. It is commonly identified as "type A" connection. It may require a long connection from the WWHR device (which is usually installed nearby the shower) back to the domestic hot water heater. For practical reasons (building layout and resulting length of pipes), other connection schemes may be preferred.

Type B connection

Figure 5 shows the "type B connection", where the WWHR device **only preheats the cold domestic water supplied to the shower**.

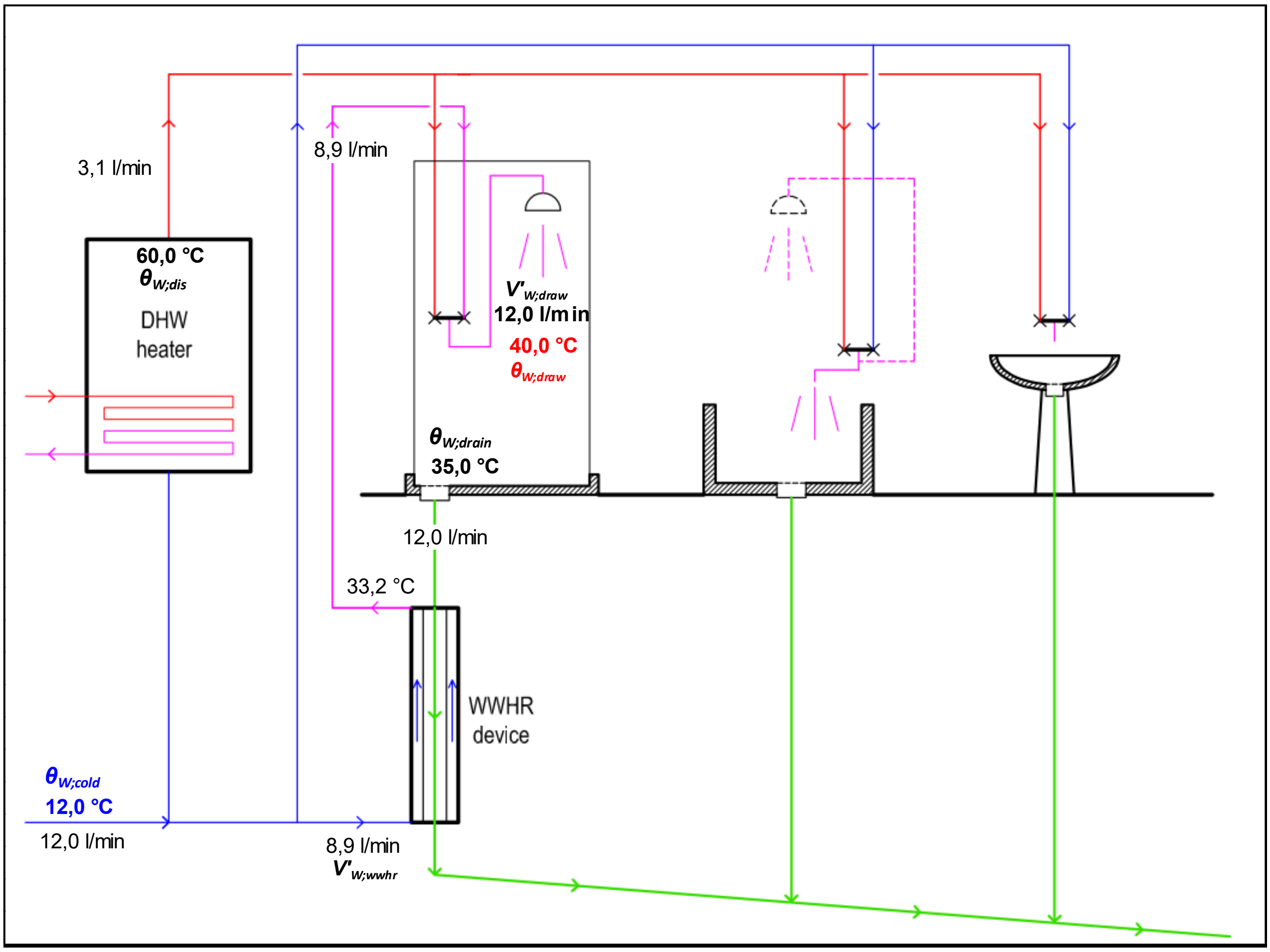

Figure 5. Alternative installation – type B connection.

This connection is mainly used when several WWHR devices are connected to a common domestic hot water preparation system.

This connection allows to install the WWHR device near the shower, with minimum preheated water pipe length.

However, the flow is no more balanced and the maximum recoverable power is given by:

$$\Phi_{W;nd;rbl} = \dot{V}_{W;wwhr} \times \left(\theta_{W;drain} - \theta_{W;cold}\right) \times \rho_W \times C_w \tag{8}$$

where $V'_{W;wwhr}$ is the flow rate of cold water through the WWHR device, r_W and C_w are the density and specific heat of water and the other symbols are shown in **Figure 5**.

The flow rate through the WWHR device $V'_{W;wwhr}$ depends on the domestic hot water heater set point but also on the efficiency of the WWHR device: the higher the efficiency of the WWHR device, the higher the recoverable heat. The recoverable fraction of needs for type B connection $k_{wwhr;rbl;B}$ is given by:

$$k_{wwhr;rbl;B} = \frac{\theta_{W;drain} - \theta_{W;cold}}{\theta_{W;draw} - \theta_{W;cold}} \times \frac{\theta_{W;dis} - \theta_{W;draw}}{\theta_{W;dis} - \eta_{wwhr} \cdot \left(\theta_{W;drain} - \theta_{W;cold}\right)} \tag{9}$$

where (see **Figure 5**) $\theta_{W;dis}$ is the domestic hot water temperature in the distribution circuit, equal to the set-point temperature of the domestic hot water heater.

This dependency of the recoverable heat on the WWHR device efficiency may require some iterations in the calculation procedure. As an example, for the given conditions in **Figure 5** and with a WWHR device efficiency of 75%, the **recoverable** heat is 53 % of the domestic hot water needs and the **recovered** heat 40%. For consistency, the efficiency of the WWHR device has been assumed somewhat higher than in the type A connection due to the reduced flow rate in the domestic water (secondary) side.

The recoverable heat for type B connection:

- increases with higher storage temperature (higher flow rate through the WWHR device to the cold-water connection of the shower);
- increases with higher WWHR device efficiency;
- decreases with higher cold-water temperature.

This makes type B connection more suitable with high temperature heat generators, like boilers, direct electric heaters and CHP.

Type C connection

Figure 6 shows the "type C connection", where the WWHR device **only preheats the cold domestic water supplied to the domestic hot water heater**. Cold water is fed to the mixer of the shower.

In case of retrofit, this connection does not require to modify the domestic hot water distribution and is often easily accessible.

However, the flow is no more balanced and the maximum recoverable heat is given by:

$$\Phi_{W;nd;rbl} = \dot{V}_{W;wwhr} \times \left(\theta_{W;drain} - \theta_{W;cold}\right) \times \rho_W \times C_w \tag{10}$$

Where $V'_{W;wwhr}$ is the flow rate of cold water to the WWHR device, r_W and C_w are the density and specific heat of water and the other symbols are shown in **Figure 6**.

The flow rate through the WWHR device does not depend on the efficiency of the WWHR device. It is given by:

$$\dot{V}_{W;wwhr} = \dot{V}_{W;draw} \times \frac{\theta_{W;draw} - \theta_{W;cold}}{\theta_{W;dis} - \theta_{W;cold}} \tag{11}$$

Therefore, the recoverable fraction of needs for type C connection $k_{wwhr;rbl;C}$ is given by:

$$k_{wwhr;rbl;C} = \frac{\theta_{W;drain} - \theta_{W;cold}}{\theta_{W;dis} - \theta_{W;cold}} \tag{12}$$

As an example, for the given conditions in **Figure 6**, the **recoverable** heat is 48 % of the domestic hot water needs and the **recovered** heat 38%.

The recoverable heat for type C connection:

- decreases with higher storage temperature (lower flow rate through the WWHR device);
- does not depend on the WWHR device efficiency;
- decreases with higher cold-water temperature.

The impact of system design and commissioning choices

The graph in **Figure 7** shows the maximum <u>recoverable</u> percentage of needs $k_{wwhr;rbl}$ depending on connection type (A, B and C) and domestic hot water heater set-point (40°C to 60°C) with the following assumptions:

- draw off temperature 40°C;
- shower drain temperature 35°C;
- cold water temperature 12°C.

For type B connection, the recoverable part of needs also depends on the WWHR device efficiency, therefore the graph includes the curves for efficiency 25, 50, 75 and 100%.

The impact of the connection type is evident but also that of the domestic hot water heater set-point. A lower set-point (than 60°C) is beneficial for the recoverable heat of type C connection whilst it can seriously reduce the recoverable heat with type B connection.

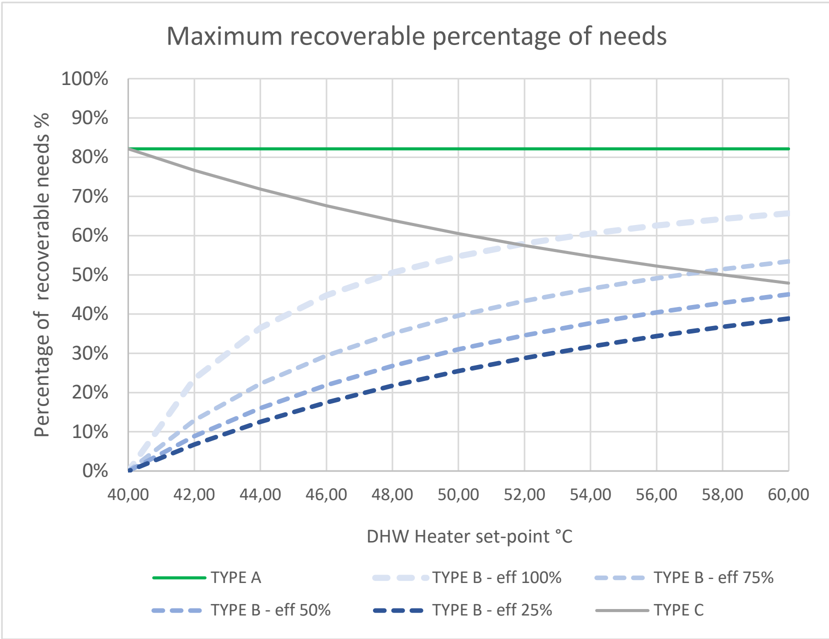

Figure 7. Recoverable fraction of domestic hot water needs $k_{wwhr;rbl}$.

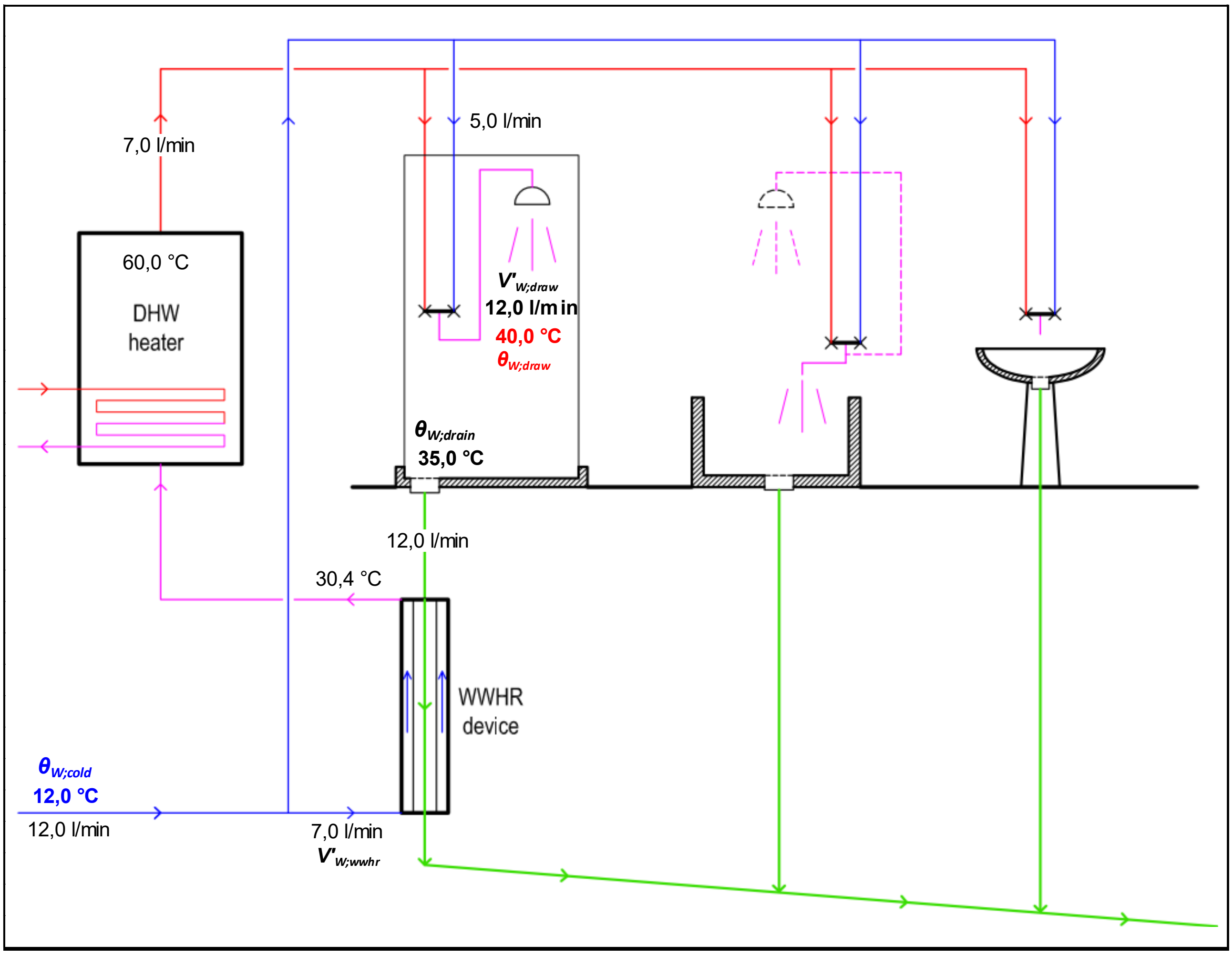

Figure 6. Alternative installation – type C connection.

Heat recovery with several showers

It is common to have more than one shower in a single-family house or in a medium to large building unit. Additionally, heat recovery may be applied to locker rooms showers of sports halls where arrays of showers are installed.

If there are several showers, using type A connection:

- either the drains are collected to a unique common WWHR device, suitably sized for the maximum simultaneous drain flow rate (similar to what is shown in **Figure 3** but all showers);
- or, if multiple heat recovery devices are required to serve several showers, the devices should be connected in series on the cold-water side.

The second option will cause a reduction of the heat recovery efficiency due to additional heat losses of the preheated domestic water flowing through inactive WWHR devices and may also cause a high pressure drop of domestic water.

In both cases a preheated domestic water distribution pipe is required to feed all showers.

Type B connection may be used independently on each one of multiple showers or groups of showers. Each shower (or group of showers) is an independent heat recovery installation

Type C connection requires a series connection of the WWHR devices on the cold-water side, like for type A connection but no change is required in the cold and hot domestic water distribution piping.

Effect of the opening of other taps

Given the configurations shown in **Figures 2, 5 and 6**, if other taps are opened during WWHR device operation, the effect is a slight increase of heat recovery for type A and type C connection. Type B connection operating conditions are independent from other devices unless the drain of other devices is collected to the same WWHR device.

If the drains of all devices of a bathroom are collected to the waste water heat recovery of a shower, this may provide some additional domestic hot water heat recovery when warm water is discharged.

Summary

This preliminary analysis highlights the influencing factors that should be taken into account in the calculation methods:

- the connection scheme for each WWHR device (de facto standardised as "A" to "C"), which determines the **recoverable heat** identified as the fraction $k_{wwhr;rbl}$ of needs (see **Figure 7**);
- the efficiency of the heat recovery device η_{wwhr}, which determines the fraction of recoverable heat which is actually **recovered**;
- the effect of transient operation, depending on;
  - the volume of preheated water and drain water in the pipes, WWHR device and shower basin;
  - the use pattern (volume of water for each of tapping event);

  which causes the loss of part of the previously recovered energy; this is taken into account by applying the utilisation factor $k_{wwhr;use}$;

- the effect of multiple WWHR devices connection.

In total the net recovered heat $Q_{W;wwhr;rvd}$ is given by:

$$Q_{W;wwhr;rvd} = Q_{W;nd} \times k_{wwhr;rbl;X} \times \eta_{wwhr} \times k_{wwhr;use} \quad (13)$$

where the symbols have been defined in the text and $k_{wwhr;rbl;X}$ is the recoverable fraction of needs for connection type X, which may be A, B or C.

It is important to distinguish between:

- the influencing factors depending on product properties, such as WWHR device steady state efficiency, water volume contents during steady state operation and heat capacity of heat exchanger materials;
- versus influencing factors depending on installation choices and use properties, such as the total volume of preheated water connections and the volume of water drawn at each tapping event.

so that product dependent influencing factors can be properly identified by product testing without influence of the test setting properties. ■

Recent developments on Environment Product Declarations (EPDs) for HVAC products in Europe

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What is LCA?

Life Cycle Assessment (LCA) is a systematic method to analyse the potential environmental impacts of products or services during their entire life cycle, where CO_2-equivalent emissions are one of several core environmental impact indicators to be declared. Standards ISO 14040 and ISO 14044 define the general framework for LCA with broad applicability, but limited granularity.

For sufficient granularity, LCA for buildings follow European Standard EN 15978 by summing the quantified impacts per indicator and life-cycle stage. The analysis covers all stages of the product life cycle (see **Figure 1**), which are:

- Production stage (incl. raw material supply and transport): Stages A1-A3.
- Construction stage (incl. installation on site): Stages A4-A5.
- Use-stage (incl. energy, use of water, repairs): Stages B1-B7.
- End-of-life stage (incl. waste disposal): Stages C1-C4.
- Finally, beyond life-cycle impacts, e.g. reuse and recycling. Stage D.

The assessment is so comprehensive that, for example, that two completely identical HVAC products

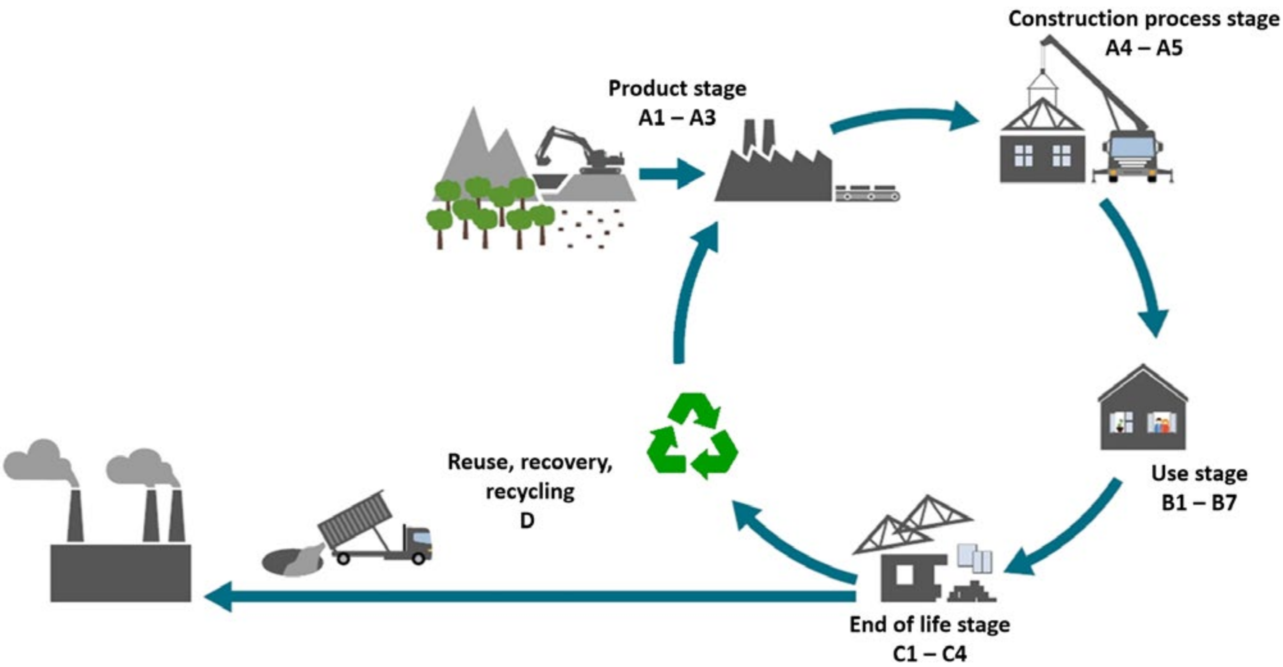

Figure 1. Stages in a building's life cycle as defined in EN 15978. [Figure reproduced from "Bæredyktigt byggeri", Energistyrelsen, 2015]

manufactured in the same factory in Europe will have different environmental performance if the steel in the two products is sourced from a steelworks that changes its electrical supply mix or source of iron ore.

What is an Environmental Product Declaration – EPD?

An EPD is information on the environmental impact of a product throughout its life cycle, including CO_2-equivalent emissions. EPDs are typically used as input to a Life Cycle Analysis (LCA) at building-level.

The most common type of EPD is a "Type III Environmental Performance Declaration", which is verified by an independent third-party in accordance with standard ISO 14025. Type III EPDs are based on predetermined/standardized set of rules and environmental data. Type III environmental declarations are the basis for labelling schemes such as Eco-Leaf and Eco-profile. In the following, I call Type III EPDs simply as "EPDs".

The use of EPDs in European construction was stimulated by *European Construction Product Regulation* (CPR 305/2011), and its seventh basic requirement "Sustainable use of natural resources". EPDs for construction products are developed based on the already mentioned ISO 14025, and EN 15804 which gives core rules for construction products. EPDs were first developed for basic construction elements such as steel, concrete, brick, or windows, whilst there has been a significant lack of EPDs for technical building services including HVAC products. However, Nordic HVAC manufacturers are starting to publish large numbers of validated EPDs.

Previously EPDs were usually published solely as PDF documents, but there is growing need for computer-readable EPD data formats such as the new EN ISO 22057. According to EN 15804, EPDs should be published in a standardised digital communication format. This is necessary for utilization of EPDs within a BIM-environment.

Different types of EPDs and their data quality

An EPD may contain specific data for actual products or be more generic based on average data for a product category. Examples include:

- Generic EPDs representing an average for a product category.
- Industry-average EPDs for a specific product group and geographical market.
- Product-specific EPDs for a specific product from a specific manufacturer.

- Project-specific EPDs for a specific project, including the environmental impact of transportation from supplier to the construction site.

In most European countries both the market and the authorities have set greenhouse gas emission requirements for new and major renovation of buildings. EPDs are the preferred sources of information for meeting these requirements.

Are EPDs mandatory?

EPDs for construction and HVAC products are not currently mandatory. However, ongoing developments in many EU Member States related to the integration of LCA calculations in national Building Codes and voluntary schemes for assessing sustainability and environmental performance of buildings, are driving HVAC manufacturers to publish EPDs for their products.

Who can issue an EPD?

ISO 14025 requires that a Type III EPD be independently verified. In practice this means that data from LCA and information modules are verified by a third party licensed by an EPD Programme Operator, and the EPD is issued by the programme operator. Many operators harmonize their practice as members of umbrella organization ECO Platform (www.eco-platform.org).

How is an EPD typically used?

EPDs typically provide information about a specific product. This information is relevant when performing a building-level LCA analysis. However, contrary to the impression of many stakeholders in the building industry, extreme care must be taken when comparing the environmental performance of competing products. This is because EPDs are often based on different assumptions, rendering them non-comparable. For example, the EPDs for two air handling unit products may have different capacities, operating times, replacement intervals, different components, and the air filters may have different quality and lifespan. One means to ease this issue is harmonized documentation by Product Category Rules (PCR); another is that end-users of EPDs should assess whole system-level performance. This involves collecting all relevant EPDs for a building, ensure that all stages are accounted for (many EPDs have missing stages), and make realistic assumptions about the use-stage.

What are Product Category Rules (PCR)?

As mentioned above, the ISO standards setting out the framework for LCA calculations necessary for EPDs are very general. Guidance on preparation of EPDs for specific products are supplemented in *Product Category Rules* (PCRs). Normally PCRs are developed individually by each EPD programme operator, as shown in **Figure 2**. For construction products including heating, cooling, lighting and ventilation components, the

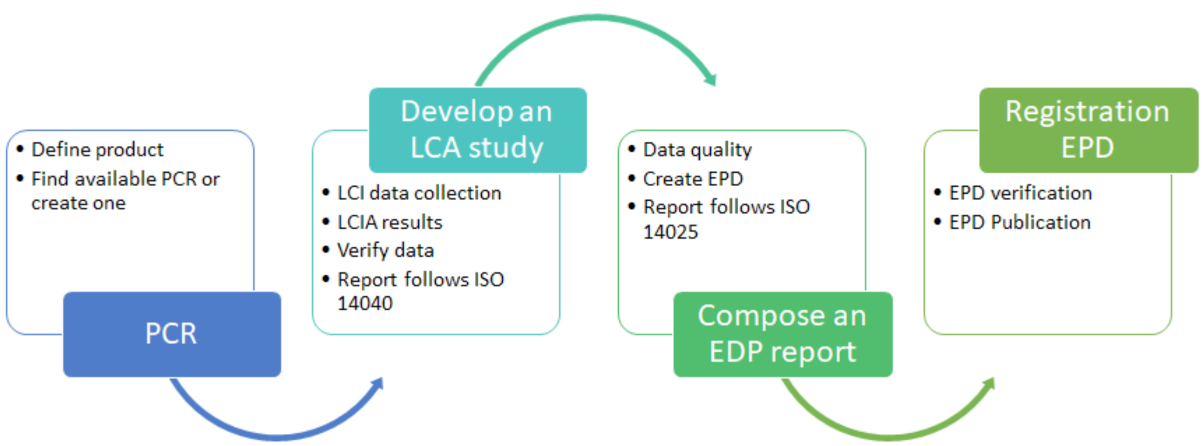

Figure 2. Illustration of the stages in the framework for development of EPDs. [Figure reproduced from Wikipedia "Environmental Product Declaration", licensed under CC BY-SA.4]

CEN standard EN 15804 with core rules, referencing EN 15978 for LCA, are the core rules to be followed. In addition, relevant *Complementary Product Category Rules* (c-PCR) which provide additional compliant and non-contradictory requirements to EN 15804, shall be used when available.

If the EPD for a ventilation product (e.g. air handling unit) is based on the core rules of EN 15804, which does not address the use-stage (i.e. operational energy use and maintenance), the use-stage modules of LCA are not declared, or declared optionally based on a predefined scenario. These assumptions (scenarios) should be then declared in the EPD but they can vary considerably between EPD programme operators. However, a c-PCR (complimentary PCR) may be defined and used for the specific product category.

Development of a complimentary PCR and EPD-generator for ventilation products

The Norwegian HVAC & Refrigeration Association (VKE) has recently focused on developing c-PCR and EPD resources specifically for ventilation products. The c-PCR is published as NPCR 030:2021. The ultimate aim of the project is to develop and verify a EPD "generator" to develop, verify and register machine-readable EPDs for their products, that can be shared with customers.

The most rational and affordable way to prepare EPDs, if a manufacturer has a large number of different products and varieties, is to use a EPD generator. When an EPD is developed in a semi-automated EPD generator (such as https://lca.no/epd-generator/), then the generator itself must be verified. This means that VKE's members, after the generator has been verified and approved, can develop verified EPDs themselves and can develop and verify their own EPDs.

Picking the best environmental HVAC products based on LCA

Comprehensive greenhouse gas calculations used for planning, construction, operation and procurement are necessary to make the best environmental choices related to products and solutions. EPDs are fundamental to being able to carry out greenhouse gas calculations for the construction and operation of buildings.

It is important to remember that comparison of the environmental performance of HVAC products using the EPD information shall be based on the product's use in and its impacts on the building and shall consider the complete life cycle. EPD that are not in a building context are not tools to compare construction products.

HVAC products will be installed and used in many different kinds of systems in buildings with completely different use. The performance over the lifecycle will be highly dependent on occupancy patterns, e.g. indoor air quality, ventilation rates, internal air temperatures, tapping patterns for domestic hot water etc. The proper scenario for the use-stage for the actual buildings must be applied in the LCA when assessing the environmental performance. The use-stage scenarios for different building categories are often standardised in national building codes and used for energy performance calculations such as energy performance certificates. ■

References

NPCR 030:2021 "Part B for ventilation components", 2021 https://www.epd-norge.no/pcr-register/npcr-030-2021-part-b-for-ventilation-components-references-to-en-15804-a2-article3282-353.html.

EN-ISO 14025:2010 *"Environmental labels and declarations - Type III environmental declarations - Principles and procedures".*

EN-ISO 14040:2006 *"Environmental management - Life cycle assessment - Principles and framework".*

EN-ISO 14044:2006 *"Environmental management - Life cycle assessment - Requirements and guidelines".*

EN 15804:2012+A2:2019/AC:2021 *"Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products".*

EN 15978:2011 *"Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method".*

EN-ISO 22057:2022 *"Sustainability in buildings and civil engineering works — Data templates for the use of environmental product declarations (EPDs) for construction products in building information modelling (BIM)".*

Comparative LCA of Water Installation Tube Systems based on Copper, PEX-Al and PEX

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Foreword

The study conducted by Sphera and led by Dr. Constantin Herrmann investigates how copper tubing affects the environmental impact of drinking water installations systems over its entire life cycle, and compares them with those of drinking water installation systems based on multilayer aluminium-cross-linked plastic polyethylene (PEX-Al) and plastic cross-linked polyethylene (PEX) in Europe.

The study was critically reviewed by an external scientific panel of three independent reviewers (per the requirements of ISO 14040/44 and ISO/TS 14071, 2014). In accordance with the ISO requirements (ISO 14044, 2006), the overarching international standard for LCA, this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

Product Function(s) and Functional Unit

The water installation systems considered are installed in houses and apartments as part of the larger plumbing and water distribution infrastructure. The function dispensed by the product system is the supply of hot and cold water within a dwelling to provide water supply at the point of use such as a washbasin or lavatory. The functional unit is defined as the 'System supplying hot and cold water to an apartment of an area of 100 m² and the installation is dimensioned according to EN 806. The installation design is identical for all three tube systems and the same conditions are taken into consideration, such as entry data, for all three systems (e.g., operating pressure). This unit, defined according to the function, allows for adequate comparability between the three different systems.

Life Cycle Impact Assessment (LCIA) methodology and system boundaries

This assessment predominantly reports on the EN 15804 impact assessment indicators that are based on Environmental Footprint v3.0 impact assessment methods. According to EN 15804 (EN 15804+A2, 2019/2020) system boundaries are equivalent to a cradle-to-gate with options EPD including modules A1-A5, C1-C4 and module D. Modules B1-B7 are excluded. The reference service life (RSL) is identical for all investigated systems. The systems are supposed to serve the entire typical building lifetime of a minimum of 50 years (EN 15978, 2011/2012) and are typically also applicable for longer duration.

All background data are taken from the latest GaBi databases 2020 (Sphera Solutions GmbH, 2020a) and reflects the most recent and updated industry data on all relevant upstream (e.g., energy, intermediates, resources etc.) and downstream processes (e.g., waste treatment etc.).

SYSTEM BOUNDARIES:

Included	Excluded
✓ Individual installation system supplying water within the apartment ✓ Raw material provision and manufacture of all components, types and parts the installation of a system's needs (modules A1-A3) ✓ Transport to site and installation of the system into the apartment (modules A4-A5) ✓ End of Life (EoL) efforts as well as credits (modules C1-C4 and D)	× Common distributive installation supplying water to apartments × Use stage (modules B1-B7) × Overheads, infrastructure and other indirectly related aspects

LCIA Results

The reported impact categories represent impact potentials and are approximations of environmental impacts that could occur if the emissions would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

The EoL stage is of particular importance for copper tubing. It consists of five steps, modules C1-C4 and module D. The copper looped scrap is based on the sum of scrap from manufacturing of copper tubes and the EoL of the system. Recycling, such as the EoL recycling rate and recycling content (e.g., apart dissipative loss, copper is infinitely recyclable) for the assessed tubing systems are industry averages in accordance with state-of-the-art industrial practices and expert judgement. It represents a quantified illustration of an exemplary circular economy model.

The LCIA results of all three product systems have been calculated for ten impact categories (climate change as one aggregated value) according to EN 15804, only the most impactful regarding the green energy transition are shown in **table below** (see ANNEX for full results).

The **figures 1-3** on the right show the contribution of the life cycle stages A, C and D, for the three systems.

Benefits from module D (green), the possibility of the substitution of copper cathode, lower the overall impacts of all impact categories. Landfilling and the incineration of waste without credits (worst case approach) in module C (grey) only shows positive impacts.

For the PEX-Al and the PEX system, waste incineration in module C (grey) and credits in module D (green) result in net negative impacts for eight out of the ten impact categories, of which ODP and ADPm are so low that they can be neglected. Only GWP and AWARE have higher C impacts than D credits.

Impact Category	Description	Unit
Climate change, Global Warming Potential (GWP)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions cause an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect, and has adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent (CO_2 eq.)
Acidification Potential (AP)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	moles H^+ equivalent (H^+ eq.)
Resource use, fossil fuels and energy carriers, Abiotic Depletion Potential fossil (ADPf)	A measure of the total amount of non-renewable primary energy extracted from the earth. Resource use is expressed in energy demand from non-renewable resources including both fossil sources (e.g. petroleum, natural gas, etc.) and uranium for nuclear fuel. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ (net calorific value)
Water Use (AWARE)	An assessment of water scarcity accounting for the net intake and release of fresh water across the life of the product system considering the availability of water in different regions. The method is also called Available Water Remaining (AWARE).	m^3 of water equivalent (m^3 world eq.)

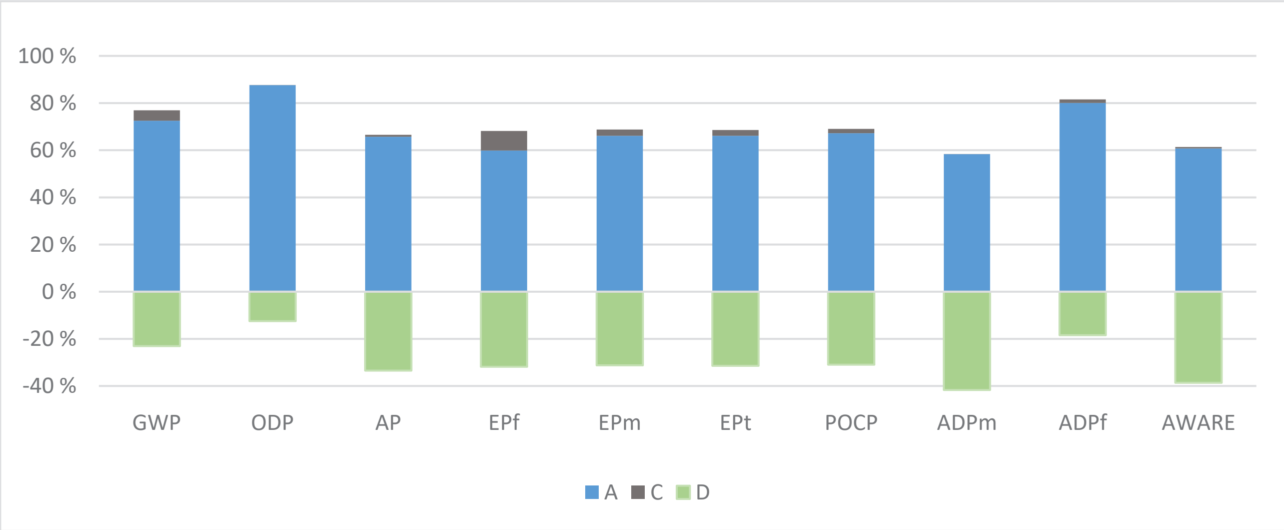


Fig.1. Copper

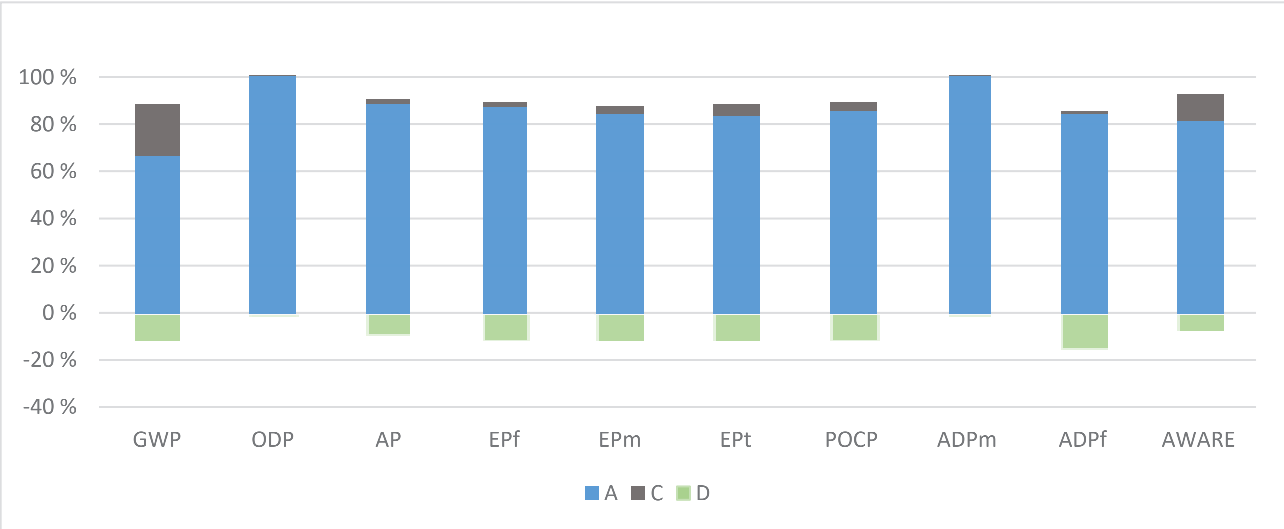


Fig.2. PEX-Al

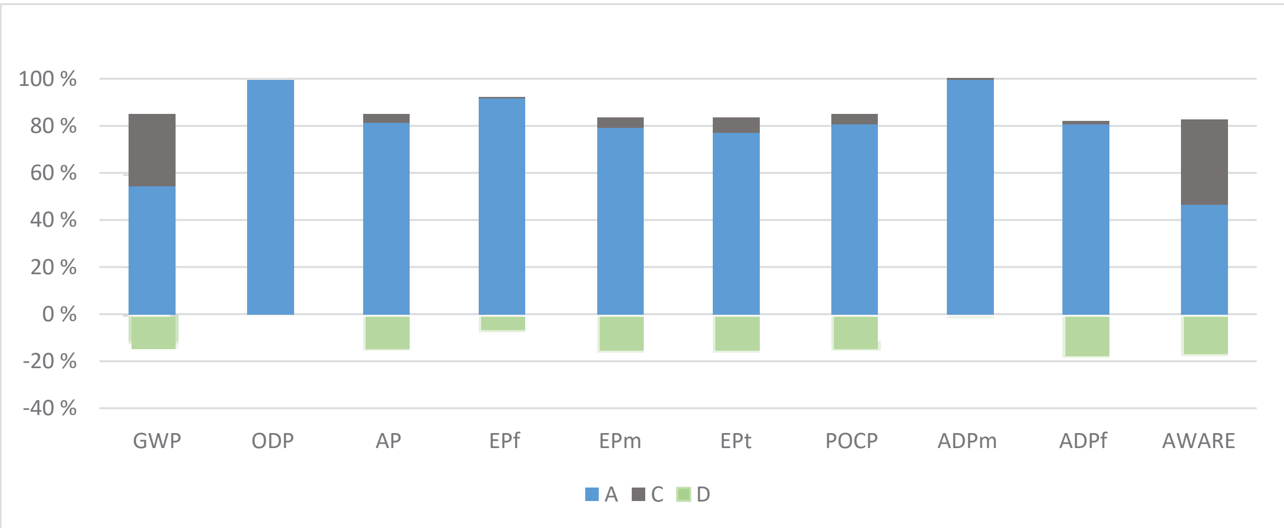


Fig.3. PEX

Comparison

The comparison of the results of the three systems for each impact category shows the absolute values for modules A, C and D (left column for each system) as well as the net total (right column for each system). It is emphasized that the baseline for a comparison refers to the separately displayed modules excluding module D as it refers to future life cycles with credits from avoided primary material beyond the product system under consideration. However, the closed-loop market for copper is so much established that the module D credits belong to a state-of-the-art market situation. Therefore, the comparison can be seen twofold, one with modules A and C only and one including module D. For simplification, the net credit value is displayed and has to be understood as additional information.

1 - Global Warming Potential

The PEX and PEX-Al Systems show similar results for the sum of A and C (44 and 46 kg CO_2 eq.) while the Copper System is linked to lower GWP results of 36 kg CO_2 eq. The benefits outside the product system in module D provide a remarkable upside for the copper system compared to the PEX-Al system and the PEX system (Cu: -10.9, PEX-Al –5,92, 46% difference to Cu, PEX –8,10, 26% difference to Cu) This results in 25 kg CO_2 eq. for the copper system compared to the 38 kg CO_2 eq. of the two PEX systems. (**Fig.4**)

2 - Acidification Potential

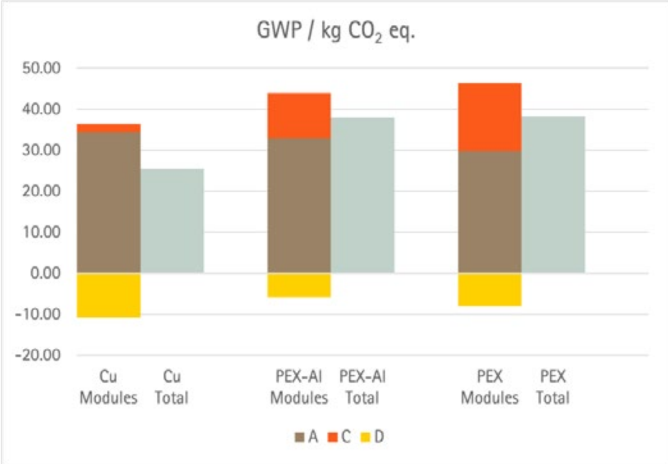
Both PEX-based systems (Modules A+C) are related to significant lower acidification potential than the copper system. However, including benefits from module D, the copper system is reduced to compare almost equally to PEX-Al (some influence). (**Fig.5**)

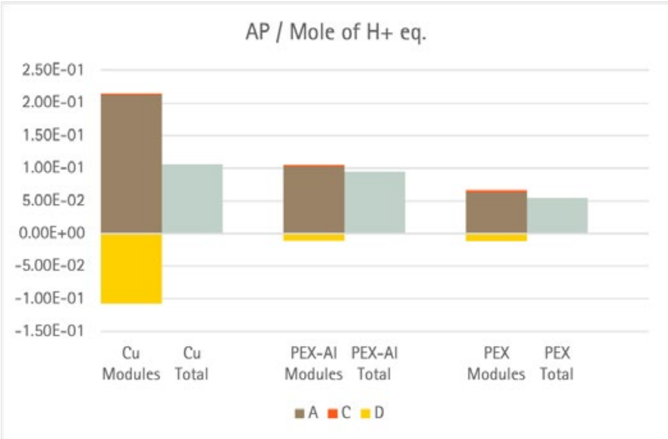
3 - Abiotic Depletion Potential Fossil

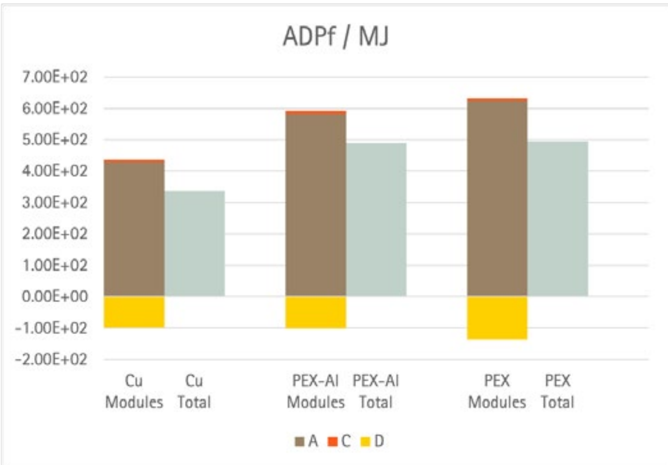
Both PEX-based systems are related to highest fossil abiotic depletion potential and are relevantly higher compared to the copper system for both situations, the modules A and C as well as at the net total. (**Fig.6**)

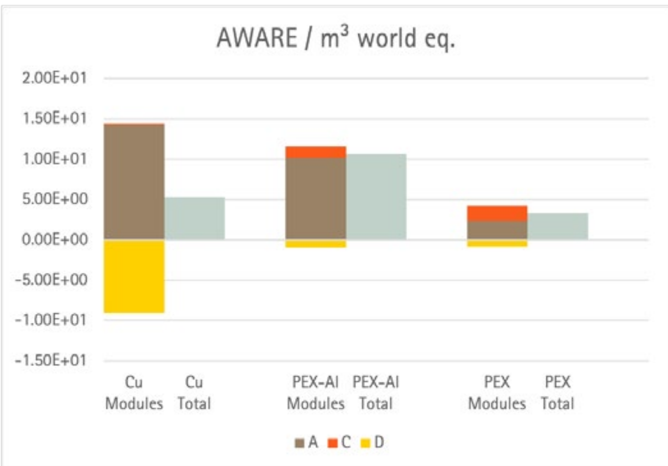
4 - Water Use

From a net total perspective, PEX-Al has the highest potential impact in the AWARE category. This is based on the water consumption for manufacturing, which does face lower potential credits in module D compared to the impacts of C. This causes the net potential impacts of the PEX-Al system to be significantly higher than for the copper system, whereas the net impacts of the PEX system are still relevantly lower than those of the copper system. (**Fig.7**)









Conclusion

Within the three systems of consideration, the materials and their fabrication dominate between 85 and 90 percent of the life cycle. The copper tubing system provides potential credits from recycling in module D in future product life cycles. The PEX systems instead are linked to benefits from energy recovery of the incineration. The balance between impacts from material incineration and credits from energy systems is also seen from the high dynamic European energy systems change due to energy transition towards low carbon energy—changes specifically for impact categories such as GWP, AP, ADPf and AWARE are then likely to occur.

The comparative LCA shows that the copper-based water tube installation system is equally in the level of environmental impact for module A+C compared to PEX-Al and PEX (lead indicator GWP). In addition, the recyclability of copper provides potential credits in module D in future product life cycles, so that the net total values show a clear advantage (lower values) for copper compared to PEX-Al as well as PEX. This applies to ADPf in the same way, for which even module A+C is already lower. AP shows higher impacts from of the copper system for module A+C but are potentially reduced by module D down to a comparable level as the PEX based systems. For water consumption (AWARE) the module A+C of copper is higher than the PEX systems, but rank in between both (lower than PEX-Al, higher than PEX) using net total values.

Additionally, the copper system has even more reduction potentials from material savings and avoidance of primary material as the sensitivity and scenario analyses show. ■

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MODERATE: Marketable Open Data Solutions for Building Energy Optimisation

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MODERATE is a Horizon Europe funded project that started in June 2022. Its aim is to develop a marketplace platform that improves availability and interoperability between datasets for the building industry, leveraging open data and open-source solutions. The objective is to promote data exchange between different producers and consumers while complying with legal and ethical constraints. The project innovates building data collection, synthesis, and services for management, optimization, and decision-making.

MODERATE aims to create a fully open platform that offers open data and data-driven services. Large and diverse datasets will be available on buildings of different types, such as residential, commercial, and offices. Different data-driven services and software pipelines will also be accessible as open-source solutions, allowing targeted users to test solutions before investing in tailored development. Ultimately, the availability of data and services will bridge the gap between confidential data, low-quality, or unavailable data and informed decision-making, with the final goal of reducing carbon emissions and mitigating climate change in the building sector. This article focuses on two components of the MODERATE platform that contribute to the enhanced use of building data:

1. Improved data collection and exchange through data synthetisation: The platform uses data synthetisation techniques to ensure that sensitive data is anonymised, but most of the data's value is retained for analysing building performance. Data synthetisation makes it more secure for data owners to share their data and complies with the General Data Protection Regulation (GDPR). This way, the MODERATE platform can combine multiple datasets within the building sector and obtain aggregated results.
2. Analysing the data through data-driven services: The platform will include ten data-driven services that transform raw data into meaningful knowledge. These services cover different aspects of the building industry and work with static, dynamic or both types of data.

The platform allows data owners to retain control of their own data while enabling its use in a wider market for experts.

Data synthetisation techniques for secure data exchange

The increasing use of building monitoring and control systems has created an opportunity for data-driven approaches in the construction sector. However, security and privacy concerns retain companies to share their data. Synthetic data can be used as an alternative, since it masks any sensitive information, like household or person's identity, and maintains the original statistical properties. This ensures that no confidentiality or privacy issues are breached, while the quality of data remains very high. Additionally, synthetic data allows for high scalability of data and different data sources can be merged to generate an enriched dataset to analyse data at a more aggregated level.

Synthetic data is increasingly being used in the energy sector for various applications, like a prediction of energy demand [1], fault detection in energy systems [2] and building stocks [3].

Synthetic data is artificially generated data which mimics the real data by using the underlying statistical properties and at the same time masks the most sensitive properties of this data. After the synthetisation process, it's impossible to assign the data a specific person or household entity. This ensures that no confidentiality or privacy issues are breached while the quality of data remains very high since it keeps the most valuable properties of the real data. This process allows for a high scalability of the data, where different data sources can be merged to generate an enriched dataset to analyse data at a more aggregated level.

The synthetised data within the de MODERATE platform will include data coming from EPCs across Europe, electricity load profiles from smart meters, heating profiles and data coming from temperature sensors.

Synthetic data is artificially generated using different statistical and ML techniques, like hidden Markov Chain [4], autoregressive models [5] and other ML algorithms. The advent of Generative Adversial Network (GAN) has revolutionized this field thanks to its ability to generate realistic and high-quality data and its flexibility to create different variants of GANs using the fundamental piece of work [6]. GAN is a type of deep learning algorithm

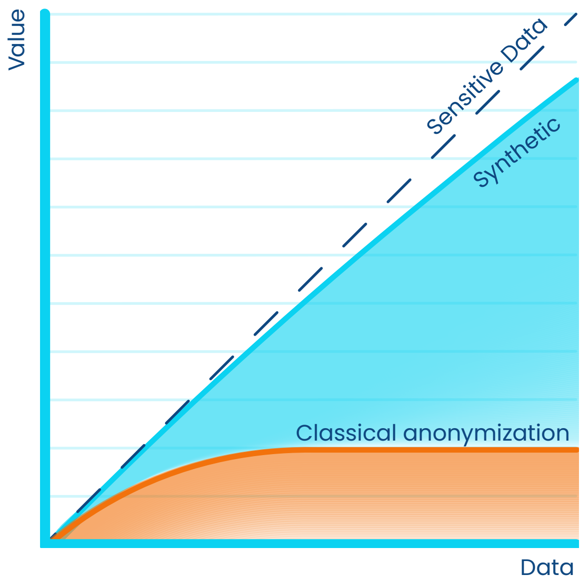

Figure 1. Data Synthetisation anonymises the most sensitive data while keeping most of the data's value through machine-learning techniques, making it much more useful than classical anonymisation.

that uses two neural networks to generate new data. The two networks, the generator and the discriminator, compete with each other in a game of cat and mouse. The generator creates new data, while the discriminator determines whether the samples are real or fake (**Figure 2**). The ultimate goal is to create synthetic data that is indistinguishable from the real.

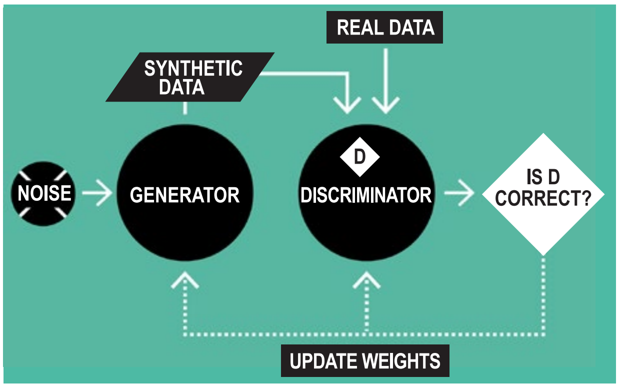

Figure 2. GAN's workflow (picture by SquareUp).

Turning raw data into meaningful knowledge

In addition to improved data collection and harmonization, the MODERATE platform will offer 10 data-driven services that enable users to analyse the performance of buildings and gain meaningful insights from the raw (synthesized) data available on the platform.

As can be seen on **Figure 3**, the MODERATE platform will offer three distinct categories of data-driven services for monitoring building performance:

System management services: These services can be used for monitoring and controlling the building performance through data analysis, providing real-time insights into energy consumption and potential inefficiencies through fault detection. The services included in this category are:

- *Fault detection & forecasting*: This service ensures a reliable monitoring and control system that can be used by utility companies, ESCOs, and facility managers to identify faults in real-time and enable predictive maintenance of the buildings systems they manage. Through a user-friendly web application users will be able to predict and understand possible failures in their systems.
- *Energy system optimization*: This service uses machine learning techniques to generate possible optimizations in building systems based on the available data available in the platform. This will facilitate the work

of energy and facility managers, ensuring that the potential of the building defined in the design phase is respected and identifying the right set-up that guarantees the best level of comfort at the lowest cost.

- *Energy Conservation Measure (ECM)*: The ECM application assesses potential energy savings through requalification measures like improved insulation of building facade or upgraded HVAC systems. It calculates and rank. The possible ECMs identifying the best efficiency intervention, leading to economic savings and CO_2 reduction. The calculation of each ECM is performed using a dynamic building model created using the ISO 52016 standard. The required inputs can be provided manually or through a direct connection to a BIM model. The ECM is a measure of energy efficiency that compares the additional costs of energy efficiency measures to maintenance and building stock valorisation costs.

Building optimization and assessment: These services use AI models to evaluate building performance and identify areas for improvement in terms of solar roof potential, cost savings, and overall building performance. The services included in this category are:

- *Solar cadastre*: it is a tool that allows you to visualize and assess the photovoltaic potential in different areas by looking at the roof surface and irradiance in that area. The tool easily calculates the energy savings and the payback time of a solar PV investment in a certain area.
- *Local energy communities assessment*: This service is used in tandem with the solar cadastre and is more at municipality level. The tool can identify the feasibility to develop an energy community based on the availability of rooftop PV in a specific area. It compares the energy demand with the potential of solar PV and can help identify the optimal areas to setup an energy community.
- *Measurement & Verification for building assessment*: The M&V for Building Assessment service uses a standard procedure (IPMVP) to verify actual energy savings achieved through improvement actions. It helps ESCOs to define accurate Energy Performance Contracts by identifying savings and providing guidelines to choose the best option.
- *Benchmarking tool*: The benchmarking tool compares building performance for energy and comfort, facilitating comparison and energy accounting with similar buildings to assess improvement opportunities and verify energy savings. It benefits real estate, municipalities, policy makers, building managers, and planners. The tool will be an open-source web app, using synthetic data generated as a reference for specific analyses.

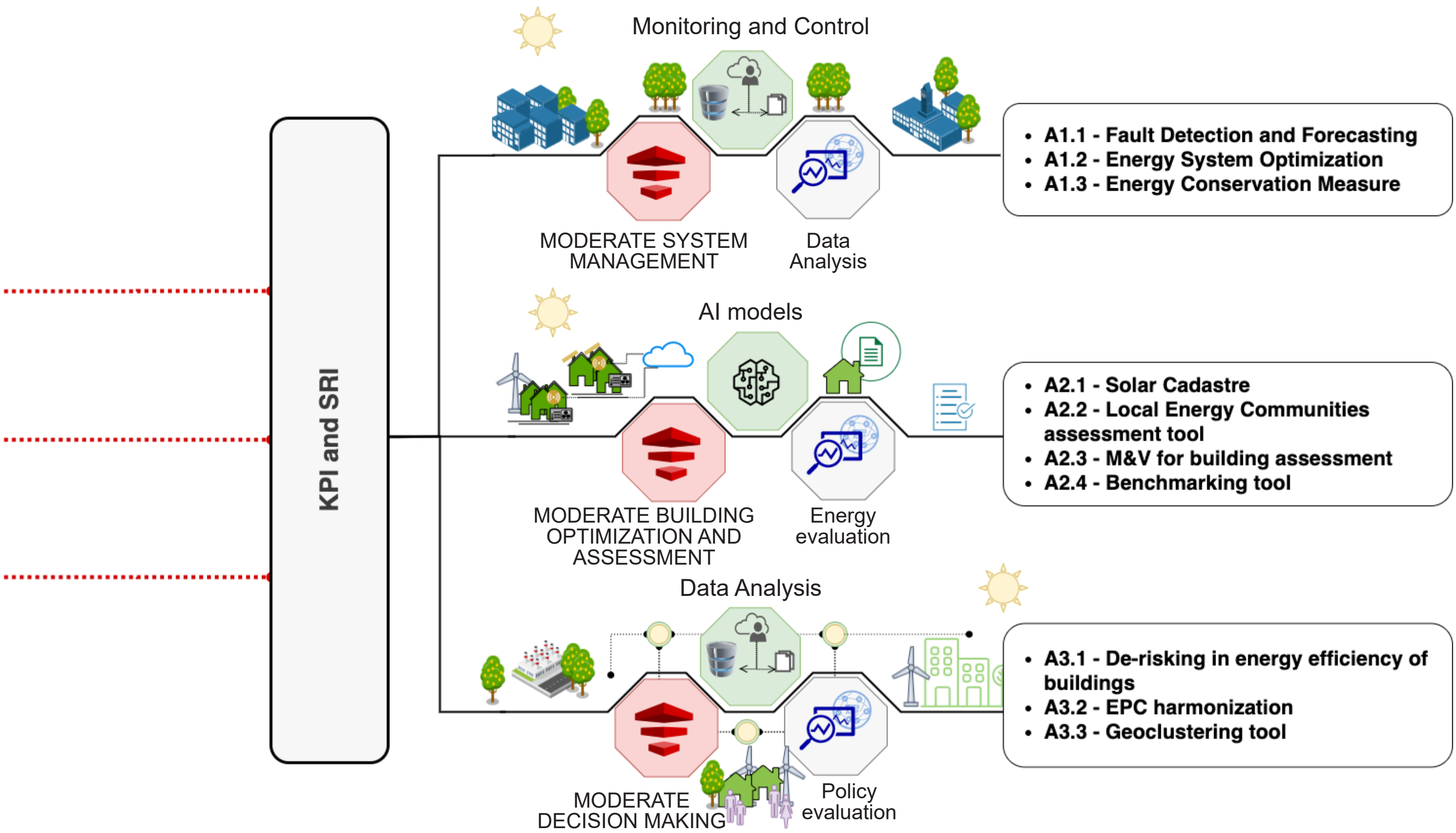

Figure 3. Overview of the MODERATE data-driven analytical services.

Decision-making services: This category is focused on analysing data to support policy evaluation and decision-making, helping building managers make informed choices about resource allocation and energy management.

- *De-risking investments in building energy*: National policies are driving investment in energy-efficient building renovations for reduced consumption and improved indoor comfort. This service will use synthetic data to guide investors on what are the most financially attractive investments to improve the performance of their buildings, impacting policy by enabling better decision-making for energy-efficient building investments.
- *Energy Performance Certificate Harmonization*: The EPC harmonization service aims to standardize EPCs across regions and countries based on a European ontology. It will associate energy consumption data to help define policies and promotions for reducing thermal consumption and CO_2 emissions.
- *Geo-clustering tool*: The geo-clustering tool evaluates building stock performance using cluster techniques. It compares the performance of buildings in the same or different areas to assess possible savings in refurbishment. Building designers can use it to determine the best technology for a specific use and climate, while researchers can analyse the impact of building features on energy consumption and thermal comfort. ■

▶ For more information, see the project website: https://moderate-project.eu/

▶ Follow us on LinkedIn & Twitter: https://www.linkedin.com/showcase/moderate-he/ & https://twitter.com/MODERATE_HE

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MODERATE

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ACREX 2023, that's a wrap!

After three days of engaging discussions, presentations, and productive networking, ACREX India 2023 has come to a close. The event was a great success, attendees had the opportunity to explore the latest advancements in sustainable building practices and connect with like-minded professionals from various sectors.

The President of REHVA, Catalin Lungu, along with Marie Joannes, REHVA Staff, and Tomasz Cholewa, co-chair of the decarbonisation Task Force, attended ACREX India 2023 from March 14 to March 16. The REHVA team was invited by ISHRAE and sponsored by Eurovent Certita Certification to partake in a range of inspiring events during the three-day conference.

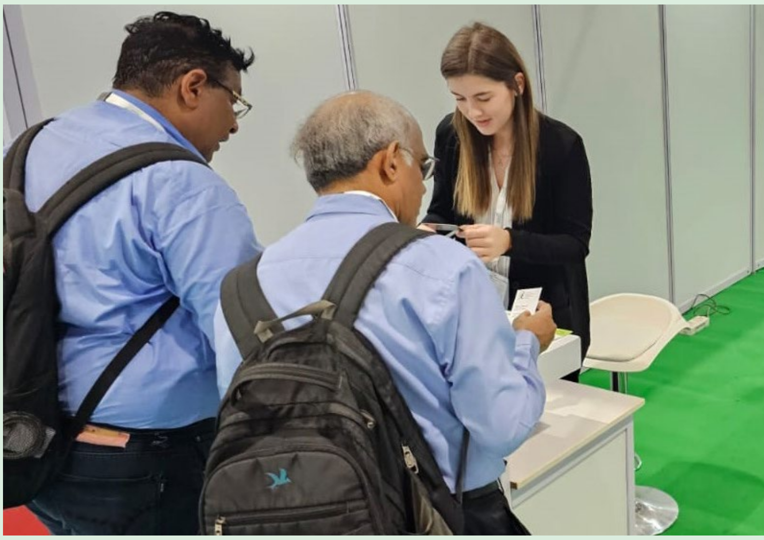
Catalin Lungu, President of REHVA, delivered a brief address during the Curtain Raiser Function on March 13, invoking the G20 slogan "One Earth, One Family, One Future". Through this reference, he underscored the importance of collective action to achieve the conference's theme, "Engineering toward Net Zero". Lungu emphasized that collaboration and cooperation are essential to reach this goal. He also highlighted the crucial role of sustained partnerships and friendship between ISHRAE and REHVA in creating a sustainable future.

ACREX India 2023 proved to be a resounding success, drawing over 40,000 visitors who had the opportunity to explore the offerings of more than 450 exhibitors. REHVA was an active participant throughout the three-day exhibition, welcoming visitors to its booth and engaging with attendees from the HVAC&R industry.

On March 14, a packed and engaged audience witnessed a powerful seminar on "Engineering toward net zero," presented jointly by ISHRAE and REHVA. The event featured a diverse panel of industry-leading experts who delivered insightful and thought-provoking presentations.

Catalin Lungu delivered a presentation titled "LEVEL(s) and SRI-EU tools for decarbonization of the built environment." Lungu showcased Europe's progress in the field and introduced key technical tools, including LEVEL(s), SRI, and SLE, which are instrumental in achieving decarbonization goals.

Eric Foucherot, from Eurovent Certita Certification, delivered an insightful presentation on "Energy Efficient Ventilation: investors should take control".



Eric Foucherot discussed a range of topics, including the life cycle costs associated with Air Handling Units. Foucherot's presentation sparked a conversation on the need for meaningful incentivization policies to encourage the adoption of energy-efficient systems.

Tomasz Cholewa, co-chair of the decarbonisation Task Force at REHVA, presented "HVAC professionals as key players in energy retrofit and decarbonisation of existing buildings." Cholewa highlighted the significant role played by HVAC professionals in reducing energy consumption in buildings. He presented the audience with compelling statistics and suggested ways to reduce energy consumption through renovations, user education, Energy Renovation of Building "Enveloppe," and the use of renewable energy sources. Cholewa also used the opportunity to showcase REHVA's European Guidebook 32, which focuses on energy-efficient renovation of existing buildings.

As a token of gratitude for their valuable contributions, the speakers at the "Engineering toward net zero" seminar were awarded Certificates of Appreciation. The certificates recognized their exceptional efforts in delivering informative and engaging presentations, which helped to enrich the discourse around sustainable building practices.

Eurovent Certita Certification's Head of International Affairs & Partnerships, Eric Foucherot said, "It was a pleasure to be involved in the *Engineering towards net zero* seminar sessions co-organised by ISHRAE and REHVA. Once again, our partnership with REHVA has allowed us to engage with industry on some of the key issues affecting decarbonisation and net zero. It was a great opportunity to discuss the many responsibilities of the HVACR sector, not just in India, but beyond."

REHVA extends its sincere gratitude to ISHRAE for the invitation and organization of ACREX India 2023. The event was a fantastic opportunity for us to connect with industry leaders and engage in stimulating conversations on the path toward a sustainable built environment. We are already eagerly anticipating ACREX 2024 and the possibilities it holds.

REHVA would also like to thank Eurovent Certita Certification for sponsoring our participation in ACREX2023. The support provided by Eurovent Certita Certification was instrumental in enabling our team to attend and contribute to the event, and we greatly appreciate their continued commitment to our shared goals. ■

ISHRAE and REHVA: continuously joining forces to advance HVAC

ISHRAE (Indian Society of Heating, Refrigerating and Air Conditioning Engineers), and REHVA, recently held a joint meeting in Mumbai, India to discuss their shared goals and explore opportunities for collaboration.

The meeting took place during ACREX INDIA 2023, with representatives from both organizations expressing enthusiasm for working together to advance the field of HVAC&R and improve the quality of life for people around the world.

One of the topics discussed was the need for greater cooperation on research and development initiatives, particularly in areas such as energy efficiency, indoor air quality, and sustainable building design. Both organizations acknowledged the value of sharing knowledge and best practices and expressed a willingness to explore ways to facilitate this exchange.

Overall, the meeting was a positive and productive one, with both organizations expressing a strong desire to continue the dialogue and explore opportunities for cooperation in the future. As the world continues to grapple with pressing issues such as climate change and public health, the partnership between ISHRAE and REHVA holds great promise for advancing the field of HVAC&R and making a positive impact on society. ■

Update on the F-Gas Regulation negotiations: The shift to (very) low-GWP refrigerants

In March 2022 the European Commission published its proposal for a Revision of the F-Gas Regulation (2022/0099 COD) to replace the current regulation from 2014. The key objective of the revision is to have a more ambitious phase-down of HFCs, meaning a much stronger shift to (very) low-GWP refrigerants in the coming years which will significantly impact the RACHP sector. In this article we'll provide a short recap of the Commission's proposal on the F-Gas revision, go more in-depth into certain amendments by the European Parliament and Council that impact the RACHP sector and compare them with each other. At the end we talk about the next steps and provide a short update on the proposal for the restriction of PFAS.

JASPER VERMAUT
EU Policy & Project Officer

Commission's Proposal

The Commission released a revision of the 2014 F-Gas Regulation to align with the Green Deal ambitions of carbon neutrality and streamline with the Kigali Amendment of the Montreal Protocol by extending the HFC phase-down after 2030. Two provisions are important for the RACHP to keep in mind: **Product prohibitions** for air-conditioners and heat pumps that make use of refrigerants with a higher GWP, and a much **steeper HFC phase-down**.

COM: Product Prohibitions (Annex IV points 17 & 18)

Table 1 provides an overview of the AC-HP products that will be banned from the EU market based on their use of F-Gases. The Commission proposed to ban plug-in & other self-contained AC-HP systems that use F-Gases with a GWP of 150 or more from 2025 onwards, together with single-split systems that contain less than 3 kg of F-Gases with a GWP of 750 or more.

From 2027 onwards the prohibitions would become stricter for all split systems, those with a capacity of 12 kW or lower can maximum use F-Gases with a GWP lower than 150. Those with a higher capacity have to stay under 750 GWP.

This means that the popular R32, which has a 100-year GWP of 675 and gained popularity as a refrigerant in recent years due to its comparatively lower GWP to other HFCs and very high efficiency, can only be used in split systems that have a capacity higher than 12 kW from 2027 onwards.

COM: Steeper HFC Phase-Down Timeline (Annex VII)

As can be seen in **Figure 1** (see further), the Commission has proposed a much more ambitious HFC phase-down in comparison to what's currently in place under the 2014 Regulation. The end objective is to have a reduction of 98% HFCs by 2048 in comparison to 2015 levels.

Table 1. *Prohibitions (/bans) on AC-HP products within the Commission's Proposal. Source: Table made based on information in F-Gas Regulation Revision – Commission Proposal COM(2022) 150 final: Annex IV (points 17 & 18).*

Type of AC-HP system	Capacity	Max. allowed F-Gas GWP	Enforcement date	Exemption
Plug-in & other self-contained	All	< 150	1 January 2025	None
Single-split	< 3kg F-Gases	< 750	1 January 2025	None
Split	≤ 12 kW	< 150	1 January 2027	Can be exempted through safety standards
Split	> 12 kW	< 750	1 January 2027	Can be exempted through safety standards

The new timeline will go into effect from 2024 onwards, with the largest decrease to occur from 2027–2029. While the 2014 Regulation allowed for a maximum quantity of HFCs equivalent to 42 MtCO2e in this time period, the revised timeline decreases this amount to less than half of that, specifically to 18 MtCO2e.

Keeping in mind this steep decrease and the abovementioned prohibitions, it's clear that the Commission has the aim to steer the RACHP market to very low-GWP refrigerants from 2027 onwards, with 2024 – 2026 as a transition period. Combined with the PFAS restriction that is being discussed (see further), there is a push towards a shift to natural refrigerants.

European Parliament Amendments

Dutch MEP Bas Eickhout of the Greens led the debates as rapporteur for the ENVI Committee, having previously served in the same role for the 2014 Regulation negotiations. He continues to champion for a more ambitious shift away from F-Gases and towards natural refrigerants, which is reflected in the Parliament's final report (P9_TA(2023)0092) that was approved with a large majority in the Plenary session on 30 March, mainly due to the support of the Greens, S&D and Renew with a more divided EPP. The margins were more narrow during the vote for some separate Plenary amendments to make the HFC phase-down and prohibitions more flexible (e.g. amendments 175 – 179 and amendment 185), where especially Renew and EPP were strongly divided within their own groups.

The approved amendments push for a more ambitious phase-*out* of HFCs and for much stronger bans on products using F-Gases, banning the use of *all* F-Gases in different types of AC-HP systems. Three sets of amendments which are crucial for the RACHP sector are the possibility to allow additional HFC quotas for heat pumps to not endanger the RePowerEU objectives, additional prohibitions and a new timeline to phase-*out* HFCs.

EP: Coherency with REACH (art. 35 par. 1c)

A new paragraph has been added, requiring the Commission to reassess and update the F-Gas Regulation as necessary once the revision of the REACH Regulation is completed. This is to ensure that the F-Gas Regulation is coherent with any potential new restrictions on the use of PFAS within REACH.

EP: Flexibility for heat pumps under RePowerEu (Art. 17 par. 6a)

The Parliament introduced an amendment which should allow for more flexibility for the heat pump sector to not endanger the needed acceleration for their deployment under RePowerEU. The Commission will assess the impact of the HFC quota phase-down on the heat pump market on an annual basis, until 2029. If the assessment concludes that the phase-down is creating disruptions on the deployment, the Commission will be allowed to place a limited amount of additional HFC quotas on the market for heat pumps.

With this amendment the Parliament responds to concerns from the industry that a too ambitious phase-down would hamper the rapid deployment of heat pumps and create an additional barrier to reach the RePowerEU targets to roll out 10 million hydronic heat pumps by 2027 and double the deployment rate by 2030.

EP: Stronger product prohibitions (Annex IV points 17 & 18)

Table 2 shows the amendments from the Parliament on the product bans in comparison to the Commission's proposal in **bold and underlined** (again only the relevant bans for AC-HP have been included in this table). This is likely the most contentious set of amendments by the Parliament, where they've introduced strict bans on all F-Gases in different types of AC-HP systems from 2026 and 2028 onwards as you can see in **Table 2**.

Table 2. *Prohibitions (/bans) on AC-HP products within the Commission's Proposal. Source: Table made based on information in F-Gas Regulation Revision – European Parliament Report P9_TA(2023)0092 : Annex IV (points 17 & 18). Amendments to the Commission proposal are* **bold and underlined** *while the Commission's original text is* ~~striked through~~.

Type of AC-HP system	Capacity	Max. allowed F-Gas GWP	Enforcement date	Exemption
Plug-in, **monobloc** & other self-contained	All	~~< 150~~ **All F-Gases banned**	1 January ~~2025~~ **2026**	None
Single-split, **including fixed double duct systems**	< 3kg F-Gases	~~< 750~~ **All F-Gases banned**	1 January ~~2025~~ **2028**	None
Split	≤ 12 kW	~~< 150~~ **All F-Gases banned**	1 January ~~2027~~ **2028**	Can be exempted through safety standards
Split	> 12 kW **≤ 200 kW**	< 750	1 January ~~2027~~ **2028**	Can be exempted through safety standards
Split	**> 200 kW**	**All F-Gases banned**	**1 January 2028**	**None**

EP: Revised HFC phase-out (Annex VII)

Figure 1 displays two significant changes that the Parliament intends to introduce to the HFC phase-down timeline, in comparison to the Commission's proposal:

1. While the Commission plans to decrease the HFCs in the market by 98% by 2050, relative to 2015 levels, the Parliament suggests a complete phase-out of HFCs by 2050. The reasoning behind this proposal is not only environmental but also based on the belief that a complete phase-out sends a stronger market signal to move away from F-Gases instead of keeping a small part. However, some market actors fear that a complete phase-out without exceptions may not be feasible in some products (this doesn't necessarily apply to AC-HP products however).
2. In the period 2027–2029 the Parliament increased the quota level to 12%, rather than 10% in the Commission's proposal, compared to 2015 levels. One of the arguments supporting this proposal is that the cut-off point between 2026 and 2027 in the Commission's proposal was too steep. During the Plenary session in Parliament, there was a widely discussed amendment to increase the allowed HFC level to 18% in this time period. However, this amendment was voted down by a fairly small margin.

Council Negotiation Mandate

On 5 April, 5 days after the Parliament, the Council agreed its mandate to enter into negotiations (file 8162/23) with the other institutions with their own amendments.

Important to note that their amendments include a **distinction between air-to-air and air-to-water heat pumps in the product prohibitions**, which some industry actors have been asking for as the use of natural refrigerants is more complicated with the former when looking at heat pumps that are on the market today. Additionally, the Council propose a **limited exemption for heat pumps to the HFC phase-down** (similar to the Parliament's amendment)

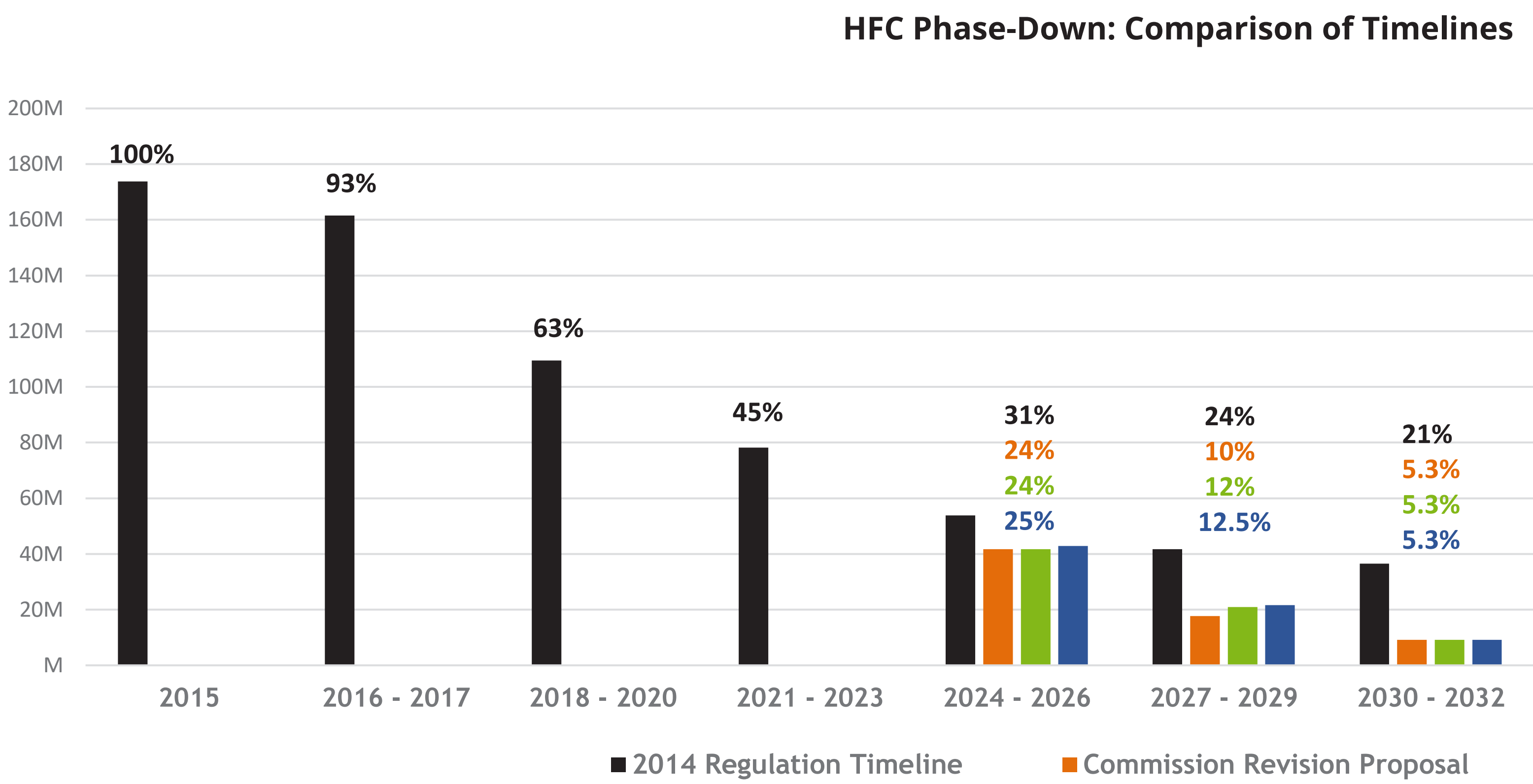


Figure 1. Comparison of timelines of the HFC phase-down(/out) between

and a **more lenient HFC phase-down timeline** in comparison to the Commission and Parliament.

Council: Flexibility for heat pumps under RePowerEU (Art. 17 par. 6b)

As mentioned, this proposed amendment by the Council is similar to what the Parliament has proposed as well to allow for a limited flexibility on the use of HFCs in heat pumps to not cause disruptions with the RePowerEU objectives. The difference with the Parliament amendment, is that the Council asks for an assessment by the Commission after a substantiated request by a Member State and not on an annual basis.

They've also specified concrete additional quota that could be placed on the market. For the period of 2024 – 2026 this would be 4,410,247 (a 2.5% increase on the Council timeline for that same period compared to 2015 levels) and for the 2027 – 2029 it's 1,425,536 (0.8% increase).

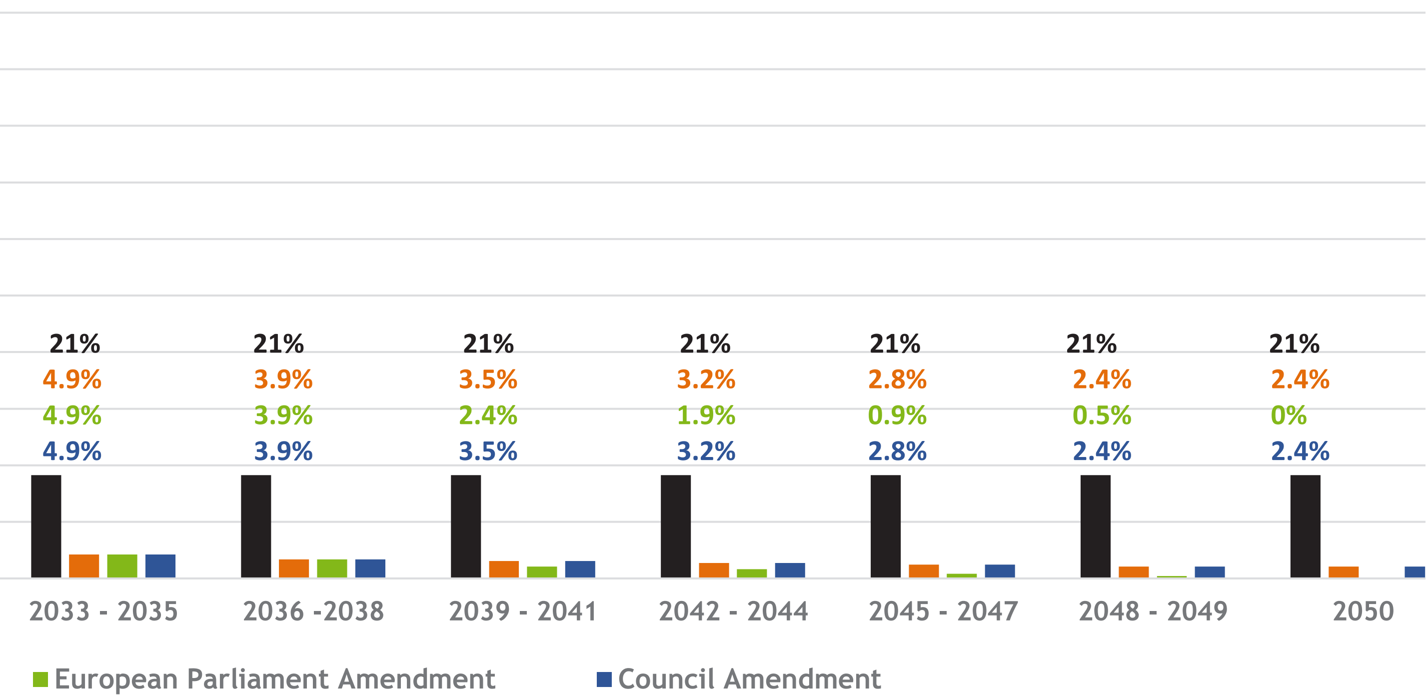
Council: More distinctions in prohibitions for heat pumps (Annex IV points 16 & 18)

As mentioned, in the product bans the Council has set a different timeline for air-to-air and air-to-water systems. This keeps in in mind that air-to-air systems with a lower GWP currently have a much lower market penetration, especially HFOs are threatened to be strongly restricted under REACH. Same as above, the differences with the Commission's proposal are in **bold and underlined** in **Table 3**.

Council: Revised HFC phase-down (Art. VII)

The revised timeline by the Council can be seen in **Figure 1**. It is worth noting that, in contrast to both the Commission and Parliament, the Council proposes slightly more leniency for 2024–2026. For 2027–2029, it also requests more leniency compared to the Commission proposal, which is similar to the Parliament's. From 2030 onwards, the Council maintains the same phase-down schedule as the Commission.

(expressed in tonnes CO2 equivalent)



2014 Regulation with different proposals for a Revision by the EU institutions.

__Table 3.__ Prohibitions (/bans) on AC-HP products within the Commission's Proposal. Source: Table made based on information in F-Gas Regulation Revision – Council file 8162/23 : Annex IV (points 16 & 18). Amendments to the Commission proposal are **bold and underlined**.

Type of AC-HP system	Capacity	Max. allowed F-Gas GWP	Enforcement date	Exemption
Plug-in & other self-contained **(incl. monobloc)**	**≤ 50 kW**	< 150	1 January ~~2025~~**2027**	**Can be exempted through safety *requirements* (not standards) with a limit to 750 GWP**
Other self-contained AC & HP	**All**	**< 150**	**1 January 2030**	**Can be exempted through safety *requirements* (not standards) with a limit to 750 GWP**
Single-split	< 3kg F-Gases	< 750	1 January 2025	None
Split **air-to-air**	≤ 12 kW	< 150	1 January ~~2027~~**2029**	Can be exempted through safety ~~standards~~ **requirements**
Split air-to-water	**≤ 12 kW**	**< 150**	**1 January 2027**	**Can be exempted through safety *requirements* (not standards)**
Split	> 12 kW	< 750	1 January ~~2027~~**2029**	Can be exempted through safety ~~standards~~ **requirements**
Split	**> 12 kW**	**< 150**	**1 January 2033**	**Can be exempted through safety *requirements* (not standards)**

Next steps

The Council and Parliament will now enter into 'trialogue' negotiations with each to find an agreement on the final text. It is expected that the institutions will find an agreement in Q3 of 2023.

When considering the provisions discussed in this article, we can expect that the institutions can find a relatively quick agreement on the HFC phase-down between 2024 and 2029. A larger obstacle will be the discussion between the 98% phase-down by 2050 or the complete phase-out of HFCs by that date as the Parliament amended. The largest point for the discussion will be the product bans however, where the Council asks for more flexibility, the Parliament aims to introduce strict bans on F-Gases in several types of AC-HP systems from 2026 and 2028 onwards.

Important to note here is – of course – the PFAS restriction which has been proposed by the governments of Denmark, Germany, the Netherlands, Norway and Sweden to the European Chemical Agency (ECHA). The proposal aims to strongly restrict PFAS under the REACH Regulation, which would basically strongly the use of certain HFCs and HFOs. Most notably HFC-134a and HFO-1234yf would be restricted under this proposal. The consultation round for the PFAS restriction is currently open and after the opinions by ECHA committees, the proposal will be handed over to the European Commission in Q3 2023 who will then consider adding it to the REACH Regulation. To find out more about the PFAS restriction and the consultation round, have a look at the webinar organized by ECHA on 5 April*. ■

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* https://echa.europa.eu/-/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach

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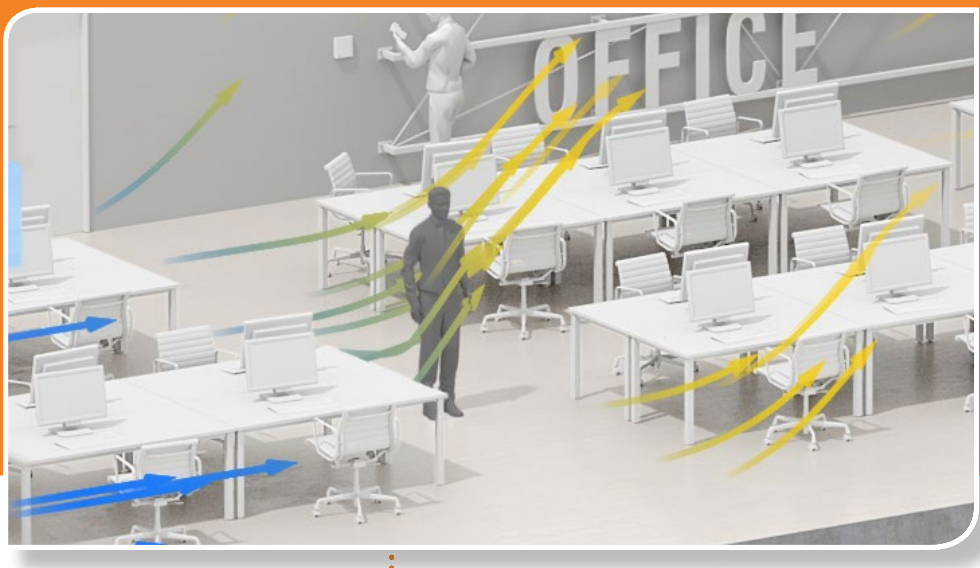
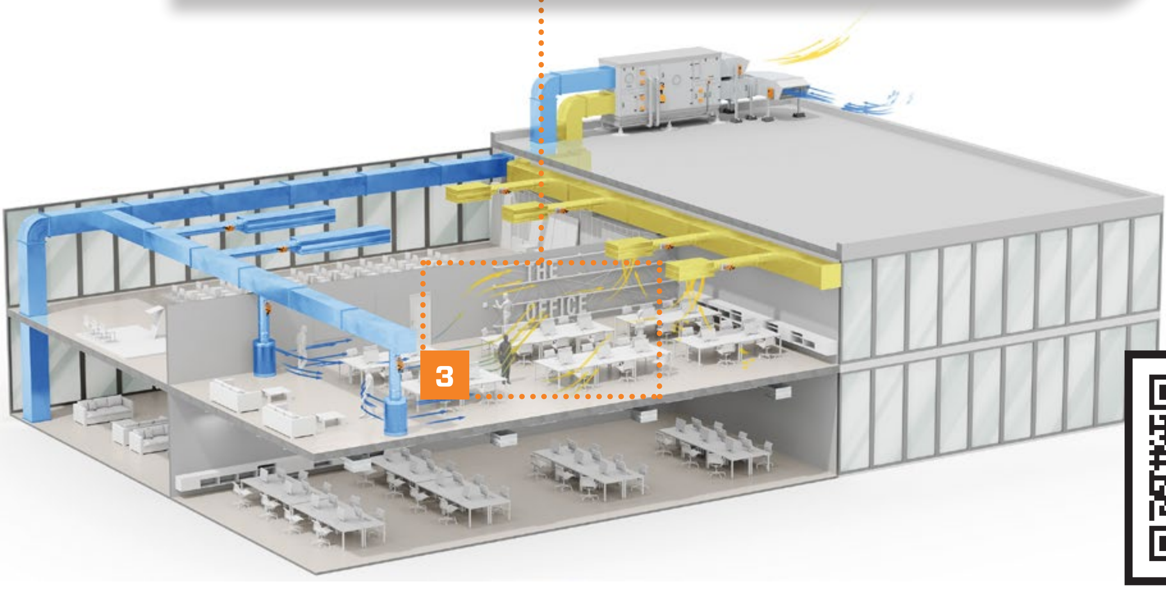
The Seven Essentials of Healthy Indoor Air

3. Well designed air dilution and airflow pattern

An important factor is the way in which the air introduced into a room flows through that room and then exits it again. Ideally, fresh air flows undiluted from the bottom up past a person and is then extracted directly from the room. It must be ensured that indoor air does not "swirl" around the room several times or become trapped in certain zones of the room. Modern airflow simulations enable typical flow patterns in a room to be studied in detail. The correct design, placement and orientation of air outlets can help prevent major healthy air errors.





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Exhibitions, Conferences and Seminars

May 2023		
11–12 May 2023	REHVA Annual Meeting (rehva.eu)	Brussels, Belgium
11-13 May 2023	ISH China & CIHE (ishc-cihe.hk.messefrankfurt.com)	Bejing, China
18–19 May 2023	Workshop, Tokyo, "Towards high quality, low-carbon ventilation in airtight buildings" (aivc.org)	Tokyo, Japan
20–23 May 2023	IAQVEC 2023 (iaqvec2023.org)	Tokyo, Japan
June 2023		
8–9 June 2023	RCEPB 15, International Conference – Energy Performance of Buildings (rcepb.ro)	Bucharest Romania
11–14 June 2023	HB2023 Europe Conference, "Beyond disciplinary boundaries – Transdisciplinary perspectives on multisensory stimulation for innovative and creative solutions in a Post-Covid era" (ukaachen.de)	Aachen, Germany
20-22 June 2023	European Sustainable Energy Week (EUSEW) 2023 (sustainable-energy-week.ec.europa.eu)	Brussels, Belgium
24–28 June 2023	2023 ASHRAE Annual Conference (ashrae.org)	Tampa, FL, USA
July 2023		
25-27 July 2023	HVACR Vietnam (hvacrvietnam.com)	Hanoi, Vietnam
August 2023		
14–16 August 2023	SuDBE 2023 (sudbeconference.com)	Espoo, Finland
September 2023		
28–30 September 2023	EFS 2023 (efs2023.uc.pt)	Prague, Czech Republic
October 2023		
4–5 October 2023	43rd AIVC – 11th TightVent & 9th venticool Conference: Ventilation, IEQ and health in sustainable buildings (aivc2023conference.org)	Aalborg University, Copenhagen, Denmark
25–27 October 2023	Decarbonization Conference for the Built Environment (ashrae.org)	Washington D.C., USA

Due to the COVID-19 circumstances, the dates of events might change. Please follow the event's official website.

ISH China & CIHE
Beijing, 11 – 13 May 2023
Photos: Messe Frankfurt (Shanghai) Co Ltd

Industry players to seize ample opportunities at ISH China & CIHE 2023

China's HVAC market is well placed to thrive with plentiful business opportunities. Manufacturers have been actively developing energy-efficient HVAC solutions, in response to the Chinese government's initiatives on sustainable development. With the presence of leading global and domestic brands featuring their innovative solutions and products, the line-up of international pavilions and specialised areas will act as the highlight of ISH China & CIHE 2023.

Organised by Messe Frankfurt (Shanghai) Co Ltd and CIEC GL events (Beijing) International Exhibition Co Ltd, ISH China & CIHE – China's leading international trade fair for heating, ventilation, air-conditioning, sanitation & home comfort systems is set to open from 11–13 May 2023 at the China International Exhibition Center (Shunyi Hall) in Beijing. Focusing on three major themes: Energy, Water and Life, which are in line with China's green initiatives and energy infrastructure optimisation targets, more than 1,300 exhibitors will showcase the latest HVAC, plumbing, smart heating and home comfort technologies and products across 106,800 sqm of exhibition space.

As China's latest national policies underline the green economy, the accelerating growth of the HVAC market sees new business opportunities for industry players, who are prepared to showcase their latest products and innovations to professional buyers. A number of leading companies and brands worldwide have confirmed their participation at the 2023 edition, which include:

AMA&HIEN, Amitime, Amnesty, ARODD, BDR, Beigao, CALEFFI, DA, Danfoss, Devotion, Electrolux, Fangkuai, GMICÖU, GONGDA KEYA, GREE, Grundfos, Gude, Haier, Hailin, Hnbwrn, Hongyue, Huadehuamei, Huamei, Inovisen, JESDY, Kaaniche, Kenuo, Kingfore, Kiturami, Leo, Lonpend, Mayair,

MICOE, Midea, Naturaquell, Nedfon, New Energy, Nobana, NORITZ, OUTES, PHILIPS, PHNIX, POWERWORLD, Resideo, Rinnai, RUIGE, RUNA, Shengxu , Shimge, Shinco, Shiteng, SHUANGLIANG, SIEMENS, Snowman, Solerad, ST.LAWRENCE, Suming, Tasan, Tongfang Smart Energy Saving, Tongli, Towngas Smart Energy, UNBEATABLE, Vanward, Walker, WDK, Wellhausen, Westone, WILO, Xinhuaxing, Xinxing, YORO, YUQ and more.

Strong line-up of pavilions and specialised display areas to showcase the latest innovations and technologies

This year, the German Pavilion, Canada Pavilion, Overseas Area, Zhejiang Pavilion, Water Pump Area and Clean Energy District Heating Area will be the major highlights of ISH China & CIHE. Supported by the Federal Ministry of Economic Affairs and Climate Action (BMWK), the German Pavilion will continue to be the key feature of the fair. The new Canada Pavilion will present the latest Canadian advanced manufacturing technologies and applications to meet the specific demands of the Chinese winter. Furthermore, following its success in the 2021 edition with over 100 domestic exhibitors spanning 10,000 sqm of exhibition space, the Zhejiang Pavilion will once again feature this year with product showcases including HVAC, sanitation and plumbing products.

Located in halls E1 and W2, the Overseas Area has already gathered a number of international brands, including AYVAZ, Broen, CALEFFI, EMS, Fondital, Heatmiser, KMC, Nuova Imas, Polidoro, Rima, Sermeta, Vernet, Vexve and Zero. The area will also introduce the new Minibox Service Area, which will allow international exhibitors who cannot attend the fair in-person to showcase their products and explore business opportunities online.

Being one of the key components for green heating and cooling, water pumps are again one of the highlighted products at ISH China & CIHE. The Water Pump Area will feature a number of prominent brands within the plumbing industry, including DAB, DAFU, Dooch, Goodpump, Grundfos, HOMA, Hydroo, Kaiquan, Leo, Lingxiao, Minamoto, Nanyuan, Pentax, RHEKEN, SFA, TQ GROUP, Westone, WILO and more.

With the latest innovations and clean-energy technology showcases adhering to carbon emission regulations, the Clean Energy District Heating Area organised by the China District Heating Association will be housed in hall W3 with renowned companies, including Desource, Diehl, GMSDIP, Gongda Keya, GREEN ENERGY ALLIANC, HDCHIP, Heighten, Huameng, Huizhong, HYTC, JHRJ, Jumo, Kingfore, Lcarbo, Nanjing Jiangu, Nuanliu, Ploumeter, POER, Precise, Revoheat, RUNA, Shuanghe, SHUOREN TIMES, THT, TigerIOT, TOKYO, TSCC, Wukexing, Xingbang, Xinxing Pipes, Younai and others. ■

ISH Shanghai & CIHE is another ISH event in China. For more information about ISH China & CIHE and ISH Shanghai & CIHE, please visit www.ishc-cihe.hk.messefrankfurt.com or email info@ishc-cihe.com.

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