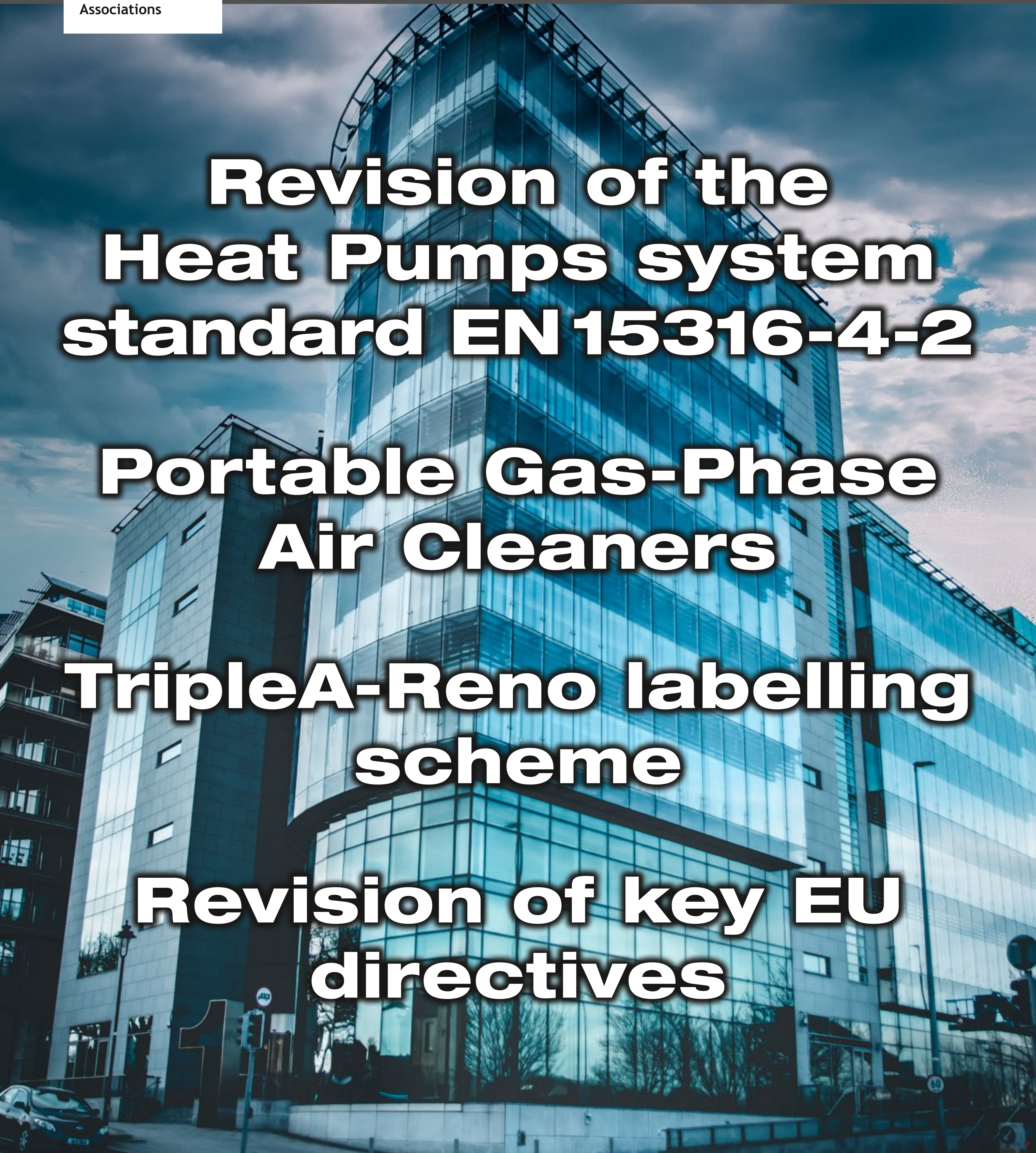
REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations
ISSN 1307-3729

The REHVA European HVAC Journal

Volume: 58 Issue: 5 October 2021 www.rehva.eu



Revision of the Heat Pumps system standard EN 15316-4-2

Portable Gas-Phase Air Cleaners

TripleA-Reno labelling scheme

Revision of key EU directives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The REHVA European HVAC Journal

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Volume: 58 Issue: 5 October 2021

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PUBLISHER
TEKNİK SEKTÖR YAYINCILIĞI A.Ş.
Barbaros Mahallesi, Uğur Sk. No: 2/2
Üsküdar/İstanbul, Turkey

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Instructions for authors are available at **www.rehva.eu** (> Publications & Resources > Journal Information). Send the manuscripts of articles for the journal to Jaap Hogeling **jh@rehva.eu**.

EU Green Deal, Renovation Wave, Fit for 55 by 2030 towards Zero Carbon emission by 2050, drivers for the EPBD revision in 2022

Buildings are acknowledged as one of the key focus areas for the European Green Deal and more specific the Renovation Wave Strategy. The ambition is to at least double annual renovations (up to 3%) of EU (public) building stock with focus on deep renovation. These policy actions are also the basis for the urgent revision of EPBD (version 2018) to direct the national renovation strategies to achieve a decarbonised building stock by 2050. Target: draft revised EPBD ready by end of 2021 (see also the article by **Anita Derjanecz** on page 57-59). We expect vision regarding the decarbonisation of building stock, a large majority of consulted stakeholders (74%) welcomed an EU-harmonised GHG (CO_2e) metric; which is great as the current EPBD includes just an encouragement to MS's to report on GHG emission in the EP Certificate, some countries do, but not all. The in 2020 published standard EN 17423 "Energy performance of buildings - Determination and reporting of Primary Energy Factors (PEF) and CO_2 emission coefficients - General Principles", offers transparency on declaring the PEF's and CO_2 Emission coefficients. In most EU MS's the building authorities are responsible for assessing and declaring these values for all used energy carriers, it is of great importance that this should documented according EN 17423. This standard provides a transparent framework for reporting on the choices related to the procedure to determine values for energy delivered to and exported from the buildings as described in EN ISO 52000-1. As we know, these declared values have an great impact on the level of the reported EP's and carbon emission reported in the building EP Certificate. Using this will lead to more comparability of the EPC's in Europe.

But that is not all we should try to make the EPC's more transparent. Currently we have 27 + national EP assessment procedures, all claiming to follow the EPB standards (not all and not for 100%). This is also a reason why it is still difficult to compare EPC's (and connected NZEB values). Different conditions (climate and use), different definitions (example the useful floor area) are acceptable if declared in a transparent way but different calculation (assessment) procedures makes comparing difficult. Many MS's are even not able to declare their different assumptions according the annex A of the EPB standards. Many use still monthly procedures which includes the use of non-transparent assessed factors.

In order to assess the capabilities of national EP calculation methodologies, to reflect correctly the ambitious policy goals, to be technically neutral, to reach comparable, reliable results, the quality of this calculation methodology should be evaluated. For this we need a common general framework for evaluating the quality of the EP calculation methodologies. Developing this framework is a challenge but feasible. In this line we should also repeat the advice: "REHVA supports the development of an opensource software kernel and dynamic performance calculation tools meeting art. 3 of the EPBD". Apart that this software enables an hourly procedure, which is easier to use, more transparent, reproduceable and innovation supportive, it is expected that this software will reduce the performance gap (the difference between calculated and measured EP ratings).

A revised EPBD supporting this, is essential if we want to be "Fit for 55 by 2030" towards Zero Carbon emission by 2050. ■

JAAP HOGELING
Editor-in-Chief
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Heat pumps: lost in standards...and found

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Introduction from RJ Editor in Chief

We are aware that the length of this article is exceptional. However, given the relevance of this article for our professional community we decided to allow this. The prEN 15316-4-2 on Heat Pump systems will be published for enquiry late 2021. This article supports the understanding of the revisions and the improved and extended procedure included in this standard. In RJ 2021-04 we also included an article from Socal, this article focused on the product standards. To understand this article and the revision of the HP System standard some knowledge of these HP product standards is advised. The most relevant product standards for heat pumps are EN 14511 and EN 14825, maybe 16247 for domestic hot water heaters. REHVA hopes that by publishing this article we will contribute to a lively and constructive enquiry phase of this standard. We also advice our readers to access the supporting information on this issue at the EPB Center website: www.epb.center. — ***Jaap Hogeling***

Keywords:
EPBD - CEN - standards - heat pump

Summary

The draft of the revised EN 15316-4-2 will be published for public enquiry in the next months. This article analyses the main features of this new text.

The calculation procedure has been organised according to a new frame which is independent of the heat pump typology and calculation paths and options. Then the specific features of the two main calculation paths are presented.

"Path A" still requires some discussion and attention on the correction of COP for part load. Several such correction methods are included in the draft to allow testing them. Even the definition of "part load" itself deserves some more attention.

Some more insight is provided about "path B". The test conditions used in EN 14825 are presented. This makes clear why it's not straightforward to extract the information on the dependency of the COP from each parameter: they all vary from one test point to the other.

The temperature pattern within the heat pump is illustrated in details, including what happens if the fans of the evaporator and condenser modulate or they do not. This results in a possible trade-off between comfort and energy performance that might be taken into account in the calculation method.

Finally, it is suggested to introduce a mechanism to allow some tolerance for a transient power output deficit of the heat pump when a peak for domestic hot water production occurs. Without this feature, the risk is to invalidate the whole calculation process without a real reason.

Introduction

The former article already introduced EN 15316-4-2 and some basic features of the draft new revision, that should be published for public enquiry in the coming months (late autumn 2021).

This article will analyse more in details the contents and technical background of this new draft.

The frame

There are several types of heat pumps and several possible alternatives for the calculation of the energy performance of heat pumps.

The first concern when drafting this revision was establishing a clear common frame that could:

- support all the various calculation options for each heat pump typology;
- guarantee in all cases the connection with the general calculation frame set-up by EN 15316-1;
- handle several operating conditions in the same calculation interval.

The result is a reviewed step-by-step procedure which is summarised in Annex C of the new draft. For each step, the available alternatives and the reference to the relevant clause are given in tables.

Step 1 is the acquisition of the required energy output per each service provided in the calculation interval. This information comes from the general part EN 15316-1. Currently, the draft supports two services: space heating and domestic hot water. Additional foreseen services can be a direct connection to a hot water storage and space cooling. In fact, now that the frame is defined and working, one realises that it could be used for cooling as well.

Step 2 is the calculation of the source temperature, depending on source type and operating conditions. This is a missing part in the current EN 15316-4-2, which considers only external air. Actually, the issue is only partially solved in the draft revision because there are only simplified models for such sources as ground heat exchangers.

It would be interesting to develop models for the ground exchangers that are also used for free cooling or free heating. Some attention will be required to avoid iterations if the model should take into account the power required from the source: simplifying assumptions like an estimated COP may be a good solution. Sources like ground water and surface water need measured local data.

Step 3 is the calculation of the sink temperature per each service. This is an important information that comes from the general part EN 15316-1. For a correct calculation of heat pump performance, the use of the procedures given in annex C (heating circuit operating temperatures) and D (generators circuit temperatures) of EN 15316-1 is essential. These annexes are basic methods but additional options and related procedures may be developed nationally. An example of a useful additional feature is a simple heating curve (flow temperature as a function of outdoor temperature). Methods in annex C of EN 15316-1 are all based on heat demand, since they were primarily developed for use with a monthly method.

If cooling would be integrated in the frame as an additional service, then the role of source and sink in steps 2 and 3 shall be exchanged.

At step 4, source and sink temperatures are known and the operational and control limits are checked. Operational limits are the maximum and minimum operating temperatures of source and sink for the heat pump. It is the physical limit of the machine. Control limits are control set-points, that may be set e.g. to select which generator to run for economic or energy efficiency reasons.

If the limit temperature is exceeded for one service, then there will be no contribution of the heat pump to that service in the calculation interval

At step 5, the required services are assigned a priority level.

Currently there is only one criterion: domestic hot water first, at full power, then space heating using the remaining time in the calculation interval. Other criteria are possible but not yet defined. However, it has to be noted that this scheme probably covers 99% of real situations. If space cooling were added, it would replace space heating in the sequence.

At step 6, the maximum available power for each service is determined, taking into account source and sink temperature. This is needed to define:

- the required operation time for the high priority services;
- if the required output for the least priority service can be fulfilled in the remaining time in the calculation interval.

Here the calculation method depends on the path:

- for path A (based on EN 14511 data), the maximum available power is known as a function of source and sink temperature;
- for path B (based on EN 14825 data), there is only one value of maximum power and the increase in available power output with source temperature is not known.

Which calculation path to use is determined by the heat pump typology, according to the criterion given in table B.40, which allows full flexibility.

At step 7, the running time and load factor (LRx) for each priority are determined, based on the required output energy and the available power as a function of operating temperatures.

Typically, the domestic hot water service (if required) will be supplied at full load (LRw = 1) whilst the space heating will be supplied at the resulting part load LRh. If LRh is greater than 1, that means that the heat pump cannot satisfy the load: LRh is assumed equal to 1 and the remaining energy will be supplied by the integrated back-up or by the next generator in the sequence (if there is one).

Step 8 is the calculation of the main energy input for each priority.

Two calculation paths are possible for this step:

- path A, which is based on a map of full load COP (EN 14511 data) and then a correction according to part load;
- path B, which is based EN 14825 which provide a correlation between the output power and the II principle efficiency of the compressor.

More details are given in the following dedicated clauses in this article.

Annex C of the standard gives some more details about each calculation path:

- **steps 11 to 19** for path A
- **steps 21 to 29** for path B.

Which calculation path to use is determined by the heat pump typology, according to the criterion given in table B.41, which allows full flexibility.

At the end of the sections, step 19 or 29, the main energy input for each service is known.

Step 30 is the calculation of back-up energy. This should be used only for a back-up which is integrated in the heat pump. Handling a sequence of generators and dispatching the required heat to the available generators is a task of the general part module, EN 15316-1.

Currently the back-up calculation assumes that there is a back-up with a maximum power available and that it can fulfil the remaining heat demand using the whole calculation interval.

This is a simplified initial model but the following observations may lead to an update after public enquiry.

- The whole calculation interval is not always available. If domestic hot water is provided in the first part of the calculation interval, heating can be provided only in the remaining time.
- Assuming that the calculation interval is available for back-up operation means simultaneous operation of the main compressor and of the back-up, which should be possible without overloading the electricity supply.
- The electric back-up may be used to overcome the temperature limitation, not the missing power. As an example, legionella cycle may ask for a flow temperature of 70°C. If this is not possible for the main compressor, the final heating from e.g. 60°C to 70°C may be covered by the electric back-up.

Some improvement is possible here but it involves also coordination with the general part (when is legionella cycle required?).

Step 31 deals with external auxiliaries for each priority.

External auxiliaries are all those auxiliaries that are not taken into account into the COP declaration.

This is especially relevant for absorption heat pumps and for some types of sources (ground water, surface water, ground heat exchangers) where pumping energy may be significant. In the absence of a standardised way to declare these auxiliaries, a first simple model, common to several other system standards, is proposed: the values of auxiliary power is asked at zero, minimum modulation and full power, then you interpolate between these points.

Step 32 deals with losses towards the environment for each priority.

At step 33, all results for each priority are attributed to the pertaining service.

Step 34 deals with the collection of all data and the generation of partial performance indicators.

This frame allows:

- the selection of the appropriate method depending on the heat pump typology, which is specified via a number of tables in informative annex B (B.38 to B.42) that can be superseded by a national version;
- adding, combining, updating and upgrading each step of the procedure in the future revisions.

In the following, specific aspects of the method are presented with more details.

Specific features of path A

Extrapolation and interpolation

The starting point of path A for any typology of heat pump is the performance map at full load, depending on source and sink temperature. This includes two maps, actually two tables of values:

- one for full load power output;
- the second for full load COP.

The reference source and sink temperatures for each type of source and sink are taken from EN 14511 and the table can be filled with data according to EN 14511. Maximum power output and COP for other conditions are calculated by linear interpolation or extrapolation.

As in the previous version of the standard, if less data is available (the extreme case is having only one value e.g. power output and COP at A7W35), default multiplying factors are provided to fill in the whole table starting from one known values as shown in **Figure 1**.

If data from EN 14511 (or other typology specific standard) is known, the whole table can be filled in with the declared values. Examples are given in annex D of the draft review of the standard.

The principle is the same for all typologies of heat pumps. The reference temperatures only depend on the source and sink type. Heat pumps may also operate in summer, for domestic hot water service or if reheat is needed for dehumidification. In this case, the array of air source temperatures shall include values up to about 30°C. Extrapolation from 12°C is very likely to be inaccurate.

What is full load?

One potential issue is the definition of "full load".

Obviously, for on-off heat pumps (or staged units with several on-off compressors) there is no doubt, there is only one possible operating condition at "full load".

Modulating heat pump use a variable speed drive of the compressor, typically an inverter. In that case, the on-board software may intentionally limit the maximum compressor speed depending on the outdoor temperature. This makes sense because it is unlikely that you need the full power for heating at 15°C outdoor temperature, except if you also have to produce domestic hot water or if you need to recover after an indoor temperature set-back. This also avoids to operate in a condition where the power output is potentially very high and this requires oversized exchangers (evaporator and condenser) otherwise the COP drops because of their poor approach[1]at high power (see also next clause).

			Source temperature							
			$\theta_{src,-3}$ -15	$\theta_{src,-2}$ -7	$\theta_{src,-1}$ 2	$\theta_{src,0}$ 7	$\theta_{src,1}$ 12	$\theta_{src,2}$ 20	$\theta_{src,3}$ 30	Multiplying factor
Sink temperature	$\theta_{snk,-1}$	25	1.75	2.18	3.47	4.33	4.77	5.43	5.43	1.10
Sink temperature	$\theta_{snk,0}$	35	1.59	1.99	3.15	**3.94**	4.33	4.94	4.94	1.00
Sink temperature	$\theta_{snk,1}$	45	1.27	1.59	2.52	3.15	3.47	3.95	3.95	0.80
Sink temperature	$\theta_{snk,2}$	55	1.02	1.27	2.02	2.52	2.77	3.16	3.16	0.80
Sink temperature	$\theta_{snk,3}$	65	0.81	1.02	1.61	2.02	2.22	2.53	2.53	0.80
		Multiplying factor	0.80	0.63	0.80	1.00	1.10	1.14	1.00	

Figure 1. Sample performance map for an AW heat pump (full load COP).

An example of such performance map with intentional heat output limitation is given in **Figure 2**, where the output power is electronically limited above –5°C. You may also note that data for domestic hot water operation are provided as well (12 to 30°C air temperature, 45 to 55 leaving water temperature).

In this case, it should be taken into account that data above –5°C are not full load but already part load when performing the correction for part load operation. A possible solution is to report the compressor speed for each declared maximum power performance data. It is known and it would make it easy to avoid an incorrect estimation of part load correction.

How to correct for part load

There are several effects that may contribute to the change of COP at part load:

- the decrease of the approach of evaporator and condenser, that results in lower temperature ad pressure difference between condenser and evaporator;
- the change in heated fluid temperature difference (e.g. heated indoor air flowing through the condenser) when inlet temperature of heated fluid is used as a reference;
- auxiliaries (such as evaporator fan or circulation pumps for an absorption heat pump) may run at constant or variable speed. At constant speed this allows a reduction of the approach due to less power to transfer but the relative effect of auxiliaries on COP increases.

An example of the effect of part load on operating conditions is given in **figures 3 and 4** that show the temperatures in the refrigeration cycle of an air to water heat pump at full load and part load with the same source and sink temperature.

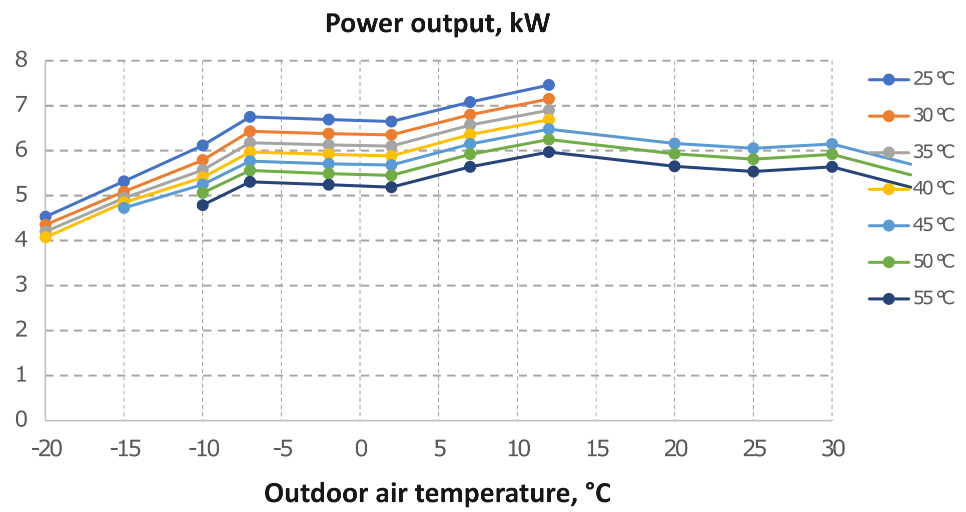

Figure 2. Sample performance map for an AW heat pump (full load power, electronically limited).

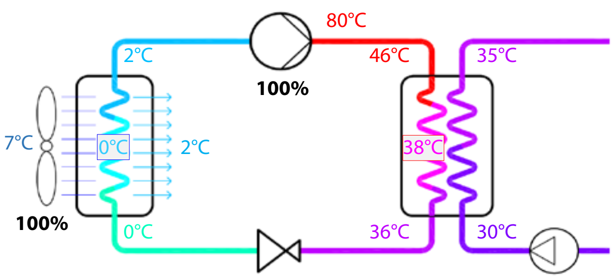

Figure 3. Example of full load operating conditions for an air to water heat pump.

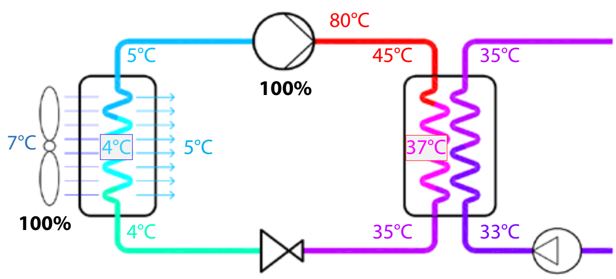

Figure 4. Example of part load operating conditions for the same air to water heat pump.

The temperature difference between condenser and evaporator changes from 38°C (38–0) to 33°C (37–4). The contributing factors are:

- a reduction of the outdoor air temperature drop on the evaporator (–3°C)
- a reduction of the approach in the evaporator (–1°C)
- a reduction of the approach in the condenser (-1°C)

This is likely to result in an increase of COP of 15%, if the compressor operates with the same II principle efficiency. Knowing the initial approaches and temperature differences on evaporator and condenser, it is an easy and reasonably accurate way to estimate the increase of the compressor efficiency at part load. However, you have to take into account also that the evaporator fan is running at constant speed, so this will affect more the COP at part load and partly compensate the increase in compressor COP.

A manufacturer may decide to reduce the evaporator fan speed at part load. In doing so, the auxiliary energy will be reduced but the reduction of the evaporator approach will be lost. This option could be triggered also by the intention to reduce noise of the outdoor unit.

In this draft review of the standard, several methods are proposed for the correction of COP at part load, which were already presented in the previous article:

- default correction factors as a function of part load;
- given as a series of tabulated values depending on the heat pump typology (for absorption heat pumps);
- given as parameters for a standardised curve (optimum load factor, maximum increase of COP, etc) as specified in a DIN method for air to water heat pumps;
- as a function of the parameters C_d (EN 14825 method), for ON-OFF operation
- assuming a share of auxiliary power at full load and some increase of net compressor efficiency at an optimum part load (the method in the current version of the standard)

Which method to use depending on the heat pump typology and the required parameters are specified in tables B.11 through B.14 and B.42 in annex B to the draft EN 15316-4-2.

Specific features of path B

The principle

The intent of the so called "path B" is to leverage test data measured according to EN 14825.

The testing conditions considered by EN 14825 for air to air and air to water heat pumps are:

- 4 points at outdoor temperature of –7, +2, +7 and +12°C, identified by the letters A, B, C and D;
- the "bivalent temperature", labelled "BIV" (or "F"), at which it is assumed that the test load (called "building load") matches the heat pump maximum output (i.e. CR is 100%, see previous article on heat pumps);
- the minimum operating temperature of the heat pump, labelled "TOL" (or "E") for temperature operation limit;
- point "G" is an optional test point at –15°C, which is required only if SCOP for cold climate is declared.

The difficulty is that all three operating parameters (source and sink temperature, power output) are changing in each test point, according to the following rules.

- Source temperature (external air temperature) T_X is defined for points A, B, C, D (T_A, T_B, T_C and T_D) and optional point G (T_G).
- The sink temperature is 20°C for air-to-air heat pumps. It is a linear function of the external temperature for air-to-water heat pumps and values are shown in table 1 for medium temperature application.
- The testing power P_X is a linear function of external air temperature and the results are shown in **Table 1**. For the average climate, the design power P_{DES} occurs at T_{DES}= –10°C and P_X=0 at 16°C. However, if the heat pump operates ON-OFF in point D (and possibly C), then the COP is measured only in the ON condition and a degradation factor is used to correct the measured COP value.

The testing power is called "building load" because the heat demand decreasing linearly with outdoor temperature simulates the behaviour of a building. Actually, there is no building: this assumption is coupled with a bin distribution to generate a weighting factor of the measured COPs in the four test points A to D, to obtain the SCOP.

Given size of the heat pump, the testing power can be adjusted by the manufacturer. T_{BIV} can be selected freely in the interval from T_A to T_{DES}. Two common choices are the following.

- $T_{BIV}=T_{DES}$. This means that the heat pump can provide the whole fictive load in all test points and up to T_{DES} = –10°C. No back-up energy is taken into account in the calculation of SCOP.
- $T_{BIV}=T_A$. This means that the heat pump can provide the fictive load only until $T_{BIV}=T_A$= –7°C The consequence is that in the determination of the SCOP, some back-up electric energy is included in the calculation, which reduces the COP at point A. This is possibly compensated by a reduced penalty at point D, where the heat pump may operate ON-OFF due to the minimum load.

The resulting test conditions combination is shown in **Table 1** for the average climate and medium temperature application and for a heat pump that has an actual power output of 10 kW at –7°C, depending on the choice for T_{BIV}.

It is obviously not easy to extract the influence of a single parameter from this data-set.

To overcome this difficulty, this calculation path assumes that the II principle efficiency **2** of the compressor be a function only of the required output power. This correlation is extracted once for all from the test data according to EN 14825. So, the procedure is:

- calculate II principle efficiency dependency on the required output power;
- calculate II principle efficiency for the required power output;
- calculate COP based on source and sink temperature and II principle efficiency.

Figures 5 and 6 show the temperatures in an air to air heat pump at full load.

The first part of the calculation method in path B aims at determining the evaporation and condensation temperature, given the source and sink temperatures and the power output in the available points. In the example shown in **figures 5 and 6**, the starting point are the temperatures of external air and indoor air, 7°C and 20°C respectively.

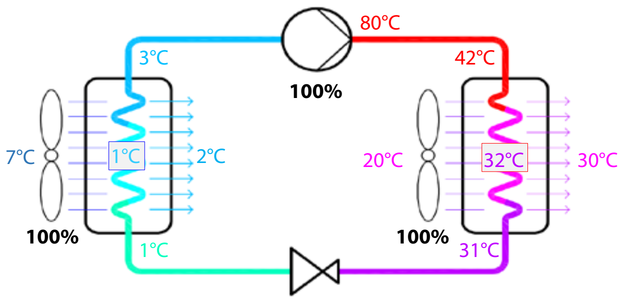

Figure 5. Example of full load operating conditions for an air-to-air heat pump.

The first assumption is that the temperature difference between respectively:

- the outdoor air (source) temperature (7°C) and the evaporation temperature (1°C)
- the condensation temperature (32°C) and the indoor air (sink) temperature (20°C)

are proportional to the output power. This is the calculation performed in tables E.3 and E.5 of annex E to EN 15316-4-2.

Table 1. *The resulting test conditions combination for the average climate and medium temperature application and for a heat pump that has an actual power output of 10 kW at –7°C, depending on the choice for* T_{BIV}*.*

Condition	Outdoor air temperature °C	Outlet water temperature °C	Test power with $T_{BIV} = T_A$ = –7°C kW	Test power with $T_{BIV} = T_{DES}$ = –10°C kW
E (DES)	–10	55	11.3 (PDES)	9.0 (PDES)
F (BIV)	–10…–7	52	10.0	9.0
A	–7	52	10.0	8.0
B	2	42	6.1	4.8
C	7	35	3.9	3.1
D	12	30	3.7	2.9

It has to be noted that these differences are made of two components:

- the approach of the condenser and the evaporator, which is likely to be proportional to power;
- the temperature difference of the air flowing through the evaporator and through the condenser, which is proportional to the power **if the air flow rate is constant**.

As an example, looking at **Figure 5**, flowing through the condenser, indoor air temperature increases from 20 to 30°C at full load. The leaving air temperature will be 25°C at 50% load only if the indoor unit fan will be still running at full speed.

Once the evaporation and condensation temperature are known in the available test points, then the II principle efficiency is calculated for each available point and associated to the output power in that point.

The result is a function like the one in **Figure 7**.

At point D, the heat pump is often operating ON-OFF. That's why points C and D are quite near in this example: test data in point D do not refer to the actual operating condition but only to the ON condition at minimum modulation. Then the measured COP value is corrected for intermittency using the Cd factor method.

The next step is calculating the evaporation and condensation temperature in the actual operating conditions in the calculation interval and the corresponding ideal COP using the Carnot equation.

Finally, you obtain the calculated COP at actual operating conditions by applying to the ideal COP the interpolated II principle efficiency at actual power output resulting from the function shown in **Figure 7**. If the actual output power is lower than that at point D (≈6 kW), then the actual COP at point D is further corrected for intermittency using the Cd factor method.

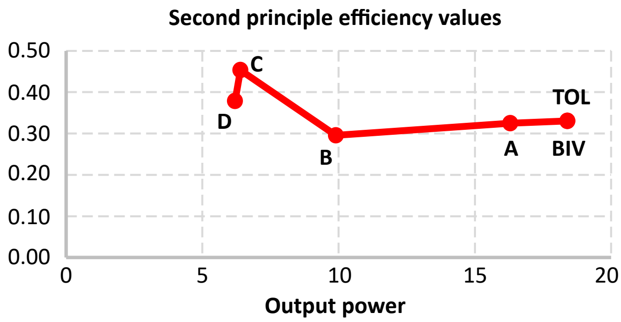

Figure 7. Example of resulting function: II principle efficiency as a function of output power.

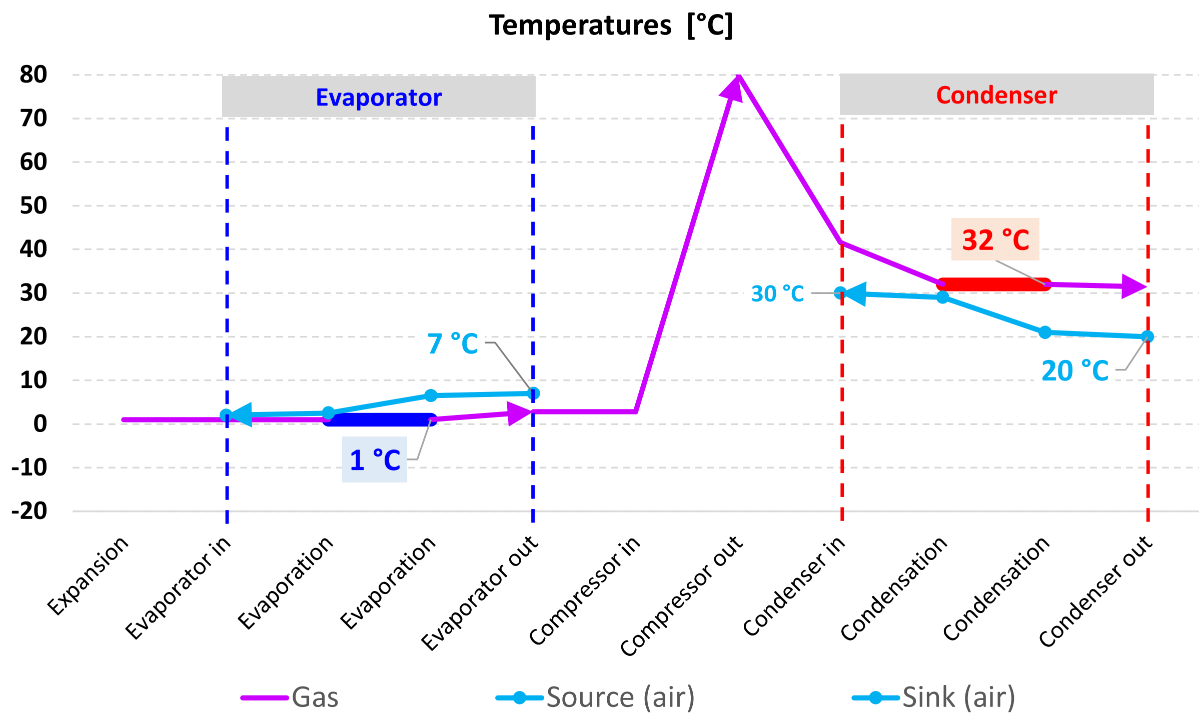

Figure 6. Example of full load temperature diagram along an air-to-air heat pump compression cycle.

Again, it is assumed that the source and sink fluids flow rates in the evaporator and condenser stay constant. This means that the part load operating conditions corresponding to **Figure 5** (full load operating conditions) should be as shown in **Figure 8**.

The decrease in condensation temperature at part load (32°C to 26°C) is obtained if the air flow rate through the condenser stays constant. That's one of the reasons for the COP peak at part load. If the condenser fan (indoor unit) modulates, then the operating conditions might be as shown in **Figure 9**.

That means that "quiet operation" requires some trade-off between comfort and efficiency and the control strategy of the fan should be somehow taken into account. This is generally true, it is not a specific issue of path B.

Once evaporation and condensation temperatures are known in actual operating conditions, then the COP in the actual operating conditions is calculated according to the II principle efficiency at the actual output power.

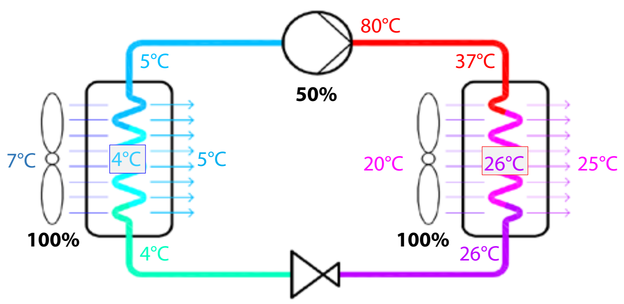

Figure 8. 50% load operating condition, coherent with path B assumptions and **Figure 5** full load conditions.

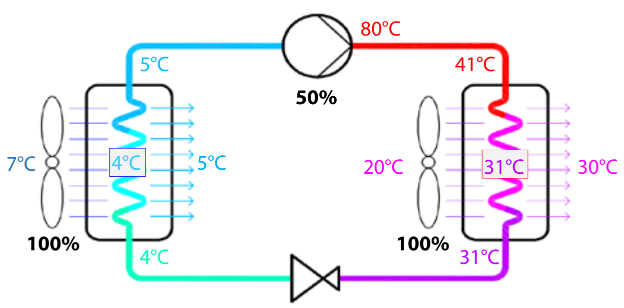

Figure 9. 50% load operating condition, if condenser fan modulates.

Limitations of the current path B method

The current version of the path B method has some limitations in the possible use.

One limitation issues from the data-set provided by EN 14825: data on the maximum output power is available only for on-off heat pumps. For modulating heat pumps, it is assumed that the maximum power is that at the bivalent temperature. The increase in available power with higher source temperature is not described. This makes it difficult to handle situations with multiple generators, where one has to determine the contribution of each one based on their capacity.

Another limitation (also because of EN 14825 data-set) is the lack of information on the behaviour when producing domestic hot water and when operating in summer. A broad extrapolation would be required.

One or several path B

In the text of EN 15316-4-2 and in the accompanying spreadsheet, you will find separate clauses and separate calculation procedures for air to air and air to water heat pumps. The concept of the procedure is the same but the information available (input data list), the exceptions and particular cases have differences that make it simpler to have separate procedures.

The tables

In the examples in annex E (and in the current accompanying spreadsheet), calculation path B is demonstrated using tables. This is to better explain the procedure. In the revision following public enquiry the tables should disappear from the standard and the spreadsheet and shall be replaced by the required equations.

The entire calculation of the second principle efficiency as a function of the required output power (i.e. everything required to establish the graph in **Figure** 7) should be moved to a separate section to be applied only once for all when the product data of the heat pump is defined. There is no need to perform it at each calculation interval.

Further improvements

Transient deficit

A possible supplementary feature for the hourly method, is to allow a transient delay in the heat pump output. When there is a request for domestic hot water in one hour, it has priority over heating and it takes significant time to restore the set-point conditions into the storage. During peak heating request, the remaining time available in the hour can be too short to satisfy the heating demand, even at full load. Computationally there would be a part of the heating demand which is not satisfied. Actually, if the heat pump is correctly sized, this is just a transient deficit that will be recovered in the following hours. Due to the building time constant, the effect on comfort (temperature drop) is not perceivable. If the heat pump is undersized, the heat output deficit will not be recovered, it will increase hour by hour and day by day.

This feature can be easily introduced by:

- saving as a calculation output the total heat deficit at the end of the current hour;
- summing that total heat deficit to the heating needs at the beginning of the next hour.

If the total deficit is continuously increasing for several hours, this means that the heat pump is undersized.

If the total deficit has a sudden rise when domestic hot water service is requested and then decays in the next few hours, then this should be accepted.

With this feature, no advantage is given because needs are not reduced by a diminished internal temperature, which would be the case if the information about the actual reduced available power were passed to the heating needs module EN ISO 52016-1. In total, the heat pump will produce the whole heating needs but this will happen partly in the next hours with a higher load factor, just like things happen in reality. An example of such behaviour is shown in **Figure 10**.

Peaks of missing energy for heating are due to the heat request for the domestic hot water preparation (thermostat asking to restore the temperature in the domestic hot water storage).

A possible criterion is that the transient deficit can be considered acceptable if:

- there are no more than 3 (or any other number) consecutive hours of increasing total heat deficit;
- the deficit is again zero in a maximum of 6 (or any other number) hours.

If these criteria are not met, then a warning should be issued and the output power deficit handled as a true one.

This is also useful as a filter to sudden surges of heating needs power generated by EN ISO 52016-1, that are due to the assumption of perfect temperature control. A step in gains is automatically transformed into an instantaneous step in heating (or cooling) needs whilst in reality it takes some time and some indoor temperature drift for the system to react.

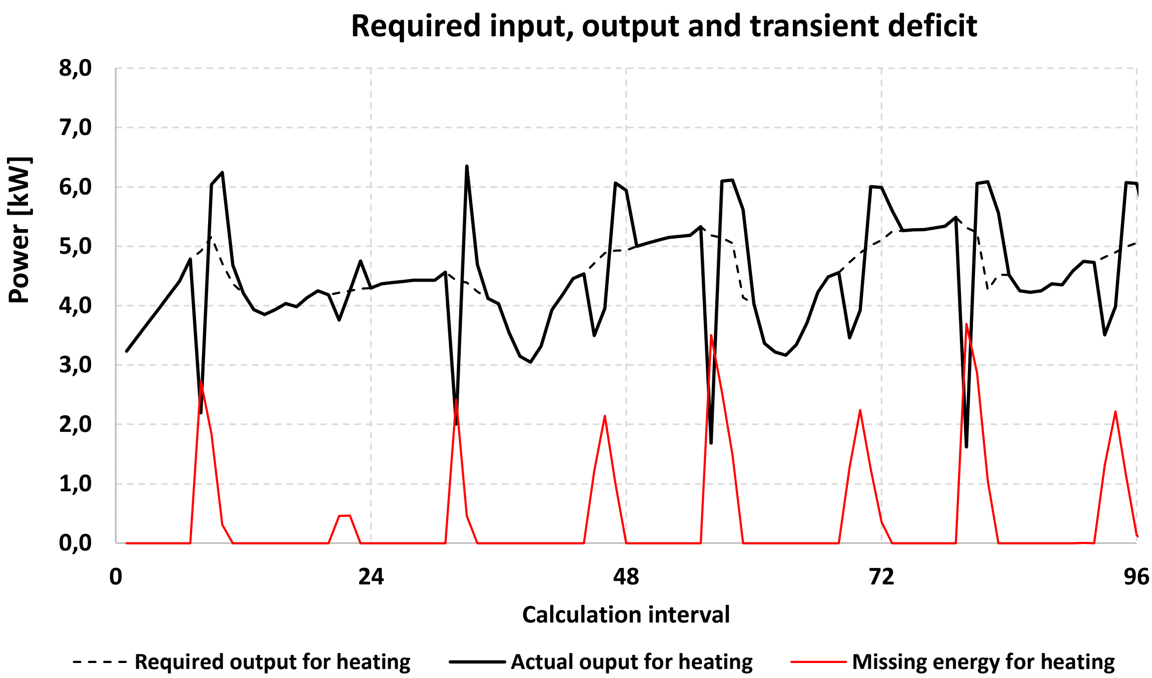

Figure 10. Example of transient heating power deficit.

Domestic hot water only
The case of domestic hot water only should be further refined, taken into account into the priority criterion and a better connection should be sought with the specific product standard.

A clarification about the meaning of the "thermostat-off", "stand-by" and "crankcase heating" auxiliary power defined in EN 14825 is needed. As an example, it's difficult to understand what can be the difference between "thermostat-off" and "stand-by".

Publication

The new draft will be sent by CEN central secretariat to the national standardisation bodies for the public enquiry in the coming months.

The accompanying demonstration spreadsheet will be published on EPB-Center website, together with a short video explaining the calculation method and the features of the spreadsheet.

If you read this article, you should be ready for the impact. Have fun in commenting the new draft for EN 15316-4-2. ■

Standards

prEN 15316-4-2: 2021 Energy performance of buildings — Method for calculation of system energy requirements and system efficiencies – Part 4-2: Space heating generation systems, heat pump systems, Module M3-8-2, M8-8-2 (publication for enquiry expected late autumn 2021).

EN 15316-4-2:2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies – Part 4-2: Space heating generation systems, heat pump systems, Module M3-8-2, M8-8-2.

EN 15316-1: 2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies – Part 1: General and Energy performance expression, Module M3-1, M3-4, M3- 9, M8-1, M8-4.

EN 14511:2018 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors – Part 1: Terms and definitions; Part 2: Test conditions; Part 3: Test methods; Part 4: Requirements.

EN 14825:2018 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commercial and process cooling - Testing and rating at part load conditions and calculation of seasonal performance. (currently under revision, the prEN was published in 2020).

Literature

Heat pumps: lost in standards…, Laurent Socal, REHVA Journal 2020-04 (https://www.rehva.eu/rehva-journal/chapter/heat-pumps-lost-in-standards)

References

[1] The "approach" is the increase in temperature differences in a real heat exchanger with respect to an ideal (infinite) heat exchanger. It increases at high power and tends to zero at low loads.

[2] The "II principle efficiency" is the ratio between the actual COP in a given operating condition and the maximum theoretical COP with the same source and sink temperature.

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Heat Pump (HP) and solar appliances are socially well accepted Renewable Energy based energy systems. The SunHorizon project demonstrates TRL7 innovative HP solutions (thermal compression, adsorption, reversible) coupled with solar technologies (thermal, photovoltaic, hybrid) to provide heating and cooling to residential and tertiary buildings with lower emissions and energy bills.

Keywords: Heat pump solutions; solar driven heat pumps, EU Project, renovation, buildings.

Context

The analysis on the European HP market showed a constant increasing trend. However, two barriers are identified, the initial investment cost and the price difference between electricity and natural gas.

Furthermore, the solar market analysis identifies solar technologies as a growing market within the EU, both for electricity generation and thermal energy. In this case, the main barriers consist in the lack of access to subsidies and the fact that the EU legislation on Energy Performance of Buildings (EPBD) just covers new buildings, which is a minority of the total building stock.

As stated in EU Strategy on H&C (2016), *"large-scale demonstration projects of energy-efficient and low/zero-carbon technologies are needed to help reduce technical and market barriers by providing robust data to evaluate their performance in each market segment"* [1]. SunHorizon project wants to reach this goal and is a breakthrough demonstration-to-market project with 21 partners and 8 demos in Europe.

The project focuses on *"reducing system costs and improving performance as well as optimising existing technologies for H&C applications and for some of the most promising market segments"* [2]. Its technologies are properly managed by a *cloud based functional monitoring platform* with services such as demand prediction, proactive and predictive maintenance tools, or a hybrid advance controller, supported by a *smart user interface*; the services will help on maximizing solar exploitation and give inputs to the manufacturer for the design and installation.

The project team is industry-driven, including 12 industrial partners, 5 top level Research and Technology Organisations (RTOs) and 4 associations. The 8 demo sites cover a wide range of European climate conditions, different energy markets and end-users, going from single houses to apartment blocks, public buildings, swimming pool and sport centre.

The SunHorizon project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 818329.

SunHorizon technologies

5 different technology combinations, known as Technology Packages (TP), are supplied to the demo sites, combining the technologies listed below. One of the main goals of SunHorizon is to introduce technology innovations to be firstly validated at laboratory scale and, finally, on real demo-site applications. For each technology provider, the main innovations include:

- **BoostHEAT (BH)** provides a gas-driven HP consisting of one or more thermal compressors in parallel, fed by a low-NOx burner, and using CO_2 as working fluid. BH has improved within the project the compressor operation, the production chain and the software architecture
- **Fahrenheit (FAHR)** is a hybrid unit connecting in parallel a thermally driven adsorption chiller, using water (R718) as refrigerant and a vapour compression. FAHR has improved its technology by adding a new absorber to achieve an efficiency increase up to 40%, new heat exchangers and an improved coating process of the adsorbers
- **BDR Thermea group** provides two types of reversible HP: brine-water and air-water. Within the project, BDR has improved and optimized the control hardware and software allowing a higher reliability and efficiency improvement
- **TVP Solar** provides High Vacuum Flat Plate Solar Thermal technology, able to achieve extremely high delivering temperature, with the highest efficiency certified by the international standard Solar KeyMark. TVP has improved their absorber material, exit ports design and improvement of safety design and controls.
- **The DualSun (DS)** solar panel is an advanced hybrid solar (PV-T) technology that produces simultaneously electricity (photovoltaic) and hot water (solar thermal). The design of the panels has been improved by reducing thickness and weight, obtaining a faster and more reliable connection between panels and improving both electrical and thermal performance;
- **Ratiotherm** storage, delivering optimal solutions to achieve highly stratified storages, to maximise the integration among different sources and consumers. The stratification device of the tank has been adapted to expected flow rates and temperature levels.

Descriptions of each TP are described in the following.

Figure 1. Individual technologies included in SunHorizon project, and relative energy needs covered.

Technology package 1 (TP1)
TP1 consists in a parallel integration of TVP solar collectors to cover most of the heating demand (space heating and domestic hot water) and BH to cover non-solar periods. Via the stratification system the solar heat use is maximized. TP1 is applied in an apartment building in Berlin (Germany) and in a Sport centre in Verviers (Belgium).

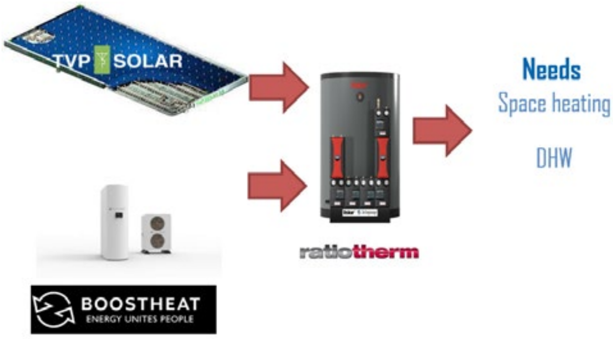

Figure 2. Technology package 1 presentation.

Technology package 2 (TP2):
TP2 has DS PVT panels which thermal output assists the BH evaporator and covers preheating of demand, enhancing the HP performance. Furthermore, the electricity needs are covered with the photovoltaic output. TP2 is applied in an apartment building in Nurnberg (Germany), two single-family houses in Riga (Latvia) and in a swimming pool centre in Verviers (Belgium).

Figure 3. Technology package 2 presentation.

Technology package 3 (TP3):
TP3 has TVP collectors to cover the heating demand in winter, while in summer the solar output drives the adsorption chiller from Fahrenheit to meet the space cooling needs. TP3 is applied to a tertiary building in Sant Cugat, replacing the constant speed HP currently installed, which is electrically- driven.

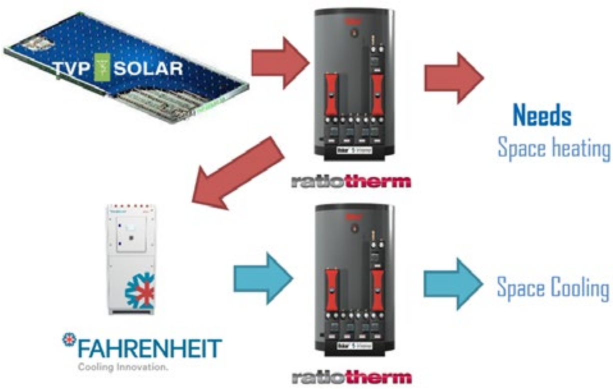

Figure 4. Technology package 3 presentation.

Technology package 4 (TP4)
Similarly, with TP2, two variants of TP4 are proposed in Madrid and Piera demo sites relying on reversible HP from BDR, dual production of solar heat and electricity, versatile thermal storage. In Madrid, 9-apartments building, the COP of the BDR brine/water HP benefits from both thermal and electricity outputs of the DS hybrid PVT panels while air/water HP is used as back up. The electricity production covers the HP's consumption and the dwellings demand. In Piera residential building, BDR solar thermal panels reduces the DHW request on the reversible air/water BDR HP while it can be activated to store BDR photovoltaic panels electricity either as heat or cold in the thermal storage, thus maximising the electricity self-consumption.

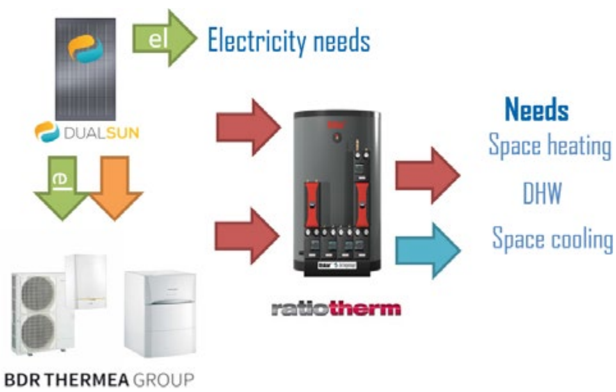

Figure 5. Technology package 4 (BDR+ DS).

Technology package 5 (TP5):
TP5 is composed by TVP solar collectors, RT high stratification storage tank, FAHR hybrid chiller and the BH thermal HP. The hot water

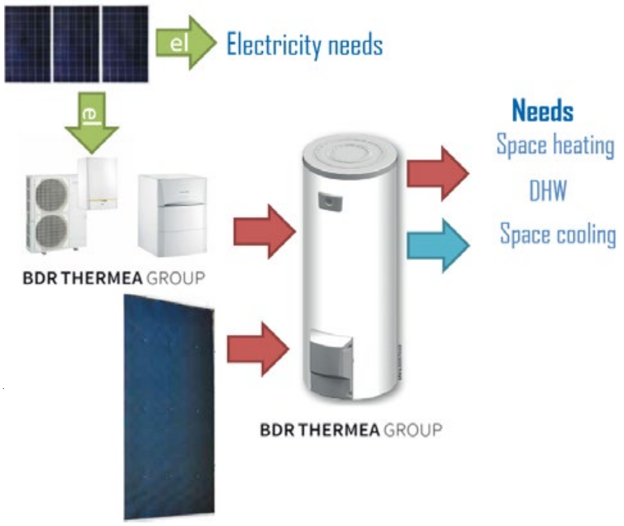

Figure 6. Technology package 4 presentation (BDR only).

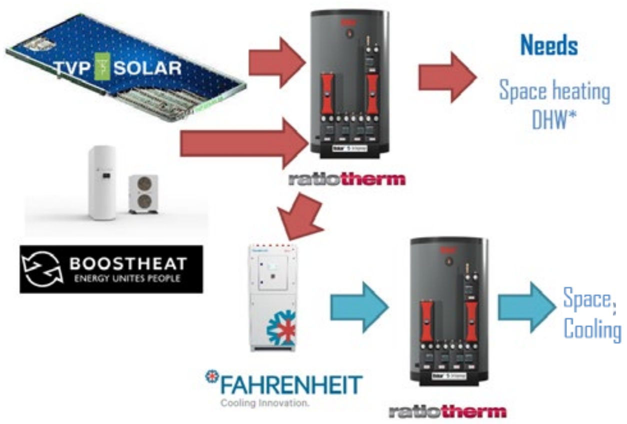

Figure 7. Technology package 5 presentation.

produced by TVP is stored in the high stratification RT tank, providing high temperature to the adsorption input and for DHW and space heating. The chilled water produced by FAHR hybrid chiller is stored in a smaller tank and then delivered to the space cooling system. During winter the pre-heated water by TVP is delivered to the BH unit that, if necessary, heats it up to cover the space heating and DHW demand.

Expected impacts

The technical partners of the project (CEA, CARTIF, CNR/ITAE and RINA) estimated the building energy demand of the 8 Demonstrators (9 buildings in total) using TRNSYS software, calibrated on theirs monthly gas and electricity bills. The existing and future scenario were compared in terms of non-renewable primary energy savings, costs and greenhouse gas emission savings, and the electricity self-consumption ratio. From the results, it is estimated that SunHorizon technology packages will allow to achieve 33-70% GHG emissions savings and 30-85% operation costs savings in the different demo sites. *TP1 to TP4 will be demonstrated in different demo sites, while TP5 will be only tested in simulation, in 3 locations and 2 types of buildings (tertiary and apartment building).*

The detailed performance of each technology package is shown in **Table 1**.

Table 1. *Technology package performance.*

SunHorizon TP		Solar-HP integration concept	Results from simulations
TP1	TVP + BH	Parallel integration	In **Berlin**: 43% of primary energy savings, and 37% of costs savings for the user In **Verviers**: ~30% of primary energy and costs savings.
TP2	DS + BH	Mixed solar-assisted/ parallel integration	In **Nurnberg**: ~ 33% of primary energy and costs savings, 80% of electrical self-consumption ratio (SCR). In **Verviers**: ~25% of primary energy and costs savings. 95.1% of SCR In **Riga**: ~37% of primary energy and costs savings. 43% of SCR
TP3	TVP + FAHR	Solar-driven HP for cooling	In **Sant Cugat**: ~35% of primary energy and costs savings
TP4	BDR	Mixed solar-assisted/ parallel integration	In **Madrid**: ~76% of primary energy and 84% of costs savings, and 37% of SCR In **Piera**: ~59% of primary energy and 53% of costs savings, and 47% of SCR
TP5	TVP + BH + FAHR	Mixed solar-driven/ parallel integration	For tertiary building the primary energy saving ranges from 19% to 57% depending on the location. For the multifamily residence building the primary energy saving ranges from 33% to 41%

Take-Aways

SunHorizon project is a pre-industrial project with high TRL that combines different type of heat pump with solar technologies that will help to meet the H&C demand with lower emissions, energy bills and fossil fuel dependency. The main take-aways from the project are:

- It is possible to enhance the performance of PVT panels (DS), when coupled with brine-water HP;
- Compared to other flat plate panels, the approx. 30% higher thermal efficiency of TVP panels allows either for reducing the solar field area or for achieving higher amount of non-renewable energy savings;
- 33–70% GHG emissions savings and 30-85% operation costs savings can be achieved, when we compare the performance of SunHorizon with a gas boiler system and an air conditioner;
- Without policy support it is difficult for the technology packages to be applied in the refurbishment of existing buildings.

If you want to know more about the project and follow up, visit the SunHorizon website: https://www.sunhorizon-project.eu/. ■

References

[1] European Commission (2016). Overview of support activities and projects of the European Union on energy efficiency and renewable energy in the heating and cooling sector.

[2] SunHorizon project https://www.sunhorizon-project.eu/.

Resizing radiators in the system

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Deep renovation

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

Example of renovation effect

When old buildings are renovated, the heating needs of the rooms become significantly smaller. It has been shown that even with old buildings the annual energy consumption can be reduced even to less than 50 kWh/(m²a). It is typical that the ratio of heating needs between different rooms also changes, for example, when additional thermal insulation cannot always be applied uniformly to all rooms. Improved ventilation also often changes the heating demand ratio between rooms. For these reasons, a proper new heating demand calculation must be made for the building to be renovated.

As an example, we look at the situation in a typical low-rise building of the 50s and 60s, where the energy consumption of a building is typically around 200 kWh/(m²a).

The comparison is made up of rooms of similar dimensions on the three floors of the building (**Figure 1**).

The calculation of heat demand is based on the instructions in the Energy Efficiency 2018 section of the Finnish Building Code. The starting values for the old building are taken from the appendix to the Ministry of the Environment's Energy Certificate Guide 2018 – typical original design values for existing old buildings.

Note! In the calculation example, a bidirectional ventilation system has been selected as the new ventilation system. Alternatively, the ventilation can be achieved with a unidirectional ventilation system, in which the heat of the exhaust air is transferred to the heating and domestic hot water by means of an exhaust air heat pump. In this case, the old radiators are replaced with supply air radiators.

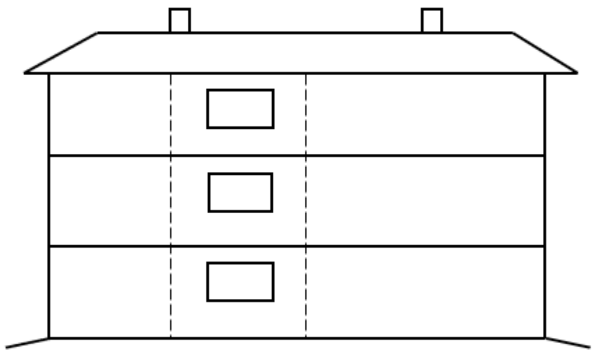

Figure 1. Similar rooms on three overlapping floors.

Calculation values	Old starting situation	Situation after renovation
Areas, m^2:		
• Floor area	20	20
• Outer wall	7	7
• Window 2.0x1.5	3	3
• Upper, middle and lower sole	20	20
Room height, m:	2.5	2.5
U-values, W/(m^2K):		
• Exterior walls	0.8	0.17 (+15 cm additional insulation)
• Windows and exterior doors	3.0	1.0
• Upper sole	0.5	0.1 (+25 cm additional insulation)
• Bottom base	0.5	0.5 (no additional insulation, earthy)
Ventilation, 1/h:	0.5 (stack ventilation)	0.5 (heat recovery η = 80%)
Other input data:		
• Cold bridges and infiltration of air according to calculation instructions.		
• Design temperatures indoor 21°C and outdoor –26°C		

Heat demand, W	Old starting situation	Situation after renovation	Compared to the old
• 1st floor	1304	429	33%
• 2nd floor	1119	244	22%
• 3rd floor	1604	353	22%

Conclusions

- If the old radiators were kept, the 1st floor (ground floor) room would require 50% higher relative output (33%/22% = 1.50) than the rooms on the other floors. The flow temperature control, the heating curve, is set according to the highest heating demand, i.e. according to the requirements of the 1st floor room. In this case, other rooms receive over-heated water, which leads to the continuous open-close operation of the thermostats, the fluctuation of the room temperatures and the imbalance of the heating network.
- In terms of energy efficiency, and especially when using a heat pump for heat production, it is recommended to replace the undersized 1st floor radiator with ones that are 50% bigger and thus more efficient, so that the flow temperature can be controlled at a lower heating curve level and uniformly for all radiators.

Recommendation

The heating network should be re-dimensioned, and the system valves modernized when the building is renovated with the goal of a nearly-zero-energy building level. There are several factors that have changed: heat demand, distribution of heat, temperature levels and water flows, and possibly a new way of heat production. Typically, the risers and transfer pipes are maintained, the static line control valves are replaced with automatic differential pressure regulators according to the new dimensioning, and the radiators are equipped with new pre-set thermostatic valves.

In many cases, old radiators are replaced throughout with new ones. In this way, the design temperatures can be selected optimally for both the heating system

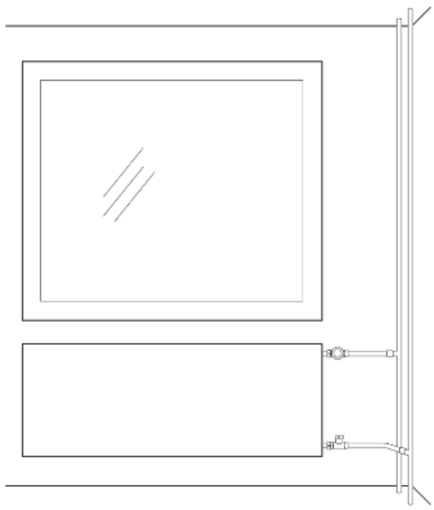

Figure 2. A properly dimensioned radiator has a large heat radiating surface. Radiator replacement is simplified when the connection pipes from the risers to the radiator valves are renewed if possible.

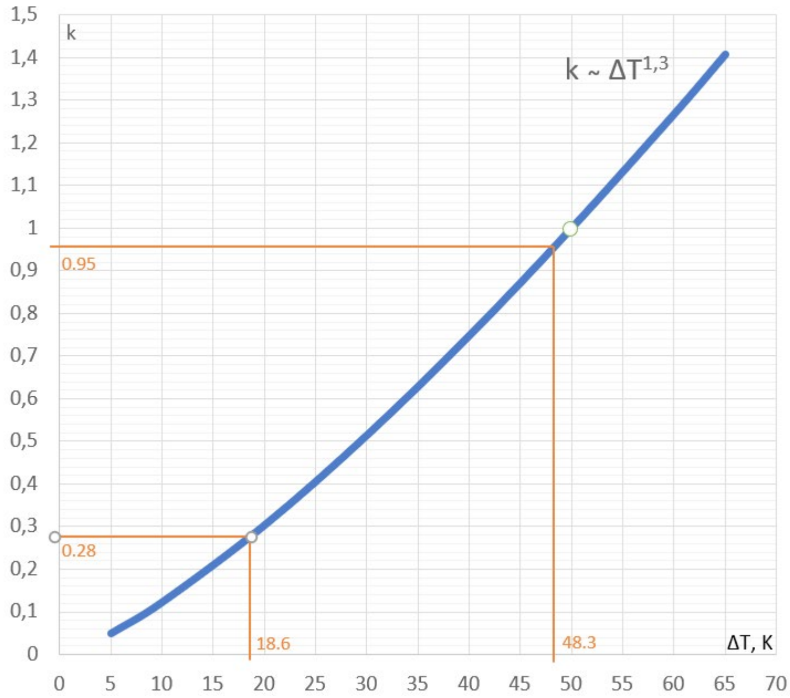

Figure 3. Dependence of radiator output ratio k on excess temperature ΔT. For example, the radiator output at an excess temperature ΔT18.6K ($T_{flow}/T_{rtn}/T_{in}$ = 45/35/21°C) can be calculated using a diagram when the radiator output is known at another excess temperature, for example ΔT48.3K (80/60/21°C) the output is 1000 W. New output is obtained: 1000 W · 0.28/0.95 = 295 W.

Radiator excess temperature

$$\Delta T = \frac{T_{flow} - T_{rtn}}{\ln \dfrac{T_{flow} - T_{in}}{T_{rtn} - T_{in}}},$$

where T_{flow} = flow temperature
T_{rtn} = return temperature
T_{in} = indoor temperature

Type	10	11	20	21	22	30	33
OP rate	1.00	1.59	1.75	2.12	2.64	2.40	3.63

Figure 4. Output ratios of panel radiators according to radiator type. The type designation describes the number of panels and convection plates. For example, type 21 means that the radiator has two water circulating panels and in addition one convection plate. For example, the output of type 22 is 2.64 / 1.59 = 1.67 times higher than the output of type 11 at the same width / height dimensions.

Height	300	400	450	500	600	900
OP rate	1.00	1.25	1.37	1.45	1.70	2.31

Figure 5. Output ratios of panel radiators according to height. For example, a 600 mm high radiator of the same type and width is 1.70 / 1.25 = 1.36 times higher than a 400 mm high one. The output of panel radiators is linear in proportion to their width.

and the heat production. All heat sinks in the building can be replaced at the same time which reduces the future replacement needs of individual radiators. This is a macroeconomic solution. The new radiators also enhance the aesthetic look of the rooms.

Recommended radiator network design temperatures:

- Heat pumps 45/35/21°C
- Combustion boilers 55/45/21°C
- District heating 60/30/21°C

Some tabular data related to the comparison of radiator output

The reference value k = 1.0 for ΔT50K in the diagram refers to the heat output capacity of the radiator reported in accordance with EN 442 standard.

The values shown in **Figures 3, 4 and 5** can be used for preliminary estimates. However, it is advisable to use more precise output calculation programs published by radiator manufacturers, for example. ■

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Effect of Portable Gas-Phase Air Cleaners on Indoor Air Quality




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This paper introduces a state-of-the-art review of portable gas-phase air-cleaning technologies on nonindustrial premises. The paper is based on a review of scientific papers. The opportunities and limitations regarding the available techniques are discussed. The paper addresses gas adsorption filtration, including adsorbent media, photocatalytic oxidation, air ion generators, ozone generators, and plants.

Portable gas-phase air cleaners use different technologies to remove gaseous pollutants, which include inorganic gases (e.g. carbon monoxide and nitrogen dioxide), ozone (O_3), and organic gases (e.g. volatile organic compounds (VOCs) and aldehydes). Hundreds of different gaseous pollutants have been detected in indoor air. Sources of inorganic gases include gas stoves, tobacco smoke, and vehicles. Sources of O_3 include infiltration from outdoors and O_3 generation from indoor sources, such as laser printers. Sources of organic gases include tobacco smoke, building materials, furnishings, animal metabolic processes, outdoor sources, cooking and plant products and such products as paints, adhesives, dyes, solvents, caulks, cleaners, deodorisers, cleaning chemicals, waxes, hobby and craft materials and pesticides. In addition, radon can also be found in indoor air. Portable air-cleaning devices are not effective at reducing radon levels in a building and are not recommended as a radon mitigation measure (Environmental Protection Agency (EPA), 2009).

There are six principal types of gas-phase air cleaners. The most commonly applied methods are adsorbent media air filters, such as activated carbon (AC), chemisorbent media air filters, photocatalytic oxidation (PCO), plasma, O_3 generators and plants.

Regardless of the type of technology, three requirements must be fulfilled. First, high filtration efficiency must be provided for a broad range of chemical substances. Second, low airflow resistance (small pressure drop) is required. Finally, the release or generation of harmful substances must be prevented. The performance of a portable gas-phase air cleaner depends on several factors:

- device flow rate, and velocity through the media
- filter type and efficiency,
- construction quality, which affects the air-bypass around the filter,
- gas concentration and types in the air,

- room conditions, such as air temperature and humidity, which affect the capacity of adsorbents to remove odours and chemicals, and
- unit placement in the room.

At least three primary descriptors of the efficiency of cleaning systems exist:
- the VOC degradation rate,
- the one-pass removal efficiency, and
- the clean air delivery rate [Li Puma et al., 2009; Mo et al., 2009] (initially defined by the Association of Home Appliance Manufacturers and well recognised by manufacturers), indicating the clean air volume delivered by the treatment system (usually in $m^3 h^{-1}$).

Summary of the reported technologies *

This summary **Table 1** is preceding the detailed descriptions and explanations regarding the different technologies to encourage the reader to dive into those details.

Table 1. *Summary of the technologies.*

Technology	Advantage	Disadvantage	Application
Adsorbent Media	• Gaseous pollutants adsorb on porous granular media or condense in pores of media. • Many types of sorbents with activated carbon most commonly used. • Widely available technology • Can remove broad range of gaseous pollutants with moderate to high efficiency	• Pollutants can be released from sorbent into indoor air • Low effectiveness for low molecular weight pollutants including formaldehyde • Must periodically replace sorbent • Sorbent lifetime for indoor air applications not well understood • Large amount of sorbent needed for long lifetime • High sorbent cost • Often high airflow resistance increasing fan energy use	• Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners
Chemisorbent Media	• Gaseous pollutants adsorb on and chemically react with porous granular media • Widely available technology • Can remove broad range of gaseous pollutants with moderate to high efficiency	• High chemisorbent cost • Often high airflow resistance increasing fan energy use	• Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners
Photocatalytic Oxidation	• Gaseous pollutants adsorb on a surface coated with a photocatalyst that is irradiated with a light source, usually a source of ultraviolet light; some adsorbed pollutants decompose • Can remove a range of gaseous pollutants • Usually lower airflow resistance than sorbents and chemisorbents, thus, lower fan energy use • Can destroy some bioaerosols • Many systems have low pollutant removal efficiency	• Lamp energy use • Cost of periodically replacing lamps • Photocatalysts become inactive, with unknown photocatalyst life • Incomplete breakdown of some pollutants can result in formation of new pollutants potentially harmful to health	• Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners
Air Ion Generators	• Radicals (small reactive molecules) created by electric discharge can oxidize and decompose volatile organic compounds and nitrogen oxides • Quiet and energy efficient • May improve particle removal performance of some particle air cleaners	• Very limited data available on pollutant removal performance in buildings • Can produce ozone, see comments on ozone air cleaners	• Usual application is a stand-alone portable air cleaner
Ozone Generators	• Ozone generated and released into indoor air can react with and breakdown some airborne volatile organic compounds • Quiet and energy efficient	• Releases ozone into indoor air and ozone is a harmful pollutant • Generally ineffective in significantly reducing airborne volatile organic compounds unless ozone concentrations are very high • Reactions of ozone with airborne volatile organic compounds can lead to production of formaldehyde and ultrafine particles that pose health risks	• Usual application is a stand-alone portable air cleaner
Plants	• Plants in buildings can remove some volatile organic compounds • Quiet and energy efficient	• Not proven to significantly reduce indoor pollutant levels with practical number of plants • Plants and molds on plants and soil can be a source of pollutants	• Plants placed throughout building or in attached greenhouse • One system forces air through plant root zone

* For more information, see the ASHRAE Position Document on Filtration and Air Cleaning.
https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf

Filtration – Gaseous Materials

Adsorbent Media

Several portable air-cleaning technologies are designed to either remove gaseous air pollutants or convert them into harmless by-products using a combination of physical and chemical processes. A variety of gas-phase air cleaners remove gases using adsorbent media, such as active carbon (AC), to adsorb the pollutants. Other forms of adsorbents are activated aluminium, silica gel, zeolites and organic synthetics (Spry, 2007). Adsorption is a mass transfer process in which gases collide with a solid surface, are attracted to a surface, and remain on the surface. A variety of VOCs can be adsorbed, but the process is typically inefficient for low molecular weight constituents and permanent gases (Daniels, 2007). The adsorption process can be divided into two main groups: physical adsorption (e.g. the adsorption of AC for gas) and chemical adsorption (e.g. activated alumina or AC impregnated with potassium or sodium permanganate, which reacts with formaldehyde and several other compounds) (Fisk, 2007, 2006). Physical adsorption has a very high surface area per unit mass because the adsorbents have extensive microscopic pores, and the process is reversible (i.e. adsorbed VOCs can be released and emitted back into the air). However, the chemical adsorption process is irreversible; consequently, the reacted compound is not subsequently released back into the air.

In general, the adsorption of organic compounds onto carbonaceous adsorbents is primarily controlled by five potential interactions: the hydrophobic effect, -bonds, hydrogen bonds, Van der Waals interactions, and covalent and electrostatic interactions (Wang et al., 2013). Biochar is a kind of carbon material prepared by slow pyrolysis of biomass under an inert atmosphere similar to AC. The production of biochar might result in the release of VOCs, such as methanol, acetic acid, acetone, methyl acetone and acetaldehyde (Tiilikkala et al., 2010). However, biochar has high adsorption efficiency and low cost, so it still has excellent potential for VOC adsorption.

Schieweck (2020) conducted a systematic experimental study dedicated to the removal of museum pollutants. The authors assessed the filtration efficiency of 37 different adsorbent media under both active and passive conditions (with and without forced air exchange). Adsorbents comprised ACs with and without impregnation, including AC cloths, carbon-coated foams, natural and synthetic zeolites, molecular sieves, silica gels, archival cardboard, polymer-impregnated matrixes, and others. The results revealed that the filtration of formaldehyde was challenging for nearly all adsorbents tested. Just 5 out of 37 products exhibited very good (one-pass removal efficiency > 80%) or good performance (removal efficiency > 60%).

Réguer et al. (2011) studied the effect of varying toluene concentrations on the breakthrough from ACs. The breakthrough curves were modelled and experimental made at an inlet concentration 10 times higher than the indoor air level. The results concluded that the henry coefficient (the ratio between the concentration of toluene in ACs at equilibrium and the concentration of toluene in the gas phase at equilibrium) stayed the same at the varying concentration. Weschler et al. (1992) installed panels filled with AC in a test duct with a 0.61 m by 0.30 m cross-section and measured VOC concentrations upstream and downstream of the AC with passive samplers. The air entering the test duct was drawn from indoors; thus, the test duct simulated real deployment. The test duct contained six 2.54-cm-thick carbon-filled panels installed in a zig-zag pattern. The total panel face area was 2.0 m^2, and the total mass of AC was 20.4 kg (45 lb). The airflow rate through the duct was 0.28 m^3/s; thus, the nominal retention time in the carbon bed was 0.18 s, well above the recommended minimum of 0.1 s. The system contained 73 kg of carbon per 1 m^3/s of airflow (75 lb per 1000 cfm). The long-term study results of adsorbent performance in a single building demonstrated the initial efficiency and efficiency after 18 months for toluene at 90% and 90%, for p-xylene at 80% and 90%, and for o-xylene at 60% and 70%.

Xiao et al. (2018) developed an *in situ* thermally regenerated air purifier (TRAP) comprising two chambers and three valves. The switching of the values enabled pollutant adsorption, adsorptive material recycling, and outdoor air intake. Chen et al. (2019) developed a novel flexible adsorption board module with an adjustable surface temperature fabricated with AC, polyimide, and copper foil, as illustrated in **Figure 1**. Its laminated structure reduced airflow resistance by two orders of magnitude compared with the packed adsorption bed. The built-in copper foil generated Joule heat rapidly and efficiently delivered this heat to the adsorbent, effectively reducing energy consumption. The overall removal efficiency of the fabricated laminated plate was about 30% at the face velocity of 0.8 to 1.2 m/s. The pressure drop was about 5 Pa. Its removal ability can be regenerated *in situ* in 8 min by increasing the surface temperature to 80°C. The fabricated laminated plate exhibited good durability after 52 cycles of adsorption-regeneration tests. Chen et al.

(2021) proposed a vertical macro-channel modified method to achieve rapid diffusion into the adsorbent during the initial adsorption period. Regular, vertical macro-channels through the adsorption board based on the study by Chen et al. (2019) were fabricated using laser drilling to enhance the mass transfer inside the board. The experimental results demonstrated that, after modification, the penetration times for formaldehyde and xylene extended from 3.8 to 6.2 h and from 62 to 99 h, respectively. The simple macro-channel modification of the adsorption board may be used as an alternative design for adsorption applications in indoor air purification.

The study results by Bayer and Hendry (2005) illustrate the difficulties of evaluating adsorbent system performance in uncontrolled field studies. The VOC concentrations can be low, leading to significant measurement errors.

Photocatalytic Oxidation

The PCO process is where, upon adsorption of a photon, a semiconductor acts as a catalyst in producing reactive radicals, primarily hydroxyl radicals, which can oxidise organic compounds and mineralise them (Goswami, 2003). Common photocatalysts in PCO are titanium dioxide (TiO_2), zinc oxide (ZnO), tungsten trioxide, zinc sulphide, and cadmium sulphide (Gaya and Abdullah, 2008; Tseng et al., 2010). Photocatalytic active coatings made of the semiconductor TiO_2 (Mo et al., 2009) have been developed for indoor air application. In its anatase modification, TiO_2 has a bandgap of 3.2 eV and can be activated under ultraviolet (UV) light (λ = 387 nm). By light irradiation with a corresponding wavelength, electrons from the valence band are transferred to the conduction band, forming electron-hole pairs (**Figure 2**). Compared with conventional PCO under UV light (254 or 365 nm), vacuum UV (VUV) light can significantly enhance photocatalytic degradation efficiency. Moreover, by providing a strong oxidation environment and preventing the generation and accumulation of intermediates, VUV light reduces catalyst deactivation (Huang et al., 2017; Shayegan et al., 2017). Despite these benefits, performing PCO with VUV lamps produces O_3 molecules as a by-product. Moreover, O_3 is a powerful oxidising species that can react with VOC pollutants and promote photocatalytic efficiency. However, residual O_3 can damage the environment and human health.

The excited electrons can proceed in a single-electron reduction and, in the presence of O_2, form a superoxide radical anion O_2 •−. Simultaneously, the electron holes (h+) can react with H_2O to yield hydroxyl radicals OH• (single-electron oxidation). These resulting radicals are highly reactive and can degrade a wide range of VOCs and potentially mineralise VOCs into less harmful oxidation products, such as water and carbon dioxide (Héquet, 2018; Mo et al., 2009; Pelaez et al., 2012). The application of TiO_2 for photodegradation of organic contaminates has generated significant attention due to its unique characteristics and environmental friendliness (Ji et al., 2017; Tejasvi et al., 2015).

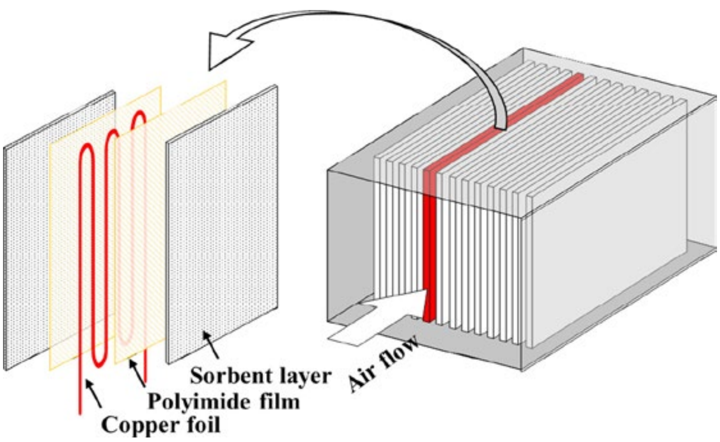

Figure 1. Illustration of the surface temperature adjustable laminated plate structure (left) and the air purifier module comprising multiple parallel plates (right). (Chen et al., 2019)

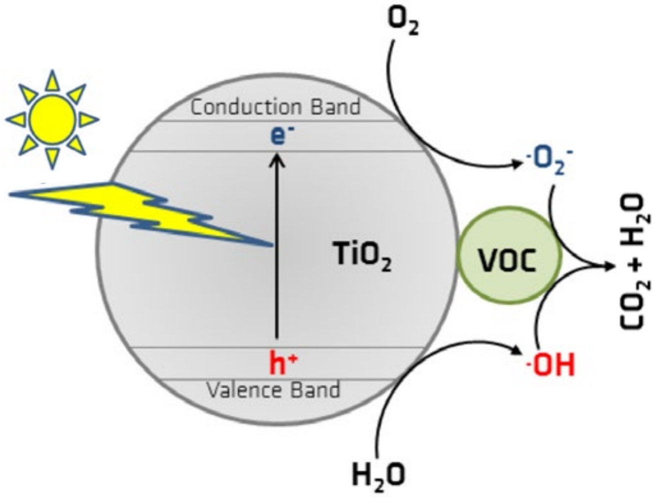

Figure 2. Schematic representation of photocatalytic oxidation of a volatile organic compound (VOC) (Mull et al., 2017).

Destaillats et al. (2012) studied the degradation of seven VOCs using a prototype air cleaner provided with flat or pleated PCO filtering media in a 20-m³ stainless-steel chamber at ACH = 1 h−1 under realistic indoor conditions. The media was made of quartz fibres (9 µm in diameter) coated using a sol-gel process with a mixture of 10% to 25% of nanosized TiO_2 and 50% to 90% of silicon dioxide and with a BET specific surface area of 120 $m^2 g^{-1}$. The authors measured the VOC removal efficiency of PCO air purifiers with airflow from 178 to 878 $m^3 h^{-1}$. The results indicate that the VOC concentration decreased only marginally across the PCO air purifiers at high airflow rates, whereas a decrease in the airflow rate increased the VOC removal efficiency from 5% to 44%. Thus, the PCO cleaning efficiency is not improved when the air recirculation rate is set at higher values.

Zhang and Hsieh (2020) demonstrated a dual-functional polyester fibrous air filter consisting of self-assembled TiO_2 nanoparticles and percolated silver nanowires with high air permeability, electrostatic particulate matter removal, and photocatalytic formaldehyde decomposition abilities. With the aid of the decorated photocatalytic TiO_2 nanoparticles, the same network can effectively degrade gaseous formaldehyde under UV irradiation.

Air Ion Generators

Air ions are electrically charged molecules or atoms in the atmosphere (Goldstein and Arshavskaya, 1997). An air ion is formed when a gaseous molecule or atom receives sufficiently high energy to eject an electron (Laza, 2000). Negative air ion (NAI) generators gain electrons, whereas positive air ion generators lose electrons. Several types of negative air ion generators are based on corona discharges, thermionic electron emission, photoexcitation, and the Lenard effect for creating NAIs (Lin and Lin, 2017). Among these mechanisms, the corona discharge is an efficient method to generate NAIs. When a high negative voltage is applied to a conductor/electrode and the generated electric field is sufficiently high, corona discharge occurs (Altamimi et al., 2014; Ogar et al., 2017). This type of NAI generator has been commercialised and is the most commonly employed variant. The schematic picture of this technology is presented in **Figure 3**. Under certain use conditions, ion generator air cleaners can produce levels of O_3 significantly above those thought to be harmful to human health (EPA, 2021).

Wu and Lee (2004) reported that no by-products were generated at a discharge voltage below 16.0 kV. The concentrations of O_3 and nitrogen oxides (NOx) increased with the discharge voltage above 17.0 kV. Therefore, the discharge voltage should be set at 15.0 kV to avoid the generation of O_3 or NOx.

Air ionisation systems have been installed in domestic and office locations to improve indoor air quality. They have also been installed to control volatile compounds and particulates in institutional, commercial and industrial locations.

Daniels (2001) investigated a case study where an air ionisation system was installed in a large engineering centre (Siemens AG, Berlin) with several hundred office workers in a multi-floor facility. Indoor VOCs and O_3 levels were measured continuously in this facility during operational periods with and without air ionisation. The author reported reductions in the levels of 59 specific VOCs representing nine broad classes. For instance, the total VOC (TVOC) level reduced by 50%, and the aromatic substances reduced by 47%. The arithmetic average over one month of operation without air ionisation was 0.7 ppbv, with a maximum of 5.8 ppbv. The arithmetic average over one month of operation with air ionisation was 6.6 ppbv, with a maximum of 14.4 ppbv. The levels in the outside air were not measured directly but were calculated in the range of 10 to 20 ppbv.

Daniels (2001) investigated another case study involving a billing centre near a major international airport (Visa, Zurich) where office workers were subjected to exhaust gases from ground transportation and aeroplane jet engines. Three representative VOCs were

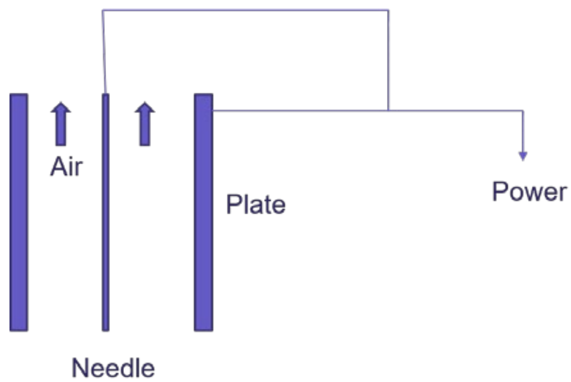

Figure 3. Schematic view of the corona discharge ioniser technology (Rahimi, 2013).

quantitated with and without ionisation. The results indicated that the concentration levels of isooctane, benzene and toluene reduced by approximately 35%, 58% and 46%, respectively.

Air ionisation systems have also combined with air filtration to enhance the removal of VOCs and particulates. Tian et al. (2020) proposed and fabricated new electrostatically assisted heterocaking (EAHC) filters using polyurethane (PU) foam with an extremely low pressure drop as base filters and heterogeneously loading high-ε_r heterocaking (HC) (including manganese dioxide, AC, ZnO, copper oxide, and barium titanate). The schematic of the EAHC air filter module is presented in **Figure 4a**. **Figure 4b** presents the schematic of HC fibres in a polarising field compared with standard filter fibres. Some indoor hazardous gases, such as O_3 and formaldehyde, are expected to be removed when the loaded HC fibres are made of an adsorbent or catalyst. The HC filter preparation process is displayed in **Figure 4c**. The quantitative experiments revealed that the EAHC filter has high single-pass filtration efficiency for airborne PM, O_3, and formaldehyde and has a low pressure drop and low power dissipation. Tian et al. (2021) and Gao et al. (2021) developed new surface coatings on the filtration fibers and dramatically reduced particles and ozone synchronously.

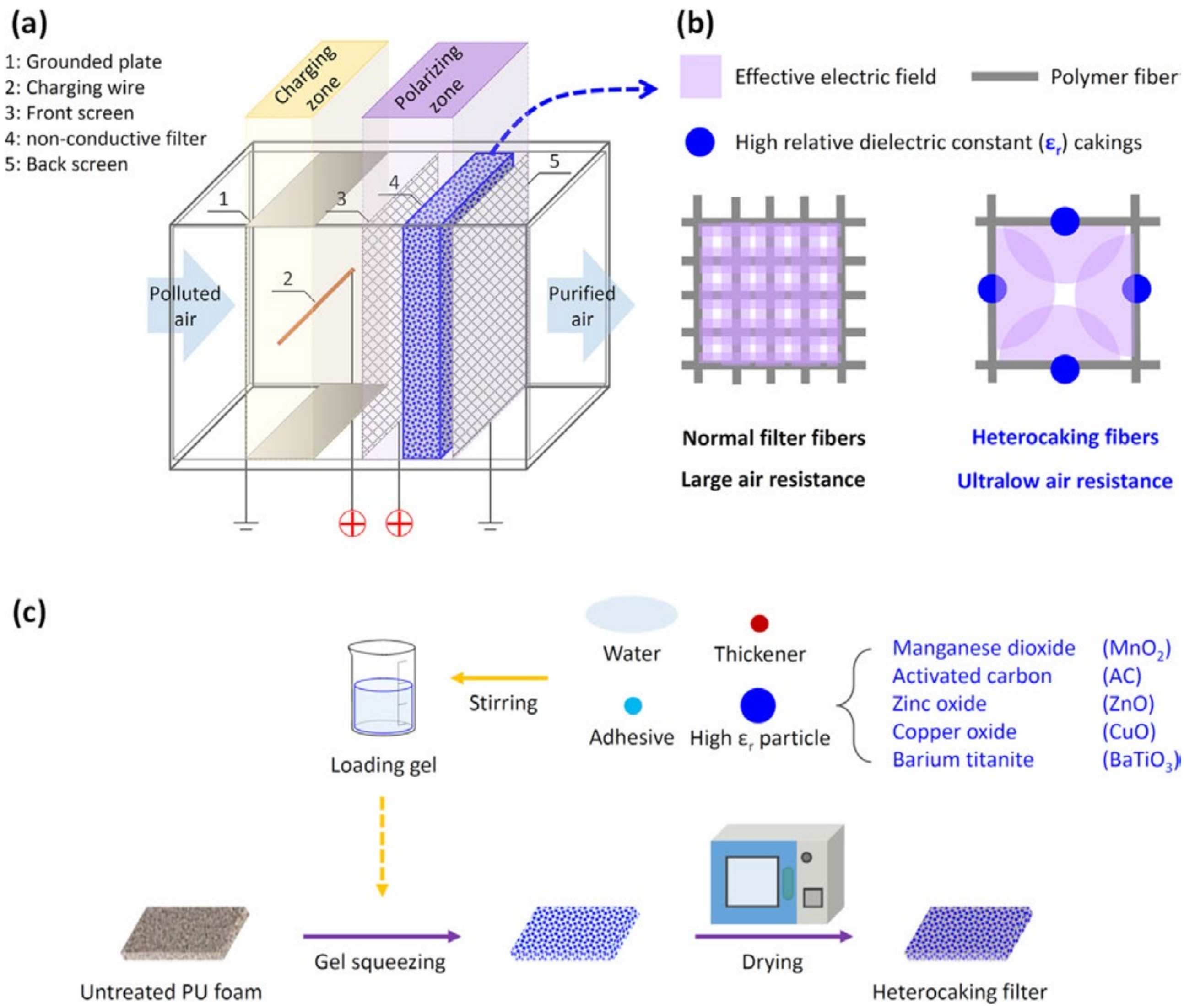

Figure 4. (a) Schematic of the electrostatically assisted heterocaking (EAHC) air filter module, (b) schematic of heterocaking (HC) fibres in a polarising field compared with standard filter fibres, and (c) preparation process of HC filters by a fast and large-scale roll-to-roll gel squeezing method. (Tian et al., 2020).

Chen et al. (2020) developed an ioniser-assisted filtration method with an external electrostatic field to efficiently remove gaseous diisobutyl phthalate and dibutyl phthalate. They used low pressure drop PU foam as substrate filters and loaded fine AC powder into PU foam as PU-C foam. The proposed method has developed a new filter based on the existing inexpensive coarse filter, which is easy to implement for the active control of gaseous PAEs.

Ozone Generators

An O_3 generator is a device that produces O_3 by adding energy to oxygen molecules (O_2), which causes the oxygen atoms to separate and temporarily recombine with other oxygen molecules. The process can be accomplished in the following methods: corona discharge and UV radiation. The corona discharge produces O_3 through a method equivalent to lightning, and the UV radiation method is comparable to how the sun's UV radiation splits O_2 molecules to form individual oxygen atoms. **Figure 5** illustrates how a corona discharge O_3 generator operates.

Ozone generators have been used to control indoor air pollution. However, O_3 is associated with adverse health effects, and it is vital to ensure that people and pets are not exposed to high levels of O_3. In addition to the harmful effects of O_3 itself, indoor O_3 can react with building materials, furnishings, and other indoor chemical compounds. Long et al. (2000) studied the indoor chemical reactions involving O_3 and found that the chemical reactions can be a significant source of indoor ultra-fine particles. Shaughnessy et al. (1994) reported that O_3 generators are not effective in removing carbon monoxide. In addition, Esswein and Boeniger (1994) reported that O_3 generators are not effective in removing carbon formaldehyde. Weschler et al. (1992) conducted a laboratory experiment that mixed O_3 with chemicals from new carpets. The authors reported that O_3 reduced many of these chemicals, including those that can produce new carpet odour. However, in the process, the reaction produced a variety of aldehydes, and the total concentration of organic chemicals in the air increased rather than decreased after the introduction of O_3. The reaction rates of O_3 with most VOCs were slow in indoor environments because the characteristic residence times of air and pollutant mixtures in typical indoor settings were too short for the reactions to proceed effectively (Weschler, 2000). Chen et al. (2005) evaluated several air cleaners in the indoor environment and found low VOC removal efficiencies by O_3-based air purifiers and that the indoor O_3 could be at unsafe levels.

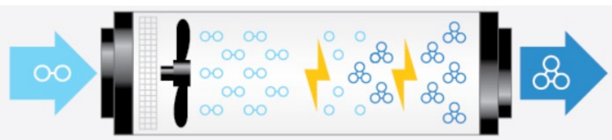

Figure 5. Visualisation of how a corona discharge ozone generator operates (Ozone solutions. 2021). https://ozonesolutions.com/blog/what-is-ozone/

Plants

Several articles have described air-cleaning plants used by NASA (Wolverton, 1996). Wolverton et al. (1989) found that indoor plants can scrub the air of TVOCs, such as formaldehyde and benzene. Orwell et al. (2004) found that soil microorganisms in potted plants also play a part in cleaning indoor air. In another study, Kim et al. (2010) examined 86 species of houseplants from five general classes for their ability to remove formaldehyde. In their experiments, ferns had the highest formaldehyde-removal efficiency of all the plants tested, especially *Osmunda japonica*, commonly known as the Japanese royal fern or *zenmai*. These research studies have positively shown that potted plants could reduce TVOCs from 10% to 90% in 24 h (Llewellyn and Dixon, 2011). In another study, Larsson (2004) examined formaldehyde and TVOCs. The author concluded that the indoor plants reduced formaldehyde by 0.1 to 1.0 mg FAD m^{-2} h^{-1} during the daytime, and the reduction for TVOCs was 0.1 to 2 mg TVOC per m^{-2} h^{-1} during the daytime. The author stated that none of the above-reported effects were considered so critical that they would become an applicable tool in altering indoor air quality.

Energy

Middlebrooks (2000) compared pressure drops in three systems with the same mass of granular AC and a 1.0 m/s (200 fpm) face velocity. The reported pressure drops were 38 Pa in the system with 20 to 50 mesh carbon bonded to a pleated nonwoven media, 640 Pa with 20 to 50 mesh carbon in trays, and 75 Pa (0.3-inch H_2O) with seven-fold larger 4x8 mesh carbon in trays.

The advantages of PCO are the relatively low pressure drop, ability to treat a wide variety of compounds, and the theoretically long lifecycle of the reactive process. The disadvantages include the electricity used in the lamps and ballasts if fluorescent lamps are used. The power consumed by the largest model is equivalent to 3- to 100-watt standard light bulbs (AiroCide, 2021).

Ozone is produced industrially by bombarding oxygen with UV radiation or passing air through a high-voltage alternate current electrical discharge. Therefore, along with the oxygen requirement, power is also an important consideration. This kind of system typically uses a medium frequency from 800 Hz to 1000 Hz. The O_3 concentrations increase with augmented power. Ozone produced from the air may require up to 15 W/g of O_3, as the power cost of air compression must be included in the cost of O_3 production (Baratharaj, 2013).

Conclusion

Adsorbent-based gas-phase air cleaning is effective for removing a variety of gases, vapours and odours if appropriate types and amounts of adsorbents are used. This removal may impose quite a high pressure drop. The filter replacement interval is of significant importance.

Moreover, PCO has high conversion efficiencies for VOCs at a low pressure drop. However, PCO air cleaners produce O_3 molecules as a by-product. The NAI generator air cleaners can, under certain conditions, produce levels of O_3 and NOx significantly above the levels thought to be harmful to human health.

In addition, available scientific evidence indicates that O_3 is generally ineffective at controlling indoor air pollution at concentrations that do not exceed public health standards. In the process of reacting with chemicals indoors, O_3 can produce other chemicals that can be irritating and corrosive. Many factors affect O_3 concentrations produced by machines that generate O_3, including the amount of O_3 produced by the machines, size of the indoor space, amount of material in the room with which O_3 reacts, outdoor O_3 concentrations and ventilation. These factors make it challenging to control O_3 concentrations.

Throughout this review, we found that additional research is needed for more reliable conclusions on the long-term performance of portable gas-phase air cleaners, the noise level of the portable air cleaners when working at full capacity, O_3 emission rates, energy use and related costs. In addition, examinations should be conducted in the laboratory and field to compare the performance of portable air cleaners in a well-controlled laboratory environment to that in a real situation. In addition, the performance criteria that must be met to use portable air cleaners must be defined, and the testing criteria for room air cleaners must be specified. ■

References

Please find the list of references in the html version of this article at rehva.eu

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TripleA-reno:

Combined Labelling Scheme of Dwellings



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Introduction

The overall objective of the TripleA-reno project is to increase acceptance of - and facilitate decision making on - deep and nZEB renovation for consumers and end-users of residential buildings. As part of the project, the aim was to develop a combined labelling scheme for dwellings, which includes energy performance, indoor environmental and well-being indicators. The excel template of the combined labelling scheme can be downloaded in the references list [1], the webtool of the combined labelling scheme will soon be available on the TripleA-reno website [2]. This article is based on a conference paper from Cold Climate 2021 which introduced the Combined Labelling Scheme of dwellings [3].

Why is the combined labelling scheme necessary?

The renovation of building stock plays a major role in meeting the energy efficiency targets set in the EU Member States. This weighted annual energy renovation rate is calculated to be about 1%. If this rate persists, the building sector will clearly and significantly fail to deliver its share of the overall need for primary energy reduction and, consequently, reduce greenhouse gas emissions [4].

After performing an assessment on the existing certification schemes, we found that there is no combined labelling scheme available yet with a focus on dwellings which combines indicators on energy performance, indoor environmental quality and well-being together. M.A. Ortiz et al. studied [5] the well-being and the interaction between influencing factors and concludes the energy use is a consequence of trying to attain homeostasis (comfort, neutral state, lack of stress). This means that people use energy to satisfy their needs and to achieve well-being. In line with this result, the TripleA-reno combined labelling focuses on end-users and informs them about the energy performance and well-being aspects of their homes. The well-being and IEQ indicators label the technical building systems' capabilities from well-being and IEQ point of view. However, in order to know what figures are realised in the analysed residential building or apartment, a series of on-site measurement of parameters that influence IEQ and well-being is also necessary.

TripleA-reno combined labelling: energy performance, indoor environmental quality, well-being

The methodology used of the most important certification schemes was reviewed, including regulations and standards, in order to determine the relevant indicators and requirements. As a result of the assessment, the TripleA-reno combined labelling scheme was developed, which includes the following indicators:

Table 1. *Combined labelling indicators and main features.*

Indicators	Main features
Energy performance	Both calculated and measured energy uses are presented.
Indoor environment and well-being	IEQ and well-being capability of the building and technical building systems.
Measured indoor environment and well-being	Based on measured figures, related to the specific dwelling and dependent on occupant habits.

This article is prepared within the scope of the TripleA-reno project, which has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement number 784972. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' views.

Energy performance indicators

The calculated total primary energy use is included in the TripleA-reno labelling scheme. According to the EPBD, the primary energy consumption for dwellings takes into account only the energy consumption of heating, cooling, domestic hot water and ventilation. Household electricity is not considered when primary energy consumption of different residential buildings or building units is compared. However, from the end-user point of view, the calculated total primary energy consumption may be too difficult to understand; furthermore, there are significant differences among primary energy factors of different energy sources. Therefore, it makes sense to show the delivered energy use besides the total primary energy use.

Regarding the type of energy use, both the calculated and measured delivered energy uses are included in the TripleA-reno labelling. The calculated delivered energy use is an objective way to evaluate the energy performance, while measured energy can be a useful indicator to compare energy consumption before and after deep renovation. The energy consumption monitoring can be implemented based on measurements from power and gas meters and thermal flow meter for district heating/cooling or consumption bills (e.g. oil, biomass).

There are several different building structures with varying thermal transmittances (U-values) in buildings, e.g. walls, roofs, windows. The area-weighted average is a simple mathematical technique for combining different amounts of various components into a single number. The area-weighted average thermal transmittance is included as an energy performance indicator in the TripleA-reno combined labelling as it is useful when comparing building structures before and after the renovation, or when one compares the energy characteristics of structures in different buildings. The area-weighted average thermal transmittance regards only the above-ground structures.

The EPBD recast defines that the energy requirements of nearly zero energy building should be covered to a significant extent from renewable sources [6]. The share of renewable energy use in the total primary energy use is included in the TripleA-reno combined labelling.

Table 2. *Features of the energy performance indicators of TripleA-reno combined labelling.*

Nr.	Name, unit	Reference/ description	Source
1.1	Energy efficiency class [-]	Align with national energy performance certification (EPBD) and EN ISO 52003-1.	EPBD
1.2	Calculated total primary energy use, [kWh/m²a]	EN ISO 52000 standard series.	Level(s)
1.3.1	Calculated delivered energy use (fuel), [kWh/m²a]	EN ISO 52000 standard series.	Level(s)
1.3.2	Calculated delivered energy use (electricity), [kWh/m²a]	EN ISO 52000 standard series.	Level(s)
1.3.3	Calculated delivered energy use (district energy), [kWh/m²a]	EN ISO 52000 standard series.	Level(s)
1.3	Calculated delivered energy use, [kWh/m²a]	Sum of all calculated delivered energy use.	Level(s)
1.4.1	Measured delivered energy use (fuel), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	–
1.4.2	Measured delivered energy use (electricity), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	–
1.4.3	Measured delivered energy use (district energy), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	–
1.4	Measured delivered energy use, [kWh/m²a]	Sum of all measured energy use.	–
1.5	Share of renewable energy sources, [%]	Renewable primary energy use divided by total primary energy use: $$RER_P = \frac{\sum E_{Pren}}{\sum E_{Ptot}}$$	N ISO52000-1 equation 17
1.6	Area weighted average thermal transmittance, [W/m2K]	Regarding the above- ground structures: $$\bar{U} = \frac{\sum Ai \cdot Ui}{\sum Ai}$$	–

Well-being and IEQ indicators

In the developed TripleA-reno combined labelling, the well-being and IEQ indicators focus on the most critical features of the technical building systems, which on the one hand influence IEQ and occupant well-being in residential buildings, and on the other these can be improved through renovation. The following indicators are included:

- The first two indicators are control over both heating & cooling systems. Having control over the room temperature is more effective than at apartment or building-level to adapt the indoor temperature according to the specific needs of the occupants. As opposed to a central building system where occupants only have limited influence.
- The third indicator to measure is the supply of airflow per person with mechanical ventilation. If the air change rate is inadequate, the concentration of indoor contaminants, such as CO_2 and VOC, will increase, which reduces the indoor air quality and occupants' well-being which in turn has a negative influence on the occupants' health. Natural ventilation is not within the TripleA-reno labelling scope as the project focuses on existing buildings.
- Air-tightness of windows and doors is the fourth indicator, which is not directly included in the labelling schemes we've reviewed. Low air-tightness of windows can cause discomfort for occupants, especially during winter when a draft can occur. Furthermore, low air-tightness increases infiltration, which results in higher heating and cooling energy consumption.
- Exterior shading is the fifth indicator of the TripleA-reno combined labelling. The exterior shading can provide better thermal comfort, since the temperature of indoor spaces and the glass of windows will be limited, and on the other hand the same indoor temperature can be kept with lower energy use in the cooling season when using exterior shading.
- The sixth indicator of the TripleA-reno combined labelling provides information to the occupant on the radiant heating/cooling systems to asses if they operate in at least 50% of the conditioned floor area.

Table 3. *Well-being and IEQ indicator of TripleA-reno combined labelling.*

Nr.	Name, unit	Reference/categories	Source
2.1	Control of the heating system	1. No heating system 2. No control 3. Central (building) temperature control 4. Apartment temperature control 5. Room temperature control	–
2.2	Control of the cooling system	1. No cooling system 2. No control 3. Central (building) temperature control 4. Apartment temperature control 5. Room temperature control	–
2.3	Supply air flow per person (in case of mechanical ventilation) [l/s, pers]	EN 16798-1 category I, II, III fresh air flow per number of occupants	Level(s)
2.4	Air-tightness of windows and doors	1.Poor air-tightness: warped, poorly fitted or unsealed windows and doors. 2.Medium air-tightness: windows and doors with well-fitted sealings. 3.Good air-tightness: factory-fitted shaped sealing profiles or certification document according to EN 12207 Class 4	–
2.5	Exterior shading [%]	Percentage of the windows with exterior shading. Windows are taken into account only from East to West.	–
2.6	Radiant heating and/or cooling system [%]	Radiant heating and/or cooling system (floor, wall, ceiling) operates in rooms at least 50% of the conditioned floor area	WELL
2.7	Radiant temperature asymmetry	Radiant temperature asymmetry meets ISO 7730 Category B requirement	ISO 7730

Measured well-being and IEQ indicators

TripleA-reno focuses on motivating the renovation of residential buildings; therefore, parameters have been collected that significantly affect the occupants' well-being and IEQ in residential buildings which can be improved through renovations. Operative temperature, relative humidity and CO_2 concentration are the parameters that people are most sensitive about. The operative temperature and CO_2 have to be evaluated through categories of the EN 16798-1 standard. They can be placed within a certain category if 85% of the measured data falls within the range of that category. The relative humidity has to be in the comfort range, which is between 25 and 70%RH.

The most common air contaminants, such as TVOC and formaldehyde, are taken integrated in the TripleA-reno labelling. Building materials, furnishings, fabrics, cleaning products, personal care products and air fresheners can all emit volatile organic compounds (VOCs) into the indoor environment. Owing to VOCs' complexity, the individual health effects can vary greatly in different cases. Long-term exposure to even low TVOC concentrations can lead to a variety of symptoms including increased perception unpleasant odours and tastes, irritation of eyes/nose/throat, dry skin and itching, increased sensitivity to infections of the respiratory tract, neurotoxic symptoms (fatigue, headaches, reduced mental performance).

Formaldehyde (HCHO) can be released from plastics, furniture, and adhesives in homes, which can be further concentrated in the living space during the winter. Formaldehyde is a colourless aldehyde gas and, similar to TVOC, even small quantities of formaldehyde in the room air may affect human health. The symptoms include concentration disorders, nervousness, headaches, dizziness, but also nausea, swelling of the mucosa, conjunctival irritations and lacrimation [7].

In the TripleA-reno labelling, the allowed concentration of TVOC for the well-being limit was taken from the WELL [8] and LEED [9] labelling schemes and is set at 500 µg/m³. However, the costly and complex laboratory analysis (ISO 16000-6) is not required because the TVOC measurement is only informative. The allowed concentration of formaldehyde was taken from the WHO and is set at 100 µg/m³. The laboratory analysis (ISO 16000-3) is not a requirement because the formaldehyde measurement is informative. The allowed concentration of PM2.5 and PM10 was taken from WELL labelling scheme: PM2.5 = 15 µg/m³, PM10 = 50 µg/m³. The measurement can be implemented with a light-scattering airborne particle counter in accordance with ISO 21501-4.

Table 4. *Measured well-being and IEQ indicators of TripleA-reno combined labelling scheme.*

Nr.	Name, unit	Reference/categories	Source
3.1	Operative temperature – heating* [°C]	Measured data compared to EN 16798-1 temperature ranges.	–
3.2	Operative temperature – cooling* [°C]	Measured data compared to EN 16798-1 temperature ranges.	–
3.3	Relative humidity of indoor air is between 25% and 70% [%RH]	Measured data compared to 25 to 70%RH	–
3.4	CO_2 concentration [ppm]	Measured data compared to EN 16798-1 categories.	–
3.5	TVOC [µg/m³]	Measured data compared to the limit (500 µg/m³)	Well-being limit adapted from WELL, LEED
3.6	Formaldehyde [ppb]	Measured data compared to the limit (100 µg/m³)	WHO IAQ guideline 2010, 30 min mean value
3.7	PM2,5 [µg/m³]	Measured data compared to the limit (15 µg/m³)	Well-being limit adapted from WELL (The WHO annual mean is 10 µg/m³)
3.8	PM10 [µg/m³]	Measured data compared to the limit (50 µg/m³)	Well-being limit adapted from WELL (The WHO annual mean is 20 µg/m³)

* During the site survey operative temperature in the heating season or the cooling season has to be measured according to the actual season.

Required measurements

The requirements of the measurements are summarised shortly in this section. The measurement place is the living room. The operative temperature, the relative humidity and the CO_2 concentration of indoor air should be measured for at least one week by 5-minute time series. The measured data of indoor temperature and CO_2 concentration has to be compared to the ranges of EN 16798-1 standard, while the relative humidity has to be compared to the comfort range that is from 25 to 70%RH. The TVOC and the formaldehyde measurements should be completed two times on the spot, at the beginning and the end of one-week measurements of temperature, relative humidity and CO_2 concentration. The measurement of PM2.5 and PM10 should also be completed two times on the spot, but it requires at least 30-minute-long measurements, at the beginning and the end of one-week measurements of temperature, relative humidity and CO_2 concentration. During the evaluation of the measured figures, the category satisfied by at least 85% of the measured figures must be chosen.

Labelling

The energy performance indicators express the energy characteristic of the building, which contains the energy efficiency class, the calculated and the measured energy use, which are displayed to the end-user one by one. The energy efficiency class (A+, A, B, C, ...) of the analysed dwelling clearly conveys the energy efficiency

Table 5. *Scoring of the well-being and IEQ indicators.*

Nr.	Name	Scores
2.1	Control of the heating system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
2.2	Control of the cooling system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
2.3	Supply air flow per person (in case of mechanical ventilation)	Fresh air flow per number of occupants meets EN 16798-1 category I, II: 20 points Fresh air flow per number of occupants meets EN 16798-1 category III: 10 points Less than EN 16798-1 category III: 0 points
2.4	Air-tightness of windows and doors	Good air-tightness: 10 points Medium air-tightness: 5 points Poor air-tightness: 0 point
2.5	Exterior shading	10 points for 100% of windows from East to West have exterior shading 9 points for 90%-99% 8 points for 80-89% 7 points for 70-79% 6 points for 60-69% 5 points for 50-59% 4 points for 40-49% 3 points for 30-39% 2 points for 20-29% 1 point for 10-19% 0 point for 0-9%
2.6	Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area	Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area: 10 points Radiant heating and/or cooling system operates in rooms less than 50% of the conditioned floor area: 0 points
2.7	Radiant temperature asymmetry	Radiant temperature asymmetry meets ISO 7730 Category A or B: 10 points Radiant temperature asymmetry meets ISO 7730 Category C or worse: 0 points

of the current condition. The calculated figures, such as total primary energy use, delivered energy use per energy sources, measured energy use per energy sources, the share of RES and the area-weighted average thermal transmittance provide information on the main energy characteristics of the analysed dwelling.

Concerning the joint assessment of well-being and IEQ, the labelling output is put in one class to ensure a user-friendly output. However, the labelling presents not only the result (the achieved class) but also all indicators with their gained and theoretical maximum points, which details the result and provides information on what should be improved. The steps to label the well-being and IEQ indicators are:

1. Score calculating: the relevant well-being and IEQ indicators gain points according to **Table 5** and **Table 6**.
2. Sum the gained scores of the relevant indicators.
3. Sum the theoretical maximum scores of the relevant indicators. These include maximum points for all the relevant indicators. For example, if there is no cooling system or mechanical ventilation system in the building, those will not be concerned when calculating maximum points that can be achieved.
4. Calculate the percentage of total gained points / total theoretical maximum points.
5. Labelling based on the calculated percentage of total and theoretical maximum points according to **Table 7**.

Table 5 demonstrates the well-being and IEQ indicators scoring, **Table 6** introduces the measured well-being and IEQ indicators, and **Table 7** shows the labelling. ■

Table 7. *Labelling results in the TripleA-reno combined labelling.*

Calculated percentage of total and theoretical maximum points	Labelling
90-100%	Excellent
80-89%	Good
60-79%	Acceptable
50-59%	Weak
0-49%	Very weak

Table 6. *Scoring of the measured well-being and IEQ indicators.*

Nr.	Name	Scores
3.1	Operative temperature – heating	30 points - EN 16798-1 Category II 15 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.2	Operative temperature – cooling	15 points - EN 16798-1 Category II 8 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.3	Relative humidity of indoor air is between 25 and 70%	5 points if RH is between 25 and 70%RH
3.4	CO_2 concentration	20 points - EN 16798-1 Category II 10 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.5	TVOC	10 points - TVOC is under 500 µg/m^3 0 point - TVOC is 500 µg/m^3 or more
3.6	Formaldehyde	10 points - Formaldehyde is under 100 µg/m^3 0 point - Formaldehyde is 100 µg/m^3 or more
3.7	PM2,5	5 points if PM2.5 is under 15 µg/m^3 0 point if PM2.5 is 15 µg/m^3 or more
3.8	PM10	5 points if PM10 is under 50 µg/m^3 0 point if PM10 is 50 µg/m^3 or more

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TripleA-reno:

Demonstration of Combined Labelling Scheme

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Introduction: Demonstration buildings

This article is a follow up to the "TripleA-reno: Combined Labelling Scheme of dwellings" (p. 38), describing the demonstration cases of the labelling scheme. The validation of the combined labelling scheme on energy performance, IEQ and well-being was executed with real data from the TripleA-Reno project's demonstration buildings. The combined labelling template was applied to 14 dwellings in several European countries. The proposed combined labelling scheme was developed during the validation procedure according to the feedback from experts responsible for demonstration buildings. In the following sections, the main labelling results and experiences are presented for case studies located in Hungary, Italy, Spain and the Netherlands.

This article is prepared within the scope of the TripleA-reno project, which has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement number 784972. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' views.

Case study, Hungary

The Hungarian demo building is located in Szigetszentmiklos, 30 km from Budapest. The building was built in 1982 with prefabricated concrete panel construction technology. The building has a total of 60 apartments and the walls and roof have poor thermal characteristics. Most of the windows were replaced with new PVC framed windows. The building is connected to the district heating system, which provides thermal energy for heating and domestic hot water purposes. Within the building there is a 1-pipe heating system, the heating appliances are radiators equipped with a manual valve.

Two of the examined apartments have an energy efficiency class "F" while another has "D". The walls and roof of the building have very weak thermal insulation; therefore, the area-weighted average thermal transmittance (1.09–1.23 W/m²K), the delivered energy use (150–234 kWh/m²a) and the primary energy consumption (159–243 kWh/m²a) are high in the analysed dwellings. The renewable energy ratio was almost zero during the examination. The building has central heating control which often results in overheating in some apartments, while the indoor temperature was even beyond category III of the EN 16798-1 standard.

The well-being and IEQ indicators of the technical building systems were evaluated, and the result was weak for both apartments "1" and "2", and acceptable for "apartment 3". The better well-being and IEQ indicator in "apartment 3" is due to a local air conditioning system (split unit) in the living room, which provides room temperature control; therefore, the occupant in this apartment is at least able to control the indoor temperature in the cooling season. The pilot building is an old building; therefore, there is no radiant heating or cooling system. The main reason for the poor well-being and IEQ indicators is due central temperature control in the building, meaning that occupants cannot control the indoor temperature according to their needs which leads to inadequate thermal comfort.

Figure 1. The TripleA-reno Demonstration Building in Szigetszentmiklos, Hungary. A block of 60 apartments which was built in 1982.

The measured well-being and IEQ indicator was acceptable for "apartment 2" and very weak for apartments "1" and "3". The measurement was done during the heating season, in "apartment 2" the measured operative temperature met the EN 16798-1 category II, however apartments "1" and "3" – which are on the edge of the building – met Category IV or worse. The temperature was also measured in the apartments during the cooling season, and the indoor temperature of each apartment met the EN 16798-1 category III requirement. The measured CO_2 concentration was Category II in "apartment 1" and category III in the others. All these apartments have natural ventilation, which means the CO_2 concentration depends on how regularly and long the occupants leave the windows open. The relative humidity was out of the comfort range (25–70% RH) in each apartment. Also, the TVOC did not meet the 500 µg/m³ limit in the apartments. The measured formaldehyde figures were well below the WHO limit (100 µg/m³), except in "apartment 1". For the PM2.5 and PM10 figures: in "apartment 2" the PM2.5 was under the limit, while PM10 was over; in apartments "1" and "3" both PM2.5 and PM10 were over the limit.

Based on the combined labelling, thermal insulation of the walls and roof is recommended, which results in less use of heating and improves the IEQ (operative temperature: indicators 3.1 and 3.2). Installing thermostatic valves on the radiators is recommended, ensuring room control of the heating system, reducing heating energy use, and improving thermal comfort (no more overheating) and well-being (automatic operation). Installing a thermal solar collector system for the whole building is suggested, which reduces the energy use of domestic hot water production and increases renewable energy ratio. There is natural ventilation in the building; therefore, when the outdoor PM is high (during traffic hours or when there is heating of solid fuel in the area), the windows should remain closed if possible.

Case study, Italy

The Italian demo building is located in Concordia Sagittaria, which is 60 km from Venezia. The building was built between 1977 and 1978, is owned by ATER Venezia and hosts 21 apartments on four floors above ground. The external walls are made of a double layer of hollow bricks with thin thermal insulation. The heating system and the domestic hot water production are centralised: there is an oil-fired heating boiler, which provides thermal energy for heating and domestic hot water. The apartments have low performing window glasses and frames, and there is neither room thermostat, nor thermostatic radiator valves to control the indoor temperature.

The energy efficiency class is "F" or "G" for all the analysed apartments. The primary energy consumption (209–294 kWh/m²a), the delivered energy use (123–173 kWh/m²a) and the average thermal transmittance (1.12–1.66 W/m²K) are significantly high. The reason for variable calculated figures is the different apartment's position inside the building. The measured delivered energy consumption is 20–25% higher than the calculated delivered energy use. This gap could be reasonably due to the central heating control that causes overheating in the apartments. Furthermore, the absence of thermostatic valves combined with the low energy performance of walls and windows increases this problem. The renewable energy ratio is zero in the current condition.

In all the surveyed dwellings the well-being IEQ indicators of the technical building systems highlighted a very weak performance, only the exterior shading indicator reached the maximum score. The heating system has central temperature control; therefore, occupants cannot control the indoor temperature. This is one of the most frequent complaints reported by residents. Windows and doors have really poor air-tightness resulting in draughts and infiltrations, which caused evident plaster blooming and mould presence on the external walls. Finally, the Concordia building is an old building; therefore, there is no radiant floor, wall or ceiling heating/cooling system. These characteristics provide little chance for the occupants to achieve well-being and create good indoor environmental quality.

Operative temperature, relative humidity, and CO_2 concentration were measured in four apartments in winter and summer. The operative temperature reaches only category III of EN-16798-1 standard in three apartments due to the central temperature control. The relative humidity was in the 25–70%RH comfort range in three apartments, and it was out of the comfort

Figure 2. The TripleA-reno Demonstration Building in Concordia Sagittaria, Italy. 21 apartments built between 1977–78.

range in one apartment. There is natural ventilation in the building; the measured CO_2 concentration was category II in two apartments and category III in the other two apartments. The windows' appropriate and regular opening results in better indoor air quality, which provides a better labelling outcome.

The tender of the energy renovation project for the Concordia building is in progress; the design specifications are in line with the combined labelling assessment recommendations for improved energy performance and comfort indicators. The renovation includes the thermal insulation of the walls and roof. All windows and doors will be replaced with thermal break frames and low emission glasses. The oil boiler will be replaced by a condensing gas boiler, improving the energy efficiency. The energy production will be supplemented by installing a photovoltaic system on the roof with 10 kW peak power. Thermostatic valves will be installed in the apartments in combination with the implementation of independent energy consumption accounting.

Case study, Spain

The Spanish demo case is located in Almoradí, a medium-sized town close to the Alicante Mediterranean shore (Costa Blanca). The demo case involves five multifamily buildings built in 1982, and is owned by the Regional Social Housing Company EVHA. The walls have poor energy performance. The apartments were initially constructed with wooden framed windows with single glass. There is electric heating in the rooms and air conditioning unit for heating and cooling in the living rooms. The lack of maintenance and few economic resources of the inhabitants have resulted in a degraded building complex, with an unattractive and outdated image.

Figure 3. TripleA-reno Demonstration Building in Almoradi, Spain. Five multifamily buildings built in 1982.

The energy efficiency class is "G" for the three examined apartments. The building walls have very weak thermal insulation; the original wood-frame windows also have poor energy efficiency; therefore, the area-weighted average thermal transmittance (1.09–2.08 W/m²K), and the primary energy consumption (284–301 kWh/m²a) are high in the analysed dwellings. The renewable energy ratio is zero in the current condition. The measured delivered energy consumption is lower than the calculated delivered energy consumption. The reason of this gap clearly turned out during the on-site visit and measurement, because the indoor temperature was even out of category IV of the EN 16798-1 standard in two apartments, i.e. the temperature and the occupant behaviour is significantly different from the standard user profile.

The well-being and IEQ indicators of the technical building systems were evaluated, and the results are acceptable. Indicators 2.1, 2.2 (control of heating, cooling system) and 2.5 (exterior shading) got the maximum scores, but for 2.2 it has to be noted that occupants installed local air conditioning split units only in their living rooms; therefore, occupants can control the living room's indoor temperature in the cooling season. In all apartments, 100% of windows from East to West orientation have exterior shading, but the windows and the doors are old and have very poor air-tightness. The building is old and there is no radiant heating or cooling system. These characteristics provide an acceptable chance for the occupants to achieve well-being and create good indoor environmental quality in their living rooms, but none in the rest of their homes.

The measured well-being and IEQ indicators were assessed, and the labelling result is acceptable (61–64%) for all the apartments. In "apartment 1" the measured operative temperature meets EN 16798-1 category III, while apartments "2" and "3" meet category IV. All apartments have and properly use, natural ventilation, resulting in adequate CO_2 concentration levels (EN 16798-1 category II). The relative humidity was within the comfort range most of the time. The TVOC was measured in the apartments and exceeded the 500 µg/m³ limit in all of them. On the contrary, the measured formaldehyde figures were well below the WHO limit (100 µg/m³). PM2.5 and PM10 figures were measured as well and were under the limits for apartments "2" and "3", while "apartment 1" was over the limit, which can be explained due to the position of the apartment on the ground floor with a façade facing a busy traffic road.

Thermal insulation of the walls and replacing the windows is recommended, which results in less cooling (and heating) energy use and will improve IEQ (Indicator 3.1 and 3.2, operative temperature). Sealing shutter boxes and perimeter of the windows will improve air-tightness. It is recommended that the home user have information on the indoor/outdoor conditions to make sound decisions regarding the on/off of their air conditioning equipment or open/close windows. Installing a thermal solar collector system for the whole building is suggested, which reduces the energy use of domestic hot water production and increases renewable energy ratio.

Case study, Netherlands

Two dwellings were assessed in the Netherlands, located in Eindhoven. Dwelling-1 is a typical Dutch style, 2-storeys, semi-detached house reflecting the architectural style of the 1930s, the era of its construction. The dwelling-2 is the second dwelling of a row house.

The energy efficiency class is "G" for dwelling-1, the calculated primary energy use is 413 kWh/m²a, and the area-weighted average thermal transmittance is 1.48 W/m²K, due to weak thermal insulation performance of walls and windows. The building structures of dwelling-2 have a slightly better thermal performance that results in lower area-weighted average thermal transmittance (1.28 W/m²K), while the primary energy consumption (145 kWh/m²a) is much lower compared to dwelling-1 because heated dwellings surround it on two sides.

The well-being and IEQ indicators of the technical building systems were evaluated, and the results are weak for both surveyed dwellings. The main reasons for the low level of well-being and IEQ indicator are the heating system's central control, the low air-tightness of windows and doors and the lack of exterior shading.

Operative temperature, relative humidity and CO_2 concentration were measured both in winter and summer period. The operative temperature reaches category III of EN-16798-1 standard in both dwellings in the heating season due to the central temperature control. The operative temperature in the summer period got the worst result, i.e. category IV of EN-16798-1 standard in both dwellings. In dwelling-1, the relative humidity was in the comfort range; however, the CO_2 concentration meets only category III of standard 16798-1. In contrast, the relative humidity in dwelling-2 was out the comfort range, but the CO_2 concentration was category II of standard 16798-1.

The measured temperature, CO_2 concentration and relative humidity values provide "very weak" result in dwelling-1 and "weak" result in dwelling-2, which means occupants may have issues to ensure good indoor environmental quality in their homes.

Based on the combined labelling assessment, the thermal insulation of walls and changing windows are recommended, which reduces heating and cooling energy use and improves comfort. In dwelling-1, it is recommended to install a CO_2 sensor and adapt the user behaviour by more often open windows to reduce the CO_2 concentration when the room is occupied by more than one person. In dwelling-1, the relative humidity should be reduced by installing an exhaust fan in the bathroom.

Conclusion

The TripleA-reno combined labelling scheme can inform people about the energy performance, IEQ and well-being of their homes. The energy performance indicators are essential to motivate occupants to renovate their homes. It has to be stressed out that, besides that calculated primary energy use, both calculated and measured delivered energy use are presented. The calculated delivered energy use is practical for objective comparison of different dwellings, while the measured delivered energy consumption is capable of presenting the realised energy performance especially before and after a renovation project and can also be useful to evaluate occupant behaviour.

Beyond the energy performance assessment, the evaluation of technical building systems in terms of well-being and IEQ can indicate which improvements are necessary to achieve better IEQ. If the rating of the technical building system provides a bad result, it does not always mean the actual indoor environmental quality is poor, but in such conditions, it is expected to be much more challenging to maintain good indoor environmental quality and well-being. The actual condition can be assessed with on-site measurements including temperature, relative humidity and indoor air pollutants. The TripleA-reno combined labelling is suitable for highlighting areas that need to be addressed to ensure better indoor environmental quality and well-being. ■

HVAC World Student Competition 2020*
Article from the 1st prize winner

Flow Visualization of Ammonia inside a Plate Heat Exchanger

As ammonia is environmentally benign, a growing global interest takes place in ammonia for commercial refrigeration in HVAC/R. A scientific knowledge gap exists on condensing ammonia which results in faulty heat exchanger designs. This study shows the first flow visualization results of vertical downward condensing ammonia in a corrugated plate heat exchanger.

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Keywords: Flow patterns, plate heat exchangers, flow visualization, condensing ammonia

Introduction

Two-phase behaviour of fluids is not yet fully understood by science, resulting in over or under- estimating by several published heat transfer and pressure drop correlations for plate heat exchangers, which are limited by the range of conditions they cover [1]. Reference [2] concludes that better predictions of flow patterns in plate heat exchangers will improve the calculation of heat transfer and pressure drop. Flow patterns are determined visually by an experimental setup where the flow is observed through a transparent plate.

Flow patterns and flow pattern maps

Flow patterns are defined by the geometric configurations of vapor and liquid and are classified into four main flow patterns: bubbly, slug, churn and film flow. It is expected that the various flow patterns relate to different forms of heat transfer inside condensers. A flow pattern map (FPM) helps distinguish the various regimes in a graphical way. Reference [2] created an FPM for two-phase vertical downward flow in plate heat exchangers including the fluid property modifying group Λ [-], see (1), that enables the inclusion of fluid properties into the FPM. The parameter is defined as a function of the liquid properties relative to those of water under the same conditions:

$$\Lambda = \mu_L \mu_w^{-1} \rho_L^{-1/4} \rho_w^{1/4} \sigma_L^{-3/4} \sigma_w^{3/4} \qquad (1)$$

where the fluid properties μ, ρ and σ represent the dynamic viscosity, density and viscosity. The subscript L represents the liquid of the fluid and w represents water at the same operational conditions. The axes of the FPM make use of dimensionless groups: the liquid

* Sponsored by EUROVENT, on May 27th 2021, in collaboration with ISHRAE, the HVAC World Student Competition 2020 took place online. The competition was held between the competitors representing ASHRAE (United States), ISHRAE (India), CCHVAC (China), SAREK (South Korea), and REHVA (Europe). The jury team members, Manuel Gameiro da Silva (REHVA), Jun Choi (SAREK), Joe Firrantello (ASHRAE), Narayanan Srikantan Chandrasekar (ISHRAE), and Angui Li (CCHVAC) were assigned to judge the performance and quality of the work of the competitors.

Reynolds number Re_L [-] and the two-phase Froude number Fr_{TP} [-]. The liquid Reynolds number represents the ratio of inertia forces over viscous forces and is defined by (2):

$$Re_L = G(1-x)d_h\mu_L^{-1} \quad (2)$$

Where G [kgm^{-2}s^{-1}] is the total mass flux, x [-] the vapor quality and d_h [m] the hydraulic diameter. The two-phase Froude number represents the ratio of inertia to gravity and is expected to play a role in vertical plate heat exchangers and is defined by (3):

$$Fr_{TP} = xG\left(gd_h\,\rho_G\,(\rho_L-\rho_G\,)\right)^{-0.5} \quad (3)$$

Where g [kgs^{-2}] represents the gravitational constant. Flow visualization of pure ammonia condensing flow inside a corrugated vertical plate heat exchanger has not been investigated previously. This study compares the results of pure ammonia flow visualization in a vertical downward PHE to the FPM constructed by [2]. This article explains the experimental setup and the performed research to enable the construction of a durable transparent test plate. The test procedure, experimental results and discussions are presented.

Experimental Setup

A. Experimental Apparatus and Procedure

In cooperation with the Delft University of Technology, Bluerise B.V. constructed a small-scale test plant to test the performance of a cycle for Ocean Thermal Energy Conversion (OTEC) purposes, which contains similar components to that of a refrigeration cycle. The 100 W OTEC-demo consists of an Organic Rankine cycle using pure ammonia as the working fluid. **Figure 1** shows a schematic representation of the experimental setup. Pure ammonia is vaporized while flowing through the evaporator due to the counter current hot water flow. The two-phase ammonia is condensed in the Gasketed Plate Heat Exchanger (GPHE) by a cold-water stream from the cold-water tank.

B. Test section for Visualization

The test section is a GPHE, containing a cold-water channel and a working fluid channel. The PHE includes a 95 cm × 12.5 cm transparent corrugated polymer plate that enables visualization of the condensing ammonia on the working fluid side. The visualization plate is a hybrid plate where the top layer consists of Polystyrene to act as a chemical barrier between the ammonia and the thick plexiglass plate. The plate is illuminated by a 500 cm LED strip

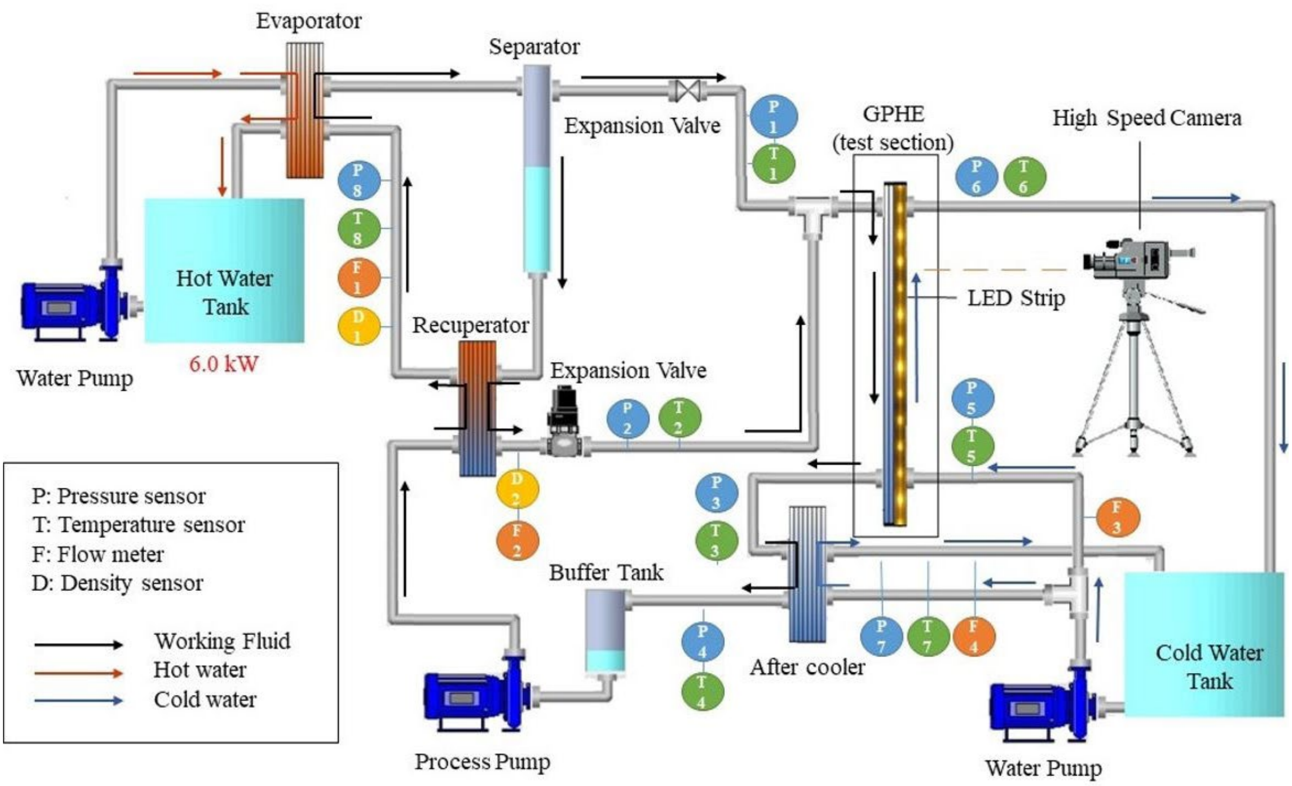

Figure 1. Experimental setup diagram of OTEC demo cycle.

including 300 LED's that encircles the plate from its sides twice. A 3000 fps high speed camera is placed in front of the visualization plate to capture the flow patterns under varying operating conditions. **Figure 2** shows the visualization section including pressure plate and illumination and the placement of the camera.

Test Procedure

The ammonia mass flux G_a [kgm^{-2}s] is determined by (4). The ammonia mass flow $\dot{m}_a$ [kgs^{-1}] is measured by flow meter F1, see Fig. 1. The flow passage area A_f [m^2] is calculated by multiplying the effective heat transfer width L_w [m] with the channel gap d_g [m].

$$G_a = \dot{m}_a A_f^{-1} \quad (4)$$

The single-phase condition at the outlet of the after cooler is used to determine the enthalpy of the liquid ammonia. The average vapor quality $\bar{x}$ [-] inside the GPHE is determined by (5), where x_{in} [-] and x_{out} [-] represent the vapor qualities at the in- and outlet of the condenser. An energy balance is used to determine the two-phase enthalpy at the inlet of the after cooler, which is assumed to be the same as the enthalpy at the outlet of the GPHE. A second energy balance determines the enthalpy of the ammonia at the inlet of the GPHE h_{in} [kgkJ^{-1}] which is determined by (6). $h_{L,sat}$ [kgkJ^{-1}] and $h_{V,sat}$ [kgkJ^{-1}] represent the saturated liquid and vapour phase enthalpy of the ammonia at the inlet conditions of the condenser.

$$\bar{x} = 0.5(x_{in} + x_{out}) \quad (5)$$

$$x_{in} = (h_{in} - h_{L,sat})(h_{V,sat} - h_{L,sat})^{-1} \quad (6)$$

Experiments are performed where the mass flux G_a is kept constant and the vapor quality x_{in} is increased. Both the influence of the mass flux and inlet quality on the flow configurations are recorded for the top, middle and bottom windows.

Experimental Results

For all recorded conditions, a framerate of 3000 fps with a resolution of 1024 × 1024 pixels is used. The transparent plate remained intact for 7 days, but on the 8th day of performing experiments degradation in the material was visible in the form of small cracks in the PS surface and crystal shaped spots between the PS and PMMA layer that grew in size over time. It is concluded that PS has a limited durability when in contact with pure ammonia.

A. Flow Pattern and Flow Path

For all performed experiments, no bubbles, slugs or churns were detected, and only film flow and partial film flow are observed. The path of the flow remained similar under the various circumstances. Due to the shapes of the distribution zone at the inlet, the liquid flow is pushed to the left which causes most of the liquid flow to disperse over the left upper diagonal of the window. It is expected that in that zone also vapor is present, but less than in the lower diagonal. The area of the upper diagonal covered by mainly a rough liquid film decreases for smaller mass fluxes. This area is indicated by the zones that reflect light in various directions. Most of the vapor flows at the lower diagonal of the top window, indicated by a still image. In the middle window the corrugation direction switches and this sudden change in flow direction causes the liquid to evenly distribute over the corrugations in the lower part of the middle window. Less vapor is detected. The bottom window is mostly covered in a smooth liquid film.

Figure 2. Left: Visualization section. Right: Visualization section and position high speed camera.

B. Influence of Mass flux and Vapor Quality on flow configuration

A distinction can be made between film flow and partial film flow. Film flow includes a liquid layer on both plates while partial film flow leaves dry zones when the amount of liquid film is limited and unable to cover the entire plate. If partial film flow occurs in the GPHE and dry zones are present on the transparent plate, an opaque surface will be visible. The dry zones are indicated by a black circumference, see **Figure 3** and **Figure 4**. Only the top window is represented in the figure since this window shows the varying configurations most clearly.

Figure 3 shows that for a constant vapor quality but increasing mass flux the dry zone decreases. **Figure 3 a, b** indicate partial film flow by the occurrence of the dry zone. **Figure 3 c** shows that for an increased mass flux of 81 $kgm^{-2}s^{-1}$, the dry zone disappears, i.e. indicating film flow. This indicates that the mass flux G has a strong influence on the flow pattern transition from partial film flow to film flow. A low mass flux shows smooth liquid film characteristics, indicated in the upper left diagonal of **Figure 3 a** by a clear image. For increasing mass flux, the film transitions to rough film characteristics, see **Figure 3 c**, indicated by the strong light reflectance of the left upper diagonal. **Figure 4** shows that for a constant mass flux and an increasing vapor quality the area of the dry zone increases. This only occurs for lower mass fluxes and within partial film flow only.

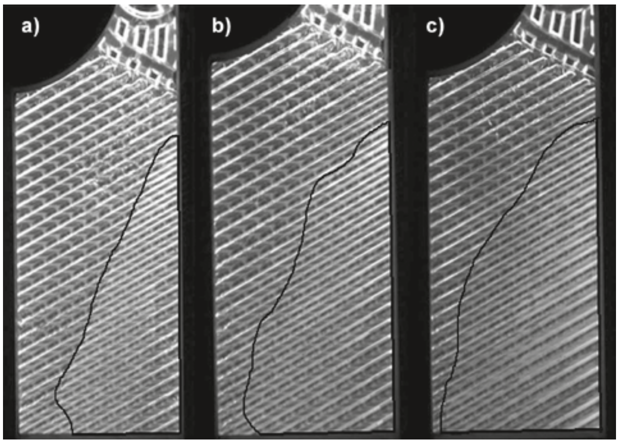

Figure 3. $\bar{x}$ = 0.31 [-]. a) G = 43 [$kgm^{-2}s^{-1}$]. b) G = 64 [$kgm^{-2}s^{-1}$]. c) G = 81 [$kgm^{-2}s^{-1}$].

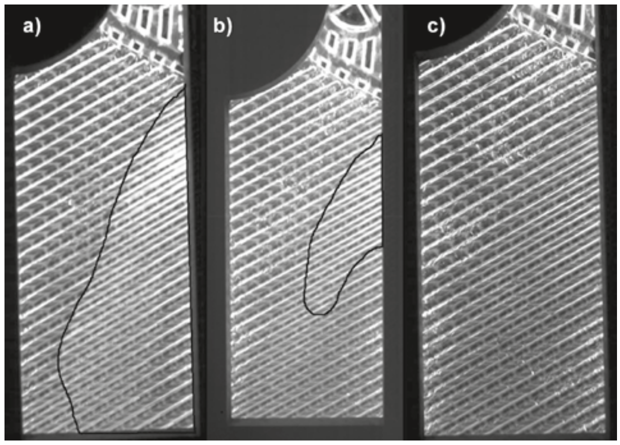

Figure 4. G = 43 [$kgm^{-2}s^{-1}$]. a) $\bar{x}$ = 0.22 [-]. b) $\bar{x}$ = 0.48 [-]. c) $\bar{x}$ = 0.62 [-].

C. Comparison of Results to Flow Pattern Map by [2].

The operating conditions of the experiments are represented in **Figure 5**. It shows an FPM generated by [2] for plate heat exchangers that makes use of the dimensionless quantities Re_L and Fr_{TP} which account for gravity, viscous forces and inertia. This construction is based on results from previous visualization experiments for two-phase vertical downward flow of mainly air-water mixtures in plate heat exchangers. The dimensionless fluid property modifying parameter Λ is included on the Y-axis to correct for fluid property deviations of other fluids such as refrigerants. This parameter is included to widen the applicability of the map from air-water to multiple fluids, such as refrigerants. For the experimental conditions of the flow visualization experiments in this research, the map predicts churn flow. The results of the flow visualization experiments show film and partial film flow, which indicates that this map is not yet applicable for ammonia flow pattern prediction.

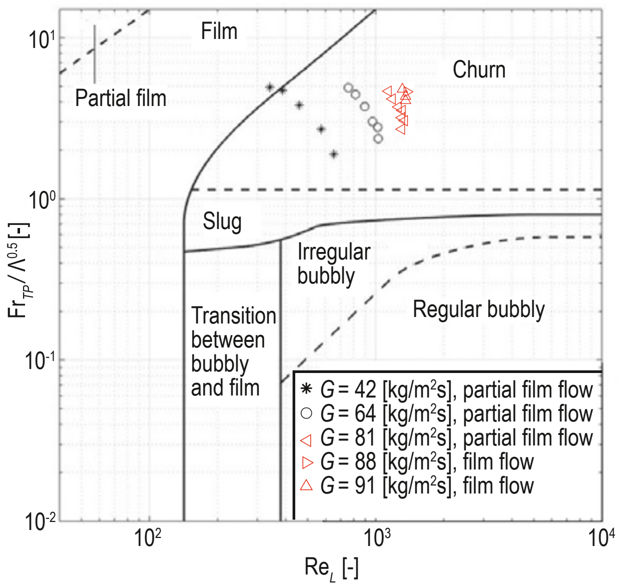

Figure 5. Experimental operating conditions shown in simplified flow pattern map of two-phase flow in PHEs by [2].

D. Proposed Flow Pattern Map

An FPM for the downward condensing ammonia in the GPHE is constructed based on the parameters proposed by [2]. **Figure 6** presents the proposed FPM for downward condensing ammonia inside a GPHE with a corrugation angle of β = 60°C. This map can be used to predict the occurring flow pattern of downward condensing ammonia in a PHE for operational conditions within the indicated limits. The dashed line describes the transition from partial film flow to film flow. An indication for rough film flow and smooth film flow is included that describe the transition from a smooth liquid film to a rough liquid film. More visualization studies with a wider range of experimental conditions on condensing flow of pure ammonia in vertical PHE's are required to accurately describe the flow pattern behaviour of pure ammonia in this type of heat exchangers and to extend the applicability of FPMs for different fluids.

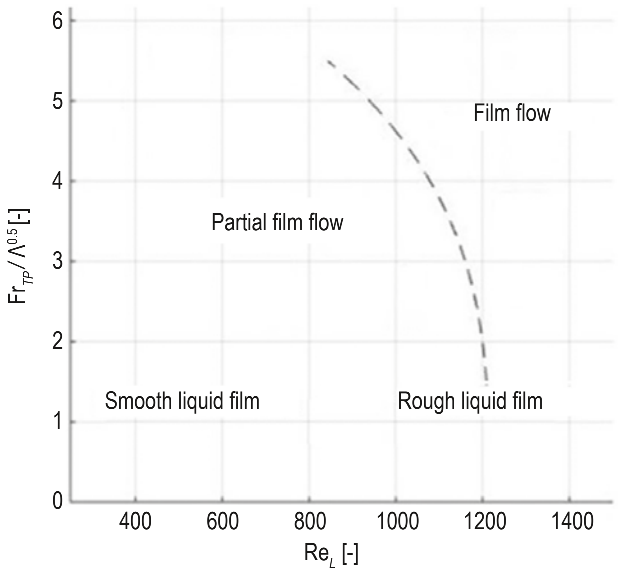

Figure 6. The proposed flow pattern map as a function of Fr_{TP}, Λ, and Re_L for condensing ammonia inside a corrugated GPHE describing the transition from partial film flow to film flow.

Discussion of results

Flow patterns are defined visually, therefore flow pattern classification remains subjective to this day. The approach of performing the experiments and the experimental conditions influence the judgement of the observer on how flow patterns are related to transition lines in the FPM. This note should be taken into account when forming PFMs or making assumptions on the flow pattern behaviour based on FPMs constructed from a limited number of experiments.

Conclusions

The flow morphology of pure ammonia in a vertical downward GPHE has been captured. A corrugated visualization plate is produced from transparent PS by a CNC-machine and has proven to be chemically compatible for seven days. For all conditions introduced, film flow and partial film flow are observed. An increased vapor quality increases the area of the indicated dry-zone (partial film flow) on the visualization plate. The mass flux determines the transition from partial film flow to film flow. Increasing the mass flux enhances the rough film flow, creating more liquid entrainment in the lower diagonal resulting in film flow. The operating conditions during the performed ammonia condensation experiments (liquid Reynolds number and two-phase Froude number) have been indicated in the FPM constructed by [2]. The results indicate that the FPM, which is mainly based on air-water experiments, is not applicable for condensing ammonia. For this reason, an FPM is proposed for condensing ammonia inside a corrugated GPHE describing the transition from partial film flow to film flow. The results of this study can be used to improve performance calculations of condensing ammonia in plate heat exchangers. More extensive visualization studies are required to:

- Extend the applicability of the FPM for different condensing fluids inside GPHE's
- Improve two-phase correlations for ammonia on a large scale and therefore optimize heat exchanger designs used in HVAC/R systems. ■

Acknowledgements

I would like to acknowledge the financial support from the China Scholarship Council and Koudegroep Delft-Wageningen.

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Revision of key EU directives to spur building decarbonisation and the renovation wave

ANITA DERJANECZ
REHVA Managing Director

Overview

With the European Green Deal the EU committed to stronger action on climate change to reduce GHG emissions by at least 50% to 55% by 2030. This was strengthened for the building sector by the Renovation Wave Strategy which announced the revision of the EPBD along EED and RED to reach ambitious goals: reducing the energy use of heating and cooling by 18% while increasing the share of renewables to 38-42%, leading to a 18% decrease in the total energy demand of buildings and a 69% decrease in CO_2 emission by the deep energy renovation of 35 million buildings. This article provides an overview analysis of the revision of these three key directives.

The requirement of decarbonising the building sector put a strong focus on heating and cooling. The revision of the REDII and EED directives started in 2020, the European Commission published its proposal of both revised directives in July 2021 expecting comments from stakeholders by beginning of November. The EPBD revision process started in 2021 with the Commission proposal expected to be released by end of 2021.

Revision of the Renewable Energy Directive

The review process [**1**] started in March 2020 with the aim to strengthen the renewable heating and cooling target, introduce a requirement for minimum proportions of renewable energy in buildings and facilitate access of waste and renewable heat and cool into energy systems. The revision explores a toolbox of measures to promote advanced heating and cooling, including highly efficient low-temperature renewable and waste heat and cold technologies. After the online feedback period on the Inception impact report by September 2020 a public consultation followed from November 2020 till February 2021. Based on the results, the Commission released the proposed revision of the RED (COM(2021)557) [**2**] on 14 July 2021. The proposal is open for feedback until early November [**3**].

Main changes relevant for the HVAC/building sector in the RED proposal:

- A new Article 15 on renewable heating & cooling (H/C) with the **indicative target of RES in buildings increased to 49% by 2030**. This should be supported by a binding baseline for annual increases in the national share of final energy consumption of renewable energy for the H/C sector.
- Higher **obligation on MS to increase the share of RES in the H/C sector by 1.1% per** year (from 0.8%).
- For **district heating and cooling (DHC)** the **mandatory annual target** for energy form RES + waste heat and cold increases **2.1%** (from 1%)
- MS shall require in their building regulations and codes the use of **minimum levels** of energy from renewable sources in buildings
- MS shall introduce measures in their building regulations and codes to increase the share of electricity in heating and cooling from renewable sources in the building stock, including

national measures relating to substantial increases in **renewables self-consumption**, **renewable energy communities and local energy storage**, in combination with energy efficiency improvements

- MS are obliged to **enhance system integration between DHC systems and other energy networks**, by developing efficient DHC to promote heating and cooling from RES. MS must ensure that **third party suppliers of energy from RES and waste heat & cold can connect** to heating & cooling systems with a capacity of above 25MWth. MS are obliged to ensure that the consumer rights and the **revised rules for operating DHC systems** are **clearly defined, publicly available and enforced**.
- **Qualification and certification of installers**: the proposal is obliging MS to put in place measures to support participation in training programs and make the list of qualified installers public to ensure sufficient installers are (Article 18(3) REDII).

EC studies on renewable heating and renewable cooling for a Delegated act

DG Energy commissioned 2 technical studies to assess the renewable aspects of space heating and cooling. The studies should serve as input for policy development to increasing the share of RES in H/C, including methodologies for accounting these shares. The 2 studies are developed by 2 expert teams, both led by TU Vienna, with limited stakeholder involvement. The studies were presented on 14 and 15 July 2021 in two online stakeholder workshops for member state representatives and invited industry stakeholders.

The study on Renewable space heating aims to provide a better information basis for policy design targeting decarbonisation of the space heating sector. It contains a set of country fact sheets on RES potential, energy consumption, energy carriers, technologies, and the regulatory framework. The study will model alternative decarbonisation pathways to understand the long-term perspectives and costs of different decarbonisation technology scenarios in different climatic and geographical settings in Europe. It will also give recommendations for policy design to developed and discuss with relevant stakeholders from EU and the Member States. The study will focus on heat consumption in buildings and will cover space heating and the supply of sanitary hot water. The final report will be submitted to the Commission end of August and is expected to be published in October 2021.

The study on Renewable Cooling covers a new topic for EU policy makers that is not yet integrated in the EU energy policies. Compared to heating there are still many open questions relating to cooling, to date even a clear definition for renewable cooling is missing and only a limited amount of market and technological data is available. The objectives of the study are to provide the baseline information and calculation methodologies to the Commission, specifically:

- Quantify current final energy consumption for cooling (and development by 2030 and 2050)
- Overview and a taxonomy of technologies for cooling and related technological trends
- Investigate how much various cooling technologies can deliver renewable cooling
- Deliver the equations concerning the recommended methods
- Impacts as well as benefits and costs of the proposed definitions
- Provide recommendations on how to use statistical reporting for renewable cooling

The study was finished and submitted to the EC by the study team at the end of August 2021. Based on the study on renewable cooling, the EC will adopt by end of 2021 a delegated act establishing a calculation methodology of RES used for cooling and DHC district cooling. The draft of the Delegated Act will be consulted with Member States and stakeholders in accordance with the legal requirements for the adoption of such acts.

It's important to note that the studies ignore ventilation technology and heat recovery ventilation as a renewable energy source. This was pointed out by the participating industry stakeholders at the meetings.

Revision of the Energy Efficiency Directive

Following the feedback period on the Inception Impact Assessment roadmap in 2020 and the online public consultation closed in February 2021, the EC released the proposed EED revision [**4**] on 14 July 2021. Key changes relevant to the HVAC/building sector:

- New **binding EU level targets** by 2030: decrease primary energy consumption by 39%, final energy consumption by 36%.
- **Mandatory application of the Energy Efficiency First principle** in planning and investment decisions: energy efficient products, services and solutions must be considered as the first option in policy, planning

and investment decisions, when setting new rules for the supply side and other policy areas.

- **Annual savings obligation of EU MS** remains 0.8% for 2021–2023 but will increase to 1.5% from 2024 to 2030.
- A new annual target of **1.7% reduction in total energy use of the public sector.**
- **Broadened scope of renovation obligation: min. 3% mandatory annual renovation rate** of the total floor area **of all public sector buildings to at least NZEB level**. The scope is extended from central government building to all public buildings & sectors, including healthcare, education, and public housing, etc. MS are obliged to publish an **inventory of public buildings over 250m²** with a minimum information of the floor area and the EP certificate of the buildings and update it one a year. The possibility to count alternative measures to renovation to reach these saving is deleted.
- As part of the exemplary role of the public sector Article 7 also includes a provision that contracting authorities may require that tenders disclose a Global Warming Potential of new buildings (**numeric indicator in $kgCO_2e/m^2$** (of useful internal floor area) for each life cycle stage averaged for one year of a reference study period of 50 years), in particular for new buildings above 2000 square meters.
- The **energy audit and energy management system requirements** change from type of enterprise to average annual energy consumption. An obligation to monitor the energy performance of data centres is introduced.
- Comprehensive **heating and cooling assessments** will become part of the national energy and climate plans. Furthermore, local authorities above 50,000 inhabitants are encouraged to prepare local Heating and Cooling plans.
- New, gradually increasing **minimum requirements for efficient district heating and cooling (DHC)** systems will be introduced, with broader requirements and obligations on reuse of waste heat and reporting the share of RES & statistics regarding DH and cogeneration.
- Additional requirements to promote **energy performance contracting** (ECP): Non-residential buildings with the useful floor area above 1000 m² should be required to assess the feasibility of **using EPC for renovation**, MS should encourage public bodies to **combine EPC with energy services** including demand response and storage.
- Member States must ensure the availability **qualification, accreditation and certification** schemes for different energy service providers, energy auditors, energy managers and installers. These schemes must be **assessed every 4 years and updated** according to the identified skill needs starting from December 2024.
- **Conversion factors & PE factors:** to calculate savings in kWh electricity, MS shall apply a default coefficient of 2.1 unless they don't due to justified national circumstances. If they establish their own coefficient it shall happen through a transparent methodology based on national circumstances affecting primary energy consumption and notify the Commission along with the calculation methodology and underlying data in the update of their integrated National Energy and Climate Plans.

The consultation is supposed to end in early November to current state, however, the Commission has been postponing the deadlines from mid-September till November in the past weeks. The trialogue and final approval of the two directives will probably run in the first quarter of 2022.

Revision of the Energy Performance of Buildings Directive

The EPBD revision mandated by the Renovation wave started later, REHVA followed and actively contributed at each step of the process, collecting inputs from REHVA members The review opened on 22 February 2021 with a feedback period on the Inception Impact Assessment roadmap. REHVA submitted its feedback along 242 stakeholders. The second step was a public consultation by 22 June 2021 based on a targeted online questionnaire.

REHVA in its feedback supported the amendment of the EPBD for the effective implementation of the Renovation Wave. Summary of the submitted opinion:

1. **Mandatory minimum energy performance standards** for different building categories should contain IEQ and ventilation criteria ensuring indoor climate improvement by energy renovation. Stricter MEPS for non-residential and public buildings prioritized by the renovation wave may be a start, but ventilation criteria should be defined also for residential buildings where IAQ is often deteriorated by energy renovation. MEPS can be developed from existing NZEB requirements for major renovation and shall be defined for both deep and step-by-step renovation with clear performance targets. Incentives should be linked to comprehensive IEQ and energy performance requirements.

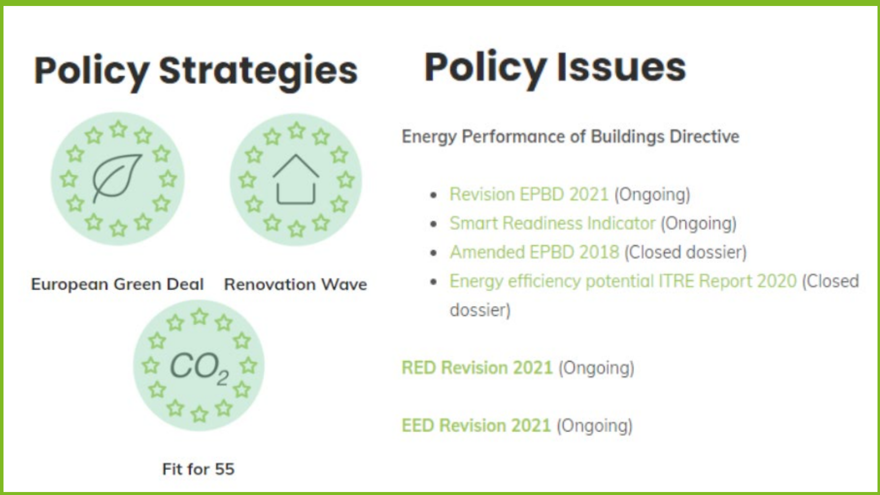
2. **Updating the EPC framework**
   - Current EPCs are not consistent with actual energy use and this has decreased end-users' trust. EPCs should provide relevant data for end users who, when selling or renting, prefer energy-use information that relates to energy bills. Including measured energy use and cost data connected user behaviour data (user patterns, occupancy schedules as in EN 16798-1) would make EPCs meaningful for end users and strengthen credibility.
   - The EPBD should define non-renewable primary energy as main performance indicator in line with the energy efficiency first principle. Additional minimum safeguards may be added in line with the EU taxonomy.
   - Existing minimum requirements may lead to buildings with similar energy cost causing very different power load to the grid. Adding an HVAC and lighting electricity power indicator (W/m²) would suit the balancing of energy demand and supply, in line with the SRI flexibility criteria.
   - **EPCs should contain an IEQ indicator** like in the EN/ISO EN 16798–1 standard [**5**] and a certificate of ventilation system performance. REHVA recommends the ALDREN-TAIL indicator [**6**] to rate IEQ of buildings undergoing deep energy renovation.
   - REHVA supports the development of an open-source software kernel and dynamic performance calculation tools meeting Art. 3 requirements of the EPBD. The EPBD review should mandate the development of a delegated regulation on a common energy calculation framework.
   - REHVA supports a common EU voluntary certification scheme as developed by ALDREN.

3. REHVA supports **a deep renovation standard** in the context of financing. Performance based and descriptive technical requirements should be a prerequisite for finance. Reporting in-use performance by EPC after 1-year operation and digital technical monitoring, quality management [**7**] during the renovation lifecycle should be part of the standard.

The detailed submitted opinion is available in the EU Policy tracking section of the REHVA Knowledge Hub [**8**].

Follow the REHVA EU Policy tracking for regular updates

To better present the many ongoing policy developments and revisions under the EU Green Deal and the Renovation wave, REHVA revamped its EU policy tracking service in the REHVA Knowledge Hub [**8**]. The issue tracking provides expert briefings, a well-structured coverage of technical meetings with insider information, as well as REHVA internal documents about specific advocacy actions. Find tailored briefings and regular updates about the current revisions of EPBD, REDII, EED and other EU legislation; an overview of EU policy strategies like the EU Green Deal, Renovation wave, Fit for 55; information on ongoing technical studies relevant to the HVAC and building sector and more.



Between 31 March and 3 June 2021, DG Energy organised 5 online stakeholder workshops coordinated by a consultancy company team. The workshops focused on selected topics using online polls with predefined answers, which were not always fully comprehensive or meaningful. Up to 250 participants attended the individual sessions which made moderation extremely challenging and led to parallel discussions in the chat field and orally. The issue of integrating IEQ criteria in the EPBD was repeatedly raised and demanded by several stakeholders, including REHVA. Unfortunately, no public records are published about the outcomes and the discussions, and it is not clear whether and how the Commission or the contracted consultancy company will use the outcomes.

The Commission is supposed to publish its proposal for the third EPBD revision by end of 2021, however it seems that there is a delay in the revision processes, due to the many parallel dossiers and other EU policy challenges. It is likely that the process is delayed, like in the case of the two pervious directives. After the final directive is tabled, the European Parliament and the Council of the European Union will discuss and amend the proposal (so-called "trialogues"), until an inter-institutional agreement can be found for the final text. ■

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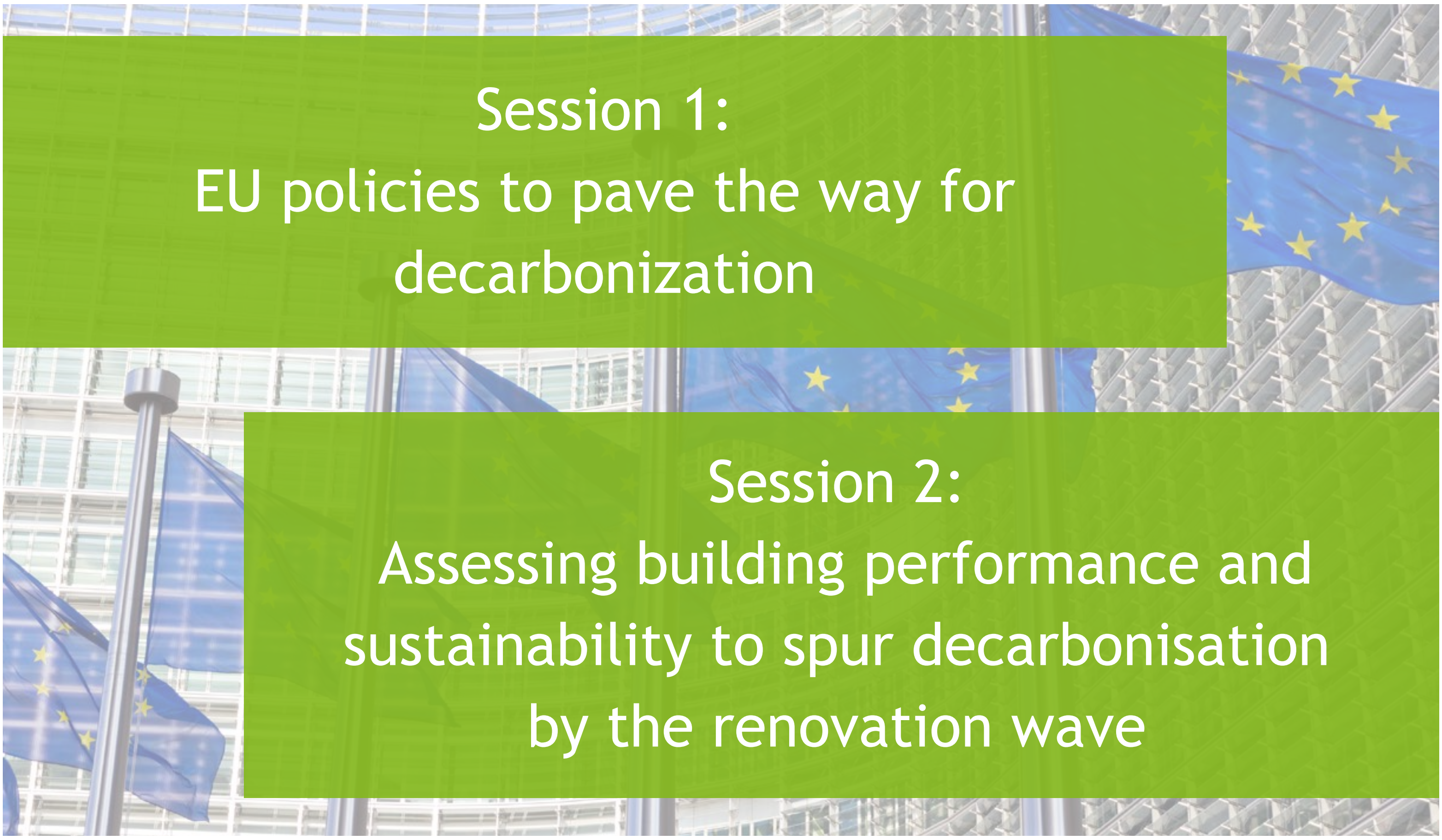

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The 100 most influential people of 2021

Meet the TIME 100 Next 2021: the emerging leaders from around the world who are shaping the future and defining the next generation of leadership [**1**].

It is with great admiration we may inform the RJ readers about this election/award of Distinguished Professor **Lidia Morawska**, PhD, she was the driving force behind the paper "A paradigm shift to combat indoor respiratory infection" Science 14 May 2021: Vol 372, Iss. 6543, p. 689-691 [**2**]. Several REHVA and REHVA member experts contributed to this paper [**3**].

When trying to slow the spread of a fast-moving virus, it is essential to know how that virus is spread. In the beginning of the COVID-19 pandemic, scientists overestimated the potential for contaminated surfaces to spread the virus, and we underestimated how far the aerosol particles that people exhaled could travel and remain infectious. It caused us to badly misjudge the risks in closed spaces where there was poor air circulation. Through the fog of this viral war, some scientists saw clearly. Lidia Morawska stands out among peers for her work in recognizing the importance of aerosol transmission and marshalling the data that would convince the World Health Organization and other authoritative bodies to do the same. She assembled a team of more than 200 scientists and public-health authorities to recognize the role of aerosols in spreading SARS-CoV-2 and change how we measure and lessen our risk of contracting the virus. Her advocacy helped change practices everywhere from schools to workplaces, making these environments safer for more people around the world.

SCOTT GOTTLIEB

Former U.S. commissioner of food and drugs

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[1] https://time.com/collection/100-most-influential-people-2021/

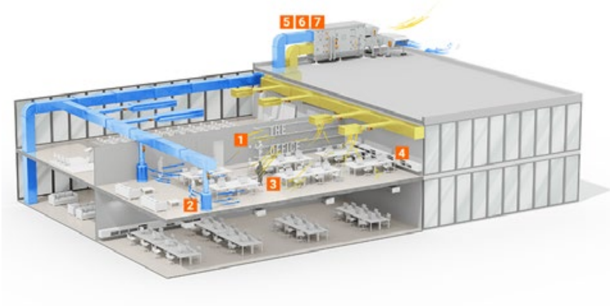
[2] https://www.science.org/doi/10.1126/science.abg2025

[3] **Abstract:**

There is great disparity in the way we think about and address different sources of environmental infection. Governments have for decades promulgated a large amount of legislation and invested heavily in food safety, sanitation, and drinking water for public health purposes. By contrast, airborne pathogens and respiratory infections, whether seasonal influenza or COVID-19, are addressed fairly weakly, if at all, in terms of regulations, standards, and building design and operation, pertaining to the air we breathe. We suggest that the rapid growth in our understanding of the mechanisms behind respiratory infection transmission should drive a paradigm shift in how we view and address the transmission of respiratory infections to protect against unnecessary suffering and economic losses. It starts with a recognition that preventing respiratory infection, like reducing waterborne or foodborne disease, is a tractable problem.

Seven basic requirements for planning and operating ventilation systems to ensure healthy indoor air

RETO RAIMANN
Global Business Development Manager at Belimo



Most people spend around 90% of their lives indoors and breathe around 12,000 litres of air every day. Air is our most important resource, and we often assume that air – as in nature – is also free of contamination and pollution in buildings and thus does not affect our health. In many cases, however, this assumption is wrong. Basically, depending on the type of room and building, its use for either living or work, and the type and quality of the outdoor air supplied through windows or ventilation systems, the air can be considerably contaminated with substances that are hazardous to our health. These include, for example, fine dust, allergens, viruses, bacteria and VOCs. It is surprising how few occupants and operators know or care about the quality of the air in their rooms. In this context, in addition to suitable temperature and air humidity, air quality is the determining factor as to whether people feel comfortable and to how motivated and concentrated they feel in performing their tasks. Important air parameters such as humidity, CO_2 content or VOC concentration are hardly ever measured and less often displayed – even though there are a multitude of easy-to-implement and inexpensive options for doing so.

Belimo has surveyed consulting engineers and experts in the field of ventilation worldwide, to find out what is particularly important in ensuring healthy indoor air and which factors are key. Based on this survey, the following seven essential factors for healthy indoor air in non-residential buildings emerged.

1. Consistent measurement of indoor air quality

To monitor indoor air quality, the variables of air humidity, temperature, CO_2 content and VOC concentration are ideally measured with sensors. The signals from these sensors control the air treatment in the ventilation unit, the volumetric flows of the supply and then extract air as required or indicate that the occupants of the room need to act: e.g., by opening a window in the event of poor indoor air quality, with not enough outdoor air. The measurement and display of at least the following air parameters should be standard in building technology today.

Air humidity

It is essential for health that rooms have a relative air humidity of between about 40 and 60%. This is often critical, especially in winter, as the outdoor air is very dry. When this dry outdoor air is heated and flows into the rooms, it often results in relative humidity levels in the range of only 20%. The air in such rooms should be urgently humidified. In addition, there is another important aspect, especially as a result of the Corona pandemic: in dry air, exhaled Corona aerosols evaporate more easily, and the very small and light viruses can then spread further and more extensively throughout a room. At higher humidity levels, the droplets evaporate less quickly and sink to the ground more rapidly. In addition, many bacteria and viruses have a more contagious effect in dry air, if the air is too dry, the immune system is weakened by dried-out mucous membranes in the nose and throat.

CO_2

For many years now, standards and directives have included the CO_2 that we exhale and the resulting CO_2 content in indoor air as an indicator for assessing air quality. Here, the standard for good indoor air quality and for an adequate supply of outdoor air to the room is a maximum limit value of 1,000 ppm CO_2 in the air. Depending on the location, outdoor air has a CO_2 content of about 400 to 500 ppm. Starting at CO_2 concentrations above about 1,000 ppm, the ability to concentrate slowly decreases; at values above 2,000 ppm, lapses in concentration, fatigue or headaches increasingly occur. Since the beginning of the Corona pandemic, CO_2 concentration in indoor air has taken on additional significance. Now, to better dilute pollutants and odorous substances in indoor air and especially to reduce the risk of infection, higher outdoor air rates are recommended by virologists. The CO_2 level now suggested for improved infection control in any room is around 1,000 ppm – the lower the better.

VOCs

Volatile organic compounds (VOCs) are organic compounds that come from many different sources, including perfumes, paints, printers, carpeting, building materials, and cleaning products. These substances are often released into indoor air in large quantities and the air quality deteriorates. Even low concentrations of VOC can cause irritation to mucous membranes (eyes, nose and respiratory tract) as well as headaches, fatigue and nausea.

In rooms where higher VOC concentrations can occur, it is essential to measure them with suitable sensors, so that if necessary, appropriate measures can be taken, such as increased ventilation or air purification.

2. Supplying and discharging the exact amount of air in a zone

Central ventilation systems usually supply several zones in the building with conditioned outdoor air. The outdoor air is first filtered in the system and can then be heated, chilled, humidified or dehumidified as required. Here, however, it is important that each room actually receives the amount of supply air calculated, based on technical rules and on the number of people, or room size. A changing number of people in a room must also be taken into account: if the number of people in an office or meeting room changes, the supply air volume and correspondingly, the extract air volume extracted from the room, should be adjusted accordingly. This ensures continuously good indoor air quality and savings in energy and operating costs (less supply air with fewer people). To assess the current occupancy of a room, CO_2 sensors can be used.

To achieve these goals, the zones and rooms must be supplied with variable air volume flows (VAV). If, for example, a room sensor detects excessively high CO_2 content above the set limit value, the VAV units are opened and the room is provided with a higher volume of supply air (outdoor air).

3. Optimal air distribution in the room

With regards to air hygiene, the manner in which supply air is introduced into a room is vital. A distinction is made here between mixed ventilation systems and source ventilation systems. In mixed ventilation, the supply air enters the room at high velocity and high momentum through swirl or slot diffusers mounted on the ceiling. Due to the large induction effect of the supply air jets, indoor air and supply air are mixed very intensively so that the same temperatures, humidity levels and air qualities occur in almost all places in the room. In comparison, with the source ventilation system, the supply air flows into the room through large-area perforated air diffusers with a low sub-normal temperature and a very low momentum near the floor. The cooler supply air is then distributed evenly over the floor and flows along heat sources – for example people – towards the ceiling, where it is extracted as extract air. In the process, the air carries the heat given off by the people as well as pollutants and odours. Considering the possible (cross) spread of Corona aerosols in a room emitted by an infected person, source ventilation with a directed, stable upward flow and only low cross spread of viruses is a better solution in terms of ventilation technology.

Modern air-flow simulations enable typical flow patterns in a room to be studied in detail. The proper design, placement, and orientation of air outlets can prevent major air hygiene errors.

4. Correct overpressure and negative pressure

The air quality of a room can also be affected by unwanted, possibly highly polluted air flows entering a zone from outside (e.g. from a busy road) or from other rooms (e.g. a canteen). This often happens when air-pressure ratios between different rooms are not correctly balanced. Especially in connection with the possible spread of Corona aerosols in buildings, "cross-contamination" between different rooms poses a hazard. This unwanted effect can be prevented by using VAV controllers in the supply and extract air of rooms, as well as differential pressure sensors and controllers. The sensors and controllers then control the air volume flows and therefore reliably prevent unwanted air flows.

5. Correct temperature and humidity conditioning

In a central ventilation system, the supply air can be conditioned exactly to the desired temperature after pre-tempering in a heat recovery system in a heating or cooling coil. The same applies to the humidification or dehumidification of the outdoor air to the intended supply air humidity. Here, the ventilation system for air conditioning must cover a very wide performance and control spectrum, ranging from very cold and dry to very hot and humid outdoor air - at supply air temperatures of about 20 to 26°C in cooling or heating mode.

High-quality control components on all individual components, in the ventilation unit and co-ordinated interaction, ensure that as required, the air conditioning is not only as accurate as possible, but also energy efficient.

6. Correct air filtration

To prevent dust in outdoor air from entering the ventilation system and thereby the rooms with supply air, suitable filters must be used in the ventilation unit. Filtering dust has two goals: fine and very fine dust must be prevented from entering the air we breathe, as it can damage respiratory organs and the lungs. At the same time, filtering dust from the air flow protects against particles from settling in components in the ventilation unit (heat exchanger, heat recovery) and, in extreme cases, severely impairing the flow through the component. This can lead to reduced air volume flows, increased pressure losses, higher fan power and operating costs.

The air filters to be used in the ventilation unit are based on the outdoor air quality at the building location and the desired quality (particle purity) of the supply air. Fewer particles in the supply air and more polluted outdoor air, results in higher quality air filtration. A proven standard is two-stage air filtration ISO ePM10 > 50% (M5) as pre-filter and ISO ePM1 > 50% (F7) as final after-filter. If the outdoor air also contains gaseous impurities, these can be separated, for example, in a supplementary activated carbon filter.

Since outdoor air can be assumed to be virus-free, no further measures need to be taken when preparing it for supply air. This does not apply if part of the extract air is mixed with the supply air as recirculation air. In this case, high-quality filters must be used to separate and kill any Corona viruses that may be present in the extract and recirculation air. HEPA air filters, for example, are suitable for this purpose. Pressure sensors and dynamic air flow measurements are used to effectively monitor the air filters. If contamination of the filter increases, the pressure drop across the filter increases, which is compensated for by a higher electrical power consumption of the fan. When measuring the volume flow through the filter, it is possible to assess whether and when the filter needs to be replaced.

7. The right amount of outdoor air for buildings

Many small and medium-sized non-residential buildings today do not have an automated outdoor air supply through a ventilation system. Rather, it is assumed that occupants ventilate their rooms from time to time themselves by using a window. If this does not take place or only to a limited extent, for example, when outdoor temperatures are too cold or too hot, which can greatly impair thermal comfort in the room, the concentrations of pollutants, odours and CO_2 in the indoor air rise sharply. Air quality deteriorates considerably, health risks increase, and the ability to concentrate and work efficiently decreases. The same applies to the concentration of Corona aerosols as soon as an infected person is in the room: without a sufficient supply of fresh air to the room, the risk of infection increases quickly and considerably. By operating air purifiers, odorous substances, bacteria and also Corona aerosols can be separated and killed and indoor air quality can be improved.

Based on the aspects mentioned in points 1 to 7, a ventilation system with central air conditioning should form part of the standard equipment when planning a new building or renovation. Many countries have recommended or required regulations and standards for ventilation in commercial buildings, and depending on the building type and use, require minimum air exchange rates or minimum air quality with a CO_2 content in indoor air below 1,000 ppm. It must also be taken into account that only in controlled ventilation systems, is it possible to achieve permanent and effective separation of fine dust, bacteria and other pollutants that are hazardous to health. This is not possible by opening a window. ■

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EXPERT INTERVIEW:

Heating and cooling in hotels:

Increasing profitability and sustainability with the right solutions

Historically, many hotel owners and managers have based their investment decisions on construction costs. However, especially with regard to a suitable HVAC system for a hotel, running costs are increasingly becoming the focal point instead, in addition to a growing awareness of energy efficiency and sustainable building operation. While air-based fan coil units remain the default HVAC system in the hospitality sector, ceiling cooling systems offer hotels an alternative solution to the HVAC question. We have discussed the advantages of ceiling cooling systems with Dr. Jan Babiak, Project Manager, International Engineering at Uponor, one of the leading international providers of heating and cooling solutions.

Mr Babiak, why are fan coil units the default HVAC system for hotels? How do they work?

Indeed, fan coil units, or FCU, have been the traditional system for air conditioning in hotels for quite some time. These systems are air-based, which means that fans are connected to the individual rooms by ductwork and blow cool or warm air into the spaces. The whole system is connected to a thermostat, which controls the speed of the fans. FCU are very popular with hotel owners due to their relatively low initial investment cost. However, they do

come with high operation and maintenance costs as well as noise generation and uncomfortable drafts. This can lead to lower guest satisfaction.

What are the alternatives?

Radiant heating and cooling ceiling systems can be a suitable alternative to fan coil units. Hotel owners can reduce their HVAC system's global cost by up to 59 % and its CO_2 emissions by 42 %—and guests benefit from less noise, for example.

You mentioned the HVAC system's "global cost". What is that, compared to the initial investment you mentioned earlier?

The initial investment cost is only a small part of the money that hotel owners are going to have to spend on their cooling system over the course of its life cycle. So, the global cost for building and building elements is calculated by summing up the initial investment and the running and maintenance costs. To go into a little more detail: This approach also applies a so-called discount rate for each year

to the running costs, because the system will lose its initial value over time, and considers its remaining or residual value. The method of global cost ensures an overall consideration of all costs and values across the life cycle of the system or a specific period of time. The goal is to provide hotel owners with the information they need to choose the most economical solution. In accordance with EU regulations, a global cost calculation covers a period of 15 years and helps determine the cost-optimal levels for the minimum energy performance requirements of buildings and building elements.

So, what is the global cost of fan coil units?

The global cost for FCUs is actually very high, especially if you compare it to the potential alternatives that employ radiant heating and cooling technology. The reason is that with fan coil units, hotel owners are required to reinvest after 13 years due to the system's short expected life cycle and quick value depreciation, in addition to a generally higher energy consumption and higher maintenance costs. These systems are not only higher-maintenance, but also use more resources, which means hotel owners could benefit from a switch also from a sustainability perspective.

How does ceiling cooling work?

As opposed to FCUs, which employ air-flow to heat or cool a room, radiant heating and cooling systems are water-based and function by means of the heat radiation principle with heated or chilled surfaces: Energy is transferred by warm or cool water that flows through pipes and heats or cools the room. These systems are usually part of the building structure, for example as an addition to the ceiling in a room. This can be implemented in different ways: The Uponor Thermatop M, for example, is a suspended radiant heating and cooling ceiling system for residential and commercial properties (**Figure 2**). It consists of diffusion-resistant multilayer composite pipe and

Figure 2. Uponor Thermatop M is a suspended radiant heating and cooling ceiling system that consists of diffusion-resistant multilayer composite pipes. It is mounted on conventional ceiling substructures.

comprises standardised modules that are mounted on conventional ceiling substructures. Renovis, another Uponor solution, is a drywall system with a thick plasterboard panel in which piping has been pre-installed at the factory (**Figure 3**). The elements can be mounted as drywall panels on pretty much all wall substrates. This facilitates integration within an existing high-temperature system with radiators and makes Renovis ideal for renovation projects. In the case of concrete ceilings in buildings with higher heating and cooling requirements—such as hotels—thermally active building systems, or TABS for short, like Uponor Contec ON are a suitable solution (**Figure 4**). They are integrated into the concrete ceiling during the construction of the building.

Figure 3. Uponor Renovis is a drywall system in which piping has been pre-installed at the factory. The elements can be mounted on virtually all wall substrates. This makes Renovis also ideal for renovation projects.

That makes three potential alternatives – but which one is the "best" in terms of efficiency and costs?

They all are good and suitable solutions. In the end, it depends on the hotel and on what the owners are looking for. To answer this question, we have to look at the individual categories that comprise global cost. For example, the initial investment costs that we talked about earlier are often a crucial decision criterion. They consist of product costs and installation costs. When we compare these three systems with a conventional fan coil unit, Contec ON is the most economical solution for a new building with up to 21 per cent lower initial investment costs.

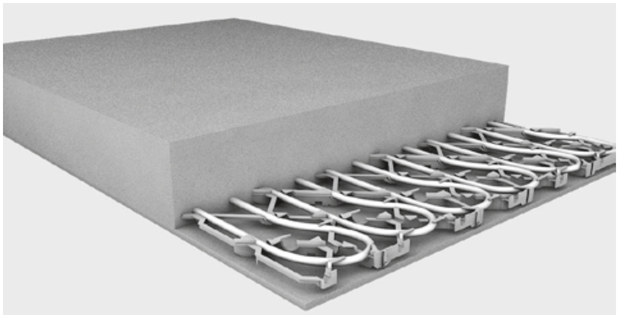
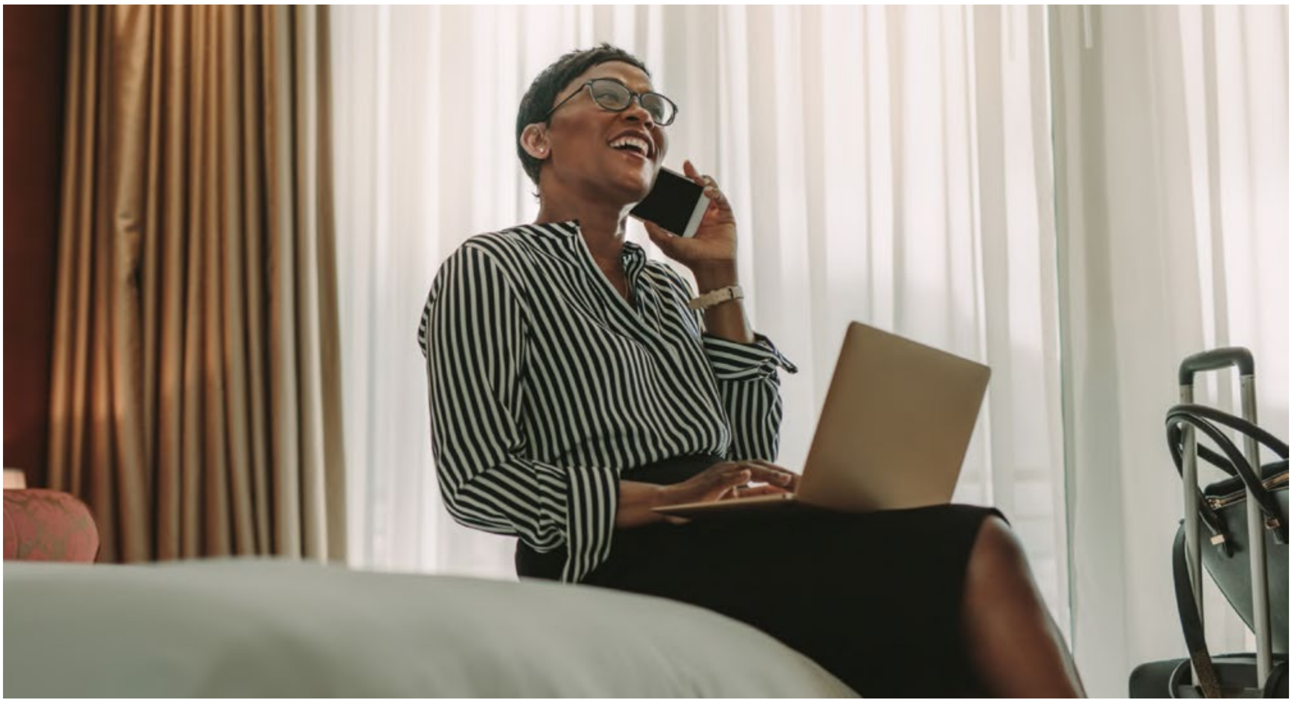
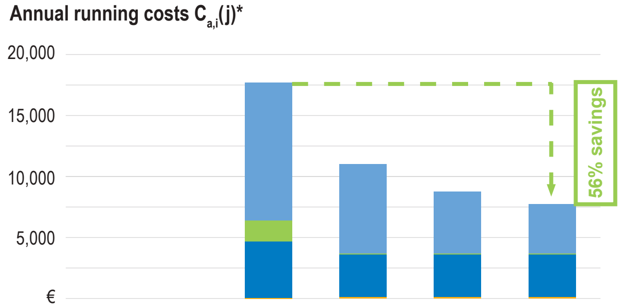


Figure 4. Thermally activate building systems like Uponor Contec ON are a very economical solution. They are integrated into the concrete ceiling during the construction of the building.



But what about the running costs?

Right. With annual running costs, hotel owners have to consider a few important aspects: maintenance as well as energy and reinvestment costs for equipment that might need to be renewed at some point. Because radiant heating and cooling are much more energy-efficient than air-based systems, they consequently offer quite the energy savings. Another aspect to keep in mind is that in hotel rooms, the demand for cooling is generally much higher than the demand for heating; this makes cooling a very important area for generating savings – especially against the background of the rising temperature level during the summer months, also in Central Europe. In a model calculation for a German hotel with one hundred rooms, we determined that the different Uponor solutions ensure up to 56 % lower annual running costs compared to the conventional FCU (**Figure 5**). In more detail, fan coil units generate up to three times higher maintenance costs compared to Contec ON due to higher maintenance and spare parts efforts.



	FCU	Thermatop M	Renovis	Contec ON
Maintenance costs	11,495	7,435	5,223	4,110
HVAC aux costs (electricity for fans and pumps)	1,436	53	53	53
Cooling costs (electricity)	4,628	3,458	3,458	3,511
Heating costs (gas)	67	112	112	134

* Annual running costs of the selected systems for a 100-room hotel with τ = 1

Figure 5. With radiant heating and cooling systems, hotel owners can save up to 56 per cent of annual running costs compared to fan coil units.

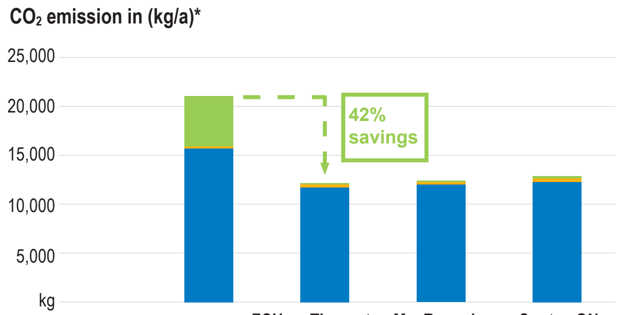
You mentioned that radiant heating and cooling systems are more energy-efficient. Why is that?

Compared to radiant heating and cooling systems, where the energy is transferred in a water circuit driven by a pump, fan coil units heat or cool the space with heated or chilled air driven by a fan. Based on the lower thermal capacity of air compared to water, these systems require significantly more auxiliary energy to operate the fans in order to transfer the same amount of heating and cooling energy into the room.

▶ Additional to this: these radiant Heating & Cooling systems are low-temperature heating and high-temperature cooling systems. This allows for higher generation efficiency for H&C generators, especially when Heat-Pump systems are used to generate this heat and cold.

What role does energy-efficiency play in general in the global cost calculation?

The energy aspect plays a very important role in the global cost calculation—cost and energy efficiency go hand in hand, definitely in terms of efficient energy consumption, but also when it comes to the energy source. For example, all Uponor radiant ceilings are compatible with any energy sources, especially



	FCU	Thermatop M	Renovis	Contec ON
Cooling	4,908	111	120	192
Heating	169	281	281	338
HVAC aux	15,834	11,830	11,830	12,012

* CO_2 emission of the selected systems for a 100-room hotel with τ = 1
The CO_2 emissions for gas and electricity are 0.201 and 0.65 kg/kWh respectively

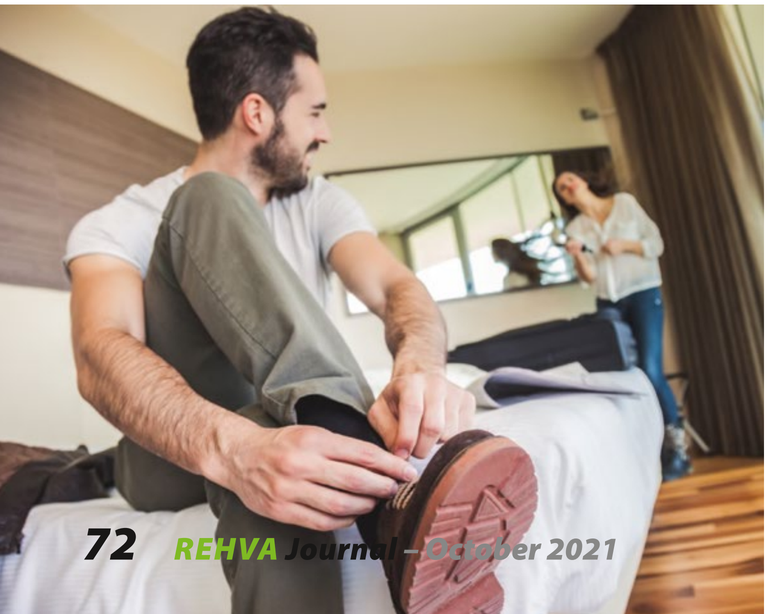
Figure 6. Radiant heating and cooling systems reduce the overall CO_2 emissions by up to 42 per cent.

renewable ones. Taking a look at their CO_2 emissions, all radiant systems are more or less at the same level—but up to 42 % under the fan coil units, which constitutes a very good result in terms of sustainability and energy conservation (**Figure 6**).

You mentioned that all heating and cooling systems lose value over time. How does this factor into the global cost calculation?

The remaining or residual value of a system is important to consider when calculating global cost. It is determined by both the initial investment, which depreciates over time, and the life span of the system:

the longer the lifespan and the higher the residual value in the end of the assessment period, the lower the global cost. For structural radiant systems like Contec ON, for example, which features a lifespan of 60 years or more—the same as a building—this creates a substantial advantage compared to components like FCU with a lifespan of only twelve years. In comparison, out of the three Uponor products I mentioned, Thermatop M represents the highest residual value across the full life cycle. This is driven by the higher investment cost, but also by the long lifetime and thus lower depreciation. In general, the residual value of all three Uponor radiant heating and cooling solutions remains high based on the long lifetime of these systems. This results in global costs that are up to 59 % lower than with FCU.



What does that mean for hotel owners?

In conclusion, the Uponor radiant heating and cooling ceiling solutions have proven to be cost-effective for a hotel building despite higher investment costs in the construction phase. The reason is simple: The future savings in the operating phase compensate for the initial costs and thus increase the net cash flow during the whole life cycle of the hotel building. Apart from the financial aspects, the image factor cannot be ignored. Hoteliers who focus on sustainability and make a contribution to climate protection can improve their reputation among guests. Ecological aspects in particular and green building certifications are becoming increasingly important in travel planning. ■

Uponor Whitepaper

More details on global costs as well as an in-depth comparison between fan coil units and the Uponor radiant heating and cooling systems can be found in the White Paper "Global Cost study for different HVAC solutions in hotels, see https://www.uponor.com/en-en/planner-support/whitepaper

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Exhibitions, Conferences and Seminars in 2021

Conferences and seminars 2021*

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

25-29 Oct	EUSEW EU sustainable energy week	Online	https://www.eusew.eu/
26-27 Oct	European Heat Pump Summit	Nuremberg, Germany	https://www.hp-summit.de/en
28 Oct	Gebäudetechnik Kongress	Online	https://www.gebaeudetechnik-kongress.ch/
4-5 Nov	REHVA Brussels Summit 2022	Brussels, Belgium	https://www.rehva.eu/
09 Nov	Rakennusten energiaseminaari 2021	Helsinki, Finland	https://finvac.org/rakennustenenergiaseminaari/
17-19 Nov	Varmeteknisk konferanse 2021	Oslo, Norway	https://nemitek.no/varmeteknisk-konferanse
01-30 Nov	ASEAN SUPER 8 Virtual Connect Exhibition 2021	Online	https://www.super8asean.com/
01-03 Dec	52nd International Congress and Exhibition on HVAC	Belgrade, Serbia	http://kgh-kongres.rs/index.php/sr/
08-10 Dec	Driftskonferansen 2021	Oslo, Norway	https://www.driftskonferansen.no/

Conferences and seminars 2022

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

The World Sustainable Energy Days 2022

Energy transition – full speed ahead!

"Energy transition – full speed ahead!" is the focus of the next World Sustainable Energy Days (WSED) in Wels/Austria from 2-4 March 2022.

The new "Fit for 55" package aims to put the EU on track towards climate neutrality. Energy accounts for 75% of GHG emissions. Speeding up the energy transition is critical!

In 2022, the WSED present the far-reaching transformation of policies, technologies and markets for achieving the EU's climate neutrality goals, and how to raise the pace of change. They show how citizens and businesses can profit from this, how we can increase acceptance, trigger investments, and get things moving – full speed!

A comprehensive package

The WSED are a leading annual conference on the energy transition and climate neutrality with more than 650 participants from over 60 countries each year. They offer 6 dedicated conferences, more than 100 international speakers, technical site visits and a sustainable energy tradeshow. Meet the entire energy transition world and enjoy Austrian hospitality!

Upper Austria – a leader in the clean energy transition

The WSED are organised by the OÖ Energiesparverband, the energy agency of Upper Austria. Upper Austria, one of Austria's 9 regions, is well on its way in the clean energy transition. Through significant increases in energy efficiency and renewables, greenhouse gas emissions from buildings were reduced by 39% in 10 years. 60% of all space heating and 31% of the primary energy in the region already come from renewables. Over 2.5 billion Euro are invested each year in the energy transition. ■

Mark your calendar for 2-4 March 2022 and join REHVA and the worldwide energy transition community at the World Sustainable Energy Days!

World Sustainable Energy Days 2022

Conferences and events:

- European Energy Efficiency Conference
- European Pellet Conference
- Young Energy Researchers Conference
- Energy Efficiency Policy Conference
- Industrial Energy Efficiency Conference
- Smart E-Mobility Conference
- Innovation Workshops

CLIMA 2022

Eye on 2030 | Towards digitalized, healthy, circular and energy efficient HVAC

REHVA 14th HVAC World Congress

15th - 18th May, Rotterdam, The Netherlands

High on the agenda:
European transformation of the energy system

CLIMA 2022 is an international congress with energy concerning plant engineering as one of the main topics. To become climate neutral by 2050, Europe must transform its energy system (which accounts for 75% of EU greenhouse gas emissions). The recently adopted EU plans/strategies to integrate energy systems (European Green Deal and NextGenerationEU) must pave the way for a more efficient and interconnected energy sector, driven by the double goal of a cleaner planet and a stronger economy.

JAN HENSEN
Em. Prof. Dr., CLIMA 2022 topic coordinator, Energy

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The EU strategy for energy system integration will provide the framework for the transition to green energy. The current situation is based on separate energy systems (silos) with different vertical value chains that coexist and closely link energy sources to their specific end-users, e.g. petroleum products as fuel for the transport sector. This model cannot achieve climate neutrality cost-effectively by 2050; the changing costs of innovative solutions must be integrated into the way we operate our energy system. New connections between sectors must be created, and technological advances must be exploited.

Energy system integration means planning and managing the system as a whole, based on the interconnectedness of different energy carriers, infrastructures, and sectors of consumption. Such an interconnected and flexible system will be more efficient and will reduce costs for society. It could, for example, be a system where the electricity for electric cars comes from solar panels on roofs, while buildings are heated with waste heat from a nearby factory, and factories are powered by green hydrogen produced from offshore wind energy.

Short-term political goals and challenges

Firstly, a more ‘circular’ energy system, with energy efficiency at its core. The strategy will identify concrete actions to put the ‘energy efficiency first’ principle into practice and use local energy sources more effectively in our buildings or neighbourhoods. There is significant potential in reusing waste heat from industry, data centres or other sources, and energy produced

Innovative storage of sustainable energy like this in the Amsterdam Arena is expected to be a recognised part of Clima 2022.

from bio-waste or in wastewater treatment plants. The 'Renovatieversneller' (a Renovation-accelerator, a Dutch governmental initiative to subsidise sustainable restoration projects) will be an important part of these reforms.

Secondly, greater direct electrification of end-use sectors. Because the energy sector has the largest share of renewable energy sources, we need to use more and more electricity wherever possible: for example, for heat pumps in buildings, electric vehicles in transport or electric furnaces in certain industries. A network of one million charging points for electric vehicles will be among the most visible results, along with the increase in solar and wind power.

For those sectors where electrification is difficult, the strategy promotes clean fuels, including renewable hydrogen and sustainable biofuels and biogas. The EU Commission will make a new proposal for a classification and certification system for renewable and low-carbon fuels.

The EU strategy comprises 38 actions to create a more integrated energy system. These include the revision of existing legislation, financial support, research and application of new technologies and digital tools, directives for the Member States on fiscal measures and phasing out fossil fuel subsidies, reform of the market governance and infrastructure planning, and improved consumer information. An analysis of the existing obstacles in these areas will be used for concrete proposals, for example, the revision of the Trans-European Networks for Energy (TEN-E) regulation or the revision of the energy taxation directive and the regulatory framework for the gas market.

When houses become small power plants, the government, grid operators, and energy companies must respond.

CLIMA 2022 focuses on the relationship between the above and the installation technology sector. The development of building management systems that use heat, cold and electricity from renewable sources is accelerating, creating a need for flexibility and, therefore, energy storage and energy exchange between buildings. In addition, there is a need for innovative HVAC products and performance optimisation through improved design, operation and maintenance of the various integrated mechanical and electrical subsystems. Typically, this includes reducing and balancing energy needs for heating, cooling and ventilation. While this is not exactly trivial in the case of new buildings, it poses enormous technical, social, economic and political challenges for existing buildings.

It is evident that solutions differ from country to country. Exchanging experiences and learning from each other are the main objectives of CLIMA 2022. This is not limited to the technical aspects but includes economic, cultural, legal and organisational aspects. The overall energy system becomes more dynamic and is influenced by additional actors with non-traditional roles. When houses become small power plants, when large building complexes start to exchange energy, or when smart data companies control energy consumption, the government, grid operators, energy companies, financial institutions, and our sector must respond.

CLIMA 2022, therefore, welcomes original contributions that introduce, share, broaden and improve scientific and practical knowledge and experience on the following sub-topics:

- Renewable and smart energy solutions for buildings and sites: energy storage; energy exchange; energy flexibility; renewable energy production;
- Designing innovative HVAC systems for optimised operational performance: high-performance HVAC systems and components; smart technologies; optimised control; optimised maintenance; data-driven operation; digital twins; reducing and balancing the energy demand in buildings: energy transition; technological breakthroughs in insulation; ventilation; shading; systemic innovations;
- Legislation, business models and shifting responsibilities: new legislation; public-private partnerships; market initiatives; new business models; new players in the energy market. ■

EUROPEAN GUIDEBOOKS

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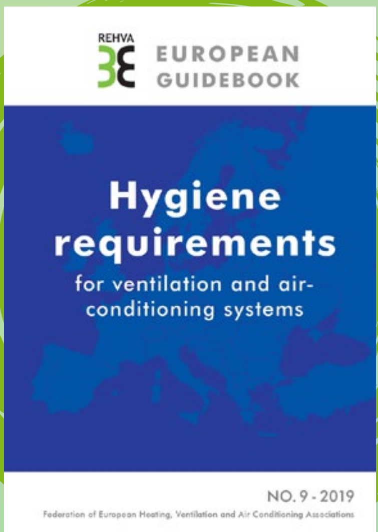

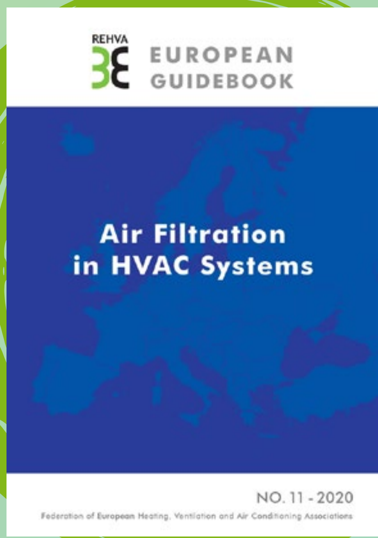

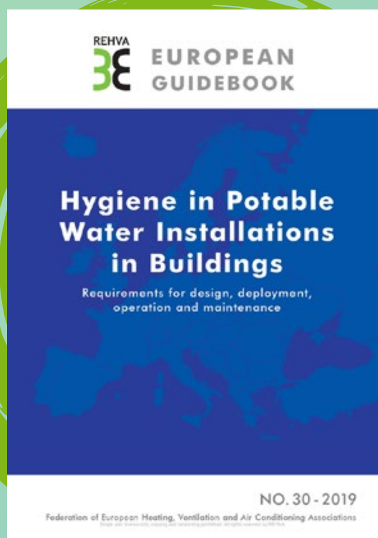

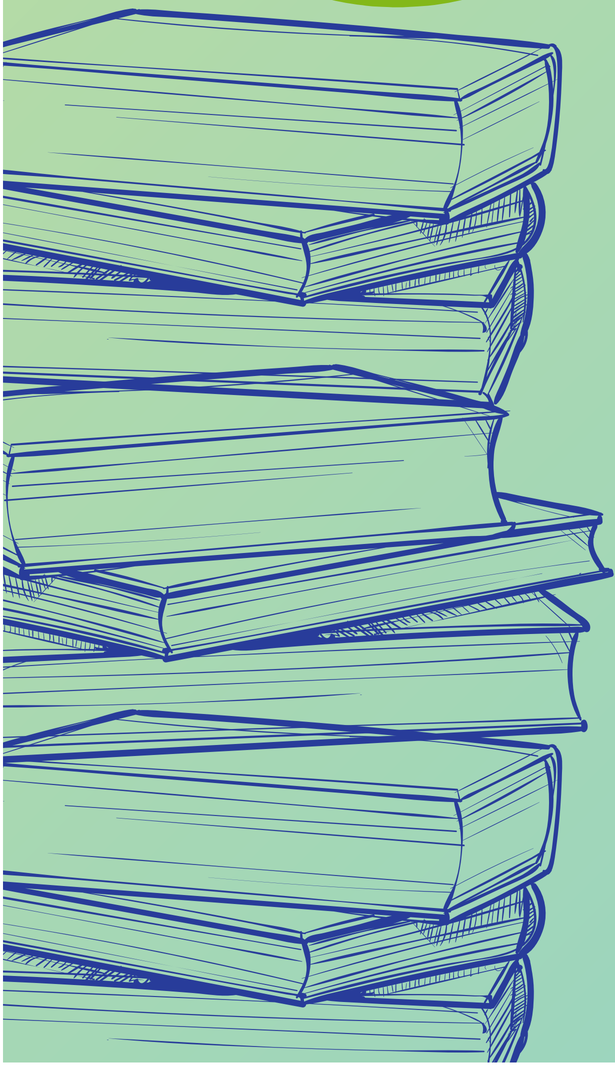

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