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COVID-19 Guidance

Safe, conserving and energy recovering water technology

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- Modern ventilation and air conditioning technology, including COVID-19 studies
- Energy efficient heating and cooling systems
- Building automation and monitoring systems
- Nearly zero energy and carbon buildings

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Towards a new normal in 2021

2020 was a very stressing year for most of us. The COVID-19 epidemic is not yet losing its grip on our society. Hope is appearing at the horizon and after mid 2021 we expect to be almost back to a new normal. A new normal where we are aware of our vulnerability for infectious diseases caused by those COVID viruses or alike and the role the indoor climate and the ventilation systems have.

2021 and years to come will require our attention for IEQ and climate change measures. Our existing and new buildings need to become resilient against airborne infection diseases and become zero carbon at the same time. The back to normal will not be continuing to do the same we did before. The Renovation Wave and agreed decarbonisation target was already announced and became last week official. The target of the EU: 55% reduction by 2030 towards zero emission by 2050 has now to be combined with a COVID resilient IEQ target. What the latter means is slowly becoming clearer.

REHVA did a great job by developing their COVID-19 guidance and course. The tools are available and further developing. REHVA Journal decided to include the core of the guidance in this issue as an historic proof and handy document but at the same time referring to our website where all future updates are going to be published. The REHVA TRC Task Force on COVID-19 worked very hard during the last 9 months and will continue to do so. Many experts from our REHVA members contributed to this. There was also a very active exchange of information with other platforms of which many are part of the IEG-GA (IEQ Global Alliance www.ieq-ga.net) where REHVA holds the secretariat.

The more prominent inclusion of IEQ in the EU Renovation Wave and the decarbonisation target will require the HVAC&R professionals to come forward with more innovative solutions. The holistic approach at building and system level will be extended to the energy grid. The set of EPB standards as developed and used to implement the EPBD in EU has last November been extended with EN 17423 on EPB and Primary Energy Factors (PEF) and CO_2 emission coefficients (see www.epb.center). This standard is creating a level playing field on these issues. Needed to answer questions on the future of the gas infrastructure, the positioning of the expected H_2 market, the use of certified zero-carbon biofuels and the decarbonisation of our electricity grid. All challenges to be cleared in the near future.

As we cannot wait REHVA journal offers you articles about our currently used and improved technologies. Articles on heat pumps, on an improved standard on HP system performance and new technical developments on HP's. Heat pump application is currently the answer towards zero carbon. Improving our energy efficiency using BMS, phase change materials and waste water heat recovery are also part of the equation and articles in this issue.

The REHVA board, the editorial board of the REHVA Journal and REHVA staff wishes all our readers a healthy, prosperous and inspiring 2021. We thank our readers and all authors that contributed to the success of this journal for their interest and contributions during 2020. ■

JAAP HOGELING
Editor-in-Chief
REHVA Journal

Heat pump standard EN 15316-4-2 – From compliance to real consumption

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Europe target carbon neutrality for 2050. Electrically driven heat pumps are considered as key in energy transition. This article describes the development of the energy performance calculation in heat pump standards from simplified versions, destinated to fulfil compliance with building regulations, towards more detailed hourly methods to get closer to the real consumption. The principles and main influencing parameters are explained.

Keywords: energy efficiency calculation, heat pumps, European Standards

In the past, the assessment of the building energy performance in building regulations was destinated to distinguish between energy efficient and less efficient buildings. To be close to the "real" energy consumption was not a main target. The regulations focused first on the building envelope. The technical systems where simply characterised by seasonal efficiencies. The evaluation methods were simplified, adapted to check the compliance to building regulation. The heat pump standard EN 15316-4-2 from 2007 was in line with this approach.

➢ EN 15316-4-2: 2007 Method for calculation of system energy requirements and system efficiencies — Part 4.2: Space heating generation systems, heat pump systems

In EN 15316-4-2 from 2007, two performance calculation methods are described:

- Simplified seasonal performance method based on system typology (tabulated values, not case specific);
- Detailed case specific calculation based on component efficiency data (Bin-method).

In the simplified seasonal performance method, the considered calculation period is the heating season. The performance is calculated with tabulated values for fixed performance classes of heat pumps. The operating conditions of the heating system related to climate, heat source and heat sink type are fixed by typology. The method is not case (building) specific.

Note: The methodology related to the Ecodesign Directive is also a simplified seasonal performance method based on system typology.

To be more case specific a more detailed method was provided. Supplementary data are needed in order to take into account the specific operating conditions of each individual installation. The calculation period is split-up in bins dependent on the outdoor air temperature. The annual frequency of the outdoor air temperature is cumulated and divided into temperature intervals (bins). The operating conditions of the bins are characterised by an operating point in the centre of each bin. The area under the cumulative frequency, the cumulative heating degree hours, is correlated with the energy requirement for space heating.

The cumulative frequency is only dependent on the outdoor air temperature, and therefore does not consider solar and internal gains. For existing buildings, the approximation of the energy demand by the outdoor air temperature maybe enough, while for nearly zero energy buildings it may not. The relation between the sink temperature of water-based heat pump systems (heat distribution temperatures) and the source outdoor temperature is not always directly related to the outdoor air temperature. It depends on the control system.

Part load conditions, as continuous modulation or on-off operating are neglected in the frame of this standard if not quantified by available test data. If no test data on part load operating are available, only the auxiliary stand-by consumption was taken into account to evaluate the degradation of the COP in part load operating.

➢ EN 15316-4-2: 2017 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

The trend towards nearly zero energy buildings and the availability of additional product data (EN 14825) related to part load operation leaded ten years later to the revision of EN 15316-4-2 with two major improvements:

- Calculation of COP and thermal capacity at full load based on EN 14511 series (Path A);
- Calculation of COP and thermal capacity including part load based on EN 14825 (Path B).

For both methods a major improvement was the introduction of a matrix presenting performance coefficients for the COP and thermal capacity. These coefficients are determined at the beginning of the calculation. Both methods are hourly methods.

The coefficients may be taken by default or interpolated from test results. They are adapted to the operating conditions based on the exergetic approach presented in Annex D of EN 15316-4-2:2017.

The hypothesis of the exergetic approach is that the thermodynamic quality of the process stays constant over the whole operating range. The thermodynamic quality of a process is expressed by the exergetic efficiency which is the ratio between the real COP of the process and an ideal Carnot COP. However, in real processes, the exergetic efficiency does not stay constant over the entire operating range (e.g. compressor efficiency). Therefore, the extrapolation of test values provides best results only near the test points. If more test points are available, closer is the performance map to the real results of the heat pump.

The performance coefficient of the Carnot cycle depends on the outlet temperature of the condenser fluid and the inlet temperature of the evaporator fluid. Assumption are made for the temperature spread between the source / sink temperatures and the evaporator / condenser fluid temperatures. For water-based components the temperature difference between the heat transfer medium and the refrigerant fluid can be approximated by $\Delta Tsk = \Delta Tsc = 4$ K. For air-based components $\Delta Tsk = \Delta Tsc = 15$ K may be set. The minimum temperature difference between the heat transfer medium and the refrigerant shall be kept.

Attention is also paid to auxiliary consumption. Auxiliary consumption only comprises the fractions not included in the COP according to EN 14511 standard testing. The auxiliary consumption is a function of the part load ratio.

Calculation of COP at full load based on EN 14511 series (Path A)

In Path A, matrix presenting default coefficients for calculation of the COP and thermal capacity at full load are provided. If only one test value is available, they are built from this unique reference value corresponding to nominal conditions of the sink and source temperatures of heat pump types (see **Figure 1**).

Note: The test values of EN 14511 have not to be and are not at 100% capacity of inverter-controlled heat pumps. The values at −7°C or −15°C are at 100% capacity, but the values at 2°C, 7°C or higher may be given at a lower capacity (e.g. 60%).

The whole matrix of the performance coefficients is obtained using the weighting factors which account:

- in the last row only for temperature changes at the source;
- in the last column only for temperature changes at the sink.

The values for the COP at full load for other operating conditions are calculated by multiplying the default performance coefficients starting at the unique reference (see **Figure 2**).

If additional test data are available, the default coefficients can be replaced by heat pump specific coefficients.

The example in **Figure 1** indicate that if:

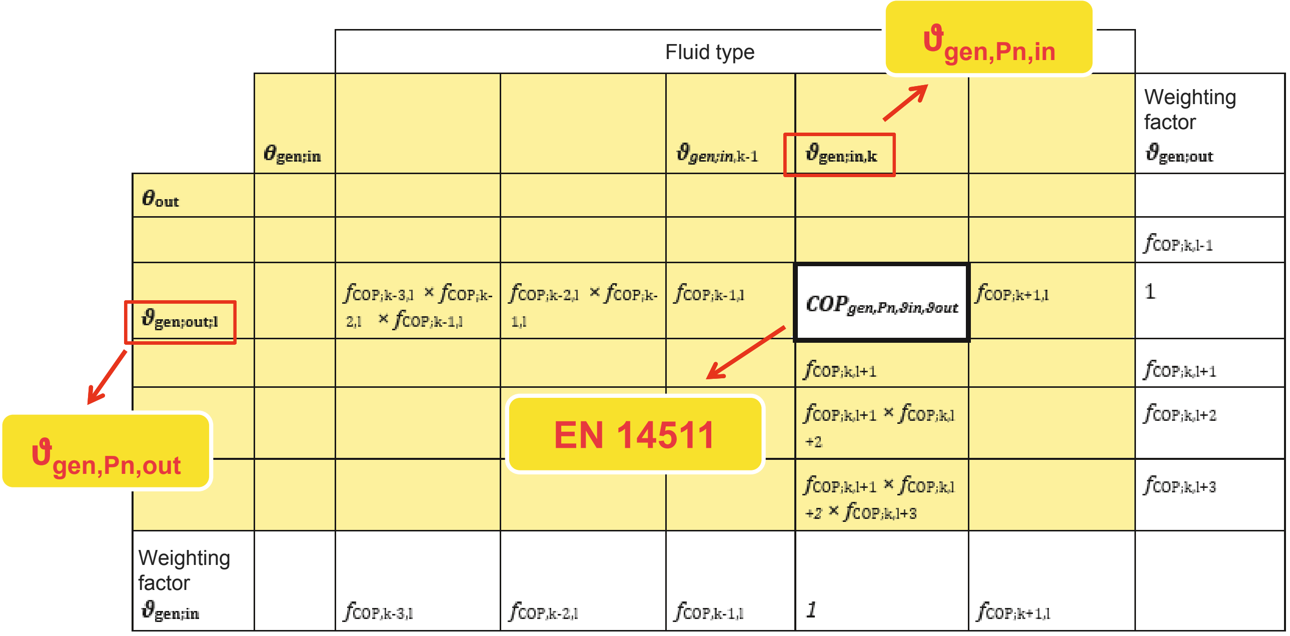
- only the source temperature varies from -15°C to +20 °C the COP is multiplied by 3,9 (1,25/0,32);
- only the sink temperature varies from 65°C to 25°C the COP is multiplied by 2,1 (1,1/0,51);

In total, if the operating conditions change from the less favourable operating conditions (sc: –7°C,sk:65°C) to the most favourable operating conditions (sc: 20°C, sk: 25°C) the COP is multiplied by more than 8 at full load conditions.

This example underlines the sensibility of a heat pump on the operating conditions. It shows that with a seasonal or bin method it is not possible to take this sensibility on operating conditions into account in a precise manner.

Air-Water heat pumps - Weighting factors for calculation of the COP										
										Air
Water		0 °C	0 °C	0 °C	0 °C	0 °C	0 °C	0 °C	0 °C	$\Delta\theta_{in;ref}$
		–15 °C	–15 °C	–7 °C	2 °C	7 °C	20 °C	20 °C	20 °C	ϑ_{in}
$\Delta\theta_{out;ref}$	ϑ_{out}									Weighting factor ϑ_{out}
3	25									1
3	25									1.1
5	35					$COP_{gen.Pn.ref}$				1
5	45									0.8
8	55									0.8
10	65									0.8
	Weighting factor ϑ_{in}	1	0.8	0.5	0.8	1	1.25	1	1.0	

Figure 1. Performance matrix with default values EN 15316-4-2: 2017.



	$\theta_{gen;in}$			$\vartheta_{gen;in,k-1}$	$\vartheta_{gen;in,k}$		Weighting factor $\vartheta_{gen;out}$
θ_{out}							
							$f_{COP;k,l-1}$
$\vartheta_{gen;out;l}$		$f_{COP;k-3,l} \times f_{COP;k-2,l} \times f_{COP;k-1,l}$	$f_{COP;k-2,l} \times f_{COP;k-1,l}$	$f_{COP;k-1,l}$	$COP_{gen,Pn,\vartheta in,\vartheta out}$	$f_{COP;k+1,l}$	1
					$f_{COP;k,l+1}$		$f_{COP;k,l+1}$
					$f_{COP;k,l+1} \times f_{COP;k,l+2}$		$f_{COP;k,l+2}$
					$f_{COP;k,l+1} \times f_{COP;k,l+2} \times f_{COP;k,l+3}$		$f_{COP;k,l+3}$
Weighting factor $\vartheta_{gen;in}$		$f_{COP,k-3,l}$	$f_{COP,k-2,l}$	$f_{COP,k-1,l}$	1	$f_{COP;k+1,l}$	

Figure 2. Principle for establishing the whole matrix (source: CEN-CE project).

In Path A, the influence of the part load can only be considered by typologies as no test data are available (no product specific test data on part load in EN 14511).

Therefore, the following conventions have been made:

- when the compressor operates continuous modulating, the variation of the COP from the minimum value for continuous operation to full load is a linear function of the load factor;
- when the compressor operates in ON/OFF mode, the compressor power is increased due to non-reversibility of the heat pump (inertia). Dynamic effects related to transient thermal conditions are transformed into a time delay depending on the type of emitters and heat pump characteristics. The time delay is calculated as a ratio of both time constant and as a function of the load ratio. Default values are provided in the standard.

Compared to the previous version of 15316-4-2 from 2007, the introduction of the performance map facilitates the usability of available product performance data a full load (Path A). Especially if there are more test results available, the influence of the operating conditions on the heat pump performance at full load is well defined, because the influencing parameters vary one by one.

To take into account part load operating, the full load performance is corrected. As there are no test results available for part load, the conventions to consider part load operating has been completed compared to the previous versions of the standard. But they remain conventions which are not product specific.

Calculation of COP including part load based on EN 14825 (Path B)

EN 14825 was worked out to deliver the data required by the ECODESIGN directive. Heat pumps are tested at part load conditions.

Figure 3 shows the conventional operating conditions (e.g. average, warm, cold climate, the load ratio) published in the product fiche. According to EN 14825 the manufacturer is obligated to test the unit for various temperature applications (low temperature 35°C, intermediate temperature 45°C, medium temperature 55°C, high temperature 65°C) in the three typical climates (average, warm and cold).

In Path B the COP at operating conditions are derived from the test results according to EN 14825. The values are interpolated from the results and adapted to the operating conditions by using the exergetic approach already describe before.

<table>
<tr><th colspan="10">Input data based on EN 14825 test results</th></tr>
<tr><td colspan="10"></td></tr>
<tr><th></th><th colspan="3">Load Ratio for different climates</th><th colspan="3" rowspan="2">Output temperature
$COP\vartheta_{in};\vartheta_{out;ref}$</th><th colspan="3" rowspan="2">Thermal capacity
$\Phi\ \vartheta_{in};\vartheta_{out;ref}$</th></tr>
<tr><th>Point</th><th>Average
%</th><th>Warm
%</th><th>Cold
%</th></tr>
<tr><td>A</td><td>0,88</td><td></td><td>0,61</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td>0,54</td><td>1,00</td><td>0,37</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td>0,35</td><td>0,64</td><td>0,24</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D</td><td>0,15</td><td>0,29</td><td>0,11</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td>TOL</td><td></td><td>TOL</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>F</td><td>ϑbiv</td><td>ϑbiv</td><td>ϑbiv</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>G</td><td></td><td></td><td>0,82</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="3">Term</th><th>Unit</th><th colspan="3">Symbol</th><th colspan="3">Value</th></tr>
<tr><td colspan="3">Thermostat off</td><td>kW</td><td colspan="3">P_hto</td><td colspan="3"></td></tr>
<tr><td colspan="3">Standby</td><td>kW</td><td colspan="3">P_stby</td><td colspan="3"></td></tr>
<tr><td colspan="3">Off mode</td><td>kW</td><td colspan="3">P_off</td><td colspan="3"></td></tr>
<tr><td colspan="3">Pdegration</td><td>kW</td><td colspan="3">P_cd</td><td colspan="3"></td></tr>
<tr><td colspan="3">Degradation factor</td><td>–</td><td colspan="3">f_cd</td><td colspan="3"></td></tr>
</table>

Figure 3. Product fiche related to EN 14825.

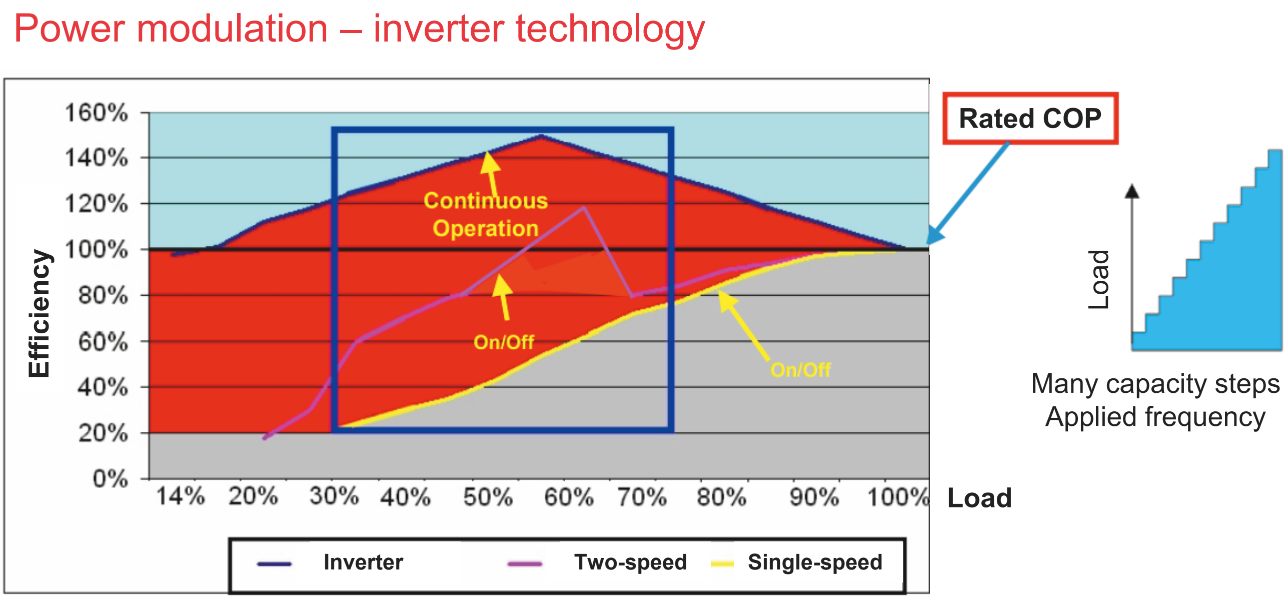


Figure 4. Influence of part load operating on heat pump efficiency (source: CEN-CE project).

The added value of Path B is the more detailed calculation of part load operating based on test results. **Figure** 4 show the influence of part load on the efficiency related to different power control (inverter continuous operating, single speed on-off control etc). At 50% load the efficiency may vary from 40% to 150% of efficiency.

Path B distinguish between on-off operating and continuous modulating operating at part load.

In on-off operating the declared COP is lowered by the degradation factor (up to 25%) and the load ratio. The degradation factor is indicated in the product fiche. This approach is similar to Path A.

In continuous modulating operating, e.g. reduced compressor speed, the difference between the condenser and evaporator fluid temperature is reducing. For example, for an Air/Air unit in point D - EN 14825 (source temperature 2°C, sink temperature 20°C) the difference between the evaporator and condenser fluid temperature may vary from 36 K at 100% load, to 25 K at 15% load. These temperature changes influence the COP. These temperature changes are used in Path B to construct the performance map for part load operating. The performance coefficients at different points of the performance map are then obtained by interpolation between the different test points of EN 14825.

These effects are not taken into account explicitly in Path A.

Conclusion

The heat pump standards changed from simple seasonal methods related to building regulation compliance check to more detailed hourly methods closer to real energy consumption.

These changes were needed by the increasing quality of buildings towards nearly zero energy buildings, which request more precise calculation methods, but also by the claim of building owner and occupants that the promised energy savings are verified by energy savings in reality. To be closer to the real consumption is a general tendency also seen in other sectors. The most well know example is the car industry.

The progress of the calculation methods has been made possible and reliable by additional product test results and the accessibility of product data.

EN 15316-4-2:2017 allows to consider the high variability of the heat pump performance on operating conditions in a more precise way. The counterpart of this evolution is that the new standards are not always easy to apply. The standards are more detailed, not always explicit.

Training is needed to apply them, support is needed to transpose them at national level, product test data has still to be improved and made easily accessible at European level. ■

Ecological and Energy Efficiency Study of Heat Pumps with Capillary Evaporators

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This study represents a research in the field of energy efficiency and environmental optimizations of heat pumps, analysing the comparative performances obtained by changing the refrigerant R407C with R290. For testing, an open circuit water-to-water heat pump was used, with capillary evaporators with an innovative spiral shape.

The simulations showed that the heat pump ensures an important reduction of the electricity consumption and Total Equivalent Warming Impact to an ordinary air conditioning system.

Keywords: Heat Pump, EER, COP, TEWI, Capillary Evaporators, Energy Efficiency.

Heat transfer performance is one of the most important areas of research in the field of thermal engineering. There is a large number of refrigerants used in compression refrigeration systems. Their use implies for each case some reservations in terms of environmental impact (Following the Montreal Protocol 1987 refrigerants CFCs "chlorofluorocarbons" were finally abandoned in 2000 and gradually replaced by HCFCs or HFCs and within it providing an opportunity for the development of substitutes), toxicity (NH_3), flammability (HC) or high pressure (CO_2), which gives them degrees of danger accordingly.

Ashok G. Matani et al. (2010), conducted an experimental study to observe the performance of different ecological refrigeration mixtures (HC and R401a mixture).

This innovative system can use a renewable energy resource, respectively groundwater, rivers or sea water and can achieve both the heating and cooling requirements of a location.

Method and international analysis

E. Halimic et al. (2011) tested the operation of a compression refrigeration system using R401a, R134a and R290 refrigerants. The results (**Figure 1**) indicated that the performance obtained with refrigerant R134a are close to those obtained with refrigerant R401a but lower than those obtained with refrigerant R290.

E. Navarro et al. (2012) conducted a comparative study between R1234yf, R134a and R290, using a piston compressor, with two operating speeds and vaporization temperatures from –20°C to 20°C, with the condensation temperature variation between 40°C and 65°C.

The measurements performed and the subsequent analysis led to the following conclusions:

- R290 has shown a significant improvement in volumetric efficiency, and heat losses are considerably lower than for the other two coolants. It should be noted that R290 has a significantly higher volumetric capacity than the other two refrigerants, which may reduce the size of this type of system (Brown, J.S., et al., 2010).
- The new refrigerant, R1234yf, has better efficiency compared to R-134a for pressure ratios greater than 8. It has less heat loss than R134a, but 20% more than R290 (Mathur, G.D., et al., 2010). From this study, was concluded that R1234yf and R290 can be good substitutes for R-134a.
- In terms of efficiency, R290 (**Figure 2**), demonstrated a better performance for the whole range of conditions tested (improvement on average by 30%

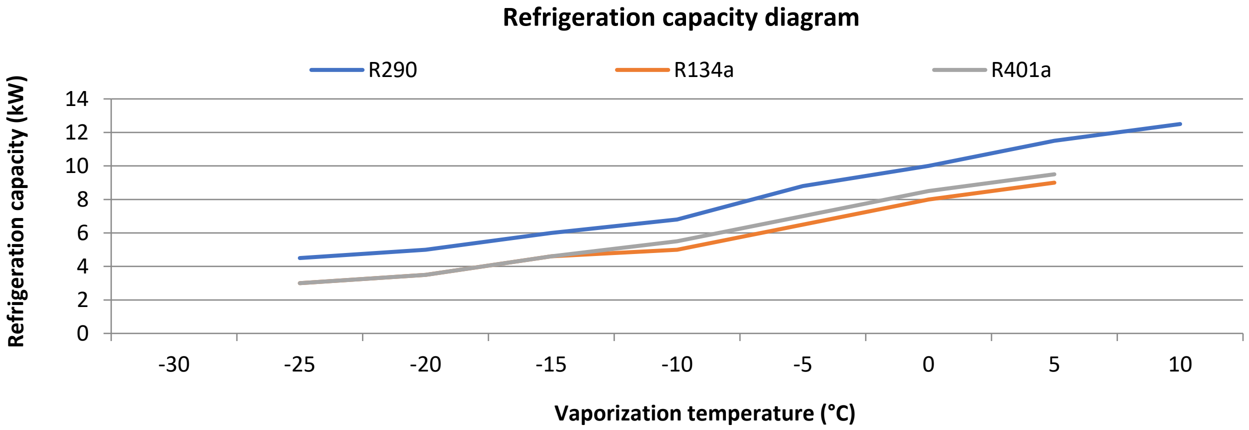

Figure 1. Refrigeration capacity analysis.

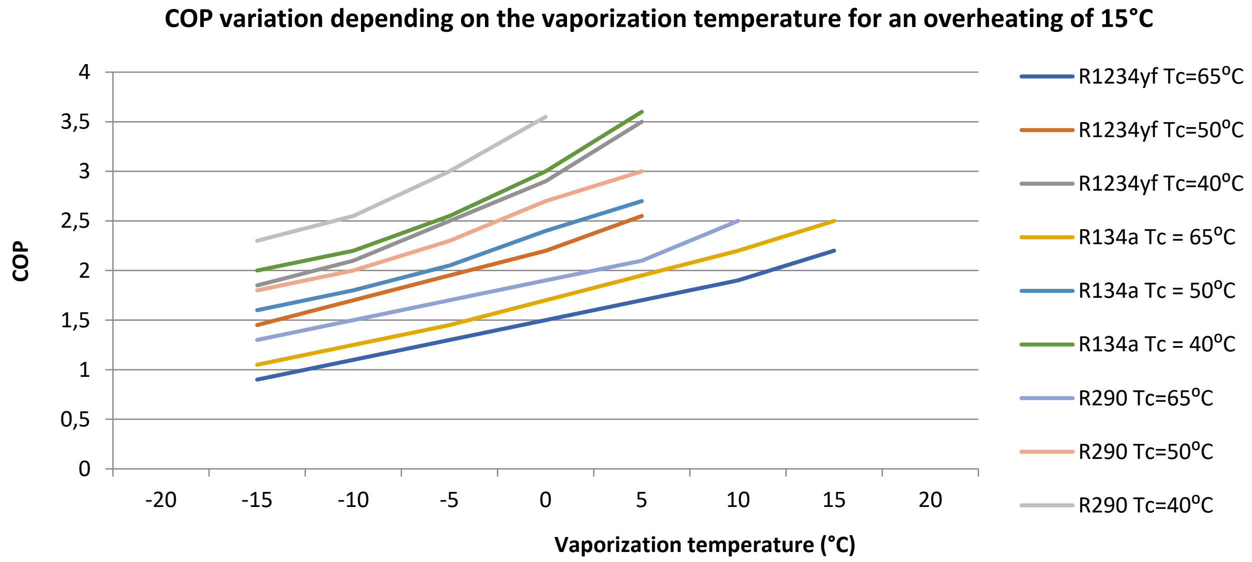

Figure 2. COP variation for tested refrigerants.

of volumetric efficiency and by 15% of compressor efficiency). R1234yf showed higher heat losses than R290, even with a significantly lower compressor discharge temperature.

Ki-Jung Park and others (2007), analysed the performance of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a and dimethyl ether in order to replace R22 refrigerant in residential air conditioners and heat pumps at evaporation temperatures and condensation of 7°C and 45°C, respectively. The test results confirmed a value of the performance coefficient of these mixtures up to 5.7% higher than in the case of operation with R22. The conclusions were that the mixtures used led to superior performance with reasonable energy savings, without any environmental problems and, consequently, can be used in the long term as alternatives for residential air conditioning and heating applications with heat pumps.

Ki-Jung Park et. al., (2007), analysed the thermodynamic performance obtained with two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a and dimethyl ether (R170) in order to analyse the possibilities of substituting R22 refrigerant in residential air conditioning installations.

The test results led to COP values up to 5.7% higher than when using R22 refrigerant.

K. Mani et. al., (2008) , analysed the operating parameters of a refrigeration system with steam compression using the R290 / R600 mixture (68% / 32%) in order to replace the R134a refrigerants.

In conclusion, the mixture R290 / R600a (68/32% by weight) can be considered as a substitute refrigerant R134a due to the real ecological advantages.

AS Dalkilic et al. (2010), studied the performance of a compression refrigeration plant using mixtures of R134a, R152a, R32, R290, R1270, R600 and R600a refrigerants combined in various ratios and the results were compared with the functional parameters of the same plant using refrigerants R22 and R134a.

The results show that all alternative refrigerants investigated in the analysis have a COP slightly lower than R22 and R134a for the condensation temperature of 50°C and the evaporation temperatures ranging from –30°C to 10°C.

The results have shown that the mixture of R290 / R1270 refrigerants (20% / 80% by weight) can replace refrigerant R22 with close energy results, having in view the ecological properties of these mixtures.

Vincenzo La Rocca et. al. (2011), analysed the performance of a refrigeration system with vapour compression using refrigerant R22 compared to those obtained by replacing this refrigerant with new refrigerants, HFC, respectively:

R417a, R422a and R422d. The conclusion was that the performances obtained with the new tested refrigerants were inferior to those achieved by operating with the R22 refrigerant.

Yunho Hwang et al. (2007), compared the operating performance of a refrigeration system using R404 and R410A refrigerants compared to R290. The conclusion was that the energy performance obtained with R290 refrigerant is lower than that obtained with R404 and R410A refrigerants but the ecological performance of R290 are absolute.

Venkataramana Murthy et al. (2014), considered the possibility of replacing refrigerant R22 with environmentally friendly refrigerants (R134a, R407C and R290) in order to comply with the provisions of the Montreal Protocol using for testing a refrigeration system equipped with a rotary encapsulated compressor using SUNISO4 oil and an air-cooled condenser. The evaporator used was a 2m long capillary.

The conclusion from all studies analysed in the first part of this article, was that the R290 refrigerant ensures a higher COP (**Figure 3**), compared to the R134a, R407C refrigerants and next chapter will show such results for a heat pump with original capillary evaporator.

Results and discussion

In order to determine the energy performance of the use of the R290 refrigerant compared to the R407C refrigerant for an innovative heat pump (HP) analysed in this paper, operation simulations were performed using specialized programs. The COP value was analysed for the entire usual range of condensation temperatures **Figures 4-9** represents the COP variation depending on the vaporization (Te) and condensation temperature (Tc).

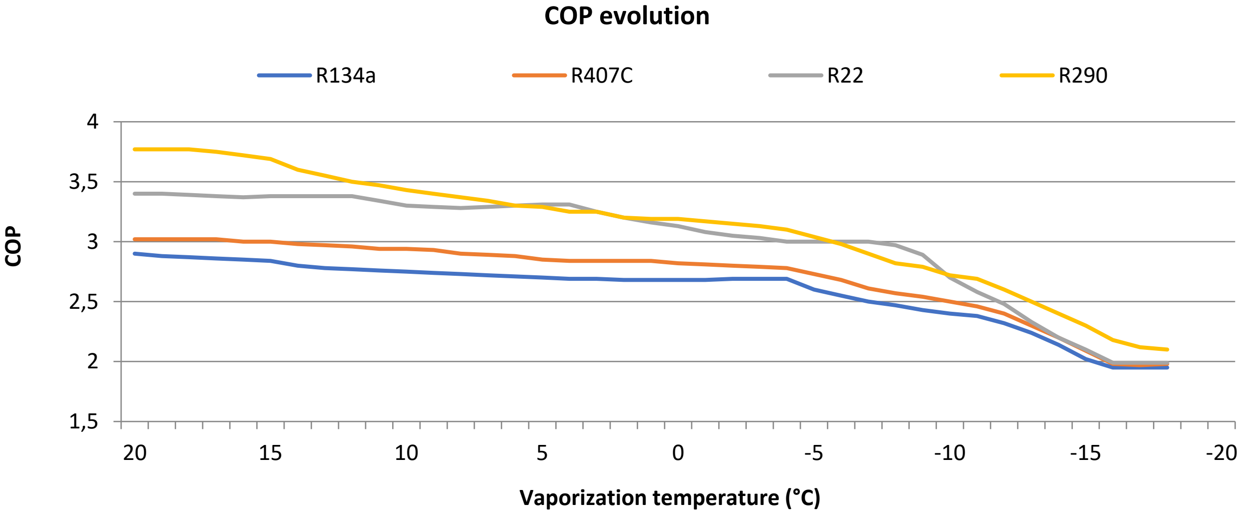

Figure 3. COP evolution for the refrigerants tested in the refrigeration installation.

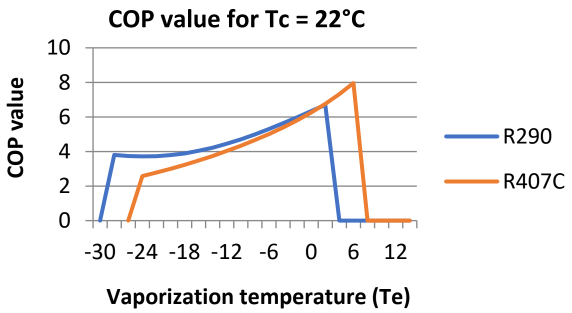

Figure 4. COP value for Tc = 22°C.

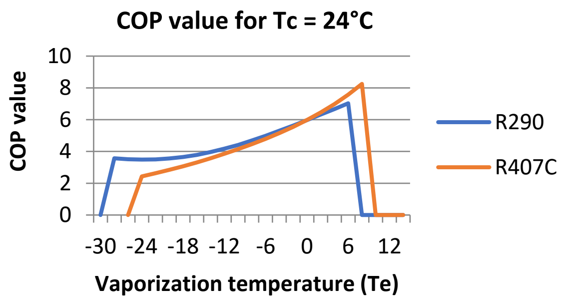

Figure 5. COP value for Tc = 24°C.

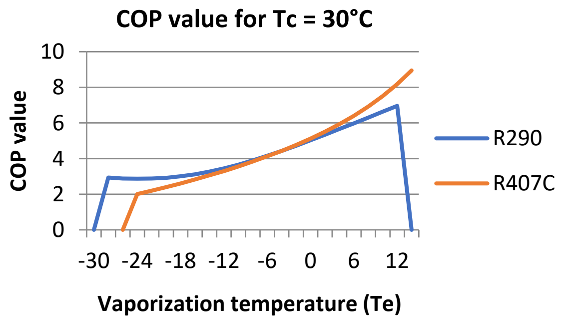

Figure 6. COP value for Tc = 30°C.

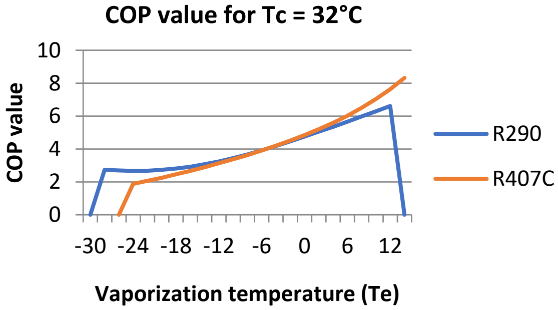

Figure 7. COP value for Tc = 30°C.

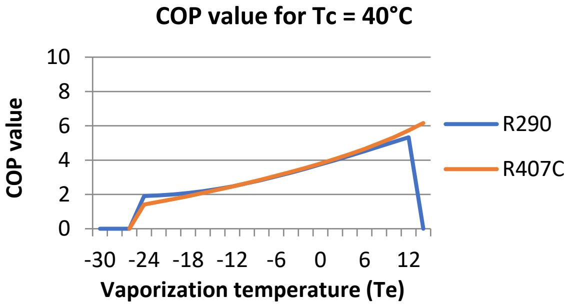

Figure 8. COP value for Tc = 40°C.

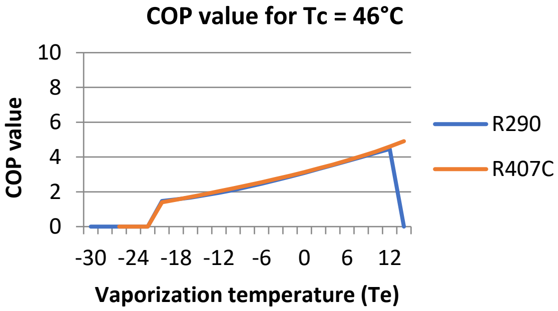

Figure 9. COP value for Tc = 46°C.

In his paper entitled "Comparing the energy efficiency and irreversibility of R22, R134a, R290 and R407C to replace R22 in an air conditioning system", published in the Journal of Mechanical Science and Technology (2013), the authors, Padmanabhan, VMV and Palanisamy , SK mentioned that the COP of R290 is higher compared to R22; R134a and R407C (**Figure 10**).

In conclusion, it is obvious that the refrigerant R290 has a better potential (except for the expansion process) and can be considered for substitution given by the superior parameters compared to other refrigerants, with the observation to take into account the increased flammability. of it, within the handling and storage operations Țârlea G. M et al. (2019).

In the **Table 1** it is shown the Total Equivalent Warming Impact calculation (see EN 378) for R407C and R290 and more than 40% ecological advantage of R290.

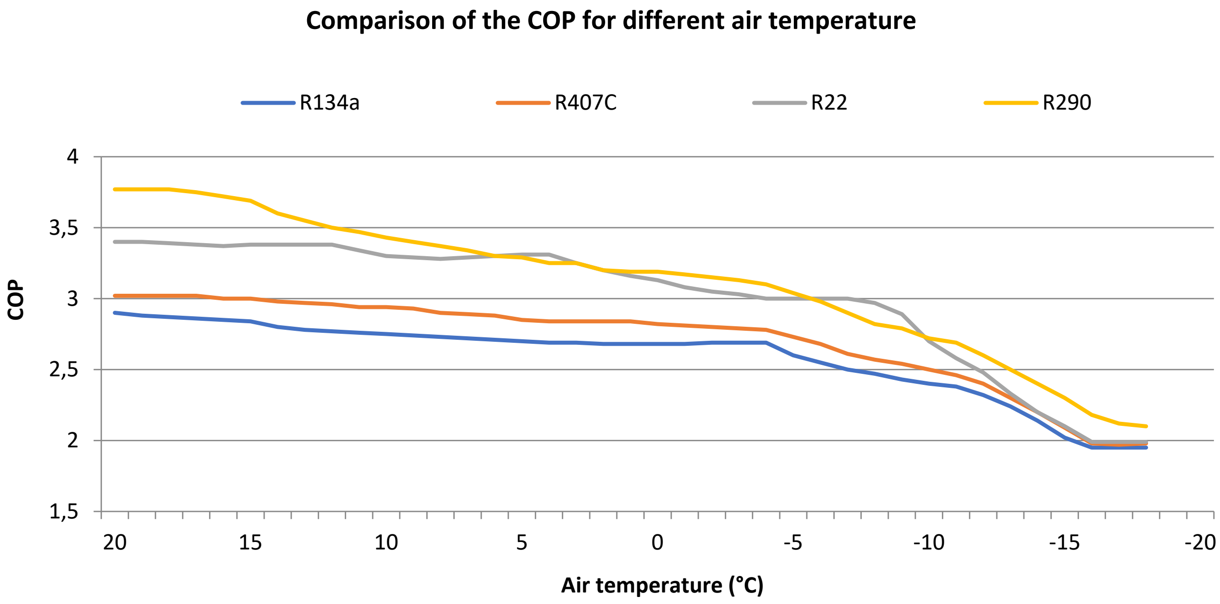

Figure 10. Comparison of the COP at different air temperatures.

Table 1. TEWI calculation.

	R407C	R290	Unit
GWP	1 620	3	–
Leakage	0.36	0.2	kg/year
Number	30	30	year
Mass	4.5	2.5	kg
α recover	0.8	0.8	–
E annual	2.462	2.462	kWh/year
B	0.28985	0.28985	kg/Kwh
GWP x L x n	17.496	18	–
GWP x m (1 – α recover)	1.458	1.5	–
n x E annual x β	21 408.321	21 408.321	–
TEWI (kg CO_2)	40 362.32	21 427.82	–
TEWI (tons CO_2)	40.36	21.42	–

Conclusions

For conclusions, the energetic, ecological and financial parameters were analysed comparing two systems that use respectively the R407C and R290 refrigerant, using the Pack Calculation program for an innovative HP (**Figure 11**).

The results offered by the program were the following:

1) For a year-long operation in climatic conditions in Bucharest, the average COP achieved by the heat pump system using the R407C refrigerant calculated by the program was 2.34 while the system using the R290 refrigerant provides an average COP of 3.03;
2) In front of the heat pump that uses the R407C refrigerant, the heat pump that uses the R290 refrigerant achieves an energy saving of 971kWh, which represents at the annual consumption level of the heat pump that uses the R407C refrigerant, a saving of 22%.
3) From the point of view of ecological analysis, during operation, the heat pump that uses the R407C refrigerant generates a higher TEWI (40,36 tons CO_2) compared to the heat pump that uses the R290 refrigerant (21,42 tons CO_2).

The operating time for the R290 refrigerant is much larger than for the R407C. From the point of view of condensation temperature, the R290 refrigerant operating tire starts at 16°C and ends at 68°C, while the R407C refrigerant operating tire starts at 22°C condensing and ends at condensation temperature of 64°C. From the point of view of vaporization temperature, the R290 refrigerant tire starts at −28°C and ends at 12°C. For condensation temperatures up to 36°C and low vaporization temperatures, between −26°C and −6°C the heat pump with refrigerant R290 ensures a higher COP than when using refrigerant R407C. For condensation temperatures between 46°C-48°C, the COP is identical for operation with both refrigerants over the entire range of usual values of the vaporization temperature. From the ecological point of view of the TEWI factor, operation with the R290 refrigerant is the ideal ecological option. ■

Figure 11. Heat Pumps with Innovative Capillary Evaporators.

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Heat Pump Efficiency in Existing Buildings

– Results from a Field Measurement Campaign



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In newly built single-family houses in Germany, heat pump systems have become the most popular heating system. However, heat pump systems also operate reliably in existing buildings. This is a conclusion of a field test of heat pumps in existing residential buildings conducted by Fraunhofer ISE. This article gives an overview of the operation conditions of the application area, the energy-related performance of the systems as well as their impact on greenhouse gas savings.

Keywords: heat pumps, existing buildings, renovation, single family houses, field trial, monitoring

The Project

Several studies pointed out the significant role of heat pumps in the future heat supply of buildings [IWES/IBP 2017; BCG/PROGNOS 2018; DENA 2017, ISE 2020a]. The results of these investigations underline that the use of heat pumps in existing buildings must increase significantly in order to reach sustainability targets. The research project "HPsmart in existing buildings" (12/2014 – 07/2019) addressed this area of application with heat pumps in existing residential buildings. The project focused on two central research topics: load management with heat pumps and the analysis of the efficiency of heat pumps in existing single-family houses (SFH). This article addresses the latter topic and gives an overview of the measured heating temperatures and the seasonal performance figures (SPF), as well as an ecological classification of the results. More detailed explanations and further analyses are described in the project report [ISE 2020b].

The project consortium consists of eight heat pump manufacturers and three energy suppliers and is led by Fraunhofer ISE. A scientific monitoring of 56 heat pumps installed in 42 single-family homes and 14 two- to four-family houses was conducted. This includes 32 systems with ambient air as the heat source. Mostly one heat pump combines space heating (SH) and domestic hot water (DHW) in a single component whereas nine systems applied two heat pumps dedicated to these services – one heat pump with ambient air as heat source (for SH) and the other one with room air as heat source (for DHW)). Furthermore, 13 heat pumps using the ground as heat source (exclusively geothermal probes) and two heat pumps with ice storage on the source side were examined. All systems provide SH as well as DHW. Ten of the systems are designed as bivalent systems, comprising a natural gas or fuel oil boiler in addition to the heat pump unit. Solar thermal systems are installed in four systems. In many of the buildings, a stove is installed, for example in the living room. According to the information provided by the residents, these stoves are very rarely operated in most of the houses and contribute substantially to space heating in four monitoring objects only.

Building and Heating Temperature

The oldest building in the field test was built in 1850, the newest one in 2005. The buildings are classified according to their year of construction. The classification is oriented towards the implementation of the first Thermal Insulation Regulation in Germany (WSchV´77). 57% of the buildings were built before 1979 and have been renovated energetically to varying degrees. In 89% of the cases the windows were replaced, 86% have renovated roofs and 57% renovated outer walls significantly. The buildings constructed after 1979 were – from an energy point of view – only slightly renovated.

In order to characterize the original and the current energetic state of the building envelope in a semi-quantitative way, the "building coefficient" was introduced within this project. **Figure 1** represents an area-weighted average heat transition coefficient (U-value) of the exterior wall, window and roof. The calculation bases on the information provided by the house owners, such as the structure of the original building envelope and the renovation measures that were carried out. According to these data, around 60% of the buildings constructed up to 1979 currently have a "building coefficient" between the thresholds of the Thermal Insulation Regulation 1977 and those of the version revised in 1995. One quarter of the buildings have a significantly better energy condition.

In consequence of differently realized renovation measures – and the variation in user habits – there is no correlation between the specific heating consumption and the age of the building. The specific, weather-adjusted heat consumption of the buildings range from 50 kWh/(m²·a) to 250 kWh/(m²·a), with a median of 110 kWh/(m²·a). The space heating load is one of the factors influencing the required heating circuit temperature. This is influenced by the selection of the heat transfer system (e.g. radiator vs. floor heating), its dimensioning (e.g. width, height and type of a panel radiator) and commissioning (e.g. with/without hydraulic adjustment and optimization of the heating curve).

In approximately 25% of the buildings, only radiators are installed and in less than 20% of the buildings only underfloor heating is installed. Around 50% of the buildings combine both radiators and panel heating systems. In the following, these systems will be referred to as combined heating systems and are classified in three groups: "radiator guided" (21 systems), "surface heating guided" (2 systems) and not clearly assignable (6 systems).

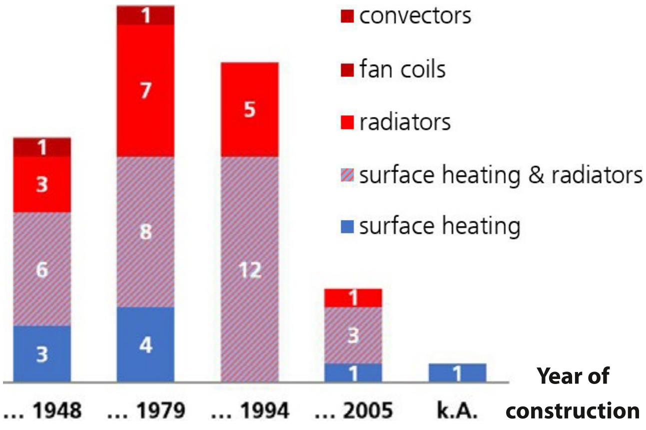

Figure 2. Distribution of building ages and heat transfer systems (year of construction of one building is unknown) [ISE 2020b].

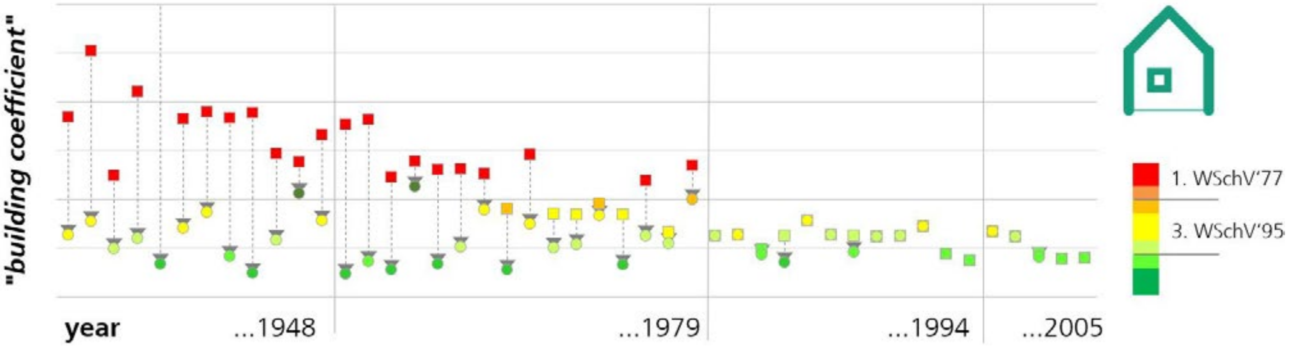

Figure 1. "Building coefficient" in the state of construction (rectangular icon) and in the present state (round Marker) for 45 buildings sorted by the age of building [ISE 2020b].

Figure 3 shows the average heating circuit temperature (energy weighted average values of flow and return) for the individual monitoring objects. The type of heat transfer system is color-coded in the figure. On the one hand the expected tendency of the distribution of the different heat transfer systems is shown: Panel heating systems are often operated at lower temperatures than radiator systems. Seven of the systems, which are exclusively equipped with surface heating or a "surface heating guided" combined system, are operated at an average heating circuit temperature in the range of 31°C to 33°C. One system in this category has a significantly lower average heating circuit temperature (27°C), three systems have significantly higher average heating circuit temperatures (36°C to 39°C).

On the other hand, the evaluation shows that even panel radiators can be operated at temperatures that are in the range of the temperature level of panel heating systems. This presupposes appropriate dimensioning (and good commissioning). The majority of the systems (84%), which are exclusively equipped with radiators or are "radiator-guided" combined system, use – fairly evenly distributed – average heating circuit temperatures between 34°C and 43°C. Two systems in this category are operated at even lower temperatures and four at higher temperatures. One system with an average heating circuit temperature of 53°C has by far the highest average heating circuit temperature.

Efficiency Analysis and Green House Gas Emissions

For the comparative analysis of the seasonal performance factor (SPF) a common system boundary for its calculation is shown in **Figure 4**. The SPF considers the provided thermal energy for space heating (SH) and domestic hot water (DHW) which are both measured close to the heat pump and not include possible storages. As input the electrical energy consumption of the compressor, the control, the brine pump respectively the ventilator and the electrical back-up heater are included in the calculation. To ensure a comparative data base, the results of 29 ambient air source heat pumps (ASHP) and 12 ground source heat pumps (GSHP) are considered.

Out of the 41 considered heat pumps around 75% were installed from 2013 to 2016. The remaining heat pumps were installed before, apart from one heat pump. For efficiency analysis the coefficient of performance (COP) – which represents the basic quality of the devices in terms of efficiency – is important to mention. Thus, the COP values of the ASHP reach from 3.2 to 4.2 (A2/W35) and from 4.5 to 5.0 (B0/W35) for the GSHP. Most ASHP are operated in monoenergetic mode whereby six systems are designed as bivalent systems. According to the different operation strategies for the bivalent systems only 4 boilers cover the heat demand significantly from 20% to 40%. The GSHP

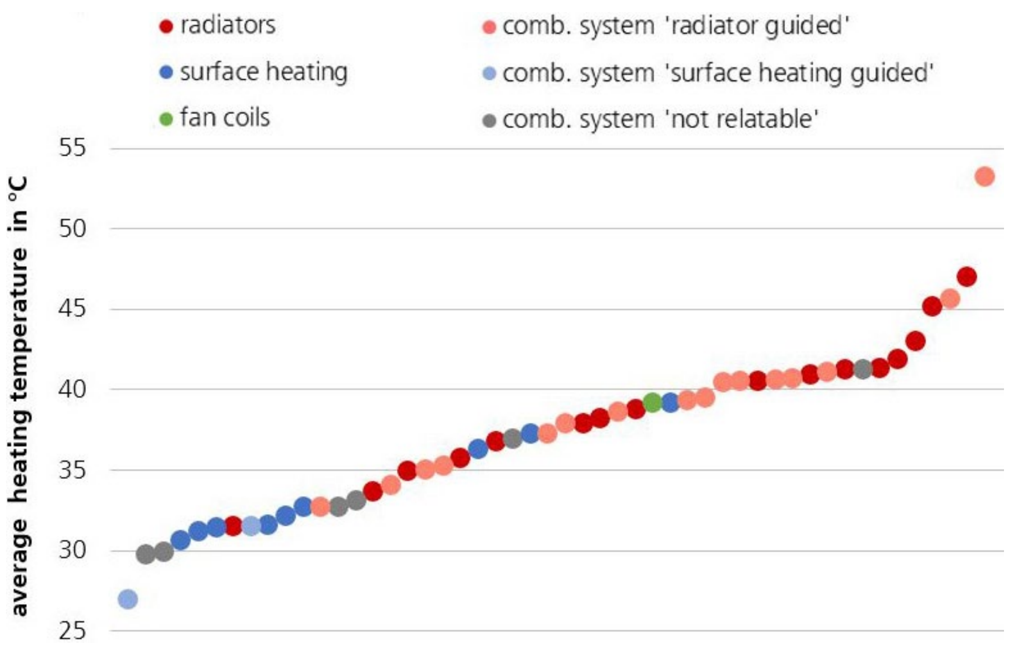

Figure 3. Average operating temperature of the heat pump in space heating mode of 50 systems (data base: bivalent heat pump systems with a coverage fraction of the boiler > 10% are not shown; evaluation period 2018/2019 with the exception of 2 systems that were evaluated for the period 2017/2018).

are solely monovalent or monoenergetic driven. Solar thermal systems support DHW production with three GSHP but none of the ASHP. The characteristic of the buildings and heat transfer systems of the 41 monitoring objects show a similar bandwidth and distribution as shown for the 56 monitoring objects before (overall data base of the project).

Figure 5 shows the SPF values of the 41 assessed heat pump systems for the measurement period from July 2018 to June 2019, divided into the heat sources ambient air and ground. For the ASHP SPF values from 2.5 to 3.8 were determined, the average SPF amounts to 3.1. Two SPF outliers (4.1 and 4.6) are not considered in the averaging. As expected, the SPF values of the GSHP reach a higher level with values from 3.3 to 4.7. The average was calculated to 4.1. The SPF bandwidths reflect the various efficiency influences such as the individual COP values, the operating temperatures on the sink and source sides or the relation between the produced energy for DHW and SH. The average share of the thermal energy production for SH amounts to 85% which underlines the significance of the heating circuit temperature in terms of efficiency.

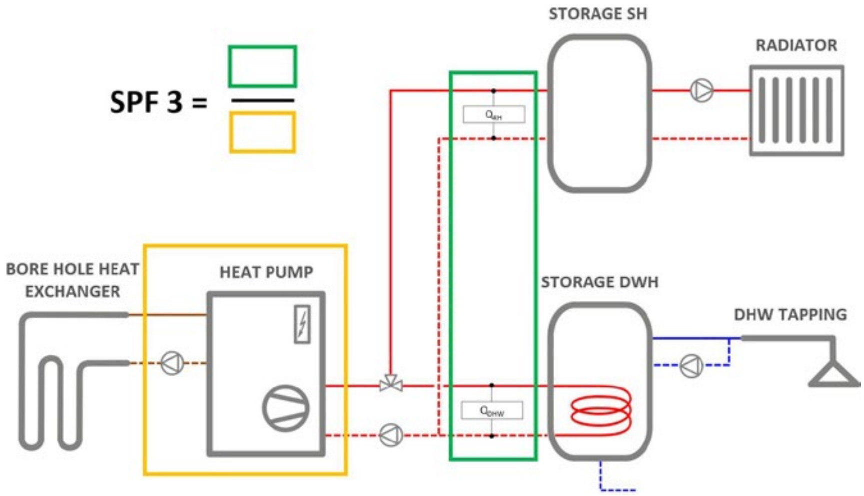

Figure 4. System boundary 3 for the seasonal performance factor calculation illustrated with an exemplary hydraulic scheme [ISE 2020b].

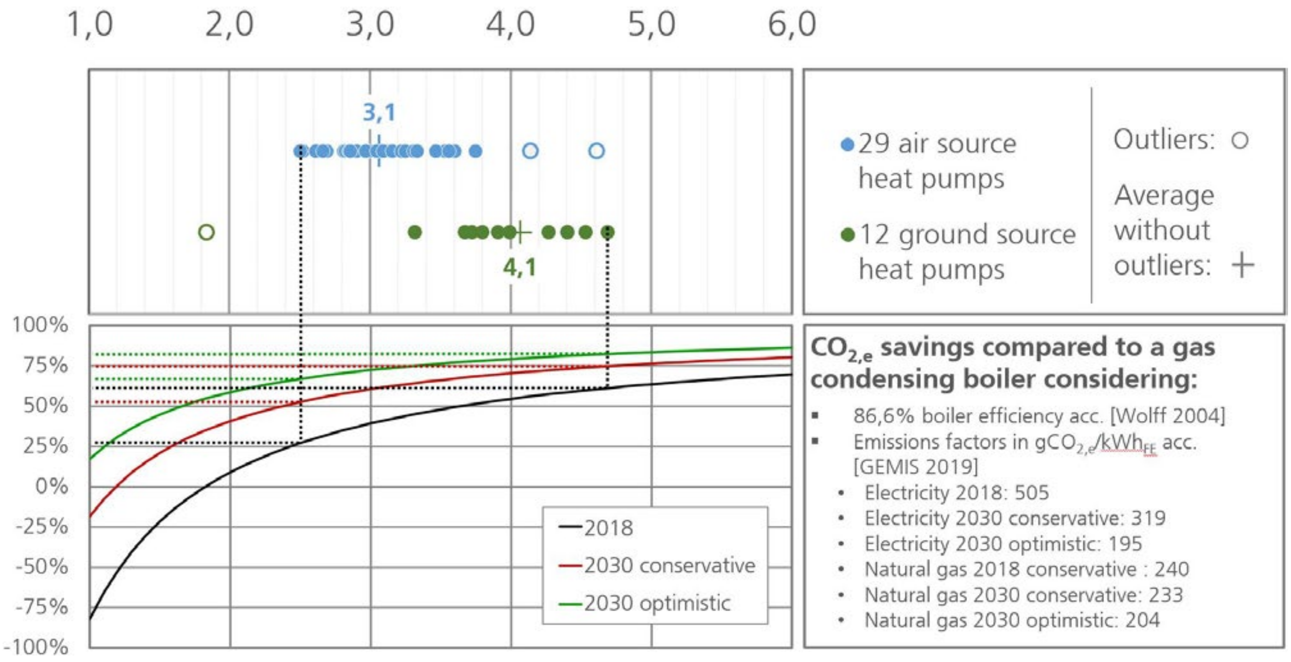

Figure 5. SPF of the investigated ambient air and brine heat pumps and their mean value as well as an estimation of the reduction in emissions (CO_2 equivalents) compared with a gas condensing boiler, taking into account the lowest and highest SPF (without outliers) for electricity/natural gas parameters for the years 2018 and 2030 in Germany [ISE 2020b].

The maximum temperatures provided by the heat pumps (daily average) for SH reach from 35/30°C to 65/57°C (average 45/39°C) and were measured at an average ambient temperature of merely −3,4°C. Subsequently, the required heating temperatures at design ambient temperatures (e.g. −12 to −16°C) would have been higher. However, significant in terms of SPF values are the average heating circuit temperatures during the operation. Those values are indicated as energy weighed average values of supply and return temperatures and reach from 30°C to 43°C (average 36°C) for the ASHP and 31°C to 52°C (average 39°C) for the GSHP. This shows that the estimation of SPF values for space heating in the project planning phase does not rely solely on the heating temperature according the design ambient temperature but on the necessary average space heating temperature based on the heating curve and the expected average ambient temperature. Those ambient temperatures were measured with 4°C in average.

The final energy consumption of the electrical back-up heater plays a minor role in terms of efficiency influence. For 11 of the 29 ASHP the back-up heater was set in operation for SH or DHW production. For five of these systems the relative electrical work of the back-up heater – related to the compressor work – was higher than 2%. For GSHP only 2 systems used the back-up heater. Significant back-up heater operation was only detected with activated legionella mode, with wrong parametrization or defect of heat pumps (once).

The lower part of **Figure 5** shows an estimation of greenhouse gas savings compared to a gas condensing boiler system. This is based on a simplified balance approach based on annual data [ISE 2020b]. As SPF bandwidth the efficiency values of the heat pumps with the lowest and the highest SPF values 2.5 and 4.7 (without outliers) are considered. The boiler´s efficiency is assumed with 86.6% based on the higher calorific value and is also determined within a field measurement project [Wolff 2004]. Considering the emission factors for 2018 in Germany the savings are between 27% und 61%. According to the presumed future emission factors the positive contribution of the increasing share of renewables in the electricity sector can be seen. With a conservative expansion scenario, the savings would reach 53% to 75%. The optimistic scenario, based on national climate protections plans with the ambitious goal of greenhouse gas reduction of 95% until 2050, savings would reach values from 67% to 82%.

Summary and Further Research

Compared to previous measurement campaigns [ISE 2011, ISE 2014] obvious malfunctions and faults – recognizable during the measurement – appeared rather seldom. The results from the measurements in context of the buildings showed, that renovation of the buildings to a standard for new building is not necessary to operate heat pumps ecological reasonable. The construction year of the building should not be an exclusion criterion for heat pump applications. The significant parameter is the necessary temperature level for space heating and thus the individual conditions according to the specific heat load and the type and dimensioning of the heat transfer systems. In this regard the efficiency prognosis – and thereby the ecological and economical values – should base on medium heating circuit temperatures and not on design temperatures. ■

Acknowledgement

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Heat pumps are key to decarbonizing residential heating

The Green Deal is considered to be the EU's 'man-on-the-moon moment'. Decarbonizing the heating sector will be key to making Europe a climate-neutral economy by 2050. Heat pumps will play an essential role in combining decarbonization with sustainable economic growth. Here is why.

Keywords: heat pump, decarbonisation, renewable energy, hybrid, heating

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Europe wants to become the world's first climate-neutral continent by 2050, and the EU Commission aims to reduce emissions by at least 55% by 2030.

Decarbonizing Europe and recovering from the COVID-19 pandemic are massive challenge. In implementing the EU Green Deal, we will see the EU and its Member States promoting low carbon technologies, like heat pumps, by ensuring a fair carbon-based energy pricing and by discouraging incentives for fossil fuel heating.

Why heat pumps?

Today, the European building stock is responsible for approximately 36% of all CO_2 emissions in the Union. Taking into account that almost 50% of Union's final energy consumption is used for heating and cooling, of which 80% is used in buildings [1], the potential for decarbonizing this sector is massive.

Heat pumps make use of **renewable energies** such as thermal energy from the air, the water or the ground. These renewable energy sources are abundantly available in Europe, so they do not need to be imported.

Heat pumps are **a proven solution**, and Europe has the technology, the expertise and the investments to expand further. From single family to multi-family homes, from renovation to new housing, from small to large commercial buildings and industrial plants, heat pumps today are ready and fit for the EU Green Deal. Heat pumps are **a low carbon heating technology** as for each kWh of required heat, the carbon impact of a heat pump today is about half of a high efficiency gas boiler, with an even lower carbon footprint potential due to **increased use of renewable electricity.** For example, by 2030, the share of EU renewable electricity production is set to be at least double today's level of 32% of renewable electricity at around 65% or more [2].

In addition, heat pumps are essential to enable **balancing of the power grid**, thus supporting the further deployment of a renewable energy production, for example by acting as a thermal storage battery and a tool for flexibly balancing the energy supply and demand.

Heat pumps are a true replacement for combustion heating

As Europe's heating habits are mostly focused on hydronic heating, it looks like the hydronic heat pumps (air to water, geothermic) are the obvious suitable heat pumps to replace a combustion boiler in residential homes.

Over the years, the heat pump industry players have achieved significant improvements to allow a 100% replacement of boilers in existing homes.

Some achievements in industry's progress are:

- **Improved efficiency levels**, increasing the use of renewable energy (vs electricity): In 2007, the first generation of Daikin Altherma heat pumps was showing a COP of 4.56. The third generation of Daikin Altherma launched in 2019 reaches a COP of 5.1, concluding an increase of 12% over 12 years. As far as the Seasonal COP (SCOP) is concerned, the second generation of Daikin Altherma from 2012 displayed 3.29 in average climate 35°C conditions while Daikin Altherma 3 hits 4.56. On a European level, the EU introduced the energy label framework, first in 1992, but it is only in 2015 that all space heaters had to carry an energy label describing its efficiency up to A^{++}. This scale was moved up in 2019 to elevate the requirements up to A^{+++} label.
- **Introducing solutions to reduce the sound output** of the heat pump's outdoor unit, to meet end users increased sensitivity to ambient noise and/or local government requirements in urban or densely populated areas. Solutions go from applying sound covers on existing units, offering limited sound reduction without effecting overall heat pump efficiency to dedicated outdoor units including newly developed components like fans to secure lower sound effect in operation mode.
- **Implementing state of the art connectivity technology**, from factory mounted integrated man-machine interface, allowing easy & remote commissioning of units, up to online and voice control via app, enhancing the end user efficient use & monitoring of the heat pump.
- **Creating specific design features** transforming the heat pump from machine to a white good-like indoor units up to an attractive outdoor unit.

Open caption of a modern, improved heat pump.

Hybrid solutions have been developed as an intermediate solution. In many countries hybrid heat pump solutions have been developed, with an air to water heat pump is used in combination with a combustion boiler, especially to start decarbonization in on-grid areas. Some hybrid heat pumps do manage the trade-off between both technologies by searching for the most economical or ecological condition depending on the specific operation conditions. Other hybrid heat pumps are more functioning as simple bi-valent options, where domestic hot water production is generated only by the combustion part.

A considerable benefit of hydronic heat pumps within the new build market is its **cooling feature** allowing to maximizing the reduction of CO_2 emissions, as well as benefiting of a single investment that covers the provision of total comfort in a house. Cooling becomes increasingly a requirement, partly due to climate change effect resulting in higher average temperature, and partly due to the higher insulation level of new built houses. Cooling via heat pump convectors or underfloor heating is the ideal opportunity to cool down the house. Today, hydronic heat pumps provide space heating, domestic hot water and cooling in one system. This creates an additional opportunity in efficiency to make use of one single system as opposed to the standard set up of boiler for heating and a second HVAC system used for cooling.

Hybrids do have a place in the market, especially in a transition period during which end users are made familiar with the heat pump technology. By using smart control technology hybrids can also offer flexible switching between energy carriers (gas, electricity); which is reinforced by the use of storage tanks for the use of domestic hot water. While a hybrid heat pump provides sufficient day to day comfort, we believe that CO_2 emission can be further reduced when combined with storage tanks.

In the long run, the full electric hydronic heat pump seems to offer a clear benefit over the hybrid alternatives, from a carbon footprint viewpoint, as electricity becomes greener, while securing full residential comfort is fully guaranteed.

A source of economic growth

Investing in heat pumps also boosts EU economic growth as these products are widely developed and manufactured in Europe.

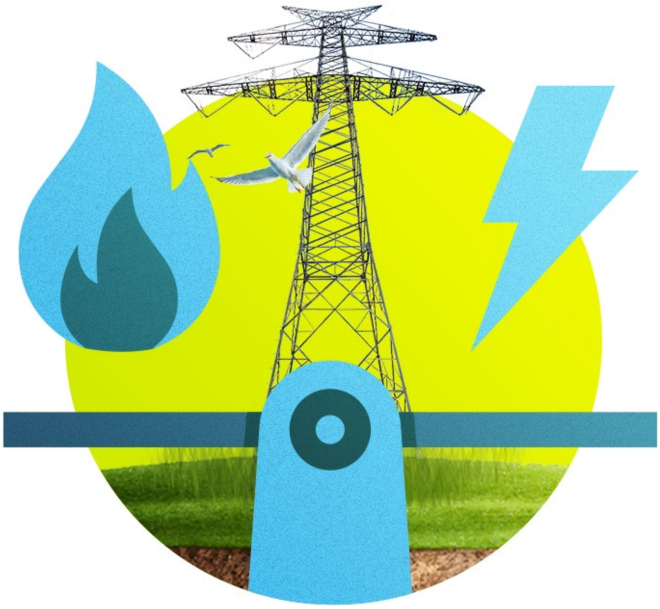
Every euro invested in heat pump technology is a euro invested in **local job creation**. The heat pump industry as a whole currently employs 225,000 people in Europe [3]. New and further investments in renewable heating will pay dividends for the European economy as well as for our environment.

Swedish success story

Making use of heat pumps to accelerate decarbonisation is possible. For example, Sweden started an ambitious policy in the 1980s to replace fossil fuel boilers with heat pumps. Today, heat pumps are the standard for heating Swedish homes. This push to make heat pumps the standard technology for residential heating helped reduce total greenhouse gas emissions by 33.7% between 1990 and 2018 [4]. Other European countries are starting to follow suit. Recently, countries including France, Germany, Italy and the Netherlands have launched similar heat pump promotion and boiler replacement schemes.

End carbon-based incentives

It is however crucial that, following the EU Green Deal initiative, policy makers in the EU member states take action to make this transition happen. I see they can act on two levels to achieve decarbonization.



GREEN DEAL: decarbonizing the grid and increasing the energy efficiency.

First, EU member states could **commit to ending the use of fossil fuels**. The most polluting heating systems must be phased out. Austria no longer allows oil-based boilers to be installed in new homes as of January 2020. This is an excellent initiative. Policy makers could avoid incentives for fossil fuels. Even today, direct or indirect incentives benefit oil or gas-based boilers, due to different taxation of heat pumps compared with boilers for instance.

Secondly, **renewable technologies also need a level playing field**. The gap between electricity and gas prices in many member states is too high to make a heat pump an economically attractive investment for EU citizens [5]. Incentives can bridge that gap for a certain period, but in the long run, the cost of energy should reflect the carbon intensity more. Carbon pricing can contribute to further emissions reduction by extending the EU Emission Trading System (ETS) to all emissions of fossil fuel combustion in buildings and revising the Energy Taxation directive [6].

Motivating consumers

Consumers who are looking to replace their fossil fuel systems need to be motivated to take a closer look at heat pumps. The industry innovates relentlessly to make heat pumps attractive through a mix of product features, pricing, design, and installer- and end user friendliness [7].

The industry can put more effort in explaining the benefits of heat pumps so that end users become more aware of them.

Governments draw consumers' attention to heat pumps through incentives for residential renovations, but also other means could make opting for heat pumps beneficial, such as reflecting the use of renewable energy in the building's total energy score. This sends a strong signal and invites consumers to do a detailed calculation of total cost of ownership and ecological advantages [8]. At this point, the benefits of heat pumps will become evident to consumers.

Heat pumps should become accessible to all Europeans

In the short term, government incentives can help accelerate the transition to carbon-neutral heating and make heat pumps accessible to all Europeans, but in the longer-term accurate energy prices and a correct indication of the energy and carbon performance of a building need to be the end user motivations to invest in heat pump technology. ■

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[7] See Daikin's Altherma 3 H HT: https://www.daikin.eu/en_us/product-group/air-to-water-heat-pump-high-temperature/daikin-altherma-3h-ht.html

[8] Daikin for instance provides a solution selection tool to installers and consumer called Stand by me, https://standbyme.daikin.eu/

Magnetocaloric heat pumps:

Innovative heating and cooling systems

For HVAC professionals and general audience

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The increasing demand for energy-efficient heating systems and the booming of the air conditioner market create an urge for new cost-effective heating and cooling solutions. Currently, the vapour-compression heat pumps dominate this market. However, these conventional systems present some limitations. New innovative systems based on different caloric effects, such as the magnetocaloric effect, have the potential to overcome those limitations. In the recent years, several prototypes of magnetocaloric heat pumps have been successfully built and tested. They show very promising performances that are similar to that of conventional systems. Nonetheless, more R&D are needed before they become competitive.

Worldwide increasing demand for heating and cooling in buildings

In most of the developed countries, the building sector is the largest energy end-user. In Europe, it accounts for 40% of the total energy demand. Moreover, indoor space heating represents 75% of the building energy needs in cold-winter regions.

On the other hand, cooling is the fastest growing use of energy in buildings. Because of global warming, heat island effect in densifying urban areas, increase of purchasing power, and increase of indoor thermal comfort standards, the cooling demand is booming all over the world, especially in populated countries with warm summer like China, India or Indonesia. The International Energy Agency (IEA) has estimated that air conditioners accounts for nearly 20% of the total electricity usage in buildings today. The energy needs for cooling could triple by 2050, with 2/3 of the households in the world being equipped with an air conditioner.

Consequently, the development of energy-efficient heating and cooling systems is critical to sharply decrease the overall energy needs and tackle the environmental challenges that our societies are facing.

Conventional heat pumps

A heat pump is a device that moves heat from a heat source to a heat sink that has a higher temperature. This is very convenient to cool down (like a fridge or an air conditioner), but it can also be used to heat up buildings or domestic hot water. The main advantage of heat pumps is that they have a high Coefficient of Performance (COP). Current heat pumps typically have a COP of 3–5, which mean that with 1 $\mathrm{kWh_{elec}}$ of input energy they can produce 3 to 5 $\mathrm{kWh_{therm}}$ of useful heating or cooling, while gas, oil or electric boilers can only produce between 0.8 and 1 $\mathrm{kWh_{therm}}$ of useful heating. Consequently, heat pumps use 3 to 5 times less energy than gas, oil or electric boilers.

To perform heat transfer, conventional heat pumps use of a vapour-compression thermodynamic cycle: a fluid (the refrigerant) is compressed or expanded (which increases or decreases its temperature) and circulated between the heat source and the heat sink. This technology is currently one of the best ways to provide heating and cooling to buildings in a cost-effective manner. However, the refrigerant fluids used in these vapour-compression heat pumps present some environmental issues: they are either flammable, explosive, toxic, or with a large greenhouse effect.

Innovative heat pump systems based on the caloric effects

Several innovative technologies are currently considered as viable alternatives to conventional vapour-compression systems to provide heating and cooling. Among them, the utilization of the caloric effects in certain solid refrigerant materials is gaining a large attention. The caloric effects are physical phenomena occurring in specific materials resulting in a change of temperature (heating up or cooling down) in the latter when a parameter of the surrounding environment changes:

- Electrocaloric effect: temperature change by variation of the electrical field.
- Barocaloric effect: temperature change by variation of the pressure.
- Elastocaloric effect: temperature change by variation of mechanical stress (stretching or squeezing).
- Magnetocaloric effect: temperature change by variation of magnetic field.

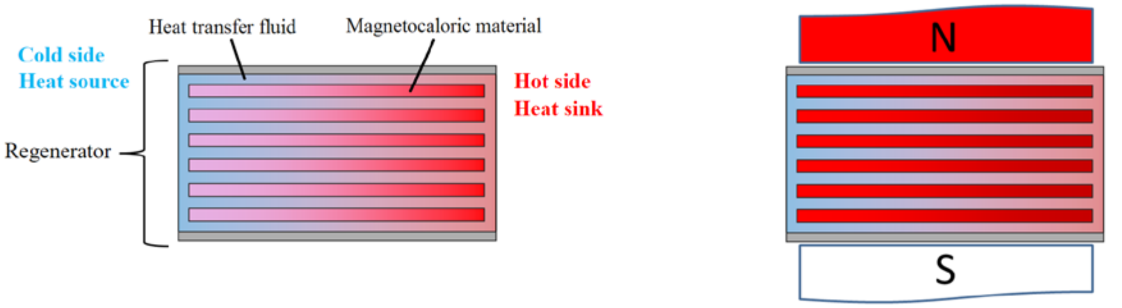
Like the vapour-compression thermodynamic cycle, these caloric effects can be employed to transfer thermal energy and thus produce useful heating or cooling power. However, devices based on caloric effects have the potential to reach higher COPs than conventional heat pumps. Moreover, they do not require any harmful fluid refrigerant, and benefit of a low noise level operation.

Those technologies have very different levels of maturity. Currently, most of the studies are focussing on magnetocaloric devices. However, in the very recent years, many research groups are now working on elastocaloric heat pump prototypes.

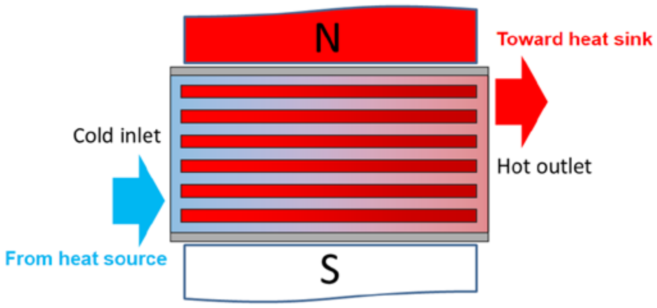
The magnetocaloric heat pumps

The thermodynamic cycle at the core of the current magnetocaloric heat pump technology is the Active Magnetic Regenerator (AMR) cycle. It has been developed and patented in 1982 by John A. Barclay and William A. Steyert, and employs magnetocaloric materials (materials experiencing the magnetocaloric effect) as a solid refrigerant and thermal regenerator. The magnetocaloric material (such as Gadolinium) is contained as a porous media (packed-sphere bed or parallel plate matrix) in a regenerator casing that allows bi-directional circulation of the coolant fluid through it. This fluid is typically a water-based brine. It ensures the thermal energy transfer from the cold side (heat source) to the warm side of the system (heat sink). The alternating activation and deactivation of the magnetocaloric effect in the solid refrigerant are achieved by magnetizing and demagnetizing the regenerator with an external magnetic field source such as an electromagnet or a rotating permanent magnet.

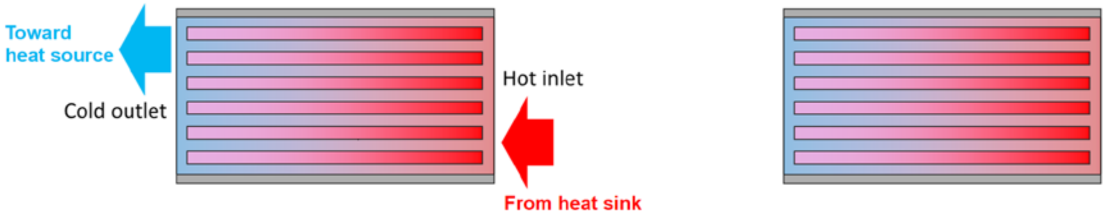
Figure 1 illustrates in details the different steps of this thermodynamic AMR cycle. **Figure 1 (a)**: At the beginning of the cycle, there is a temperature gradient inside the regenerator and no magnetic field is applied. **Figure 1 (b)**: The cycle starts with the magnetization of the magnetocaloric material that leads to a temperature increase in the regenerator. The heated magnetocaloric material then transfers thermal energy to the heat carrier fluid. **Figure 1 (c)**: This fluid is pushed from the cold side to the warm side of the system (cold-to-hot blow). The hotter fluid is circulated into the heat sink and rejects some heat. The colder fluid coming from the heat source cools down the regenerator. **Figure 1 (d)**: The magnetic field is removed, leading to the demagnetization of the magnetocaloric materials, and thus a temperature decrease. Consequently, the cold fluid in the regenerator is cooled down further. **Figure 1 (e)**: At the end of the cycle, the fluid is pushed back from the warm side to the cold side of the system (hot-to-cold blow). The colder fluid is circulated into the heat source and extracts some heat from it. The hotter fluid coming from the heat sink re-heats (heat regeneration) the magnetocaloric material inside the regenerator. **Figure 1(f)**: Once the fluid flow is stopped, the device is back to the initial state of the AMR cycle.



(a) Initial state *(b) Magnetization: temperature increase*



(c) Cold-to-hot blow: heat rejection *(d) Demagnetization: temperature decrease*



(e) Hot-to-cold blow: Heat injection *(f) Back to initial state*

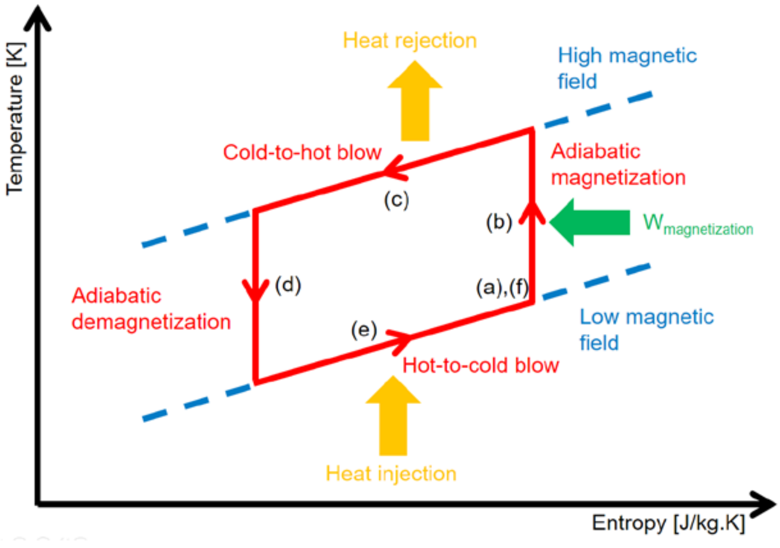


Figure 1. The active magnetic regenerator thermodynamic cycle of the magnetocaloric heat pump.

The active magnetic regenerator configuration is considered to produce the most energy-efficient thermodynamic cycle for magnetic heating and cooling devices. It also enables an operational temperature span between the heat source and the heat sink to be significantly larger than the temperature change induced by the magnetocaloric effect alone.

Since the 1980s, several laboratories have developed innovative heat pumps using the magnetocaloric effect to perform heating and cooling. The performances of those prototypes are encouraging with a gradual improvement of their COPs (now comparable to that of conventional vapour-compression systems) and nominal power. Studies showed that a magnetocaloric heat pump can be integrated into a building and provide for its space heating and domestic hot water needs.

Although a promising technology and a nice piece of engineering, the magnetocaloric heat pumps have yet to prove their competitiveness against the mature technology of vapour-compression systems. The main challenges reside in the development of cheaper magnetocaloric material, and the optimization of some key components such as the rotating magnet assembly and the heat exchangers. ■

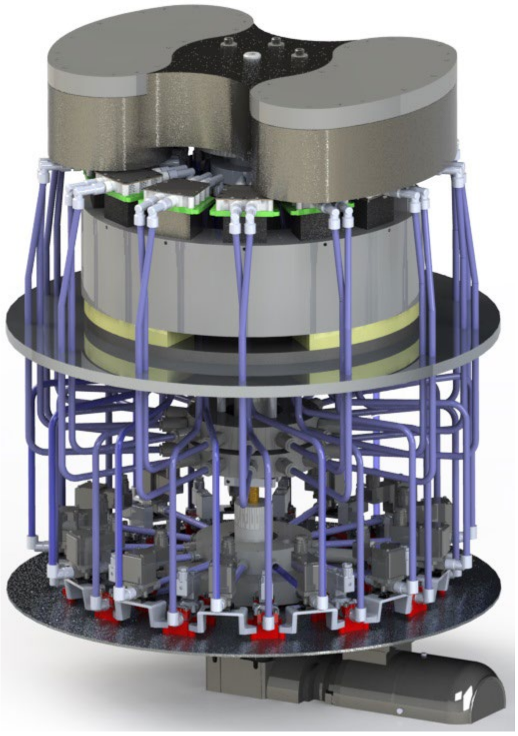


Figure 2. ”MagQueen”: prototype of a magnetocaloric heat pump designed to provide space heating for a low-energy single-family house in Denmark (ENOVHEAT project).

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This article is based on two peer-reviewed scientific papers published in international scientific journals:

H. Johra, K. Filonenko, P. Heiselberg, C. Veje, T. Lei, S. Dall’Olio, K. Engelbrecht, C. Bahl. Integration of a magnetocaloric heat pump in a low-energy residential building. *Building Simulation* 11 (2018) 753-763. https://doi.org/10.1007/s12273-018-0428-x

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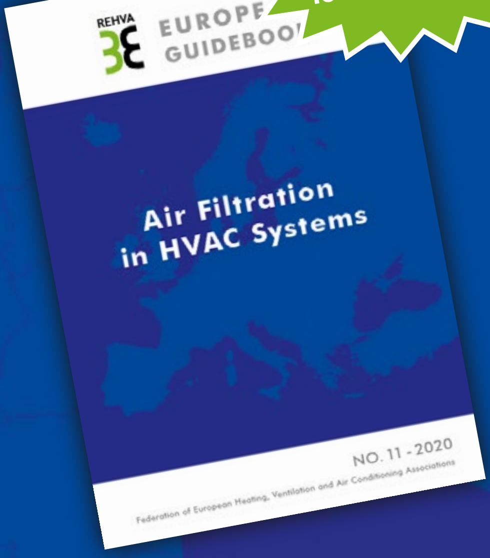
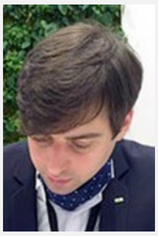


Building Management System in an Energy Positive House

– Case study: EFdeN House from Solar Decathlon



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The present paper presents the active and passive strategies implemented in the EFdeN project, a house which represented Romania at Solar Decathlon Europe 2014. The study focuses on the BMS system logic presentation which integrates all the systems implemented in the project and correlates all the active and passive strategies in order to achieve the optimum IEQ with minimum energy consumption. Using experimental measurements of sound pressure levels, air temperature, CO_2 levels, relative humidity and energy consumption a clear view on the advantages of these strategies was possible. The implementation of all the passive & active strategies combined with the BMS control prove to be an excellent combo for achieving perfect indoor environmental quality parameters (IEQ) with minimum of energy spent. Moreover, the energy production using PV panels exceeded the energy use thus the EFdeN house can be classified as an energy positive building.

After COP21, one of the most important United Nations Climate Change Conference in the history of human beings [1]., the member countries decided to do what it takes to limit the world average temperature increase bellow the value of 1.5°C above the values registered during the preindustrial period. WMO (acronym for World Meteorological Organization) [2] highlights that in 2015 the critical threshold of 1°C above the pre-industrial level was reached, the last four years represented the hottest period in history and 2019 became the 2nd warmest year on record. Finally, according to the European Commission climate and energy framework [3], until 2030 all the European Union member states must achieve at least: 40% cuts in greenhouse gas emissions, 27% share for renewable energy and a 27% improvement in energy efficiency.

Moreover, DEPB (acronym for Directive 2010/31/EU of the Energy Performance of Buildings) [4], mentions that beginning with this year, 2020, all the new buildings constructed must achieve the nZEB standard (nearly zero energy building).

Considering all these alarm signals and arguments, in order to achieve these goals and to prevent the global warming devastating impact, it is mandatory to build energy-efficient sustainable buildings with highly efficient and performant materials [8]. Moreover, in order to reduce energy consumptions for heating, cooling and ventilation which are the most important consumers in a household it is important to implement intelligent systems which are using renewable energy sources.

The current study was conducted on the EFdeN prototype (**Figure 1**), a project realized by a team of Romanian students from several universities from Bucharest which has represented Romania at Solar Decathlon Europe 2014. The energy-efficiency strategies of the building and the systems were implemented by the students of the Technical University of Civil Engineering under the coordination of their professor. This team conceived, designed, analyzed and effectively built the prototype which now became a Research Center for Comfort Conditions and a study HUB for students within our campus.

The EFdeN prototype is currently built by students in the courtyard of the faculty, where we are testing and monitoring the comfort conditions (**Figure 1**). The building consists of two floors – ground floor and first floor, with 2.5 m floor height, with the following destinations: residential building and exhibition pavilion. Furthermore, the house is open to public for social awareness, for promoting the reduction of energy consumption in buildings and lower CO_2 emissions, also for the promotion of green and NZEB buildings in Romania, after all, having a strong socio-economic impact.

Moreover, the project is perfectly suited to the European directives promoting energy performance of buildings and transposes them perfectly, even transcending them. In the current context of high energy consumption in the buildings and the EU's 20-20-20 target, it is imperative to implement energy efficient solutions and to use the right materials in order to reduce energy consumption, subject treated in this article.

The building consists of two floors – ground floor and first floor (**Figure 2**), with floor height of 2.5 m, with the following destinations: residential building and exhibition pavilion. The house has a total footprint of 96 m², a 170 m² built surface area, 118 m² heated area and 400 m³ total volume. In order to achieve this goal, we have implemented a lot of active strategies and passive strategies. The active strategies used in order to reduce energy consumption are: air to water heat pump (HP) with maximum COP of 4.02 for heating, cooling and domestic hot water, vacuum tube collectors (VTC) for domestic hot water and heating, cold water tank, domestic hot water tank, heating tank, radiant panels in walls and ceilings, heat recovery unit (HRU) with maximum efficiency of 94%, LED lamps, shading system, photovoltaic system (PV) with 5.5 kW installed power, water cleaning system for photovoltaic panels, electronic taps used in order to reduce water consumption and a building management system (BMS) that integrates all the strategies and assures the communication between all the systems implemented.

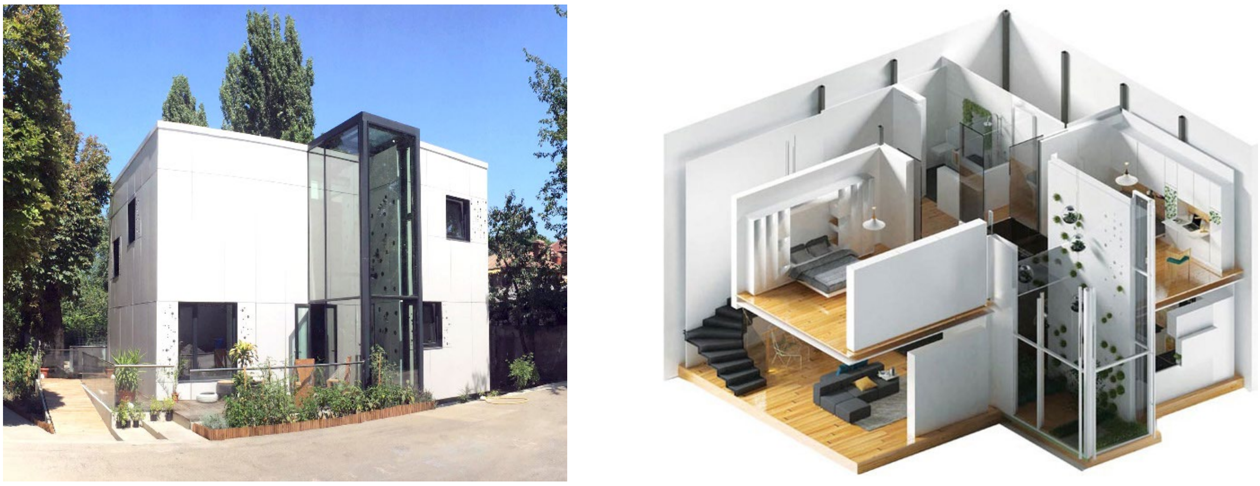

Figure 1. EFdeN House currently built in the courtyard of Faculty of Building Services Engineering in Bucharest, Romania.

The passive strategies (**Figure 2**) used in order to reduce energy consumption without operational costs are: the house form (cubic), orientation (generous glass areas on the southern facades), natural and night ventilation, taking preheated fresh air from the greenhouse (especially in the transition periods), the use of thermal mass surfaces (granite located in areas where sun radiation penetrates the building), thermal buffers (room that are positioned strategically), ventilated ceramic facade, shadings and the use of phase changing materials.

The house also presents excellent insulation as it can be seen from **Table 1**.

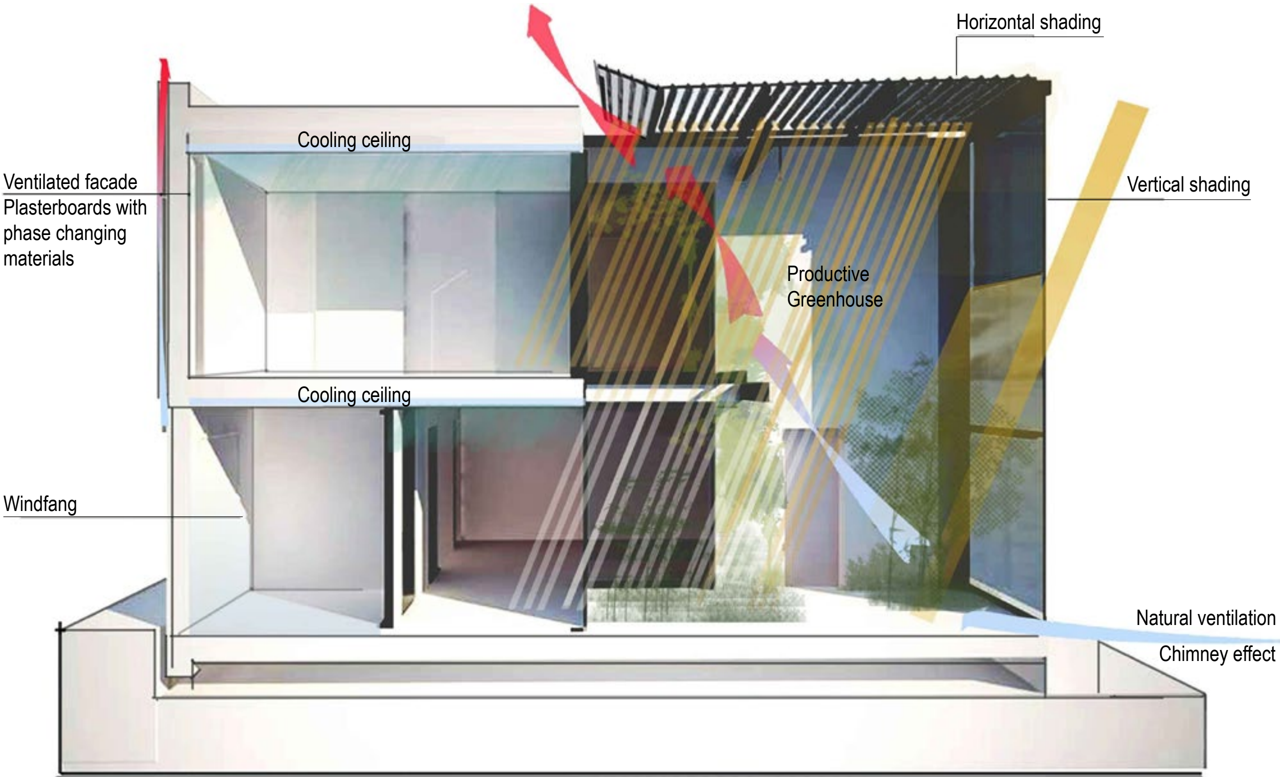

Figure 2. Overview of the passive strategies implemented within the house prototype.

Table 1. *Construction elements and their properties.*

Name of the construction element	Main layers	U [W/m²K]
Exterior wall	Ceramic panels 3 mm, Air layer 6 cm (ventilated façade), OSB panel 12 mm, Mineral wool 25 cm, OSB panel 12 mm, Mineral Wool 10 cm, Gypsum plasterboard / PCM/ Radiant panel	0.129
Interior wall	Gypsum plasterboard / PCM/ Radiant panel, Mineral Wool 15 cm, Gypsum plasterboard / PCM/ Radiant panel	0.39
Terrace	Waterproof layer 3 mm, Stone wool 5-15 cm, OSB panel 12 mm, Mineral wool 25 cm, Gypsum plasterboard / PCM/ Radiant panel	0.121
Floor above ground	OSB panel 12 mm, Mineral wool 25 cm, OSB panel 12 mm, Parquet + Cork/Granite 3 cm	0.124
Exterior windows	Triple glazing low-E	0.8
Interior windows between the house and the greenhouse	Triple glazing low-E	0.8
Exterior windows between greenhouse and exterior	Double glazing low-E	1

The present paper focuses on the BMS system logic presentation which integrates all the systems implemented in the project and correlates all the active and passive strategies in order to achieve the optimum IEQ with minimum energy consumption.

The present study objectives are to:

a) design and monitor a self-learning building management system for maintaining a high level of thermal comfort
b) monitor the indoor environmental quality (thermal, visual, acoustic, air quality) using experimental campaigns.

Self-learning Building Management System for enhanced energy efficiency

The BMS is the system implemented to make the inhabitant's life easier, more comfortable, it helps to optimize consumption and, of course, helps us monitoring the house. By putting together a large variety of sensors such as temperature, CO_2, humidity, light level and presence detection for both monitoring the comfort parameters and learning the users behaviour; actuators and the central control unit, the BMS is able to monitor many parameters at short intervals of time, synthesize all incoming data, take decisions according to algorithms and user-defined parameters and actuate different household elements in order to make the most comfortable environment possible with the least amount of energy, making sure almost none is wasted. The BMS system has a link with the other house systems with the help of analogue and digital inputs and outputs. The KNX network was the perfect solution that allowed us to integrate all equipment and systems from various manufacturers, having the flexibility to adapt the BMS to the situations that we faced. We integrated subsystems with remote user interface, in a single decentralized system, stable and extendable (**Figure 3**).

The light intensity in the environment is monitored by light intensity sensors and gives feedback to dimming ballasts, in order to maintain a constant light level throughout the day. Also, the light level can be controlled from the push-buttons and remotely, from the user interface. For switching light control we used switching actuators, presence sensors and push-buttons, this type of control being used for the greenhouse, exterior, technical rooms, lobbies and bathrooms lighting. Human movement sensors are used to detect presence in a certain area in order to command the lightings to turn on and off and are also used to learn the behaviour of the occupants. We integrate the TV and audio systems to control them remotely via the KNX network from the user interface due to IR to KNX gateway.

An important feature of the electrical system is the automatic shutdown. In case a fire breaks out, a differential temperature detector will trigger the emergency and immediately the central control unit shuts down electrical power to the stove and oven, while to the user is given a message to be made aware of the situation.

High air quality is maintained by the house ventilation control system, which is linked to temperature, CO_2 and humidity KNX sensors. The fresh air (taken either from outside or from the greenhouse) is heated/cooled using the HRU equipped with a heating battery (the thermal fluid comes from a buffer tank linked to VTC, HP). The air is introduced in each room via air dampers, controlled individually by KNX actuators. The temperature comfort is assured by radiant panels controlled by zone. KNX heating actuators controls by set point each valve's zone. The thermal agent comes from the same buffer tanks.

The human machine interface is compatible with many mobile devices and operating systems, such as tablets, smartphones and pc. The web-based visualization can be accessed via internet from all over the world. We have floor plans and system diagrams (photovoltaic,

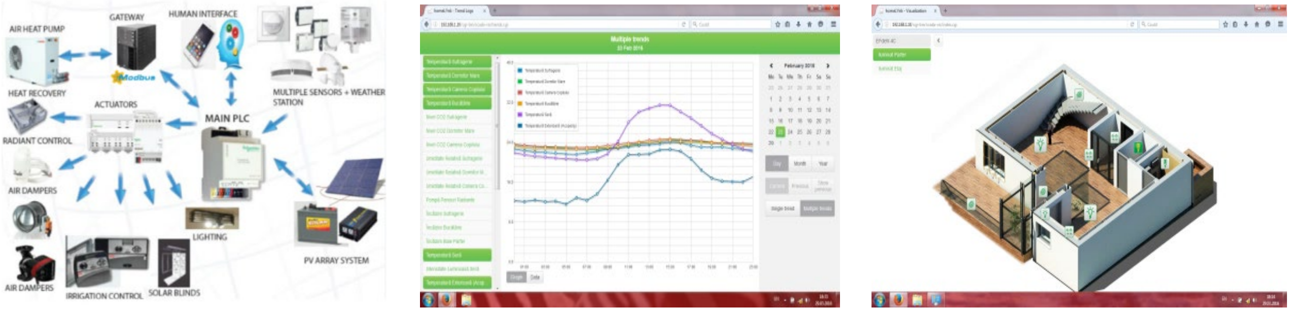

Figure 3. Equipment's integrated in the BMS system and monitoring interface

metering, heating, cooling, ventilation, sensors) both as overview and detailed screens. Trends can show overview regarding thing like energy consumption or comfort parameters evolution. Through the homeLYnk webserver we can access and control elements of the KNX system. We can monitor sensor values (temperature, CO_2, humidity, brightness, wind) or equipment status (air dumpers, heating actuators, pumps or energy meter). It is possible to control the lighting, the shading systems, the HVAC equipment's and water pumps and all these through the web interface.

Multiple energy meters are used to be able to break down energy consumption. We have meters for consumed energy, produced energy, stored energy, lighting, sockets, electrical vehicle charging, BMS, laptop/TV, plumbing, HVAC. All these meters are connected to the KNX system and can be used to interact with a smart grid. Having these data, we can do the electrical energy balance during certain periods, and after a numerical campaign the results showed us that the house produces 36% more than it consumes per year (6844 kWh produce and only 4330 kWh consumed).

Noise measurements results

In order to assess the interior environmental quality an extensive experimental study was necessary. The team measured the sound pressure level in all the rooms of the house in the case when all the systems are working at maximum capacity (heat recovery unit, circulation pumps, heat pump etc.).

Several microphones were placed in all the rooms of the house (technical room, bedroom, master bedroom, living room and kitchen and dining room) – see **Figure 5**. The results were compared with the reference values normed by the STAS 6156:1986 Romanian Standard and EN 15251:2007 [5] (under 35 dB for bedrooms and under 40 dB for living room) for all the frequencies (125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz). For the evaluation of the sound pressure levels the following equipment's were used: Bruel&Kjaer 2270 sound level meter class 1 precision, Bruel&Kjaer type 3050 6-channel input module in order to collect the data from the microphones and the Bruel&Kjaer Software Pulse Labshop v. 15.1.0 in order to collect and analyse the results [7].

Figure 5. Pictures during the measurements conducted by our team [6].

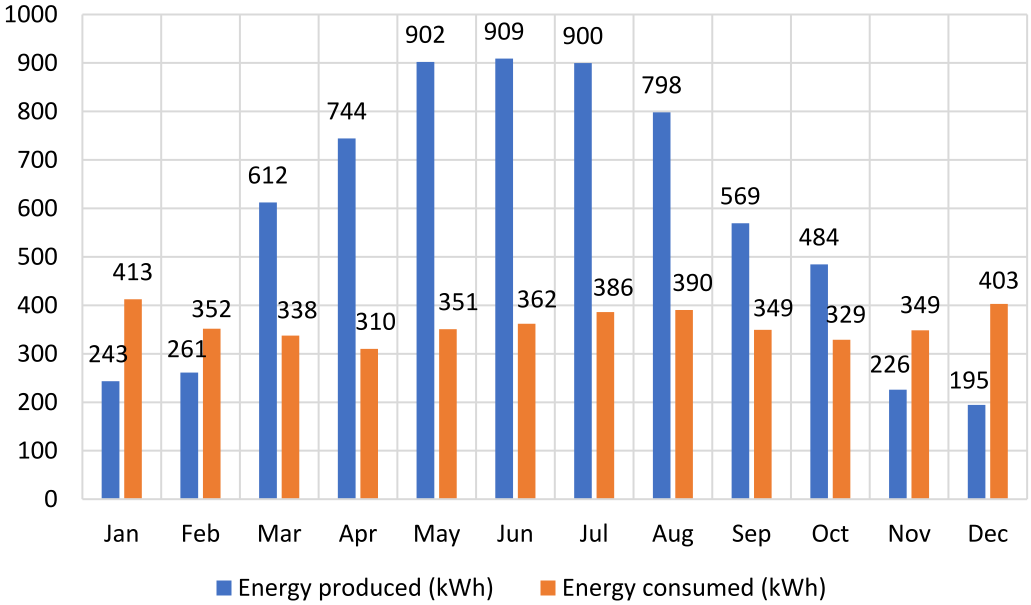

Figure 4. Monthly energy balance of the building.

As it can be observed from the **Figure 6**, the sound pressure level in all the rooms is below the maximum allowable values required by the Romanian and European Standards. This is due to the high acoustic insulation of the interior walls and soundproof of the technical room.

Indoor air temperature, CO_2 level and relative humidity are also important parameters describing the indoor environmental comfort according to the national standard and international standards like EN 15251:2007 [5]. The data presented in the figures bellow were collected during the experimental studies conducted in the EFdeN prototype during one week from one winter month (more exactly 8th – 14th February 2016). The set point for all the parameters is controlled and adjusted by the BMS or by users via a web based interfaced.

Air temperature measurements results

Figure 7 emphasize the measurements of indoor temperature in the living room, indoor temperature in the bedroom and outdoor temperature (which are highly correlated). Moreover, on the graphic we can

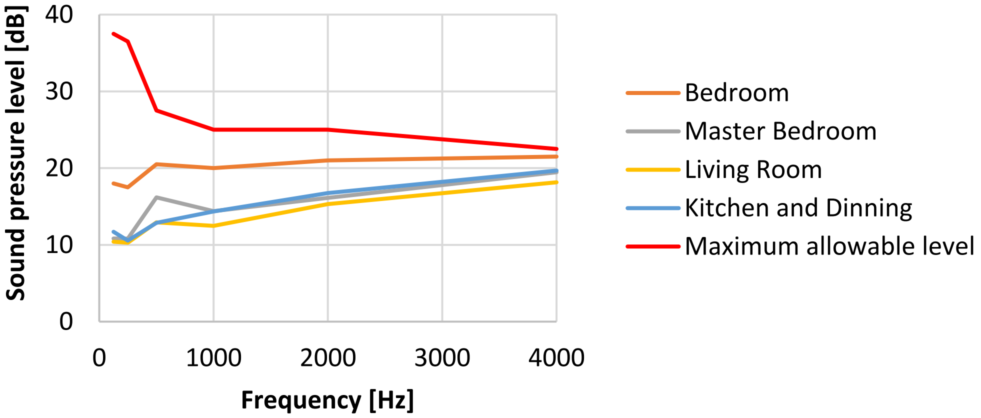

Figure 6. Sound pressure level measurement in multiple rooms.

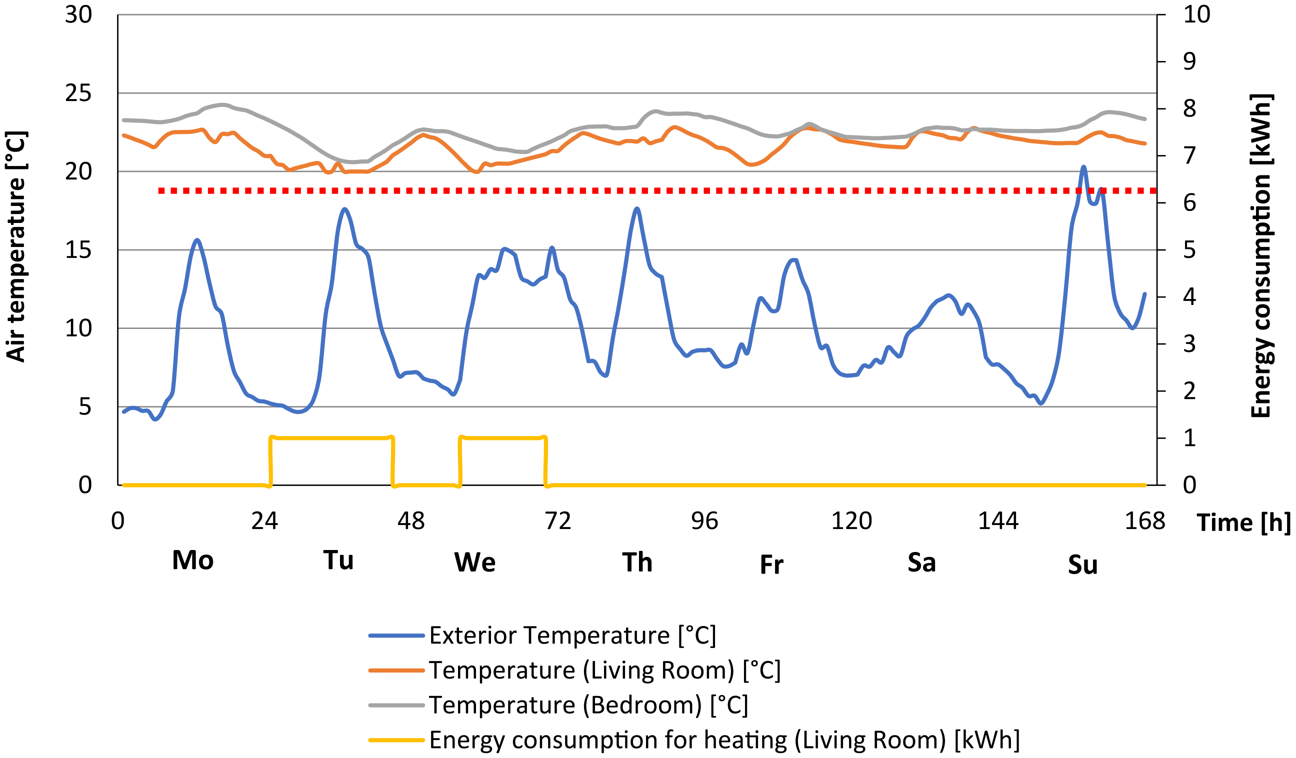

Figure 7. Temperature and energy consumption for heating during one week from a winter month.

observe the energy consumptions for heating during the seven days studied. Even if the outdoor temperature variation is between 4.2°C and 20.3°C, the indoor temperature variation is between 20°C (which is the temperature set point in both rooms) and 24°C in the bedroom, respectively 23.6°C in the living room. The amplitude variation is 16.1°C for the outdoor ambient air, while inside we obtain only up to 4°C amplitude variation. During the week studied we could observe that the heating system started during day 2 and day 3 (Tuesday and Wednesday) when indoor temperature values reached the set point. Furthermore, during this week the heating system consumed only 38 kWh during the 37 hours of functioning. Also, it can be observed that the variation of the interior temperatures, unlike the exterior temperature, is more uniform due to the thermal inertia added by using PCMs and special concrete. Thermal mass elements are crucial in case of low inertia buildings in order to store energy during the sunny periods when solar radiation is available.

CO_2 level measurements results

CO_2 levels measurements were also conducted during the same seven days analysed. **Figure 8** presents the CO_2 level variation in the two rooms studied: living room and bedroom. Moreover, the variations are related to the rotary heat recovery unit (HRU) energy consumption, equipment which starts when the indoor values reach the set point of 800 ppm. EFdeN prototype is not only a house, a prototype, but became also a Research Center and study HUB for students, so many meetings are scheduled every day, but the ventilation system was designed for a normal family occupation. This is why we can notice some peak values of CO_2 concentrations especially during four days of the experimental measurements: Wednesday, Thursday, Friday and Saturday. In order to keep the CO_2 levels below target, HRU worked for about 55 hours during one week, thus consuming only 10 kWh electrical energy. The European Standard EN 15251 mentions a limit of 800 ppm for category 1 of comfort and a limit of 1200 ppm for category 3 of comfort. During the seven days analysed the values measured are in the limits of category 1 more than 85% of the time and in the limits of category 3 100% of the period.

A good strategy in order to limit the values reached during meetings is to start the HRU with certain time before the start of them, or to lower the set point to 750 ppm, thus determining higher energy consumption.

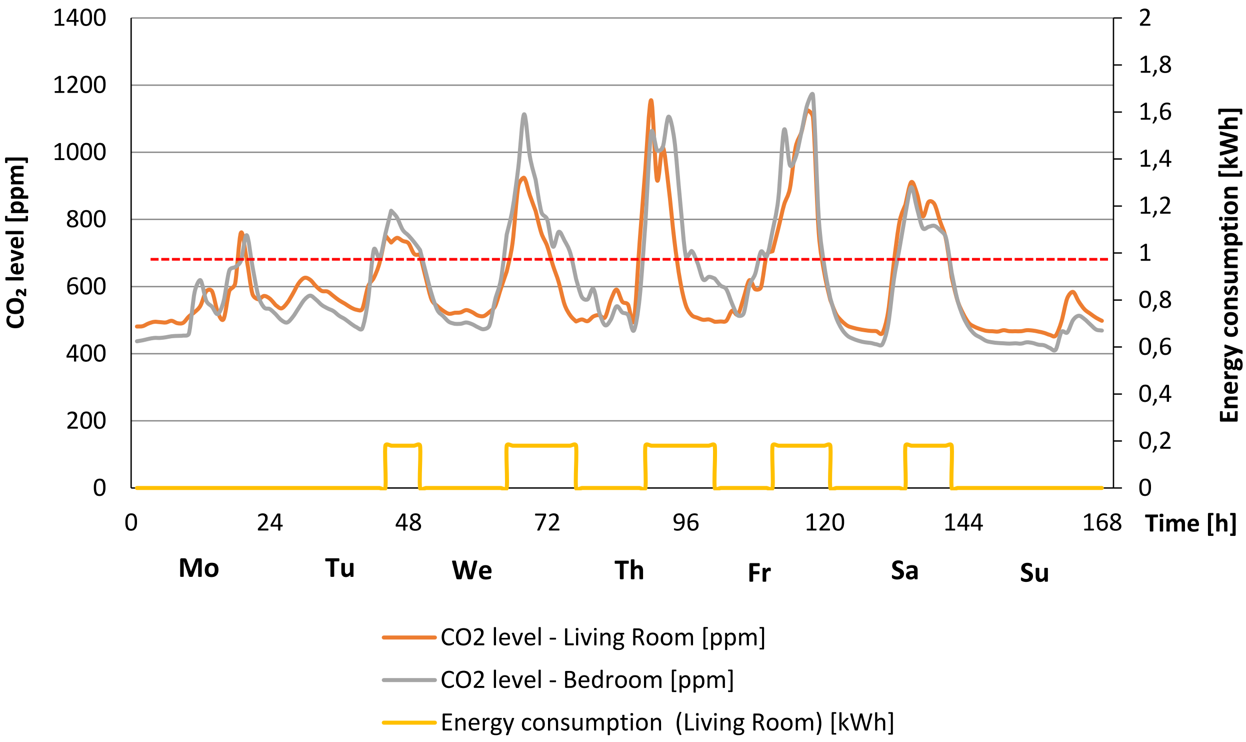

Figure 8. CO_2 level and energy consumption for HRU during one week from a winter month.

Relative humidity measurements results

Figure 9 highlights the relative humidity levels for the week studied. As it can be observed the values are within normal limits, except some short periods correlated with the meetings above mentioned which determined increased humidity and CO_2 levels. The values measured for the two rooms are between 34% and 51.5% in the bedroom case, respectively between 34% and 55% in the living case where the occupation level was higher also. The relative humidity was also controlled by the HRU used in order to reduce CO_2 levels inside the house.

According to the EN 15251 Standard, a relative humidity ratio between 30% and 50% corresponds to category 1 comfort level, while a ratio between 25% and 60% corresponds to category 2 comfort level. By taking this into account, in more than 86% of the time, the relative humidity values are in the range proposed for category 1, while in 100% of the period studied, the values are in the range proposed by the standard for category 1 of comfort.

The greenhouse`s effect as thermal buffer was a key point of the energy reduction strategy while the BMS "decided" in many cases to use the preheated air from the greenhouse instead of radiant panels to heat the building. In conclusion, all the passive and active strategies implemented in this building were correctly designed to achieve optimum values for indoor comfort and energy consumption.

Conclusions and perspectives

Following the experimental studies conducted it can be concluded that the passive and active strategies designed and implemented in the EFdeN energy-efficient building were complementary and well combined in order to achieve the indoor environmental quality with minimum energy consumption. The main element of the house, the BMS system, was found to be the necessary asset in linking these strategies. Other conclusions are mentioned:

- the indoor air temperature variation is uniform during the entire period;
- the sound pressure levels were below the maximum acceptable limits thus the indoor acoustic comfort is considered very good;
- the CO_2 levels were in the limits proposed by EN Standards in almost 85% of the time and classified in very low polluting;

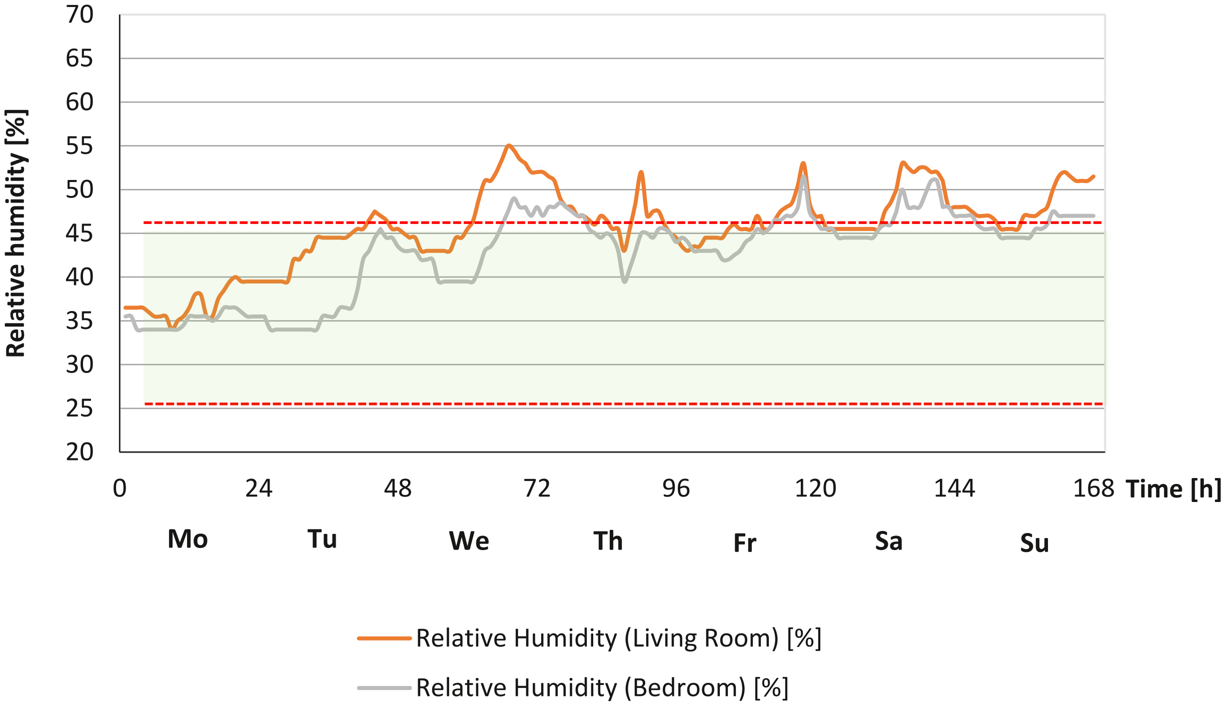

Figure 9. Relative humidity variation during one week from a winter month.

- the relative humidity levels were also in the good accordance with the standards with 86% of the time classified in category 1;
- the energy consumed in order to maintain IEQ was exceeded by the energy produced by the photovoltaic panels therefore the building can be mentioned as an energy-positive house. ■

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Evaluation of Building Envelope Performance Constructed with Phase-Change Materials in Terms of Heating and Cooling Energy Consumption

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It is a priority to take precautions in the building envelope design as the building envelope is the determinant of these energy consumptions. One of the new approaches used to control the heat transfer of the building envelope is phase-change materials. In this study, in a single-storey building, a 10 m / 10 m sized zone, in Diyarbakır (hot and dry climatic zone) and in Erzurum (cold climatic zone) was taken into consideration. Only the southern facade of the determined zone has a transparent component in order to reduce the heating loads, the phase-change material was applied in the building envelope of the studied zone. The thickness of the phase change material and the percentage of the transparent component on the applied surface were increased at every step, and alternatives of different building envelopes were created. For every different alternative, annual heating and cooling energy consumptions of the zone were calculated.

Today, majority of the energy consumed in the world is used in buildings. This rate is approximately 30% for buildings in Turkey [1]. Studies mostly focus on heating energy consumption when energy consumed in buildings is discussed and reduction on energy consumption is generally concentrated on heating energy. However, cooling demand in buildings is also increasing as the side effect of the climate change [2]. Therefore, reducing cooling energy consumption has also become a necessity.

When we look at cooling and heating energy consumptions and comfort requirements for different climate regions in residential buildings in Turkey, we see that the distribution of energy consumption and priorities (heating-cooling) vary depending on the climatic region. Reduction of cooling energy consumption is important in hot-dry climatic regions while reduction of heating energy consumption is important in cold climatic regions. Based on the above, it is possible to reduce energy consumptions by taking the right decisions about the variables which affect heating and cooling energy loads in buildings in different climatic regions [1,3].

A building envelope, a component which separates indoor from outdoor, is an important variable that plays a role in converting and transferring the effects of outdoor climate conditions to indoors and in creating indoor thermal comfort conditions depending on its thermo-physical properties [3]. Therefore, every decision regarding a building envelope can have a direct effect on the energy consumption of the zone enclosed by the envelope and vary depending on the climatic conditions [4].

Phase Change Material (PCM) applications on building envelopes use the materials' thermal energy storage properties to reduce heating, cooling and total energy consumption. PCMs can be defined as innovative materials alternative to conventional thermal mass, which absorb heat and stores in the building component on which they are applied; delay the effects of outdoor climatic elements and decrease their amplitude to transfer to indoors. PCMs can store thermal energy as latent heat [5,6,7]. Additionally, latent heat storage capacity of PCMs per zone mass is higher than sensible heat. Since PCM's temperature remains almost constant during the phase transition (energy storage process) of the building component they are applied on, it is suitable for energy storage and recovery applications. Melting temperature value should be close to indoor temperature value when selecting PCMs [8]. Solidification temperature of PCMs should be a few degrees lower than indoor temperature which is necessary to balance indoor thermal comfort conditions [9]. These materials use the principle of preventing heat losses on the building components they are applied on.

Performances of PCMs can vary depending on different climate regions. PCMs have a reducing effect on heating energy consumption in winter and cooling energy consumption in summer using the energy stored during the day and released later. These materials are generally used as a passive strategy to reduce energy loads in cooling required regions [9]. However, PCMs were demonstrated to have a significant effect on the reduction of heating loads in previous studies [10,11].

PCMs are mostly applied by integrating into plaster, filler, concrete and other building materials or as a surface of blocks among building component layers [6]. With effective use of this material, heat transfer through building envelopes can be controlled to reduce energy loads.

Method

In this study, several alternatives for building envelopes were developed for the zone included in the study to reduce heating and cooling energy consumption. These alternatives were evaluated for a building with a single zone in Diyarbakır and Erzurum. Energy performance of the building envelop surface on which Phase Change Materials were applied was comparatively evaluated with the simulation tool EnergyPlus™ version 9.0.1.

Determining Building Related Variables

In this study energy consumptions of a building with a single zone were evaluated with PCM alternatives with varying thicknesses in different climate regions and with façades with different transparency ratios. Based on these, building component alternatives were developed to achieve minimum annual heating, cooling and total energy consumption in Diyarbakır, a representative city in the hot dry climatic region of Turkey and in Erzurum, a representative city in the cold climatic region of Turkey. Thus, PCM performance was evaluated for heating and cooling energy consumption in Diyarbakır and Erzurum.

In accordance with the standard TS-825 "Thermal insulation requirements for buildings", total heat transfer coefficient values which should be achieved on building envelopes in Diyarbakır (region 2) and in Erzurum (region 5) were determined based on the upper limits recommended by the regulation and are shown in **Table 1**.

Table 1. *U values recommended for regions [12].*

	U_{WALL} (W/m²K)	U_{ROOF} (W/m²K)	U_{FLOOR} (W/m²K)	U_{WINDOW} (W/m²K)
Reg. 2	0.57	0.38	0.57	1.8
Reg. 5	0.36	0.21	0.36	1.8

Typical meteorological year (TMY) file type was used as climate data in this study. A typical meteorological year (TMY) is a set of meteorological data with data values for every hour in a year for a given geographical location. According to the selected TMY files; The monthly average outdoor temperature variation in both provinces is shown in **Figure 1**.

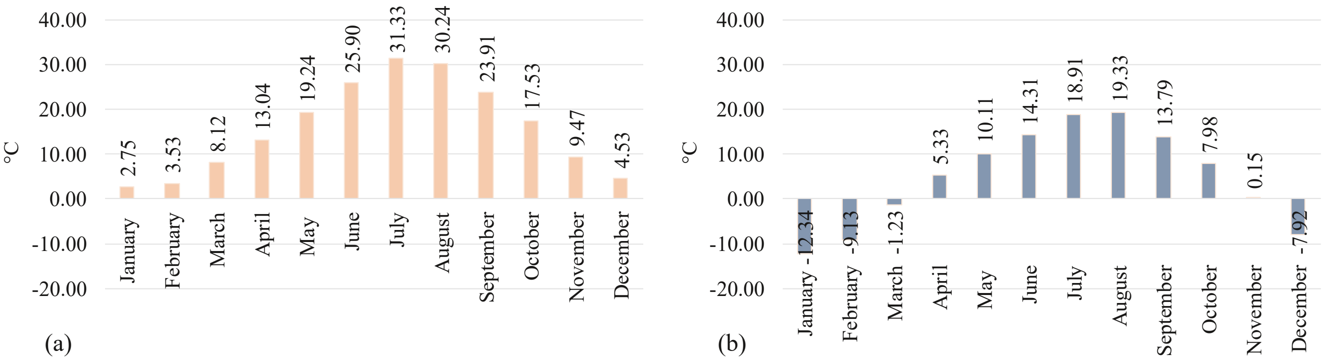


Figure 1. Monthly average outdoor temperature variation for Diyarbakır(a) and Erzurum(b).

The study was conducted on a square building with a single zone and flat roof and with a building footprint of 10 × 10 meters on a level ground. Different transparency ratios were used for the south façade of the zone to have a comparative evaluation. These ratios for the south façade were 10%, 20%, 30%, 40%, 50%, 60% while for other façades only 0% was used. The zone evaluated is shown in the **Figure 2**.

Total heat transfer coefficient of transparent element was taken as U = 1.5 W/m^{2}K in all calculations in accordance with the standard TS-825 "Thermal insulation requirements for buildings". Solar heat gain coefficient of the transparent component was 0.6 and visible transmittance was 0.7. The building envelope layering details are shown in **Table 3**.

Determining the variables of calculation

The zone selected for the evaluation was assumed to be used for 24 hours. Thermal comfort value for indoor temperature during the year was taken as 20°C in the heating period and 26°C in the cooling period. The hourly outdoor temperature variation for the 21st day of each month is shown in **Figure 3** for both provinces. Based on this, it is seen that the heating system will operate for a while during the day even in spring time. Other variables included in the calculation are shown in **Table 4**.

▶

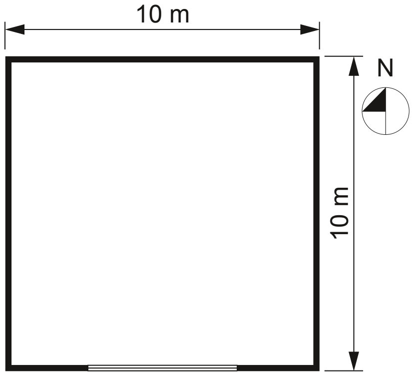


Figure 2. Zone evaluated in the study.

Table 3. *Building Envelope Layering Details of the zone in accordance with the standard TS-825.*

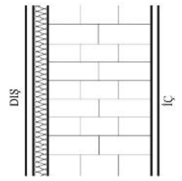
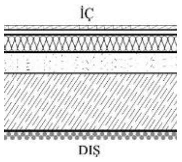
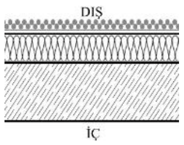
Opaque Components		Materials	λ (W/mK)	Diyarbakır (D)	U	Erzurum (E)	U
				Thickness(m)	(W/m^2 K)	Thickness(m)	(W/m^2 K)
Exterior Wall		1. Lime Mortar 2. XPS Extruded Polystyrene 3. Brick 4. Gypsum Plastering	0.8 0.034 0.72 0.4	0.01 0.045 0.19 0.01	0.564	0.02 0.075 0.19 0.01	0.345
Ground Floor		1. Timber Flooring 2. Floor/Roof Screed 3. XPS Extruded Polystyrene 4. Cast Concrete (Light) 5. Cast Concrete	0.14 0.41 0.034 1.9 1.13	0.03 0.03 0.04 0.05 0.12	0.569	0.03 0.03 0.075 0.05 0.12	0.359
Roof		1. Miscel Mater 2. Floor/Roof Screed 3. XPS Extruded Polystyrene 4. Cast Concrete 5. Gypsum Plastering	1.3 0.41 0.034 1.13 0.4	0.08 0.03 0.075 0.15 0.01	0.379	0.08 0.03 0.15 0.15 0.01	0.205

Table 4. *Other variables included in the calculation.*

1	Illuminance level per square meter in the zone	8 W/m^2
2	Infiltration rate (according to the ASHRAE Standard 55 and BEP-TR Calculation Method for Building Energy Performance).	0.5 h^{-1} [12].
3	Night Ventilation	is neglected
4	Natural Ventilation	Closed
5	Mechanical Ventilation	Mechanical ventilation was assumed to be activated only when indoor air temperature rises above the thermal comfort value (26°C for cooling period).
6	Occupant Intensity (TUIK 2017)	4 persons [13].
7	Equipment Use	Daily usage density was determined. [12,14].
8	Climate data for 2 and 5. degree day regions	2009 Meteonorm climate data files were used.
9	Calculation Algorithm	Finite differences calculation method
10	Selected PCM types	SPE26E for Diyarbakır - BioPCM/M27/Q21 for Erzurum

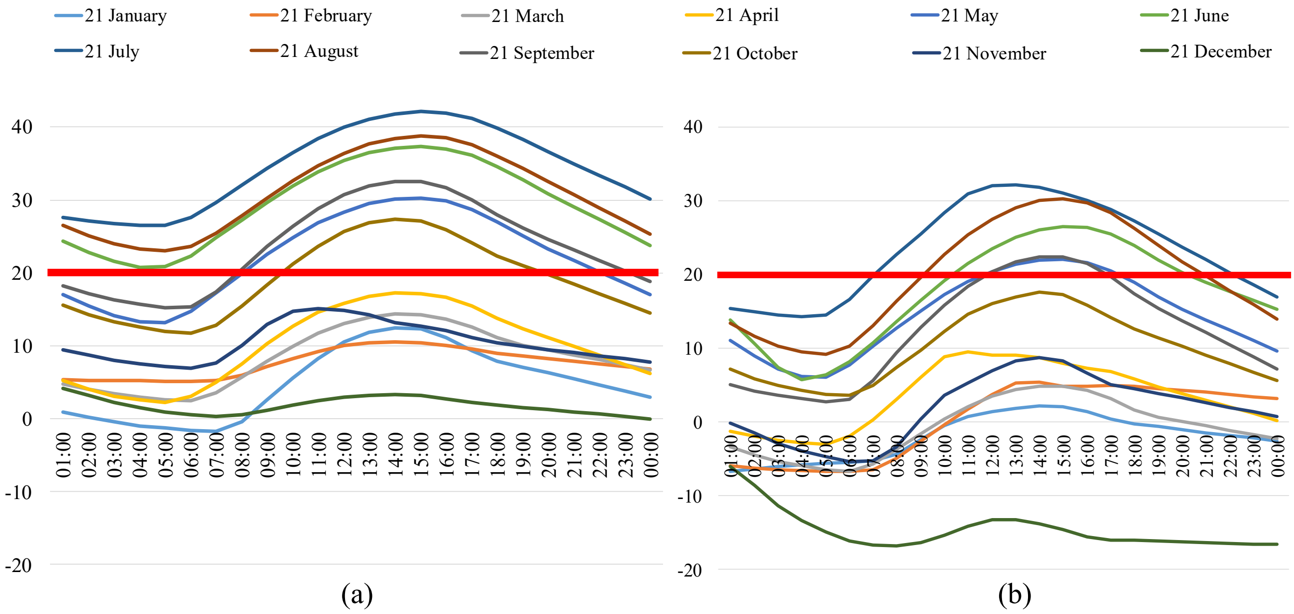


Figure 3. Hourly outdoor temperature variation for the 21st day of each month for Diyarbakır(a) and Erzurum(b).

PCM types shown in **Table 4** were entered in the EnergyPlus™ 9.0.1 simulation program. Performance evaluation of the surfaces on which PCM was applied was repeated for different alternatives developed with these materials. When designing alternatives, PCM material was considered as a separate layer like other materials. Melting temperature of the PCM selected in the study is a determining factor during phase change. Based on previous studies, indoor temperature value close to PCM melting temperature allows PCMs to show a better performance [5,6]. Therefore, in this study, different PCM types were used in Erzurum and Diyarbakır which have different climate characteristics. Material properties are shown in **Table 5**.

Table 5. *Thermophysical properties of the PCM used in the study.*

Thermophysical properties	SP26E	BioPCM/M27/Q21
Sensible Heat	2 000 J/kg-K	1 970
Melting Temperature	26°C	21°C
Conductivity	0.9 W/mK	0.2
Density	1 500 Kg/m^3	235

Determining the position and thickness of phase change materials on a building envelope

Previous studies on the subject reported that application of PCMs on the inner surface of the insulation material led to a better performance related to reduction in energy consumptions [11]. Therefore, PCM was applied on the inner surface of the insulation material in this study. To evaluate heating and cooling energy consumption performance of the building envelope on which PCM was applied;

- Building envelope alternative with no PCM and
- Building envelope alternatives with 3 cm, 4 cm, 5 cm PCM were developed (**Table 6**).

PCM thickness alternatives created for the zone were evaluated by applying on all façades of the building envelope (exterior walls, roof, internal floor).

In order to make a comparative evaluation for the zone; alternatives with and without PCM were combined with varying transparency ratios of 10%, 20%, 30%, 40%, 50%, 60%.

Table 6. *U values of the building envelope if different PCM thicknesses are applied.*

	PCM thicknesses	U_{WALL} (W/m²K)	U_{FLOOR} (W/m²K)	U_{ROOF} (W/m²K)
Erzurum	3 cm	0.328	0.34	0.199
	4 cm	0.323	0.335	0.197
	5 cm	0.318	0.329	0.195
Diyarbakır	3 cm	0.553	0.558	0.375
	4 cm	0.55	0.555	0.373
	5 cm	0.546	0.551	0.372

Results

Annual heating and total energy consumption values in the zone, which changed with the changes in the façade transparency ratios and PCM thickness were calculated for Diyarbakır and Erzurum. Heating and cooling energy consumptions in Diyarbakır and Erzurum are shown in **Table** 7.

When we look at the heating and cooling energy consumptions of the cities; the alternative with 5 cm PCM was the alternative with the lowest consumption in both cities, which was in direct proportion with the increasing PCM thickness. Additionally, as the transparency ratio increased, heating energy consumption for the two cities decreased and cooling energy consumption increased.

Evaluating the heating and cooling energy consumptions of the zone in the alternatives developed for the study the following can be reported:

For the Diyarbakır climate: compared to the alternative without PCM, the alternative with 5 cm PCM reduced the heating energy consumption of the zone by 15.56% with 60% transparency ratio, 15.22% with 50% transparency ratio, 14.89% with 40% transparency ratio, 14.63% with 30% transparency ratio, 14.09% with 20% transparency ratio and 13.69% with 10% transparency ratio.

Compared to the alternative without PCM, the alternative with 5 cm PCM reduced the cooling energy consumption of the zone by 31.86% with 60% transparency ratio, 33.58% with 50% transparency ratio, 34.88% with 40% transparency ratio, 33.87% with 30% transparency ratio, 36.79% with 20% transparency ratio and 36.82% with 10% transparency ratio.

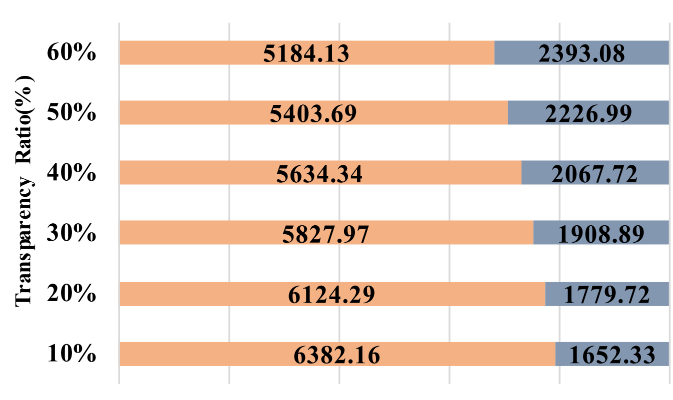
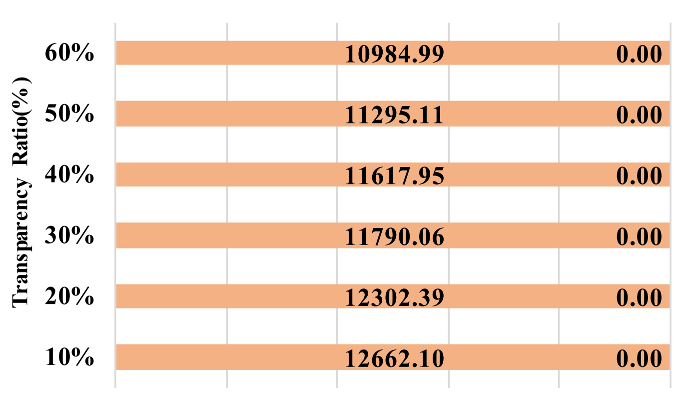
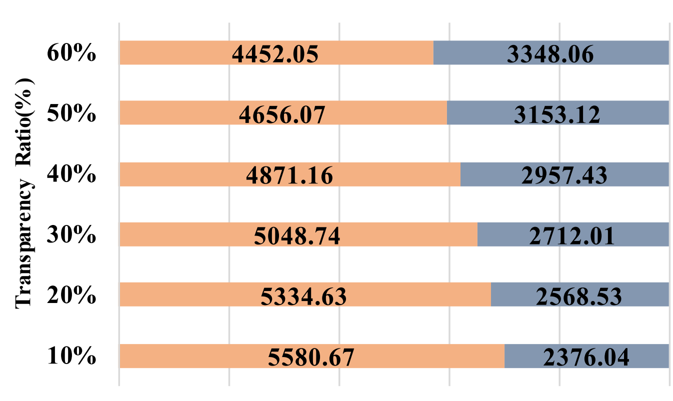
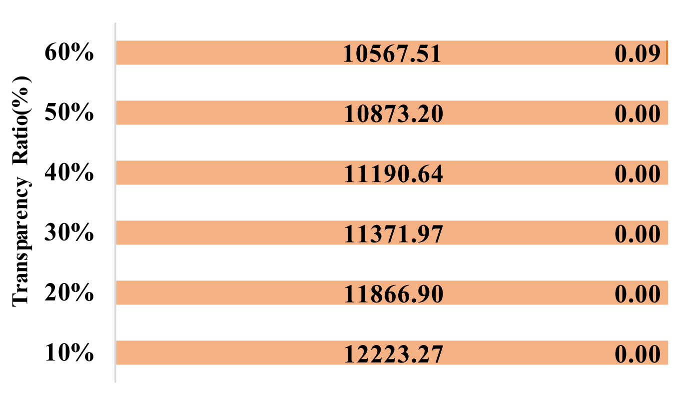
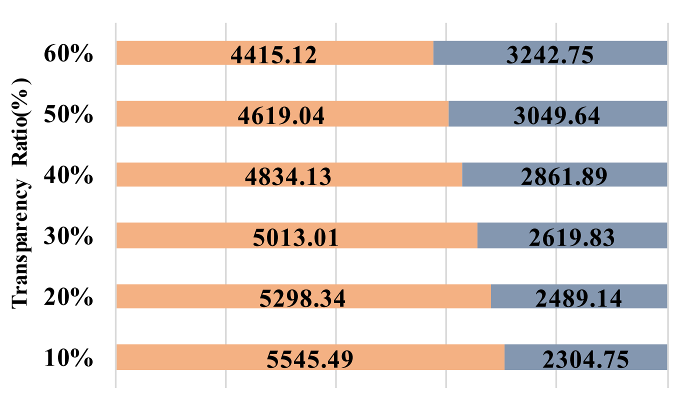
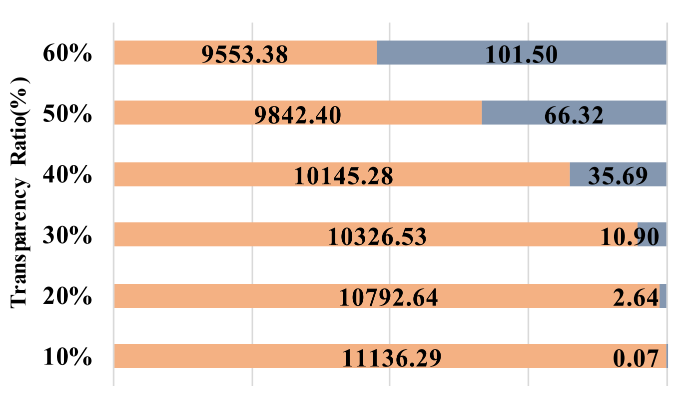
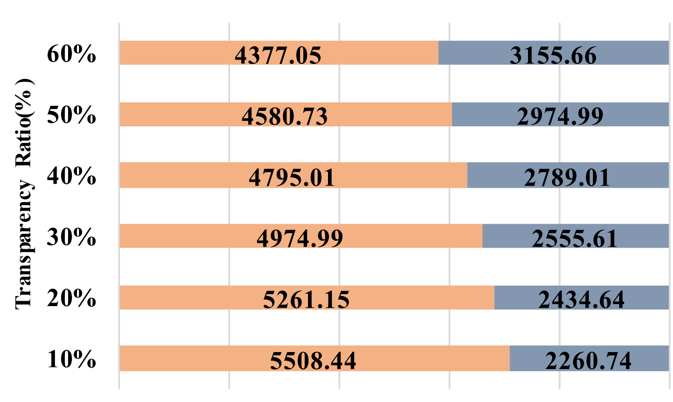
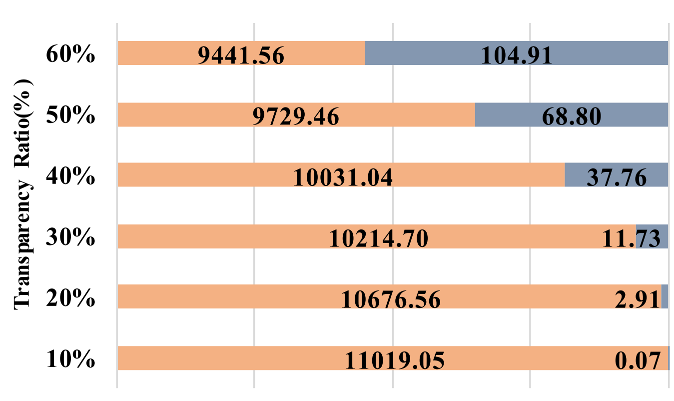
For the Erzurum climate: compared to the alternative with no PCM, the alternative with 5 cm PCM reduced the heating energy consumption of the zone by 14.05% with 60% transparency ratio, 13.86% with 50% transparency ratio, 13.65% with 40% transparency ratio, 13.36% with 30% transparency ratio, 13.21% with 20% transparency ratio and 12.97% with 10% transparency ratio.

Compared to the alternative with no PCM, the alternative with 5 cm PCM had the highest increase in the cooling energy consumption of the building. No cooling energy consumption was observed in the alternative with no PCM. In the alternative with 3 cm PCM and 60% transparency ratio and in the alternatives with 4 and 5 cm PCM with 10%, 20%, 30%, 40%, 50%, 60% transparency ratios, cooling energy was consumed.

Discussion

When today's energy consumption rates are analysed, it is seen that energy used in buildings has a higher percentage. This study comparatively evaluated the contribution of the application of PCMs with different

Table 7. *The demonstration of cooling, heating loads and total loads calculated for different PCM thicknesses in Diyarbakır and Erzurum.*

#	DİYARBAKIR	ERZURUM
With no PCM		
With 3 cm PCM		
With 4 cm PCM		
With 5 cm PCM		
#	🟦 Cooling Energy Consumption (kWh)	🟧 Heating Energy Consumption (kWh)

thicknesses on the building envelope to the heating and cooling energy performance of the building depending on different transparency ratios of façades. The findings of the study are summarized below;

- When correct design decisions are taken, PCM seems to contribute to the reduction of total annual energy consumption in buildings.
- The best alternative with PCM for the reduction of heating energy consumption is the alternative with 5 cm PCM.
- For cooling energy consumption; the best alternative for Diyarbakır was the alternative with no PCM.
- In the alternatives with PCM, increase in the thickness of the material leads to a reduction in cooling energy consumption. However, it is still higher than the alternative with no PCM. Because PCM may have shown a thermal insulation material performance by surrounding the shell as an additional layer.
- For Erzurum, increase in the PCM thickness leads to an increase in the cooling energy consumption.
- When all transparency ratios used for PCM were compared for both cities, increasing transparency ratio decreased heating energy consumption but increased cooling energy consumption.

Based on this study and its findings; further studies on evaluation of PCM application according to the orientation of the zone in the building and variation of PCM applications in order to balance energy loads in the zone can be recommended. ■

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An Approach for Simulation in Support of the Design of Net-Zero Water Buildings (NZWB)

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Current approaches towards making buildings more efficient in terms of water consumption are often qualitative and simply based on the inclusion of certain water-saving and recycling design features, or simple water quantity assessments. This paper presents a conceptual framework of an approach that will allow an objective qualification of whether or not buildings qualify as Net-Zero Water Building (NZWB) on the basis of a detailed water supply and demand balance. It also allows to contribute and move beyond traditional deterministic calculations.

Efforts to manage a sustainable use of resources in the built environment predominantly focus on efficient use of energy and materials. However, sustainable use of water is of increasing interest in the built environment, especially since climate change is leading to longer and more severe droughts. Where initial efforts focused on the application of relatively straightforward design principles such as rainwater collection and the reuse of grey water, more holistic approaches to manage water in and around buildings are now appearing. In parallel to towards the design of a Net-Zero Energy Buildings (NZEB), the concept of a Net-Zero Water Building (NZWB) has emerged.

Water is an increasingly scarce resource, with rainfall reduced by climate change while population growth puts pressure on the demand side. As with energy, buildings are responsible for a significant percentage of national water use; for instance, figures reported for the USA are in the order of 15% [1]. The cost of water and energy is quickly approaching the same order of magnitude as gas and electricity, with annual household bills in the UK reported at around £ 600 for gas, £ 750 for electricity, and £ 400 for water [2]. Current approaches towards making buildings more efficient in terms of water consumption are often qualitative and simply based on the inclusion of certain water-saving and recycling design features, or simple water quantity assessments.

This paper contributes to efforts towards NZWB design, with the ultimate aim to develop buildings that are more resilient towards changes in rainfall patterns due to climate change. It has the following objectives: i) review the state-of-the-art in NZWB, ii) develop and initial simulation-based water performance assessment method that allows to quantify water use and to identify which buildings qualify as NZWB, iii) explore strategies to turn existing as well as newly designed buildings into NZWBs.

Methodology

This paper builds upon a literature review of the state-of-the-art in Net-Zero Water Buildings, which is used to underpin the development of a conceptual framework for the qualification of buildings as NZWB. The framework is demonstrated though application to a simple residential case in Ankara, Turkey.

NZWB: State-of-the-Art

There is a small emergent body of literature on NZWB. In the USA, the ANSI/ASHRAE/USGB/IES Standard 189.1 [3] on the design of high-performance green buildings gives some generic guidance on making buildings water efficient, but does not include the net-zero concept. In the UK, CIBSE Guide G [4] provides details about the design of water supply and plumbing systems, but again does not address net-zero buildings. The US Department of Energy has published a handbook that provides general guidelines for the development of Net-Zero Energy, water and waste buildings. This discusses system boundaries in some detail and provides a general sequence of development stages, but no calculation formulas [5]. A comprehensive academic overview of NZWBs is provided by Joustra and Yeh (2015) [6] [7]. Further publications typically relate to specific aspects of the water balance, such as: rainwater harvesting [8], flow in drainage systems [9] or general water resource management [10]. Another body of work addresses water use at the urban scale, see for instance Rathnayaka et al. (2017) [11]. Empirical studies are also reported, see for instance Costa Proença and Ghisi (2010) [12]. However, most quantification efforts are deterministic, and unsuitable for the propagation of uncertainties in both supply and demand. Joustra and Yeh, 2015 [6] explore the application of the net-zero and net-positive concept to the building water cycle; they claim that each building water cycle is unique and that this limits the development of a generic net-zero water strategy.

Water is used in or near buildings for drinking, hygiene, cooking, cleaning, sanitation, irrigation, safety, recreation and aesthetics, and for various machines and processes [6]. Water use can be studied at different scales: that of individual buildings, clusters or districts, and the regional level [13]. Water use in cities is sometimes named ‘water footprint’ and is measured in litres used per person (capita) per day; footprints range from as low as 20 ℓ/pd in poor countries to as high as 650 ℓ/pd in the USA [13].

Findings on the benefits of ‘green’ water systems vary. Ghimire et al. (2017) [14] have conducted life cycle analysis and report that rainwater harvesting outperforms municipal supply systems; yet Hasik et al. (2017) [15] claim that water-efficient buildings perform better than net-zero water buildings. Yan et al. (2018) [16] conclude that water from a point-of-use treatment system performs worse in terms of Life Cycle Analysis (LCA) than water from a centralized treatment plant. Stephan and Stephan (2017) [17] note that wastewater treatment requires subsidies to be financially competitive.

Rainwater harvesting is one solution to coping with water scarcity. However, rainwater harvesting still faces environmental, political, economic, societal and technical challenges. For instance, Lee et al. (2016) [18] discuss these issues in the context of Malaysia. A study on the wash-off from road surfaces is presented by Andrés-Doménech et al. (2018) [19], with the recommendation to install off-line water retention systems in SUDS in order to improve the quality of discharge water.

Some demographic variables that are known to have an impact on water end use are household size, presence of children, efficiency of appliances, and more in general the dwelling type [11]. Water management in buildings often lacks an integrated approach; while there is attention to use alternative sources such as rainwater or to reuse wastewater there is no systematic approach. Joustra and Yeh (2015) [7] present an Integrated Building Water Management (IBWM) framework that tries to address this issue. For water management, comparison with the water use of peer households may help to incentivize water saving behaviour by occupants [20]. Challenges to the use of rainwater harvesting systems may be economic and legislative. Furthermore, there is a lack of empirical data on system operation, and on the relation between water quality and system maintenance [8].

Looking at water in a different way, cities and the buildings therein also need to consider an increased risk of flooding. In this context, urban flood resilience can be defined as “*the ability of an urban system exposed to a flood hazard to resist, absorb, accommodate, adapt to, transform and recover from the effects of flooding in a* *timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions*" [21].

Water systems

Water sources include potable water, reclaimed water, rainwater, storm water, condensate, greywater and blackwater [6]. The main components of a water distribution system are reservoirs, pipes, pumps, tank and junctions [22]. Rainwater harvesting systems typically consist of collection surfaces, gutters and downpipes, a tank, and a water distribution system; mostly it also includes pumps, debris screens and filters [8]. Water use can be reduced by flow limiters, which may be incorporated in different appliances. Benefits of such reduction are both environmental and financial [23]. Sustainable Urban Drainage System (SUDS) may include water retention ponds which store water and dampen the effect of floods [24]. These ponds harvest water for later use. SUDS reduce the runoff peak flow from rainfall, using a combination of water retention, transport and infiltration mechanisms [25]. Emerging concepts such as smart networks and the Internet of Things (IoT) may also be applied to the water network and help to monitor the network status, manage risk, forecast demand and supply, and handle incidents [26].

Important parameters for the evaluation of a rainwater harvesting system are the catchment area, collection efficiency, and tank volume. Further factors include rainfall and water demand. Evaluation often is measured in terms of Rainwater Use Efficiency (RUE), Water Saving Efficiency (WSE) and Cycle Number (CN). Often it is useful to consider V/A, in other words the ratio of tank volume to catchment area [27]. For rainwater harvesting systems, typically rooftop area is defined by building size, and demand depends on use; a key variable for decision makers is tank size [28]. Water storage in 'green' systems may lead to higher water age in building systems, which in turn may have consequences for water quality and human health [29].

A study into the water savings, water supply reliability and potential cost savings of fitting rainwater collection tanks in the Greater Sydney area is the work by Rahman et al. (2012) [30]. It is noted that the evaluation of economic benefits is strongly dependent on incentives such as rebates offered by the authorities. Costa Proença and Ghisi (2010) [12] have explored the water end-use of offices in Brazil, comparing and contrasting the findings from interviews with building occupants with metered monthly water use data.

Net-Zero Water Buildings (NZWB)

A common definition of net zero water, by Joustra and Yeh (2015) [6] citing US Army, is: "*facilities that maintain the same quantity and quality of natural water resources, such as groundwater and surface water, by decreasing consumption and directing water to the same watershed*" [6]. Net-zero water status may be achieved by using low-flow water fixtures as we all a decentralized (local to the building) water treatment and reuse system [15].

Self-sufficiency of water supply may be available in households of countries with enough rainfall like the Netherlands. Typical measures required include rainwater harvesting, minimization of water demand, cascading, and multisource. However, to achieve self-sufficiency one needs to overcome temporal, spatial and location-bound constraints [31].

Water Use, Flows and Discharge Modelling

The basic water mass balance for buildings or urban areas is presented by Joustra and Yeh (2015) [6] as:

$$\Delta S = I + C + D + P - (W + R + G + ET) \qquad (1)$$

where:
ΔS = change is stored water in a system
I = inflow from adjacent systems
C = centralized flows into the system
D = decentralized flows into the system
P = precipitation
W = wastewater discharge
R = stormwater runoff
G = infiltration to groundwater
ET = evapotranspiration

Kenway et al. (2011) [32] show how this balance can also be applied at the city scale. Based on Mun and Han (2012) [27] the water balance for rainwater harvesting systems can be written as:

$$V_{tk} = \sum (Q_{i,t} - Q_{o,t} - Q_{s,t}) \qquad (2)$$

where
V_{tk} = tank volume (m^3)
$Q_{i,t}$ = runoff from the roof (m^3/day)
$Q_{o,t}$ = overflow for the tank (m^3/day)
$Q_{s,t}$ = rainwater supply (m^3/day)
t = elapsed time (days)

Water System Efficiency, ET, can be defined as the amount of water conserved in relation to total water demand; in formula $ET = 100 \times (V/D)$ where V is volume of water conserved (m^3) and D is total water demand [33].

The classical method for predicting water use in buildings is based on "Hunter's curve", a method dating back to 1940 which estimates the 99th percentile of water use in public buildings on the basis of the number of fixtures in a building (n), probability that the fixture is busy (p), and the flow rate of a busy fixture (q). A more recent method is the Wistort method from 1994, which proposed a direct analytic method to estimate peak loads. Further work is ongoing to develop a CDF plot that relates peak flow to probability [34].

Moving to modelling and simulation, a model to generate stochastic domestic end-use water demands is SIMDEUM (SIMulation of water Demand; an End-Use Model); this has also been shown to apply to non-domestic cases. SIMDEUM correlates functional rooms, end use, user's frequency of use, pulse intensity, pulse duration, diurnal pattern and time of water use [35]. A simple method to predict water runoff from rainfall is the Soil Conservation Service Curve Number (SCS-CN) curve; this is an empirical relationship that relates rainfall, soil water retention, and rainfall intercepted before runoff [36]. An advanced model for the prediction of urban residential water end-use demands is presented by Rathnayaka et al. (2017) [11]. Their model considers various spatial scales, from household to building development to suburb or district. In terms of temporal scales, they differentiate between hourly, daily, weekly, seasonal and yearly profiles. EPANET is a German commercial tool for the simulation of water distribution systems that computes water flows and hydraulic heads [22] (Hallmann and Suhl, 2016). Detailed modelling of partially filled pipes that contain both fluid flow and gas can be done on the basis of the finite difference method; Campbell (2012) [9] discusses the simulation of such pipes using the AIRNET program. Sahin et al. (2016) [10] note that water systems may be modelled using system dynamics, bayesian networks, coupled component models, agent-based models and knowledge-based models. For an analysis of the impact of water governance decisions they explore system dynamics and agent-based models. Alfredsen and Sæther (2000) [37] present water resource modelling in terms of flood calculations in river systems, which may incorporate reservoirs and water transfer structures. Sulis and Sechi (2013) [38] provide an overview and comparison of regional scale model that can represent a multi-reservoir water use system, discussing AQUATOOL, MODSIM, RIBASIM, WARGI-SIM and WEAP. WEAP21 models' water at the watershed level. UWOT, the Urban Water Optioneering Tool, focuses on the urban environment [7]. Another water management tool is MB or Mike Basin [24]. AQUATOOL is a decision support system that is widely used by river basin authorities. It contains, amongst others, a module to model rainfall runoff in complex river basins and a module to simulate water supply/resources [39].

Rain run-off simulations may be used on GIS data, describing the terrain, buildings, catchment properties and sewer network. Simulation also requires the definition of a design storm that describes the amount of rain and the rainfall intensity over time. A tool that can capture how Sustainable Urban Drainage Systems (SuDS) deal with rainwater is Storm Water Management Model (SWMM) [25].

SWMM is a tool developed by the US Environmental Protection Agency (EPA). SWMM allows the dynamic simulation of rainfall runoff from surfaces in urban and suburban areas. Palla et al. (2017) [40] present a case study where SWMM is used to analysis system performance of a domestic urban block in Genoa, Italy. Stave (2003) [41] presents the first-principle development of a water conservation management systems dynamics model for Las Vegas, USA. Xi and Poh (2013) [42] use system dynamics to model water management in the city state of Singapore.

Rainfall data may consist of historical observations or could also be synthetic; one way of creating artificial rainfall data is by means of Markov chain models [28]. The adequacy of short-term (1 or 2 years) and long-term (10–30 years) rainfall time series for the assessment of using rainwater to supply potable water in homes is discussed Ghisi et al. (2012) [43]. Various water usage scenarios can be generated using Monte Carlo simulation [28].

One way to express how rainwater harvesting systems are meeting the demand by building occupants is through the Deficit Rate or DR – the amount of water that needs to be bought when the system is unable to provide the water that is needed [28]. Crawford and Pullen (2011) [44] categorize embodied water analysis methods as process analysis, input-output (I-O) analysis, and hybrid analysis. Park et al. (2018) [45] model the rain flow on facades in order to predict the collection of dirt caused by runoff and to assess aesthetic impact using a CFD tool named RealFlow. STUMP, Stormwater Treatment Unit model for MicroPollutants, is a dynamic model that describes the movement of MicroPollutants in both the particulate and dissolved phases [46]. SGMP, Standard Groundwater Model Package, is a tool that allows to analyse the impact of water management measures on groundwater levels using partial-differential equations [47]. Another tool that allows to model groundwater and surface water is HydroGeoSphere [48]. Zeng et al. (2016) [49] demonstrate the modelling of a wetland ecosystem, which predicts system discharge and allows allocation to human activities while considering wetland pollution and ecological effects. The underlying model is based on linear programming. Leenhardt et al. (2012) [50] present case studies that explore how scientist and stakeholders can use water-resource models to make informed water management decisions.

Like all construction objects, sewer and sanitation systems, treatment plants and similar can all be modelled using BIM technology [51]. Calculations of risks in drinking water supply may require advanced approaches such as Dynamic Fault Tree (DTF) analysis combined with Markov chain and Mote Carlo simulations; see for instance Lindhe et al. (2012) [52]. A theoretical discussion of urban wastewater system reliability, risk and resilience is provided by Sweetapple et al. (2018) [53].

Water measurement and monitoring

Monitoring of hot water consumption, measured at a time step of 1 minute for 119 homes in Canada, is reported by George et al. (2015) [54]. De Gois et al. (2015) [55] evaluate the water use of a mall in Brazil, combining both on-site observation and monitoring with calculation of the daily water consumption. Marzouk and Othman (2017) [51] describe a bespoke program in C# which analyses flow meter readings from different sectors in a sewer system. Vezzaro et al. (2015) [46] present water quality analysis conducted across the catchment area of the Albertslund municipality in Denmark, which is fed into a simulation model to study the efficiency of a range of control strategies. Blokker et al. (2011) [35] report on the validation of a water end use prediction model using measurements from an office building, a hotel and a nursing home. Ward et al. (2012) [33] describe the empirical assessment of a university building with a large rainwater harvesting system in the UK; their paper provides an overview of further studies in other countries across the world. An empirical study of sediment retention in SUDS is presented by Allen et al. (2018) [56]. Empirical studies using scale models of urban surfaces combined with artificial rain are reported by Liu et al. (2018) [36]. Water use is sometimes reported as one of the parameters in more wide-ranging monitoring efforts on buildings that report energy use; see for instance Gill et al. (2011) [57] who report on the monitoring of affordable houses in the UK.

Yet detailed measurement of water end-use is not always feasible; main water meters do not differentiate between specific fixtures and allowing water meters at a higher resolution level might impair use of the water system [12]. Vieira et al. (2018) [20] discuss a case study that comprised 43 households, where 100 participants kept water diaries and household water consumption was metered on a weekly basis. The paper by Rathnayaka et al. (2017) [11] provides an overview of some water measurement data available from different surveys done by third parties.

Energy consumption of rainwater harvesting systems is reviewed by Vieira et al. (2014) [58]; they report that theoretical studies typically report around 0.20 kWh/m³ whereas empirical data, which also captures pump start-up energy and stand-by modes, is in the order of 140 kWh/m³.

Assessment framework for the qualification of buildings as NZWB

Theoretically, qualification of a building as net Zero Water Building can be determined by simple water mass balance equations. However, in practice it is necessary to understand the impact of the relation between water storage and usage by analysing the water balance over time, and under uncertainties. The assessment framework thus requires three elements: i) Urban scale balance: the basic water mass balance for urban areas. This comes from the equation of Joustra and Yeh (2015a) [6] in which the possible water storage can be presented, ii) Building scale balance: within the urban context, a similar water mass balance is used for individual buildings. Building scale parameters vary depending on the design, function and occupant schedule of the building, iii) Monte Carlo Simulation: The data for the site (building scale) is processed in Monte Carlo Simulation to analyse the effect of rainfall variation on the water mass balance.

Achieving the status of net Zero Water Building introduces a specific criterion which needs to be considered during design: averaged out over a year, the water entering the building system boundary from other sources than the utility supply needs to equal the use. The resulting framework is depicted in **Figure 1**. Implementation of the water mass balance is in a spreadsheet application that enables easy MC simulation efforts.

Application to a case study building

In order to develop these ideas, the framework is applied to a residential case study building. This building is an existing house located in an arid climate, Ankara, Turkey. It was constructed late 1990's. The house is a typical single-family house of 250 m² with 4 floors including basement and attic. There are 4 occupants (2 adults and 2 children). The annual measured water consumption of the house is ≈156 m³. The water usage breakdown of the house based on occupants' notifica-

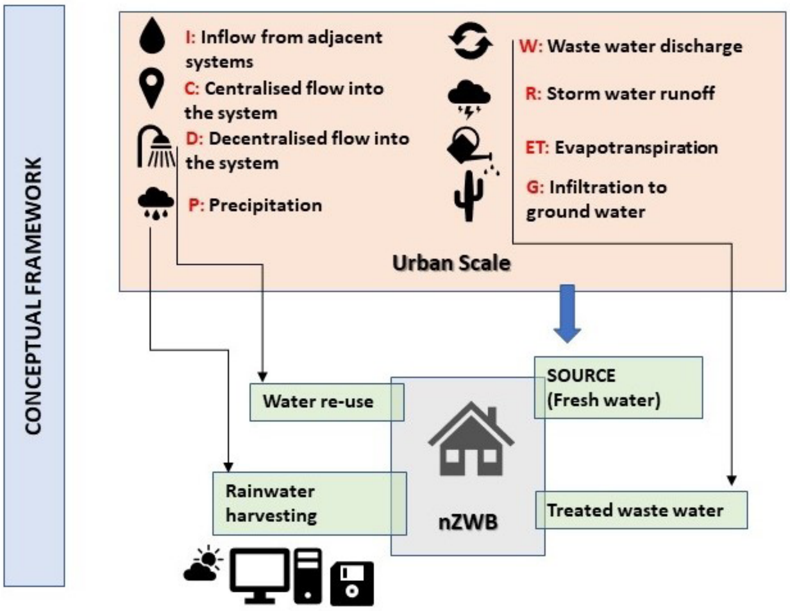

Figure 1. Conceptual nZWB analysis framework.

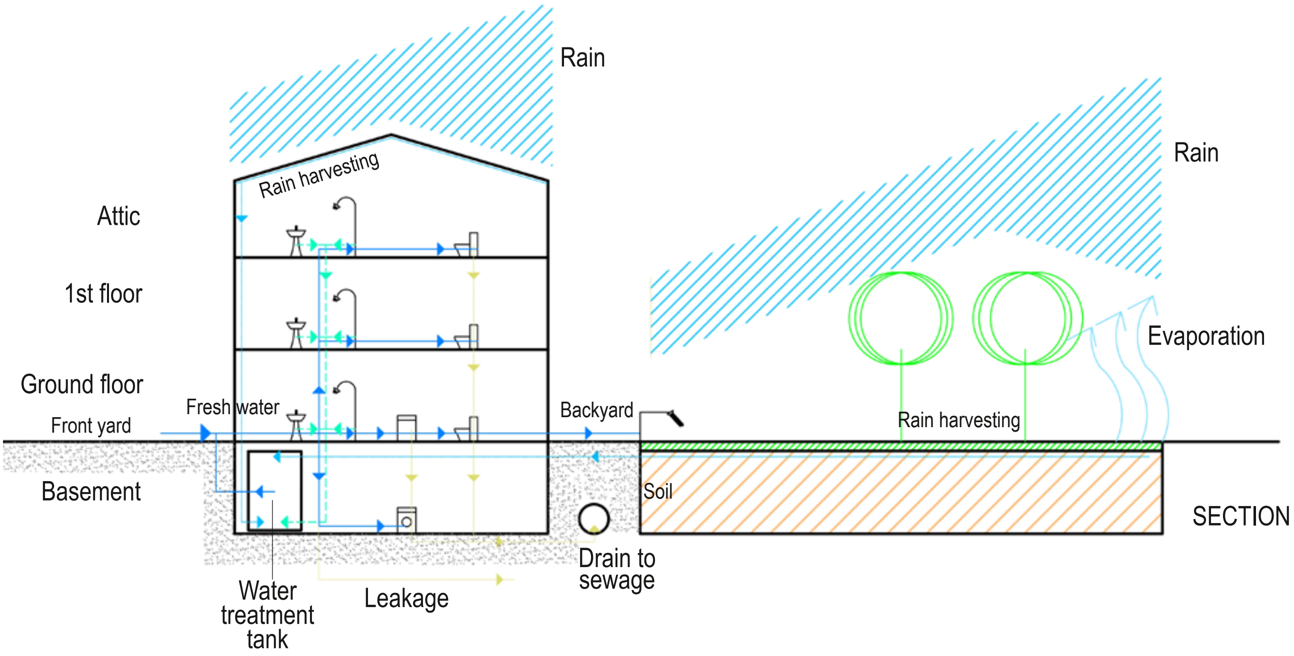

Figure 2. Typical domestic house.

tions is presented in **Figure 3**. Regarding the expression of the home-owners, shower, faucet and toilet usages are the highest percentages relatively.

In terms of rainwater availability, Ankara's annual precipitation value is 387 mm/year. The roof area of the house is 65 m². The slope of the roof has an impact on how much water is collected in the downpipes; for this case, an approximate loss of 25% has been assumed. The total amount of possible rain water harvesting from the roof is therefore: 65 × 387 × 0.75 = 18 866.25 litre /year. The garden area is 100 m². 50% of rainwater leaks into the soil. The rest can be harvested. The total amount of possible rain water harvesting from garden is: 100 × 387 × 0.5 = 19 350 litre/year.

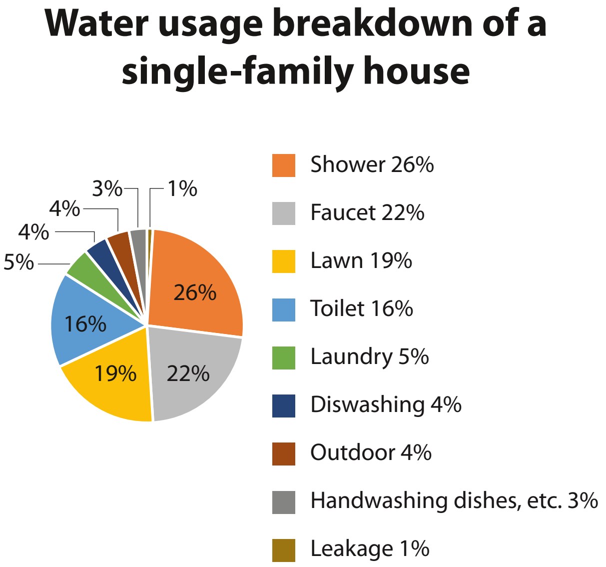
Water usage breakdown of a single-family house

Figure 3. Typical water uses in a single-family home.

Analysis of treated grey-water and rainwater harvesting is more complex. The treated greywater can only be captured for recycling from the faucet and shower. The treated amount of greywater will be 75% of the total. In other words, 75% of total 26% shower water use + 22% faucet water use can be listed as the treated water recycle. Thus (26 + 22) × 0.75 = 36% greywater recycled.

For this example, possible potential of water recycle rates of each item are shown in the Sankey diagram in **Figure 4**. Inputs and outputs for the Sankey diagram is derived from actual water meter readings of the residence plus data gathered of the occupants depending on their daily life usage patterns plus estimated calculations of rain harvesting potentials stated earlier in the paper. Actual water meter readings back to a full year and is broke down related to occupant usage patterns. Annual water usage of 156 m³ as taken fresh water from the grid and remarked in the diagram as water (100%).

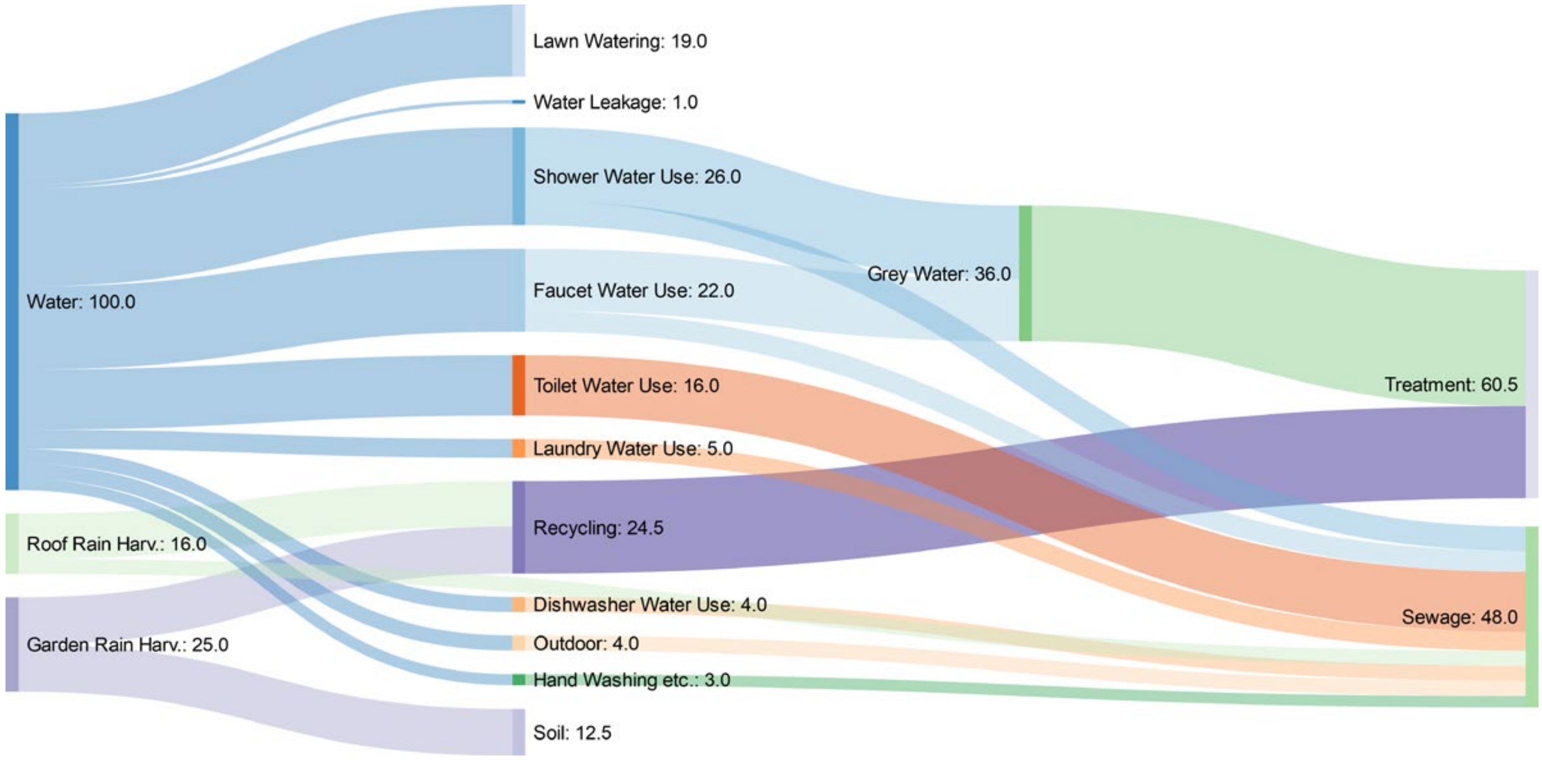

Figure 4. Sankey diagram of domestic water flows.

Roof and garden rain harvesting values (16% and 25% respectively proportional to fresh water) are based on estimated calculations. The diagram also figures out possible grey water usage potentials with other recycling options with their possible percentages.

Attempts by the authors to expand this deterministic quantification to full Monte Carlo simulation are ongoing. However, there are various challenges. An initial and unexpected one is that many of the building simulation weather files provided by sources such as the Energy-Plus weather data for Ankara seem to have missing or erroneous rainfall data. However, even without actual Monte Carlo simulations the simple example already shows that in order to design for NZWB:

- Water storage is crucial:
  Simple annual numbers do not cover the detailed matching of supply and demand. Dynamic, hourly analysis is required to analyse whether a building is actually nZWB throughout the year. This requires a new type of building water simulation not presently available.

- Work on the harvesting side:
  To create NZWB there is a need to design new and better roofs to collect water, and to find innovative ways of collecting rainfall that would not hit the roof but is near enough, collecting water from facades, outbuildings, pavements are the key concepts of harvesting.

- Redesign internal water flows:
  Further work needs to review and redirect internal water flows, taking into account the degradation from drinking water to grey water to black water.

- Water cleaning possibilities:
  Local building-integrated water micro cleaning plants are needed to restore water to a higher quality.

- Water use reduction:
  Efforts are also needed to find further ways to reduce water use, by using efficient appliances, timing, occupant training, right-sizing tanks and reservoirs, reducing pipe length.

Discussion and conclusion

This paper reports on efforts towards NZWB design and its quantification, with the intention to develop buildings that are more resilient towards changes in rainfall patterns due to climate change. It reviews the state-of-the-art in NZWB, noting that most definitions of the concept are aspirational rather than based on well-defined engineering calculation. The paper then develops a conceptual framework that allows to quantify water use and to identify which buildings qualify as NZWB. The proposed assessment framework includes not only urban scale but also building scale approach to water use balance and possible evaluation strategies depending on Monte Carlo analysis. Future work will include an initial simulation-based water performance assessment method and a monitoring campaign that can be used to validate quantification efforts.

The most critical discussion on the subject is the limitations imposed by weather conditions and roof size. NZWB may not be feasible everywhere and the benchmarks of feasibility should be determined by quantitative methods. There are also specific problems as the lack of an option to put water back into the grid, as one can do with energy. The relation between urban scale and building scale water balance is critical at that point. Future work needs to consider these circumstances while performing measurement and monitoring campaign. ■

References are included in the web version of this article rehva.eu/rehva-journal

Energy savings in hot water supply by legionella modelling

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Abstract

Legionella contamination in domestic hot water (DHW) systems can cause severe health problems and the actual concentration is often unknown. Prevention measures such as thermal disinfection are highly energy-demanding and hardly improved during the last decade. Within this study, we investigated the interplay between the risk of legionella on the one side and energy saving potential in a DHW supply system on the other side. A proper prediction of legionella concentration could enable both: targeted legionella risk management and reducing energy demand for legionella risk management. Therefore, a mathematical description for the legionella development was formulated. We established a MATLAB/Simulink model considering all components of a typical single-family house. The results support that legionella risk is mainly dependent on the hydraulic conditions (e.g. hot water storage volume, tapped water volume). Single households with hot water consumption of 50 ℓ/d (at 42°C) and 150 ℓ storage tank size remained below 100 CFU/100 mℓ. Thus, no prevention or counter measures were required and the energy demand for thermal disinfection could be saved completely. Simulations indicate that energy demand for DHW systems could be decreased by 62% by operating with disinfection-on-demand and replacing electric heating with a heat pump (tank size 300 ℓ and profile S). The integration of a UV light-emitting diode (UV-LED) technology reduced additional 6% of energy demand in our setup and could replace thermal disinfection completely in some cases. These results pave the way for alternative hot water supply components with a lower temperature level (e.g. heat pumps).

Introduction

Bacterial contamination of domestic water supply is one major reason for water related health risks (WHO, 2011). In particular, legionella pneumophila (legionella) is of key interest as causative agent for Legionellosis and Legionnaires' disease (WHO, 2007). Being present in natural water bodies, legionella can find favourable multiplication conditions in DHW systems such as beneficial temperature levels and water stagnation. A common threshold value for legionella in drinking water is 100 CFU/100 mℓ (DVGW, 2004; Lee et al., 2017; Van Kenhove et al., 2019). The detection of legionella is mainly based on grab samples, leaving a gap of unknown concentration between sampling due to the high dynamics of domestic hot water consumption. This leads to a potential risk of contamination within domestic infrastructure.

Hot water production and mainly legionella prevention in DHW are responsible for around 17% of total energy demand of German households (Eurostat, 2019). While energy consumption for room heating was reduced by 21% between 2010 and 2018, energy consumption for hot water production remained more or less the same in the last decade (Eurostat, 2019). Common disinfection strategies recommend a storage temperature of 55°C and a disinfection at 60°C (DVGW, 2004; Lee et al., 2017; Van Kenhove et al., 2019). Reducing disinfection demand and lower water temperatures would enable more energy-efficient operation with a heat pump (Hepbasli & Kalinci, 2009), but it is proposed that the potential risk of legionella becomes higher.

This study aims to challenge the trade-off between energy demand and sanitation. Furthermore, we investigate the potential risk of legionella for a typical DHW supply under different hydraulic conditions based on a simulation approach.

Building model

The simulations are performed using MATLAB/Simulink (Matlab R2017b, MathWorks, Natick, MA, USA). We used MATLAB to implement a typical DHW system including tapping locations at three different points: kitchen sink, washbasin and shower (**Figure 1**). The most important infrastructure data and assumptions are:

- pipe volume below 3 ℓ
- pipe inner diameter = 15 mm
- flow velocity 0.07 ℓ/s / 0.15 ℓ/s
- pipe material = polyethylene/aluminium/polyethylene
- conductivity of pipe insulation = 0.035 W/m K
- set room temperature of 20°C (kitchen) or 26°C (bath room)

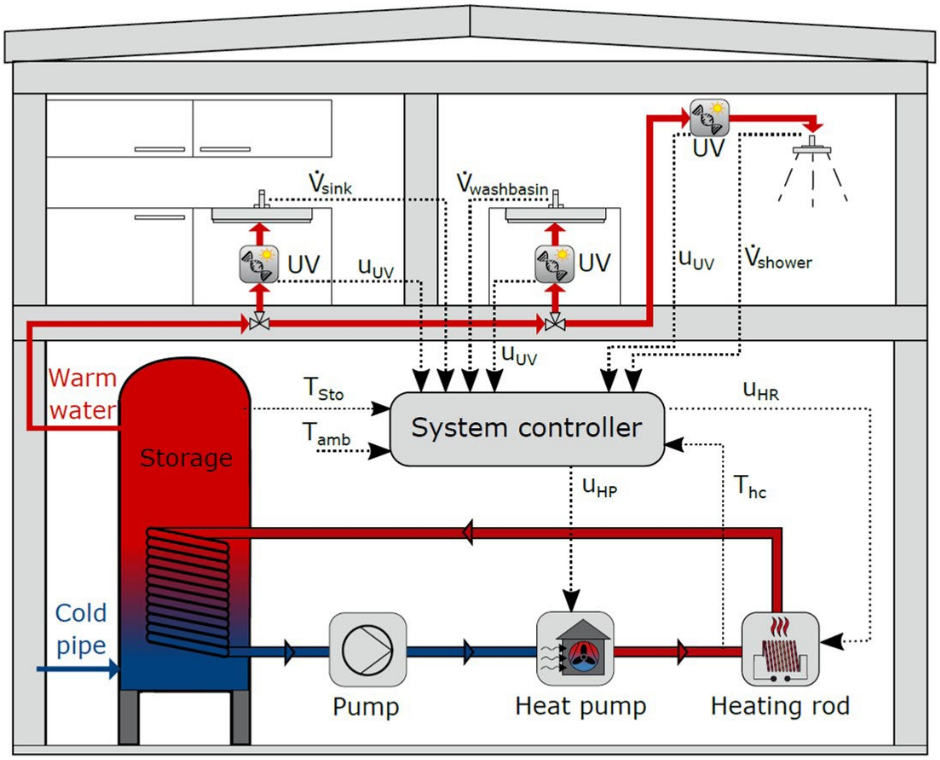

Figure 1. Modelled DHW supply system with key components including water storage, tapping locations, pipes, heat pump and UV LEDs.

We considered three tapping profiles to model the operating conditions: profile S (50ℓ/d at 42°C), profile M (150 ℓ/d at 42°C) and profile L (300 ℓ/day at 42°C) (DIN 16147).

Legionella model

The legionella concentration in the DHW system is predicted with a mathematical model integrated in the MATLAB/Simulink model. The model considers:

- temperature-related legionella growth and disinfection rate according to Brundrett (1992)
- detachment rates of biofilm from the pipe due to hydraulic conditions (Shen et al., 2015)
- UV disinfection rates according to Rattanakul et al. (2018).

During stagnation, the concentration of legionella in biofilm

X_b (or in water phase X_w) at time step t_i depends on the concentration of the previous time step t_{i-1}. Temperature-dependent growth or decay is expressed in $\mu(T)$ for a time step of size Δt.

$$X_b(t_i) = X_b(t_{i-1}) \cdot e^{\mu(T(t_i))\cdot\Delta t} \tag{1}$$

$$X_w(t_i) = X_w(t_{i-1}) \cdot e^{\mu(T(t_i))\cdot\Delta t} \tag{2}$$

In case of a tapping event, biofilm in detached from pipe walls and enters the water phase. The amount of legionella cells released into the water phase depends on the initial concentration in biofilm before tapping $X_{b,init}$ and the velocity-dependent detachment factor for this time step $\Delta k_d(t_{tap})$ adapted from Shen et al. (2015).

$$X_b(t_i) = X_b(t_{i-1}) - X_{b,init}(t_i) \cdot \Delta k_d(t_{tap}) \tag{3}$$

$$X_w(t_i) = \\ X_w(t_{i-1}) \cdot e^{\mu(T(t_i))\cdot\Delta t} + X_{b,init}(t_i) \cdot \Delta k_d(t_{tap}) \tag{4}$$

At the beginning of a tap event, detachment rates are higher than during subsequent time steps. Minimal legionella concentration in the water phase is set at 1 CFU/100 mℓ. To investigate the energy saving potential, thermal disinfection shall only be conducted if necessary. Disinfection cycles in this work are triggered on demand at a set threshold of 100 CFU/100 mℓ.

Simulation of legionella risk

The potential legionella risk in a DHW system mainly depends on the hydraulic conditions and the equilibrium between growth and detachment of legionella. Large daily water consumption profiles with a small water storage tank result in small water retention times and therefore small legionella concentration and vice versa. The simulation results indicate that the equilibrium legionella concentration depends on the sizes of storage tanks. Below a critical storage volume of 100 ℓ and a tapping profile S (or larger), the legionella concentration remains below the threshold without additional disinfection (**Figure 2**), because retention times in the DHW system are too short for notable growth.

However, the simulation shown above is only valid for continuous tapping. Legionella concentration in water and biofilm phase is investigated separately during a stagnation period of two weeks for profile S and a tank size of 300 ℓ (**Figure 3**). Before stagnation, the legionella concentration in biofilm remains at its minimum value, as the vast amount of biofilm has been detached from the pipe walls during tapping. During stagnation, highest concentrations up to 1000 CFU/100mℓ are predicted inside the washbasin and shower pipe. This effect results from higher room temperatures in the bathroom and concluding faster grow rates. Furthermore, the grey curve shows that every shower event detaches 65% of the legionella cells from the biofilm into the water phase. Directly after a stagnation period, more frequent disinfection cycles are needed until equilibrium concentration is reached again. The concentration inside the kitchen sink pipe remains continuously low, because room temperatures around 20°C do not favour legionella growth. However, results indicate that individual water consumption behaviour and the DHW setup have a big impact on legionella concentration.

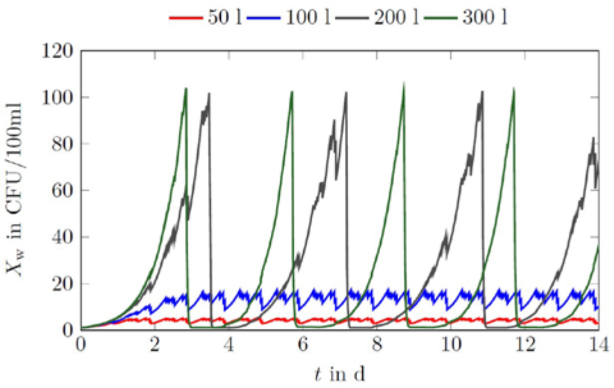

Figure 2. The effect of storage tank size on legionella concentration, considering user profile S.

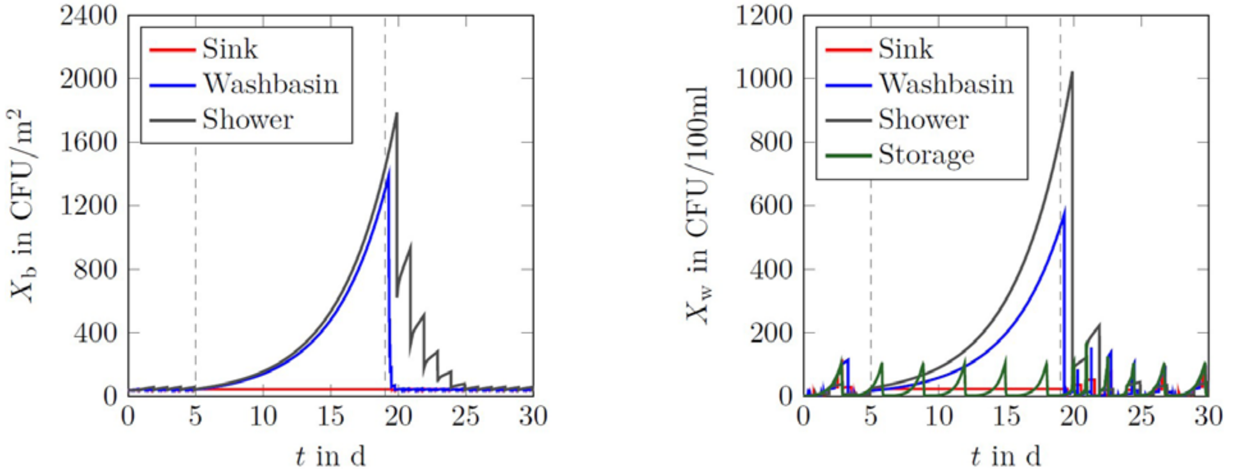

Figure 3. Legionella concentration during a stagnation of 14 days from day 5 to day 19 in biofilm (left) and water phase (right).

Energy saving potential in DHW

Thermal disinfection is currently the common strategy in DHW supplies with a recommended storage temperature of 55°C and disinfection temperature of 60°C (DVGW, 2004). The influence of hydraulic conditions (infrastructure, user´s behaviour) reveal that additional disinfection is redundant in many cases and therefore energy savings are possible. A "disinfection-on-demand" as described in the previous chapter enables energy saving while maintaining safe health conditions. Hence, water could be stored at low temperatures needed for consumption (around 42°C) and disinfection is only started if necessary.

With only few disinfection cycles necessary and operating at low temperatures, heat pumps are more efficient and energy can be saved. Operating at disinfection-on-demand and replacing electric heating with a heat pump, energy demand decreased 62% (tank size 300 ℓ and profile S).

Another possible technology for low energy hot water production is the implementation of UV-LEDs in DHW supply systems. Operating UV-LED modules with UV dose of 10 mJ/cm² at 280 nm, the UV-LED technology is able to reduce the actual legionella concentration around a factor of $2.5{\cdot}10^{-5}$, according to disinfection kinetics proposed by Rattanakul et al. (2018). Depending on the ratio of draw-off volume and storage tank volume, the legionella concentration reaches an equilibrium (**Figure** 4). In general, the risk of legionella increases with longer residence time of the water in the reservoir. In **Figure** 4, this corresponds to a larger tank volume and lower water consumption. Up to a tank volume of 150 ℓ and continuous tapping at profile S, M or L, no disinfection is needed according to our simulation. Operating at profile M or L, disinfection is redundant even to a storage size of 400 ℓ. Considering 160 ℓ as a typical water storage tank size for a single-family house, we assume that energy for disinfection purpose can be saved completely for single family homes (daily tapping assumed). Therefore, heat pumps can operate at low temperatures. Considering that 67% of the German building stock are single family houses (Statistisches Bundesamt, 2019), this would result in a significant decrease of total energy demand.

Simulation results support that legionella risk is relatively low for single-family houses compared to other building types such as multi-family homes, hospitals or hotels (Leoni, 2005; Borella 2004).

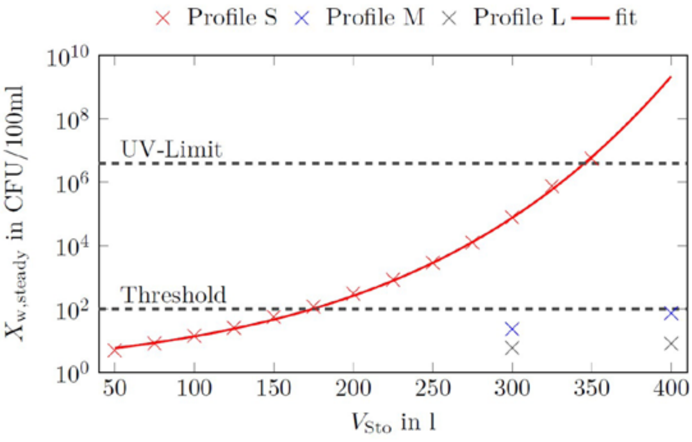

Figure 4. Legionella concentration equilibrium for different tapping profiles and storage tank sizes.

The following empiric equation approximates the red curve for tapping profile S described above. The equilibrium legionella concentration $X_{w,steady}$ is estimated depending on the storage volume V_{Sto}:

$$X_{w,steady}(V_{Sto}) = e^{800 \cdot e^{-\left(\frac{V_{Sto}-1560}{610}\right)^2}} \quad (5)$$

In some cases, thermal disinfection can be replaced by UV LED disinfection. Up to a tank size of 350 ℓ and a tapping profile of S or larger, hot water can be disinfected with UV LEDs without additional thermal disinfection (UV-Limit, **Figure** 4). Considering a heat pump and disinfection-on-demand, an energy saving of 6% is possible through the additional use of UV LEDs.

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Conclusions

In this study, we identified legionella-related health risk and energy saving potential for different DHW infrastructures and water consumption profiles. Hydraulic simulations imply that there is low legionella risk for family households and daily tapping of profile M or larger. We recommend storage volumes below 150 ℓ for single-person households (profile S) to minimize the stagnation in the storage. Operation of heat pump and disinfection-on-demand reduced energy demand around 62%.

In case of daily tapping the legionella concentration remains on an equilibrium state. This equilibrium concentration increases with higher storage volumes and decreases with larger consumption profiles. This relation is described with an equation to estimate the legionella risk. In the future, UV LED disinfection can replace thermal disinfection up to a storage volume of 325 ℓ for a single-person household (profile S), resulting in additional energy savings of 6%. ■

Acknowledgements

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Wastewater heat recovery systems:
a simple, cost-effective way to help meet the Renovation Wave energy saving and decarbonisation targets

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Introduction

According to the European Commission, buildings are responsible for approximately 40 percent of energy consumption and 36 percent of CO_2 emissions in the EU. Renovation and improved energy efficiency have the potential to lead to significant energy and CO_2 emission savings and the Commission's Renovation Wave strategy has set ambitious targets, requiring effective technical solutions.

Over recent years, the energy needed to produce hot water has become an ever-larger share of total household energy use due to the dramatic fall in energy required for domestic space heating. Every day, more than 22,000,000 m^3 of hot water are consumed by European homes alone. It is the main source of energy consumption for new housing, and yet 80 percent of this heat ends up in sewers and is wasted. Considering 80 percent of hot water is used in showers, harvesting heat from shower drains could be a simple way to save around 40 percent of energy and CO_2 emissions.

How Wastewater Heat Recovery (WWHR) Works

Principle

Most heat recovery systems have no moving parts and require no electricity to operate. A specifically engineered heat exchanger transfers heat energy from the waste hot shower water to the incoming fresh water supply, warming it from around 10 up to 30°C. When the cold water arrives at the mixing valve, it is much warmer, and therefore substantially less hot water is required from the water heater or solar array.

The shower is not only the application with the highest consumption of hot water, but also the place where heat exchange is easily possible. This is because a constant stream of warm wastewater flows downwards while a cold stream of fresh water flows upwards to the shower mixer. These two streams only need to be brought close together and massive energy savings can be achieved. In this case no storage and control system are necessary. A wastewater heat recovery system could effectively recapture and reuse instantly up to 70 percent of waste energy, reducing energy consumption in a cost-effective manner.

In addition, the shower water is relatively unpolluted, compared to other domestic wastewater from kitchen sinks, and is therefore also ideal for heat exchange. The recaptured heat from the shower might also be used to preheat the tank water.

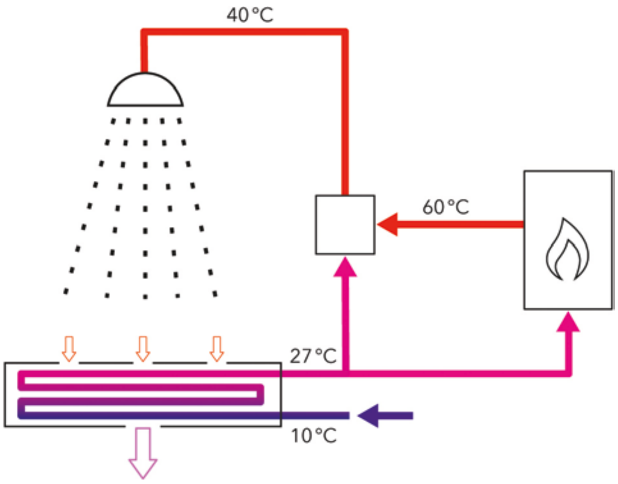


Figure 1. The preheated fresh water goes to a mixing valve or to a boiler/storage tank.

Efficiency
System efficiency varies by manufacturer and product. The lower the flow rate, the higher the efficiency, the higher the flow rate, the higher the performance. Efficiency, as a percentage of energy gained from drain water varies by system used, up to 70 percent.

Additional benefits of a WWHR system

1. The hot water preparation system can be designed smaller, reducing running costs.
2. Installed renewable systems (photovoltaic, solar thermal or heat pumps) can be downsized or energy generated redirected for uses other than for hot water.
3. Circular construction is supported as systems have a long lifespan and contain easy to recycle and highly recycled materials (copper, stainless steel).
4. The recovery and generation of energy adapt continuously and in real time with the usage, without over- or under-production (no storage and control system necessary)
5. Systems are hidden, either by integration into showers, or installation in ducts or technical rooms.

Market ready solution

Europe has the greatest technological lead in the world on this subject, with 326 patent applications since 2010, which is 70 percent of all patent applications in the world. Together, WWHR systems have already recovered 300 GWh corresponding to the annual domestic hot water consumption of 17,000 households. The most used system is the vertical pipe with more than 150,000 systems already installed in Europe.

WWHR systems can be used in single- and multi-family homes, and non-residential premises with higher hot water consumption: sports facilities, hairdressers, hotels, and swimming pools. Systems can be individual or collective, serving multiple showers or dwellings simultaneously. Due to ease of installation, they can be applied in renovations as well.

Recognition of WWHR in national building codes is growing. In France, the national energy efficiency standards, RT2012 and the forthcoming RE2020, acknowledge the contribution WWHR can make to targets for heat from renewables.

In the Netherlands, WWHR systems are included in the calculation software for new construction projects as they have a positive bearing on the energy performance of a building. This is the case for the existing EPC (energy performance coefficient) regulation. It will also be the case with the BENG (nearly energy neutral buildings) regulation that will come into effect on 01 January 2021.

In October 2019, the Ministry of Housing, Communities and Local Government (MHCLG) in the UK published a consultation on the Future Homes Standard, regarding changes to Part L of the Building Regulations for new dwellings. WWHRS

Figure 2. Horizontal type heat exchanger with efficiency around 50%.

Figure 3. Vertical type heat exchanger with efficiency 60–64%.

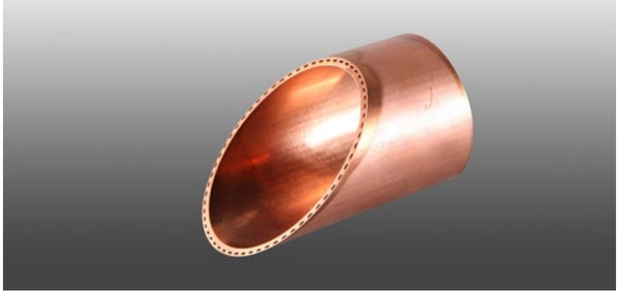


Figure 4. Double-walled tubes ensure safe and reliable separation of potable and grey water.

is widely recognised as one of the most cost-effective SAP-listed energy efficiency technologies available, and proposed changes to Part L in 2020 suggest WWHRS will have an even bigger impact under the new regulations.

Evaluation of WWHR potential for decarbonisation – household level

In calculations at household level energy consumption and emissions of shower systems depend on many variables, e.g. temperature of incoming cold, hot water and shower water used, shower time, fuel used to heat water (electricity, gas…) size/design of shower enclosure and flow rate.

Assumptions used in sample calculation:

Shower time:	9 min./shower
Cold water temperature:	10°C
Hot water temp. from the boiler:	60°C
Mixed shower water temp.:	38°C
Flow rate:	9.2 ℓ/min
Number of days:	365 (one shower/person/day)
Number of residents per home:	2.30
WWHR unit efficiency:	**56% (market average)**

CO_2 emission coefficient (based on Dutch standard NTA8800, "Energy performance of buildings – Determination method"):

Electricity:	0.34 kg/kWh
Gas:	0.183 kg/kWh

In this sample household, with deployment of an average efficiency WWHR system, 833 kWh electrical energy and associated 283 kg of CO_2 emissions can be saved, or consumption of 85 m^3 natural gas, equivalent to 153 kg CO_2 can be avoided.

37 percent of energy consumption and CO_2 emissions are avoided by deploying a WWHR system with an average efficiency (56 percent).

Return on Investment

Electricity and natural gas prices vary across Member States and there is a wide range of WWHR systems available on the market, so the exact return on investment needs to be calculated specifically for each project.

An average family can save around €50–150 annually on their hot water bill after deployment of a WWHR unit and this justifies the investment into this safe, energy efficient, environmentally friendly, simple, and easy to install, operate and maintain system with a long lifespan.

A 2030 WWHR Scenario – energy saving potential in 2030

In October 2020, the European Commission published its Renovation Wave Strategy to improve the energy performance of buildings. The Commission aims to at least double renovation rates in the next ten years and make sure renovations lead to higher energy and resource efficiency. By 2030, **35 million buildings could be renovated.** In our calculation we assume 82 percent of these are residential dwellings. In addition to this, by 2030 around **16 million new dwellings** will be completed in the EU.

In the **Table 2**, an annual energy saving for a "2030 WWHR scenario" is calculated for the year of 2030, assuming 50 percent of new built and energy renovated dwellings deploy WWHR systems by 2030.

Contribution to the Renovation Wave Strategy targets

The Commission has proposed in the Climate Target Plan 2030 to cut net greenhouse gas emissions in the EU by at least 55% by 2030 compared to 1990.

Table 1. *A sample calculation of annual energy consumptions and emissions of a shower with and without an average efficiency (56 percent) WWHR system.*

	Household Without WWHR		Household With WWHR		Household Saving with WWHR	
Hot water preparation	Energy demand per year	CO_2 emissions per year	Energy demand per year	CO_2 emissions per year	Energy saving per year	CO_2 emissions saving per year
Electricity	2,264 kWh	770 kg	1,430 kWh	486 kg	833 kWh	283 kg
Gas	231 m^3/year	414 kg	144 m^3/year	262 kg	85 m^3/year	153 kg

***Table 2.** 2030 WWHR scenario - energy saving potential in 2030.*

2030 WWHR scenario	**Renovated**	**Newly built**
Number of dwellings by 2030	28 700 000	16 000 000
2030 WWHR Scenario – number of dwellings by 2030 (50 percent of dwellings deploying WWHR)	14 350 000	8 000 000
Household annual energy saving (kWh/year) – See Table 1	800	800
Total annual energy savings in 2030 (TWh/year)	11.48	6.40
Grand total energy savings in 2030 (TWh/year)	17.88	
Grand total energy savings in 2030 (Mtoe/year)	1.54	

***Table 3.** Final energy consumption and GHG emission savings needed.*

2030 WWHR scenario	**Final Energy Consumption (Mtoe) −14% (2030 vs. 2015)**	**GHG (Mton CO_2-eq) −60% (2030 vs. 2015)**
2015	370	456
2030 (BSL scenario)	334	239
2030 Green Deal (REG scenario)	320	180
Savings needed	50	276

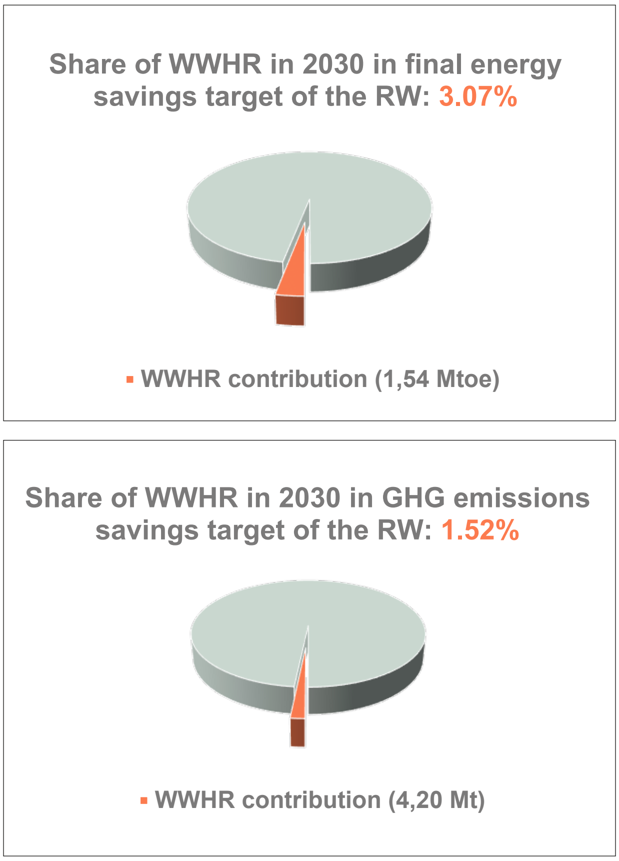


Figure 5. Contribution of WWHR 2030 scenario to the Renovation Wave Strategy targets.

According to the Renovation Wave Strategy, to achieve the 55% emission reduction target, by 2030 the EU should reduce buildings' greenhouse gas emissions by 60%, their final energy consumption by 14% and energy consumption for heating and cooling by 18% (compared to 2015).

Policy recognition needed for WWHR

The benefits of WWHR in buildings, while recognised in some national building codes, are not adequately acknowledged in EU legislation. This is despite re-use of produced energy having a high energy saving and decarbonisation potential for sanitary hot water preparation. Policy support is crucial to maximise the impact of WWHR systems we seek recognition in the EPBD of WWHR systems as energy from renewable sources and for their contribution in determination of primary energy use at building level to be taken into account. Inclusion of the WWHR technology in Renovation Wave induced policy tools, such as building renovation passport, minimum energy performance standards for existing buildings, the deep renovation standard, and minimum levels of renewables in buildings is also necessary. Member states should also include WWHR in their long-term renovation strategies. As far as energy labelling is concerned, WWHR should be considered in the package label for heating systems as a subsystem in the label, increasing overall system efficiency. ■

WWHR systems could make a significant contribution to the 2030 Renovation Wave targets by contributing 3.07 percent (1.54 Mtoe) towards the final energy savings target and 1.52 percent (4.20 Mt) towards the GHG emissions saving targets. This is based on the assumption that by 2030 half of the residential buildings targeted by the Renovation Wave strategy (14.35 million) and half of newly built dwellings (8 million) will deploy WWHR systems.

EPEE 20 years anniversary Interview

Jürgen Fischer

- In 2020, elected Chair of EPEE, the European Partnership for Energy and the Environment.
- Master's Degree in Economics
- In 2008, joined Danfoss as Vice President for Industrial Automation
- In 2010, became Senior Vice President for Automatic Controls and in 2013, appointed President of the Refrigeration and A/C Division
- Since 2015, has been President of Danfoss Cooling
- Member of SEforALL, a Global UN Panel for Cooling for All, and a member of the Advisory Board of TÜV SÜD Germany

Andrea Voigt

- In 2009, appointed Director General of EPEE
- Master in Public Administration, Master in linguistic science and a Marketing degree
- Over two decades of experience in the HVACR industry with a strong focus on energy efficiency and climate related topics
- Board member of the EU Coalition for Energy Savings, the Cool Coalition (UNEP), and the Global Panel on Access to Cooling (UN SEforALL)

1. Congratulations to the 20th anniversary. Tell us about the two decades history, how EPEE was created and how did it evolve to what it is today?

Andrea Voigt, EPEE Director General: Dear REHVA friends, thank you very much for your good wishes!

Yes, EPEE was founded 20 years ago, time flies! Back then, our association was a small coalition of a handful of companies focussing on the RoHS Directive and the first version of the F-Gas Regulation. EPEE members fought hard for the principles of leak tightness of HVACR equipment and certification of installers based on experience gathered from the Netherlands and it was considered a major success when these principles were enshrined in the first version of the F-Gas Regulation in 2006. Both of them are still essential pillars of the second version of the F-Gas Regulation, have set a precedent for other regions in the world such as Japan, and will certainly continue to play an important role in the third version of the F-Gas Regulation for which the review has just started.

Today, EPEE is much more than the small coalition it was back in 2000. We currently have over 50 members, uniting the leaders of our industry and truly representing the full value chain of the refrigeration, air-conditioning and heat pump sector. Our scope has broadened considerably, as we follow all major topics that are relevant for our members with a strong emphasis on energy efficiency in the broadest sense from products through to systems, indoor air quality, circular economy, etc. Being Brussels based, our focus obviously continues to be on Europe, where we are also a member of a number of important alliances such as the Coalition for Energy Savings which I am going to chair as of 2021. The latter is a cross-sectoral alliance of businesses, local authorities, cooperatives and civil society organisations striving to make energy efficiency and savings the first consideration of energy and economic policies in the EU. In addition to Europe, we have built up, over the past two decades, a strong network with friends across the globe. For example, we are a partner of the Cool Coalition which brings together key stakeholders from industry, civil society, academia and governments, we signed a Memorandum of Understanding with the United Nations Environment Programme (UNEP) and we are a member of the Global Panel on Access to Cooling of the Sustainable Energy For All Initiative.

2. What do you see as key technology trends for the HVCR-R industry in the coming decade?

Jürgen Fischer, EPEE Chairman: We believe that major trends in this coming decade will be energy efficiency coupled with GWP reduction of refrigerants, based on two major transitions: the refrigerant transition and the energy transition in the context of climate neutrality by 2050 under the European Green Deal.

In terms of the refrigerant transition, in Europe, the F-Gas Regulation drives the move towards lower GWP refrigerants and on a global level, it will be the Kigali Amendment to the Montreal Protocol which has already been ratified by over 100 countries. This means that besides lowering the GWP of refrigerants – whether by moving to lower GWP HFCs, HFOs or non-fluorinated alternatives – there will be a strong focus on reducing charge sizes, leak tightness, and also recycling and reclaim of refrigerants based on circularity principles.

In terms of the energy transition, heating and cooling have a key role to play as they consume roughly half of the total final energy in Europe with 80% still being based on fossil fuels, mainly for heating purposes. Sector coupling, in particular in view of the electrification of the heating sector, will therefore be essential. This means for example that technologies such as heat pumps, whether on-site or powering district heating and cooling networks will see significant growth. In parallel, the electricity mix will be increasingly based on renewables calling for systemic efficiency with solutions such as waste heat recovery, thermal storage and demand side flexibility for the grid to be able to handle fluctuating renewable energies and peak demand. In the same vein, it will be crucial to reduce the energy demand by looking at parameters such as maintenance and controls, informing and empowering consumers to intervene when systems are not running efficiently, etc. These are exciting times for our sector, with huge opportunities serving the energy and climate agenda while fostering sustainable growth.

3. Tell us about the Count on Cooling campaign

AV: We launched the Count on Cooling campaign at the beginning of the year – unfortunately not with the flagship event for which we had originally planned due to the COVID-19 crisis, but still with a very well attended online event. The objective of our campaign is threefold: One, it is to raise awareness about the crucial role of cooling for society, for a healthy and productive indoor climate, safe and fresh food, medicine and vaccines. In fact, when we designed the main messages of our campaign back in 2019, we did not suspect how much our sector would be in the spotlight with the need to keep vaccines refrigerated in light of the major pandemic which is currently overshadowing our life. Two, it is to demonstrate that cooling is part of the solution to achieve carbon neutrality by 2050, by taking an integrated approach with heating and supporting the phase-out of fossil fuels. And three, to explain our approach to sustainable cooling and showcase the solutions and technologies that are readily available for broad deployment.

In short, we have identified five major steps to provide sustainable cooling: Optimise the need for cooling, use energy and resources efficiently, mitigate the climate impact of refrigerants, shift to renewable energies and address the investment cost. More information about these steps can be found in our white paper, which is available for download and also summarised in a short video under www.countoncooling.eu. Over the course of the year, we presented our approach at numerous occasions, organised online events and prepared informative material. For next year, we will continue our activities and will be happy to cooperate with friends and partners such as REHVA to further spread the word on the importance of sustainable heating and cooling.

4. What are the most important climate & energy policy and regulatory issues for EPEE in this very busy and times with many important EU and global policies relevant for your sector?

AV: these are very busy times and as previously mentioned, they present a wealth of opportunities for our sector. But we need to make sure that our solutions are well understood by policy makers, that they get the attention they deserve and that synergies between different regulatory frameworks are well taken into account. This may sound very straight forward but as so often the devil is in the detail and the importance of associations such as EPEE and REHVA cannot be underestimated to make our voice heard loud and clear. The good news is that the European Green Deal has brought forward initiatives which break through the silo-thinking. The Energy System Integration Strategy and the Renovation Wave are good examples in that respect, as they take an integrated approach on different sectors, among others integrating buildings in the energy system. In that sense, and from a very broad perspective, it is important for EPEE members that energy efficiency is seen as an enabler for decarbonisation, helping to facilitate the move to renewable energies. More specifically, we are working on the Energy Efficiency Directive, the Energy Performance of Buildings Directive and the Renewable Energy Directive which will all be re-opened in view of achieving an increased greenhouse gas emission reduction target in 2030 and climate neutrality in 2050. Another top priority is of course the review of the F-Gas Regulation which has just started, alongside with various Ecodesign measures including those covering space heaters, professional refrigeration, and air heating and cooling products. Other important topics include the circular economy and energy taxation, to name only a few. On a global level, we will continue to closely follow the Kigali Amendment to the Montreal Protocol with its global phase-down of HFCs and the increased focus on energy efficiency. Again, it is important not to think in silos but to make sure that energy efficiency is not sacrificed when moving towards lower GWP refrigerants. In that context, we are partnering with UNEP and Gluckman Consulting, developing software tools that are intended to help governments model different scenarios and pathways towards achieving the HFC phase-down.

5. How do you think the covid-19 pandemic will change the HVAC-R industry and the EU association sector?

JF: The importance of Indoor Air Quality (IAQ) has been a topic in Europe for many years already, yet, it has always been lacking the political will to truly and broadly implement it with dedicated measures. With the pandemic, IAQ has suddenly gained much more attention. A safe and sound indoor environment is not seen any more as a "nice-to-have" but rather as a sine-qua-non condition for health and well-being. It is an essential parameter that can be delivered by heating and cooling equipment and, with well-insulated buildings driven by energy efficiency requirements, it will become even more important and qualify our industry's technologies as win-win solutions that do not only deliver energy savings and enable the phase-out of fossil fuels but also contribute to the health of people. We may imagine that building automation controls combined with sensor technologies will play an important role in that respect, too, measuring key parameters in terms of occupancy, air quality, and also safety as more and more flammable refrigerants will be used in heat pumps, etc.

AV: As the different facets of our sector come closer together with heating and cooling being increasingly seen as two sides of the same coin, for example via waste heat recovery from cooling equipment used for heating purposes, or via heat pumps that can provide both, heating and cooling, or with ventilation being increasingly required alongside heating and cooling, we may also see closer cooperation or perhaps, in the medium term, even consolidation in the association landscape. Today, we have associations for all individual sectors, for heating, for cooling, for ventilation, for heat pumps. Perhaps, we will see some of them grow together or at least form closer alliances than has been the case in the past. These developments would be mainly triggered by the political context, in my view. In addition, the pandemic may require some companies to re-evaluate which associations they support with their human and financial resources. This may further drive consolidation in the association landscape. Time will tell how this will evolve, I guess.

6. EPEE has been an active REHVA supporter for a decade. How do you see the role of REHVA and our cooperation?

AV: I think our associations are very complementary, both in terms of activities and in terms of membership. Where EPEE's focus has always been more on the policy side, I have always considered REHVA's focus more on the technical and standardisation side of things. EPEE's members are companies whereas REHVA's members are individuals (via national associations). EPEE has a strong focus on refrigeration, air-conditioning and heat pumps, whilst REHVA also concentrates on ventilation. The beauty is that despite these different focus areas and set-up, we have many common interests from indoor air quality through to energy efficiency in buildings. That makes us strong allies and partners and for the future, given the many challenges and opportunities that our sector will be facing, I would very much wish that we can continue to build on our good relationship and further strengthen it. Looking forward to the next decade! ■

Granlund 60 years anniversary Interview

Jukka Vasara

- Appointed Granlund Vice-President in 2018
- M.Sc. in Mechanical Engineering from the Helsinki University of Technology
- In 1989, became Managing Director at Granlund Kuopio
- Over three decades of experience with focus on Hospitals, Clean rooms, Building Energy Saving and Air Conditioning
- Committee member of ISO/TC 209, CEN/TC 243 and CEN/TC 156 WG 18

1. Congratulations for the 60th anniversary of Granlund! Tell us about the history of the company, how did it start and developed to what it is today. What are the key values that drive the company?

Jukka Vasara, Granlund Vice-President: Olof Granlund and Antti Oksanen founded the company in Helsinki in 1960. Since that the company has grown over the decades from a Helsinki-based HVAC engineering office to a real estate and construction expert group operating throughout Finland and abroad.

In the early 1960s, HVAC technology developed rapidly with the intensification of construction activities after the post-war period of scarcity. Olof and Antti saw the potential of the design business, joined forces and experience, and set up an office with seven employees in the beginning.

Today we have over 1,000 customers in 30 countries and employ over 1 000 professionals. We aim to be a workplace that boosts motivation, offers opportunities, and helps people to develop. We value **diverse expertise,** and our workplace atmosphere is based on mutual respect.

2. I assume COVID-19 also disrupted the anniversary celebrations. How do you plan to commemorate this milestone?

JV: Granlund's anniversary year has been exceptional worldwide. Due to the corona pandemic, the festivities will move to post-corona time.

We were supposed to have a big party in honour of the 60-years, but the party had to be cancelled due to the corona pandemic. We decided to postpone the celebrations until next year when the situation is hopefully better.

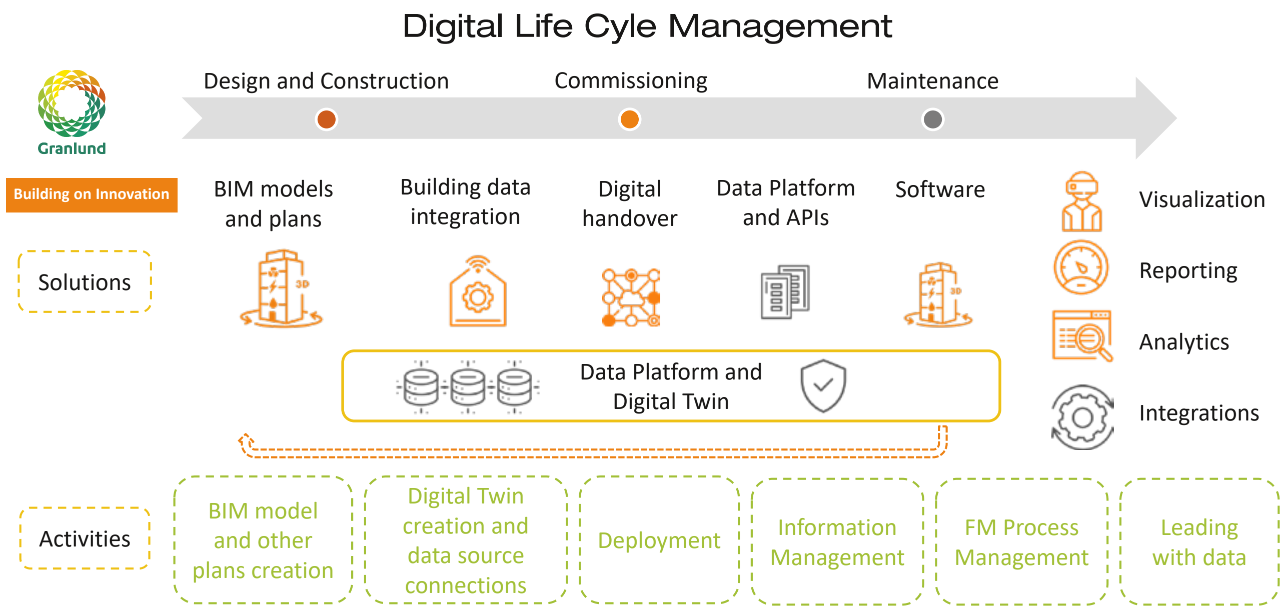
3. What are the most important technology and market trends that will influence Granlund and the real estate & construction industry sector? Where do you see Granlund in 10 years?

JV: Granlund has grown throughout its history, but the growth has accelerated massively in recent years. Last year's turnover was just over 91 M€ and the aim is to double the turnover within the next five years.

Our key goal is to make properties more functional and smarter and to improve human well-being in the built environment. Our areas of expertise include technical building services design, property, energy and environmental consultation, software and renovation.

Granlund intends to strongly expand in service expertise: we will take on an even bigger role in the service management and energy efficiency in properties, the quality of indoor conditions and the functionality of technology.

Granlund's growth strategy in 2016–2020 focused on promoting well-being, user orientation and new solutions. The strategy has realised very well as planned. Granlund focuses on its strengths, namely on technical building services design, property and energy consulting



and real estate management software. Also, renovations planning, building development and digital property services have emerged alongside. During the next strategy period, responsibility and productivity will be emphasised in our own and our client's operations. We want to contribute to raise our industry to a new level regarding both of these areas. Success also means strong development of customer orientation and quality.

4. High performing, low carbon buildings – compliant with European regulatory trends – need a holistic approach, considering the entire building life cycle from design till operation. Digitalisation is key in this context. What is your take on this? Which innovations and solutions can Granlund offer for transforming the building sector?

JV: We promote energy and environmental responsibility in the society through properties. Energy efficiency, carbon footprint reduction and environmental responsibility are crucial aspects in all of our design, renovation and consulting projects. In addition, our software, Granlund Manager provides state-of-the-art technology that generates energy savings. We want to be an impartial expert partner to our customers and participate in joint efforts to build a better tomorrow. Therefore, we commit in making objective decisions according to sustainability principles. For us, quality control means first and foremost responsibility for our actions.

Our success is based on active development and innovation. We constantly seek, develop and test new procedures, software, and service. We are on the frontline of deploying advanced digital tools and operating models, such as virtual technologies, the Big Room, Lean and BIM models. Each year, we invest approximately 6–8 per cent of consolidated net sales in research and development. Our goal is to develop sustainability technologies and new ways to manage information in order to serve the users of properties even better. A good example is the digital twin that will transform property maintenance and services.

5. The EU launched a Renovation wave strategy aiming to double the annual renovation of buildings by 2050. Do you follow these policy trends? What do you see as challenges when it comes to building renovation?

JV: Granlund is actively following EU policies on energy and renovation areas. In fact, we have been developing and implementing EU policies together with other European organisations in several R&D projects, e.g. latest under Horizon 2020 program.

It would be important for these renovation projects to focus on energy-saving solutions. According to Granlund's experience, the biggest savings for society will be achieved when HVAC and automation systems are renovated in accordance with modern technology.

Repairing buildings is always more challenging than building new constructions. However, it is important to find solutions that can achieve good indoor air and energy savings.

6. Granlund has been a valued REHVA supporter for a decade. What do you consider as important values of REHVA as supporter? How can REHVA support our industry sector better?

JV: In my opinion, REHVA's most important tasks are to raise the profile of the MEP services industry at EU level and to harmonize practices. One great example of REHVA's operations has been the guidelines in the Covid-19 pandemic for HVAC systems. ■

REHVA Brussels Summit 2020

REHVA organized the fourth, very successful edition of its Brussels Summit on 3–6 November 2020. This exceptional online event brought together HVAC experts from REHVA Member Associations, Supporter Companies and global MoU Partners with EU stakeholders involved in the building sector. The internal meetings along the whole week were complemented by a high-level online conference that consisted of a technical seminar on COVID-19 and an EU policy session on the Renovation wave. The two sessions attracted a record number of over 500 participants.

Author: **ANITA DERJANECZ**, REHVA Managing Director

REHVA Committee Meetings

The REHVA committee meetings and the plenary meeting of Member Associations took place online along the whole week. They discussed the COVID-19 guidance and a range of ideas on future activities, including new Task Forces and how to develop knowledge dissemination and REHVA products to increase the visibility of REHVA. The Technology & Research Committee re-elected **Jarek Kurnitski** as Chair, and elected 2 co-chairs: **Guangyu Cao** (NORVAC, Norway) and **Ilinca Nastase** (AIIR, Romania). The Publishing and Marketing Committee meeting discussed new publications and how to boost digital knowledge dissemination, followed by presentations by the staff on sales and online marketing performance. In the Education Committee participants shared ideas on how to organise the REHVA Student Competition, which has to be organised online in January 2021 due to the pandemic, followed by an equally online World Student Competition. Participants learned also about the first experience and future development of the ongoing REHVA COVID-19 Course.

Technical Seminar on “Impact of COVID-19 on HVAC and building operation”

LIDIA MORAWSKA
Queensland University of Technology

JAREK KURNITSKI
REHVA

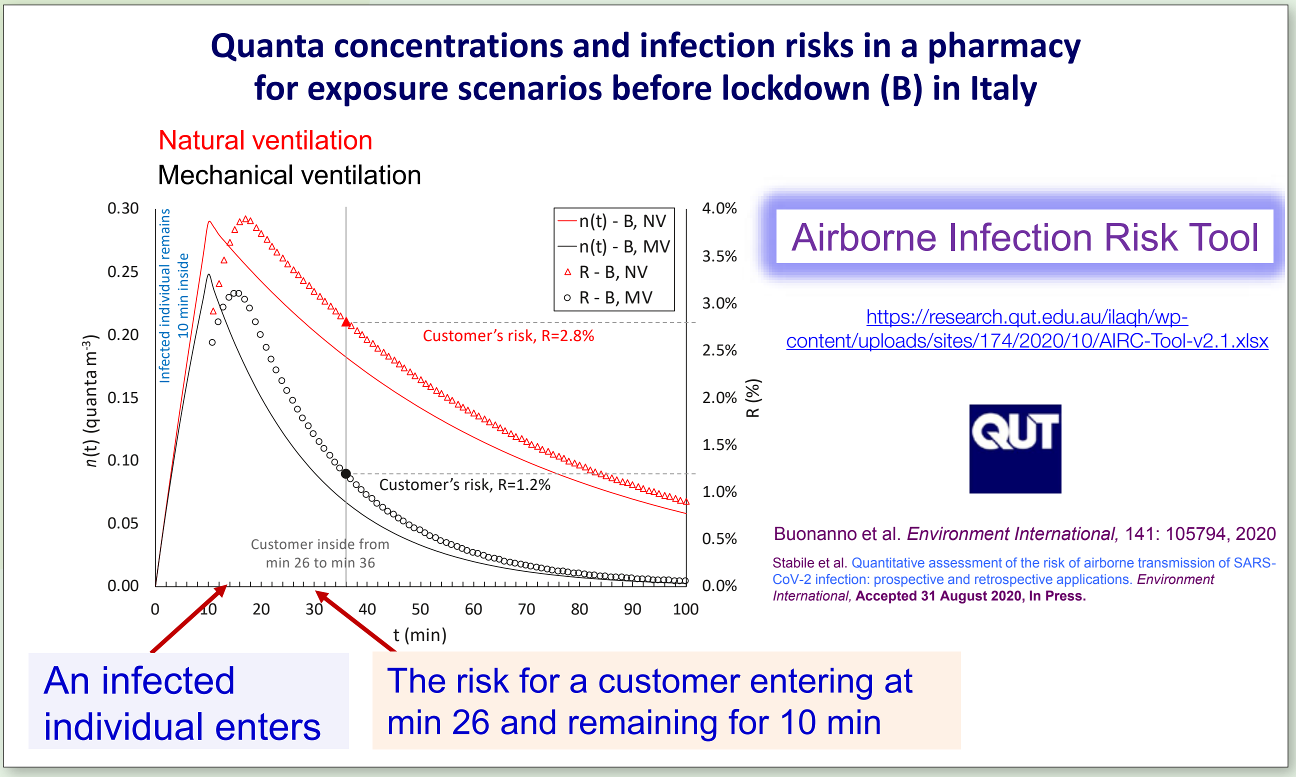
HYWEL DAVIES
CIBSE

ATZE BOERSTRA
REHVA

TARJA TAKKI-HALTTUNEN
Halton Group

The Technical Seminar on the impact of COVID-19 on the building operations opened by REHVA’s President **Frank Hovorka**, discussed solutions in the HVAC and building sector facing the unprecedented challenge of the current pandemic. Experienced speakers covered research, good practices and innovations that emerged from the crisis.

Lidia Morawska, director of the International Laboratory for Air Quality and Health in Queensland University of Technology and director of the WHO Collaborating Centre for Air Pollution and Health gave a keynote lecture with the title “*Buildings and Us: what we learned from COVID-19 and what will change*”. Prof. Morawska presented case studies on airborne transmission from scientific papers showing the importance of ventilation in the case of Sars-Cov-2.



Quanta concentrations and infection risks in a pharmacy for exposure scenarios before lockdown (B) in Italy

Natural ventilation
Mechanical ventilation

An infected individual enters

The risk for a customer entering at min 26 and remaining for 10 min

Airborne Infection Risk Tool

https://research.qut.edu.au/ilaqh/wp-content/uploads/sites/174/2020/10/AIRC-Tool-v2.1.xlsx

QUT

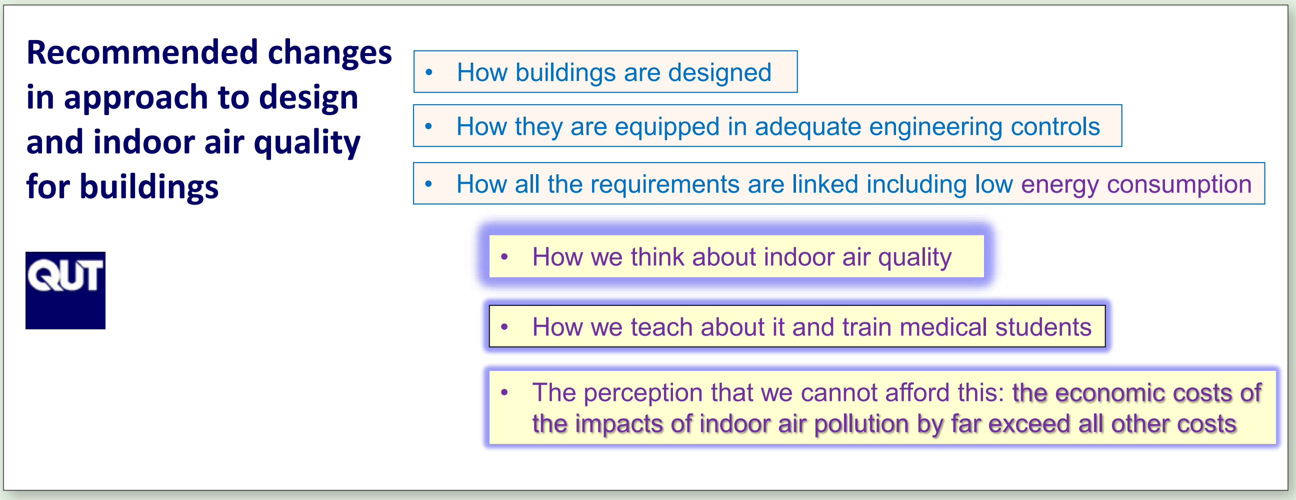
Buonanno et al. *Environment International,* 141: 105794, 2020

Stabile et al. Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: prospective and retrospective applications. *Environment International,* **Accepted 31 August 2020, In Press.**

© Slide from Lidia Morawska’s presentation

She underlined that the airborne transmission of COVID-19 has emerged as the most significant mode in typical building settings, which can't be tackled with the current energy-demand focused building regulations and practice, such as sealing up buildings from outdoor air and recirculate indoor air. She reminded on long-existing research data about the impact of IAQ on infectious respiratory diseases and health, as well as on the macroeconomic costs of infectious respiratory diseases demonstrated at a massive scale by the current pandemic. She stressed the need to apply the science on airborne transmission in developing adequate guidelines for building design and operation with advanced engineering controls. She highlighted that we need increased awareness of the importance of IAQ and a paradigm shift in interpreting and displaying sensor data in a way that it enables building occupants to understand and act on indoor environment quality. She closed her presentation by reminding us that all global pandemics in history have transformed humanity, hoping that this time it may transform buildings to provide humans with healthy and safe indoor environments.

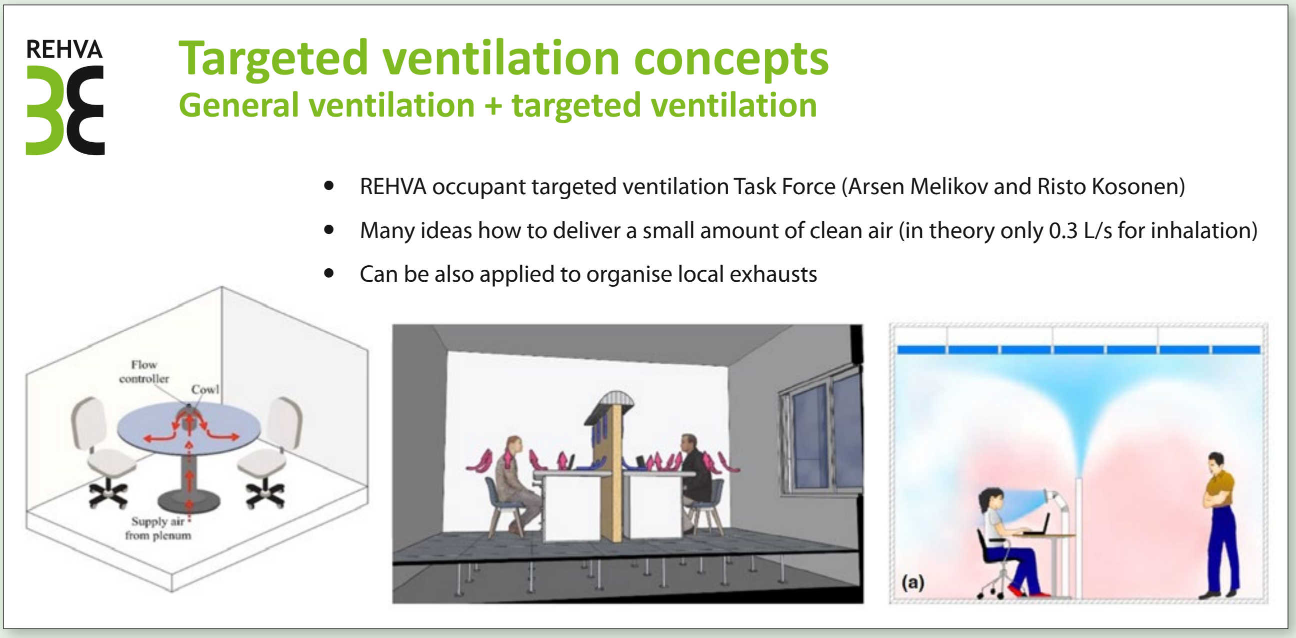
Jarek Kurnitski, chair of REHVA TRC and COVID-19 task force talked about "*HVAC research & technology trends emerging after the COVID-19 pandemic*". He presented main parameters to estimate the individual risk of infection in public buildings, providing some insights on REHVA's calculation tool that could assist on evaluating the viral transmission risk in different room settings. He reminded the main recommendation of REHVA's COVID-19 guidance, stating that in buildings with no mechanical ventilation, the use of openable windows and the installation of CÒ$_2$ sensors are recommended. Yet, regardless of the presence of mechanical ventilation, improvements on the indoor environment could be implemented with the installation of targeted ventilation solutions, by delivering small amount of fresh



Recommended changes in approach to design and indoor air quality for buildings

- How buildings are designed
- How they are equipped in adequate engineering controls
- How all the requirements are linked including low energy consumption
- How we think about indoor air quality
- How we teach about it and train medical students
- The perception that we cannot afford this: the economic costs of the impacts of indoor air pollution by far exceed all other costs

© Slide from Lidia Morawska's presentation



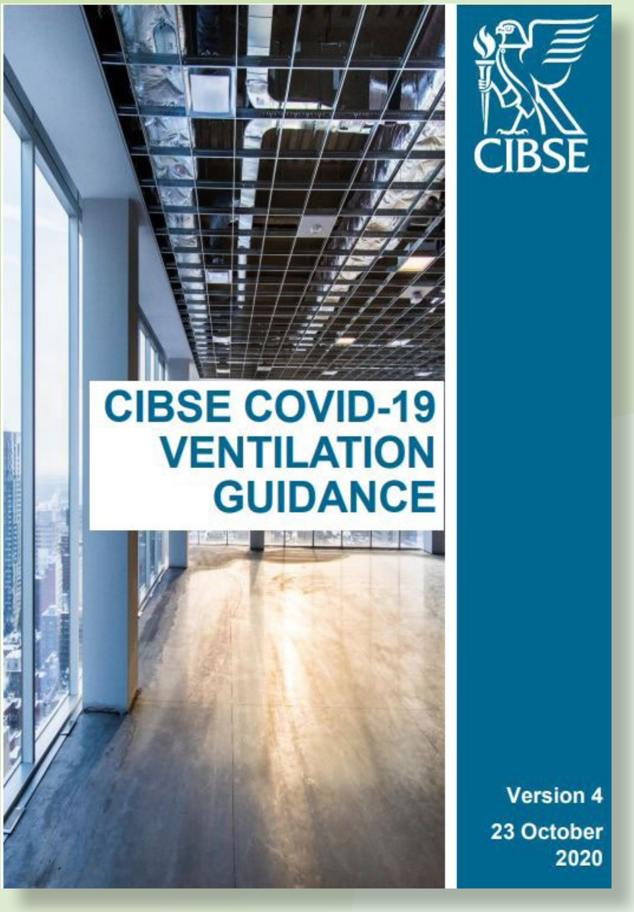
REHVA

Targeted ventilation concepts

General ventilation + targeted ventilation

- REHVA occupant targeted ventilation Task Force (Arsen Melikov and Risto Kosonen)
- Many ideas how to deliver a small amount of clean air (in theory only 0.3 L/s for inhalation)
- Can be also applied to organise local exhausts

© Slide from Jarek Kurnitski's presentation air on occupants' breathing zone. The application of such solutions could be particularly effective in indoor spaces with fixed seats, such as public transport and airplanes, having a vital role on controlling the spread of the virus. This topic is currently under analysis by a TRC task force. Conclusion remarks indicated a need for revising and updating current buildings codes and standards to make buildings future-proof against viral outbreaks, underlining that more investments for implementing practical solutions are vital to achieving this goal.

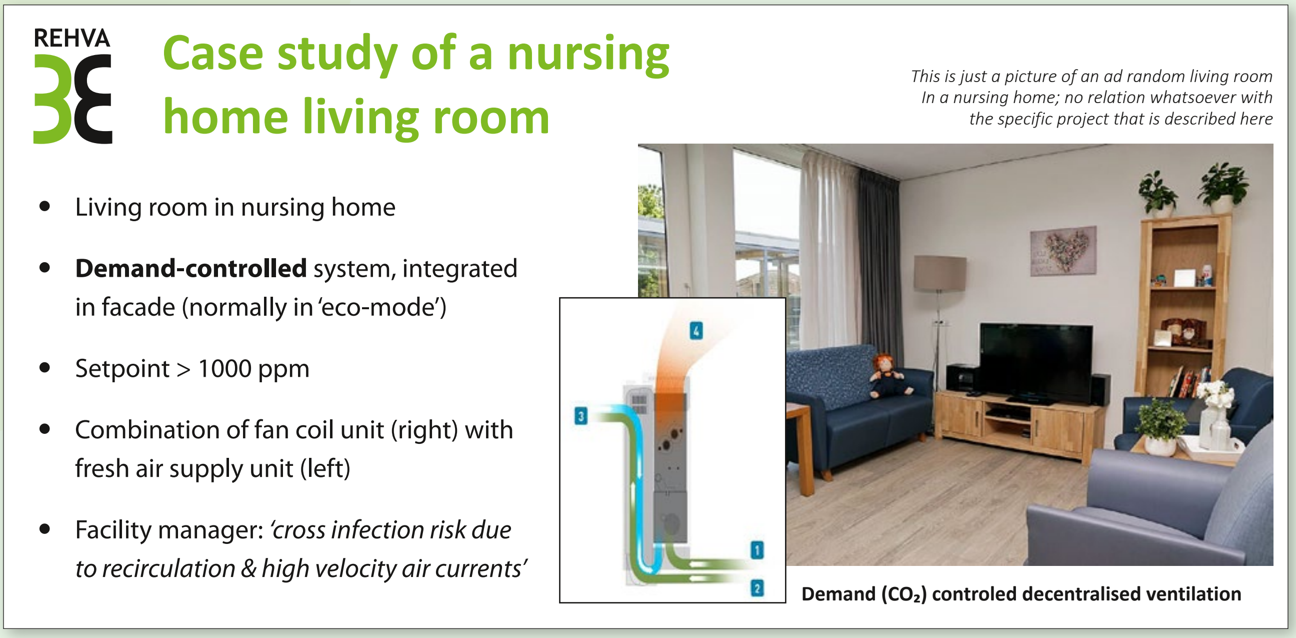

CIBSE

CIBSE COVID-19
VENTILATION
GUIDANCE

Version 4
23 October
2020

Hywel Davies, Technical Director at CIBSE presented *"Safely re-occupy and use buildings during the pandemic"*, introducing some necessary actions and guidelines that should be considered before buildings are occupied again after the pandemic. He highlighted that a risk assessment is an important part in this direction and measures should be tailor-made for each space, based on parameters such as ventilation, occupancy time and user behaviour. Where natural ventilation is used, he recommended to open ventilators or windows as much as possible without at the same time compromising thermal comfort. He concluded that while measures to reduce infection risk are important, they should be based on occupants' needs, stating that user-centred measures are the only way forward if we want them to be effective.

Atze Boerstra REHVA's Vice President focused on *"COVID-19 guidance & case studies for specific space types"*. Common findings from viral infection cases in different types of indoor spaces indicate the absence of adequate ventilation rates, where in some cases long occupancy times in conjunction with small room size can contribute to higher infection risk. He clarified that high fresh-air supply rates - in relation to room volume and number of occupants – are crucial to decreasing the infection risk, recommending the installation of IAQ monitors (CO$_2$ traffic lights) that can warn occupants when a room is under-ventilated and hence more prone to facilitate a possible infection.


REHVA

Case study of a nursing home living room

This is just a picture of an ad random living room In a nursing home; no relation whatsoever with the specific project that is described here

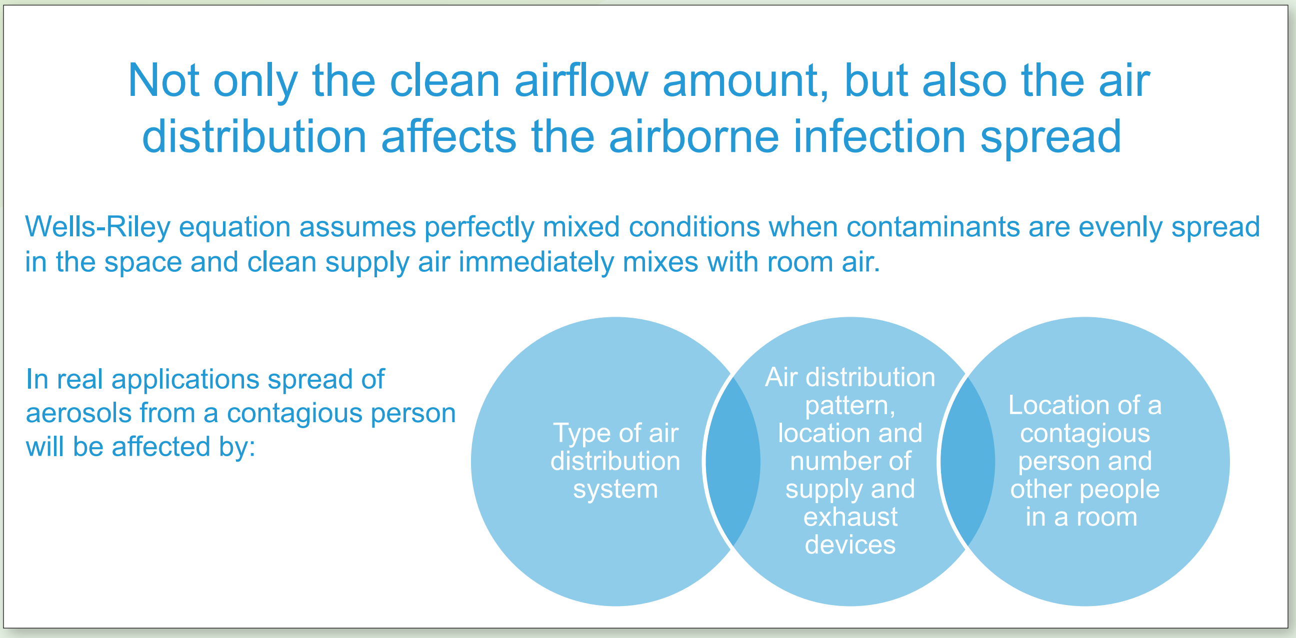
- Living room in nursing home
- **Demand-controlled** system, integrated in facade (normally in 'eco-mode')
- Setpoint > 1000 ppm
- Combination of fan coil unit (right) with fresh air supply unit (left)
- Facility manager: *'cross infection risk due to recirculation & high velocity air currents'*

Demand (CO$_2$) controled decentralised ventilation

© Slide from Atze Boerstra's presentation

Tarja Takki-Halttunen, Co-owner and Vice Chair of Halton Group rounded up the seminar with her presentation on *“HVAC solutions & innovation for safe indoor environment in a pandemic”* covering risk assessment using case study examples. She elucidated the role of the different ventilation patterns and their possible impact on reducing infection risk. Tarja gave an overview of existing tailored ventilation, air distribution and air treatment solutions that became important in the pandemic. She highlighted a use case demonstrating how displacement ventilation provides better IAQ in a classroom setting compared to mixing ventilation and might be a better choice if airborne transmission is a concern. She tackled new and emerging solutions that need to be evaluated in terms of effectiveness and safety and concluded with a positive remark about an ongoing technological development that would enable the real time detection of airborne viral particles.

The Technical Seminar ended with a Q&A session between speakers and attendees moderated by Atze Boerstra, REHVA Vice President.



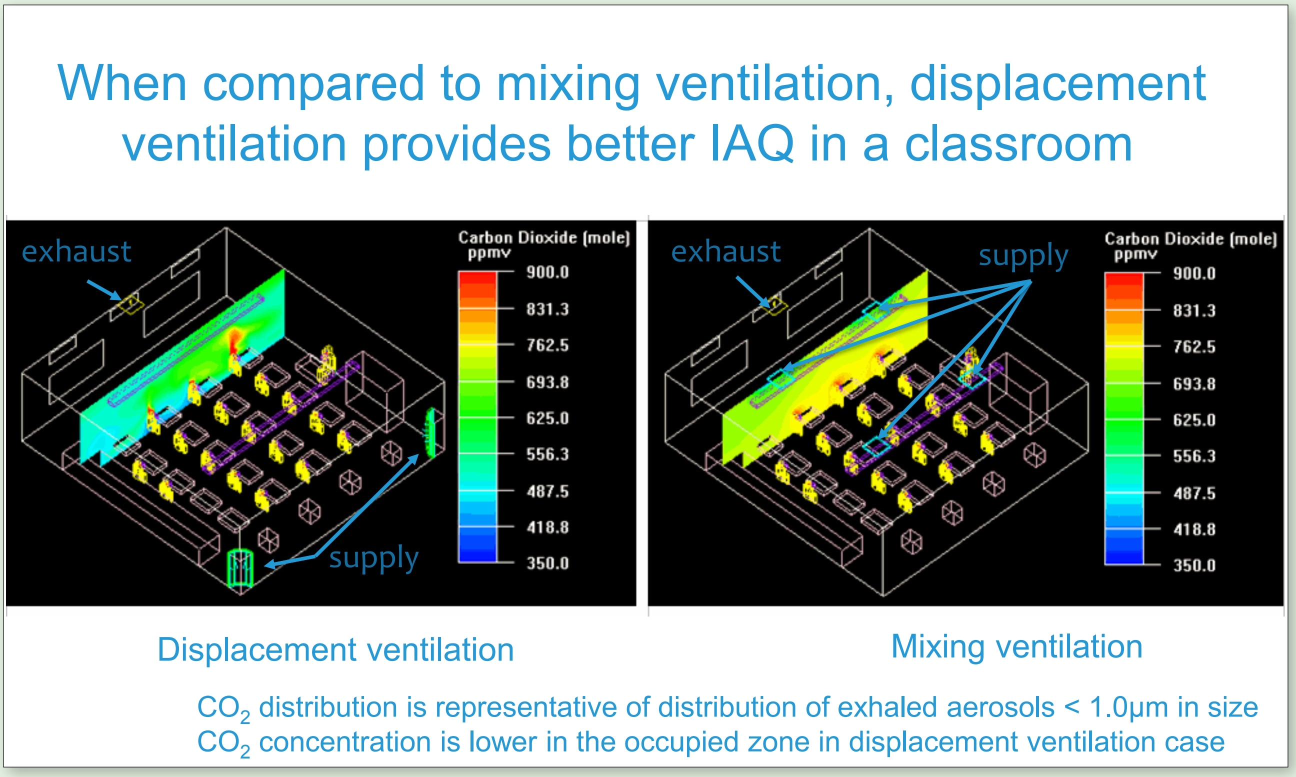
Not only the clean airflow amount, but also the air distribution affects the airborne infection spread

Wells-Riley equation assumes perfectly mixed conditions when contaminants are evenly spread in the space and clean supply air immediately mixes with room air.

In real applications spread of aerosols from a contagious person will be affected by:

- Type of air distribution system
- Air distribution pattern, location and number of supply and exhaust devices
- Location of a contagious person and other people in a room

© Slide from Tarja Takki-Halttunen's presentation



When compared to mixing ventilation, displacement ventilation provides better IAQ in a classroom

Displacement ventilation

Mixing ventilation

CO_2 distribution is representative of distribution of exhaled aerosols < 1.0µm in size

CO_2 concentration is lower in the occupied zone in displacement ventilation case

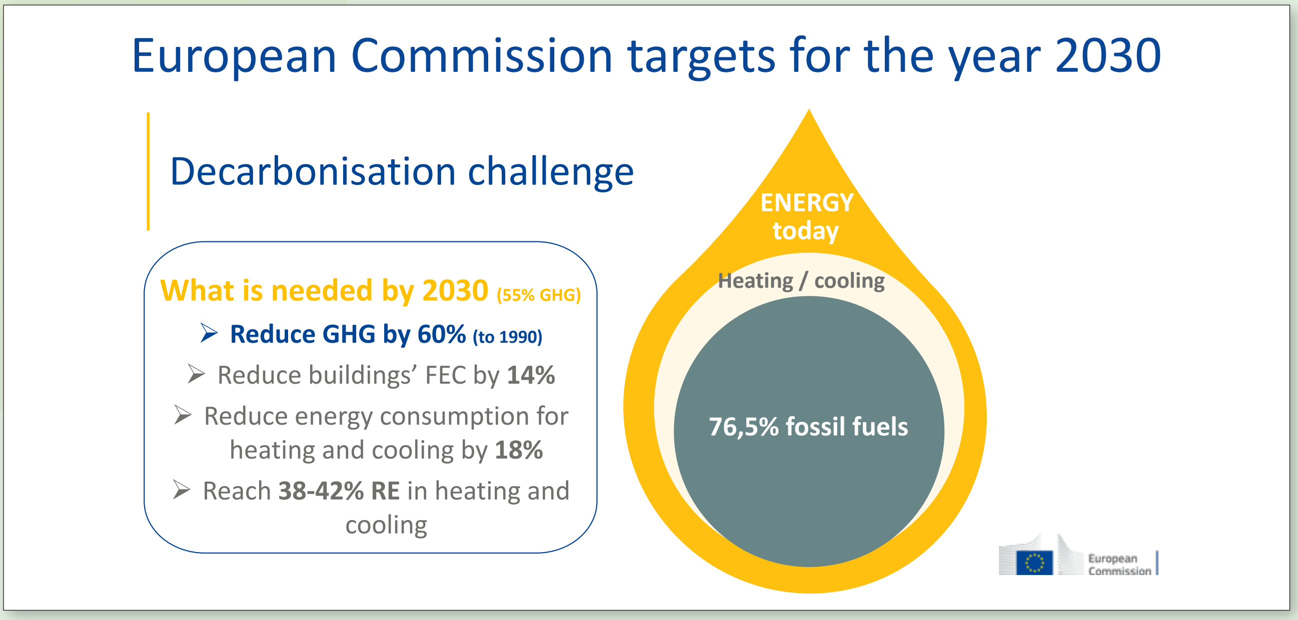
© Slide from Tarja Takki-Halttunen's presentation

Policy Conference on “Renovation wave to deliver healthy buildings in the post COVID-19 Europe”

The policy conference brought together high-level representatives from EU institutions, NGOs and think tanks to share perspectives on the Renovation wave strategy and its implementation.

Stefan Moser, Head of Unit - Energy Efficiency: Buildings and Products at DG ENER from the European Commission opened the late morning session presenting the “*Renovation Wave on the Commission's agenda*”. He highlighted that the key objectives of the Renovation Wave initiative are to improve the environment by bringing energy consumption down, stimulate job creation within the construction sector and improve health and lives in general by upgrading the infrastructure. The Renovation Wave aims at doubling the current 1% deep energy renovation rate of the EU building stock, resulting in the retrofit of up to 35 million building units.

This is an efficiency and decarbonisation challenge at the same time, the objectives in the next 10 years are to reduce the energy consumption in heating and cooling by 18% while increasing the share of renewables to 38-42%, in order to decrease the total energy demand of buildings by 18% and the total CO_2 emissions by 60%. When talking about the actions to remove



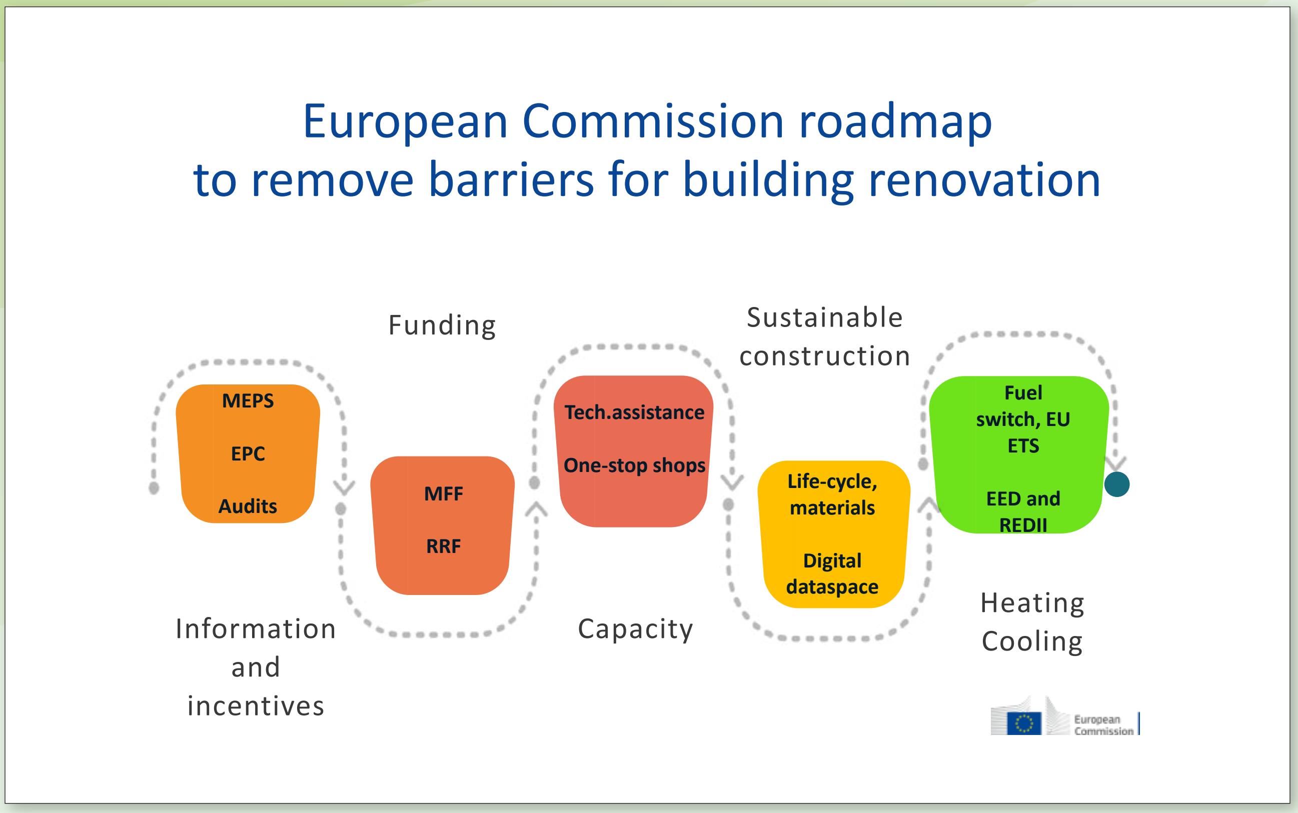
European Commission targets for the year 2030

Decarbonisation challenge

What is needed by 2030 (55% GHG)

- ➢ **Reduce GHG by 60%** (to 1990)
- ➢ Reduce buildings' FEC by **14%**
- ➢ Reduce energy consumption for heating and cooling by **18%**
- ➢ Reach **38-42% RE** in heating and cooling

© Slide from Stefan Moser's presentation



European Commission roadmap
to remove barriers for building renovation

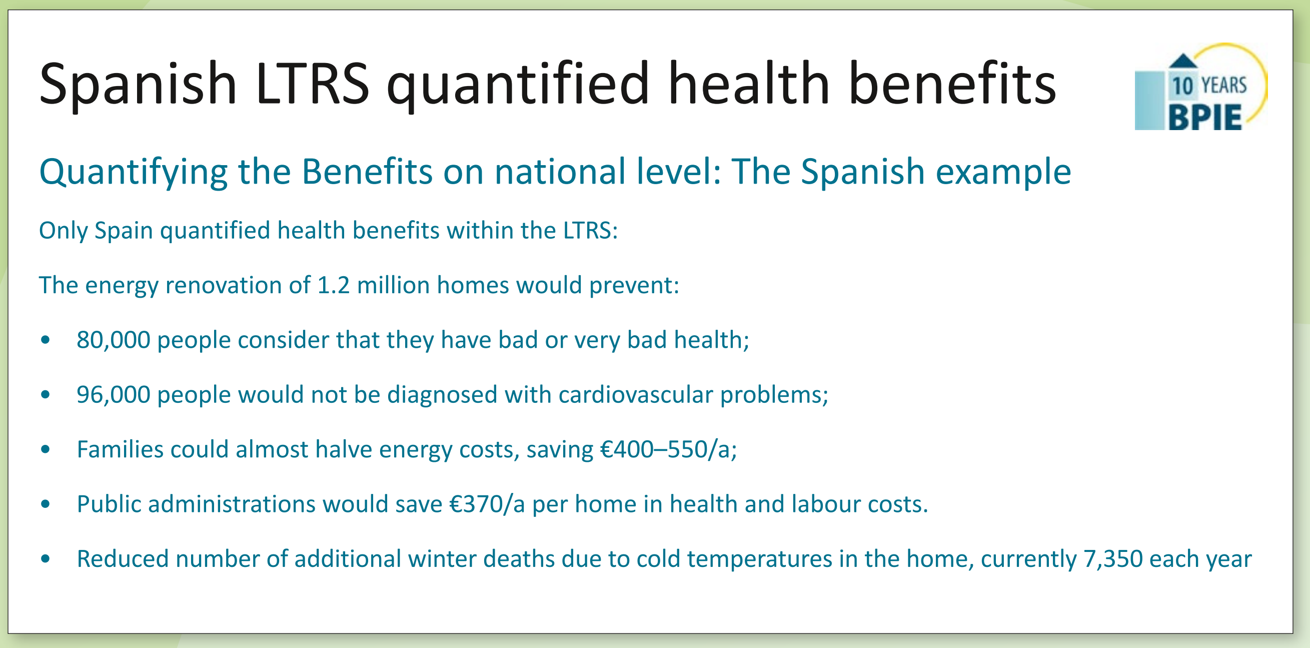
© Slide from Stefan Moser's presentation

barriers of building renovation, he emphasized the importance of information (e.g. improved Energy Performance Certificates), funding (e.g. Recovery & Resilience Fund), capacity (e.g. one-stop shops to streamline information) and sustainable construction (e.g. promoting smart tools).

Miapetra Kumpula-Natri, Finnish MEP (S&D) has been involved as rapporteur in the ITRE report on Increasing the energy efficiency potential of the European building stock (Cuffe report) targeting the Renovation Wave. In her speech on "*Building renovation policies and indoor environmental quality*" she went deeper into the question to how the EU can support the local level to stimulate renovations. She mentioned that member states have not been active enough in developing their long-term renovation strategies and the European Commission should support and ensure the ambitious implementation of the EPBD and other legislation. She highlighted the indoor environment quality related points of the Cuffe report, which promote healthy buildings and the ultimate need to improve indoor climate quality with energy renovation and calls for increased indoor air quality standards. She expressed the strong hope and wis of the European Parliament that European Commission will consider these recommendations in the future policy developments.

Oliver Rapf, executive director of Buildings Performance Institute Europe (BPIE), the influential Brussels-based think tank celebrating its 10th anniversary this year, presented their recently published analysis of national long-term renovation strategies, focusing on the question how they perform in tackling indoor environment quality. The presentation "*Healthy Buildings in the 2020 national Long-term Renovation Strategies* looked at the plans of Spain, Denmark, Ireland, Finland, Austria and Belgium that all address this aspect in different ways. He concluded that health in buildings is acknowledged as wider benefit by MSs, mostly related through to tackling energy poverty. Most LTRSs do not define IEQ among the wider benefits, only Spain considered this adequately.

Adrian Joyce, Secretary General at EuroAce and Director of the Renovate Europe Campaign applauded in his presentation: "*Renovation Wave on the Ground – How to get the job done!*" the long-awaited Renovation Wave strategy concentrating much-needed efforts and financial resources on the existing building stock. He highlighted the proposed future regulatory actions to be tackled by the exceptional EPBD review: introducing minimum energy performance standards and developing a new, digital EPC framework.



Spanish LTRS quantified health benefits

10 YEARS BPIE

Quantifying the Benefits on national level: The Spanish example

Only Spain quantified health benefits within the LTRS:

The energy renovation of 1.2 million homes would prevent:

- 80,000 people consider that they have bad or very bad health;
- 96,000 people would not be diagnosed with cardiovascular problems;
- Families could almost halve energy costs, saving €400–550/a;
- Public administrations would save €370/a per home in health and labour costs.
- Reduced number of additional winter deaths due to cold temperatures in the home, currently 7,350 each year

© Slide from Oliver Rapf's presentation

Mobilisation needs and actors

“Mobilisation” is the Key Word

Who and what needs to be mobilised 1:

- National Governments on
  - Long-term Renovation Strategies
  - Recovery and Resilience Plans
  - Stakeholder Engagement
- Building Owners in all Sectors
- Financing at EU and National Levels

EuroACE Energy Efficient Buildings

© Slide from Adrian Joyce's presentation

Regarding the practical implementation he stressed the need for overall ‘Mobilisation’ of all involved actors as a key term for the Renovation Wave to be successful: National governments need to engage their local stakeholders more into the renovation strategies, finance sector needs to provide appropriate and simplified framework, building owners need help to overcome market barriers by one-stop-shops. He stressed the need for adequate technical assistance that goes beyond simply getting finance but should also ensure the technical quality of implementation.

The conference was closed by Q&A session among speakers and attendees moderated by **Anita Derjanecz**, REHVA Managing Director. The presentations and the recording of the conference sessions are available on the REHVA website*. ■

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* https://www.rehva.eu/knowledge-base/event-presentations/event-detail/rehva-brussels-summit-2020

CLIMA 2022
REHVA 14th HVAC World Congress
15th - 18th May, Rotterdam, The Netherlands

CLIMA 2022 ROTTERDAM

Update No. 1

These are unusual times. Nevertheless, TVVL and the CLIMA 2022 organising committee have started preparation work for REHVA's 14th HVAC World Congress CLIMA 2022 to be held May 15-18 in Rotterdam, The Netherlands. Three members of the organising committee are interviewed to give a short update about the status quo. These three persons are: **Olaf Oosting** (TVVL board representative), **Lada Hensen Centnerová** (congress vice-president), and **Atze Boerstra** (congress president).

What kind of preparation work have you been involved in over the last couple of months?

Atze: 'One of the main issues was the congress location. We have been in close contact with the Rotterdam Ahoy Convention Center (RACC) since autumn 2019. Their new entrance building is more or less ready now and can be visited, virtually, here: https://lichtstorm.com/pano/ahoy/. We have not signed the final contract yet as with the corona pandemic things are far from normal. Luckily, they have been ultra-flexible with us. They, like us, are determined to make a success of the CLIMA congress, no matter what.

Any ideas on how the corona pandemic will impact the 2022 edition of the CLIMA congress?

Atze: 'Apart from all the impracticalities and uncertainties caused by COVID-19: this pandemic has, of course, led to all kinds of new questions about the transmission of airborne infectious diseases that are of utmost importance to our field. So, naturally, during the congress, we will schedule an ample amount of time to discuss and learn about HVAC systems and other building services to help limit the transmission of corona (and other) viruses in buildings. I am pretty sure that at least one of our keynote speakers will talk about this.'

Representatives of the CLIMA 2022 organising committee

ATZE BOERSTRA
Congress President

OLAF OOSTING
TVVL board representative

LADA HENSEN CENTNEROVÁ
Congress Vice-president

Olaf: 'Of course one could look at the pandemic as an ultimate threat to events that involve bringing lots of people from all over the world in close contact with each other for several days. Personally, I also see the present situation as an interesting challenge for our organizing team. The next CLIMA congress could be extra exciting as, for the first time in REHVA's history, we are now forced to combine physical and virtual attendance. It won't be easy, such a hybrid formula, but I am confident that we will manage to find a way.'

Any ideas yet about the advantages and disadvantages of such a hybrid conference form?

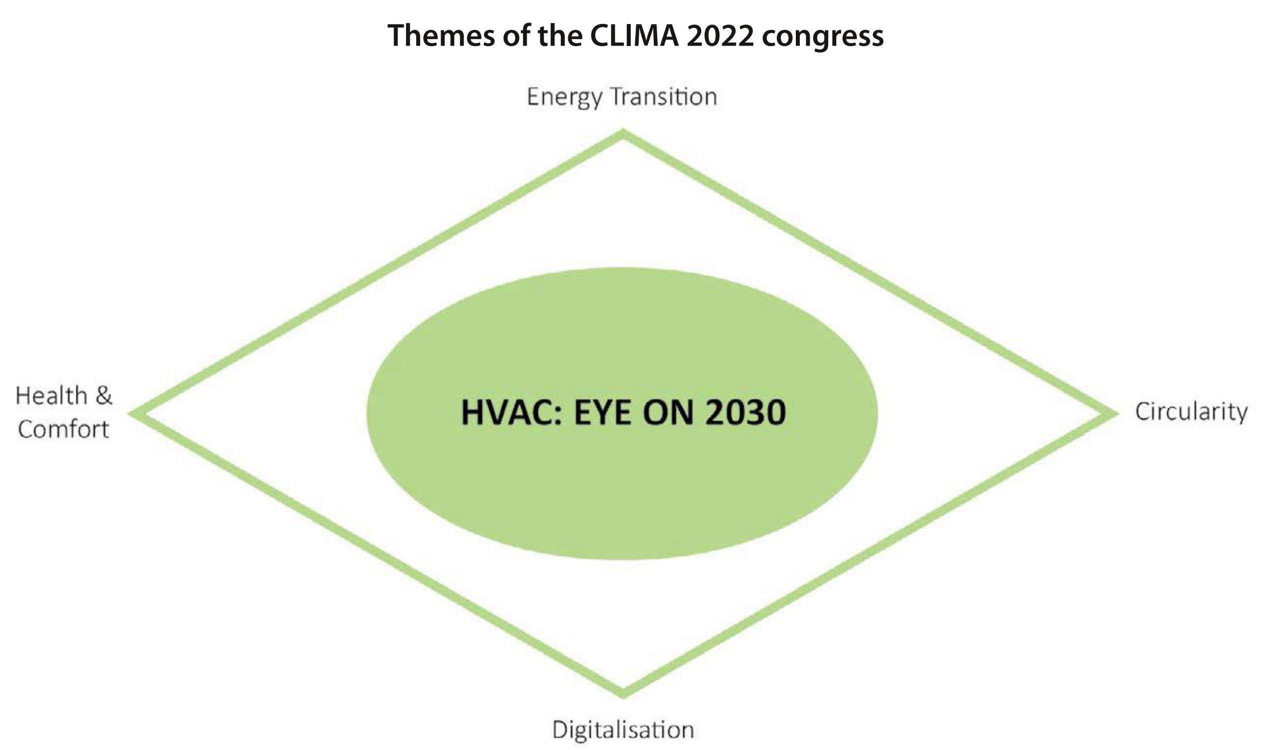
Olaf: 'One huge advantage is that we might have a much larger audience than the 700 to 1000 or so persons that usually attend a CLIMA congress. Think of all the people who normally don't find the time or resources to travel to REHVA events. With a hybrid format, they could log in from far away to attend virtually. At the same time, the present pandemic, of course, brings uncertainties about the number of people still be willing to join us in the live event, face to face in May 2022. All of this also largely depends on what will happen in the coming months in terms of possible COVID-19 cures and vaccines.'

Lada: 'A congress, of course, is about meeting each other, but it is also about exchanging research results, and this is something that at least to a certain extent can also be done successfully with virtual presentations and workshops. Personally, I have already seen several good examples in this context (e.g. the recent Indoor Air conference in Republic of Korea).

Which are the central topics of Clima 2022?

Atze: 'Our core topics are Health (health & comfort), Energy, Circularity and Digitalisation. These are four aspects which, in my opinion, already have a substantial impact on how we design, build and maintain our HVAC systems. I am very much looking forward to sharing the latest research related to these core topics with each other and discussing how to stay on top in our field. Note, by the way, that each day of the conference will be dedicated to one of the topics, at least in the morning programs and the keynote presentations.

Olaf: 'I think one of the biggest challenges will be not to focus on just one of these aspects over the coming years (e.g. just on health because we want to keep the indoor air free of viruses). Instead, we should find a way to simultaneously improve the health, energy and circularity performance of our building services. Digitalisation can help us improving the integration of the other three topics. And that is exactly what we will be focusing on, integrally, during the congress.'



How about the committees, are they in place already?

Lada: We have a tandem which is chairing the Scientific Committee. Prof. Laure Itard from TU Delft is the chair, and I (from TU Eindhoven) am her co-chair. We invited 12 Dutch academics and professionals to join us in the Dutch part of the scientific committee. For each of the conference's topics, we have 'a tandem' of an academic and an HVAC professional who will together coordinate their subject field. This way, we are sure to create a challenging link between science and high-level practice. All other committee members have their own tasks. Soon we will start inviting international colleagues to join the *international* scientific committee that will help us to integrate other (inter) national views and ideas.

Atze: Apart from this we are in the process of setting up an International Advisory Committee, whose task will be to advise us on broader questions relating to the organisation and program of such an international congress.

Rotterdam's city centre attracts shoppers.

When will the call for abstracts and workshops go out?

Lada: 'We have adjusted the original schedule a little due to COVID-19. Nobody knows what will happen the coming months, whether, for example, we will have an effective vaccine half a year from now, whether CLIMA participants will be able to come to Rotterdam without any travel restrictions or if they will prefer to join us online. That is why we have decided to set the deadline for submission of abstracts and workshops to just ten months before the conference. This will also provide everyone with better opportunities to submit information about the most recent advances!

For more information, see the schedule below:

Call for abstracts	1 March 2021
Submission deadline for abstracts	15 June 2021
Acceptance of Abstracts	5 September 2021
Deadline for full paper submission	10 January 2022
Acceptance of papers	15 February 2022

Is it still possible to join as a sponsor?

Olaf: 'Via our TVVL channels but also via REHVA's Supporters Committee on behalf of TVVL, I have approached sponsors with the help of Juan Traversi and Anita Derjanecz, amongst others.

We have already received several positive reactions and are looking for additional sponsors for the different topics. If you want to be a main sponsor, please contact us quickly. If your company feels hesitant because of the COVID situation, please contact me to discuss the possible options. I, Olaf Oosting, am available at ooo@valstar-simonis.nl

Explain in a few words why we should come to Rotterdam in 2022?

Lada: 'I am confident that we will come up with a very interesting program, with enough time to exchange the latest research, interactive workshops and a line-up with very inspiring keynote speakers. That alone should be a good reason to come to Rotterdam or join us online and attend CLIMA 2022.'

Olaf: 'As Organising Committee we will discuss the impact of the pandemic during every meeting. We are doing everything we can to welcome at least 700 in-person visitors at the congress. The Netherlands in general and Rotterdam, in particular, are very well equipped for a congress like CLIMA 2022. Not just in terms of international accessibility (e.g. train and plane connections) and the high quality of our service industry (e.g. hotels and restaurants). But also in more (multi)cultural terms and organisational experience. Just come over to Rotterdam and enjoy our beautiful city!'

Atze: 'Some of my most beautiful professional memories are directly related to the 50 or so conferences and congresses that I have attended so far. Ideally, events like these are about quality science and new ideas but ALSO about spending good time together and making new friends. So we will not just focus on valuable content but also on what we call 'the feelgood vibe'. I promise that if you do decide to come to Rotterdam, you will most certainly return home with some good memories of your own and a smile on your face.'

For more information, please subscribe to our newsletter on clima2022.org and we will keep you updated on the 14th REHVA World Congress CLIMA 2022. ■

CLIMA 2022

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

REHVA 14th HVAC World Congress

15th - 18th May, Rotterdam, The Netherlands

REHVA COVID-19 Guidance Document 4.0

REHVA published its first COVID-19 guidance mid-March 2020. After 2 updates (April and August), the fourth version is focusing on how to reopen and safely use buildings after the lockdown, providing advice on specific components, buildings/space types, and suggesting mitigation measures.

Main changes to previous version are related to ventilation of buildings during out of occupancy time, operation of fan coil and split units and releasing a new appendix presenting infection risk probability calculation method. New guidance allows to stop ventilation 2 hours after occupancy and ventilation needs to be switched on to nominal speed 2 hours before the occupancy in the morning. Therefore, a continuous but lower speed night time and weekend ventilation operation has been removed as not a necessary precautionary measure that didn't find supporting scientific evidence. Existing evidence shows that ventilating with 2 – 3 volumes of the space is enough to clean air from any pollutants including viruses. This amount of ventilation is secured with 2 hour extended ventilation rule. New guidance allows to stop also the toilet ventilation which can be operated in the same fashion as the main ventilation system.

The effect of fan coils and split units has been under discussion since spring. New guidance allows to operate these units normally, according to cooling and heating needs, but provides new advice how to secure outdoor air ventilation and also how to avoid directed air flows from one person to another which can contribute to the spread of viruses. It is stressed that outdoor ventilation needs to be arranged either by mechanical or window airing means in spaces conditioned with units having cooling only or heating only functions. Precaution is put to high air velocities in the occupied zone, it is recommended to change room layouts if air velocities will exceed 0.3 m/s as higher velocities could carry considerable amounts of viruses from one person to another.

Infection probability calculation method is introduced in appendix and supported by Excel calculator. With this calculator it is easy to calculate infection risk probabilities for any specific room – just by the input of geometry and ventilation rate, for most of common indoor activities. This type of risk assessment is recommended to decide how to operate buildings and if necessary to limit occupancy time or in some spaces the number of occupants.

The REHVA guidance summarises advice on the operation and use of building service systems during an epidemic of a coronavirus disease. The fourth version of the guidance document overwrites all previous ones. Updates are expected in the upcoming months as more academic data becomes available.

Jarek Kurnitski,
Chair of REHVA COVID-19 Task Force,
Prof., Tallinn University of Technology,
Chair of REHVA Technology and Research Committee

Contents

* Appendices & literature, please see https://www.rehva.eu/activities/covid-19-guidance ▶

1. Introduction

In this document, REHVA summarises advice on the operation and use of building service systems during an epidemic of a coronavirus disease (COVID-19), to reduce the risk of transmission of COVID-19 depending on HVAC (Heating, Ventilation, and Air Conditioning) systems related factors. The advice below should be treated as *interim* guidance; the document may be complemented with new evidence and information when it becomes available.

The suggestions below are meant as an addition to the general guidance for employers and building owners that are presented in the WHO document 'Getting workplaces ready for COVID-19'[1]. The text below is intended primarily for HVAC professionals and facility managers. It may be useful for occupational and public health specialists and other professionals involved in decisions on how to use buildings.

In this document, building services related precautions are covered. The scope is limited to commercial and public buildings (e.g., offices, schools, shopping areas, sports premises, etc.) where only occasional occupancy of infected persons is expected, and some advice is given for temporary hospital and healthcare settings. Residential buildings are out of the scope of this document.

The guidance is focused on temporary, easy-to-organise measures that can be implemented in existing buildings that are in use during or after epidemic with normal or reduced occupancy rates. Some long-term recommendations are also presented.

Disclaimer:

This document expresses REHVA expert advice and views based on the available scientific knowledge of COVID-19 available at the time of publication. In many aspects, SARS-CoV-2 information is not complete and some evidence[2] from previous airborne viruses may have been used for best practice recommendations. REHVA, the contributors and all those involved in the publication exclude all and any liability for any direct, indirect, incidental damages or any other damages that could result from, or be connected with, the use of the information presented in this document.

Summary

New evidence on SARS-CoV-2 airborne transmission and general recognition of long-range aerosol-based transmission have developed recently. This has made ventilation measures the most important engineering controls in the infection control. While physical distancing is important to avoid a close contact, the risk of an airborne transmission and cross-infection over distances more than 1.5 m from an infected person can be reduced with adequate ventilation and effective air distribution solutions. In such a situation at least three levels of guidance are required: (1) how to operate HVAC and other building services in existing buildings right now during an epidemic; (2) how to conduct a risk assessment and assess the safety of different buildings and rooms; and (3) what would be more far-reaching actions to further reduce the spread of viral diseases in future in buildings with improved ventilation systems. Every space and operation of building is unique and requires specific assessment. We make 15 recommendations that can be applied in existing buildings at a relatively low cost to reduce the number of cross-infections indoors. Regarding airflow rates, more ventilation is always better, but is not the only consideration. Large spaces such as classrooms which are ventilated according to current standards tend to be reasonably safe, but small rooms occupied by a couple of persons show the highest probability of infection even if well ventilated. While there are many possibilities to improve ventilation solutions in future, it is important to recognise that current technology and knowledge already allows the use of many rooms in buildings during a COVID-19 type of outbreak if ventilation meets existing standards and a risk assessment is conducted as described in this document.

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[1] https://www.who.int/docs/default-source/coronaviruse/getting-workplace-ready-for-covid-19.pdf

[2] In the last two decades we have been confronted with three coronavirus disease outbreaks: (i) SARS in 2002-2003 (SARS-CoV-1), (ii) MERS in 2012 (MERS-CoV) and COVID-19 in 2019-2020 (SARS-CoV-2).

Version November 17, 2020. this document updates all previous versions, i.e.: August 3, April 3 and March 17. Updates will follow as necessary. See: https://www.rehva.eu/activities/covid-19-guidance

2. Transmission routes

It is important for every epidemic to understand the transmission routes of the infectious agent. For COVID-19 and for many other respiratory viruses three transmission routes are dominant: (1) combined droplet and airborne transmission in 1 – 2 m close contact region arising from droplets and aerosols emitted when sneezing, coughing, singing, shouting, talking and breathing; (2) long-range airborne (aerosol-based) transmission; and (3) surface (fomite) contact through hand-hand, hand-surface, etc. contacts. The means to deal with these routes are physical distance to avoid the close contact, ventilation to avoid airborne transmission and hand hygiene to avoid surface contact. This document mainly focuses on reduction measures of airborne transmission while personal protective equipment such as wearing masks is out of the scope of the document. Additional transmission routes that have gained some attention are the faecal-oral route and resuspension of SARS-CoV-2, which are also addressed in this document.

The size of a coronavirus particle is 80 – 160 nanometre [i] (1 nanometre = 0.001 micron) and it remains active on surfaces for many hours or a couple of days unless there is specific cleaning [ii,iii,iv]. In indoor air SARS-CoV-2 can remain active up to 3 hours and up to 2 – 3 days on room surfaces at common indoor conditions [v]. An airborne virus is not naked but is contained inside expelled respiratory fluid droplets. Large droplets fall down, but small droplets stay airborne and can travel long distances carried by airflows in the rooms and in extract air ducts of ventilation systems, as well as in the supply ducts when air is recirculated. Evidence suggests that airborne transmission has caused, among others, well known infections of SARS-CoV-1 in the past [vi,vii].

Expelled respiratory droplets that are suspended in air (which means airborne), range from less than 1 µm (micrometre = micron) to more than 100 µm in diameter, which is the largest particle size that can be inhaled. They are also referred to as aerosols, i.e. particles suspended in air, since droplets are liquid particles. The main airborne transmission mechanisms are illustrated in **Figure 1**.

Airborne transmission depends on the droplet size [viii,ixx] and is usually divided into close contact and long-range regions as follows:

1. Short-range droplet transmission region for close contact events can be defined through the distance travelled before the drops and large droplets (up to 2 000 µm = 2 mm) fall down to surfaces. At an initial droplet velocity of 10 m/s larger droplets fall down within 1.5 m. Respiratory activities correspond to a droplet velocity of 1 m/s for normal breathing, 5 m/s for talking, 10 m/s for coughing and 20 – 50 m/s for sneezing. Expelled droplets evaporate and desiccate in the air so that the final droplet nuclei shrink to roughly a half or one-third

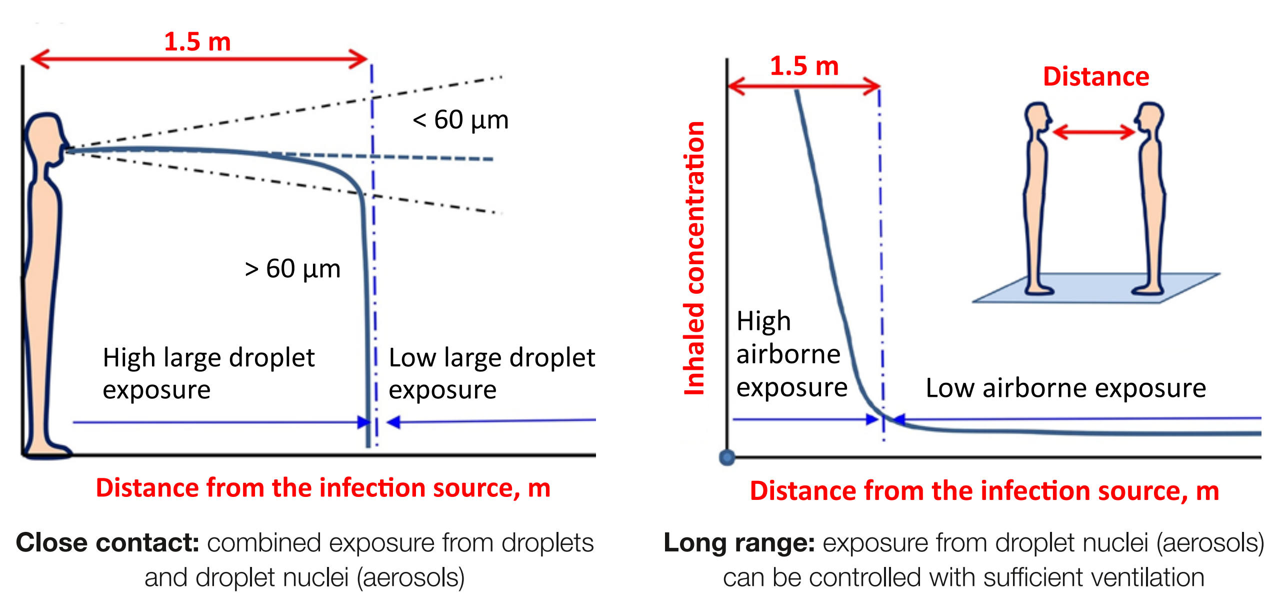

Figure 1. The distinction between close contact combined droplet and aerosol transmission (left) and long-range aerosol transmission (right) which can be controlled with ventilation diluting the virus concentration to a low level. (Figure: courtesy of L. Liu, Y. Li, P. V. Nielsen et al. [xii])

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of the initial diameter [xi]. Droplets with initial diameter smaller than 60 µm do not reach the ground before they desiccate entirely and may be carried further than 1.5 m by airflows.

2. Long-range airborne transmission applies beyond 1.5 m distance for droplets < 60 µm. Droplet desiccation is a fast process; for instance, 50 µm droplets desiccate in about two seconds and 10 µm droplets in 0.1 s to droplet nuclei with roughly a half of the initial diameter[3]. Droplet nuclei < 10 µm may be carried by airflows for long distances since the settling speeds for 10 µm, and 5 µm particles (equilibrium diameter of droplet nuclei) are only 0.3 cm/s and 0.08 cm/s, so it takes about 8.3 and 33 minutes respectively to fall 1.5 m. Because of instant desiccation, the term “droplet” is often used for desiccated droplet nuclei which still include some fluid explaining why viruses can survive. Droplet nuclei form a suspension of particles in the air, i.e. an aerosol. With effective mixing ventilation, the aerosol concentration is almost constant from 1 – 1.5 m distance onward. This concentration is most dominantly affected by air change rates in adequately ventilated rooms but is also reduced by deposition and decay of virus-laden particles.

The distance of 1.5 m for large droplets to fall, shown in **Figure 2**, left, applies if there is no air movement in the room. Usually, air distribution of ventilation and convection air flows of heat gains cause air velocities between 0.05 – 0.2 m/s in typical rooms with human occupancy. Using these velocities as lower and upper bounds together with particle settling velocities allows an estimate of how far droplets can travel before falling 1.5 m under the influence of gravity. These estimates illustrate that even larger than 30 µm droplets can travel much more than 1 – 2 meters.

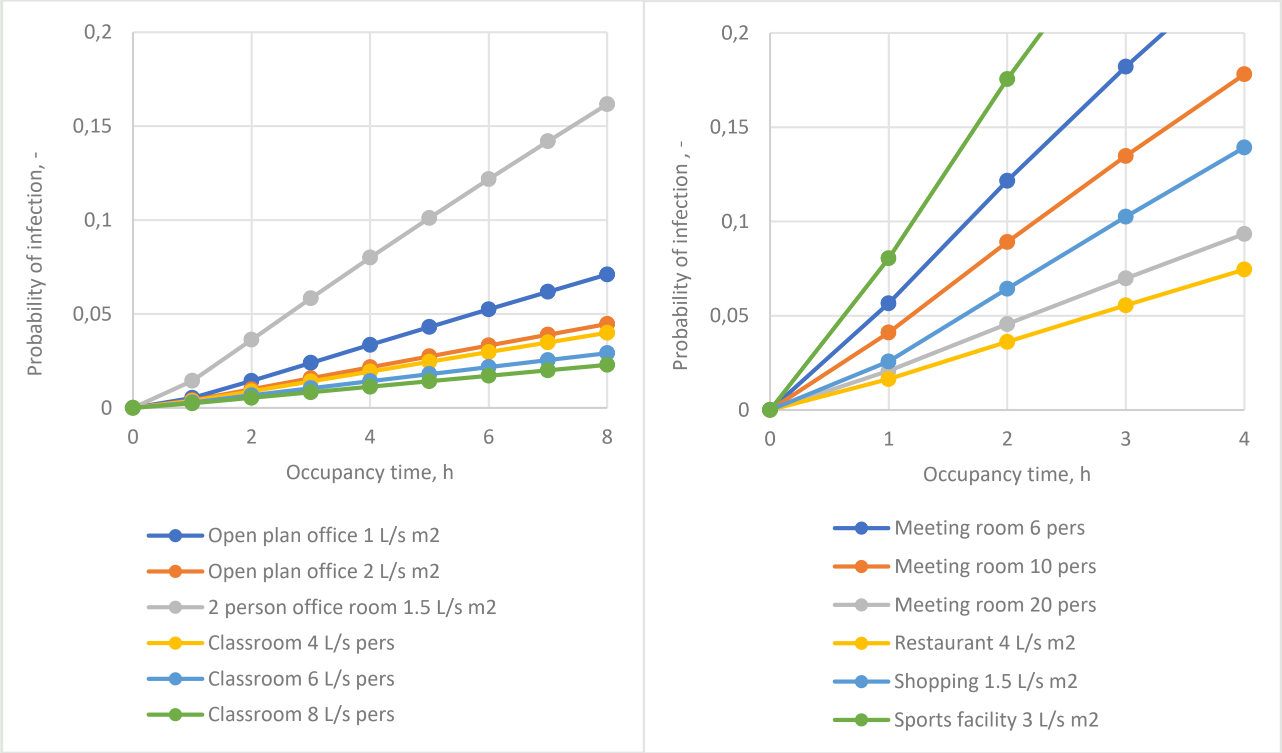

Figure 2. Traveling distance estimates for different sizes of droplets to be carried by room air velocities of 0.05 and 0.2 m/s before settling 1.5 m under the influence of gravity. The travelled distance accounts for movement after the initial jet has relaxed and is calculated with the equilibrium diameter of completely desiccated respiratory droplets (µm values in the figure refer to equilibrium diameters). With turbulence distance travelled is less, but settling time is longer.

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[3] Physics of suspended respiratory droplets in air shows that a droplet with initial diameter of 20 µm will evaporate within 0.24 seconds in room air with 50% RH shrinking at the same time to a droplet nuclei with equilibrium diameter of about 10 µm. For this droplet nuclei of 10 µm, including still some fluid, it takes 8.3 minutes to fall down 1.5 m in still air.

More important than how far different size droplets travel, is the distance from the source or infected person at which a low, an almost constant aerosol concentration will be reached. As shown in **Figure 1**, right, the concentration of droplet nuclei will decrease rapidly within the first 1 – 1.5 meter from a person's exhalation [xii]. This effect is due to the aerodynamics of the exhalation flow and the flow in the microenvironment around people (plume). The droplet nuclei distribution depends on the position of people, air change rate, the type of air distribution system (e.g., mixing, displacement, or personal ventilation), and other air currents in the space [xiii]. Therefore, close contact within the first 1.5-meter creates high exposure to both large droplets and droplet nuclei that is supported by experimental and numerical studies [xii]. Aerosol concentrations and cross-infection from 1.5 m or more from an infected person can be controlled with adequate ventilation and air distribution solutions. The effect of ventilation is illustrated in **Figure 3**.

For SARS-CoV-2, the long-range aerosol-based route with infection through exposure to droplet nuclei particles was first acknowledged by the WHO for hospital aerosol-generating procedures and was addressed in the guidance to increase ventilation [xiv]. Japanese authorities were one of the first to address the possibility of aerosol transmission under certain circumstances, such as when talking to many people at a short distance in an enclosed space, and associated risk of spreading the infection even without coughing or sneezing [xv]. After that, many other authorities have followed including the US CDC, UK Government, Italian Government and the China National Health Commission. Important evidence came from a study [v] concluding that aerosol transmission is plausible, as the virus can remain viable in aerosols for multiple hours. Analyses of superspreading events have shown that closed environments with minimal ventilation strongly contributed to a characteristically high number of secondary infections [xvi]. Well known superspreading events reporting aerosol transmission are from a Guangzhou restaurant [xvii] and Skagit Valley Chorale event [xviii] where outdoor air ventilation rate was as low as 1 – 2 L/s per person. The fact that substantial evidence has quickly emerged indicating that SARS-CoV-2 is transmitted via aerosols has been required to be generally recognised by many scientists [xixxx]. To date, the European Centre for Disease Prevention and Control (ECDC) review on HVAC-systems in the context of COVID-19 as well as the German Robert-Koch-Institut have recognised aerosol transport [xxixxii]. Finally, after an open letter by 239 scientists [xxiii],the WHO in June 2020 added aerosol transmission to their transmission mode scientific brief [xxiv]. Generally, a long-range aerosol-based transmission mechanism implies that keeping 1-2 m distance from an infected person is not enough, and concentration control with ventilation is needed for effective removal of particles in indoor spaces.

Surface (fomite) contact transmission may occur when expelled large droplets fall on nearby surfaces and objects such as desks and tables. A person may be infected with COVID-19 by touching a surface or object that has the virus on it and then touching their mouth, nose, or possibly their eyes, but US CDC and other have concluded that this route is not thought to be the main way this virus spreads [xxv].

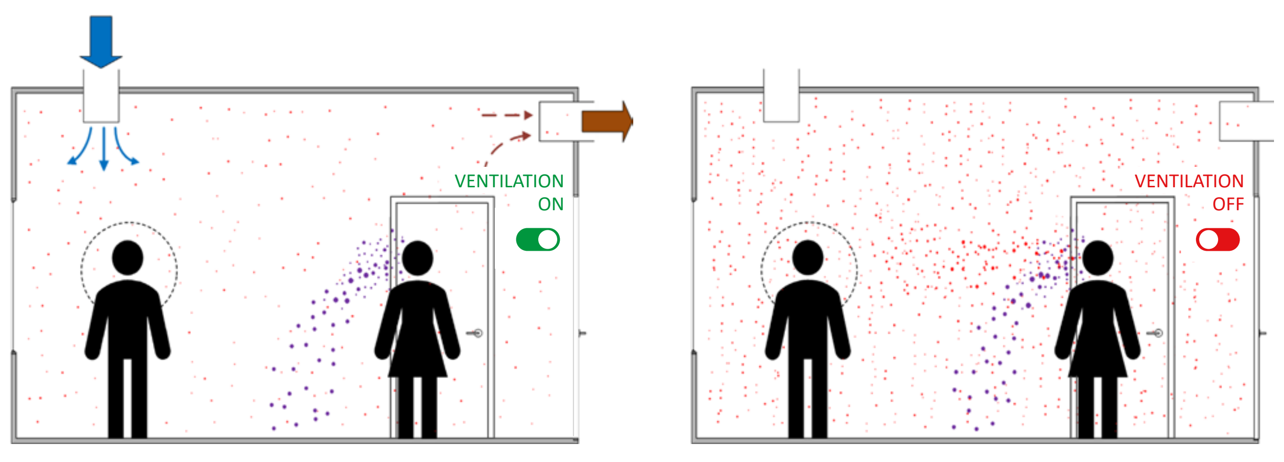

Figure 3. Illustration of how an infected person (speaking woman on the right) leads to aerosol exposure (red spikes) in the breathing zone of another person (man on the left in this case). Large droplet exhalation is marked with purple spikes. When the room is ventilated with mixing ventilation system, the number of virus-laden particles in the breathing zone is much lower than when the ventilation system is off. Left figure: ventilation system on, right figure: ventilation system off.

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The WHO recognises the faecal-oral, i.e. aerosol/sewage transmission route for SARS-CoV-2 infections [xxvi]. The WHO proposes as a precautionary measure to flush toilets with a closed lid. In this context, it is essential to avoid dried-out drains and U-traps in floors and other sanitary devices by regularly adding water (every three weeks depending on the climate) so that the water seal works appropriately. This prevents aerosol transmission through the sewage system and is in line with observations during the SARS 2002-2003 outbreak: open connections with sewage systems appeared to be a transmission route in an apartment building in Hong Kong (Amoy Garden) [xxvii]. It is known that flushing toilets are creating rising air flows containing droplets and droplet residue when toilets are flushed with open lids. SARS-CoV-2 viruses have been detected in stool samples (reported in recent scientific papers and by the Chinese authorities) [xxviii,xxix,xxx].

Conclusion about the aerosol (airborne) transmission route:

New evidence and general recognition of the aerosol-based transmission route have been developed recently. When the first version of this document was published on March 17, 2020, REHVA proposed following the ALARP principle (As Low As Reasonably Practicable) to apply a set of HVAC measures that help to control the aerosol route in buildings. To date, there is evidence on SARS-CoV-2 aerosol-based transmission, and this route is now recognised worldwide. The relative contribution of different transmission routes in the spread of COVID-19 is still under discussion. It also very much situation-dependent whether one transmission route or the other is dominant. For instance, in hospitals with an excellent 12 air changes per hour (ACH) ventilation rate, aerosol transmission is mostly eliminated, but in poorly ventilated spaces, it may be dominant. Transmission routes remain an important research subject, and it has already been reported that the short-range aerosol-based route dominates exposure to respiratory infection during close contact [xxxi]. Medical literature has started to talk about a new paradigm of infectious aerosols. It is concluded that there is no evidence to support the concept that most respiratory infections are primarily associated with large droplet transmission, and that small particle aerosols are the rule, rather than the exception, contrary to current guidelines [xxxii]. In the context of buildings and indoor spaces there is no doubt that cross-infection risk may be controlled up to 1.5 m from a person with physical distancing and beyond that distance with ventilation solutions.

3. Heating, ventilation & air-conditioning systems in the context of COVID-19

There are many possible measures that may be taken to mitigate COVID-19 transmission risks in buildings. This document covers recommendations for ventilation solutions as the main 'engineering controls', as described in the traditional infection control hierarchy (**Figure** 4) to reduce the environmental risks of airborne transmission. According to the hierarchy, ventilation and other HVAC & plumbing related measures are at a higher level than the application of administrative controls and personal protective equipment (including masks). It is therefore very important to consider ventilation and other building services system measures to protect against airborne transmission. These may be applied in existing buildings at a relatively low cost to reduce indoor infection risk.

Figure 4. Traditional infection control pyramid adapted from the US Centers for Disease Control [xxxiii].

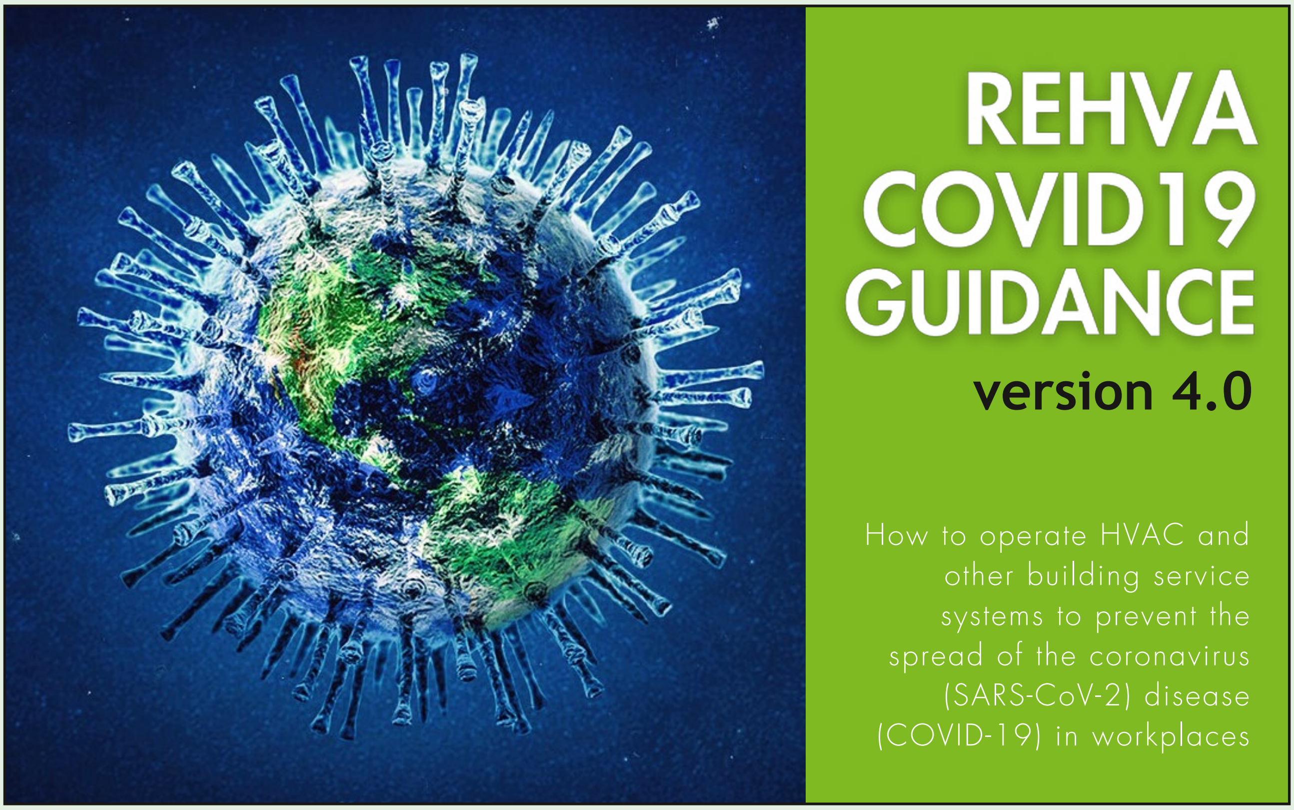
The European Centre for Disease Prevention and Control (ECDC) has prepared guidance for public health authorities in EU/EEA countries and the UK on the ventilation of indoor spaces in the context of COVID-19 [xxi]. This guidance is targeted at public health professionals and serves as a basis for REHVA to provide technical and system-specific guidance for HVAC professionals. The main evidence and conclusions by ECDC can be summarised as follows:

- The transmission of COVID-19 commonly occurs in enclosed indoor spaces.
- There is currently no evidence of human infection with SARS-CoV-2 caused by infectious aerosols distributed through the ventilation system air ducts. The risk is rated as very low.
- Well-maintained HVAC systems, including air-conditioning units, securely filter large droplets containing SARS-CoV-2. COVID-19 aerosols (small droplets and droplet nuclei) can **spread through HVAC systems within a building or vehicle**

and stand-alone air-conditioning units if the air is recirculated.

- **The airflow generated by air-conditioning units may facilitate the spread of droplets** excreted by infected people longer distances within indoor spaces.
- **HVAC systems may have a complementary role in decreasing transmission in indoor spaces by increasing the rate of air change, decreasing the recirculation of air, and increasing the use of outdoor air.**
- Building administrators should maintain heating, ventilation, and air-conditioning systems according to the manufacturer's current instructions, particularly concerning the cleaning and changing of filters. **There is no benefit or need for additional maintenance cycles** in connection with COVID-19.
- Energy-saving settings, such as **demand-controlled ventilation controlled by a timer or CO_2 detectors, should be avoided**.
- Consideration should be given to **extending the operating times of HVAC systems** before and after the regular period.
- **Direct air flow should be diverted away from groups of individuals to avoid pathogen dispersion** from infected subjects and transmission.
- Organizers and administrators responsible for gatherings and critical infrastructure settings should explore options with the assistance of their technical/maintenance teams to **avoid the use of air recirculation as much as possible**. They should consider reviewing their procedures for the use of recirculation in HVAC systems based on information provided by the manufacturer or, if unavailable, seeking advice from the manufacturer.
- **The minimum number of air exchanges per hour, following the applicable building regulations, should be ensured at all times. Increasing the number of air exchanges per hour will reduce the risk of transmission in closed spaces. This may be achieved by natural or mechanical ventilation, depending on the setting.**

In the guideline [xxxiv] ECDC stresses the importance of ventilation by concluding that ensuring the implementation of optimal ventilation adapted to each particular indoor setting could be critical in preventing outbreaks and transmission amplification events. In the guideline the minimum number of air exchanges per hour, in accordance with the applicable building regulations, is required to be ensured at all times. It is stated that increasing the number of air exchanges per hour, by means of natural or mechanical ventilation, will reduce the risk of transmission in closed spaces. Ventilation has seen as a major method because there is no evidence on the effectiveness of methods for decontamination of air (e.g. UV light irradiation) for use in community settings.



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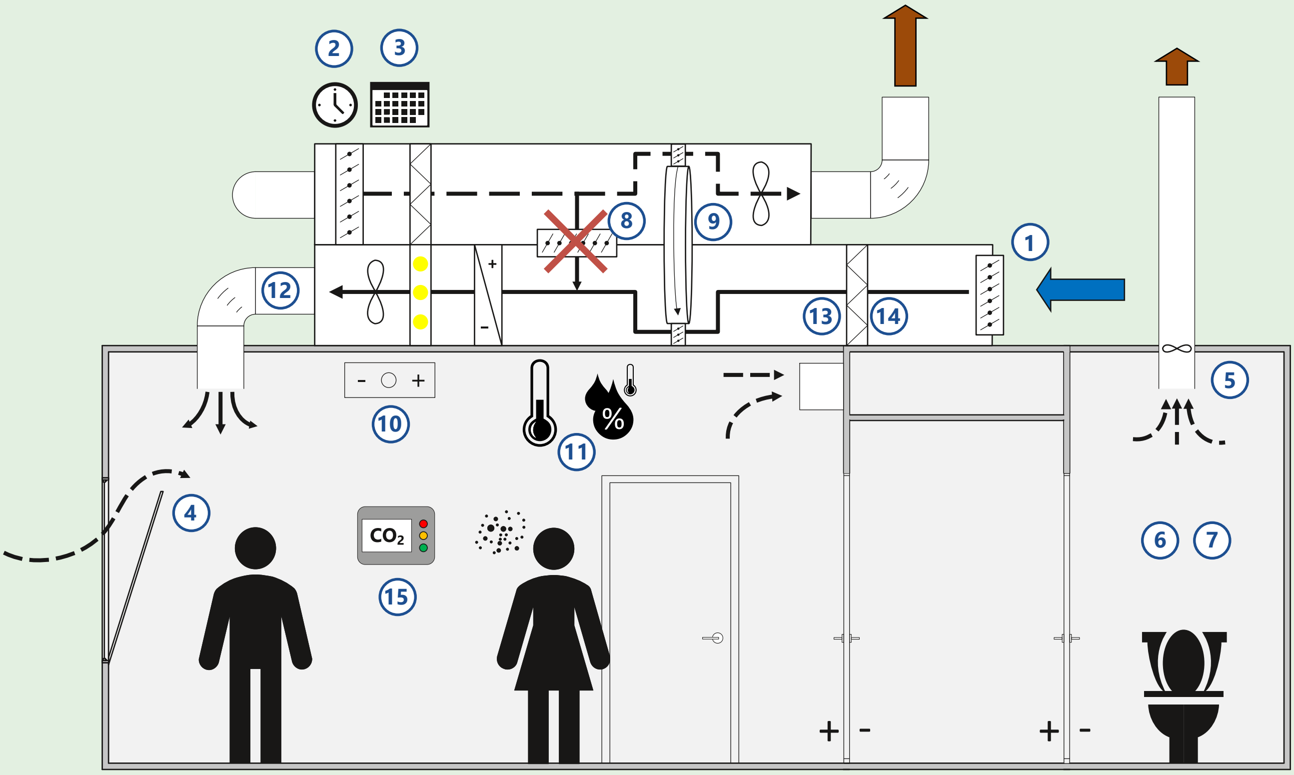
4. Practical recommendations for building services operation during an epidemic for infection risk reduction

This REHVA guidance on building services operation covers 15 main items, as illustrated in **Figure** 5.

4.1 Increase air supply and exhaust ventilation

In buildings with mechanical ventilation systems, extended operation times are recommended for these systems. Adjust the clock times of system timers to start ventilation at the nominal speed at least 2 hours before the building opening time and switch off or to a lower speed 2 hours after the building usage time. In demand-controlled ventilation systems, change the CO_2 setpoint to 400 ppm in order to maintain the operation at nominal speed. In buildings that have been vacated due to the pandemic (some offices or educational buildings), it is not recommended to switch ventilation off, but to operate continuously at reduced speed during normal operation hours. Extended operation time helps to remove virus particles from the building and to remove released virus particles from surfaces. In winter and summer, increased energy use has to be accepted, because ventilation systems have enough heating and cooling capacity to fulfil these recommendations without compromising thermal comfort.



1. Ventilation rates
2. Ventilation operation times
3. Overrule of demand control settings
4. Window opening
5. Toilet ventilation
6. Windows in toilets
7. Flushing toilets
8. Recirculation
9. Heat recovery equipment
10. Fan coils and split units
11. Heating, cooling and possible humidification setpoints
12. Duct cleaning
13. Outdoor air and extract air filters
14. Maintenance works
15. Indoor air quality (IAQ) monitoring

Figure 5. Main items of REHVA guidance for building services operation.

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The general advice is to supply as much outside air as reasonably possible. The key aspect is the total outdoor air flow rate, typically sized as supply air flow rate per square meter of floor area or per person. Clean air delivery rate from an air cleaner adds on to the supply air flow rate (see Appendix 1* for details).

If the number of occupants is reduced, do not concentrate the remaining occupants in smaller areas but maintain or enlarge the physical distance (min 2 – 3 m between persons) between them to improve the dilution effect of ventilation. More information about ventilation rates and risks in different rooms is provided in Appendix 1*.

Exhaust ventilation systems for toilets should be operated in similar mode to the main ventilation system. It should be switched to the nominal speed at least 2 hours before the building opening time and may be switched off or to a lower speed 2 hours after the building usage time.

Additional ventilation guidance for patient rooms is provided in Appendix 3* and for school personnel in Appendix 4*.

4.2 Use openable windows more

The general recommendation is to stay away from crowded and poorly ventilated spaces. In buildings without mechanical ventilation systems, it is recommended to actively use openable windows (much more than normal, even when this causes some thermal discomfort). Window opening is then the only way to boost air exchange rates. Windows should be opened for approximately 15 min when entering the room (especially when the room was occupied by others beforehand). Also, in buildings with mechanical ventilation, window opening can be used to boost ventilation further.

Open windows in toilets with a passive stack or mechanical exhaust systems may cause a contaminated airflow from the toilet to other rooms, implying that ventilation begins to work in the reverse direction. Open toilet windows should be avoided to maintain negative pressure in the toilets and the right direction of mechanical ventilation. If there is no adequate exhaust ventilation from toilets and window opening in toilets cannot be avoided, it is important to keep windows open also in other spaces to achieve cross flows throughout the building.

4.3 Humidification and air-conditioning have no practical effect

Relative humidity (RH) and temperature contribute to virus viability, droplet nuclei forming, and susceptibility of occupants' mucous membranes. The transmission of some viruses in buildings can be altered by changing air temperatures and humidity levels to reduce the viability of the virus. In the case of SARS-CoV-2, this is unfortunately not an option as coronaviruses are quite resistant to environmental changes and are susceptible only to a very high relative humidity above 80% and a temperature above 30°C [ii,iii,iv], which are not attainable and acceptable in buildings for reasons of thermal comfort and avoiding microbial growth. SARS-CoV-2 has been found viable for 14 days at 4°C; for a day at 37°C and for 30 minutes at 56°C [xxxv].

SARS-CoV-2 stability (viability) has been tested at a typical indoor temperature of 21 – 23°C and RH of 65% with very high virus stability at this temperature and RH [xxxvi]. Together with previous evidence on MERS-CoV, it is well documented that humidification up to 65% may have very limited or no effect on the stability of the SARS-CoV-2 virus. The current evidence does not support the view that moderate humidity (RH 40 – 60%) will be beneficial in reducing the viability of SARS-CoV-2 and so humidification is NOT a method to reduce the viability of SARS-CoV-2.

Small droplets (0.5 – 50 µm) will evaporate faster at any relative humidity (RH) level [xxxvii]. Nasal systems and mucous membranes are more sensitive to infections at very low RH of 10 – 20% [xxxviii,xxxix], and for this reason some humidification in winter is sometimes suggested (to levels of 20 – 30%), although the use of humidifiers has been associated with higher amounts of total and short-term sick leave [xl].

In buildings equipped with centralised humidification, there is no need to change humidification systems' setpoints (usually 25 or 30% [xli]). Usually, any adjustment of setpoints for heating or cooling systems is not needed, and systems can be operated normally, as there is no direct implication for the risk of transmission of SARS-CoV-2.

4.4 Safe use of heat recovery sections

Virus particle transmission via heat recovery devices is not an issue when an HVAC system is equipped with a twin coil unit or another heat recovery device that

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* Appendices & literature, please see https://www.rehva.eu/activities/covid-19-guidance

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guarantees 100% air separation between the return and supply side [xlii].

Some heat recovery devices may carry over particle and gas phase pollutants from the exhaust air side to the supply air side via leaks. Rotary air to air heat exchangers (i.e., rotors, called also wheels) may be liable to significant leakage in the case of poor design and maintenance. For properly operating rotary heat exchangers, fitted with purging sectors and correctly set up, leakage rates are very low, being in the range of 0 – 2% that is in practice insignificant. For existing systems, the leakage should be below 5% and should be compensated with increased outdoor air ventilation, according to EN 16798-3:2017. However, many rotary heat exchangers may not be properly installed. The most common fault is that the fans have been mounted in such a way as to create a higher pressure on the exhaust air side. This will cause leakage from the extract air into the supply air. The degree of uncontrolled transfer of polluted extract air can in these cases be of the order of 20% [xliii], which is not acceptable.

It has been shown that rotary heat exchangers which are properly constructed, installed, and maintained have almost zero transfer of particle-bound pollutants (including air-borne bacteria, viruses, and fungi), and the transfer is limited to gaseous pollutants such as tobacco smoke and other smells [xliv]. There is no evidence that virus-laden particles larger than about 0.2 µm would be transferred across the wheel. Because the major part of the leakage is caused by the pressure differences between supply and exhaust air, stopping the rotor will have only a minor impact of the leakage. Therefore, it's not necessary to switch the rotor off. The normal operation of rotors makes it also easier to keep ventilation rates higher. It is known that the carry-over leakage is highest at low airflow, so higher ventilation rates should be used as recommended in Section 4.1.

If critical leaks are detected in the heat recovery sections, pressure adjustment or bypassing (some systems may be equipped with bypass) can be an option to avoid a situation where higher pressure on the extract side will cause air leakage to the supply side. Pressure differences can be corrected by dampers or by other reasonable arrangements. In conclusion, we recommend inspecting the heat recovery equipment, including measuring the pressure difference and estimating leakage based on temperature measurement, see Appendix 2*.

4.5 No use of central recirculation

Viral material in extract (return) air ducts may re-enter a building when centralised air handling units are equipped with recirculation sectors. The general recommendation is to avoid central recirculation during SARS-CoV-2 episodes: close the recirculation dampers either using the Building Management System or manually. This is especially important in buildings that are used by susceptible end-users[4] (e.g. nursing homes).

Sometimes, air handling units and recirculation sections are equipped with return air filters. This should not be a reason to keep recirculation dampers open as these filters normally do not filter out viral material effectively since they have coarse or medium filter efficiencies (G4/M5 or ISO coarse/ePM10 filter class).

In air systems and air-and-water systems where central recirculation cannot be avoided because of limited cooling or heating capacity, the outdoor air fraction has to be increased as much as possible and additional measures are recommended for return air filtering. To completely remove particles and viruses from the return air, HEPA filters would be needed. However, due to a higher pressure drop and special required filter frames, HEPA filters are usually not easy to install in existing systems. Alternatively, duct installation of disinfection devices, such as ultraviolet germicidal irradiation (UVGI) also called germicidal ultraviolet (GUV), may be used. It is essential that this equipment is correctly sized and installed. If technically possible, it is preferred to mount a higher-class filter in existing frames and to increase exhaust fan pressure without reducing the airflow rate. A minimum improvement is the replacement of existing low-efficiency return air filters with ePM1 80% (former F8) filters. The filters of the former F8 class have a reasonable capture efficiency for virus-laden particles (capture efficiency 65 – 90% for PM1).

4.6 Room level circulation: fan coil, split and induction units

In rooms with fan coils only or split units (all-water or direct expansion systems), the first priority is to achieve adequate outdoor air ventilation. In such systems, the fan coils or split units are usually independent of mechanical ventilation which in some cases even might not exist, and there are two possible options to achieve ventilation:

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* Appendices & literature, please see https://www.rehva.eu/activities/covid-19-guidance

[4] In hospitals the use of recirculation is strictly forbidden in many countries.

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1. Active operation of window opening together with the installation of CO_2 monitors as indicators of outdoor air ventilation;
2. Installation of a standalone mechanical ventilation system (either local or centralised without recirculation, according to its technical feasibility). This is the only way to ensure a sufficient outdoor air supply in the rooms at all times.

If option one is used, CO_2 monitors are important, because fan coils and split units with both cooling or heating functions improve thermal comfort, and it may take too long before occupants perceive poor air quality and lack of ventilation [xlv]. During hours of occupation leave windows partially open (if openable) to increase the level of ventilation. See an example of a CO_2 monitor in Appendix 4 (Figure 17)*.

Fan coil units have coarse filters that practically do not filter smaller particles but may still collect potentially contaminated particles. Standard maintenance procedures are to be followed with recommendations provided in Section 4.9.

Split units and sometimes fan coils may cause high air velocities. In common spaces (larger rooms with fan coil or split units occupied by many persons), in the case of local air velocities of 0.3 m/s or more, directed air flows from one person to another should be avoided with workplaces arrangements or air jet adjustments.

4.7 Duct cleaning has no practical effect

There have been some overreactive statements recommending cleaning ventilation ducts to avoid SARS-CoV-2 transmission via ventilation systems. Duct cleaning is not effective against room-to-room infection because the ventilation system is not a contamination source if the above guidance about heat recovery and recirculation is followed. Viruses attached to small particles will not deposit easily in ventilation ducts and will normally be carried out by the airflow. [xlvi]. Therefore, no changes are needed to normal duct cleaning and maintenance procedures. Much more important is to increase the outside air supply and to avoid recirculation of air according to the recommendations above.

4.8 Additional change of outdoor air filters is not necessary

In the COVID-19 context, questions have been asked about filter replacement and the protective effect in very rare cases of outdoor virus contamination, for instance, if air exhausts are close to air intakes. Modern ventilation systems (air handling units) are equipped with fine outdoor air filters right after the outdoor air intake (filter class F7 or F8[5] or ISO ePM2.5 or ePM1), which filter particulate matter from the outdoor air well. The size of the smallest viral particles in respiratory aerosols is about 0.2 µm (PM0.2), smaller than the capture area of F8 filters (capture efficiency 65 – 90% for PM1). Still, the majority of viral material is already within the capture area of filters. This implies that in rare cases of virus-contaminated outdoor air, standard fine outdoor air filters provide reasonable protection for a low concentration and occasional occurrence of viral material in outdoor air.

Heat recovery and recirculation sections are equipped with less effective medium or coarse extract air filters (G4/M5 or ISO coarse/ePM10) whose aim is to protect equipment against dust. These filters have a very low capture efficiency for viral material (see Section 4.4 for heat recovery and 4.5 for recirculation).

From the filter replacement perspective, normal maintenance procedures can be used. Clogged filters are not a source of contamination in this context, but they reduce supply airflow, which has a negative effect on reducing indoor contamination levels. Thus, filters must be replaced according to the normal procedures when pressure or time limits are exceeded, or according to scheduled maintenance. In conclusion, it is not recommended to change existing outdoor air filters and replace them with other types of filters, nor it is recommended to change them sooner than usual.

4.9 Safety procedures for maintenance personnel

HVAC maintenance personnel may be at risk when conducting scheduled maintenance, inspection or replacement of filters (especially extract air filters) if standard safety procedures are not followed. To be safe, always assume that filters, extract air ducts, and heat

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* Appendices & literature, please see https://www.rehva.eu/activities/covid-19-guidance

[5] An outdated filter classification of EN 779:2012 which is replaced by EN ISO 16890-1:2016, Air filters for general ventilation – Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM).

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recovery equipment may have active microbiological material on them, including viable viruses. This is particularly important in any building where there has recently been an infection. Filters should be changed with the system turned off, while wearing gloves and respiratory protection and disposed of in a sealed bag.

4.10 Room air cleaners and UVGI can be useful in specific situations

Room air cleaners remove particles from the air, which provides a similar effect compared to the outdoor air ventilation. To be effective, air cleaners need to have HEPA filter efficiency, i.e., to have a HEPA filter as the last step. Unfortunately, most attractively priced room air cleaners are not effective enough. Devices that use electrostatic filtration principles instead of HEPA filters (not the same as room ionizers!) often work with similar efficiency. Because the airflow through air cleaners is limited, the floor area they can serve is usually quite small. To select the right size air cleaner, the airflow capacity of the unit (at an acceptable noise level) has to be at least 2 ACH and will have positive effect until 5 ACH [xlvii] (calculate the airflow rate through the air cleaner in m^3/h by multiplying the room volume by 2 or 5). If air cleaners are used in large spaces, they need to be placed close to people in a space and should not be placed in the corner and out of sight. Special UVGI disinfection equipment may be installed in return air ducts in systems with recirculation, or installed in room, to inactivate viruses and bacteria. Such equipment, mostly used in health care facilities needs to be correctly sized, installed and maintained. Therefore, air cleaners are an easy to apply short term mitigation measure, but in the longer run, ventilation system improvements to achieve adequate outdoor air ventilation rates are needed.

4.11 Toilet lid use instructions

If toilet seats are equipped with lids, it is recommended to flush the toilets with lids closed to minimize the release of droplets and droplet residues from air flows [xlviii,xxvi]. Building occupants should be clearly instructed to use the lids. Water seals must work at all times [xxvii]. Regularly check the water seals (drains and U-traps) and add water if required, at least every three weeks.

4.12 Risk of Legionellosis after shut-down

Throughout the duration of the SARS-CoV-2 (COVID-19) epidemic, many buildings have been experiencing reduced use or complete shut-down over extended periods of time. This includes, for example, hotels/resorts, schools, sports facilities, gyms, swimming pools, bath houses and many other types of buildings and facilities equipped with HVAC and water systems.

Depending on a variety of factors, including system layout and design, prolonged reduced (or no) use can lead to water stagnation in parts of the HVAC and water systems, enhancing the risks of an outbreak of Legionnaires' disease (Legionellosis) upon reassuming full operation.

Before restarting the system, a thorough risk analysis should be carried out to assess any Legionellosis risks involved. Several relevant authorities provide information on related risk assessment and restart procedures, including [xlix,l,li,lii,liii].

4.13 IAQ monitoring

The risk of indoor cross-contamination via aerosols is very high when rooms are not ventilated well. If ventilation control needs actions by occupants (hybrid or natural ventilation systems) or there is no dedicated ventilation system in the building, it is recommended to install CO_2 sensors at the occupied zone that warn against underventilation especially in spaces that are often used for one hour or more by groups of people, such as classrooms, meeting rooms and restaurants. During an epidemic it is recommended to temporarily change the default settings of the traffic light indicator so that the yellow/orange light (or warning) is set to 800 ppm and the red light (or alarm) up to 1000 ppm in order trigger prompt action to achieve sufficient ventilation even in situations with reduced occupancy. In some cases, standalone CO_2 sensors or 'CO_2 traffic lights' can be used, see an example in Appendix 4*. Sometimes it may work better to use CO_2 sensors that are part of a web-based sensor network. The signals from these sensors can be used to warn building occupants to use operable windows and mechanical ventilation systems with multiple settings in the right way. One can also store the data and provide facility managers with weekly or monthly data reports so that they know what is going on in their building and in rooms with high concentration, helping them to identify the infection risk.

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5. Summary of practical measures for building services operation during an epidemic

1. Provide adequate ventilation of spaces with outdoor air
2. Switch ventilation on at nominal speed at least 2 hours before the building opening time and set it off or to lower speed 2 hours after the building usage time
3. Overrule demand-controlled ventilation settings to force the ventilation system to operate at nominal speed
4. Open windows regularly (even in mechanically ventilated buildings)
5. Keep toilet ventilation in operation at nominal speed in similar fashion to the main ventilation system
6. Avoid opening windows in toilets to maintain negative pressure and the right direction of mechanical ventilation air flows
7. Instruct building occupants to flush toilets with closed lid
8. Switch air handling units with recirculation to 100% outdoor air
9. Inspect heat recovery equipment to be sure that leakages are under control
10. Ensure adequate outdoor air ventilation in rooms with fan coils or split units
11. Do not change heating, cooling and possible humidification setpoints
12. Carry out scheduled duct cleaning as normal (additional cleaning is not required)
13. Replace central outdoor air and extract air filters as normal, according to the maintenance schedule
14. Regular filter replacement and maintenance works shall be performed with common protective measures including respiratory protection
15. Introduce an IAQ (CO_2) sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately.

More information

https://www.rehva.eu/activities/covid-19-guidance

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/guidance-for-schools-workplaces-institutions

https://www.unicef.org/media/66216/file/Key%20Messages%20and%20Actions%20for%20COVID-19%20Prevention%20and%20Control%20in%20Schools_March%202020.pdf

Feedback

If you are specialist in the issues addressed in this document and you have remarks or suggestions for improvements, feel free to contact us via info@rehva.eu. Please mention 'COVID-19 interim document' as subject when you email us.

Colophon

This document was prepared by the COVID-19 Task Force of REHVA's Technology and Research Committee, based on the first version of the guidance developed in the period between March 6-15th 2020 by REHVA volunteers.

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Perfect pressure balance means we can eliminate leakage between extract and supply air in the GOLD air handling units, even with rotary heat exchangers. Together with our purge control it means you get only fresh outdoor air in the supply air to the rooms. The pressure balance control not only ensures excellent air quality but even saves energy.

With Swegon's Air Quality Control dynamic pressure compensation functionality, the GOLD will adapt to changes in the system, taking control and balance to a new level. Fortunately this only requires the push of a button, not walking the tight rope!

GOLD

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Renovation Wave Strategy announced

REHVA PRESS RELEASE. Brussels, 14 October 2020

Today at a joint press conference at 13:00 the European Commissioner for Energy Kadri Simson and Commission's Executive Vice-President Frans Timmermans announced the long-awaited Renovation wave strategy aiming at doubling the rate of deep energy renovation of European buildings, meaning to renovate 35 million building units by 2030. Simson cited the broad consensus of Member states to support deep renovation and referred to some ambitious national renovation plans in EU countries, like France and the Netherlands. The Renovation Wave shall contribute to the EU goals of cutting CO_2 by 60% by 2050.

Decarbonising buildings including the heating and cooling systems is at the heart of the strategy, stressed the Commissioner on questions form the press. Timmermans added that Europe needs a holistic view regarding decarbonisation, it is not only about buildings, but a large-scale transformation by greening cities and creating the necessary energy infrastructure to achieve our climate goals. The plan will focus on the worst performing building stock and the most vulnerable citizens.

"We are very glad to see the ambitious details of the Renovation wave strategy," said Anita Derjanecz, REHVA Managing Director. "The Renovation wave is as a huge opportunity for our sector to improve indoor environment quality along energy performance of our buildings. The strategy focuses financial resources on deep energy renovation especially in the public and residential sectors, targeting public buildings, schools, and hospitals. I hope it will govern the high quality and ambitious implementation in member states. I also welcome that the strategy acknowledges the key role of independent technical assistance in quality and upscaling or renovation."

The Renovation Plan was published* today on the EC website. High health and environmental standards and ensuring high air quality is among the key principles of the Renovation Wave, along Energy efficiency first principle, Life cycle thinking and circularity, Decarbonisation and integration of renewables and the green digital transformation.

Press release** of the EC on the Renovation Wave. ■

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* https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf

** https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1835

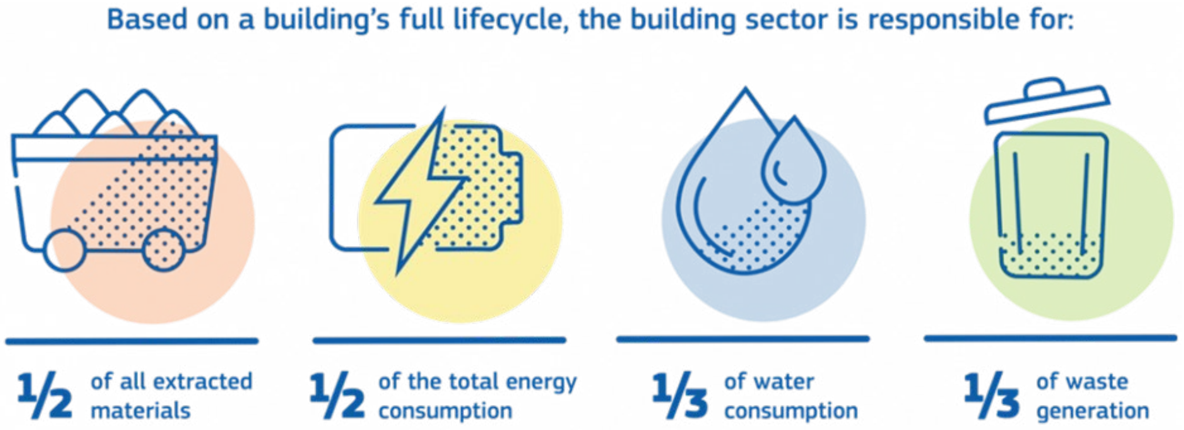
Level(s) – a sustainable buildings framework for all

Europe at the forefront of the green transition

The EU aims to lead by example on the issues of sustainability, circularity, and zero carbon emissions. Further fuelled by the health and economic effects of the COVID-19 crisis, **2020 is proving to be "the" year for Europe's green transition**.

The EU Green Deal, launched in December 2019, set out the EU's climate-neutral ambitions. The new Circular Economy Action Plan, launched in March 2020, sets the agenda for sustainable growth, making the EU economy greener while maintaining its competitiveness and securing new rights for consumers.

In the meantime, the European Commission has launched the Renovation Wave, its strategy for decarbonisation and clean energy systems, and is preparing roadmaps for further sustainability actions like the EU Climate Law and the Sustainable Europe Investment Plan. **And, now, it has officially launched Level(s).**



Any project to create sustainable buildings involves an analysis in depth of all built environment project stages and across the building chain. Architects, designers, manufacturers, engineers, builders, investors, property developers, property managers (not to mention future tenants) – all of them have their own sustainability needs and challenges. All of them have their own contribution to a building's carbon footprint, and we cannot modernise or improve buildings without the full participation of all actors in the built environment. With that in mind, **Level(s) is the first-ever European Commission framework for improving the sustainability of buildings, living by the values of flexibility, resource efficiency, and circularity.**

Carbon-neutrality is one of the biggest keywords in EU environmental policy. It is therefore no wonder that buildings and the construction sector are mentioned in the EU Green Deal as one of its areas of action. The Circular Economy Action Plan takes this one step further by mentioning Level(s) as a framework for construction and buildings to increase sustainability, with important implications for areas such as Green Public Procurement.

Level(s) also underpins several actions in another important new European Commission initiative, the Renovation Wave. A refurbished and improved building stock in the EU will have to be based on life cycle thinking and circularity principles and this is where Level(s) can support these actions.

Renovation of both public and private buildings is an essential measure in this context, and has been singled out in the European Green Deal as a key initiative to drive energy and resource efficiency in the sector and deliver on objectives.

"The concept behind the Level(s) framework started to take form once the building sector became a key area of action for the European Commission in terms of resource efficiency and circular economy", recounts **Kestutis Sadauskas, Director for ENV.B – Circular Economy and Green Growth at the European Commission's Directorate-General for the Environment (DG ENV)**. "*We realised that, to truly achieve sustainable transformation in the building sector, we need a common language that not only could be used across the building chain, but also help with data comparison across different countries.*"

So how is the Level(s) framework different from other certification schemes or assessment tools?

To start with, Level(s) is not a certification scheme. It does not come with benchmarks. It sets out a methodology for how to work with a limited number of indicators, which together represent the key aspects of a building's sustainability performance over the life cycle. In this way, it provides a common language, to inspire other initiatives to align themselves with. Level(s) was designed to encourage users to think about the whole life cycle of a building, providing a basis for quantifying, analysing and understanding the life cycle. It goes beyond a building's service life and value by including elements that happen before and after this stage, also providing indicators for recovery, reuse, and recycling of materials. When using Level(s), the user is sovereign: they choose how to implement Level(s), adapting it to their needs, pace, and understanding of the framework.

A Level(s) journey can start by implementing standard data as an entry point, and later working with more specific data items that even better represent the building project, as familiarity with the framework increases.

Level(s) can be used also for a project not undergoing certification, but which simply wants to start the sustainability journey and wants to reflect on objectives linked to sustainability performance from the beginning of a project and throughout, to understand the impacts of different design options.

Moreover, having been directly involved in the development of the Level(s) methodology, many existing certification schemes are currently looking at how to align themselves with the common language that the Level(s) indicators provide. In this way, Level(s) is also likely to impact certification of buildings.

"*The end goal is that, by using Level(s), users are investing in a cost-effective framework that helps them future-proof their building projects in line with circular economy, whole life carbon performance and other green policy goals*", explains Kestutis Sadauskas. "*We know from the Level(s) testing phase that the building sector sees the common language and metrics, and the fact that different stages of the building chain came together to find a common solution, as an important added value of this framework. In a way, we are not just harmonising data and metrics: we are also harmonising the built environment's vision of a sustainable future.*"

All in all, Level(s) is perfectly placed to help the building sector transition into a sustainable future.

Developing Level(s) – testing phase testimonials from manufacturers, investors, property developers

The Level(s) framework started being developed back in 2015 by the European Commission. It started as a great collaboration between a large number of building professionals, and it benefitted from pan-EU knowledge and expertise. The publication of the Level(s) beta version in 2017 marked the beginning of the framework's testing phase. Between 2017 and 2019, the Level(s) indicators were tested by more than 130 projects (both residential and non-residential, in new built and renovation) in 21 EU member states.

Among the Level(s) testing audiences were manufacturers, investors, and property developers – who were particularly keen to assess Level(s) added value to sustainability, circularity and quality of life as a tried-and-tested European Commission framework.

"*Level(s) is an escalator, a virtual 'travellator' on which to start and progress the journey towards better buildings.*", explains **Philippa Gill**, who was deeply involved in Level(s) testing phase. "*By this, we mean buildings that are better for those who occupy them, as well as have a low impact and hopefully even, one day, contribute positively to the environment.*"

Likewise, **Bionova / One Click LCA** was part of the Level(s) pilot process in Finland through their *Carbon Heroes Benchmark Program* for 1000 buildings. The framework was very well received by the Finnish building sector. *"Level(s) has increased the interest of public authorities and new stakeholders about whole life cycle thinking in the construction and built environment*", remarks **Panu Pasanen, Bionova / One Click LCA's CEO**. "*It has increased the understanding of the need to simplify and speak in common terms about sustainable performance of buildings, which helps people to change information and work together in the complex supply chain in the construction industry.*"

Still in Finland, the manufacturing company **Stora Enso** also led one of the Level(s) testing projects by incorporating the framework's indicators in their *Lighthouse Joensuu* project. With Level(s) informing embodied carbon calculations through its life cycle assessment (LCA) indicators, this 14-floor residential building reported resource efficiency as mass of building materials based on the bill of materials. The data allowed the project to calculate impacts of life cycle global warming from cradle to grave.

"In addition to the Lighthouse Joensuu building, we also used the Level(s) framework to calculate sustainability performance of our schools concept. The learnings of both projects have been summarised in the Level(s) Testing report from the Finnish Ministry of Environment", told us **Roy Antink, Stora Enso's Senior Vice President**. "*Level(s) has the potential to help mainstream circular and low-carbon building. It can be the common language that aligns the value chain and drives life cycle thinking from early idea inception. What is more, it can be used by (sub)national governments to measure progress on key issues such as embodied carbon and resource use – in a word, circularity.*"

Level(s) was also tested in through the LIFE Level(s) project, which was led by the Spanish Green Building Council and involved seven other Green Building Council entities. The project explored the way Level(s) indicators can be implemented on a pan-European scale through certification, data, procurement, and training.

The Lighthouse Joensuu building (Finland), one of the projects testing the Level(s) framework in 2017–2019.

The results and findings from the Level(s) testing phase have been crucial in developing the final version of the Level(s) framework, which will ensure a streamlined assessment and reporting process. It will also facilitate a quicker generation of comparable data, thanks to its provisions for knowledge-sharing across countries, companies, and throughout all stages of a building project.

"It has been fantastic to witness the enthusiasm of the building sector, with companies and authorities from start to end of the building chain, in testing and promoting Level(s) as a reliable, future-proofed framework", remarks Kestutis Sadauskas. *"It bodes well for a sustainable future in the building sector, and for the adoption of Level(s) across Europe now that the final version of the framework has been launched".*

Getting involved

Following the launch of the Level(s) framework, it is important to spread the word and facilitate access to this framework for all building sector actors, big or small. So what is the best place to start for those investors and property developers wishing to engage with Level(s)?

"*The first step for investors and property developers will be to start requiring projects teams (designers, developers, …) to deliver documents and information using the Level(s)-based assessment; and using the matrix to report back on the progress of the project from the early phases in particular.*" Recommends Panu Pasanen. "*Level(s) will help in understanding the impacts of decisions and how projects are doing in terms of building sustainability.*"

The same idea is corroborated by Philippa Gill: "*Level(s) provides a clear pathway towards a low carbon real estate market. It allows any property owner or manager to begin the journey to a more sustainable market at whichever point of the journey they are currently at; it then guides the users to use more advanced scenarios, and deeper investigations, ensuring that their journey continues".*

When it comes to manufacturers, and according to Stora Enso's Roy Antink, the important thing is to start incorporating it as part of each product's process: *"Level(s) represents the future of building construction. Regardless of its state as voluntary tool now, it is good practice to consider the framework as part of your product innovation and management. Doing so will help you future proof products and assets."*

Building sector companies can also learn more about Level(s) through the upcoming Level(s) Stakeholder Briefing Sessions. This fully digital series of events was developed to better inform building sector entities about the benefits of Level(s), and to help new users as they begin their Level(s) journey.

The Level(s) framework

Level(s) is an assessment and reporting framework that provides a common language for sustainability performance of buildings. Level(s) promotes lifecycle thinking for buildings and provides a robust approach to measuring and supporting improvement from design to end of life, for both residential buildings and offices.

Level(s) uses core sustainability indicators, tested with and by the building sector, to measure carbon, materials, water, health and comfort, climate change impacts. It takes into account lifecycle costs and value assessments.

Level(s) is open source and freely available to all.

For all those in the sector, the challenges of cost control and environmental gain are met both by the reduction in energy, materials, and water use; and by future-proofing buildings. For those commissioning, designing, or occupying buildings, Level(s) helps them ensure that their high quality, fit-for-purpose buildings meet their cost and environmental objectives. ■

The Level(s) framework was officially launched on 15 October 2020. To know more or get involved in this European Commission led framework for sustainable buildings – including the upcoming Level(s) Stakeholder Briefing Sessions - visit https://ec.europa.eu/environment/eussd/buildings.htm or contact **Ms. Josefina Lindblom**, leading the work on Level(s) at DG ENV, at ENV-LEVELS-TESTING@ec.europa.eu.

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Renovation wave strategy on the way to a climate neutral Europe

The Commission published the Renovation Wave Strategy setting ambitious targets for building renovation and the modernisation of heating and cooling systems to achieve in the next 10 years. The strategy also announced the unexpected revision of the EPBD along other directives in 2021 that may open a new opportunity to advocate for strengthening requirements on improved indoor climate quality in energy renovation. This article provides a first review of the most relevant aspects of the strategy.

Author: **ANITA DERJANECZ**, REHVA Managing Director

Renovation wave strategy targets and key principles

On 14 October, the European Commission published the long-awaited Renovation Wave Strategy Communication* (COM(2020) 662) setting ambitious objectives to reach in the next 10 years. The strategy aims to at least double the current annual renovation rate (from 1% to 2%), to reduce 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.

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* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0662

The strategy defines 7 key principles for energy renovation. High air quality and environmental standards is one of them, however IEQ is mostly considered in relation with energy poverty, the communication is missing the point that inadequate indoor climate quality is a relevant problem in all buildings hat is affecting people's life in the entire society.

- *Energy efficiency first* to make sure we only produce the energy we really need.
- *Decarbonisation and integration of renewables.* Building renovation should speed up the integration of renewables from local sources and promote broader use of waste heat. It should integrate energy systems at local and regional levels helping to decarbonise transport as well as heating and cooling.
- *High health and environmental standards.* Ensuring high air quality, good water management, protection against climate-related hazards, protection against harmful substances, fire and seismic safety and accessibility.
- Tackling *green and digital transitions* together to enable highly efficient and zero-emission buildings. Smart buildings with smart energy distribution systems can enable efficient production and use of renewables at house, district, or city level.
- *Lifecycle thinking and circularity* to minimise the caron footprint of buildings, turning parts of the construction sector into a carbon sink through the promotion of green infrastructure and the use of organic building materials.
- *Affordability*, making energy-performing and sustainable buildings available for medium and lower-income households and for vulnerable people and areas.
- *Respect for aesthetics and architectural quality*. Renovation must respect design, craftsmanship, heritage, and public space conservation principles.

Unexpected revision of the EPBD and other directives

The Renovation Wave communication announces unexpected revision of all the key building and energy related directives (EPBD, RED, EED) in certain aspects, and defines a timeline for the revisions and introduction of strengthened policies. These directives were recently revised in 2018 according to their immanent requirements. The new revisions open the possibility of further advocacy for stronger IEQ requirements linked to the specific points under revision.

By the end of 2021, the revision of the EPBD will strengthen the obligations on Energy Performance Certificates and introduce mandatory minimum energy performance standards for all types of buildings defined in the EPBD. It will also consider introducing a "deep renovation" standard as part of the measures for reinforced and targeted funding supported by technical assistance.

By June 2021, the Commission will propose the revision of the EED to extend the scope of the renovation requirements to all public administration levels and to increase the annual renovation obligation. The requirements on energy audits will be also revised to tackle the still existing quality and trust issues related to EPCs. To foster the decarbonisation of heating and cooling the EED revision aims at strengthening the capacities of public authorities to prepare, finance and implement

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the modernisation of heating and cooling in coordination with renovation projects to projects.

The requirement of decarbonising the building sector put a strong focus on heating and cooling. The revision of the RED will strengthen the renewable heating and cooling target and 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 will explore a toolbox of measures to promote advanced heating and cooling, including highly efficient low-temperature renewable and waste heat and cold technologies.

Digitalisation of EPCs

Although tackling the green and digital transitions is one of the key principles of the strategy, this is not addressed comprehensively by the measures of the strategy.

The digitisation and digitalisation of EPCs, one key aspect, is addressed though. The Commission will propose to update the EPC framework considering emerging energy performance metering technologies. This will include a uniform EU machine-readable data format for the certificates and more stringent provisions on availability and accessibility of EPC databases and federated digital repositories. As a further step, by 2023 the Commission aims to table a proposal on Building Renovation Passports and the introduction of a single digital tool unifying them with Digital Building Logbooks that will integrate all building related data provided by the upcoming Building Renovation Passports, Smart Readiness Indicators, Level and EPCs to ensure compatibility and integration of data throughout the renovation journey.

In 2021, the Commission will be also presenting a unified EU Framework for digital permitting and recommending Building Information Modelling in public.

Technical Assistance for financing

Technical assistance is considered by the strategy is a major tool to ensure more well-targeted funding, stimulate private financing and increase capacities in the public sector to implement renovation projects. The strategy plans to strengthen the European Local Energy Assistance (ELENA) facility and member states or regional authorities to replicate the model at national level. A new Technical Support Instrument of the Recovery Plan along other measures should help and increase capacity in public authorities.

However, technical assistance should not aim only at financial planning and project development, more emphasis should be put as on the technical monitoring and quality management along the entire construction life cycle delivering in-use performance improvement.

Future EU funding for energy research and building renovation

The last year of Horizon 2020 saw the launch of the European Green Deal Call with a budget of €1 billion supporting pilot applications, large scale demonstration projects and innovative products, as well as governance, value chain and social innovation.

In the new multiannual financial framework (MFF), still not adopted by the Council, the EU budget for research and market uptake of building renovation available under the Horizon 2020 Programme will continue in a different programme structure from 2021.

The EU budget to address market barriers to building renovation will move under the proposed LIFE programme 2021-2027 with four sub-programmes, several highly relevant for the building sector and renovation. The proposed LIFE Clean Energy Transition sub-programme with €1 billion total budget of will continue to support market-uptake projects currently funded from Horizon 2020 Energy Efficiency. Moreover, the proposed LIFE Circular Economy and Quality of Life sub-programme, with a €1.35 billion is dedicated to innovative approaches on lifecycle impacts and materials efficiency in the built environment. The Build Up Skills initiative that continues under the LIFE programme.

The current Horizon 2020 programmes for energy ang building technology related research and innovation will continue under the Horizon Europe programme, the detailed budget lines are not yet approved. The new Built4People private-public partnership (People-centric Sustainable Built Environment) that is being developed to bring together all relevant actors across the buildings and construction value chain to develop innovation for the transformation of the built environment towards sustainability.

The ELENA facility and the Project Development Assistance (PDA) of Horizon 2020 will continue under the Invest EU Advisory Hub. ■

Daikin is planning a cutting-edge development complex in Ghent

Impression of the preliminary design.

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Focus on the latest technologies for Europe

Daikin Europe N.V. (DENV), the European subsidiary of Daikin Industries Ltd., and leader in the field of climate solutions, has chosen Ghent as its new location for the EMEA Development Center (EDC).

The current EDC headquarters in Ostend and the branch in Ghent are slowly starting to burst at the seams. The EU is one of the pioneers with regard to climate-neutral initiatives, not least through its EU Green Deal policy (for the acceleration of decarbonisation). It's precisely in this area that the EDC plays a unique role, through its research into and development of innovative, energy-efficient alternatives to traditional heating solutions, new heat pump technology and solutions for cold chains (food and pharmaceutical products).

The EDC needs additional capacity, test chambers and larger research facilities equipped with the latest technologies. It is therefore planning the construction of a cutting-edge development complex on the Science Park site of Ghent University in the second half of 2021. The new and more extensive EDC is also very important for DENV with a view to the further development of new technologies.

Need for additional facilities

Since the foundation of Daikin's EMEA Development Center in Ostend in 2012, the leading European research platform has experienced an explosive expansion with, among others, satellite centres in Ghent, Pilzen (Czech Republic), Güglingen (Germany) and Hendek (Turkey).

Kazuhide Mizutani, General Manager EDC: "We are currently working with almost 220 R&D employees in our branches in Ostend and Ghent. This is an increase of about 140% since the foundation of the EDC in 2012. From our start-up, we have expanded our research infrastructure and built additional test chambers for temperature control. All this as a result of the increasing demand for energy-efficient alternatives to traditional heating solutions. If we want to stay ahead of the market needs and the clear environmentally friendly orientation of Europe, then further expansion is imperative."

The growth of this research market is mainly prompted by the international shift towards the phasing out of heating systems running on fossil resources in the long term. Fossil fuels are becoming scarce, and there is a global drive to reduce CO2 emissions. With its EU Green Deal policy (the acceleration of decarbonisation), Europe is playing a pioneering role in this field, and promoting energy-efficient alternatives to traditional heating solutions.

With its heat pumps, Daikin has an innovative technology that offers an environmentally friendly and energy-efficient alternative. The proportion of heat pumps within the heating market is therefore strongly growing. In addition, the industry is also increasingly looking for solutions for cold chains (food and pharmaceutical products – just think of the upcoming COVID-19 vaccines) and new heat pump technologies. Here as well, the EDC is a spearhead in terms of research and development in Europe.

Ghent = ideal location

Following a study into the ideal new location for the headquarters of the EMEA Development Center, Daikin Europe N.V. had its eye on the Ghent University Science Park.

As a Top 100 university, UGent has a renowned doctorate programme in 'Mechanical Engineering', and is, in that sense, a significant source of future employees. UGent and the EDC have already worked together, and will intensify their collaboration at the new site in the field of new heating technologies, the Internet of Things and Artificial Intelligence.

A planned investment with a total value of 140 million euro at the UGent Science Park in Zwijnaarde

The new building will consist of two parts: test facilities and office space. The test areas, with a total surface of about 4,000 m², will be among the most advanced of their type worldwide. The most modern EMC (ElectroMagnetic Compatibility) chambers will be installed, as well as test chambers for, among others, specific particles, discharge and material analyses. Daikin is planning the implementation of the new building following the most advanced energy-efficient standards, including nZEB (nearly Zero Energy Building), and a BREEAM Excellent certificate.

The office accommodation will amount to about 13,000 m², and provide space for roughly 500 employees. Daikin Europe N.V. expects to be employing around 380 employees at the EMEA Development Center by 2025. The remaining space in the office building can be taken up by employees from UGent or other research companies.

The preparatory work could start towards the end of the summer of 2021. The intention is to inaugurate the test building in May 2023, and to take the office area into use at the end of 2023.

Close cooperation with the social partners

Daikin Europe N.V. intends to bring the respective employees over to the new workplace in the best possible conditions. The management informed the social partners of its plans during today's Works Council meeting. They will now investigate together how this relocation can be carried out as smoothly as possible, with the utmost attention to the concerns and focus areas of the employees and the social partners, in line with the tradition of the company.

The EMEA Development Center will also unabatedly continue its search for interesting R&D profiles. ■

For additional information:
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Hilde Goossens
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uponor

Photos: Roman Gerike

Uponor supplied more than 400 heat interface units and 300 kilometres of underfloor heating/cooling pipe for the Grand Tower in Frankfurt am Main, Germany.

Decentralised heating and cooling distribution for Germany's tallest residential building

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Uponor has supplied more than 400 heat interface units and 300 kilometres of underfloor heating/cooling pipe for the Grand Tower in Frankfurt am Main.

- Award-winning building project with high-quality apartments in pioneering architecture
- Specially designed heat interface units for clear system separation and comfortable temperatures at all times
- Reduction of system pressure, simple retrofitting and fast troubleshooting

The Grand Tower in Frankfurt, which is now the tallest residential complex in Germany, was completed in June 2020. Inside the building, Uponor has implemented one of the largest contracts in the company's history. More than 400 apartments and penthouses in the building are fitted with Uponor heat

Germany's tallest residential complex now enhances the Frankfurt skyline.

The Grand Tower has 47 floors with more than apartments – all are equipped with heat interface stations from Uponor.

Products

- Heat and cold distribution: more than 400 Uponor heat interface units
- Underfloor heating / cooling: 300,000 metres Uponor Comfort Pipe, 16 × 1.8 millimetres

interface units (HIU). The main reason for awarding the contract was the high demands placed on the heating and cooling supply of the luxury homes. Thus, the solutions developed specifically for the project ensure optimum individual temperature comfort for residents as well as the clear separation of the primary and secondary networks in the building. The compact units were supplied as a complete package with ready-wired control technology, accelerating work procedures on-site. In addition, around 300,000 metres of Uponor Comfort Pipe are used for underfloor heating/cooling in the residential high-rise.

The Grand Tower built in Frankfurt's Europa district boasts an impressive, dynamic architecture and exclusive living comfort. The ground-breaking project thus received numerous prestigious awards such as the German Design Award and the International Property Award 2017 in advance. Indeed, the 47-storey residential high-rise offers occupants a variety of highlights, including a lobby with concierge service, a 1,000 m² roof garden and a sundeck at a height of 145 metres. Measuring between 41 and 300 m² in size, the apartments offer floor-to-ceiling windows for an impressive view of Frankfurt and the Taunus region.

Transfer points for heat and cold

These high demands in terms of flexibility and comfort are reflected in the heating and cooling supply used in the skyscraper, which is based on a district heating connection with a capacity of 2.5 MW and two chillers installed on the roof, each with an output of 600 kW. The heat interface units serve as transfer points for heat and cold to the living areas. They are supplied with heating and cooling water via the risers and use

Project partners

- Client: gsp Städtebau GmbH, Berlin
- Architect: Magnus Kaminiarz & Cie. Architektur, Frankfurt am Main
- Planning of building services: ventury GmbH, Dresden
- Execution of building services: Fachbetrieb Mathias GmbH, Waltershausen
- Supplier: Uponor GmbH

integrated heat exchangers to ensure clear system separation as well as demand-based energy distribution to the individual consumers. On the lower floors up to the 42nd storey, the residential units are equipped with underfloor heating/cooling and a bathroom radiator, while the upper floors also have cooling ceilings.

Individual living comfort

The separation of the primary and secondary heating and cooling circuits in the residential high-rise has a number of advantages. Residents can use the units to adjust room temperatures to meet their individual needs completely independently of the overall system. This also applies to the automatic switching between heating and cooling mode, which significantly increases living comfort. The six-way ball valve integrated into the decentralised HIU ensures that consumers are reliably supplied with the required flow rate of hot and cold water at all times in both heating and cooling modes.

Because the residential units are decoupled, if there is a malfunction in the complex system, the source of the fault can be identified quickly. If the fault lies in the living area, the remainder of the heating/cooling system will remain fully operational during the repairs. The units also make it easy to retrofit a cooling ceiling, as the necessary connections are already available and retrofitting can be carried out without affecting the rest of the system.

Safe and certified

At the same time, high pressure is required in the risers to ensure reliable distribution of energy in the complex and is effectively balanced by the heat interface units. For this purpose, extensive tests were carried out with the piping used in the solutions in order to have them certified for nominal pressures of up to PN 25. In addition, dynamic differential pressure regulators are used to reduce the system pressure (PN 16) to the optimum level for the secondary circuits during the transfer to the heating circuits.

The precise adjustment of the heat interface units to the stringent demands of the building played a major role in awarding the contract. In addition, Uponor provided the project partners with extensive advice and support. The high level of flexibility required in the production of the interface units was also key, as ten units per week had to be delivered to the construction site in the initial phase. ■

The Uponor heat interface units were specially designed for the Grand Tower project. They serve as transfer points for heat and cold to the living areas and include integrated six-way ball valves.

Throughout the Grand Tower, residents can adjust the room temperatures of their apartments to meet their individual needs.


21.0°C
uponor
uponor
Master bedroom
21.2
22.0

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

Exhibitions, Conferences and Seminars in 2021

Conferences and seminars 2021*

10-12 January 2021	Climamed 2020	Lisbon, Portugal	http://www.climamed.org/en/
15 February 2021	Roomvent 2020	**Online**	http://roomvent2020.org/
9-11 February 2021	Winter Conference 2021	**Online**	https://www.ashrae.org/conferences/2021-virtual-winter-conference
22-26 March 2021	ISH 2021	**Online**	https://ish.messefrankfurt.com/frankfurt/en.html
8-9 April 2021	Mostra Convegno Expocomfort 2021	Milan, Italy	https://www.mce-livedigital.it/MCE_ENG.html
20-21 April 2021	Cold Climate HVAC & Energy 2021	**Online**	https://www.scanvac.eu/events.html
21-23 June 2021	Healthy Buildings Europe 2021	**Online**	https://www.hb2021-europe.org/
15-18 August 2021	Ventilation 2021 - 13th International Industrial Ventilation Conference for Contaminant Control	Toronto, Canada	https://www.ashrae.org/conferences/topical-conferences/ventilation-2021
13-15 September 2021	IAQ 2020 – Indoor Environmental Quality Performance Approaches	Athens, Greece	https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches
29 Sept-2 Oct 2021	ISK Sodex 2021	Istanbul, Turkey	http://www.sodex.com.tr/

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

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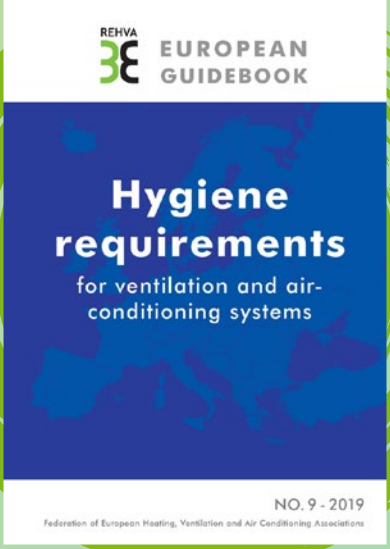
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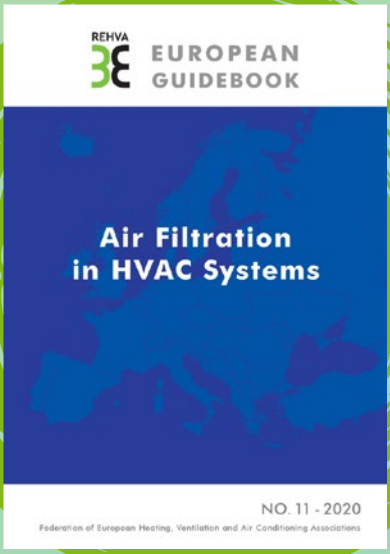
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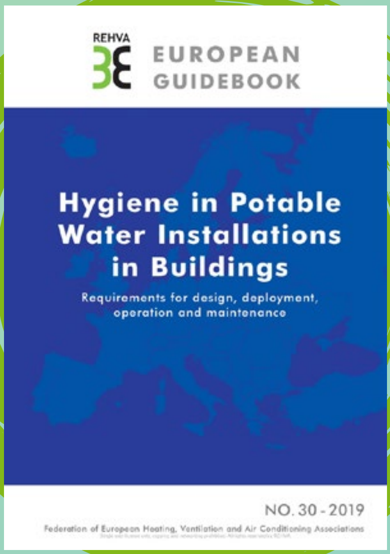
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