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How to calculate EP-value according to revised EPBD?

REHVA experts developed a guidance explaining EPBD

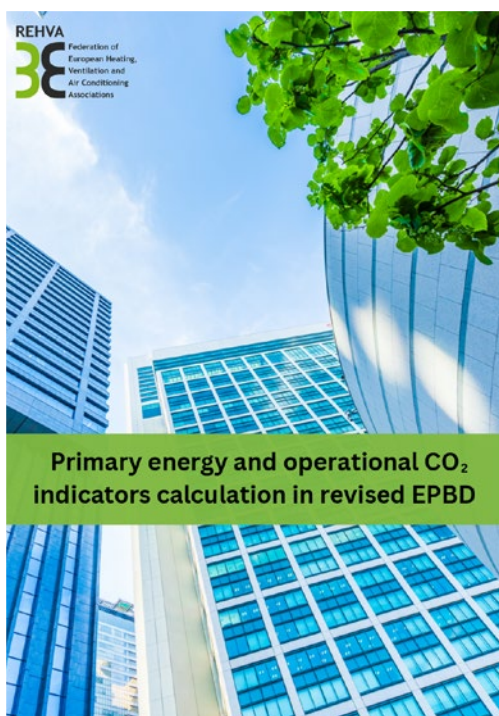
Revised EPBD includes many new items among which EP-value calculation based on the total primary energy instead of non-renewable primary energy maybe seen as a fundamental change. How to calculate EP-value according to EPBD recast and set corresponding energy and operational CO₂ thresholds for zero emission buildings would be a great question for energy experts in all Member States starting to implement the directive. REHVA experts have prepared methodology including assessment boundaries and calculation rules illustrated with calculation examples for primary energy and CO₂ indicators to support harmonised implementation of EPBD so that the ‘energy efficiency first’ principle is followed.

Efficiency first principle stresses that energy consumption both from non-renewable and renewable energy carriers should be minimised through efficiency measures, and to cover the remaining energy consumption, renewable energy generation should be used as much as possible. While non-renewable primary energy factors and CO₂ coefficients may to

approach zero, the total primary energy factors cannot be smaller than one by the definition. This provides stable environment for energy calculations as well as for end users because energy prices tend to increase in green transition.

EPBD formally adopted on April 12 will now be published in the Official Journal of the EU. Member states have two years to implement the directive into national legislation. There are technically complicated new items of IEQ which successful and harmonised implementation could be supported by HVAC associations expert bodies. Therefore, in addition to energy and CO₂ indicators calculation issues REHVA calls Member Associations to follow and support the implementation of addressing *optimal indoor environmental quality* as stated in new buildings Article 7 and existing buildings Article 8. Also note the new definition of IEQ in Article 2.

These important additions call to establish or update ventilation and IAQ requirements to support the application of demand-controlled systems in non-residential buildings, because in this context both too small or too high ventilation is not optimal. For the first time, Article 13 says clearly: “Member States shall set requirements for the implementation of adequate indoor environmental quality standards in buildings in order to maintain a healthy indoor climate.” Perhaps the most important change is the requirement for non-residential zero emission buildings in Article 13 to equip these buildings with measuring and control devices for the monitoring and regulation of indoor air quality. How about HVAC industry – do we have a robust and reliable demand-controlled systems for European wide application? ■



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Technical Guidance for EPBD Implementation

v. 18 March 2024

From the EPBD Implementation Guidance Task Force, REHVA Technology and Research Committee

Primary energy (PE) indicator is the main energy performance (EP) indicator in Energy Performance of Buildings Directive (EPBD). It is used for setting minimum requirements and in most Energy Performance Certificate (EPC) rating scale. The EPBD under revision has provided some important changes in the primary energy calculation having an impact both on indicators for Zero emission building/Nearly zero energy building (ZEB/NZEB) and EPC classes.

This document was prepared by REHVA Technology and Research Committee, EPBD Implementation Guidance Task Force.

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This document elucidates EPBD principles and provides examples of energy and operational CO₂ calculations for a NZEB reference building situated in three distinct European climates. While many articles on the EPBD employ vague terminology regarding ‘primary energy,’ the total primary energy is specified to denote the ZEB energy performance level, with primary energy factors (*PEF*) delineated for non-renewable, renewable, and total primary energy. This document clarifies the recommended methodology for calculating primary energy and operational CO₂ thresholds to facilitate national harmonised implementation.

1. Introduction

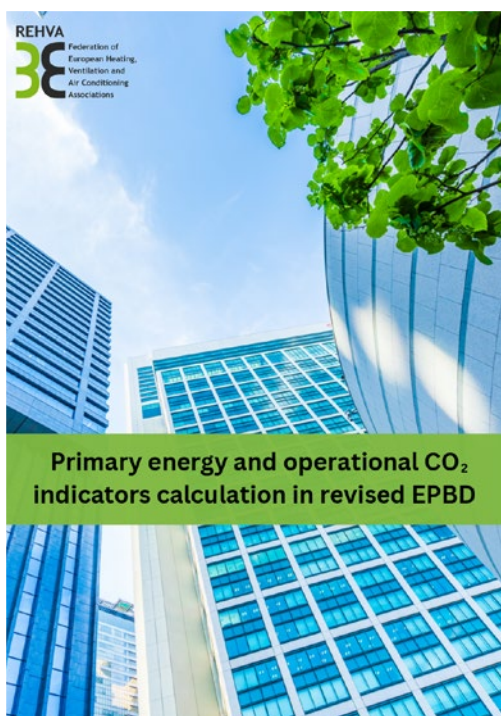
In principle, the EPBD follows the same energy definitions framework as utilized in directives like the Energy Efficiency Directive (EED) and Renewable Energy Directive (RED), with the shared objective of reducing total primary energy consumption and encouraging the use of renewable energy sources. However, applying the EPBD in the context of buildings presents challenges, particularly regarding the utilization of freely available on-site ambient energy for technologies such as heat pumps and solar panels. This raises the importance of adhering to the efficiency-first principle outlined in the EPBD, which prioritizes reducing energy consumption before utilizing renewable energy sources.

The application of this principle in energy calculations and the establishment of relevant primary energy indicators necessitates a thorough examination of the EPBD assessment boundary and key definitions,

while also considering the principle's implications for accounting for the positive effects of renewable energy. For instance, determining whether on-site PV energy should be considered as delivered energy, and whether ambient energy should be included or excluded in the total primary energy indicator, requires careful analysis. Similarly, accounting for self-used and exported PV electricity when calculating total or non-renewable primary energy indicators is crucial.

Furthermore, while the EPBD introduces new requirements to cover ZEB total primary energy with renewable or carbon-free energy, as well as district heating/cooling, the calculation of these requirements warrants examination.

Additionally, while the primary energy indicator is supplemented with an operational CO₂ indicator, it is essential to note that the energy calculation remains fundamentally the same; only different factors are applied to calculate primary energy and operational CO₂ emissions from delivered energy values. The introduction of the operational CO₂ indicator serves as a new metric to be used alongside the total primary energy indicator for ZEBs, while other minimum requirements and the EPC rating scale will continue to be based on primary energy considerations.



2. EPBD ZEB requirements

Zero Emission Buildings are defined in EPBD Articles 2 (2), 7, and 11. ZEB requirements include as set in Article 11:

- ZEB cannot cause any on-site carbon emissions from fossil fuels (1).
- Maximum threshold for the energy demand of a ZEB shall be set with a view to achieving at least the cost-optimal levels (2). The maximum threshold for the energy demand of a ZEB shall be at least 10 % lower than the threshold for total primary energy use established for nearly zero-energy buildings (3).
- Maximum threshold for the operational greenhouse gas emissions of a ZEB shall be set (5).
- The total annual primary energy use of a new or renovated ZEB shall be covered, where technically and economically feasible, by (7):
 - a) energy from renewable sources generated on-site or nearby, fulfilling the criteria laid down in Article 7 of Directive (EU) 2018/2001 (RED);
 - b) energy from renewable sources provided from a renewable energy community within the meaning of Article 22 of Directive (EU) 2018/2001 (RED);
 - c) energy from an efficient district heating and cooling system in accordance with Article 26(1) of Directive (EU) 2023/1791 (EED);
 - d) energy from carbon free sources.
- ZEB shall offer the capacity to react to external signals and adapt its energy use, generation, or storage, where economically and technically feasible (1).

The EPBD does not explicitly define a threshold for energy demand, since the EPBD defines 'energy needs' and 'energy use/energy consumption', but not 'energy demand'. Nevertheless, it stipulates that such a threshold should be at least 10% lower than the threshold for total primary energy for NZEBs. This requirement allows for the consideration of different energy indicators in addition to total primary energy when comparing to the total primary energy of NZEBs.

Furthermore, while the EPBD lacks clarity on the specification of energy demand thresholds, it clearly mandates the calculation of the total annual primary energy use for ZEBs. The subsequent analysis delves into how the calculation of total primary energy is specified within the EPBD.

Summary of key guidelines for primary energy calculation

The EPBD follows 'efficiency first' principle meaning that the total primary energy, including both renewable and non-renewable primary energy should be minimised. Transition to the total primary energy and operational greenhouse gas emissions are clearly expressed for ZEB while there is more freedom for EPC.

In buildings, calculating total primary energy can be challenging due to the utilization of freely available on-site ambient energy for technologies such as heat pumps, as well as the utilisation of on-site solar radiation for solar boilers or photovoltaic (PV) panels, which may not be fully accounted for. Applying the EPBD in accordance with the efficiency-first principle involves initially reducing energy consumption through efficiency measures and subsequently utilizing renewable energy sources to cover the remaining consumption. This document analyses how this fundamental principle can be applied in energy calculations and in establishing relevant primary energy indicators.

According to EPBD definitions, total primary energy should be calculated from delivered energy, which refers to the energy supplied through the assessment boundary. However, the EPBD does not explicitly define the assessment boundary, leading to various options and interpretations for primary energy calculation in national implementations.

In this document, it is proposed to calculate EP-values based on total primary energy and operational CO₂ from delivered energy to the building site. This approach ensures that on-site generated and self-used renewable electricity and ambient energy do not increase the EP-value, as they are not treated as delivered energy. Consequently, the calculation is based on the same energy flows for non-renewable, total primary energy, and operational CO₂, albeit with different factors. This principle aligns with the EPBD rationale of reducing energy consumption and increasing the use of energy from renewable sources, particularly through solar energy installations and heat pumps.

Two assessment boundary options are proposed, as illustrated in **Figure 1** and **2**, following the EN ISO 52000-1 building assessment boundary. These options are complemented either with an exclusion matrix or a building site boundary for primary energy calculation, both leading to the same result. Ambient energy and on-site generated renewable energy are not added to the total primary energy indicator, as the goal is to minimize total primary energy and operational CO₂ from the energy grids.

In addition to outlining the primary energy and operational CO₂ calculation procedure, this document discusses ZEB requirements, energy and operational CO₂ thresholds, and the coverage of total primary energy on an annual basis with renewable and carbon-free energy. Calculation examples for a NZEB reference building are provided for three European climates.

3. Total primary energy calculation in revised EPBD

The EPBD includes main definitions and principles for setting an assessment boundary and calculating primary energy. The following definitions constitute the starting point for the primary energy indicator calculation in EPBD:

- Art 2 definition 53 'assessment boundary' means the boundary where the delivered and exported energy are measured or calculated;¹
- Def 58 'energy use' means energy input to a technical building system providing an EPB-service intended to satisfy an energy need;
- Def 62 '**delivered energy**' means energy, expressed per energy carrier, **supplied** to the technical building systems **through the assessment boundary**, to satisfy the uses taken into account or to produce the exported energy;
- Def 63 '**exported energy**' means, expressed per energy carrier and per primary energy factor, the proportion of the renewable energy that is exported to the energy grid instead of being used on site for self-use or for other on-site uses.

Some more fundamental energy definitions are:

- Def 9 'primary energy' means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process;
- Def 14 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic), and geothermal energy, osmotic energy, ambient energy, tide, wave and other ocean energy, hydro-power, biomass, landfill gas, sewage treatment plant gas, and biogas;²
- EED definition 4 'primary energy consumption' means gross available energy **excluding** international maritime bunkers, final non-energy consumption and **ambient energy**;
- RED definition 2 'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water.

1 Note that this may depend on national practices where energy meters are installed.

2 The definition is identical to the definition from Directive (EU) 2023/2413 (amended RED)

In EPBD primary energy factor definitions (Art 2, 11-13) it is said that primary energy is calculated by multiplying the delivered energy and primary energy factor. Therefore, according to definition 62, the energy flows to be considered in PE indicator calculation are those supplied through the assessment boundary. If the assessment boundary is specified so that ambient energy and on-site photovoltaic are not supplied through the assessment boundary, they should not be considered in PE indicator calculation. However, a common building assessment boundary in EN ISO 52000-1 is specified so that both ambient energy, solar photovoltaic and solar thermal are supplied through the assessment boundary and should thus be added to primary energy which will increase the total primary energy indicator (EP-value). There are two options to avoid this situation where ambient and solar energy (promoted in EPBD) will increase the EP indicator value. Both options described in [Section 3.1](#) and [Section 3.2](#) are in line with JRC (2023) ZEB

zero balance proposal of the primary energy and the CO₂ emissions over a year, as well as with EED which excludes ambient energy in primary energy definition.

3.1 Building assessment boundary and specification of energy flows

An assessment boundary shown in **Figure 1** separates the energy use (the demand side) from the energy supply consisting of on-site energy generation, delivered energy carriers from nearby and distant, and exported energy carriers. The self-use of on-site renewable electricity covers a part of energy use and thus reduces the amount of the delivered grid electricity. Nearby and community renewable electricity depend on technical and contractual arrangements, but in the energy calculation these can be treated as delivered energy carriers distinguished from grid electricity with different *PEF*. Fuels, both renewable and non-renewable, are treated as delivered energy with relevant *PEF*.

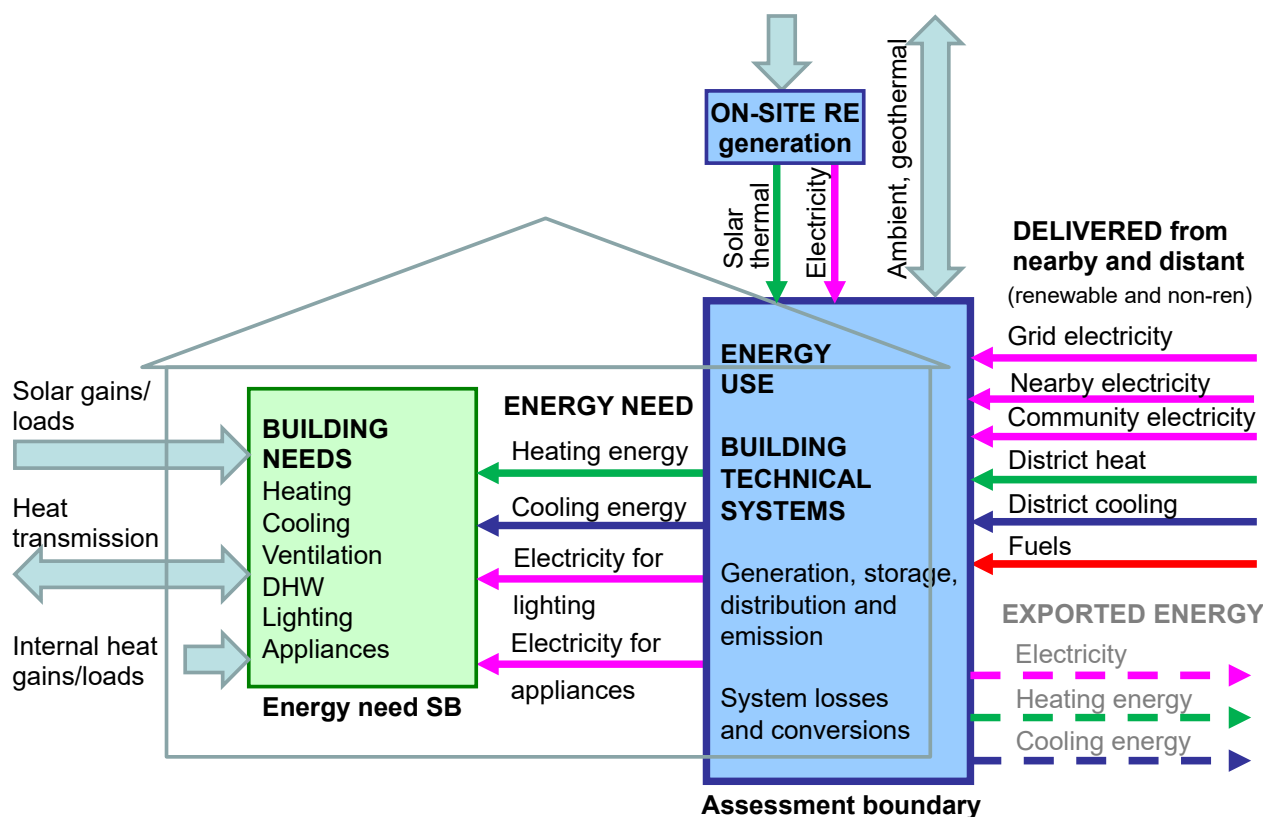


Figure 1. Assessment boundary definition (EN ISO 52000-1) that separates energy use from on-site generated, delivered, and exported energy. Exported energy is shown with dashed lines, indicating that exclusion or inclusion in EP calculation depends on k_{exp} factor 0 or 1.

The total primary energy, as defined in EN ISO 52000-1, is calculated as:

$$E_{P,tot} = \sum_i (E_{del,i} f_{del,tot,i}) - \sum_i (E_{exp,i} f_{exp,tot,i}) \quad (1)$$

In EN ISO 52000-1 k_{exp} factor 0 or 1 is defined to exclude or include exported energy. Often $k_{exp}=0$ is used to avoid overestimation of its impact, resulting in the total primary energy given by:

$$E_{P,tot} = \sum_i (E_{del,i} f_{del,tot,i}) \quad (2)$$

If exported energy is considered instead, a yearly calculation tends to overestimate the impact of on-site renewables because of surplus and low consumption situation in the summer period. To be correct, this calculation should be conducted on hourly basis with an hourly *PEF* instead of annual *PEF*. Total primary energy indicator is calculated by dividing total primary energy with useful floor area:

$$EP_{tot} = \frac{E_{P,tot}}{A_{net}} \quad (3)$$

where

EP_{tot} is the total primary energy indicator (kWh/(m² a));

$E_{P,tot}$ is the total primary energy (kWh/a);

$E_{del,i}$ is the delivered energy (kWh/a) for energy carrier i ;

$E_{exp,i}$ is the exported energy (kWh/a) for energy carrier i ;

$f_{del,tot,i}$ is the total primary energy factor (-) for the delivered energy carrier i ;

$f_{exp,tot,i}$ is the total primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier i ;

A_{net} is useful floor area (m²).

In the operational greenhouse gas emissions calculation, in similar fashion, k_{exp} factor 0 or 1 is used to exclude or include exported energy. Operational greenhouse gas emissions are calculated from delivered and exported energy:

$$EP_{CO_2} = \frac{m_{CO_2}}{A_{net}} = \frac{\sum_i (E_{del,i} K_{del,i}) - \sum_i (E_{exp,i} K_{exp,i})}{A_{net}} \quad (4)$$

where

EP_{CO_2} is the operational greenhouse gas emissions indicator (gCO₂/(m² a));

m_{CO_2} is the operational greenhouse gas emission (gCO₂/a);

$K_{del,i}$ is the CO₂ coefficient (gCO₂/kWh) for the delivered energy carrier i ;

$K_{exp,i}$ is the CO₂ coefficient (gCO₂/kWh) for the exported energy carrier i .

For total primary energy indicator calculation, the assessment boundary in **Figure 1** needs the specification of multiplier (1 or 0) to specify which energy flows through the assessment boundary are considered (1) and which ones will not (0), **Table 1**. An alternative method to specify the energy flows included, is to use the building site boundary instead of **Table 1** as shown in [Section 3.2](#).

Table 1. Specification of inclusion of energy flows through the assessment boundary.

Energy through the assessment boundary	Multiplier
Grid electricity	1
Nearby electricity	1
Community electricity	1
Fuels	1
District heat	1
District cooling	1
Solar thermal	0
Solar photovoltaic	0
Ambient energy	0
Geothermal	0

3.2 Building site boundary

The building site boundary, delineated by the borderline of the building plot as illustrated in **Figure 2**, serves as a means to differentiate between delivered and exported energy flows across the boundary. Energy use is calculated using the assessment boundary outlined in EN ISO 52000-1, but for primary energy indicator calculation, the building site boundary is utilized.

Within this boundary, on-site renewable energy, ambient energy, and geothermal energy are encompassed, and thus not supplied through the assessment boundary. Consequently, they are not accounted for in the primary energy indicator.

The positioning of the building site boundary in **Figure 2** aligns with the typical location of main energy meters and connection points, ensuring full compliance with the EPBD assessment boundary definition 53. Notably, the figure does not indicate the location of energy meters for nearby or community renewable electricity due to varying technical and

contractual arrangements, resulting in several possible options. In energy calculations, nearby or community renewable electricity is treated as delivered energy but is distinguished from grid electricity using different *PEF*.

With building site boundary on **Figure 2**, total primary energy indicator is calculated from delivered energy to building site, i.e. from delivered energy with nearby and distant origin. With data of model apartment building and *PEF* introduced in [Section 5](#), total primary energy indicator calculation example is shown in **Figure 3**. Operational CO₂ calculation uses exactly the same delivered energy flows. Therefore, for the total primary energy indicator, non-renewable primary energy indicator (not shown in **Figure 3**) and operational CO₂ calculation, the only difference is in primary energy factors and CO₂ coefficients.

With regards energy calculation, hourly energy use and generation calculation is needed to know the self-use of PV, the use of PV in other on-site uses and exported

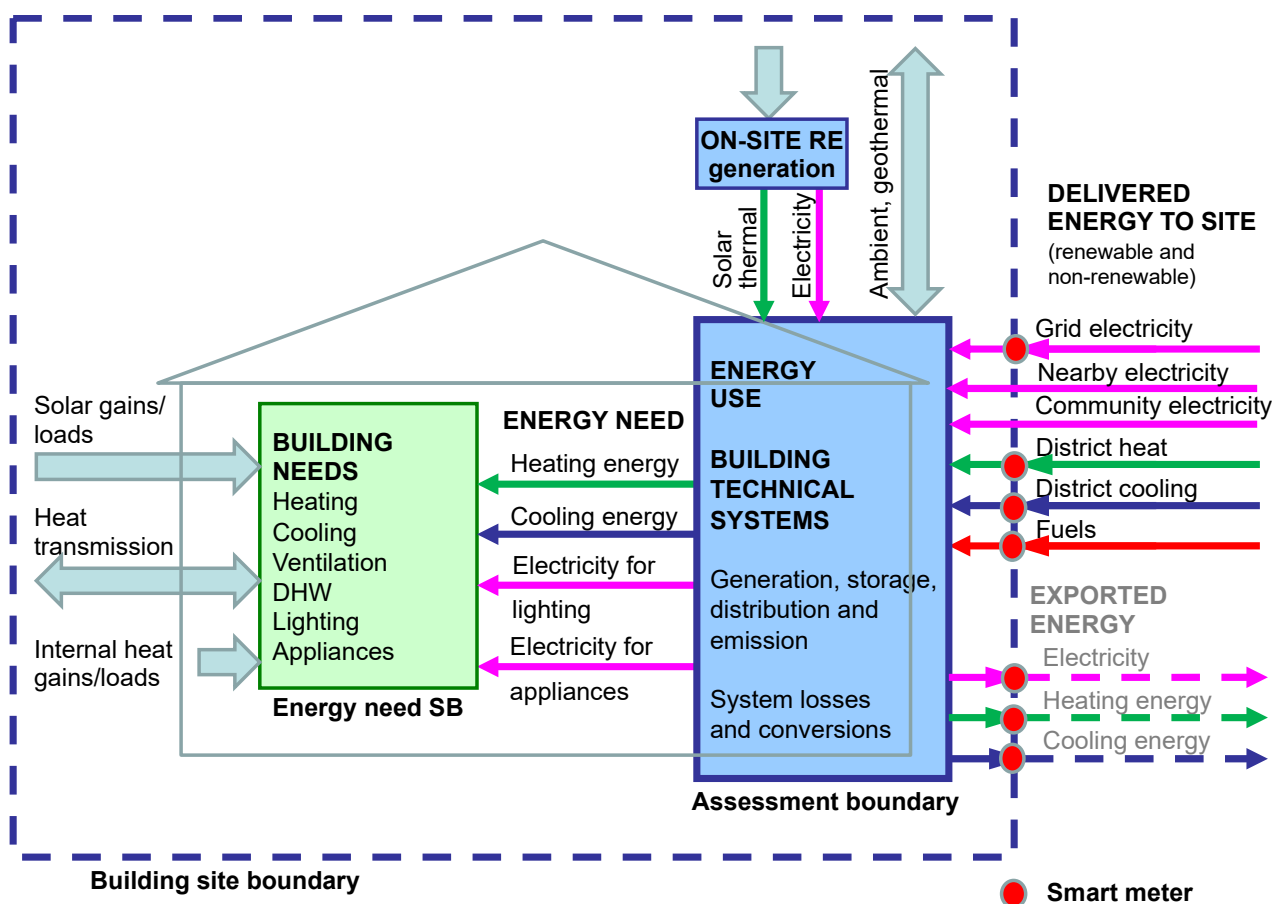


Figure 2. Building site boundary for primary energy calculation that complements building assessment boundary of EN ISO 52000-1.

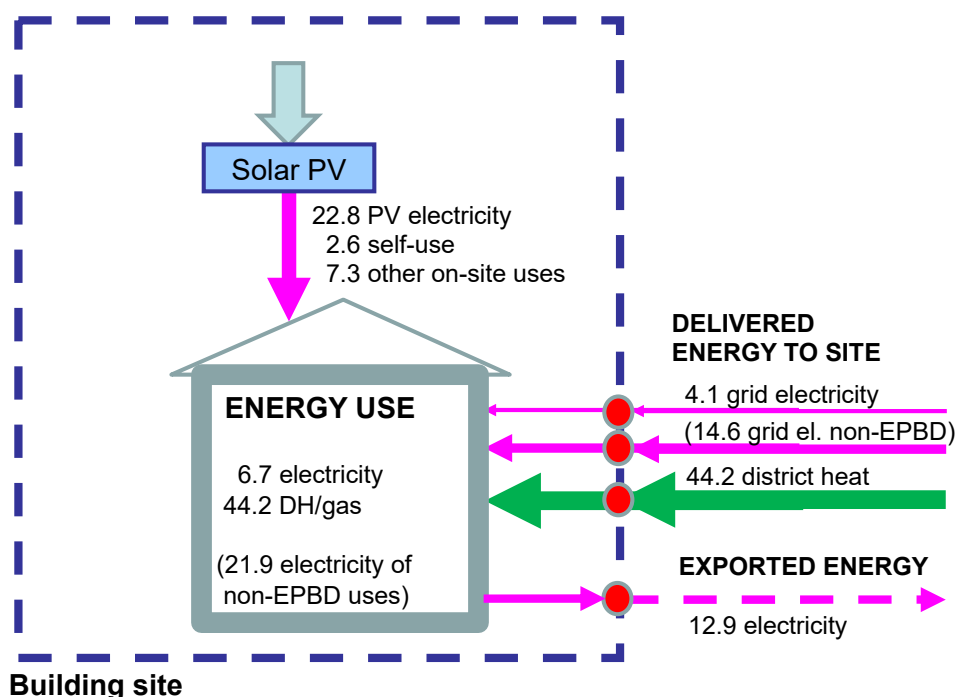
electricity. Hourly energy calculation is mentioned in EPBD ANNEX I, but monthly calculation is also accepted. Similar calculation example than that in **Figure 3** is provided in JRC ZEB report (2023) case studies. There is no exact definition for the assessment boundary in the JRC report, but the results of the case studies allow to see that the same assessment boundary has been used.

It should be noted that total PE is not able to distinguish the use of fossil fuels and energy from renewable sources including biofuels (all have total *PEF* of about 1.0). According to EPBD Article 11 ZEB ‘energy demand’ requirement is ‘maximum threshold established at the Member State level’. Here each MS has a freedom to define ZEB by following cost optimality and EPBD ANNEX I principles (referred to in Article 2 ZEB definition). According to ANNEX I, ‘a numeric indicator of primary energy use’ should be used and ‘The calculation of primary energy shall be based on primary energy factors, (distinguishing non-renewable, renewable and total) or

weighting factors’. ANNEX I also requires recognising the **benefits of district heating and cooling, and positive influence of renewable energy** which is possible with non-renewable PE indicator but is neglected by total PE indicator. However, ZEB requirements (1) and (7) take care that these benefits are recognised.

4. Calculation of the ZEB requirement on the covering of total annual primary energy use

While the total primary energy indicator is calculated as reported in in [Section 3.1](#) and [Section 3.2](#), it is possible to check how it is covered according to ZEB requirement in Article 11 (7). According to this requirement, the total annual primary energy use must be covered by on-site, nearby, or renewable energy community generated renewable energy as defined in RED, energy from efficient district heating and cooling as defined in EED and energy from carbon free sources (nuclear and renewable grid electricity). This means that on annual basis the sum of on-site, nearby,



$$EP_{\text{tot}} = 4.1 \times 1.9 + 44.2 \times 1.2 = 60.9 \text{ kWh/m}^2 \text{ a}$$

$$EP_{\text{CO}_2} = 4.1 \times 0.25 + 44.2 \times 0.13 = 6.9 \text{ kgCO}_2\text{e/m}^2 \text{ a}$$

Figure 3. Recommended EP-value calculation for EPBD services from delivered energy to building site based on total PE and operational greenhouse gas emissions. Calculation methods introduced in [Section 3.1](#) and [Section 3.2](#) provide the same result.

and community renewable energy, efficient district heating and cooling and the carbon free fraction of grid electricity should be equal or higher than the total primary energy. Renewable energy as defined in RED includes the ambient energy (heat captured by heat pumps from the environment)³, if seasonal performance factor of a heat pump is >2.4.

Example calculation is conducted in **Table 2** for the model apartment building. As this requirement is set on annual basis, all PV generation is considered. It is well visible that the covering requirement is more challenging for Nordic climate, because in the case of smaller PV system it would not be fulfilled with district heating. However, in the case of decreasing primary energy factors in future this requirement is likely to be automatically satisfied if cost optimal thresholds are applied for the total primary energy indicator, therefore the covering requirement rather serves as a checklist showing which energy sources should be used in ZEB. With gas boiler that was included for illustrative purposes, the requirement is evidently not fulfilled.

Clause (22) in EPBD justification text (before articles) explains that: *‘Different options are available to cover the energy needs of a zero-emissions building: energy generated on-site or nearby from renewable sources such as solar thermal, geothermal, solar photovoltaics, heat pumps, hydroelectric power and biomass, renewable energy provided by renewable energy communities, efficient district heating and cooling, and energy from other carbon-free sources. Energy derived from combustion of*

3 Note that for EPBD requirements in Article 11 (2,3) the ambient energy is not taken into account in the total primary energy indicator. But in the requirement of Article 11 (7) and RED definition for energy from renewable sources, ambient energy is included in the covering of the total annual primary energy use.

renewable fuels is considered to be energy from renewable sources generated on-site where the combustion of the renewable fuel takes place on-site.’ Therefore, combustion of biofuel is included in the covering of total annual primary energy. Note that in the total primary energy calculation for ZEB maximum threshold (3), as shown in **Figure 1** and **2**, renewable fuels are calculated with relevant primary energy factors.

5. Model building, primary energy factors and CO₂ coefficients to calculate EP indicators

A modern multifamily apartment building shown in **Figure 4** and expected to correspond to present NZEB requirements has been used for calculation examples which are conducted for three European climates. The main data of the model building:

- 3-storey, 12 apartments, 1120 m² heated area
- Heat recovery ventilation
- 30 kW PV system
- Cooling system
- Air to water heat pump, effective district heating (50% renewables) or gas boiler for heating

The model building is well insulated so that the U-values depend on the climatic zone as shown in **Table 3**. More detailed description of the building is reported in (Vösa et al. 2023).

Table 3. U-values of the model apartment building.

U-values W/(m ² K)	Nordic and Continental	Mediterranean
External walls	0.14	0.23
Cellar wall	0.15	0.23
Windows U _w	0.80	1.30
g-value	0.50	0.50
Roof (insulated)	0.11	0.20
Attic floor (insulated)	0.10	0.20
Ground floor to cellar	0.18	0.25
Floor on ground	0.49	0.49

Table 2. Compliance with total primary energy covering requirement in the case of model apartment building. Input data for this calculation example is reported in Section 5.

PE covering requirement	Nordic			Continental/Oceanic climate			Mediterranean		
	AWHP	DH	Gas	AWHP	DH	Gas	AWHP	DH	Gas
Total primary energy	37.7	72.0	61.9	27.3	60.9	52.1	24.8	58.2	50.1
Covering by PV	-22.7	-22.7	-22.7	-22.8	-22.8	-22.8	-30.0	-30.1	-30.1
Covering by heat pump	-23.4			-21.6			-20.7		
Covering by efficient DH		-50.4			-44.2			-40.6	
Covering by ren. grid electr	-9.9	-3.0	-3.0	-7.2	-2.1	-2.1	-6.5	-2.5	-2.5
Total PE - covering	-18.4	-4.2	36.2	-24.3	-8.2	27.2	-32.5	-15.0	17.5
Requirement fulfilled	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No

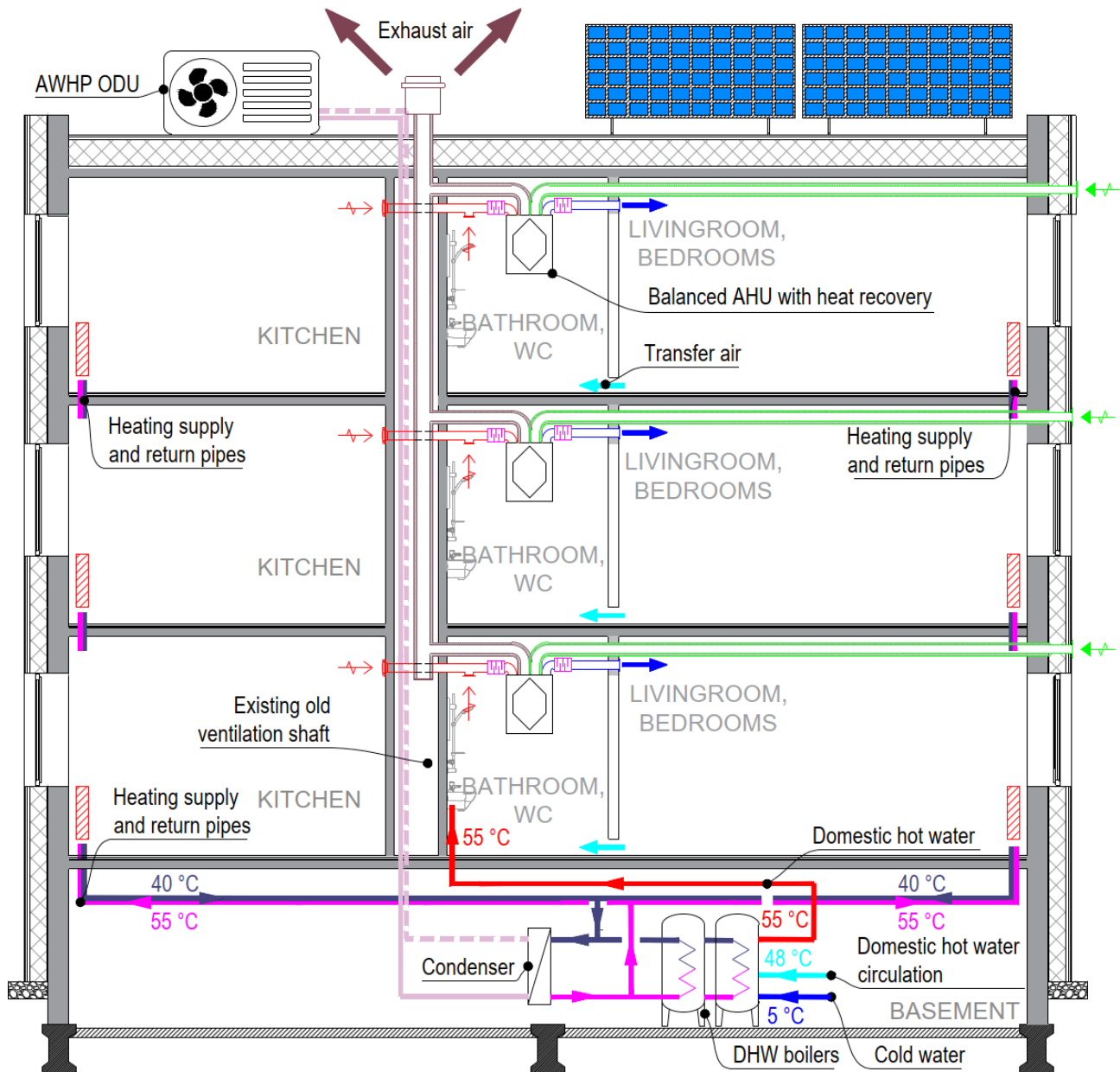


Figure 4. Schematic diagram of the model reference building with air to water heat pump. Cooling system with fan coils is not shown in the figure.

Hourly simulated energy needs, energy use with studied heating sources and PV generation are shown in **Table 4**. Energy simulations were conducted with a commercial simulation tool enabling to include a heat pump, PV, and other technical systems in a multizone whole building simulation model (Vósa et al. 2023). For illustrative purposes the same boiler efficiency has been applied for the district heat and gas boiler, therefore, for these cases the energy use data is identical, and differences are solely caused by primary energy factors.

Primary energy factors are selected to represent EU average primary energy factor for electricity in 2024 and to fulfil the minimum requirement of 50% of renewable energy sources in the efficient district heat production, **Table 5**. For electricity, total *PEF* = 1.9 is reported in (Trinomics, 2022). We assume 6% transmission losses, 50% renewable share in the generation and 38% average generation efficiency in other generation than renewables to estimate non-renewable *PEF*. These assumptions allow to calculate approximate *PEF* for electricity as follows:

- Total *PEF* = $0.5 \times (1/0.94) + 0.5 \times (1/0.94/0.38) = 1.9$
- Non-renewable *PEF* = $0.5 \times (1/0.94/0.38) = 1.4$
- Renewable *PEF* $1.9 - 1.4 = 0.5$

For efficient district heat we assume 50% share of renewables, 90% generation efficiency and 8% network losses:

- Total *PEF* = $1/0.92/0.9 = 1.2$
- Non-renewable *PEF* (zero factor for renewable energy) $0.5 \times (1/0.92/0.9) = 0.6$
- Renewable *PEF* $1.2 - 0.6 = 0.6$

For CO₂ coefficient of grid electricity, EU average value of 2022 is used (European Environment Agency 2023). CO₂ coefficient for efficient district heat is calculated from the value of natural gas with same assumptions as for *PEF*. It is assumed that renewable fuels have no operational CO₂ emissions.

6. Comparison with present approaches in MS to calculate PE indicator

To illustrate the differences that the calculation approaches currently in use in MS may cause, primary energy indicators, non-renewable and total, are calculated for the model apartment building. Energy balance components reported in **Table 4** and primary energy factors in **Table 5** are used. Energy balance between the energy use and the delivered energy carriers for Continental/Oceanic climate zone is illustrated in **Figure 5** which is used to explain step by step primary energy indicators calculation with some of the used approaches. Because many MS include non-EPBD uses (lighting and appliances) in the primary energy indicator calculation, energy use and delivered grid electricity to these non-EPBD services is shown in parentheses in the energy balance **Figure 5**. This figure shows the summary of energy use (energy input to a technical building system), on-site electricity generation and delivered/exported energy without providing any assessment boundary definition. Therefore, any MS can apply national assessment boundary and calculation rules to this example and to calculate the primary energy indicator to compare with the results provided in the following.

There are 2–3 common approaches to calculate primary energy indicator (EP-value). Based on national regulations, it can be estimated that about 2/3 of MS consider

Table 4. Energy balance of the model building: hourly simulated energy needs and energy use. *AWHP* – air to water heat pump, *DH* – district heating.

Energy balance components	Nordic			Continental/Oceanic			Mediterranean		
	Energy need	Energy use & generation		Energy need	Energy use & generation		Energy need	Energy use & generation	
	kWh/m ² a	AWHP	DH/Gas	kWh/m ² a	AWHP	DH/Gas	kWh/m ² a	AWHP	DH/Gas
Energy use									
Space heating	15.3	6.1	17.9	9.9	3.3	11.6	6.8	2.3	8.0
Domestic hot water	25.0	10.8	32.6	25.0	10.0	32.6	25.0	8.8	32.6
Supply air heating (electric)	2.7	2.7	2.7	0.5	0.5	0.5	0.1	0.1	0.1
Cooling	2.8	0.7	0.7	4.2	1.1	1.1	15.6	3.9	3.9
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Energy generation									
PV self use		5.6	2.5		5.6	2.6		7.3	4.2
PV use in other on-site uses		6.0	6.7		6.6	7.3		7.5	8.1
PV exported to grid		11.1	13.5		10.6	12.9		15.3	17.8

only PV self-use and the use in other on-site uses. About 1/3 of MS account exported energy too, which may result in negative values of EP. In the first group (2/3) the majority of MS include both EPBD and non-EPBD services in the calculation. In the second group (1/3) only EPBD uses are typically included. Therefore, at least three usual approaches to calculate PE indicators can be identified. Some MS conduct this calculation with non-renewable and some MS with total *PEF*, but here we apply total *PEF* for electricity from **Table 5**.

Table 5. Primary energy factors (*PEF*) and CO_2 coefficients used in calculation examples.

	<i>nren PEF</i>	<i>ren PEF</i>	<i>tot PEF</i>	CO_2 coefficient g CO_2e/kWh
Grid electricity	1.4	0.5	1.9	251
District heating	0.6	0.6	1.2	133
Natural gas	1	0	1	220

With air to water heat pump values shown in **Figure 5**, EP_{tot} indicators calculation result as follows:

1. PV self-use and used in other on-site uses, both EPBD and non-EPBD services included (used at least by 8 MS)

$$EP_{tot} = (20 - 5.6) \times 1.9 + (21.9 - 6.6) \times 1.9 = 56.2 \text{ kWh/m}^2 \text{ a}$$

2. PV self-use and EPBD services (used at least by 5 MS, corresponds to proposal in Ch 3)

$$EP_{tot} = (20 - 5.6) \times 1.9 = 27.3 \text{ kWh/m}^2 \text{ a}$$

3. PV export (total generation) and EPBD services (used at least by 7 MS)

$$EP_{tot} = (20 - 22.8) \times 1.9 = -5.4 \text{ kWh/m}^2 \text{ a}$$

In some MS there are limits for renewable energy maximum contribution to be accounted or another primary energy requirement to be fulfilled without considering on-site PV generation. In many cases such limits assuring energy efficiency do not exist and if exported electricity was accounted, negative *EP*-values were achieved.

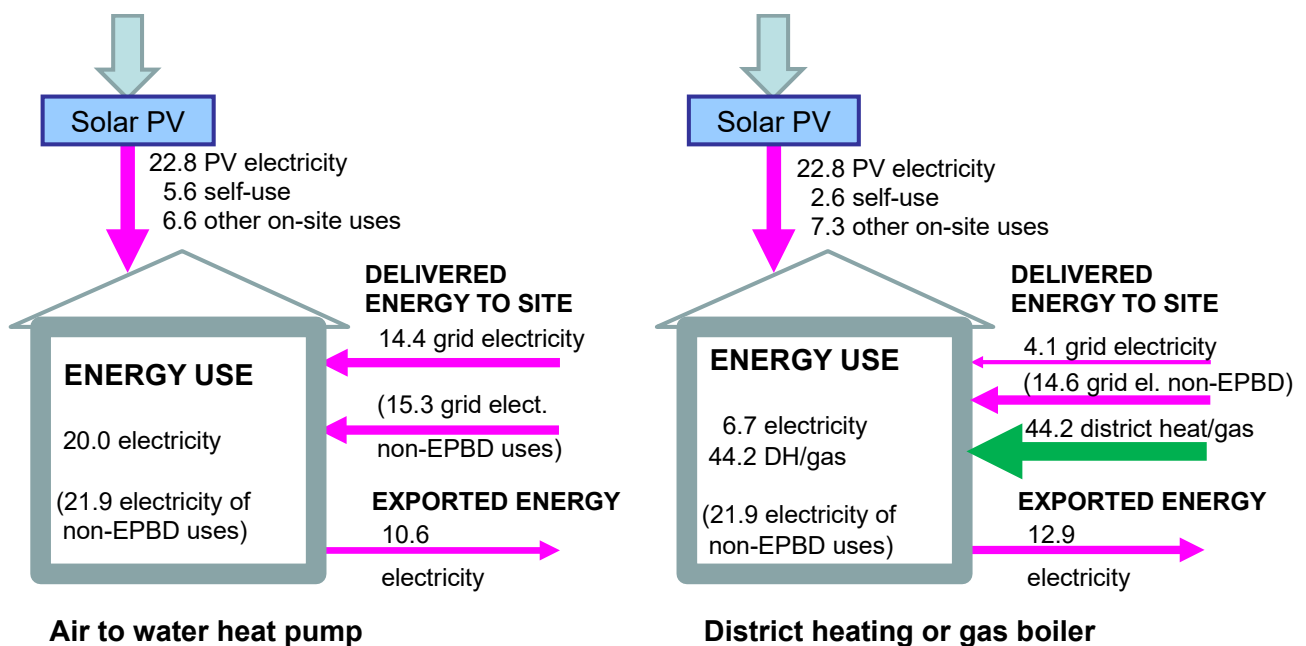


Figure 5. Energy balance of a model apartment building in Continental climate used for primary energy calculation.

EP calculations with these three methods are summarised in **Table 6** and 7, where also district heating and natural gas cases are included, and the calculation is conducted with both total and non-renewable *PEF* and with CO₂ coefficients. If non-renewable *PEF* are used, *EP* represents non-renewable primary energy indicator, and the calculation is in line with the methodology set in the EPB overarching standard EN ISO 52000-1:2017. However, with total *PEF*, the calculation conducted does not represent total primary energy calculation in the sense of the overarching standard, because PV electricity and ambient heat of a heat pump are not included in *EP*-value. In this case the total primary energy calculation is finalised to the indicator calculation only from delivered energy to site, i.e, from imported/purchased energy, that is in line with EPBD definitions and principles as discussed in [Section 3](#). Operational greenhouse gas emissions are

also calculated from the delivered energy to site – in this case PV and ambient heat are not an issue, because these do not cause operational CO₂.

Results in **Tables 6** and 7 show that *EP*-values strongly depend on the calculation approach. In Continental/Oceanic and Mediterranean climates *EP* indicators values may be negative if exported energy (total generation) is included in the calculation. Nordic climate shows the highest values, which all remain positive, but differ up to by factor 13. In the case of non-renewable PE and operational greenhouse gas emissions, air to water heat pump and district heating provide the lowest *EP* indicator values clearly followed by gas boiler. In the case of total PE, however, gas boiler provides better result than that of district heating, but it is automatically excluded by the ZEB requirement not to use fossil fuels on-site.

Table 6. Primary energy and operational greenhouse gas emissions indicators calculation with three commonly used methods in Continental/Oceanic climate. Total primary energy, self-use EPBD option follows the calculation recommended in [Section 3](#).

Energy balance components (input data for PE calculation)	Continental/Oceanic climate			
	Energy need kWh/m ² a	Energy use and generation, kWh/m ² a		
		AWHP	DH	Gas
Space heating	9.9	3.3	11.6	11.6
Domestic hot water	25.0	10.0	32.6	32.6
Supply air heating (electric)	0.5	0.5	0.5	0.5
Cooling	4.2	1.1	1.1	1.1
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1
PV self use		-5.6	-2.6	-2.6
PV use in other on-site uses		-6.6	-7.3	-7.3
PV exported to grid		-10.6	-12.9	-12.9
Non-ren. primary energy				
self-use EPBD + non-EPBD		41.4	52.6	70.3
self-use EPBD		20.1	32.3	50.0
exported included EPBD		-4.0	4.0	21.6
Total primary energy				
self-use EPBD + non-EPBD		56.2	88.5	79.7
self-use EPBD		27.3	60.9	52.1
exported included EPBD		-5.4	22.4	13.6
Operational kgCO₂e/m² a				
self-use EPBD + non-EPBD		7.4	10.6	14.4
self-use EPBD		3.6	6.9	10.8
exported included EPBD		-0.7	1.8	5.7

7. Conclusions and recommendations

The EPBD follows ‘efficiency first’ principle meaning that the total primary energy, including both renewable and non-renewable primary energy should be minimised. However, in the context of energy use in buildings, it is important to distinguish ambient energy and on-site renewable energy generation, not causing operational CO₂ emissions, from delivered energy to the site consisting of purchased final energy products. If these energy products (grid electricity, fuels, district heating and district cooling) are partly based on non-renewable energy, they cause operational CO₂ emissions which needs to be minimised. As the use of on-site generated renewable energy reduces the amount of the delivered energy to the site, this on-site renewable energy should not be added to *EP*-value. Therefore, on-site generated renewable energy should not be considered as delivered energy carrier in the *EP_{tot}* indicator calculation.

Primary energy calculation is not explicitly defined in the EPBD, leaving many options and room for interpretation at national implementation. In this document it is proposed to calculate *EP*-value based on the total primary energy with one of two alternative options reported in Section 3 that will provide the same result. Either a building assessment boundary in Figure 1 with exclusion matrix (Table 1) of energy flows, or a complementary building site boundary in Figure 2 that accounts delivered and exported energy through the boundary, can be used. While Figure 1 and Table 1 follow the overarching EPB standard EN ISO 52000-1, for revised EPBD it would be more practical to use Figure 2 with straightforward energy calculation through the boundary. In both options on-site solar and ambient energy are not considered in the total primary energy indicator calculation, as the aim is, to calculate both total and non-renewable primary energy and operational CO₂ from delivered energy products to the site.

Table 7. Primary energy and operational greenhouse gas emissions indicators calculation with three commonly used methods in Nordic and Mediterranean climates. Total primary energy, self-use EPBD option follows the calculation recommended in Section 3.

Energy balance components	Nordic				Mediterranean			
	Energy need kWh/m ² a	Energy use and generation, kWh/m ² a			Energy need kWh/m ² a	Energy use and generation, kWh/m ² a		
		AWHP	DH	Gas		AWHP	DH	Gas
Space heating	15.3	6.1	17.9	17.9	6.8	2.3	8.0	8.0
Domestic hot water	25.0	10.8	32.6	32.6	25.0	8.8	32.6	32.6
Supply air heating (electric)	2.7	2.7	2.7	2.7	0.1	0.1	0.1	0.1
Cooling	2.8	0.7	0.7	0.7	15.6	3.9	3.9	3.9
Fans, pumps, fixed lighting	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Lighting (non-EPBD)	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Appliances (non-EPBD)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
PV self use		-5.6	-2.5	-2.5		-7.3	-4.2	-4.2
PV use in other on-site uses		-6.0	-6.7	-6.7		-7.5	-8.1	-8.1
PV exported to grid		-11.1	-13.5	-13.5		-15.3	-17.8	-17.8
Non-ren. primary energy								
self-use EPBD + non-EPBD		49.9	60.0	80.1		38.4	50.7	66.9
self-use EPBD		27.8	38.7	58.9		18.2	31.3	47.6
exported included EPBD		3.8	10.4	30.6		-13.7	-4.9	11.3
Total primary energy								
self-use EPBD + non-EPBD		67.8	100.8	90.7		52.1	84.4	76.3
self-use EPBD		37.7	72.0	61.9		24.8	58.2	50.1
exported included EPBD		5.1	33.6	23.5		-18.5	9.0	0.9
Operational kgCO₂e/m² a								
self-use EPBD + non-EPBD		9.0	12.0	16.4		6.9	10.1	13.6
self-use EPBD		5.0	8.2	12.6		3.3	6.7	10.2
exported included EPBD		0.7	3.2	7.5		-2.4	0.1	3.7

For the transition of national energy performance minimum requirements, i.e., to establish ZEB, NZEB, major/deep renovation and EPC rating scale based on the total primary energy the proposed method in Section 3 can be implemented by three possible options:

1. On-site renewable energy (both on-site generation and ambient energy) is not considered as delivered energy – primary energy factors will only be applied for delivered and exported energy via energy carriers as shown in the proposed system boundary in **Figure 2**.
2. Onsite renewable energy is considered as delivered energy, but with a zero primary energy non-renewable factor when it comes to total primary energy requirements, as shown in **Figure 1** and **Table 1**.
3. Primary energy calculation is limited to imported/purchased final energy only.

All these three options provide the same results and avoid that on-site produced and used renewable energy will be added to EP_{tot} -value. This applies for:

- onsite produced PV or wind-electricity that is used onsite (at the same moment, or after onsite storage);
- ambient or geothermal energy that is used for an onsite heat pump;
- onsite solar thermal.

Otherwise, when calculating total primary energy, these technologies could be punished compared to alternative technologies, such as a conventional boiler, because total primary energy alone does not distinguish between non-renewable and renewable components. A threshold on total EP can be satisfied using smaller amount of non-renewable energy sources than renewable ones. Fortunately, the ZEB requirement not to use fossil fuels on-site avoids this problem. Regarding the building EPC market, today mostly being based on the non-renewable primary energy indicator, the proposed procedure slightly increases the EPC-values for the same building, that is very small change comparing to the situation where on-site renewable energy will be added to EP_{tot} -value.

Currently MS use either non-renewable or total PEF or weighting factors. In the transition to total primary energy, it should be noted that total PEF cannot recognise the benefits of district heating and cooling, and positive influence of renewable energy. A classic example of a heat pump in a building or in a district heating plant should lead to the same

energy performance if the efficiency is the same and there are no network losses, but this is not the case if total primary energy factors, which cannot be by the definition smaller than one, are used. This problem illustrates the need for operational CO_2 indicator that is introduced by EPBD as one ZEB requirement.

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The EPBD recast, technical framework: part 1, definitions and ZEB



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Introduction

The Energy Buildings Performance Directive last recast has been approved by the UE Parliament in March 12th and confirmed by the Council in April 12th with the aim to decarbonize the whole EU buildings stock for achieving the EU carbon neutrality in 2050. To reach such goal the Zero Emission Building definition has been introduced, aiming to reduce the non-renewable energy use while promoting renewable energy use, being the fossil fuels the most responsible for the CO₂ production and release to the atmosphere. Thresholds must be set by Member state using an update cost-optimal procedure, which should be released by June 2025. These thresholds must be at least 10% less the “total primary energy” use established at the National Member State level for Nearly-Zero Energy Buildings on the date of EPBD recast publication. Thus, it is clear that the minimum energy performance requirements for ZEBS are set as maximum permitted total primary energy use. Art.11, Zero Emission Building, introduces additional constraints to the ZEB other than this minimum energy performance as mandatory requirements on: null on-site carbon emission from fossil fuel, climate and load adaptive building, total primary energy use covered only by renewable energy sources and/or high efficiency district heating and cooling systems and/or free carbon energy sources, and, finally, the operational greenhouse gas emission complies with

a maximum threshold set at the Member State level. Furthermore, new buildings shall be designed to optimise their solar energy generation potential according to National Member State specifications. The new ZEB definition and its requirements regard new buildings from 2028 if public and from 2030 for all new building.

For the existing buildings the EPBD requires all MS's to establish a national trajectory for the progressive renovation of the residential and non-residential building stock in line with the national roadmap and the 2030, 2040 and 2050 targets contained in the Member State's building renovation plan. Thus, Member States shall set minimum energy performance requirements for existing buildings with a view to at least achieving cost-optimal levels and, where relevant, more stringent reference values such as nearly zero-energy building requirements and zero-emission buildings requirements. These performances are differently evaluated if the building is residential or non-residential: for the former, yearly primary

energy use by useful area is the performance indicator, for the latter it is defined on national basis and can be both annual primary or final energy use by useful area. These performance indicators will be then compared with thresholds (maximum permitted energy use) to verify the compliance by individual buildings and to compare the actual renovation rate with the defined roadmap. This check is foreseen to be performed through the energy performance certificates. MS's may also define additional indicators of non-renewable and renewable primary energy use, and of operational greenhouse gas emissions produced in $\text{kgCO}_{2\text{eq}}/(\text{m}^2\cdot\text{y})$. Exemptions are possible if the compliance of existing buildings with the defined thresholds is not technical feasible or economically not viable.

This huge effort to the path of decarbonization requires a clear technical framework to be effectively put into operation. Thus, in the following, a analysis of the Directive major points is carried out with the aim to identify unclear points and eventually propose some corrections aiming to provide a consistent and reliable technical framework for building energy and environmental performance assessment.

EPBD definitions' analysis

The starting point of any consistency analysis is to verify if the basic definitions are enough clear or can be cause of different interpretations.

One potential of misleading interpretation regards what is considered renewable energy source in EPBD, which is very important to clarify for correctly calculating the TOTAL primary energy use, which comprises both non-renewable and renewable energy use.

In Article 2 – Definitions, point 13., it is reported:

'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic), and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.

This definition is taken from the DIRECTIVE (EU) 2018/2001 on the promotion of the use of energy from renewable sources (recast), where it is also reported the definition of **ambient energy** as:

(2) *'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment*

with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water.

This definition has been sometimes misunderstood interpreting as the ambient, which is referring to, is only the indoor (constrained by boundaries) environment. Instead, analysing the sentence, it is clear that it refers to two distinct energy sources, a) and b):

a) *'ambient energy' means naturally occurring thermal energy, which can be stored in the ambient air, or in surface or sewage water; (i.e. former athermal and hydrothermal);*

b) *'ambient energy' means energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air.*

The interpretation key is “energy and energy”, In fact, if the intention would be to constraint the definition to a close environment (not outdoor air), the definition should be:

'ambient energy' means naturally occurring thermal energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air.

The second source was probably added in the RED to credit the internal environment as a renewable source of energy for “renewable cooling” as reported in the COMMISSION DELEGATED REGULATION (EU) 2022/759 of 14 December 2021, which is technically and scientifically totally wrong.

A second potential misleading related to such definition is the example reported between round brackets just after the solar energy source: solar thermal and solar photovoltaic. Solar energy source is only one, the solar radiation on the earth surface (EN ISO/IEC 13273-2:2016, 3.3.4.1 definition: *renewable energy harnessed by exploiting radiation of the sun*), while solar thermal and solar PV are just two different ways of exploiting such source producing two different energy carriers: hot fluid and electric current, referred there as solar thermal and solar photovoltaic (energy from and not energy of). Thus, the primary energy of such carriers, according to the EPBD Primary Energy definition (*energy from renewable and non-renewable sources which has not undergone any conversion or transformation process*), is the collected site solar irradiance

times the collection surface area, and not the produced carriers themselves (see **Figure 1**).

Clarified that for EPBD also outdoor air thermal energy is a renewable energy sources as ambient energy, as well as surface or sewage water, and solar energy too, that will have a significant impact on the TOTAL primary energy indicator calculation, as we will see later.

Another unclear point is the position of the ‘**assessment boundary**’. Its EPBD definition is:

47. ‘**assessment boundary**’ means the boundary where the delivered and exported energy are measured or calculated;

but the EPBD delivered energy definition (as well as exported) is:

56. ‘**delivered energy**’ means energy, expressed per energy carrier, supplied to the technical building systems *through the assessment boundary*, to satisfy the uses taken into account or to produce the exported energy.

Thus, there is a circular definition that does not define in a clear and unique way where the assessment boundary is placed, causing confusion and different ways of calculating the performance indicators.

Fortunately, in definition 56 it is clearly stated that *delivered energy* means energy **supplied to the technical building systems per energy carriers**. A building technical system, which locally exploits a renewable energy source converting the source energy into an energy carrier, as converter¹, does not have in input a delivered energy carrier (or just a bit for some auxiliaries as pumping energy in solar thermal collectors’ fields) but produce an energy carrier directly from the energy of the source (its input). That means that the assessment boundary must keep inside it all technical device locally exploiting the renewable energy sources, because the only present energy carrier is the output of a technical building system component to another technical building system component (storage, distribution, etc.); thus, it is not a delivered energy carrier to the technical building systems, as required by the definition. The same conclusion can be adopted if the technical building system locally exploiting a renewable energy source, as ambient heat, is a transformer² like a heat pump: its input is the source energy while

- 1 Energy converter is an equipment that converts one form of energy in another form of energy with some energy losses due to the irreversibility in the conversion process.
- 2 Energy transformer is an equipment that transforms the quality of the same form of energy from one level (energy in) to another level (energy out) requiring some work or thermal energy expenditure to operate.

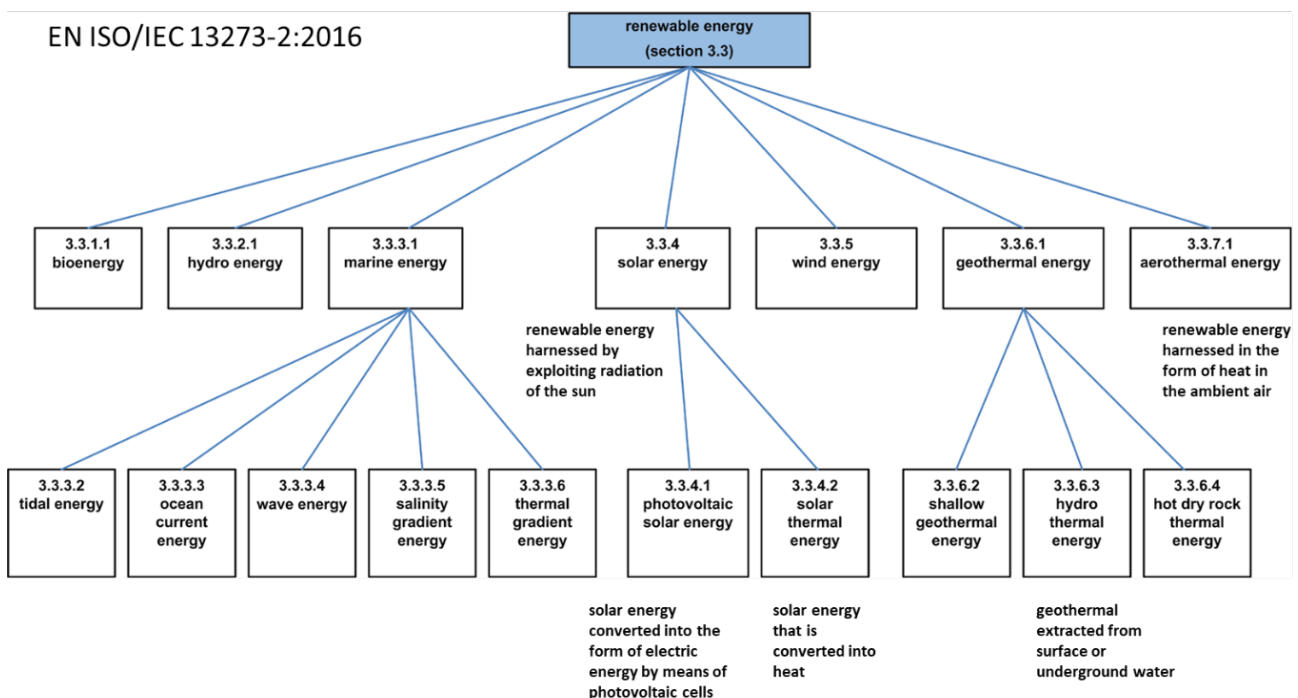


Figure 1. EN ISO/IEC 13273-2:2016 Energy efficiency and renewable energy sources — Common international terminology - Part 2: Renewable energy sources, definitions.

its output is an energy carrier directly to the indoor ambient or to another system component.

Thus, the assessment boundary is the boundary through which energy carriers are going through regardless of the direction (inward = delivered, outward = exported) and their nature (produced by non-renewable or renewable energy sources, **but only nearby or distant**) to satisfy the EPBD energy use. Building technical system/components locally exploiting on-site renewable energy sources are placed inside the assessment boundary and their effects are accounted in the reduction of delivered energy carriers and, eventually, in the presence of exported energy carriers (see **Figure 2**).

Finally, the energy use is defined as (def. 52) “energy input to a technical building system providing a EPB-service intended to satisfy an energy need;”. Thus, combining the assessment boundary definition with the energy use definition, the latter shall be calculated or metered as the difference between delivered and exported energy carriers crossing the assessment boundary:

$$E_u = \sum E_{del;j} - \sum E_{exp;j}$$

If a final energy indicator will be chosen, then this will be:

$$E_F = E_u / A_{useful}$$

If a primary energy indicator has to be used, first the primary energy use must be calculated using the primary energy factors for any involved energy carrier as:

$$E_P = \sum F_{P,del;j} E_{del;j} - \sum F_{P,exp;j} E_{exp;j}$$

Then, the indicator as:

$$EP_P = E_P / A_{useful}$$

The unclear point is what kind of primary energy shall be used: total, non-renewable or renewable?

While for new buildings it is clear that total primary energy must be used (), for the existing buildings there is no direct indication on what kind of primary energy must be used. Only reading clause 3 of article 9, “In addition to primary energy use referred to in paragraphs 1 and 2, Member States may define additional indicators of non-renewable and renewable primary energy use,...”, it is possible to understand that if primary energy use

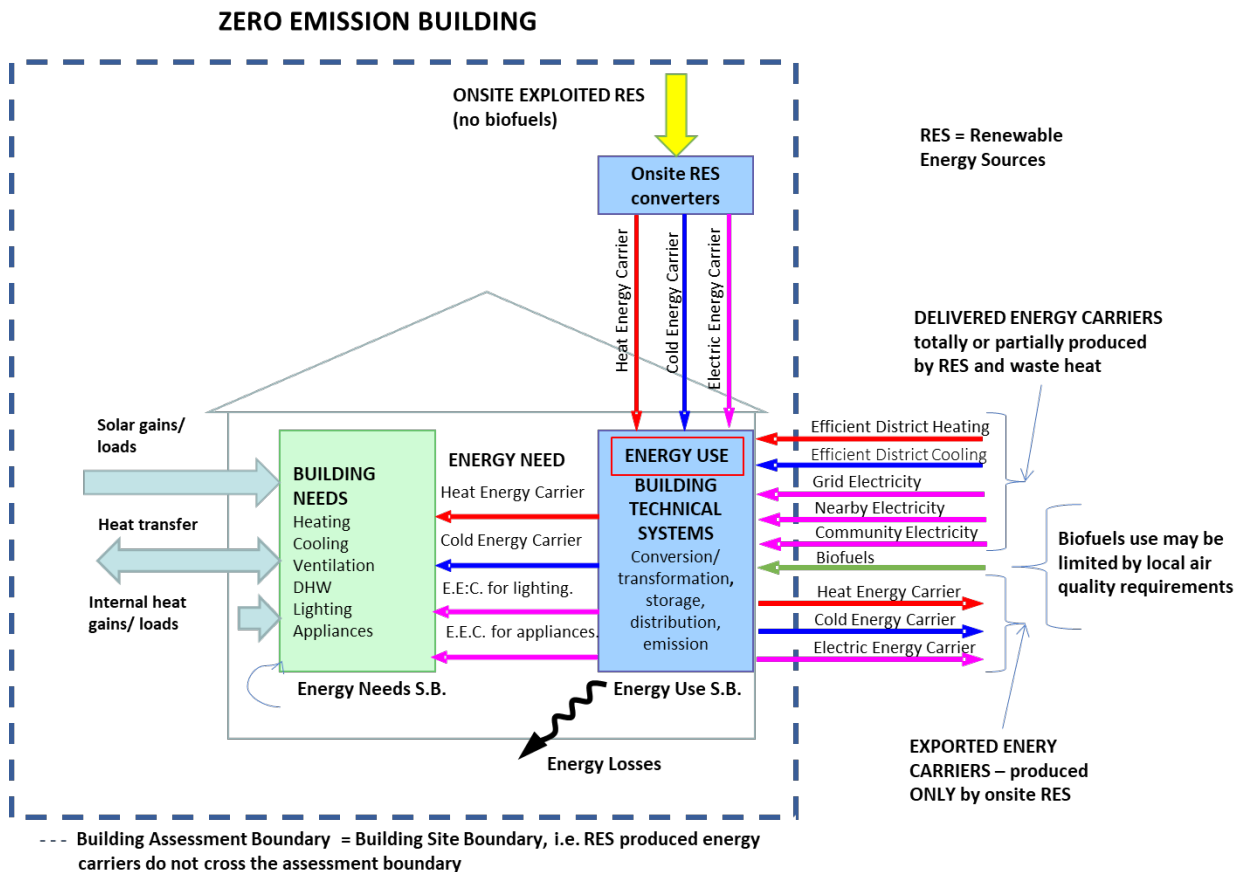


Figure 2. Building assessment boundary consistent with the EPBD recast definitions.

is referred in the Directive, that means total primary energy.

Another unclear point is what are the EPBD services that contribute to form the energy use and then the TOTAL primary energy use and related indicators, which are not anymore explicitly defined because “other uses” have been added by the Council in definition point (50), even if they are not depending on the building fabric and services systems but just on the users’ habits (as personal lighting, white and brown goods electricity use, etc.).

Finally, there are some other unclarified terms like “weighting factor” that can be used instead of “primary energy factor” in Annex I (the resulting energy performance will be in that case not anymore in terms of primary energy), as well as contradictory implicit definitions as the “renewable energy share”, which is required in Annex I and Annex V, where in the last is defined as “renewable energy produced on site in % of energy use”, that is a local energy ratio and not a primary energy ratio considering any kind of renewable energy (exploited on site, nearby or distant).

Zero Emission Building Feasibility

Zero Emission Building is defined in EPBD article 2, clause 2, as

“a building with a very high energy performance, as determined in accordance with Annex I, requiring zero or a very low amount of energy, producing zero on-site carbon emissions from fossil fuels and producing zero or a very low amount of operational greenhouse gas emissions, in accordance with the requirements set out in Article 11;”

Complemented by the requirement set up by article 7, cause 2:

“.. the life-cycle Global Warming Potential (GWP) is calculated in accordance with Annex III and disclosed through the energy performance certificate of the building ..”

and 11:

1. cannot cause any on-site carbon emissions from fossil fuels.
2. energy threshold at least 10% lower than the total primary energy of NZEB.
3. operational greenhouse gas emissions shall comply with a maximum threshold established at the Member State level.
4. the total annual primary energy use has to be covered on annual bases, **where technically and economically feasible**, by:
 - energy from renewable sources generated onsite or nearby.
 - energy from renewable sources provided from a renewable energy community.
 - energy from efficient district heating and cooling.
 - energy from carbon free sources.
5. shall offer the capacity to react to external signals and adapt its energy use, generation or storage, where economically and technically feasible (adaptive building).

Turning around such requirements, we can say that a ZEB building can only use as heating system:

- a boiler, burning only biofuels or hydrogen (no on-site carbon emissions from fossil fuels).
- a substation of an efficient district heating system³, if any available, according to EED recast (13/09/2023).
- a heat pump driven by electricity produced on-site, nearby or from renewable energy communities, or by grid electricity if fully produced from carbon free sources (i.e. renewable energy sources or nuclear power plant).
- direct electrical heating under the same conditions of electrical driven heat pumps.
- a heat pump driven by thermal energy produced on-site, nearby or from renewable energy communities, or by efficient district heating systems.

In the same way, it can only use as cooling systems:

- a chiller or an air cooler driven by electricity produced on-site, nearby or from renewable energy communities, or by grid electricity if fully produced from carbon free sources (i.e.

³ efficient district heating and cooling system is a system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat until 31 December 2017 and increasing time by time such fraction till using in 2050 only renewable energy, only waste heat, or only a combination of renewable energy and waste heat.

renewable energy sources or nuclear power plant).

- an absorption/adsorption chiller driven by heat produced by solar collectors on site or nearby or from a renewable energy community.
- natural free cooling.
- mechanical free cooling or evaporative cooling with the same limitation of the electric chiller.
- a substation of an efficient district cooling system.

In all cases for lighting and internal transportation and for any auxiliary of the heating and cooling systems, the used electricity shall be produced only by carbon free sources.

Are we ready to supply carbon free electricity to all new buildings from 2028? Or biofuels and hydrogen, or efficient district heating and cooling systems in all Europe?

Personally, I do not believe that we are ready. That means that the clause of “*where technically and economically feasible*” will be extensively used and the way this will be done will strongly differ Country by Country.

This clause has been specified as follows:

“Where it is technically and economically not feasible to fulfil the requirements under this paragraph, the total annual primary energy use may also be covered by other energy from the grid complying with criteria established at national level”.

Thus, thus the result will be to mostly use for NZEB electrical driven heat pumps chillers fed by grid electricity and some local produced PV electricity, even if the threshold on total primary energy and on operational GWP will be set not too low, because the operational GWP will consider the far production of CO_{2eq} in the grid power stations.

Partial conclusions

The aim of the Directive to have an EU common path to buildings decarbonization is only partially addressed, because the objective is a bit too strong of what is probably feasible possible. Thus, an escape possibility has been provided to each Member State from these strong constraints, giving to them the possibility to set up less stringent thresholds and requirements in the light of a technical and economic feasibility. That will mean that is strongly possible that each Member State will follow its personal route to building decarbonization increasing the differences among them instead of reducing.

What will be the consequences of having chosen the total primary energy use as the building performance indicator, at least for new buildings from 2028, will be analysed in a second paper. ■

A Pilot Study on Window Opening Behaviour in Auckland, New Zealand



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Occupant behaviour is a significant factor affecting the quality of the indoor environment (IEQ), which can have implications on the comfort and cognitive function of children in educational settings. The New Zealand (NZ) Ministry of Education (MoE) oversees more than 35,000 classrooms within 2,538 schools distributed across six climatic regions. These climatic regions are influenced by factors such as latitude, prevailing winds, surrounding ocean, and the Southern Alps, all contributing to diverse weather conditions across the elongated geography of the nation. Temperature variations in NZ are significant, with extremes ranging from -9.0°C to 41.6°C , accompanied by widely varying patterns of rainfall NIWA (2023a). These diverse climates pose a challenge for suitable educational spaces.

Keywords: Airing; natural ventilation; occupants' behaviour; primary schools; windows opening.

In Auckland, a mild, temperate maritime climate predominates, with average summertime (December to February) daytime temperatures ranging from 20 to 25°C , and winter (June to August) daytime temperatures spanning 11 to 15°C , as reported by NIWA (2023a).

According to Swarbrick (2012), the bulk of NZ's school infrastructure was built in the 1950s and 1960s. These structures were intentionally crafted for natural air circulation, consisting of single-story, timber-framed buildings equipped with large, single-glazed windows that could be opened to usher in daylight and airing for ventilation. Notably, these buildings were constructed without insulation, a feature that only became a NZ standard requirement in 1978.

A 2015 survey reports just 40% of teachers in Auckland primary schools actively use windows for airing (Gully, 2015; Liaw, 2015). Despite the minimal use, the NZ MoE still promotes natural ventilation over mechanical means.

The COVID-19 pandemic underscored the critical role of ventilation in maintaining healthy indoor environments, particularly in educational settings. To this end, the NZ MoE provided guidelines for schools to optimize classroom airing, which covered practices such as the appropriate opening of windows (MoE, 2021). A key measure implemented at our pilot school was the introduction of NZ MoE Internal Environment Monitoring (IEM) devices. These devices offer the advantage of collecting real-time data on IEQ, a

capability not possible without such technology. It is challenging for educators to recognize increasing CO₂ levels during active instruction. Typically, awareness arises only when conditions worsen, indicated by a stuffy atmosphere and drowsiness amongst learners. The IEM devices aim to empower teachers to monitor and respond to changes in IEQ proactively, allowing for timely interventions to enhance IEQ and sustain an optimal educational atmosphere. The NZ MoE IEM device can alert users when thresholds for these measurements are exceeded, prompting them to act, such as opening windows for airing, or managing the number of students in an indoor space to improve air quality. Regrettably, the data regarding IEQ is not gathered by the individual schools themselves. Instead, it is collected by the NZ MoE, which, at present, does not share this information with the public. Posters were circulated to the school from the NZ MoE, discussed at school meetings and then displayed in classrooms.

A pilot study conducted in a primary school in Auckland, NZ, assesses the patterns of window operation to better understand the relationship between teacher behaviours and the resulting IEQ within the classroom setting.

Research methodology

The chosen primary school, located in the temperate and generally mild climate of North Shore, Auckland, experiences an average annual temperature of 15.6°C and receives around 1,231 mm of rainfall, according to NIWA's (2023b) report. As depicted in **Figure 1**, the school caters to 160 students between the ages of 5 and 11 in multi-age group classes, which are positioned approximately 90 m from the main road, which helps to reduce auditory disturbances. The classrooms designated for this study are marked R1–R7 to maintain confidentiality. The facility includes seven classrooms of equal floor area and a single library space. All classrooms

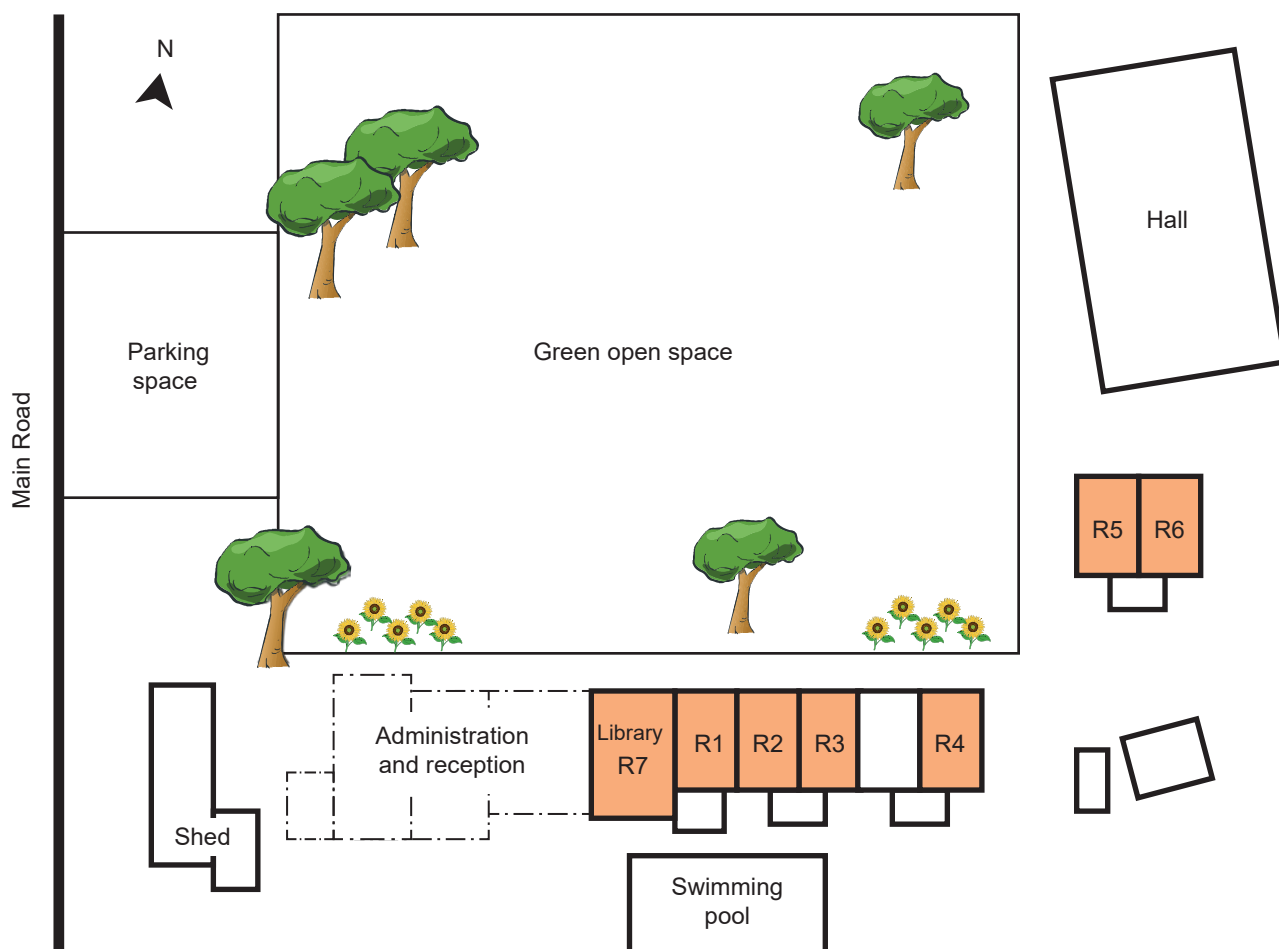


Figure 1. Site Map of School and Location and Study Classrooms

are situated on the first floor and feature doors on the North side that open directly to the play area. A system for cross ventilation is possible thanks to the presence of windows on both the North (front) and South (back) sides of the classrooms. One classroom was removed from the study due to the presence of mould mid-term.

The study involved observation sessions held on the 20th, 23rd, and 27th of March 2023 (Figure 2), from 9 am to 3 pm (NZ school time). The status of doors and windows was noted at 20-minute intervals to evaluate airing within the classrooms. Environmental conditions outside were recorded every three hours, with data obtained from the local North Shore station managed by NIWA (NIWA, 2023b). Temperature, relative humidity, and carbon dioxide (CO₂) levels were monitored using the Massey University IEM device (Weyers, 2017).

An observation form was developed (Figure 3) to obtain information on the door/window status. Visual observations were conducted to provide a general overview of the space and identify explanatory predictors influencing operations on windows and external doors. Before the commencement of the observational studies, the lead author was informed by two of the teachers that the students manage the opening/closing of the windows during the day based on the teacher's requests. To prevent teachers from being interrupted, the reasons for opening or closing windows were grouped into broad categories such as occupancy patterns, indoor environmental quality, or external factors like noise that could be easily observed without needing to ask questions. If it was unclear why a window had been adjusted, the principal investigator would inquire about it at the end of the teaching session.

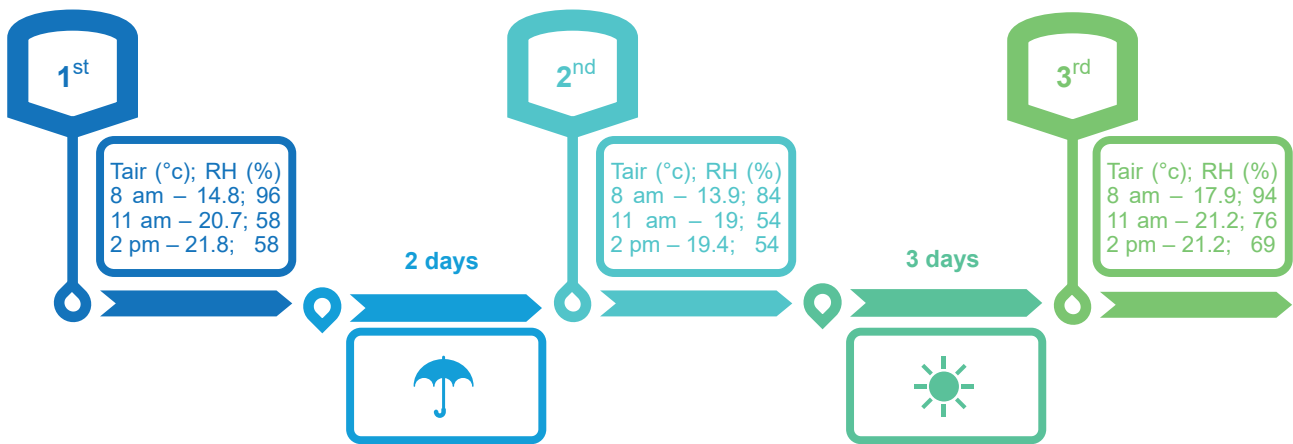


Figure 2. Air Temperature and Relative Humidity for Three Observation Days

Day: _____
Date: _____
Time: _____

Classrooms

Back casement windows

Open
 Closed

Occupancy pattern

Occupied Not occupied On lunch/tea break

At the pool Gone to assembly Other

Type of activity

Sedentary(seated) Active (Running playing)

Library

Louvers

3 Doors

3 Front windows

10 Back windows

Occupancy pattern

Occupied Not occupied On lunch/tea break

At the pool Gone to assembly Other

Type of activity

Sedentary(seated) Active (Running playing)

Computer weather status and temp

Figure 3. Observation Form for Occupancy Patterns and Window Opening Behaviour.

Results

A table with all descriptive statistics is freely available through the Research Gate Link provided at the outset, however, to set the scene, the highest temperature reached 26.9°C – typical for late March in NZ. Notably, R2 experienced a CO₂ surge on Day 1, likely linked to increased window closure caused by noise from nearby swimming lessons, as confirmed by teacher communication (20th March 2023). **Figure 2** illustrates the air temperature, relative humidity (RH), and intervening weather conditions over the seven-day observation period.

The initial day of observation was overshadowed by the prospect of rain. 11.4 mm and 5.4 mm of rain fell over the next two days respectively (NIWA, 2023b). Evidence of the impending rainfall is seen in the closure the windows at the conclusion of the first day (**Figure 4**), a precaution not deemed necessary on the subsequent days, as conditions improved. There was no rain on the second day of observations, even with an 84% RH and the dry sunny spell extended over the following three days. In a similar pattern, the third day of observation enjoyed clear skies. Rain was recorded after the third day of observations. These wetter conditions align with the high relative humidity

measurements recorded at 96% (**Figure 2**) on day one and 94% on day three (NIWA, 2023b). Each day saw a gradual rise in temperature, contributing to the need to open windows. Meanwhile, wind speeds remained below 10 km/h, which was conducive to not only opening but also keeping the windows open for extended periods.

The school caretaker opened the external doors before the start of the school day and would leave them open throughout. Windows were not manipulated until the arrival of the teachers, typically around 8:30 am, to ventilate classrooms before students arrived, accounting for 43% of the window operations. **Figure 4** visually represents the frequency of window openings in each room, considering the number of windows available for opening and how often they were operated each hour. A thorough inspection of all windows was carried out at the beginning of the project, confirming all were operational. Indoor environment prompted 38% of the actions. In classroom R2, 10% of the instances where windows were closed were in response to noise disruptions, particularly during swim time (**Figure 4**, far right image) at the nearby pool. Generally, windows stayed open unless noise or poor weather conditions prompted their closure.

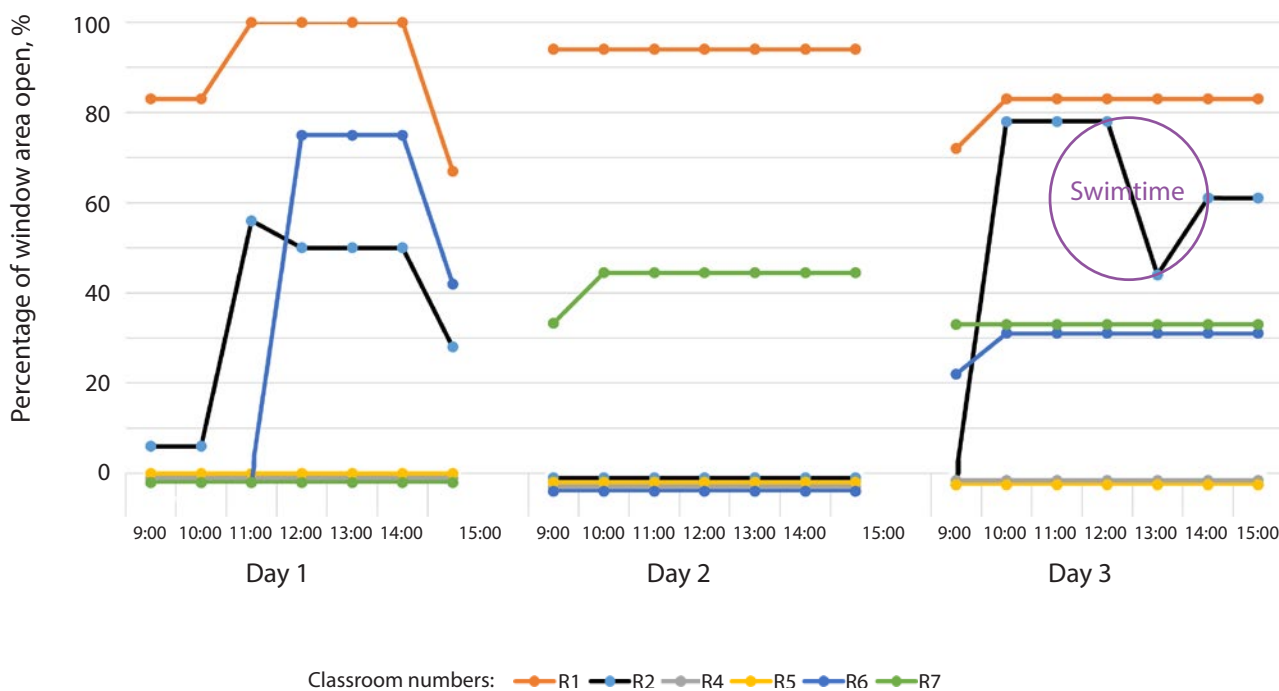


Figure 4. Percentage of window area that is open over the school day (by class) during the observation study.

The data reflects a variety of practices at the school regarding airing. Throughout the observation period, the north-facing front doors of all classrooms remained open. The behaviour in rooms R1 and R2 demonstrated consistent window opening, contributing to adequate ventilation. In contrast, the windows in R4 were usually kept closed. The teacher was unavailable for comment. R5 and R6, which share a space with a partition often function as a single teaching area (R6), showed variable window and door usage, possibly because of the team-teaching approach in this space. The PI has noted this irregularity for further investigation. Compared to the 2015 Auckland survey, the average window opening durations at this school over the observation period correspond to 30%, which is 10% lower than the pre-COVID-19 teacher survey.

A Spearman correlation tested the relationship between window open area (WOA in m²) and environmental factors to analyse window usage in reaction to IEQ (stuffy environment, thermal comfort). With visual data indicating 38% of window operations tied to IEQ, variables like indoor/outdoor temperature, humidity, CO₂ levels, and wind speed were correlated with WOA. Operations not linked to the environment, such as end-of-day closures, were omitted from this analysis. Spearman's correlations confirm significant links: a strong positive correlation between openable window area and indoor temperature ($\rho = 0.758$, $p < 0.018$), and a notable positive correlation with outdoor temperature ($\rho = 0.893$, $p = 0.001$). But an inverse, but not significant, relationship with relative humidity ($\rho = -0.341$, $p = 0.370$), and CO₂ levels ($\rho = -0.613$, $p = 0.079$) were noted.

Conclusions

The contrast in window opening routines between classrooms within one school (R1/R2 compared to R4) considering post-COVID-19 guidelines is striking, indicating a significant divergence despite receiving the same school-wide information from the principal. This outcome highlights that window opening practices are predominantly driven by individual choices, influenced by external factors such as temperature. These relationships emphasize the impact of window operation on indoor climate and air quality.

To potentially alleviate the necessity for teachers to constantly monitor IEM devices and consider the IEQ of classrooms, installing trickle vent systems could be advantageous. These systems, by regulating the temperature within the classroom, can establish a more agreeable environment for teachers, preventing

overheating in warmer months and addressing stale air concerns in colder periods. As a result, trickle vent systems enhance comfort and productivity for teachers, fostering alertness and concentration in a well-ventilated setting. Additionally, these systems offer energy-efficient benefits by enabling controlled ventilation without requiring windows to be opened, contributing to the preservation of energy while maintaining a pleasant and healthy classroom atmosphere.

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Comparison of International Test Methods for Air Cleaners



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The offer of air cleaners has increased significantly since the SARS-CoV-2 pandemic. However, up till now no consensus can be found on how to determine the performance of air cleaners. This article describes the similarities and differences between test methods for air cleaners from 13 international standards.

Keywords: Air cleaners, test methods, test standards, indoor air quality, literature overview

Overview of the investigated standards

In **Table 1**, an overview is given of the 13 investigated standards. Most of the test standards only differentiate between portable air cleaners and in-duct air cleaners and not between different technologies. However, there are some exceptions to this, e.g. tests that only apply to UV-C technology.

Test method

Test apparatus

A first characteristic of the test methods is the test apparatus used. Usually, a test chamber or a test duct is used.

The test chamber is an air-tight chamber in which the air cleaning device is placed. The size of the chamber is also defined and differs among the different standards, ranging between 1 m² and around 30 m². NF B 44-200 (2016) is an exception to the other standards, which uses a small test chamber in a test bench.

The test duct is a duct with an air inlet and outlet in which the air cleaner is placed in a manner that the airflow has to pass through the air cleaner. Most standards use a test duct for a nominal device of 610 x 610 mm, which corresponds to the dimensions of the duct. Other dimensions are also possible, if the duct is adjusted to it as described in the standards.

Standard ASHRAE 145.1 (2015) is a special case. In consequence it does not use a test chamber or test duct, but a test apparatus with a gas-phase air filtration media column, which is comparable to the test duct in terms of test set-up and test method.

Test conditions

The temperature and relative humidity of the air are prescribed and do not differ much among most of the standards. Typically, a temperature ranging between 20°C to 25°C with a deviation of 0.5 to 3°C is required.

For tests using test chambers, the air inside the test chamber has to meet these requirements prior to the test, but the air is not conditioned anymore once the test starts. For test chambers, it is also stated that the incoming air has to be clean, i.e. contain a defined maximum pollutant concentration. Filters are used to clean the air that enters the test chamber.

In the case of test ducts, the supply air should be conditioned. The background concentration of the test air is also addressed in the test standards. Examples include imposing a maximum limit for the background concentration, or filtering the supply air, measuring the background concentration during the test and taking this into account in the performance calculations.

Table 1. Overview of the test standards.

Test standard	Title
AHAM AC-1 (2020)	Method for Measuring Performance of Portable Household Electric Room Air Cleaners
AHAM AC-4 (2022)	Method of Assessing the Reduction Rate of Chemical Gases by a Room Air Cleaner
AHAM AC-5 (2022)	Method for Assessing the Reduction Rate of Key Bioaerosols by Portable Air Cleaners Using an Aerobiology Test Chamber
ASHRAE 52.2 (2017)	Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
ASHRAE 145.1 (2015)	Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Loose Granular Media
ASHRAE 145.2 (2016)	Laboratory Test Method for assessing the Performance of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices
ASHRAE 185.1 (2020)	Method of Testing UV-C Lights for Use in Air-Handling Units or Air Ducts to Inactivate Airborne Microorganisms
ASHRAE 185.2 (2020)	Method of Testing Ultraviolet Lamps for Use in HVAC&R Units or Air Ducts to Inactivate Microorganisms on Irradiated Surfaces
IEC 63086-1 (2020)	Household and similar electrical air cleaning appliances – Methods for measuring the performance Part 1: General requirements
EN ISO 10121-3 (2022)	Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 3: Classification system for GPACDs applied to treatment of outdoor air
ISO 16000-36 (2021)	Indoor air - part 36: Standard method for assessing the reduction rate of culturable airborne bacteria by air purifiers using a test chamber
EN 16846-1 (2017)	Photocatalysis — Measurement of efficiency of photocatalytic devices used for the elimination of VOC and odour in indoor air in active mode. Part 1: Batch mode test method with a closed chamber
NF B 44-200 (2016)	Independent air purification devices for tertiary sector and residential applications Test methods — Intrinsic performances

Operational mode of the air cleaner / flow rate through the air cleaner

To test the air cleaning device in a test chamber, the air cleaner has to be turned on in a specific operational mode. Depending on this, the air cleaner has a different efficiency. Most standards prescribe to test at the highest operational mode or in the automatic mode, but there are exceptions to this, e.g. to test for multiple operational modes.

If a test duct is used to test the air cleaner, an airflow rate in the test duct must be specified. The way of specifying differs among the different standards. Examples are to use the upper limit of the air cleaner's application range or to use a face velocity of 2.54 m/s.

Definition of performance

When a test chamber is used, test pollutants are usually added to the air until a certain concentration is reached. Then the supply of test pollutants stops, and the decay rate is measured. A common way of expressing the performance using this test method is the Clean Air Delivery Rate (CADR), that can be calculated by multiplying the volume (m^3) of the test chamber with the decay rate (h^{-1}) of the pollutant that is caused by the operation of the air cleaner, measured in the test chamber.

Test standards using a test duct usually have a continuous supply of pollutants for the first tests, such as measuring the removal efficiency. Afterwards, the supply of pollutants stops, and other parameters will be measured, such as the desorption. Consequently, the performance is not expressed with a CADR. Other expressions of performance that can be used are the removal efficiency at a specific time, the penetration at a specific time and the capacity for removal for a time interval, all expressed as a percentage.

Duration of the test

The duration of the test also differs among the different standards. For tests using test chambers, the test duration is mostly defined as the time from reaching and measuring the initial concentration to the end of the decay test. Some standards have a shorter measurement time, that ranges from ten minutes to an hour. The differences in measurement time are due to a faster or slower decay rate of the pollutants, characteristics of the measurement device or characteristics of the air cleaner. Other standards describe a longer test duration: e.g. to let the test run until 90% of the volatile organic compounds (VOCs) are removed, with a maximum test time up to 24 hours.

For the test methods using a test duct there is a larger difference in expressing the duration of the test. Some standards clearly specify a test duration, but often the test is allowed to stop when a certain limit is reached, such as a certain breakthrough level, which means that the test pollutant appears in the effluent air.

Test pollutants

Depending on the test, different test pollutants are used. Some standards test for a broader range of pollutants, e.g. standard NF B 44-200 (2016) uses a test gas, microorganisms, an allergen and an aerosol. Other standards have a more limited scope of test pollutants. For example, standard ISO 16000-36 (2021) only tests for two bacteria.

The test pollutants are mostly either commonly used test materials for air cleaners/filters, or they represent typical pollutants of indoor/outdoor air. Another possible selection criterion is that the used organisms cover the range of reasonable interest e.g. for UV-C device applications.

Knowledge gaps and challenges

By-products

The standards almost never prescribe a test for by-products; only two of the investigated standards explicitly address the testing of by-products and some others refer to standard UL 867 to test for ozone generation levels. However, air cleaners can introduce several unintended by-products in the air, such as ozone, but also other oxidants that can be harmful to health as well. Hence, this is an important topic to address when testing air cleaners and a proper testing method for a non-targeted analysis should be set up.

Real life performance

The tests do not predict the real-life performance of the air cleaners. The test conditions and test pollutants are pre-defined, and this does not necessarily reflect the real-life conditions in which the air cleaner will be used. This would also be hard to achieve since field conditions vary from location to location. The size of the test chambers and the fact that test pollutants are not continuously added to the test chamber is also not very realistic. As a consequence, the outcome of the test can only be used to compare the performance of different devices amongst each other, but not to predict real life performance, like the cleanliness of the space where the air cleaner is used.

Long-term performance

The tests are carried out over a limited period of time. However, breakthrough in real life conditions may take weeks or months. Therefore, the capacity test is conducted at elevated challenge concentrations to shorten the test, hence reducing the costs. As a consequence, the performance data cannot be transferred to real and long-term use conditions directly. The results can be extrapolated, but this will not always be correct, so the performance over service life cannot be predicted with the results of the test.

Conclusions

The review points out that there are many differences between the investigated test standards. One of the main differences concerns the test method that is used. Using a test chamber or a test duct imposes a different way of testing, which also influences the test duration and the definition of effectiveness. In contrast, the test conditions and the operating mode/flow rate through the air cleaner show little difference. The test pollutants used vary widely, but this is partly a consequence of the targeted type of air cleaners to be tested. If a device using UV-C technology is tested for example, only the decay of microorganisms is relevant to test.

The test standards provide a method to compare the air cleaning devices, but they do not provide results on the real use performance or the long-term performance. A non-targeted analysis to search for potentially harmful by-products is also a knowledge gap in most of the test methods.

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Household Generated Particulate Matter in Mechanically Ventilated Homes



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This study examines the impact of high occupancy levels, due to COVID-19 stay-at-home orders, on IAQ in mechanically-ventilated residential buildings. Indoor PM_{2.5} and PM₁₀ concentrations increased in most houses (64% and 40% respectively), while outdoor levels decreased (34% and 31%), indicating internal sources were the main contributor to indoor concentrations.

Keywords: Indoor Air Quality, Mechanical Ventilation, Increased Occupancy, COVID-19 lockdown, Particulate Matter

Introduction

Indoor air pollution can be detrimental to human health (Cohen et al., 2005; Donaldson et al., 2001) and can lead to increased mortality rates (Hales et al., 2012). Numerous studies have shown that human exposure to indoor pollution is often more common than exposure to outdoor pollution (Logue et al., 2012; Weschler, 2006), especially where people spend most of their time indoors at home (Klepeis et al., 2001). The control of indoor air quality (IAQ) inside homes is therefore an important factor for the health and wellbeing of residents.

Inadequate ventilation can prevent escape of substances from within the home and lead to an accumulation of

physical pollutants arising from internal sources (e.g., building materials, furnishings, personal care products, pesticides, and household cleaners). The term “Sick Building Syndrome” describes the relationship between the IAQ and its potential effects on occupants (Bernstein et al., 2008), such as headache, respiratory infection, and cognitive function (Taptiklis et al., 2017; Tookey et al., 2019). Positive pressure ventilation (PPV) systems use mechanical ventilation to extract and filter dry air from the roof space, creating a slight positive pressure to drive out stale air and maintain IAQ.

The recent Coronavirus disease (COVID-19) pandemic led to lockdown events which resulted in the general

public spending the majority of their time at home. Numerous IAQ studies have investigated the effects of increased occupancy on IAQ, however these primarily focus on buildings which rely on natural ventilation. To improve understanding of the effects of occupancy on indoor pollutant concentrations, in particular where mechanical ventilation systems are installed, this study analysed IAQ parameters ($PM_{2.5}$, PM_{10}) in homes in Auckland, before and during COVID-19 lockdown. Due to the objective of mechanical ventilation being to improve thermal comfort, this study also included an evaluation of thermal comfort parameters (temperature, RH) in response to changes in occupancy.

Methodology

IAQ were monitored in six mechanically-ventilated Auckland homes with PPV systems, each having floor areas of 120 to 273 m² and three to four bedrooms, over a six-week period (three weeks before and three weeks during the COVID-19 lockdown). Three monitors were located indoors to measure $PM_{2.5}$, PM_{10} : in the master bedroom, another bedroom and the living area. Outdoor PM measurements were obtained from nearby council-owned air quality monitoring stations. Indoor and outdoor monitors were positioned 1.0 m and 1.5 m above floor level respectively (where possible). Low-cost sensors in this study were calibrated against two robust PM monitors (Aeroqual Dust Sentry Pro) before and after the monitoring period, with a one-week co-location period. $PM_{2.5}$ showed strong correlations (R² values: 0.89–0.96) with the standard monitors.

Results and Discussion

Household Environment, Occupancy Rates and Activity

All six houses were single-storey open-plan of timber construction, with floor and roof insulation. All windows were single-glazed. All participants reported that their homes were typically only occupied outside of business hours (prior to lockdown) and were generally occupied full time during lockdown. Ventilation rates varied between 3 and 4 air exchanges per hour. Larger houses require additional fan units to guarantee this air exchange rate. The system uses a deep-pleat nano-fibre filter (F8), to remove all particles greater than 0.4 µm; tested to meet international (Eurovent and ASHRAE) standards. The PPV systems were controlled centrally, to adjust automatically according to the temperature differential measured between rooms and the roof-space.

Particulate Matter ($PM_{2.5}$, PM_{10})

The average PM concentrations (measured in the living area) across the three-week periods before and during lockdown are presented in **Table 1**. Three of the residential buildings (D, E and F) showed an increase in $PM_{2.5}$ of between 25% and 62%.

Table 1. Average indoor concentrations of $PM_{2.5}$ and PM_{10} .

Parameter	House	A	B	C	D	E	F
$PM_{2.5}$ (µg/m ³)	pre-lockdown	0.55	0.73	20.62	4.20	4.96	4.37
	during lockdown	0.80	1.73	21.21	5.24	8.01	5.78
PM_{10} (µg/m ³)	pre-lockdown	0.93	1.08	23.51	4.69	5.52	6.05
	during lockdown	0.58	0.36	21.50	6.13	9.00	7.71

This is consistent with findings by (Laltrello et al., 2022) and (Cowell et al., 2023). One house showed a substantial increase in $PM_{2.5}$ of around 136%, while two houses showed minimal change. The change in $PM_{2.5}$ levels for House A was close to the limit of the sensor accuracy. House C was identified as a rural/farming house, where the level of occupational activity outside the home was not affected by the lockdown. This house had the highest indoor concentration of $PM_{2.5}$ both pre and post lockdown.

Indoor PM_{10} concentrations increased following lockdown for three of the houses, between 27% and 63%, which is consistent with Laltrello et al. (2022) and Cowell et al. (2023). This may indicate the primary sources of PM_{10} were internal for these houses. Internal PM_{10} sources can include smoking, woodfire burning, unflued heaters and burning of candles. House F, for example, contained a fireplace. The other two houses where PM_{10} increased were geographically sheltered from the nearest roads, so internally generated PM_{10} is more likely to be the main component of indoor concentrations for these houses, and accordingly increase with occupancy. For the other three houses, the magnitude of change in PM_{10} was relatively minor (<1 µg/m³) for two of these, while the third house was the farmhouse mentioned previously, where day to day activities were not affected by the lockdown.

Average indoor $PM_{2.5}$ concentrations for two selected houses for the weeks immediately prior to and following COVID-19 lockdown are shown in **Figure 1**. These show that diurnal $PM_{2.5}$ peaks during lockdown were higher than those prior to lockdown. Background levels of $PM_{2.5}$ remained relatively low during the lockdown period as expected for people working from home, spending much of the day seated and limiting $PM_{2.5}$ emissions.

Average daily $PM_{2.5}$ and PM_{10} concentrations for each house were compared with the WHO Air Quality Guideline (AQG) limits ($15 \mu\text{g}/\text{m}^3$ and $45 \mu\text{g}/\text{m}^3$ for $PM_{2.5}$ and PM_{10} , respectively). In general, the $PM_{2.5}$ limit was exceeded more frequently than the PM_{10} limit. Similar studies (Algarni et al., 2021; Cowell et al., 2023) have shown that WHO limits are typically exceeded with increased occupancy, but these mostly apply to homes which only have natural ventilation. Prior to lockdown, House C exceeded the $PM_{2.5}$ limit on 16 of the 21 days, while the only other exceedance was one day in House E. During lockdown, House C exceeded the $PM_{2.5}$ limit 11 days out of the 3-week period, House E exceeded on two days, while Houses B and D both exceeded one day. The PM_{10} limit was only exceeded twice, two different houses, each on a different day, both during lockdown. House C was identified as comprising residents who regularly smoked cigarettes indoors. Cigarette smoking has been

shown to increase indoor concentrations of $PM_{2.5}$ up to 28 times that for non-smoking households (Algarni et al., 2021).

Indoor Vs Outdoor

Outdoor PM measurements were obtained from three local council-owned air quality monitoring stations located across central Auckland. Average PM concentrations were calculated for the three-week periods immediately prior to and following COVID-19 lockdown. Average $PM_{2.5}$ concentrations decreased by 34% (from $7.7 \mu\text{g}/\text{m}^3$ to $5.1 \mu\text{g}/\text{m}^3$), ranging between 30% and 37% for the three stations. PM_{10} decreased by 31% (from $17.3 \mu\text{g}/\text{m}^3$ to $11.9 \mu\text{g}/\text{m}^3$), ranging between 10% and 39%. Decreases in PM_{10} and $PM_{2.5}$ were expected due to reduced traffic volumes and restrictions on non-essential commerce and industry during lockdown (Laltrello et al., 2022). **Figure 2** compares indoor and outdoor $PM_{2.5}$ and PM_{10} levels for a selected house and AQ monitoring station, one week prior to and one week immediately after COVID-19 lockdown. Despite a gradual decrease in outdoor PM concentrations, indoor concentrations increased during the lockdown. Mechanical ventilation has been shown to substantially reduce indoor concentrations of outdoor-generated pollutants when compared with natural ventilation (Martins & Carrilho da Graça, 2018; Ren et al., 2017).

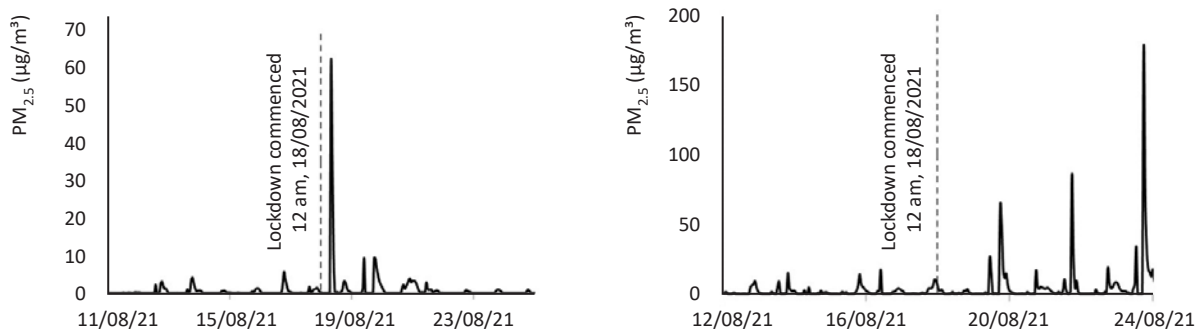


Figure 1. Indoor $PM_{2.5}$ concentrations in House A (left) and House D (right), 1-week pre/post lockdown.

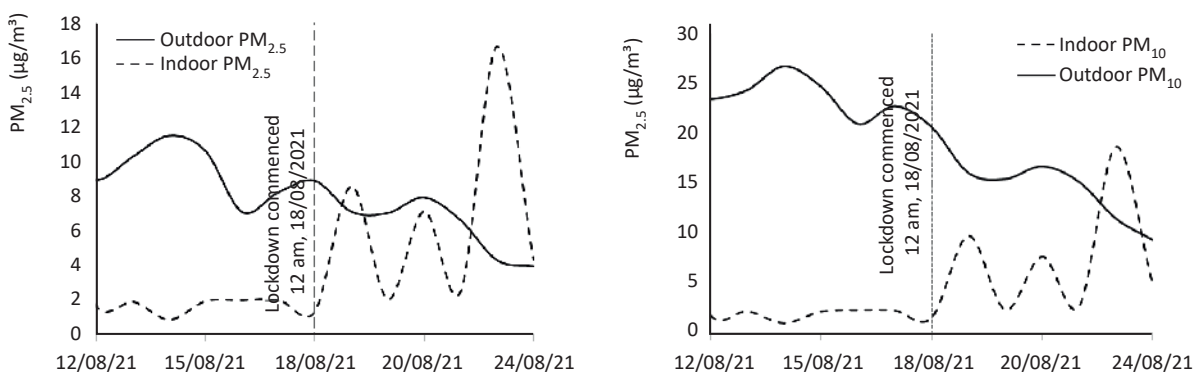


Figure 2. Indoor vs outdoor PM concentrations of $PM_{2.5}$ (left) and PM_{10} (right), 1-week pre/post lockdown (House D).

Conclusions

Outdoor concentrations of PM_{2.5} generally decreased during lockdown (34%, on average compared with pre-lockdown levels). Despite this, indoor PM_{2.5} concentrations were generally found to be between 25% and 62% higher during the lockdown period, suggesting internal sources. Furthermore, mechanical ventilation has been shown to substantially limit penetration of outdoor pollutants indoors, suggesting that internal concentrations are even more likely to have originated from internal sources. Diurnal peaks were also observed to be higher during lockdown, with highest peaks typically occurred during evenings.

Indoor PM₁₀ concentrations generally increased during lockdown (40% average) compared with outdoor concentrations. Reduced traffic and industrial activity during lockdown may have been directly responsible for reduced outdoor PM concentrations. Increased indoor PM₁₀ concentrations are therefore likely to be due to internal sources, mainly from combustion activities.

With the exception of one house (identified as a smoking household) average daily PM concentrations rarely exceeded WHO Air Quality Guideline limits for short term exposure. With mechanical ventilation, all homes were able to maintain indoor PM levels below the WHO guideline limits throughout the duration of the trial, despite the increased levels of occupancy.

Acknowledgements

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Ventilation and a Healthy and Comfortable Indoor Environment

– *What is the rationale behind the requirements?*



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Given the increasing airtightness of buildings, occupants have to more and more on their ventilation systems to ensure a comfortable and healthy indoor air quality. We trust that ventilation standards address this concern. However, significant disparities exist between countries regarding the requirements and regulations for ventilating various spaces, including dwellings, offices, and classrooms. In fact, the variation in prescribed minimum ventilation flowrates for similar building types among different countries can exceed a factor of five (see **Figure 1**).

Keywords: Residential ventilation, indoor air quality, ventilation standards.

To address this issue, the AIVC has recently released Technote 72: “Ventilation Requirements and Rationale behind Standards and Regulations of Dwellings, Office Rooms, and Classrooms.” [1]. This document aims to elucidate the rationale behind diverse international ventilation standards. Additionally, extensive research conducted over the past decade, notably detailed in Technote 68 “Residential ventilation and health” by the AIVC, has identified the primary pollutants impacting indoor air quality and health [2].

An examination of Technote 72 with data from 29 countries reveals significant disparities in ventilation requirements for dwellings, including living rooms and “wet rooms” such as kitchens, toilets, and bathrooms. To facilitate cross-country comparisons, we have expressed all requirements in dm^3/s . The rationale behind ventilation requirements encompasses factors such as human odours (often CO_2 concentration is used as a marker), moisture from activities like washing and cooking, health impacts, formaldehyde emissions, cooking fumes, bacteria, viruses, sick building syndrome symptoms, and radon.

Many ventilation regulations date back to the early 1990’s and lack comprehensive scientific reports explaining their rationale. Instead, they are often based on expert opinion or information from other standards. Historical differences may stem from energy efficiency and health concerns, such as those related to formaldehyde. Despite commonalities in rationale, there remains a wide range of ventilation requirements, particularly for kitchens.

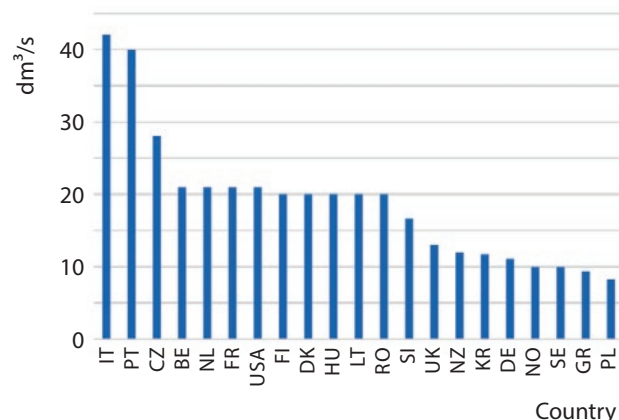


Figure 1. The minimum flow rate for kitchens. [1]

Experts generally agree that removing cooking byproducts is the primary rationale for kitchen ventilation, while moisture control drives requirements for bathrooms. For toilet rooms, preventing the spread of contaminants and odours is dominating human bio-effluents predominantly dictate ventilation requirements for habitable rooms. Notably, variations in ventilation requirements are more pronounced for habitable rooms than for office spaces and classrooms, reflecting differences in occupancy and activities.

AIVC Technote 72 underscores that ventilation standards are rooted in pollutant mitigation to prevent discomfort and health risks. Technote 68 identifies key indoor and outdoor pollutants based on concentration and associated health impacts, and describes effective ventilation strategies.

Ventilation strategies should be designed to minimize health hazards and prevent unwanted odours. To achieve this goal, it is essential to identify the pollutants that pose health risks and determine the most effective control strategies for those pollutants. High concentrations of pollutants do not necessarily indicate a health risks. Merely relying on pollutant concentration data is insufficient for identifying the pollutants that drive health hazards. Toxicity levels vary significantly among pollutants, and extensive research has been conducted to establish links between exposure levels of specific pollutants and particular adverse health outcomes.

Several studies have attempted to prioritize pollutants for mitigation in the indoor environment based on the prevalence of disease in the community, occupant exposure estimates, and the research-derived links between exposures and health outcomes. The key pollutants identified as driving chronic health impacts include

PM_{2.5} (particulate matter with a diameter less than 2.5 microns), mold/moisture, radon, environmental tobacco smoke (ETS), formaldehyde, and acrolein. To reduce exposure to contaminants, different control strategies can be applied. The most effective strategies [3] are 1. avoiding the emission of contaminants by source elimination and 2. enclosure and encapsulation of sources with e.g. a cooker hood. The remaining contaminants can be diluted with in most cases mixing ventilation by supplying fresh air. An excellent example of the first strategy is to replace gas cookers with electrical hob, minimizing the exposure to NO₂, acrolein, CO and ultrafine particles. Ventilation plays a key role in reducing exposures that can't be controlled by these measures. Effective local ventilation, such as cooker/range hoods with effective capture efficiency, is critical for removing pollutants from periodic high-emission sources such as cooking. Other unavoidable contaminants such as human odours, can be removed by using mixing ventilation or displacement ventilation. The correct amount of ventilation is still a topic of debate.

Therefore, there is a need to evaluate and develop new advanced ventilation strategies based on health and comfort criteria, but let's not forget the document factor of active involvement of building occupants in the creation of a healthy and comfortable indoor air quality.

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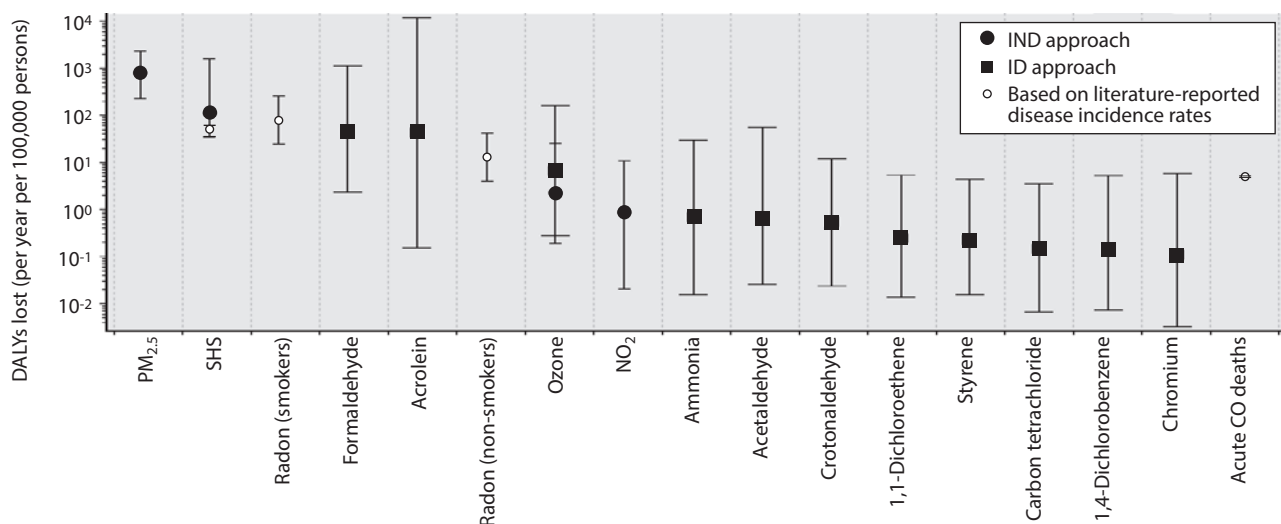


Figure 2. Estimated population averaged annual cost, in DALYs, of chronic air pollutant inhalation in U.S. residences; results for the 15 pollutants with highest mean damage estimates. Logue et al. 2012 [4]

Internal Leakage in Air Handling Units

– the Outdoor Air Correction Factor (OACF) and Exhaust Air Transfer Ratio (EATR)



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The benefits of good ventilation and indoor air quality for comfort, health and productivity in both places of work and homes is undisputed. According to WHO “poorly ventilated buildings affect air quality and can contribute to the spread of disease”

Leakage of air in ventilation systems is, of course, wasteful but it can also affect the indoor air quality so we need to minimise leakage to both optimise the energy consumption and ensure the best possible air quality.

During recent years more attention has been focused on the subject of internal leakage in air handling units and now we see that progress has been made in defining test methods and also setting requirements. The testing standard for heat exchangers for air to air heat recovery, EN 308: 2022 includes methods for measuring the OACF (Outdoor Air Correction Factor) and EATR Exhaust Air Transfer Ratio). We will explain those terms later in this article. In November 2023 a new certification scheme was agreed within Eurovent Certita. The new rules include a requirement to declare OACF and EATR, so customers will see those properties in the technical submittals from Eurovent Certified AHU manufactures. The testing of the power consumption of the AHU will, from now on, include the effect of the internal leakages.

Already, manufacturers of the heat exchangers provide the OACF and EATR so that AHU manufactures can include the information and use the data in the calculation of unit performance.

It is also quite likely that the next version of the ErP Regulation for non-residential ventilation units will include the requirement to declare the OACF and EATR.

So, what does it mean?

We differentiate between internal and external leakage. External leakage is the leakage through the unit casing between the inside and outside of the unit while internal leakage occurs between the dividing walls of the internal sections.

All types of air handling unit have a potential leakage of air past the filters which will have a negative impact on the air quality as well as dirty ducting with increased cleaning costs as a result.

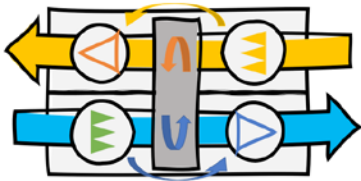
Filter bypass leakage is classified according to the filter class with the intention that the design of the filter frame and sealing is appropriate for the filtration required. Testing should be carried out in accordance with EN 1886:2007. Eurovent certified air handling units are independently tested by third party laboratories and the results are published on the Eurovent home page.

Heat exchangers for energy recovery are also potential sources for leakage. Plate heat exchangers should have small levels of leakage in themselves but a poor installation in the air handling unit can give rise to considerable leakage with energy losses and degraded air quality as a result. Well installed plate heat exchangers will have very low leakage but depending on the position of the fans and the construction of the unit there is a potential for leakage of extract air to supply air.

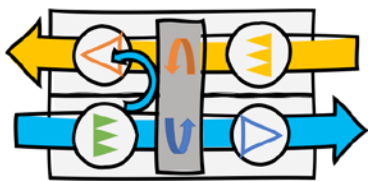
Rotary heat exchangers offer the advantage of a high efficiency with small space requirement and very little need for defrosting. But because they rotate, they are more difficult to seal effectively.

With rotary heat exchangers there are essentially four modes of leakage.

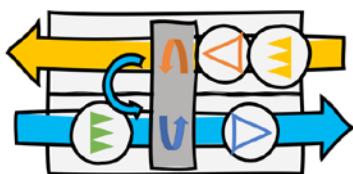
The first is the peripheral leakage. Leakage around the periphery of the rotor will have a direct effect on the overall heating power of the rotor. The reduction in temperature efficiency can be quite significant and leakage past the periphery seals will also contribute significantly to the leakage between airflows so it is important that the periphery seal is effective.



The second mode of leakage is that from the outdoor air side to the exhaust air side. Normally there will be a large pressure difference between the outdoor air side of the rotor and the exhaust side. This pressure drop drives a leakage from the supply to exhaust air side. Leakage in that direction will not affect the air quality but it will have an effect on the energy consumption. When we have the correct airflow at the supply air fan, we will have a higher airflow at the fresh air filter and that means we will have a higher pressure drop there. We must also compensate on the exhaust side to ensure that we get the correct extract airflow. This is quite a complex calculation to make requiring an iteration to arrive at the correct result but without it, the power consumption of the fans will not be correct and that means any annual energy calculation will also be wrong.



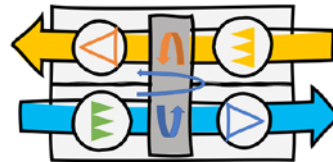
If the extract fan is placed on the extract side of the rotor, then the leakage will be in the other direction:



This will have a serious effect on the air quality and is not recommended at all.

To be able to minimise the leakage of air between the airflows the recommended arrangement of the fans is upstream of the rotor on both sides.

Rotary heat exchangers can carry extract air over to the supply air. This carry over leakage can be effectively eliminated by means of a purging sector. A small sector of the rotor is shielded off so that extract air cannot enter the rotor there and outdoor air is bled through the rotor in both directions to purge it of extract air. This purging function cleans the rotor of impurities and ensures a high quality of supply air. To drive this purging flow, we need a pressure difference; which must be created by the extract fan. The purging flow must also be added to the flow rate of the extract fan.



The fourth mode of leakage is from extract to supply on the room side of the rotor like this:

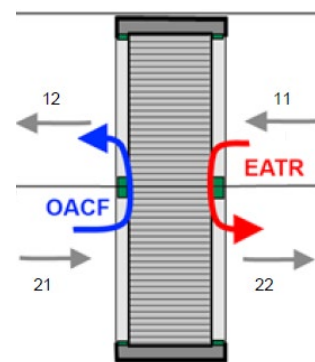


This leakage will depend on the pressure difference between the extract and the supply and if the fans are correctly positioned as shown, can be eliminated by throttling the extract air so that the pressure difference is in the right direction. This extra pressure drop must be included in the exhaust fan.

The leakages described in modes two to four above are defined in EN 16798-3:2018 (Energy performance of buildings) by two ratios:

Outdoor air correction factor (OACF)

Exhaust air transfer ratio (EATR)



OACF is the ratio of the outdoor air inlet and the supply air outlet flow:

$$OACF = \frac{q_{m,21}}{q_{m,22}}$$

From an air quality point of view, the OACF should be greater than one, because that means the leakage is from supply to exhaust. If it is less than one, then there is leakage from exhaust to supply and we want to avoid that.

EATR is the percentage of exhaust air recirculating to the supply air:

$$EATR = \frac{q_{m,22} - q_{m,22,net}}{q_{m,22}} = 1 - \frac{q_{m,22,net}}{q_{m,22}}$$

EATR is the leakage by the seal at the rotor on the room together with the carry-over leakage.

We need to consider these two leakage measures together. Both of them need to be kept within limits.

As mentioned above, test methods for OACF and EATR are defined in EN 308:2022

What is the impact on the power consumption?

To correct for the EATR it is necessary to ensure a correct pressure balance and that often means that the extract air needs to be throttled which means that an additional pressure drop is introduced. Obviously, that increases the power consumption of the extract fan.

The OACF needs to be compensated for by increasing the airflow in the extract fan so that also increases the power consumption. The OACF also means that the airflow through the intake sections of the system through to the heat exchanger needs to be a little more than the required supply airflow. That means higher pressure drop for the supply fan.

An example illustrates how much this impacts the total power consumption:

Consider a ventilation unit with rotary heat exchanger with an air flow of 1 m³/s and external static pressure 200 Pa. The EATR is 3% and the OACF is 1.08

Electrical power to fans in clean filter state before correction is made is

Supply: 0.94 kW, Exhaust 0.86 kW

Clean pressure drop of the outdoor filter is 70 Pa.

Clean pressure drop of the extract filter is 38 Pa.

1. The supply air flow is increased by 3% to compensate for the EATR. To maintain the pressure balance in the building the extract air flow is also increased by 3%.
2. The outdoor air flow is corrected by an additional 8% to compensate for the OACF and the exhaust air flow is also corrected by that 8%
3. The pressure drop through the filters recalculated at the new air flow rates and become 83 Pa and 42 Pa respectively.

The result is that the supply air fan operates at 3% higher air flow and 13 Pa higher pressure while the extract fan operates at 11% higher airflow and 2 Pa higher pressure.

The fans are recalculated with the new flow and pressure:

The electric power to the supply fan increases from 0.94 kW to 1.00 kW i.e. + 6.4%

The electric power to the extract fan increases from 0.86 kW to 1.04 kW i.e. + 20.9%

The SFP increases from 1.80 to 2.04 kW/m³/s i.e. +13.3 %

This is a typical example but the result depends, of course, on several factors so it varies from case to case.

When the power consumption is calculated in this way with the inclusion of the effect of the leakages one can be assured that it is made at the ventilation flow rate required and that the indoor air quality will not be compromised. We can also compare ventilation units with different heat recovery solutions without worrying about the impact of leakage.

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Transient Aspects of thermal comfort according to the EN 16798-1



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Background

ISO 7730 [1] is the most important standard for assessing thermal comfort in buildings. At European level, ISO 7730 is supplemented by EN 16798-1 [2], which is currently being revised and after the revision, the standard will be given a new name (number). The revision of this standard introduces a new structure that is intended to give greater weight to the individual trades addressed. The new structure is divided into five parts as follows (see **Figure 1**):

- part 1-1 – Overarching Structure
- part 1-2 – Thermal Comfort
- part 1-3 – Indoor Air Quality
- part 1-4 – Lighting
- part 1-5 – Acoustics

Input conditions for the design and energy demand calculation of technical systems in the building are considered in all parts. Only Part 1-2 (thermal comfort) will be considered below. Aspects of the design of technical systems regarding room temperature and relevant comfort criteria are documented here. All parameters

Symbols

ϑ	temperature in °C
ϑ_{op}	operative room temperature in °C
$\Delta\vartheta$	temperature difference in K
PMV	predicted mean vote in -
τ	time in s

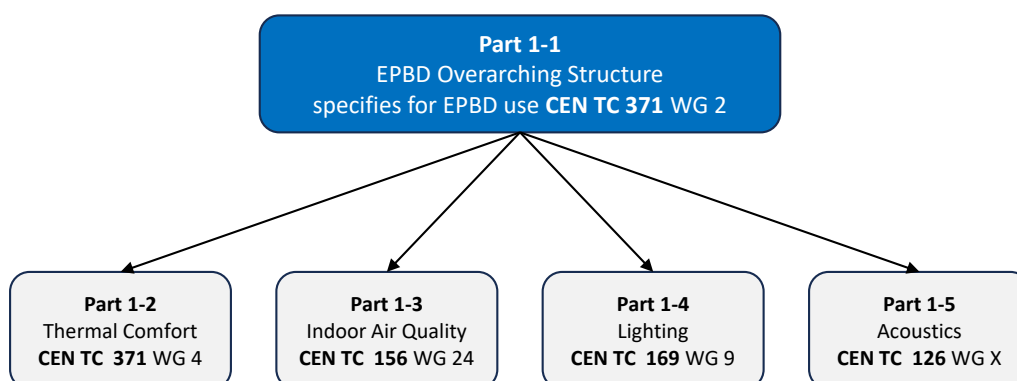


Figure 1. Structure of the new EN 16798-1.

represent stationary parameters. Transient aspects are not considered. However, if one considers the scope of validity of the above-mentioned standard, the focus is not only on the design but also on the calculation of energy requirements. However, energy considerations in the building sector are usually transient, which means that focusing exclusively on stationary aspects in the standard is not expedient. Instead, transient aspects should also be considered with a view to operational management. ISO 7730 provides a point of reference for this, in which dynamic aspects in the form of

- temperature cycle
 - temperature drifts and gradient
 - temperature transitions
- are to be described (see **Figure 2**).

However, the ISO 7730 only specifies boundary conditions under which the stationary criteria can be used to assess thermal comfort. In particular, the aspect of reheating after a night set back, which is important in practice, is not addressed.

Against this background, analyses were carried out at TU Dresden to specifically analyse the issue of thermal comfort under transient conditions. Based on ISO 7730, two scenarios were analysed, which are described in detail below.

Investigation Setup

With the “Combined energy Lab”, the TU Dresden has a test bench facility with which extensive energy analyses can be carried out in the field of building energy technology. The indoor climate room can be used to carry out stationary and transient analyses of thermal comfort. The indoor climate room has a floor area of 20 m² and a height of $h = 2.5$ m. The surface temperature of all enclosure surfaces can be varied separately. In addition, different forms of ventilation

can be realized in the room. For detailed descriptions, please refer to [3], [4] and [5].

Male and female test subjects were used for the analyses. A total of 84 people were involved in the experiment. A distribution of the test subjects according to age is shown in **Figure 3**.

As can be seen from **Figure 3**, the test subjects do not fully represent an ideal age distribution. Despite intensive efforts, there is a higher proportion of people between the ages of 20 and 40. It is striking that the women are younger than the men.

Regarding the experiment, an initialization phase was carried out first. The test subjects were able to choose their own operative room temperature. If no stationary target temperature had been selected by the subjects after one hour, the scientific staff set the operative room temperature to $\vartheta_{op} = 22$ °C. Two experiments were carried out in the actual test phase. In the first experiment, the temperature was increased by $\Delta\vartheta = +2$ K from the self-selected operative room temperature within one hour (heating case).

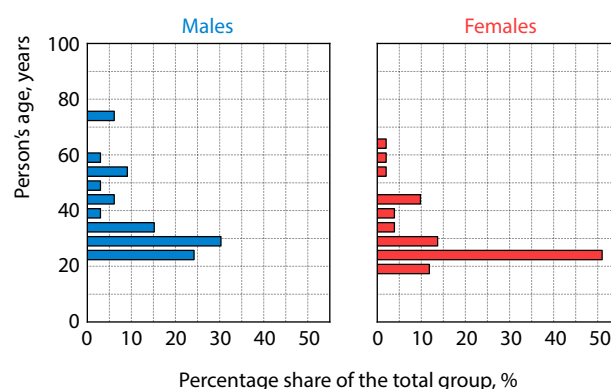


Figure 3. Age distribution of the test subjects.

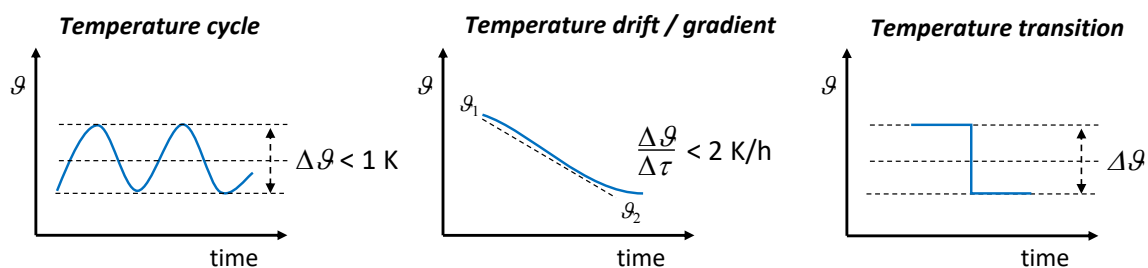


Figure 2. Structure of the new EN 16798-1.

In the second experiment, the cooling case was addressed, and the room temperature was reduced by $\Delta\vartheta = -2$ K within one hour. **Figure 4** shows the procedure regarding the temperature curve in the experiment.

At the end of the experiment, the temperature was returned to the operating room temperature selected at the beginning.

Results of the Investigation

The first result of the investigation relates to the operative room temperature selected by the test subjects themselves. **Figure 5** shows the temperature distribution.

Over 60% of the test subjects chose a temperature between $21.5 < \vartheta_{op} \leq 22$ °C in the experiment. Temperatures between $22 < \vartheta_{op} \leq 23$ °C were chosen by approx. 20% of people. Small proportions were in the ranges $\vartheta_{op} \leq 21.5$ °C and $\vartheta_{op} > 23$ °C. This result impressively confirms the operative room temperature of $\vartheta_{op} = 22$ °C documented in ISO 7730 / EN 16798-1 as the decisive room temperature in building energy technology.

For the dynamic analyses, online surveys on the thermal room situation and the change request were conducted at 10-minute intervals. **Figure 6** shows the questions and the possible answers regarding thermal comfort. ▶

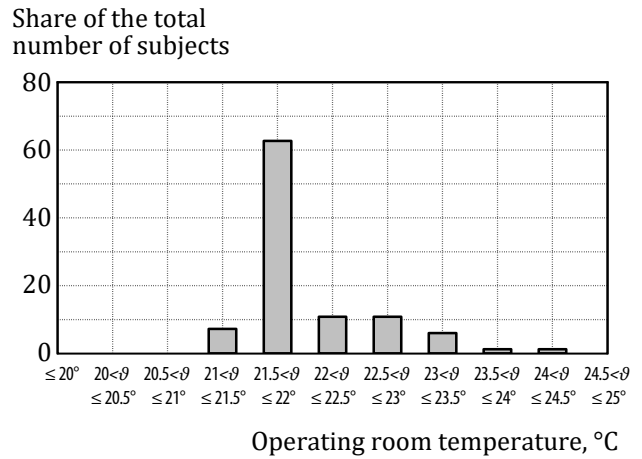
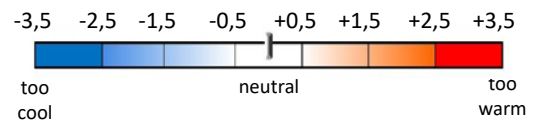


Figure 5. Share of the total number of subjects depends on ϑ_{op} .

1. How do you currently evaluate the room temperature?



2. Which change of the room temperature you want?

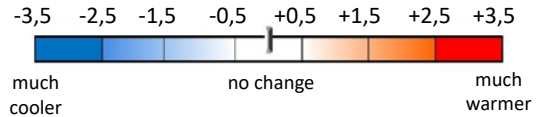


Figure 6. Questions regarding thermal comfort.

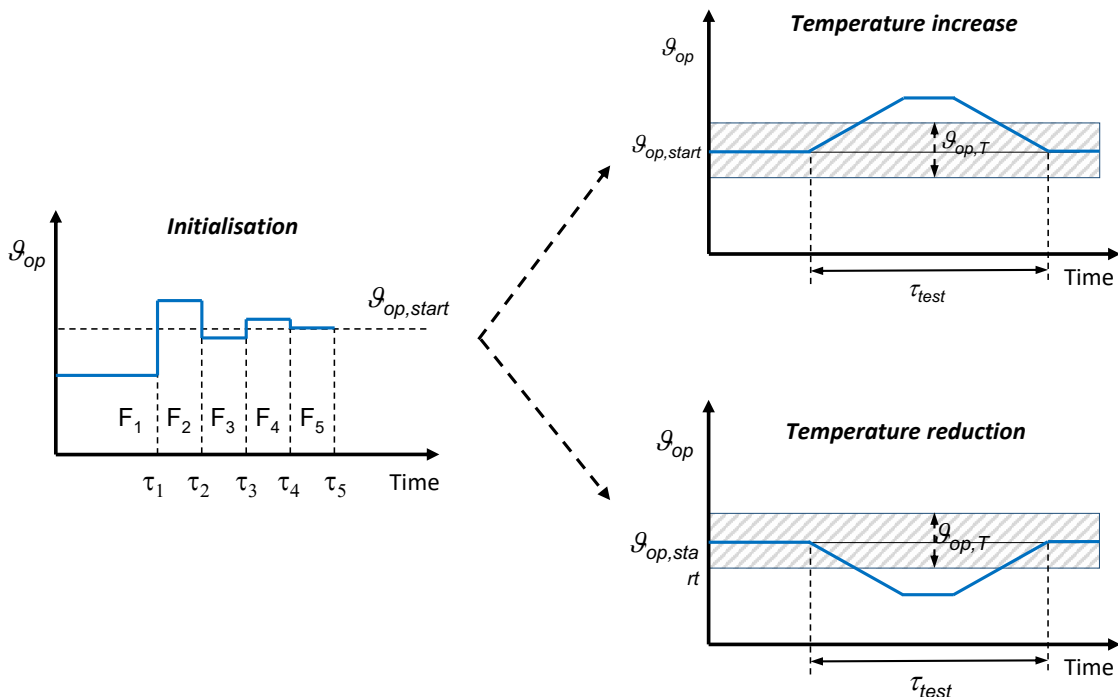


Figure 4. Initialisation phase and temperature curve during the experiments (basic representation).

► The results of the dynamic analyses are documented in **Figure 7** and **8**. **Figure 7** shows the heating case with an overheating of $\Delta\vartheta = +2$ K and **Figure 8** the cooling case with an underheating of $\Delta\vartheta = -2$ K.

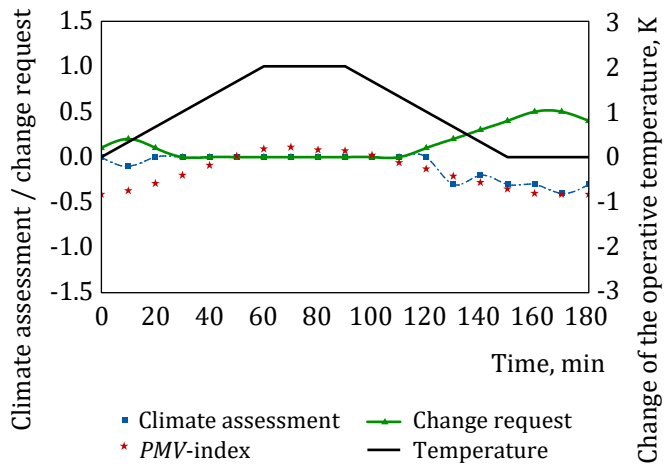


Figure 7. Heating case - transient investigations.

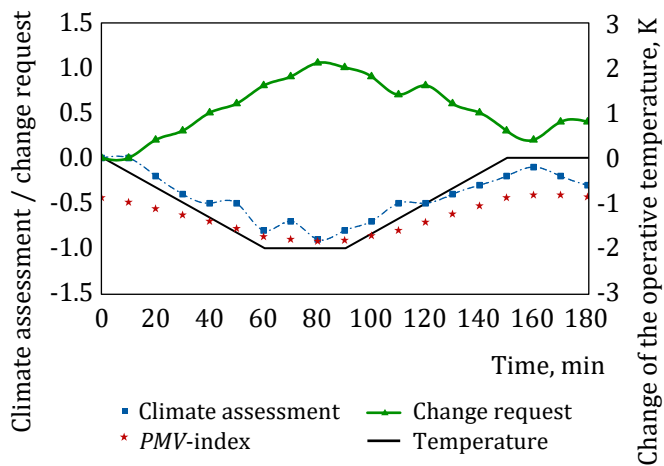


Figure 8. Cooling case - transient investigations.

In addition to the experiments with variable room temperature, a “control experiment” was carried out in which the operative room temperature was not changed (**Figure 9**). The test subjects did not know how the room temperature changed during the experiments.

The results of the **heating case** (**Figure 7**) clearly show that room temperatures above the selected setpoint are accepted by the test persons. The desire for change tends towards “0” here. However, if you look at the end of the experiment, you can see that the test subjects have become accustomed to the higher room temperatures and find a return to the original setpoint temperature they selected too “cold”. The desire for change here tends towards higher room temperatures again.

If you look at the results for the **cooling case** (**Figure 8**), you can see that the test subjects want higher room temperatures as soon as the room temperatures drop. This can be seen directly after the operative room temperature drops by $\Delta\vartheta = -0,2$ K. In the dynamic case, it can also be seen that in the heating phase at the end of the experiment, the test subjects’ desire for change decreases very quickly. This can be interpreted with the positive gradient in the direction of their own selected operative room temperature.

The **control case** (**Figure 9**) shows that the *PMV* index lies within a range of $-0.5 \leq PMV \leq 0$ during the entire experiment “without changing the room temperature”. The desire for change is also subject to only minor fluctuations and is constant at 0.5. This result shows that the gross energy turnover of the test subjects did not change during the experiment.

Figure 10 shows a comparison of the different dynamic analyses for the *PMV* index. The immediately negative evaluation with falling room temperatures can be clearly recognized here.

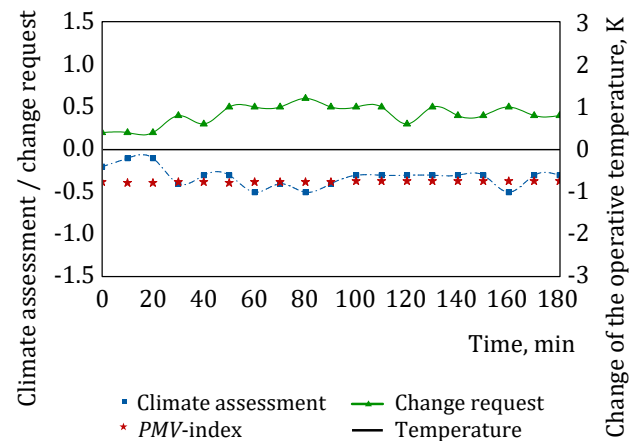


Figure 9. Control case – transient investigations.

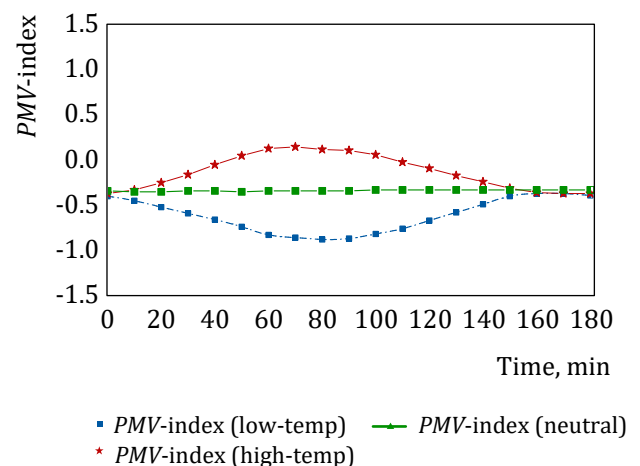


Figure 10. Comparison between the different investigations.

Table 1. Proposal for adapting the comfort categories in EN 16798-1 / ISO 7730 regarding the operative temperature.

Type	Activity in W/m ²	Category	Operative temperature ϑ_{op} in °C	Temperature difference ϑ_{op} in K
individual office / office landscape / conference room / auditorium / cafeteria / restaurant / classroom	70	A	22	+ 1 K / -0,2K
		B	22	+2 K / -0,2 K
		C	22	+3 K / -0,2 K

Conclusions for the revision of the EN 16798-1 (thermal comfort part)

The results of the dynamic tests show innovations that should be considered in the revision of EN 16798-1. The results clearly show that there are no equivalent conditions for overheating and undercooling regarding the tolerance range. The current practice in EN 16798 is a symmetrical tolerance band. This cannot be confirmed with the present results. Particularly under transient conditions, a change request is already registered by the users from a temperature undershoot of $\Delta\vartheta = -0,2$ K. For the heating case, the comfort classes of EN 16798-1 should be adapted according to **Table 1**.

Literature

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How ventilation units with external or integrated heat pumps support climate and health mitigation strategies

In an era of unprecedented climate and health challenges, the imperative to mitigate global warming and improve indoor air quality has never been more pressing. Central to this effort is the HVAC sector, which plays a pivotal role in addressing environmental and health concerns, particularly through the adoption of low-GWP and natural refrigerants, as well as innovative technologies such as fresh air ventilation units combined with external or integrated heat pumps. Alexandre Stubert, Application Manager for Air Handling Units and Heat Pumps at Systemair Group, provides insights into these developments' significance, implications for climate action, and their role in enhancing indoor air quality.



Alexandre Stubert, Application Manager for Air Handling Units and Heat Pumps at Systemair Group

Context: The Urgency of Climate Change and Healthy Indoor Air

While the importance of ensuring healthy indoor spaces has been proven throughout dozens of academic studies, the declaration of 2023 as the hottest year on record by the World Meteorological Organization underscores the urgency of climate action. With the global average temperature steadily approaching the critical threshold of 1.5 degrees Celsius above pre-industrial levels, the need for effective mitigation measures is undeniable. In this context, the HVAC sector emerges as a crucial player, with its contributions and innovations shaping the trajectory of climate change and indoor air quality mitigation efforts.

The Role of HVAC in Global Warming Potential (GWP) Dialogues

According to Stubert, the HVAC sector's impact on global warming potential (GWP) cannot be overstated. As discussions surrounding climate change intensify, evaluating and addressing the environmental footprint of HVAC systems becomes increasingly important. Recognising this, Stubert emphasises the need for a comprehensive understanding of how HVAC technologies contribute to ecological challenges and the potential for innovative solutions to mitigate their impact.

Trends Driving Adoption: Heat Pumps and Low-GWP Refrigerants

Against the backdrop of escalating temperatures worldwide, the demand for efficient and more climate-friendly heating and cooling solutions is rising. Stubert highlights a shift towards enhancing the efficiency of existing HVAC systems rather than simply increasing, for example, the number of air conditioning units and their capacity. This trend is driving the adoption of technologies such as air handling units with integrated and external heat pumps, which offer improved energy recovery and reduced carbon footprint compared to traditional heating and cooling systems. Moreover, the transition towards low-GWP and natural refrigerants aligns with efforts to mitigate climate change by reducing greenhouse gas emissions.

Exploring the Benefits of Heat Pumps in Combination with Fresh-air Ventilation Units

Heat pump and ventilation unit combinations offer many benefits, including high-efficiency heat and cooling recovery, streamlined installation processes, enhanced energy efficiency, and a positive impact on indoor air quality. Stubert explains how these systems leverage smart control technologies to dynamically respond to real-time demand, delivering precise heating or cooling as needed. By effectively regulating temperature, humidity and fresh air levels, they also contribute to creating a healthier indoor environment for occupants.

Balancing Efficiency with Environmental Impact: The Synergy of Components

A key consideration in HVAC system design is balancing energy efficiency and environmental impact. Stubert emphasises the importance of optimising the synergy between various components, such as compressors, heat exchangers, and refrigerants, to achieve this balance. By combining heat pump technologies utilising low-GWP or natural refrigerants and an air handling unit coupled with a high-efficiency heat exchanger, HVAC systems can significantly reduce their environmental footprint without sacrificing performance. Simultaneously, this approach enhances indoor air quality by delivering fresh, filtered air, which stand-alone air conditioning systems usually do not.

Levels of Adoption and Market Dynamics

While there is growing interest in heat pump technologies, Stubert acknowledges varying levels of adoption across different regions. Regulatory frameworks and market demand drive adoption, particularly in areas like the European Union, where stringent environmental regulations exist. However, Stubert notes that educating the market and demonstrating the value of these technologies remain critical challenges, particularly in regions less familiar with energy recovery systems.

Cultivating an Informed Market: The Importance of Training

Stubert advocates for comprehensive training initiatives to foster market understanding and acceptance of fresh air ventilation systems combined with heat pumps. Mechanical consultants and installers need to be educated on the benefits of these systems and their proper application in diverse settings. Moreover, training on handling flammable refrigerants is essential to ensure compliance and safety in HVAC installations. Industry and HVAC engineering associations like Eurovent and REHVA need to step up the game when it comes to defining codes of good practice and regulatory interpretations.

Looking Ahead: The Future of Sustainable HVAC

In conclusion, Stubert underscores the importance of investing in sustainable HVAC technologies to address health considerations, climate change and future-proof operations. By embracing fresh air ventilation units, heat pumps and low-GWP refrigerants, organisations can align with corporate social responsibility objectives and remain adaptable to future regulatory changes. Ultimately, transitioning towards sustainable HVAC solutions is crucial in mitigating environmental impact and building a resilient future. ■

Change is coming – are you ready?



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New Series of Interviews

In this new issue of the REHVA Journal, we start with publishing a series of interviews with expert whose work is directly or indirectly related to Climate change.

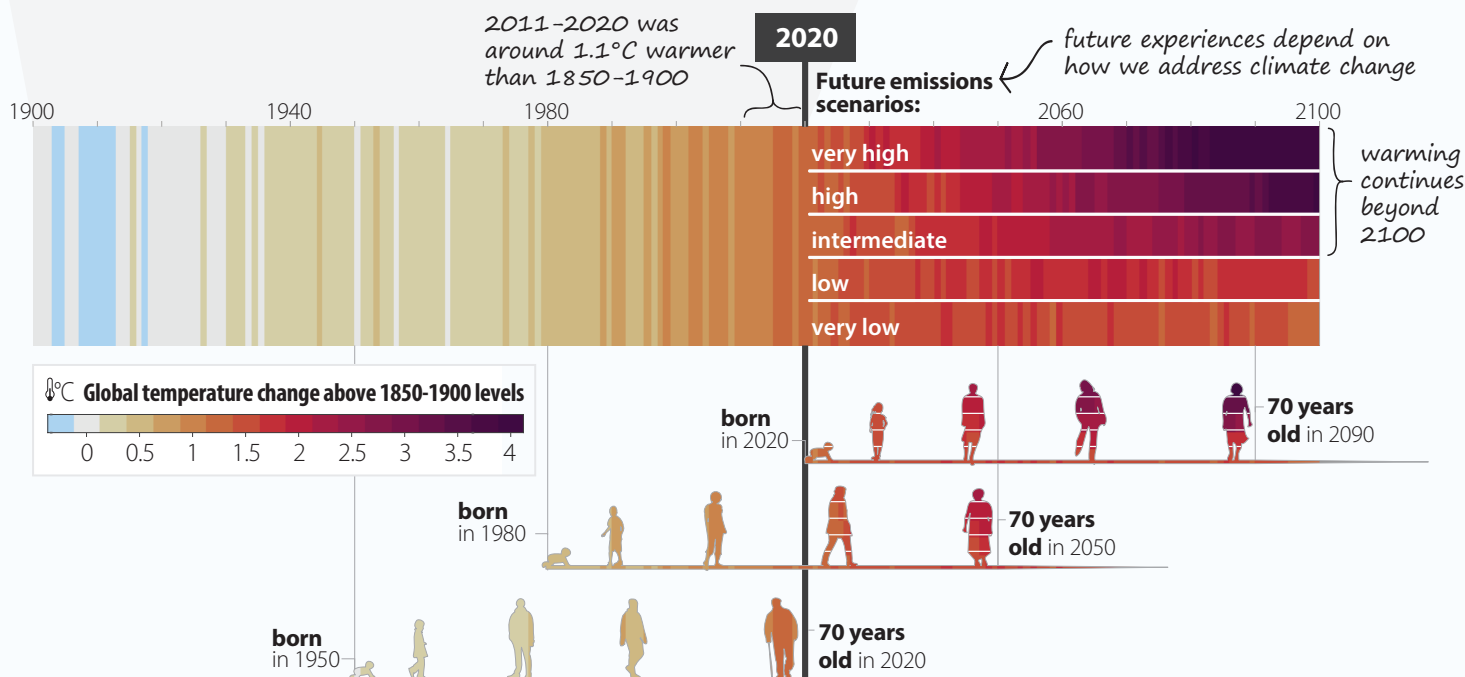
Climate change related research from different fields is influencing the HVAC industry and, as such, could be relevant for design and operation of buildings, their HVAC systems or just for our daily life. The picture below is from the [IPCC Report Climate Change 2023*](#) and shows increasing outdoor temperatures and how this may develop in the future. You can imagine here buildings instead of people and you can see that buildings which are built now, will still be there at the end of the 21st century.

We must design buildings and their systems for future climates right now! That is why all interviews in 2024 will be related to Overheating & Summer comfort, the theme which is very much related to work of REHVA experts all over Europe and beyond.

Lada Hensen Centnerová

Member of the Editorial Board of the REHVA Journal & Vice President of REHVA

The extent to which current and future generations will experience a hotter and different world, depends on choices now and in the near term



Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850–1900), which are linked to changes in climate conditions and impacts, illustrate how the climate has already changed and will change along the lifespan of three representative generations (born in 1950, 1980 and 2020). Future projections (2021–2100) of changes in global surface temperature are shown for very low (SSP1–1.9), low (SSP1–2.6), intermediate (SSP2–4.5), high (SSP3–7.0) and very high (SSP5–8.5) GHG emissions scenarios. Changes in annual global surface temperatures are presented as ‘climate stripes’, with future projections showing the human-caused long-term trends and continuing modulation by natural variability (represented here using observed levels of past natural variability). Colours on the generational icons correspond to the global surface temperature stripes for each year, with segments on future icons differentiating possible future experiences.

* <https://www.ipcc.ch/report/ar6/syr/>

The Concepts of Comfort and Health May Be Related but Are Not Synonyms

Wouter van Marken Lichtenbelt is a Professor of Ecological Energetics and Health at the Maastricht University in the Netherlands, where he is leading the group Thermophysiology & Metabolism.

Besides basal physiological research, his current research puts emphasis on how daily environmental conditions (indoor climate, light) relate to thermal comfort, thermal behavior, long-term health and prevention of the metabolic syndrome (obesity, type 2 diabetes and related cardiovascular diseases).

Recently, he wrote a Dutch popular scientific book ('Van Rillen tot Zweeten') about thermoregulation which includes aspects of the built environment.



You are known for your research related to thermoregulation and its influence on health. Could you summarize the main findings from your groundbreaking paper published in 2017 "Healthy excursions outside the thermal comfort zone" [1]?

– Yes, the main findings are that we see if you expose yourself regularly to temperatures slightly outside the thermal neutral zone (the zone where your body is physiologically doing the least to keep the temperature at the level) then that creates a healthier body.

What do you mean by 'temperatures slightly outside the thermal neutral zone'? Could you explain it using the seven-point thermal sensation scale – PMV index (used in ISO 7730)? Would that mean –1 and +1? (Figure 1)

– Yes. But there's also temperature. In that paper is also mentioned that it is understandable why there is

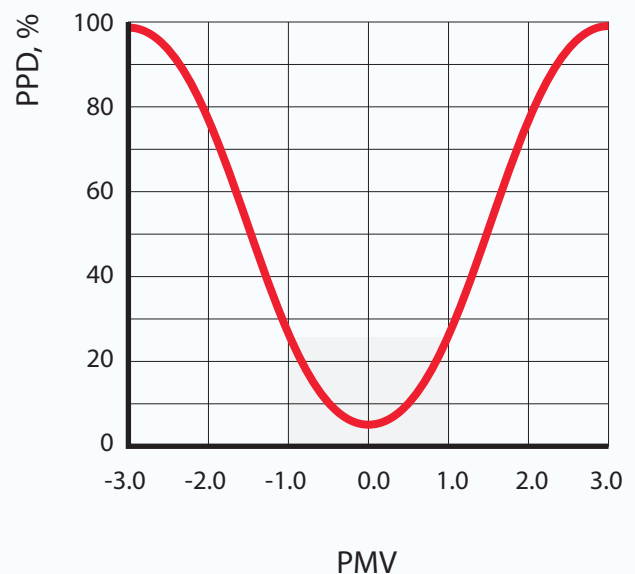


Figure 1. Adaptive Thermal Comfort and Predicted Mean Vote (PMV)

a comfort zone. The thermal neutral zone is linked to it. I think that in a more natural environments comfort is very useful because people have a drive to go to more comfortable environments. You don't want to be in a too cold environment, because you use then lots of extra energy to keep warm. And you don't want to get too warm because you use up too much water for sweating. But since we nowadays are hardly ever forced anymore outside the comfort zone, your body gets more or less 'lazy' and that's not healthy.

You write in your paper also about 'the metabolic syndrome'. Could you explain that?

– We were quite surprised to find that being exposed to mild cold or warm environments, it not only helps you to create better resilience to heat and cold, but also that, for instance, your sugar metabolism improves. We could even prove that there's an increased insulin sensitivity, which is the hormone that regulates the glucose levels in the body. Also, fat metabolism is improved. So, it's not only directly related to thermal physiology, but also to our metabolic health. The metabolic syndrome is generally related to obesity (to overweight) and has a high risk of developing type 2 diabetes but also cardiovascular diseases. We also see that if you get adapted to the heat, not the first exposure, but being regularly exposed to warm that your blood pressure decreases and the same you see in the cold. All these symptoms that are linked to the metabolic syndrome are improved.

I'm not saying this is the lifestyle number one. No, I think it's still food and physical activity rank higher, of course, but then the environmental properties may follow. Temperature can add to it and can have a significant effect combating the metabolic syndrome.

You speak about adaptation to heat but others speak about acclimation or acclimatization. Could you explain the differences?

– Adaptation is a broad way of saying that people adapt to the environment. Changes may occur within the lifetime or be the result of genetic differences. Acclimation and acclimatization are more specific adaptations of individuals and generally more short term. When it is happening in the lab (laboratory) we call it acclimation and when it is occurring in daily environment it is called acclimatization. It is in fact the same process.

The interesting thing is that we find repeatedly that the first exposure to heat or cold is more a stress like response. But if you are exposed several days, let's say for a couple of hours per day, then you see acclimatization occurring, for instance lowering of heart rate and lowering of blood pressure or a better sweating response. It resembles to what happens with regular physical activity. If you for the first time run the marathon, you get very stressed. You get your muscles are aching. But after training for a week your performance improves. Temperature acclimatization has much in parallel to physical training. That's why I sometimes call it temperature training.

In the abstract of your article from 2017 you write that the concepts of comfort and health may be related but are not synonyms. Could you elaborate on that?

– In natural conditions it is very good to get such signals from your body to your brain: Don't get too cold. Don't get too warm. If we're getting too cold, we seek for a warmer environment or put on clothes. That is a good response and it protects us and therefore it is healthy. But if we are always in the comfort zone, we don't get any more such signals, then we create a kind of lazy body, just like we never do any physical activity. So, our body needs to get outside these comfortable conditions in order to stay healthy.

Actually, the temperature variations are also needed for thermal comfort. Do you know the book *Thermal Delight in Architecture* written by Lisa Heschong [2]? She writes there that "One factor that can help us to appreciate the thermal function of a place or object is variability" and "To enjoy being warmed and cooled we need some awareness of the process".

– Yes, this is a nice concept. If you go from a little too cold environment to a little too warm, then too warm may be pleasant. So instead of just only striving after comfort, you could even create environments where you experience thermal pleasure. And what's nicer than pleasure? And that's in fact what people search for in holidays. They go to environments close to the sea, sunbath, become much too warm and then they go into water, which is way too cold. But the change makes them feel good.

Everything is then about thermal variation. But what is more important, seasonal variations or daily variations?

– The adaptive comfort model (Figure 2) is closely linked to what we find in physiology. What you see is that if people are in naturally ventilated buildings and they have some own control of the environment, they like the variations and the comfort ratings are much better. You can do it by changing throughout the day, but also in the seasons.

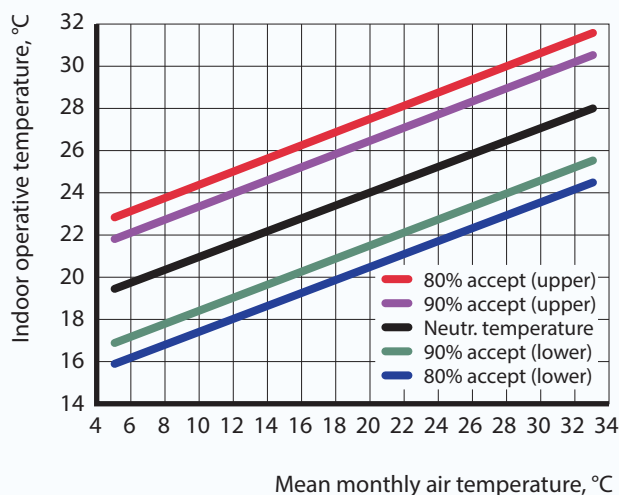


Figure 2. The adaptive comfort model.

This is of course very much building dependent. If you have a building with very high thermal mass (high heat capacity), it is very difficult to create a dynamic indoor environment during the day, because there is so much heat storage in the building.

Recently, you were co-author of an essay “Establishing resilience in times of climate change – a perspective on humans and buildings” [3] published in 2023. You write there that the adaptive thermal comfort model is generally only used for buildings without air conditioning and for the evaluation of their properties, but not for actual temperature control. Do you advocate using the adaptive thermal comfort model for design of all buildings?

– Yes. But we have to keep in mind that we want sustainable buildings, in term of energy, building materials, etc. and we want healthy buildings. We have to think of how to create a dynamic indoor environment in new buildings. Not only during their design but how to control the building when it’s really in use. We have to let the buildings temperature follow to some extent to what’s happening outside. Create a more dynamic indoor environment.

Do you mean, let indoor temperature flow during the season or also during the day?

– During the season is relatively easy but to have temperature variations during the day it is more difficult. You have to change the mindset for designing new buildings. There should always be possibility of some own control.

Let’s move to climate change and overheating. You say that higher indoor temperatures are more easily accepted after acclimatization. Knowing that there will be heat waves or outbreaks of energy, how can we actually use this?

– We learned a lot from the heat wave in 2003. We (at least in France and the Netherlands) have since then improved heat plans and when heat wave is coming, instructions are disseminated by RIVM (Dutch National Institute for Public Health and the Environment) and by social media. Don’t sit in the sunlight, drink enough, be less active, etc. But I think one thing is missing. That is that you can also acclimatize to the heat and if we take care of that during the spring or in the run up to a heat wave and expose ourself to the warmth, we can get used to temperatures of 27 degrees and feel happy with it. So, go outside when it’s warm. And as soon as there’s a real heat wave, you are much more resilient against the heat. It’s not only healthy, but also makes you resilient.

More and more people want to live a healthy life. You already said that nutrition and exercise are the most important factors, but an additional factor is exposure to high and low temperatures. What can we (REHVA members) do to support that?

– Promote designing buildings which make a more dynamic indoor climate possible, including more local variation in temperatures. Very important, in addition, is that users have at least some own control of the temperature they are exposed to. This can be by opening windows, personal control systems, or thermostat. In the end it will create both a healthier environment and more resilience to extremes weather conditions.

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REHVA is happy to organise the REHVA Student Competition in Istanbul the **Annual Meeting***, in May 2024. We welcome **Eurovent Certita Certification**, as the proud sponsor of the competition.



To welcome this new edition of the competition, REHVA wished to reminisce with its past winners on their experience. Three of our past winners have agreed to answer insightful questions on their participation in the REHVA Student Competition, sharing anecdotes and useful tips for future participants!

Iñigo Martin Melero, **Rob Vervoort**, and **Kristian Martin** have agreed to take a ride down memory lane. We asked them a few questions summarizing their path from their enrolment in the competition to their win.

* rehva.eu/events/details/rehva-annual-meeting-2024

Iñigo Martin Melero participated in the competition in 2022 in Rotterdam. He is currently working at the European Organisation for Nuclear Research (CERN), one of the most prestigious and respected scientific laboratories in the world. "I'm working as part of the Engineering department, Cooling, and Ventilation group, where I'm undergoing CFD simulations of different systems at CERN and I'm involved in the Future Circular Collider (FCC) feasibility study."



Why and how did you decide to do your thesis on this topic?

– In my case, I took a course at the university related to HVAC devices and found the topic quite fascinating and deeply related to my bachelor's in mechanical engineering. In addition, I wished to learn Computational Fluid Dynamics (CFD) techniques, so I contacted professors at my university (Universidad Miguel Hernandez de Elche) and came across the project of optimization and CFD modelling of the evaporative pre-cooling of the condenser inlet air.

Why did you decide to take part in the National Competition?

– I took part in the National Competition thanks to my Degree Thesis tutors, Manuel Lucas Miralles and Javier Ruiz Ramírez, that informed me of the opportunity that was organized by ATECYR, the Spanish member of REHVA.

What do you think made your thesis the winning one?

– I believe my thesis was the winning one because it was very innovative, it had a strong technical and scientific component (as it was published in journals). I delivered it well and confidently to the jury during the European and Worldwide rounds at CLIMA 2022, in Rotterdam.

How did participating in the REHVA Student Competition make you grow as a young professional?

– I would say that the REHVA Student Competition consolidated me as a young working professional in the HVAC field, related to technology and sustainability. It was a great event to network with other students interested in HVAC too, exchanging opinions and sharing our fields of research and expertise.

Would you like to say a few words about your experience both at the REHVA Student Competition and the HVAC World Student Competition?

– I had loads of fun at CLIMA 2022, in general. To be honest, I could never have imagined that I was going to be the winner of the European round. When I was selected as the winner, I was surprised and anxious at the same time, as I had to start preparing myself for the Worldwide round.

(...)

Do you have any tips for future participants?

– I would strongly encourage anyone to apply for their national rounds, as the experience of participating in the European round and getting to attend an international conference is very enriching. My only tip would be to practice and prepare well the presentation, as sometimes gestures and non-verbal communication counts more than the content itself. ■

Rob Vervoort, won the Competition in 2017 in London. He is still working on the finalization of his PhD work at TU/e and besides he is working for ENS Clean Air (both project engineering and research & development).



Why and how did you decide to do your thesis on this topic?

(...)

– In my first Mater's project I (numerically) studied the effects of vegetative roofs on sound levels in the vicinity of buildings. Prior to my graduation project, I was involved in a project studying the performance of wind tunnel screens, by means of computational fluid dynamics (CFD) simulations, under the supervision of prof. dr. ir. Bert Blocken and dr. ir. Twan van Hooff. During the course of my pre-graduation projection, Bert notified me that there was a company (ENS Clean Air) that contacted him to inquire if Bert's research group was able to conduct certain research tasks. Bert gave me the opportunity to take on this project, which I eventually did. The end result: my graduation thesis titled "Lungs of the city of Eindhoven", in which I studied the effect of large-scale application of air purification, inside semi-enclosed buildings, on particulate matter (PM) concentrations in an urban environment.

Why did you decide to take part in the National Competition?

– My supervisors suggested me to do so. Actually, back then I had never heard of the TVVL platform (Dutch Society for Building Services and Technology). I'm glad though my supervisors did. TVVL is quite actively communicating on the possibility to enrol for the national competition through various channels; once they became part of my network these messages never escaped my attention.

Once my supervisors informed me on this possibility, I immediately prepared a submission. I really liked the fact that there was an opportunity to present our work to a broader audience (usually mainly academicians), and to take a small leap into the unknown. In addition, from a (future) career perspective it can be beneficial to present yourself outside of your existing network.

What do you think made your thesis the winning one?

(...)

– At that moment, the study was still rather unique (i.e. very large but detailed computational domain and an innovative approach striving towards improved urban air quality). Furthermore, I think the jury considered that the work is of significance since the societal impact of PM exposure is substantial. There is ample scientific evidence that exposure to PM can result in increased mortality and morbidity, this awareness is growing

How did participating in the REHVA Student Competition make you grow as a young professional?

(...)

– I think the REHVA Student Competition primarily contributed towards gaining confidence in presenting myself out of my comfort zone. Over the last several years I've had the opportunity to do so in many different - for me unfamiliar – settings. As a result, I feel quite comfortable whenever I have to talk about my work.

Would you like to say a few words about your experience both at the REHVA Student Competition and the HVAC World Student Competition?

In my feeling, everything went by rather fast. The day before the REHVA Student Competition I took a plane from Rotterdam the Hague airport to London City. It was my first visit to London, luckily, I had some time to take a short stroll through the city upon my arrival. The student competition took place the

next morning. Before I knew the presentation session was over. The minutes just before announcement of the winner I noticed I was very tense. Arash Rasooli (winner REHVA World Competition 2016), who helped me prepare for this event, told me I did well, so it crossed my mind that I could end up in the top three. When the final verdict came in, I felt very fortunate that I was able to 'crown' months of dedicated work with this achievement. After announcing the results, and subsequent presentation in the REHVA Annual Meeting, there was only time for a quick drink with Arash before leaving for the airport. I must admit it felt really great to carry the trophy with me on the airplane. By midnight I was home to celebrate with my family. All in all, the experience as a whole was really nice.

How would you say the Competition has influenced the way you work?

(...)

– My supervisors at TU/e certainly 'trained' me in paying attention to details and to strive towards high quality research. I try to be aware of all the limitations, nuances etcetera, and try to describe everything in a very complete and factual (scientific) manner. This is something I also tried to warrant when participating in the student competition. Probably I will take this with me for the rest of my life. I can imagine that sometimes my colleagues will 'curse' me for the fact that sometimes my input comes with a lot of 'disclaimers'.

Do you have any tips for future participants?

– First of all, do not hesitate to enrol for the national competition. The threshold to register for the national competition is not high at all, at least that is what I experienced. Secondly, be confident about the work you are presenting. You have probably spent quite some time working on your thesis, show that you 'own it'. Of course, at such a point in your career, you cannot comprehend all the details related to your research (time constraints can force you to wrap things up), that is perfectly fine, at least try to – to the best of your ability – know what you're not knowing or uncertain about (every study has its limitations)! If you're well prepared, there is no need to feel tense about your presentations. In my case, I also received very helpful tips from Arash to come in well-prepared. Last but not least, do not forget to enjoy the moment, see it as an opportunity to present yourself and your work (rather than a competition). ■

Kristian Martin, won the Competition in 2018 in Brussels. He is now working as a Project Development Manager within energy efficiency improvement of properties at REHVA Supporter Granlund.



(...)

Why did you decide to take part in the National Competition?

– As I can remember I was nominated for it. I thought it sounded like a nice experience and decided to go. My group manager at that time had himself participated in the competition earlier and encouraged me to go.

What do you think made your thesis the winning one?

– Since I had been working full-time with HVAC design after my bachelor's degree, I had much practical understanding and knowledge, that I was able to link to the theoretical side, giving me a clear advantage when writing both the theoretical part of the thesis as when defining and conducting the actual simulation study.

Additionally, I worked very hard with the thesis and made a thorough work.

How did participating in the REHVA Student Competition make you grow as a young professional?

– I would say that it boosted my professional self-esteem much, especially since winning the whole competition.

The competition is a great experience and if wanting to succeed, as with anything, you have to put lots of effort into every part of it (writing an article, making an interesting and visual poster, kicking off a really first-class presentation just on time).

What is your best memory of both the REHVA Student Competition and the HVAC World Student Competition?

– The best Memory of the REHVA competition is from the announcement of the winner. I remember being honestly very surprised when I heard my name. I have not felt such great feelings of pure joy and strong satisfaction before. As been stated, I put down a lot of effort into the thesis and the competition and it was incredibly rewarding to win it!

Regarding the HVAC World Student Competition, the best memory is overall the fact of visiting China for the first time and facing the differences in culture and practice. It was a very interesting week over there.

As for the competition, I did not win, but I came home with a silver medal.

During the competitions, I had the honour of meeting lots of new interesting people which made it a very pleasant time. I will surely remember this experience and these two competitions for the rest of my life. I can strongly recommend students to participate!

(...)

Do you have any tips for future participants?

– Ask for feedback from a colleague/mentor many times during the preparation process regarding all three parts (article, poster, presentation).

Put very much and even more effort into the presentation. Know every single sentence by heart and practice it until it comes fluently in a nice way. This cannot be overstated. Time is limited and the presentation is the key component in the competition.

Do prepare for different kinds of questions from the judges and do prepare good answers. ■

Read full interviews on the [REHVA Knowledge Hub!](#)



REHVA's Paris Buildings and Climate Global Forum debrief

The Buildings and Climate Global Forum, co-organised by the French government and the United Nations, took place on 7-8 March 2024 in Paris. After the Conference of the Parties (COP28) in Dubai, the Forum gathered ministers and high-level representatives of key organisations, to initiate a new impetus for building decarbonisation and resilience. 800 participants, from all world regions, attended the meeting.

REHVA, represented by its vice-president Johann Zirngibl, participated actively on two sessions:

- Harmonizing policies for whole life carbon and resilient building goals
- Financing green buildings for sustainable development – How development banks can scale up action.

Harmonizing policies for whole life carbon and resilient building goals

This session was dealing with standards and building codes. Several national examples were presented, as the French building regulation RE 2022, LCA and the related database INIES.

There was a general agreement that more harmonisation is needed to create a level playing field, to increase comparability and transparency. However, this agreement was conditioned by the need for “local transpositions”. General goals as building decarbonisation, use of renewables, building energy efficiency are transposed by different national, regional and professional methodologies, hampering the development of harmonised tools, harmonised training and harmonised certification of skills.

REHVA's comment: Key players in harmonisation, as European (CEN) and international standardisation organisations (ISO), were not attending the panel.

The perimeter for harmonisation and local transposition is not well defined. The harmonisation should focus on the methodology, for example on how to calculate the building energy consumption. The calculation should be “physic based”. Physics do not need “local transposition”. The “local transposition” should focus on the requirement level, for example 50 kWh/m²y in one country, 30 kWh/m²y in another. Nevertheless, the requirement level should be calculated with the same methodology.

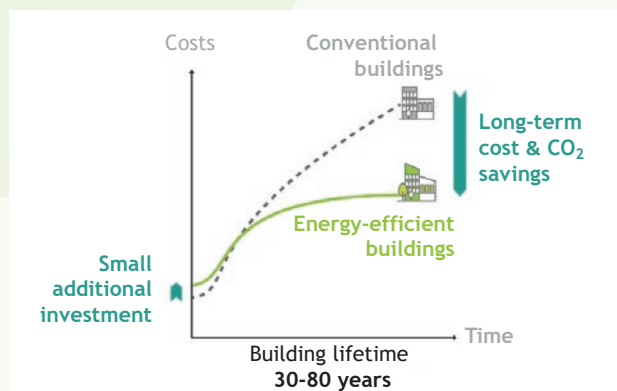


Figure 1. Initial investment and long-term savings (PEEB).

Financing green buildings for sustainable development – How development banks can scale up action

This session was focussing on development banks and related programs. One of these programs is the Program for Energy Efficiency in Buildings (PEEB). The program was initiated by the governments of France and Germany at COP22. It combines the expertise of its implementing agencies Agence Française de Développement (AFD), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and Agence de la Transition Écologique (ADEME). PEEB aims to transform the building sector by promoting sustainable building design and construction. It combines financing for energy efficiency in large-scale projects with technical assistance through policy advice. PEEB Cool supports 11 partner countries in hot climates across Africa, Asia, Eastern Europe and Latin America. PEEB Med supports 7 countries in the Mediterranean region.

The building sector has major impact on the climate. By 2060, buildings sector floor area will double. Emerging and developing economies in warm and tropical climates will have the biggest development. In Africa, 53 million houses need to be built in the next years. There will be a huge initial impact, on climate, if these buildings are constructed by bricks, mortar and concrete, and an operational lifetime impact (see **Figure 1**). The emission trading system (ETS) could be an important source of financing.

The panellist underlined that banks have difficulties to evaluate “buildings energy efficiency” and the related savings. Therefore, banks prefer ESCO models (Energy Services Companies) based on third investment and EPC (Energy Performance Contracting). The need for public incentives to facilitate private money flow was underlined.

REHVA's comment: Banks will work as banks but there is a need for a “common language” (understandable indicators) and knowledge sharing between the financial sector and ESCO's, buildings and HVAC engineers. ■

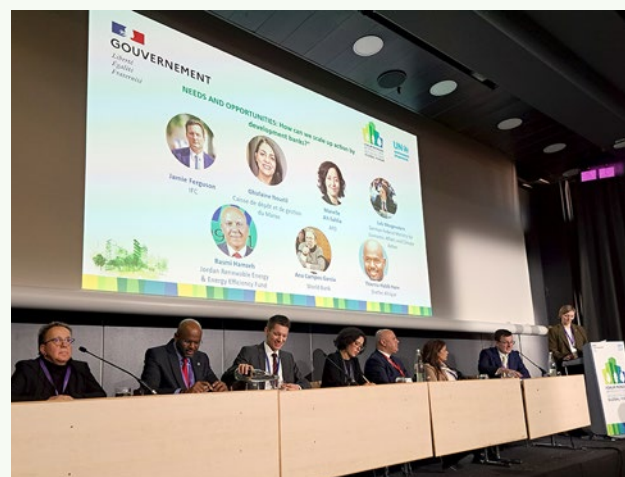


Figure 2. Financing green buildings.

REHVA had the pleasure of attending Light + Building 2024!

On Friday 8th March, REHVA hosted an Expert Talk focusing on “Data-driven Smart Building”.



Among our speakers, we had the pleasure of welcoming Lada Hensen Centnerová, Risto Kosonen, Heikki Ihasalo, Pieter Pauwels and Henri Juslen!

Light + Building is the **international industry meeting place** for pioneers, planners, craftsmen and decision-makers. The interconnection of lighting, design, building automation, facility management and security technology can be experienced here.

Risto Kosonen - *Professor at Aalto University in Finland and REHVA Vice-President*, described in his presentation “**Demand site flexibility in buildings**” the possibilities for saving energy and operational costs by using different control strategies. He also showed two use cases of energy flexibility in buildings and one in a small energy community and presented the audience with the saving results.

Our second speaker was **Heikki Ihasalo** - *Professor of Practice in Smart Building Technologies and Services at Aalto University in Finland and director of Innovations at Granlund*. His presentation, “**Machine learning in smart building operation**” gave insights into different applications of Machine learning, from occupant level (using wearables) to neighbourhood level (waste heat utilization). He reflected on the advantages of using reinforcement learning and fault detection and diagnostics (FDD) in buildings.

The third speaker **Henri Juslen** - *Chief future Illuminator at Helvar Oy Ab*, in his presentation “**Lighting networks providing new data insights for smart buildings**” gave us a good overview of why and how the lighting in smart buildings can be controlled and what the unique cases by using past data, live data or predictions are.

The last speaker **Pieter Pauwels** - *Associate Professor in Information Systems in the Built Environment at Eindhoven University of Technology in the Netherlands*, gave a presentation called “**From Connected to Automated Buildings**”, which showed us different data models and web technologies, used in the built environment. He explained what the possibilities of having building data available on the Web are so that individual smart buildings become connected smart buildings. He also talked about the element-based network of data which can support the design and operation of circular buildings.

At the end of the REHVA Expert Talk session, a discussion was moderated, where the speakers answered questions from detailed information about data storage solutions – geometry, semantics, or sensor data, to discuss the safety of occupants in buildings connected on the web or what are the consequences of EU policy on built environment. We ended the discussion with a conversation that tried to define which role REHVA could play in that process. ■

For those of you who could not attend the conference, we are pleased to share the different presentations given by our speakers:



REHVA's Expert Talk at MCE 2024!

REHVA had the pleasure of being present at MCE 2024!

On the first day, Catalin Lungu, REHVA president, awarded Rhoss with the REHVA supporters Award!

REHVA was happy to organize a REHVA Expert Seminar during Mostra Convegno on 14 March.

The theme was “**The Revised Energy Performance of Buildings Directive (EPBD) in the frame of Fit for 55 program**”.

REHVA had the pleasure of inviting as speakers:

- Catalin Lungu, REHVA President
- Livio Mazzarella, REHVA Vice-President
- Federica Sabbati, Secretary General, European Heating Industry
- Csaba de Csiky, Chairman, EnerSave Capital, Founding Member SEFA
- Alfred Freitag, eu.bac Vice President

The revised Energy Performance of Buildings Directive (EPBD) holds significant implications for the building sector and the broader goals of the Fit for 55 program. Through this seminar, we aim to deepen understanding of the revised directive, foster dialogue among stakeholders, and pave the way for collaborative efforts towards a more sustainable and energy-efficient built environment in Europe.

You missed our Expert talk? No worries!

Scan the following QR code and discover our speakers' presentations!



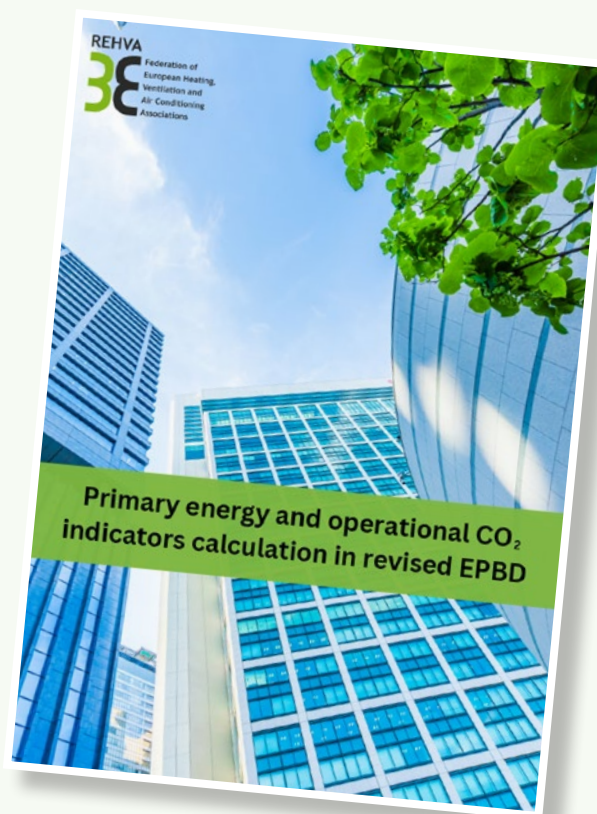
REHVA experts developed a guidance on the EPBD!

Revised EPBD includes many new items among which EP-value calculation based on the total primary energy instead of non-renewable primary energy maybe seen as a fundamental change.

How to calculate EP-value according to EPBD recast and set corresponding energy and operational CO₂ thresholds for zero emission buildings would be a great question for energy experts in all Member States starting to implement the directive.

REHVA experts have prepared methodology including assessment boundaries and calculation rules illustrated with calculation examples for primary energy and CO₂ indicators to support harmonised implementation of EPBD so that the 'energy efficiency first' principle is followed. Efficiency first principle stresses that energy consumption both from non-renewable and renewable energy carriers should be minimised through efficiency measures, and to cover the remaining energy consumption, renewable energy generation should be used as much as possible.

<https://www.rehva.eu/news/article/rehva-publishes-new-epbd-guidance>





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SCIENCE published a paper in the Policy Forum section with the title:

Mandating indoor air quality for public buildings

If some counties lead by example, standards may increasingly become normalised

By Lidia Morawska and 36+ co-authors.

People living in urban and industrialized societies, which are expanding globally, spend more than 90% of their time in the indoor environment, breathing indoor air (IA). Despite decades of research and advocacy, most countries do not have legislated indoor air quality (IAQ) performance standards for public spaces that address concentration levels of IA pollutants. Few building codes address operation, maintenance, and retrofitting, and most do not focus on airborne disease transmission. But the COVID-19 pandemic has made all levels of society, from community members to decision-makers, realize the importance of IAQ for human health, well-being, productivity, and learning. We propose that IAQ standards be mandatory for public spaces. Although enforcement of IAQ performance standards in homes is not possible, homes must be designed and equipped so that they could meet the standards.

<https://www.science.org/doi/10.1126/science.adl0677>



NEW publication of WHO:

Indoor airborne risk assessment in the context of SARS-CoV-2

Description of airborne transmission mechanism and method to develop a new standardized model for risk assessment

Context

The SARS-CoV-2 virus can spread in several ways: through zoonotic transmission, direct and indirect contact transmission, direct deposition transmission, and inhalation or airborne transmission. An increasing body of evidence [suggests that it is transmitted through infectious fluids released from an infected individual as particles of different sizes and quantities, such as during breathing, speaking, coughing and sneezing. While the largest particles travel downwards quite rapidly, the smaller ones remain suspended in the air for longer periods and can travel farther distances. When people are in close proximity, transmission of infectious particles



can occur through direct inhalation (short-range) and deposition onto the mucous linings of the respiratory tract and ocular membranes of a susceptible host particularly in the absence of face covers and ventilation. ‘Long-range’ transmission can occur in enclosed settings when infectious particles accumulate over time in a given volume, where the concentration of virions is sufficient enough to cause infection once infectious particles are inhaled by a susceptible host. A means of quantifying the risk of SARS-CoV-2 airborne transmission in a standardized manner (using a standardized model) in residential, public and health care settings is essential to inform non-pharmaceutical risk reduction measures, such as increasing ventilation, air cleaning and disinfection, source control interventions, and controlling the occupancy, as well as to communicate the risk and enable informed decisions by the occupants.

Methods

The development process of the airborne transmission modelling included several stages: defining the mechanism of airborne transmission, identifying priority questions and outcomes, retrieving the evidence, assessing, and synthesizing the evidence, formulating, and testing the model. Key findings from the identified studies have been extracted and collated. Discrepancies in the extracted findings and recommendations were then reviewed in consultation with national and international experts. The process also required the establishment of the Airborne Risk Indoor Assessment (ARIA) Technical Advisory Group which constituted an ad-hoc advisory panel supporting WHO’s World Health Emergencies preparedness, readiness and response to COVID-19

and included, amongst others, members of the Global Infection Prevention and Control Network, members of the Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19, representatives from the European Organization for Nuclear Research (CERN), technical experts from ministries of health and similar institutions (see Acknowledgements), and WHO staff and consultants from different departments including Environment, Climate Change and Health, Infection Prevention and Control, and Operations Support and Logistics. The external review group included WHO’s Global Infection Prevention and Control Network (GIPCN), WHO’s Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19 and WHO’s EPI-Tag Group. Benchmarking against available literature has been undertaken to validate the model.

Outcomes

This process resulted in a new multi-box model to quantify the risk of SARS-CoV-2 airborne transmission that incorporates additional knowledge of factors related to inhalation transmission compared to the conventional Wells–Riley equation. The new model allows for uncertainty in the parameterization and description of degree of confidence in model output. Based on this model an online, user-friendly tool to assess SARS-CoV-2 airborne transmission risk in residential, public and health care settings was developed. Its application by Infection Prevention and Control specialists, building managers, health care facility managers and the general public will inform risk reduction measures and enable informed decisions by end-users.

<https://iris.who.int/handle/10665/376346>



Smart²'s week in Brussels

Four days of standardisation activities, strategic meetings and networking



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 European Research Project Manager,
 IsZEB

Embarking on a transformative journey to redefine the landscape of smart buildings and energy efficiency, the Smart² Project¹ proudly hosted an unparalleled series of events in the heart of Brussels, from March 4th to 7th, 2024. This series was not just a sequence of gatherings but a symphony of innovation, dialogue, and exploration into the multifaceted domain of the Smart Readiness Indicator (SRI) and its pivotal role within the European Union's ambitious energy policy framework. Each day was thoughtfully curated to peel back layers of the SRI, revealing its profound implications for the future of sustainable living and smart infrastructure. Through this visionary series, Smart² has not only spotlighted the critical intersections of technology, policy, and environmental stewardship but also charted a bold course forward for stakeholders across the spectrum of the built environment.

Day 1: Laying the Foundation with CEN-CENELEC



The series of the events were initiated by a CEN-CENELEC workshop, focusing on 'Standardized On-site SRI Building Audits'². Critical topics discussed included the development of a methodology for SRI on-site audits, leveraging EN 16247 energy audits with a spotlight on SRI specifics, and exploring non-standardized procedures to monetize upgrades in energy efficiency, human comfort, and building-grid

interaction. The dialogue opened avenues for integrating SRI assessments with existing European Performance of Buildings Directive (EPBD) frameworks, raising questions about the clarity of applying different methods across building typologies and ensuring that smart buildings are perceived as accessible and straightforward.

The kick-off meeting of the workshop not only aimed to produce actionable outcomes, such as a project plan approved for further development but also set the stage for ongoing engagement, with plans for future meetings to steer the initiative. It highlighted the project's dedication to creating a robust, standardized process for SRI assessments pushing the boundaries of what is possible in smart building technology and energy efficiency. The chair of the workshop was appointed to Paris Fokaides from Euphyia Tech. (scientific coordinators of Smart²), the vice-chair to Pablo Carnero from REHVA, and the secretariat to Cristina Stanisteanu from ASRO (Romanian Standardisation Body).

Days 2 & 3: Deep Dive During the 18th Month Plenary Meeting

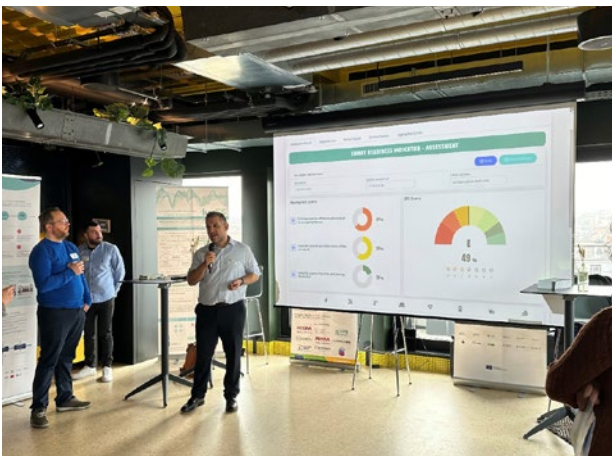
Over two transformative days, the 18th Month Plenary Meeting of the Smart² unfolded, showcasing the project’s comprehensive and integrative approach towards revolutionizing smart buildings and energy efficiency. These sessions, hosted by REHVA, went beyond routine progress reviews, immersing participants in deep dives into administrative strides, strategic innovations, and the seamless integration of the SRI

Observatory³ and FAQ⁴ tools. Through dynamic workshops and spirited exchanges, the meeting fostered a robust platform for brainstorming, debate, and consensus-building, all aimed at refining and elevating the concepts of building intelligence. These gatherings were a testament to the project’s unwavering commitment to fostering groundbreaking advancements through the synergy of collective expertise and shared vision, setting new benchmarks for what collaboration in the smart building ecosystem can achieve.



Day 4: Culminating with the SRI Joint Event

The grand finale, the SRI Joint Event, represented the collaborative spirit, bringing together the forces of the Smart² project, CINEA, DG ENER, and sister projects EasySRI, SRI ENACT, and SRI2MARKET. In addition to the LIFE funded sister projects, the fourth day was enriched by an exhibition featuring a diverse array of related projects taking the stage to showcase their unique actions and contributions, including iEPB, SmarterEPC, and tunES funded by LIFE BUILDPERFORM, alongside SmartLivingEPC, iBECOME, and CHRONICLE funded by Horizon Europe. This day was a vibrant showcase of expert talks, policy updates, and futuristic roundtables, focusing on interconnected energy systems and the pivotal role of smart technologies in the clean energy transition. It highlighted the significant strides being made towards a more efficient, smarter building infrastructure towards reshaping the European landscape, setting a clear path forward for the industry.



Throughout these four-days, the Smart² project not only showcased its latest achievements but also fostered a dialogue that extended beyond traditional boundaries. By bringing together a diverse group of stakeholders, the project has laid down a solid groundwork for future innovations in building energy performance, echoing the collective ambition of the EU to achieve a greener, more sustainable built environment.

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Notes

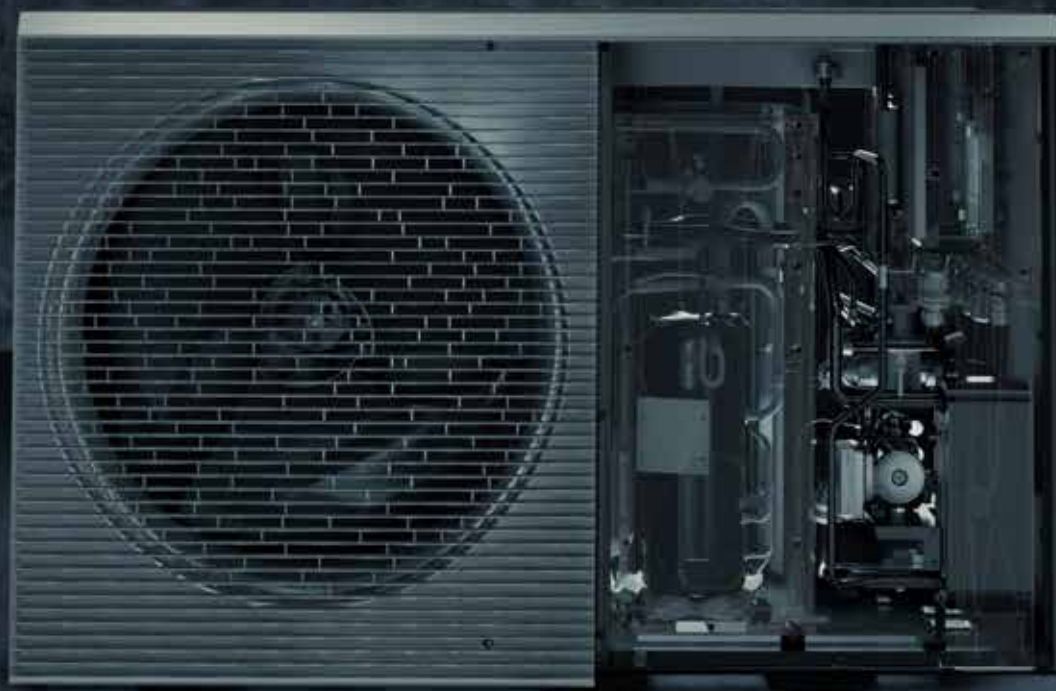
- 1 Research project funded by the European Union, under the Grant Agreement N° 101077241.
- 2 More information: <https://www.cencenelec.eu/news-and-events/news/2024/workshop/2024-02-07-sri/>
- 3 Access it at: <https://sriobservatory.eu/>
- 4 Access it at: <https://sri-faq.eu/> ■

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Please send information of your event to Ms Marie Joannes mj@rehva.eu

May 2024

11-13 May 2024	ISH China (ishc-cihe.hk.messefrankfurt.com)	Beijing, China
15-17 May 2024	REHVA Annual meeting 2024 (rehva.eu)	Istanbul, Turkey
17-18 May 2024	11th HVAC Mediterranean congress: Climamed (rehva.eu(pdf))	Istanbul, Turkey
18-19 May 2024	AICVF/ASC Conference (aivc.org)	Singapore

June 2024

9-11 June 2024	BuildSim Nordic 2024 (ibpsa-nordic.org)	Espoo, Finland
10-14 June 2024	CISM "Ventilation, health and well-being" summer courses (cism.it)	CISM - Udine, Italy
22-26 June 2024	ASHRAE Annual Conference (ashrae.org)	Indianapolis, USA

July 2024

25-27 July 2024	IBPC 2024 (ibpc2024.org)	Toronto, Canada
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October 2024

9-10 October 2024	AIVC 2024 Conference (aivc.org)	Dublin, Ireland
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June 2025

4-6 June 2025	CLIMA 2025 (climaworldcongress.org)	Milano, Italy
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ATIC vzw-asbl – Belgium



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ISH China & CIHE to feature advanced energy storage technologies in line with national policy initiatives

What ISH China & CIHE – International Trade Fair for Heating, Ventilation, Air-Conditioning, Sanitation & Home Comfort Systems
When 11 – 13 May, 2024
Where China International Exhibition Center (Shunyi Hall), Beijing, China



In recent years, China has enacted a number of policies promoting the construction of sustainable, energy-efficient buildings. These measures, coupled with growing public concern for energy conservation and environmental care, have opened up new opportunities in China's HVAC industry. As a result, energy-saving technologies are increasingly being embedded into mainstream products, with these products steadily capturing an increasing share of the market. In alignment with these trends, ISH China & CIHE - China International Trade Fair for Heating, Ventilation, Air-Conditioning, Sanitation & Home Comfort System will take place from 11 – 13 May 2024 at the China International Exhibition Center (Shunyi Hall) in Beijing. The event will showcase the latest energy storage and energy-saving boiler technologies in support of the construction industry's push towards low-carbon development.

The pursuit of China's dual carbon objectives has prompted the construction industry to intensify its focus on low-carbon building solutions. Concurrently, the government has been proactive in stimulating the development of new energy storage, recognising the fundamental role of these technologies in achieving a zero-carbon future.

Intensified government support for new energy storage technologies

On 25 January 2024, China's primary energy regulatory body released a report emphasising that government-backed initiatives had led to a successful diversification of the nation's new energy storage technologies. This is a central strategy in the country's efforts to establish

a new energy system, and is a key lever in the transition toward low-carbon energy production and consumption model.¹ Meanwhile, a second report issued in collaboration with the National Development and Reform Commission, China's central economic planning agency, sets forth a strategy to enhance energy storage capabilities within power generation facilities, across the grid, and at the point of consumption, with the goal of ensuring system-wide flexibility.²

Showcasing new energy storage products and technologies

To align with national energy goals, several Chinese government agencies have crafted a unified action plan focused on expanding solar photovoltaic power generation, energy storage, direct current and flexible power consumption, an approach collectively referred to as PEDF.³

ISH China & CIHE will address the industry's long-term needs by spotlighting the latest innovations in energy storage technologies. The exhibition will bring together leading companies and specialists in the field to share knowledge, and showcase their latest products and advancements, including photovoltaic heat pump systems, thermal storage boilers and heat pumps, as well as heat storage systems and other related technologies and equipment, which all focus on incorporating PEDF within low energy consumption buildings.

In addition, the event will adopt the "2023–2024 China Thermal Energy Storage Development Report", co-published by the China Construction Metal Structure Association, as a foundational document to help guide discussions and shape a collaborative platform for energy and heat storage technology exchange.

Transforming heating supplies and advancing boiler efficiency

While China has made notable progress in improving its heating supply infrastructure, the heating and cooling of buildings remains a significant contributor to the country's aggregate carbon emissions. Addressing this, the Chinese government has incentivised the HVAC industry to further develop sustainable heating and cooling technologies. In December 2023, the State Council advocated for an intensified push toward low-carbon energy solutions, stressing the importance of clean energy and centralised heating systems, as well as tightened controls on the usage of scattered coal, coal-fired boilers, and industrial furnaces.⁴

In line with these efforts, ISH China & CIHE 2024 will continue to assist the industry in exploring a wide range of pollution control solutions. With the support of the China District Heating Association (CDHA), the event will once again feature a specialised Clean Energy District Heating Area in Hall W3 to connect businesses within the clean heating sector, showcasing the most advanced centralised heating instruments, smart heating systems, heating controllers and other products that facilitate the development of clean urban heating. The exhibition will also host a number of concurrent fringe events and forums aimed at elevating China's district heating sector into new standards of sustainability and efficiency.

ISH China & CIHE aligns with the industry's latest developmental needs and national policy directions, while also reflecting international energy development trends. The event will promote the integration of traditional heating devices, such as boilers, with new heating technologies including hydrogen and solar energy to advance sustainable development and energise the market. In collaboration with key industry stakeholders, ISH China & CIHE aspires to guide China's HVAC industry into a cleaner, more comfortable, innovative and diverse era.

More information about ISH China & CIHE: <https://ish-cihe.hk.messefrankfurt.com/beijing/en.html>

Notes

- 1 "Transcript of the press conference of the National Energy Administration in the first quarter of 2024" National Energy Administration, The People's Republic of China, 25 January 2024 <https://qr.messefrankfurt.com/q9d54> (Retrieved February 2024).
- 2 "Implementation Plan for New Energy Storage Development during the 14th Five-Year Plan" National Development and Reform Commission, The People's Republic of China, 25 January 2024 <https://qr.messefrankfurt.com/Ef289> (Retrieved February 2024).
- 3 "The Ministry of Industry and Information Technology, The Ministry of Housing and Urban-Rural Development and others jointly issued the "Smart Photovoltaic Industry Innovation and Development Action Plan (2021-2025)", National Energy Administration, The People's Republic of China, 31 December 2021 <https://qr.messefrankfurt.com/5baa1> (Retrieved February 2024).
- 4 "Comprehensively promote the systematic deployment of building a beautiful China", National Development and Reform Commission, The People's Republic of China, 5 January 2024 <https://qr.messefrankfurt.com/5baa1> (Retrieved February 2024). ■

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