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Decarbonisation

– Does it change our HVAC&R design and installation practise?

If our focus is already on realising (Nearly) Zero Energy Buildings (NZEB), changing this focus to Zero Emission Buildings (ZEB) may not seem a fundamental change. But this is very depending on the energy carriers we still continue to use to cover the limited amount of energy we still need to run our HVAC&R systems.

This limited amount of energy should come from renewable sources, which may be available at central or local energy grid level or produced at the building site. If this is the case, we have an operational ZEB building as the embedded carbon emission is not yet part of this equation.

For new or deeply renovated buildings this may be achievable till a certain extent. Until today most of these assessments are made on yearly basis. But we know that the availability of sustainable energy is not the same all year around. This is already clearly demonstrated with the negative kWh pricing on sunny and windy days. The traditional way we operate our buildings causes peak demands during certain hours which is also influenced by the season and climate. To overcome this, our systems have to take care of energy storage in whatever way: thermal (heat and cold) or electric.

For NZEB and ZEB buildings this may be possible to realise and could even be cost-effective given the expected fluctuating energy prices. Energy prices fluctuating on hourly and even sub-hourly basis. Energy suppliers will be required to inform their consumers on hourly or sub-hourly basis on the price and carbon (CO_{2eq}) emission of the delivered energy. This carbon footprint stamp (and connected pricing) has to be used by our HVAC&R systems to act and operate. This means that in the near future building systems have to be able to communicate with the energy grid (electric or even thermal) to decide which systems can temporarily switched down or which storage should be accessed. Our building systems should become smart and a first step in that direction is the inclusion of the Smart Readiness Indicator (SRI) in the expected new EPBD. Already well-known concepts like peak-shaving become again part of our system design.

To be able to check if the HVAC&R systems where energy storage is a part of these systems can operate to certify it as a ZEB building, an hourly (or in some cases sub-hourly) calculation procedure is needed. Important input data like the climate, user pattern and expected (contracted) carbon footprint of the delivered energy carriers should also be available on hourly or sub-hourly basis. This may sound as wishful thinking but it is the only way to achieve a decarbonised building stock (on operational basis) by 2050. If we cannot achieve this on short term for our new and deeply renovated buildings, we will not be able to achieve our 2050 zero target.

If the energy storage issue should be solved at building level is an open question. In many cases it seems a logical task for the energy (thermal and/or electric) grid provider. If the grid interaction is managed by the local or central grid provider this can only be successful at a grand scale if the HVAC&R systems in buildings are able to interact. This grid and building system interaction has to result in a zero-carbon footprint of the HVAC&R operation without compromising the Indoor Environmental Quality (IEQ) and other user needs like the Domestic Hot Water and energy for non-EPB uses, which will grow in percentage in NZEB and ZEB buildings.

What to do with the existing building stock? If we are able to reach the 3% renovation target and assume that all renovation will step by step lead to deep renovation before 2050, the decarbonisation target can be achieved. The current situation in many European countries is that we lack the working force and professional capacity. As mentioned in the expected new EPBD, also tackling energy poverty and worst-performing buildings towards healthy housing/buildings will be an enormous challenge. Even if the financial barriers are overcome, capacity building will be the biggest challenge for the HVAC&R professional sector.

Apart from all these technical capacity and financial barriers, the issue of sharing building user data with 3rd parties as grid providers has to be regulated to safeguard the privacy of building users in line with the EU General Data Protection Regulation (GDPR).

With these observations I was very limited, I ignored the Life-cycle Global Warming Potential (GWP) due to the production, maintenance and decommissioning of the HVAC&R systems and the building as such. Addressing this requires more skills and capacity building, REHVA Education and Training Committee (ETC) is considering to address these issues in the near future as well. ■

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Zero-emission Building: What could be?

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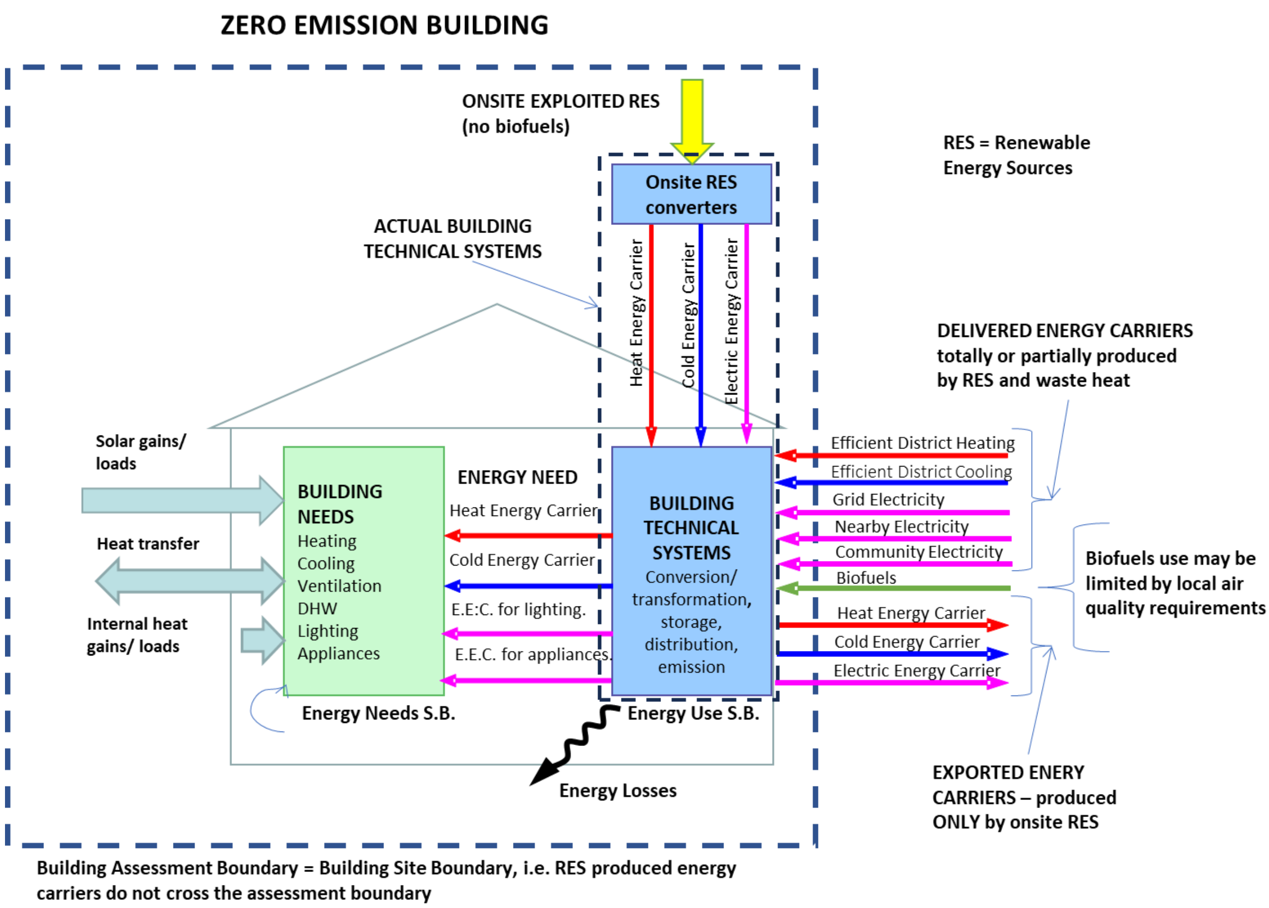
Keywords: EPBD, ZEB, NZEB, renewable energy, primary energy, GWP

With the publication of the "Renovation Wave" strategy in October 2020, the European Union set itself the challenging goal of doubling the annual rate of renovation of existing buildings by 2030, while increasing the share of deep renovations. In order to achieve these objectives, the European Commission has deemed it necessary to revise the current EPBD, 2018/844/EU (European Commission, 2018). The review activity is part of the Commission's "Fit for 55" plan proposed in July 2021, which provides for the reduction of CO_2 emissions by 55% by 2030, and then reach climate neutrality by 2050. 13 documents have already been published, including proposals to revise the Renewables and Energy Efficiency Directives and the extension of the Emission Trading Scheme (ETS) to the transport and buildings sectors; in particular, the EPBD was published in December, together with the gas market reform one.



In the EU, buildings are responsible for 40% of total energy consumption and 36% of direct and indirect energy-related greenhouse gas emissions. In addition, heating, cooling and domestic hot water production services account for 80% of the energy consumed by households.

The decarbonisation of the construction sector is therefore key to achieving the climate and energy targets set for 2030 and 2050 by Europe from the Green Deal. In fact, the plan for the climate target identifies the need to reduce greenhouse gas emissions in buildings by about 60% in order to achieve the overall emission reduction target of 55% by 2030 and all this involves at least a doubling of the renovation rates of the existing building stock.

The complexity of the European legislative procedure: the trilogue

In the context of the ordinary legislative procedure of the European Union, the *trilogue* is an informal interinstitutional negotiation bringing together representatives of the European Parliament, the Council of the European Union and the European Commission. Each new directive or its revision is subject to this formal procedure, which begins with a proposal from the European Commission and continues with a collection of views on this proposal by the various advisory bodies of the European Union, such as the European Economic and Social Committee (EESC), which represents the economic categories expressing economic interests, social and cultural issues in the respective EU countries, and the European Committee of the Regions (CoR), which brings together local and regional representatives of the European Union (regions, provinces, municipalities, etc.). Subsequently, the proposal and opinions are forwarded to both the Council and Parliament, which make changes and amendments, independently. In fact, for Parliament, the preparatory work is carried out by its specific permanent body, which in the case of the revision of the EPBD is the Committee on Industry, Research and Energy (ITRE), and only when this activity is finished, the resulting text is brought to Parliament for first reading. For the Council, it is the secretariat of the Presidency that is responsible for managing the internal discussion between the governments of the member countries in order to arrive at the formulation of an amended text, which is labeled as a "compromise proposal by the President of the Council".

Any provisional agreement reached in trilogues as mentioned above is informal and must therefore be approved in accordance with the formal procedures applicable within each of the two institutions.

The Commission's proposal

On 15 December 2021, the European Commission released its proposal to revise the Energy Efficiency of Buildings Directive. One of the most important innovations is present in the amendment of Article 1 Object, where the increase in the energy performance of buildings is accompanied by "the *reduction of greenhouse gases*"… " *to achieve a zero-emission building stock in 2050*". To achieve this new goal, in Article 2 "Definitions" the definition of the **zero-emission building (ZEB)** is introduced:

"very high energy performance building, as determined in accordance with Annex I, where the very low amount of energy still required is fully covered by energy from renewable sources generated on-site, from a renewable energy community within the meaning of Directive (EU) 2018/2001 [Amended RED] or from a district heating and cooling system, in accordance with the requirements set out in Annex III; "

definition that complements a slightly modified definition of the **nearly zero energy building (NZEB):**

"*very high energy performance building, as determined in accordance with Annex I, which cannot not be below the 2023 cost-optimal level reported by Member States in accordance with Article 6(2) and where the nearly zero or very low amount of energy required is covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*; "

whose reference article, art. 9 of the EPBD of 2010 (European Commission. 2010), however, is deleted to avoid having a double performance verification in respect to both the ZEB and the NZEB.

Three other definitions are also introduced to quantify the level of atmospheric pollution emissions of a building; specifically:

operational greenhouse gas emissions: "*greenhouse gas emissions associated with the energy consumption of the technical building systems during the use and operation of the building*";

whole life-cycle greenhouse gas emissions: "*combined greenhouse gas emissions associated with the building at all stages of the life-cycle, starting from the "cradle" (the* *extraction of raw materials that are used in the construction of the building) over the material production and processing, and the building's operation stage, to the "grave" (the deconstruction of the building and reuse, recycling, other recovery and disposal of its materials)";*

Life-cycle Global Warming Potential (GWP): "an *indicator which quantifies the global warming potential contributions of a building along its full life-cycle* ".

As reported in the definition of the ZEB (zero emission building), the technical specifications identifying this building can be found in Annex III, which states:

I. Requirements for zero-emission buildings
II. Calculation of life-cycle global warming potential (GWP) of new buildings pursuant to Article 7(2)) [**1**]

In the requirements is reported that "the *total annual primary energy use of a new zero-emission building shall comply with the maximum thresholds indicated in the table below* [**2**]", i.e., for example, for the Mediterranean climate zone, less than 60 kWh/(m²y) for residential buildings, less than 70 kWh/(m²y) for office buildings, and for all other buildings lower than the total primary energy use established at the Member State level for the nearly zero-energy building.

It is also specified that, this "*total annual primary energy use of a zero-emission building, new or renovated,* ***shall be fully covered****, on a net annual basis,* ***by***":

- ***energy from renewable sources generated on-site*** *and fulfilling the criteria of Article 7 of Directive (EU) 2018/2001 [amended RED],*
- ***renewable energy provided from a renewable energy community*** *within the meaning of Article 22 of Directive (EU) 2018/2001 [amended RED], or*
- ***renewable energy and waste heat from an efficient district heating and cooling system*** *in accordance with Article 24(1) of Directive (EU)…/… [recast of the EED].*

A zero-emission building ***shall not cause any on-site carbon emissions from fossil fuels.***

Only where, due to the nature of the building or lack of access to renewable energy communities or eligible district heating and cooling systems, it is technically not feasible to fulfil the requirements under the first paragraph, the total annual primary energy use may also be covered by energy from the grid complying with criteria established at national level.

Synthetically, it can therefore be said that the zero-emission building defined here is a building that has:

a) a total annual primary energy demand below a predetermined threshold value;
b) covered by energy (better, energy carriers) produced from renewable sources, either on site or nearby (energy communities and district heating/cooling);
c) no on-site production of CO and CO_2 emissions from fossil fuels.

If, for reasons of technical impossibility, requirement (b) cannot be met, it is then permitted to be met by using energy "*from the grid complying with criteria established at national level".*

These requirements are not free from ambiguities and inconsistencies, the main one being:

- **which primary energy**? total, non-renewable or renewable; having been assigned a numerical value it is necessary that it is clear to which quantity reference is made! This ambiguity is never clarified throughout the text. To date, all European states have adopted non-renewable primary energy to define the energy performance of the building with the exception of Italy, but by deduction from what is reported in Annex III it emerges that here reference is made to total primary energy or renewable primary energy, if we consider the total exclusion of non-renewable energy sources.

In addition, it seems that the technical impossibility clause may be satisfied only by off-site produced electricity, being the term "grid" usually used for the electric network only (excluding then district heating or cooling).

Finally, it would be necessary to clarify what is meant by annual consumption "*on a net annual basis*": balance between import and export of energy carriers?

1 The "trilogue" agrees that the GWP over the life cycle of buildings of new construction is an indicative LCA analysis, to be reported in the performance energy certificate of e building and not a binding threshold.

2 It should be noted that the term "use" refers to an energy carrier supplied and measured.

Efficient district heating and cooling

The proposal to revise the EED directive approved in September 2022 by Parliament, the subject of the trilogue with the Council and the Commission, provides the following definition:

a) until 31 December 2027, a system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat going into the network;

b) from 1 January 2028, a system using at least 50% renewable energy, 50% waste heat, 80% of high-efficiency cogenerated heat or at least a combination of such thermal energy going into the network where the share of renewable energy is at least 5% and the total share of renewable energy, waste heat or high-efficiency cogenerated heat is at least 50%;

c) from 1 January 2035, a system that uses at least 50% renewable energy and waste heat, where the share of renewable energy is at least 20%;

d) from 1 January 2045, a system using at least 75 % renewable energy and waste heat, where the share of renewable energy is at least 40 %;

e) from 1 January 2050, a system that uses only renewable energy and waste heat, in which the share of renewable energy is at least 60%.

f) in line with the energy efficiency first principle, where the share of waste heat exceeds the criteria in points (c), (d) and (e), and where the waste heat would otherwise be lost, waste heat may replace any of the other energy sources;

g) an assessment has been made of the maximum needed temperatures in distribution grid.

The EU Council President's compromise proposal

On 21/10/202 2 the European Council gave birth to its final version of the amended text compared to the Commission's proposal, after five revisions, with a small revision addition published on 24/10/2022.

The changes introduced by the Council's amendments are relevant even if they do not change the basic principles; in particular, the definition of the **zero-emission building** becomes:

"*Very high energy performance building, 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 9b.*"

In Annex III the part relating to the requirements for zero-emission buildings disappears completely, which is partly replaced by the new art. 9b where, however, it is left to the Member States to individually set the minimum performance thresholds, no longer established in the Directive. This Article reproduces almost entirely what is in part I of Annex III of the Commission proposal through 6the following paragraphs 1a and 2:

1a. *Member States shall ensure that the total annual primary energy use of a new or renovated zero-emission building is covered, where technically and economically feasible, by*:

a) energy from renewable sources generated on-site or nearby, fulfilling the criteria of Article 7 of Directive (EU) 2018/2001 [amended RED];

b) energy from renewable sources provided by a renewable energy community within the meaning of Article 22 of Directive (EU) 2018/2001 [amended RED]; or

c) energy from an efficient district heating and cooling system in accordance with Article 24(1) of Directive (EU).../... [recast of EED];

d) energy from carbon-free sources

2. *Member States shall ensure that a zero-emission building does not cause any on-site carbon emissions from fossil fuels.*

As it can be seen, the requirements in the Council document are practically identical to those formulated in the Commission proposal, except point (c) which is amended deleting the **condition that district heating and cooling systems be powered exclusively by renewable energy sources and waste heat** disappears, *regardless of the technical* feasibility clause. And except the additional point (d), which introduces the requirement that the used primary energy shall be provided by carbon-free sources (e.g. not only energy from renewable sources but also atomic energy from uranium fission). Since points a), b), c) and d) are alternative, point d), as well as paragraph 2 below, do not prevent the current use of district heating and district cooling food partially from non-renewable primary energy produced by combustion of energy carriers from fossil sources.

All this explains the change in the definition of ZEB, in which the reference to the obligation to cover energy needs with primary energy from renewable sources has disappeared.

In the revision proposal, as amended by the Council, there is also a new article, 9.bis "Solar energy in buildings", which commits member states "to *ensure that all new buildings are designed to optimise their solar energy generation potential on the basis of the solar irradiance of the site, enabling the later cost-effective installation of solar technologies.*"

Some of the inconsistencies already present in the Commission's proposal remain present, such as ambiguity about which primary energy to consider for performance assessment (although in this case it could be said to be the total) and what is meant by annual consumption "*on a net annual basis*".

The Parliament amendments

In March 2023, the European Parliament discussed and approved in plenary session the ITRE proposed amendments with modifications.

A first amendment, which concerns the zero-emission building, definition has been quite modified and becomes:

"a building with a very high energy performance, as determined in accordance with Annexes I and III, which contributes to the optimization of the energy system through demand-side flexibility, where any very low residual amount of energy still required is fully covered by energy from:

*(a) renewable sources generated or **stored** on-site;*
(b) renewable sources generated nearby off-site and delivered through the grid in accordance with Directive (EU) 2018/2001 [amended RED];
(c) a renewable energy community within the meaning of Directive (EU) 2018/2001 [amended RED]; or
(d) renewable energy and waste heat from an efficient district heating and cooling system within the meaning of Directive (EU).../.... [recast EED], in accordance with the requirements set out in Annex III; "

A new Article 9.a 'Solar energy in buildings' appears in the amendments tabled, which follows what is contained in the Council's proposal for revision.

Annex III is then amended in the table showing the primary energy limit values to be respected in order to be able to consider the building as a ZEB, attributing to existing buildings the values of the table of the Commission proposal (new buildings), while the threshold for new buildings is deferred to a subsequent delegated act the Commission shall adopt by 1 January 2025.

Annex III is also amended in the sentence "*total annual primary energy use of a zero-emission building, new or renovated, shall be fully covered, on a net annual **or seasonal** basis, by*":

- *energy from renewable sources generated **or stored** on-site and fulfilling the criteria of Article 7 of Directive (EU) 2018/2001 [amended RED*],
- ***energy for self-consumption and joined self-consumption within the meaning of Directive (EU) 2018/2001 [amended RED] or local sharing of renewable energy production, including through a third-party market actor,*** *or from a renewable energy community within the meaning of Article 22 of Directive (EU) 2018/2001 [amended RED], or*
- *renewable energy from **district heating and cooling system or waste heat**.*"

Where the two new items with respect to the Commission proposal are the **seasonal basis** and the **energy for self-consumption and joined self-consumption**.

Finally, the amended technical impossibility clause is maintained and expanded as follows:

***Where**, due to the nature of the building or lack of access to renewable energy communities **or renewable energy from** district heating and cooling systems **or waste heat**, it is technically **or economically** not feasible to fully comply with the requirements under the first paragraph, **the remaining share or all of** the total annual primary energy use may also be covered by **renewable** energy from the grid, **documented with power purchase agreements and renewable heating and cooling purchase agreements as referred to in Directive (EU) 2018/2001 [amended RED], or energy from an efficient district heating and cooling system in accordance with Article 24(1) of Directive (EU) …/… [recast EED]. The Commission shall issue guidance on how to implement and verify the above criteria with special attention to technical and economical feasibility.** [Am. 67].*

Therefore, the current position held by the European Parliament is to consider the zero-emission building **as a building powered exclusively by energy carriers produced from renewable energy sources**, exploited on site or in other sites through distribution networks with a documented guarantee of origin, with the only exception introduce by the **efficient district heating and cooling system**.

What will be the zero-emission building

It is currently difficult to predict what will be the outcome of the negotiations between the Commission, the Council and the European Parliament to reach a text shared and approved by Parliament, since the positions on the definition of the zero-emission building are similar but different, as shown in the comparative table. A common negative element is however the absence of a clear definition of which primary energy must be used for the calculation of the performance of the building, even if, reasonably, the one that could meet the various requirements is the total, whose use alone is however not advisable because it prevents discriminating between systems that exploit more or less renewable sources with the same total. ■

ZERO EMISSION BUILDING REQUIREMENTS	Commission	Council	Parliament
Annual total primary energy requirements below a predetermined threshold value:	Directive	Member States	Directive
• New Buildings: values fixed by	YES		YES, but later
• Renovated Buildings: values fixed by	NO		YES
Annual total primary energy demand covered exclusively by renewable sources	Yes, if technically feasible.	NO	YES, always
Total annual primary energy requirement covered partially covered by fossil fuels	YES, if not T.F.	YES	NO
No on-site production of CO and CO_2 emissions from fossil fuels	YES	YES	YES
Is it clearly expressed that the primary energy for performance evaluation is total?	NO	NO	NO
Guarantee of origin	YES	YES	YES

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Article by Bas Turk - The Winner of HVAC World Student Competition 2023

Quantifying potential of overheating countermeasures on humanitarian shelter

Globally, 100 million people are forcibly displaced, often residing for over 10 years in temporary shelters. Frequently located in extremely hot climates, these shelters tend to overheat. Beyond discomfort, this can result in illnesses and death. This research aims to quantify the effect of overheating countermeasures on a shelter through measurements and simulations. [1, 2]

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Keywords: building performance, calibration, heat, humanitarian shelter, measurements, overheating, prototypes, refugee, simulation, thermal

Research problem

Overheating is a problem in a wide variety of humanitarian shelter types, ranging from concrete dwellings to caravans and canvas tents, with recorded air temperatures of over 45°C [3]. The thermal performance of humanitarian shelters is rarely evaluated and no standards are in place that specify thermal requirements or methods to evaluate overheating [4]. Only anecdotal evidence exists of preventive measures that have been tested in practice: we know if they work, but not how well they work.

This research focuses on a case study, the Relief Housing Unit (RHU) version 1.2, a temporary shelter produced by the Swedish non-profit Better Shelter. The shelter shows relevance to the described problem as it has been used on a large scale - 60.000 times in 57 different countries - while overheating is known to be an area for further improvement. Better Shelter is actively looking for overheating countermeasures (OCs) that can be implemented in the design of new shelters or can serve as an add-on to existing shelters. A complete revision of the design is not desired as interventions should be easy to implement, whilst also the existing trade-off in shelter design between thermal performance, costs, weight, ease of implementation and production, and user-friendliness should be taken into account. Costs are a primary factor, as underfunding is a structural problem in every area of refugee assistance [5].

Research goal and scope

This research aims to 1) quantify the effectiveness of various overheating countermeasures on the Relief Housing Unit (RHU) by conducting a case study in a semi-controlled environment, and 2) validate a building

performance simulation model of the case study. Possible hidden modelling assumptions and uncertainties have a large effect on the simulation results, incentivizing a validation study with measurement data. This creates the need to conduct measurements. Measuring shelters inside a refugee camp is problematic due to financial and ethical constraints. Alternatively, field and laboratory measurements are conducted during summer in the Netherlands. The modelling study aims to validate a simulation model of the RHU with the measurement findings and identify the model's strengths and shortcomings, so it can be used to test OCs in future research. *This article will focus on the measurement campaign as it provides practical insights and results.*

Methods

Laboratory and field measurements are conducted regarding the solar spectral properties of the façade panels and the infiltration rate of the RHU at the measurement location, respectively. However, the thermal performance of the shelter is are complex than the material properties. Therefore, field measurements are conducted on the thermal environment of multiple RHUs from May 19th to August 13th 2021 at the Eindhoven University of Technology campus, the Netherlands. In total, the measurement setup comprises one standard setup of the RHU and four smaller versions of the shelter with one-third of the length, to safe space and transportation costs.

One of the four small shelters is used as a reference case, while the other three are used to compare OCs. In total, ten different measures are tested, displayed in **Figure 1**. In reading direction, 1) and 2) improve the solar reflectance of the envelope using a white-coloured paint and aluminium foil coating. 3) and 4) utilize roof shading to decrease the solar gains using a black and aluminium shade net. 5) aims to decrease the solar transmission of the façade panels by using a grey foam colour instead of a white one. Besides, the shelter has a beige roof colour. 6) aims to reduce the infrared heat radiation from the roof toward the occupied zone with an interior ceiling. 7) and 8) promote cross-ventilation with an exhaust fan and additional door. 9) increases the shelter's thermal mass with a 1,000 litre water tank. 10) combines the aluminium foil coating and the aluminium shade net.

The air temperature is measured at 50 and 120 centimetres height in the centre of each shelter, corresponding to occupants in sitting position and the centre height of the shelter, respectively. In addition, the mean radiant temperature (MRT), relative humidity (RH) and air velocity are measured. Besides, the surface temperatures and heat fluxes of the roof, south wall, and ground are recorded in each shelter. The measured meteorological parameters are the air temperature, RH, wind direction and speed, rain, solar irradiance, and air pressure (**Figure 2**).

Most of the time, all ventilation openings are fully open to measure the most realistic scenario. All variants are also measured without ventilation to test for the worst-case scenario. Provided that no big discrepancies are found between the full and one-third shelter, a comparison is made between the one-third shelters with OCs and with the standard buildup. The combined effect of the environmental parameters of influence on overheating will be evaluated using the Universal Thermal Climate Index (UTCI), as it presents clear stress categories (moderate, strong, very strong) that can be used to compare design alternatives [6]. Overheating is expressed in Degree-Hours, which is the temperature difference above the 'moderate' heat stress threshold summed over the measured period. A sensitivity analysis is performed to assess the effect of different performance indicators on the ranking of OCs, including the ASHRAE and Vellei adaptive comfort models, the Wet-Bulb Globe Temperature (WBGT) index for heat stress, and wet-bulb temperature limits described by Ref. [7].

Table I. *Measured transmittance (τ), reflectance (ρ), and absorptance (α) values weighted over the solar spectrum with a Perkin Elmer UV-VIS-NIR spectrophotometer.*

Panels	τ (%)	ρ (%)	α (%)	Shade Factor (%)
Aluminium coating	0.0	87	13	
White paint	1.3	71	28	
Beige paint, grey foam	0.6	44	55	
Beige paint, white foam (standard wall)	1.1	49	50	
Blue paint (standard roof)	0.2	24	76	
Shade nets	**τ (%)**	**ρ (%)**	**α (%)**	**Shade Factor (%)**
Aluminium	35	54	12	65
Green	20	8	73	80
Black	21	4	75	79

Figure 1. Tested standard RHU and RHUs equipped with overheating countermeasures.

Figure 2. From left: 1. Tripod with air temperature and RH sensors and a black globe to measure the MRT. 2. Thermistor applied to the centre of a roof panel, fixated with iron wire. 3. On-site weather station. 4. Heat flux plate.

Data presentation

Laboratory measurements — The laboratory measurement results in **Table I** show that the aluminium -coated panel is most effective at reflecting solar radiation, followed by the white paint-coated panel. The absorbing shade nets, with green and black colour, provide the highest shade factor.

Field measurements — The maximum recorded wind speed matches a 'moderate' wind velocity of force 4, while the average wind speed is weak with force 2. The CO_2 concentration decay tests resulted in an estimated infiltration rate of 0.8 ACH for the full shelter. The pyranometer positioned inside the unventilated full shelter recorded a maximum irradiance of 40 to 50 W/m². This indicates that around 5% of solar irradiance is transmitted through the façade. The indoor air temperature in the standard unventilated shelter can reach up to 38°C at 50 centimetres height, even on days when the outdoor air temperature stays below 26°C. The Indoor thermal climate of the lightweight shelter responds quickly and strongly to solar irradiance. Natural ventilation can cause a reduction in the indoor air temperature of 5.5°C. Still, the indoor air temperature in the ventilated standard shelter exceeds 35°C on the warmest recorded day, when the maximum recorded outdoor air temperature peaked at 31.6°C. Even when natural ventilation is deployed, the standard shelter on the measurement site can overheat for more than one-third of the day, see **Table II**.

The interior surface temperature of the east roof reached up to 49°C. Ventilation only has a small influence on the surface temperatures of sun-exposed façade elements (maximum 5°C reduction). The measured MRT is very similar to the air temperature, both in dynamics and values, which is typical for lightweight structures. A maximum vertical temperature gradient of 9.3°C occurs over body height (180 centimetres). The heat flow through the roof is twice as big as through the south wall and much bigger than through the ground. The airspeed in the large shelter only exceeds 0.1m/s on one measurement day.

The aluminium -coated shelter performed best, see **Table II**. However, the white paint-coated shelter and shelters with shade nets perform only slightly worse, especially when ventilation is deployed. All significantly reduce the amount of overheating in the shelter, based on the UTCI. The shelter with grey foam and beige roof, and the two measures to promote cross-ventilation did not lead to a significant reduction in overheating. No usable data was recorded for the measurement setups with the ventilated roof, thermal mass, and shade net on the aluminium -coated shelter, due to bad weather and a blackout of one week. The choice of performance indicators for overheating does not change the ranking of the tested OCs.

Discussion

No large differences were found between the indoor thermal climates of the full and one-third shelter after the ventilation capacity of the latter was decreased by closing half of the vents. Their match is considered as good regarding the aim to use the one-third shelter to compare OCs. However, the measured solar transmittance on-site is considerably larger than the findings from the laboratory. This is likely because the full building envelope is more permeable than an individual material sample.

Thermal stratification remains a point for further improvement when ventilation is deployed. The high interior surface temperature of the roof indicates the potential for roof insulation or a (ventilated) second skin roof. Though there is a radiant asymmetry between the cold floor and warm roof, the MRT presents an average value close to the air temperature. Measurements could be improved by using two half-spheres to capture the asymmetry and predict discomfort on the occupant. The heat flow measurements indicate that decreasing

***Table II.** Comparison of UTCI overheating degree-hours (°CH above moderate heat stress) in one-third shelters of setup A (top) and setup B (bottom).*

Setup A - Scenario	Standard shelter	Alu coating	Black SN	White coating
Not ventilated June 1–3	173.5 (-)	71.0 (-59%)	109.8 (-37%)	96.1 (-45%)
Ventilated June 15–17	118.1 (-)	70.1 (-41%)	81.2 (-31%)	74.7 (-37%)
Setup B - Scenario	**Standard shelter**	**Alu coating**	**Alu SN**	**GF + BR**
Not ventilated July 7–9	47.2 (-)	6.7 (-86%)	12.4 (-74%)	33.6 (-29%)
Ventilated July 15–17	39.5 (-)	16.1 (-59%)	20.5 (-48%)	43.9 (+11%)

the heat gains through the roof is most important. Contradictory to literature [8, 9], the ground has less influence on the indoor thermal climate. This matches with the expectation of reality, where the massive ground slab has little influence on the thermal climate of the lightweight structure. The heat flow through the facade increases after ventilation is deployed, as the temperature difference between the panel and indoor air increases. This indicates that ventilation would not reduce the effectiveness of additional insulation, but would rather improve it.

The shelter's thermal performance is part of a trade-off with costs, weight, ease of production and implementation, and user-friendliness. The aluminium -coated shelter had a slightly better measured thermal performance on-site than the white paint-coated shelter. However, the latter is easier to implement in the production process as the aluminium coating leads to imperfections in the panel when it is heated in a press mould and notably deteriorated on site when in contact with ground moisture. The white coating is easier to implement as an add-on to existing shelters and does not lead to an increase in production costs of new shelters. A downside of the tested coatings is their design flexibility. Removable coatings deserve attention in further research.

In this light, the tested shade nets do provide this flexibility and can be applied to both new and existing shelters. The nets can also be used to create shaded courtyards, improve privacy, or in colder periods, serve as blankets or protect the shelter from wind. A downside is a large increase in production costs of roughly 25% and the added weight of the structural frame, leading to an increase in transportation costs. A limitation of the field measurements is that the aluminium and black shade nets could not be tested simultaneously. No clear differences in performance were found, as both nets performed better than the standard shelter and worse than the shelter with aluminium -coated panels. A downside of both the reflective coatings and shade nets is that they change the external appearance of the shelter. Ref. [3] mentions that the camp authorities of Azraq refugee camp in Jordan did not allow this, mainly due to security concerns.

The measured airspeed is too low to have a significant effect on thermal comfort. This might be a problem specifically for the measurement location as it appeared to be sheltered from wind, but the situation may be worse in a densely populated refugee camp. This indicates the potential of fans, which according to the results can best be used to improve the airflow over the occupant's skin, rather than to exhaust hot air. However, measures to promote ventilation can also have a positive effect on poor air quality, which results in approximately 20,000 displaced people dying prematurely every year [10].

Translating the level and duration of overheating into the risk of health effects can give substantiation for the necessity of OCs in light of the described trade-offs. At the moment, no indicator for overheating is perfectly applicable in the humanitarian sector. Applicability issues are identified for the thermal comfort models, as prevailing mean outdoor temperatures above 33.5°C are not covered by ASHRAE Standard 55. Empirical research to develop new performance indicators, for example through questionnaires in refugee camps, is suggested for future work.

Conclusion

Laboratory and field measurements were conducted in the Netherlands on a standard RHU and RHUs with overheating countermeasures. Results show that the indoor air temperature far exceeds outdoor values on a warm sunny day and that temperatures respond quickly and strongly to solar irradiance. Decreasing the heat gains through the roof is most important while, contradictory to earlier studies, the ground has less influence on the indoor thermal climate.

Reflective envelope coatings and shade nets significantly reduce the amount of overheating in the shelter. On the other hand, darkening the façade's foam colour or installing an additional door to promote cross-ventilation did not lead to significant reductions. Fans can best be used to improve the airflow over the occupant's skin, rather than to exhaust warm air.

These conclusions only hold for the specific climatic conditions on the measurement site. Future work using building performance simulations is required to test the robustness of the findings for different locations and climates. The validated simulation model from this research can already be used to predict the effectiveness of whole-façade adaptions and adaptions to the roof to reduce solar gains for hotter climates.

Based on the research findings, Better Shelter will likely implement the tested white paint coating in the production process of shelters to be deployed in year-round hot climates. ■

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Hydrogen and heat pumps in heating production-storage-usage

We look at the application of hydrogen in the heating and cooling of buildings from the point of view of heat pumps. Hydrogen is needed mainly for industry, transport and the sustainability of the gasification network. Due to the lower efficiency of hydrogen production and significantly worse economics, the economy of heating and cooling projects does not exist at the moment.

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Keywords: Heat pump, hydrogen, heating, cooling, efficiency, economy

Every advance of human society, from the first industrial revolution to the currently ongoing fourth industrial revolution, has been associated with advances in energy use and changes in technology. Whether it was the introduction of the use of steam, electricity or the automation of the production process. All these activities were connected with the use of energy, which, if we do not count hydropower, was obtained from burning wood, coal, natural gas, oil processing or nuclear fission. All the mentioned commodities represent a certain way of storing energy, which people purposefully store and use from these commodities according to the needs and demand of society. With the exception of nuclear energy, obtaining energy from the above-mentioned areas is associated with the production of resource sources (the so-called carbon footprint), which is considered the main source leading to climate change and global warming.

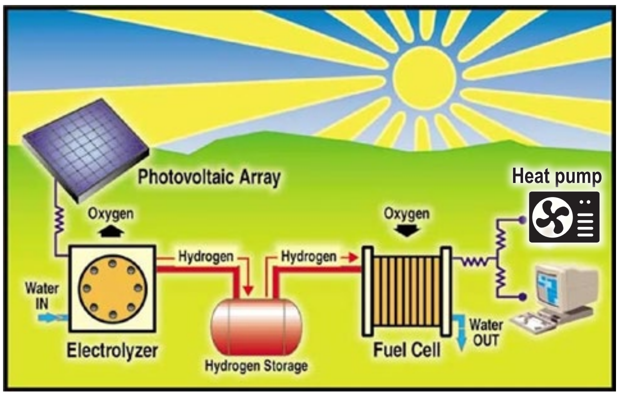

Figure 1. Integration of electrolyser, hydrogen storage, fuel cell and heat pump.

Humanity has set itself the goal of a carbon footprint and possibly a carbon-free society. This corresponds to the pressure to switch to ecological renewable energy sources such as solar, wind, geothermal and ambient energy. However, their fulfilment is also related to the need for energy storage, since in case of fluctuating energy production from the sun or wind, it is necessary to solve its storage in order to balance the supply and demand for energy.

Hydrogen and heat pumps

In addition to biomethane, hydrogen is also an alternative and promising source of "green" energy. Its combustion produces water with the release of a large amount of energy. For the wider application of hydrogen, its cheap and ecological production is key, but above all, the possibility of safe storage. If cost-effective production and storage of hydrogen is achieved, then due to the emission-free technology, despite the lower efficiency, the use of hydrogen will be interesting. For example, in the local production of hydrogen, its storage and the production of electricity in fuel cells. Electricity would be used by heat pumps for heating and cooling.

Hydrogen (H) is the lightest element on Earth. A litre of hydrogen weighs approximately 90 mg (0.09 g), so it is about eleven times lighter than air. Unlike fossil fuels (coal, natural gas...), in which energy is already accumulated and we release it from there, when using hydrogen technologies, we must first produce hydrogen by decomposing other compounds (which requires input energy in the form of work or heat) and until subsequently, either by using fuel cells or by direct combustion, release the energy from the hydrogen, so far with low efficiency.

Direct combustion is energetically and economically inefficient

Hydrogen, as the lightest existing molecule, also has a very low density. 1 kg of hydrogen gas, at normal room temperature and atmospheric pressure, occupies a volume of approximately 11 m³ (11,000 litres). So, with a low weight, it takes up a lot of space. It follows that for efficient hydrogen storage, we must focus on increasing its storage density, i.e. primarily on increasing the weight of the stored hydrogen (4).

From an energy point of view, the use of hydrogen is effective only if we achieve its high energy density during storage. An example to explain this phenomenon is **Figure 2**, which compares how much energy we can get from common fuels (gasoline, methane...) and their comparison with hydrogen. It is evident from the graph that if we take 1 m³ of these fuels (red columns in the graph), the use of hydrogen is not at all interesting, as we get the least amount of energy from one cubic meter of hydrogen. The situation changes completely if we consider weight. We get significantly more energy from one kilogram of hydrogen than from other sources (blue columns in the graph). Therefore, when developing materials and technologies for hydrogen storage, it is necessary to look primarily at how much hydrogen they are able to store.

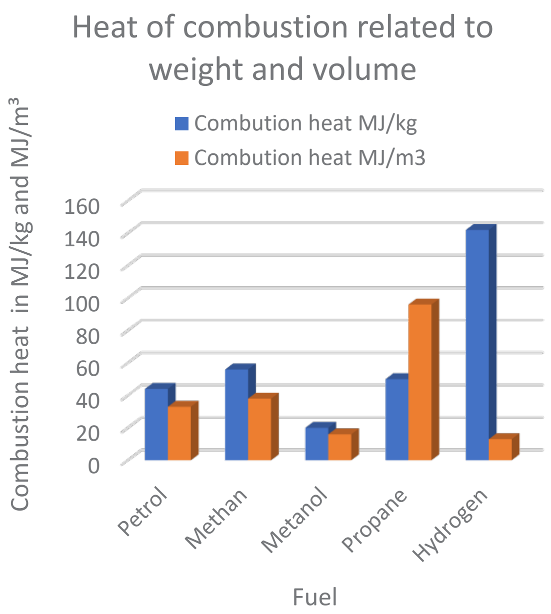

Figure 2. Energy density of common fuels and hydrogen by weight (blue bars) and by volume (red bars).

Storage of hydrogen in gaseous state

Storing hydrogen as a compressed gas is the simplest, most natural and most economical choice. This storage method is also referred to as CGH2. It involves compressing hydrogen using compressors into pressure tanks. The principle of using high pressure for hydrogen storage is shown in **Figures 3a and 3b**. Increasing the pressure increases the amount of stored gas and the energy density. The density of hydrogen at atmospheric pressure (1 bar) and a temperature of 20°C is approximately 0.084 kg/m³. When the pressure is increased to 100 bar and the same temperature, the density increases to 7.8 kg/m³, at a pressure of 300 bar it is already 20 kg/m³ and, for example, at a pressure of 700 bar it is almost 40 kg/m³. On the other hand, the use of higher pressure is economically more demanding in terms of energy and technology (compressors) as well as requirements for reservoirs. When using a pressure of 700 bar, the reservoirs are made of special materials, for example using expensive carbon fibres, which can make up 40-80% of the price of the reservoir.

Liquid hydrogen

The second practically established form of hydrogen storage as a liquid (LH2) requires very low temperatures (-253 °C) and specially insulated tanks. In addition, when liquefying hydrogen, it is necessary to pre-cool it with liquid nitrogen. Thus, the economic

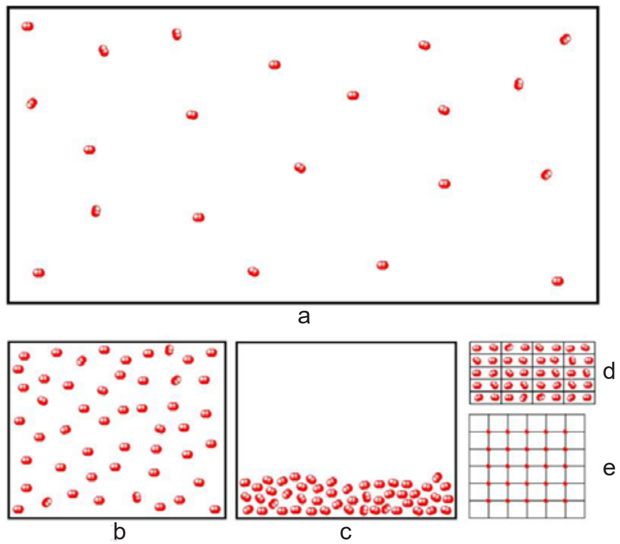

Figure 3. Illustrative representation of hydrogen molecules under different conditions: a.) hydrogen molecules in a closed vessel at normal room temperature and atmospheric pressure, b.) hydrogen molecules compressed in a pressure vessel at high pressure, c.) hydrogen molecules in a liquid state, d.) atoms hydrogen absorbed in metallic materials, e.) hydrogen molecules adsorbed in porous material (4).

costs of obtaining liquid hydrogen are relatively high, on the other hand, compared to compressed hydrogen, the same amount of liquid hydrogen has a much smaller volume and higher energy density (Fig. 3c). The density of liquid hydrogen is approximately 70 kg/m³, which is almost twice as much as the density of gaseous hydrogen (40 kg/m³) at 700 bar.

It is probably not rational to assume the use of liquid hydrogen, but despite the energy requirement, liquefied hydrogen is a suitable form for transporting it to the place of use (e.g. family houses with heat pumps).

Storage of hydrogen in hydrides

Hydrogen storage in solid structures is currently in the stage of basic research. Category of materials being investigated for hydrogen storage are hydrides (metallic or non-metallic). In these substances, hydrogen is integrated directly into the structure of solid substances and forms stronger, binding interactions with the solid substance, thus the so-called chemical sorption. In this way, it is possible to store hydrogen with a density that is not yet high. The mass storage capacity of the metal hydride is 1.43-6 %.

Hydrogen storage in porous materials

Hydrogen can be stored in porous carriers. For example, there is storage of natural gas on the earth's surface, where deposits are often formed by porous rocks in which natural gas is accumulated by adsorption. The key is the large specific surface area of the porous material. Modern porous materials can have a surface area of several thousand m2 per gram of carrier. The phenomenon of adsorption, therefore, leads to the "attachment" of hydrogen molecules to the surface and in the pores of the porous material. In this way, it is possible to store hydrogen with a density that is not yet high, up to 6% of the total weight.

Transport of hydrogen

If hydrogen were to become an integrated part of energy distribution, it will also be necessary to solve the transport and distribution of hydrogen on a large scale from the place of production to the consumer (1).

One of the existing and safe solutions is the distribution of hydrogen gas through pipelines. Hydrogen distributed in the pipeline has higher requirements for the tightness of the pipeline, the materials used. Pipeline distribution is technologically mastered. It has been used for many years. Compared to the transport of e.g. natural gas, transporting hydrogen through pipelines is more complicated and expensive due to the higher energy required to push hydrogen into the pipeline and its low volumetric energy density. This requires 3x higher gas flows. It is estimated that approximately 4.6 times more energy is needed to transport hydrogen through pipelines than to transport natural gas. In addition, significant energy losses occur during transportation, approximately 10% for every 1000 km.

In addition to pipelines, hydrogen can also be transported in pressure cylinders with a pressure of up to 350 bar or 700 bar. However, with the expected high consumption of hydrogen in the case of the introduction of hydrogen technologies, such distribution would be slow and uneconomical.

An alternative is to transport liquid hydrogen, which is difficult to store due to evaporation. Liquefaction is a time- and energy-consuming process and takes place at a temperature of -253 °C. The advantage of liquid hydrogen is its high energy density, which is three times higher than that of gasoline. Only nuclear fuel has a higher energy density.

An alternative is the transport of hydrogen bound in compounds, e.g. molecular hydrides, mentioned in the previous chapter.

Hydrogen houses

Hydrogen houses can be divided into houses with their own hydrogen production, houses buying liquid, gaseous or solid hydrogen and houses connected to a gasification network with a mixture of natural gas and hydrogen, later also potentially pure hydrogen (1). Combustion of hydrogen is energetically inefficient and therefore the development deals with the economics and energy efficiency of the integration of the production, storage and use of hydrogen in fuel cells for the production of electricity. Electricity can be used not only for heating, but also for cooling the house.

Burning hydrogen to produce heat is energetically unsuitable

The efficiency of hydrogen production is low, less than 60%. It will increase around 90 % only if we use the heat released during the electrolysis of water. Moreover, the building cannot be cooled by burning hydrogen.

60 kWhe are consumed to produce 1 kg of hydrogen with a combustion heat of 39 kWth. If 60 kWhe is used directly in the heat pump, 6 times more up to 240 kWhth heat is produced. The burning of hydrogen has a very low efficiency, and the heat produced is at least 5-6 times less than the heat produced by the available electricity directly by the heat pump.

Hydrogen as a 'buzzword' and heat pumps

It is likely that hydrogen production will be decentralized and integrated into hydrogen technologies. In that case, the physical transport of hydrogen to such facilities will not be necessary. They will work autonomously with the potential use of heat pumps. The economics of such hydrogen projects currently do not exist.

Integration of electrolyser, hydrogen storage, fuel cell and heat pump

In the case of hydrogen production by electrolysis, which is then stored and used to produce electricity in the fuel cell, which is used to drive the heat pump, the resulting efficiency of the integrated solution does not reach the energy efficiency of heat production by the heat pump with electricity from the electrification system. However, the efficiency of the electrolysis, fuel cell and heat pump combination can be increased if the heat released in the electrolysis and in the fuel cell is used. Due to the lower efficiency and significantly worse economy, such an integrated technical solution is currently and in the near future problematic.

Use of an electrolyser for hydrogen production

It is limited by the availability of green electricity, which limits the operation of the electrolyser with a power of 75-100% only for a period of 20% of the year. Conversely, the unavailability of green electricity above the technological limit of the electrolyser's performance (20%) puts the electrolyser out of operation for more than 60% of the year. The starting point should be the production of the so-called of low-carbon hydrogen with partial use of electricity from the distribution network with the assumed condition of ensuring at least 70% less greenhouse gas emissions than fossil natural gas during the entire life cycle.

Conclusion

We look at the application of hydrogen from the point of view of heat pumps from the point of view of the structure of the energy system and the need for heating and cooling buildings. Hydrogen is needed mainly for industry, transport and the sustainability of the gasification network. For now, hydrogen is in short supply and it is likely that it will have to be imported, thus only partially fulfilling the requirement of energy independence. The production of hydrogen for the gasification network, first by mixing and assuming the transport of pure hydrogen, would probably require a demanding renewal of the network in order to prevent large losses and reduce the multiple energy requirements of transport.

If hydrogen could be economically produced, stored in sufficient quantity and transported with adequate energy density, then integration with fuel cells and with a heat pump for both heating and cooling would come into consideration. Even this solution is not more energy efficient than the direct use of electricity by a heat pump and is still many times more expensive.

It follows from the above that the production of hydrogen for the purpose of heat production by combustion is energetically and economically inefficient and therefore unsuitable. The efficiency of the combination of electrolysis, hydrogen storage, fuel cells and heat pump can be increased if the heat released in electrolysis and in the fuel cell is used. Due to the lower efficiency and significantly worse economy, such integrated technical solutions are unlikely at present and in the near future, because the economy in hydrogen projects does not exist at the moment. ■

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EN 17037 a step forward: New computational methods with Sunlight, Daylight, and Quality Views for Regenerative Design

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Nomenclature

Abbreviation	Term
ADF	Average Daylight Factor
ASE	Annual Sunlight Exposure
BIM	Building Information Modelling
BRE	Building Research Establishment
CAD	Computer-aided design
CEN	European Committee for Standardization (CEN, French: Comité Européen de Normalisation)
CIE	Commission Internationale de l'Eclairage
CBDM	Climate Based Daylight Modelling
DA	Daylight Autonomy
DF	Daylight Factor
DGP	Daylight Glare Probability
E_t	Illuminance, target
$E_{t\ min.}$	Illuminance, minimum target
EN 17037	Daylight in buildings (European standard)
Fplane	Fraction of the reference plane
Ftime	Fraction of time (hours) considered based in the EN 17037 daylight method
IES	Illuminating Engineering Society
IWBI	International WELL Building Institute
LEED	Leadership in Energy and Environmental Design
LM	Lighting Method
sDA	spatial Daylight Autonomy
Tvis	Visible Light Transmittance
UDI	Useful Daylight Illuminance
UDI low	% time UDI < 100 lux
UDI up	% time UDI > 3000 lux
USGBC	U.S. Green Building Council
WELL	WELL Building Standard

Abstract

This paper investigates novel computational methods for Regenerative Design by developing further on the European Standard EN 17037, to make it useful at both urban and architectural scales. Case studies are evaluated for sunlight provision, daylight design and view quality. A comprehensive assessment of climate-based daylight metrics and EN 17037 methods, for an office building in Helsinki, for a 300 lux target, demonstrates comparable differences of 12% between sDA and Illuminance levels (EN 17037 method 2), 37% between sDA and Daylight Factor (EN 17037 method 1), and 25% between EN 17037 daylight methods 1 and 2. A new computational method for evaluating Views on the floorplan is introduced. The method considers 'view content' (View Out layers in EN 17037), 'view access', the potential viewpoint-based 'outside distance', and can be extended to consider the 'quality of environmental information' of views. Integrating computational methods and further research directions are discussed for sunlight, daylight, and view quality as a spatial metric (percentage of space).

Introduction

Even though Regenerative Design has been introduced as a separate discipline in 1994 by John Tillman Lyle (Mang & Reed, 2013), it is still an emerging field with a growing number of proponents in research and practice.

Sustainability practice as it is applied today has focused primarily on reducing environmental impacts on natural systems, and increasing efficiency in the use of resources and processes. The Regenerative Sustainability paradigm aims to shift from the slow degeneration of the planetary boundaries, toward restoring earth's systems to a healthy state and supporting the co-evolution of human and natural systems (Cole, 2012). A Regenerative Design and Development approach aims to provide for human health and well-being, improve the environmental performance of buildings and restore natural systems to a healthy state. New ways of thinking and a holistic approach required in architectural design can be supported with digital technologies.

Background

In industrialized nations, individuals spend on average 65-90% of their time indoors (Klepeis et al., 2001). Daylight is an important aspect of design for building performance and occupant well-being. The role of daylight in research and practice is growing. New evidence and daylight metrics are continuously updated in some codes and voluntary standards such as LEED v4.1 (USGBC, 2021), WELL v2 (IWBI, 2022) and EN 17037 (European Committee for Standardization [CEN], 2022). The contribution of Daylight for Regeneration Design, in research and digital practice for the built environment, is being explored nowaday with a fresh perspective in contributions that investigate the possibilities when bridging research, design process, and simulations with computational tools (Naboni & Havinga, 2019).

Daylight metrics in standards

The daylight factor (DF) has been introduced in 1895 as means to quantify the interior levels of daylight independently from the instantaneous sky luminance (Love, 1992). It is still widely used in some building regulations in European countries such as Norway, Sweden and Italy. In Italian, Finnish, Danish, and Swedish regulations, the window-to-floor ratio is used. Alternatively, the DF calculation can be done, and there are several methods of evaluation of it i.e., DF point, mean DF, and median DF. An average daylight factor (ADF) value of 2% is to be met in the case of Norway and Italy. However, ADF results can be misleading when comparing single and multi-aspect window spaces (Mardaljevic & Christoffersen, 2017). In such cases, the median DF is more informative for the daylight of a space. Additionally, the simulated 300 lux Daylight Autonomy (DA) for 50% of occupied hours was found to have a better correlation in student assessments for the boundaries of what is considered a 'daylit area' compared to the 'window-to-head-height' rule of thumb, or the 2% DF contour lines (C. F. Reinhart & Weissman, 2012).

The motivations and methodology, to transition from ADF to a target DF, determined by the interior daylight provision level, and derived from daylight availability in climate files, as well as to refine the methods and reduce misinterpretation, are explained in detail in a paper prior to the publication of EN 17037 (Mardaljevic & Christoffersen, 2017). The European standard EN 17037:2018 "Daylight in buildings" provides comprehensive methods for the evaluation of daylight properties in buildings. It introduces the Daylight Glare Probability, Sunlight provision based on exposure of windows to sun hours, and a framework for evaluating Views to the outside. Each area of assessment has three levels of recommendation. The Daylight Factor in the EN 17037 is introduced as a provisional method towards the adoption of the second method of the standard using annual Illuminances of weather files based on actual daylight hours. Currently, LEED and WELL standards require Climate Based Daylight Modelling (CBDM) metrics for daylight assessment. BREEAM evaluations are based on the ADF by latitude (BRE, 2021).

Novelty of the study

The evaluation methods of Sunlight and View Out in EN 17037 can be carried out on paper. It can be time-consuming and require a lot of skill to evaluate. Computation, 3D models, and visual programming in design tools can be used to explore how to perform analysis and carry out geometrical calculations. A computational approach can provide new insight and clarity on new methods and use cases. Additionally, the new methodologies for daylight provision in EN 17037 raise the question of how to carry out, and what are the differences between the two daylight methods, and other existing daylight metrics. Past research provides some answers in assessing EN 17037 methods for compliance, where DF resulted in being harder to meet compared to CBDM (Bournas, 2020). Another paper investigates the use of EN 17037 as a restriction for density in residential developments (Šprah & Košir, 2020). Additionally, case studies need to be investigated to gain an in-depth understanding of daylight conditions, quantify differences and make qualitative comparisons of metrics.

Methods

Novel computational methods are investigated through Grasshopper for Rhino (Robert McNeel & Associates, 2020), on basis of EN 17037 areas of assessment for Sunlight, Daylight and Views. The goal is to explore the standard as a tool in the architectural design process, from early simple models to developed design. Using the EN 17037 in design workflows rather than post-design assessments could provide clarity, increase the adoption of these methods, and inform the design with actionable insights. Faster analysis through computational methods for EN 17037 could influence positively the design of buildings. Previous research has demonstrated the links of views and daylight to health and wellness in buildings (Aries et al., 2010; Commission Internationale de l'Eclairage [CIE], 2009), but does not put forward ways to use and communicate results for designers e.g., workflows, colour-coded visuals of performance to support data-driven architectural design. Thus, the research explores new methods for EN 17037, that can result in faster and clear ways that can be utilized in academia and by practitioners.

Exposure to Sunlight

Sunlight provision in EN 17037 has three performance levels that are 1.5, 3 and 4 hours of direct sun. Direct sunlight cannot be counted below minimum solar altitudes on 1 February and 21 March, and maximum solar azimuth on 1 February for given locations in EN 17037 tables D.1 and D.2. The evaluation is performed for a reference point of a window. It does not consider computational methods, that could be used with 3D models, on a spatially distributed grid of points. The workflow herein proposed uses 'Sun Path' and 'Direct Sun Hours' components in Ladybug Tools (Sadeghipour Roudsari & Pak, 2013) to perform an EN 17037 compliant sunlight assessment. The colour-coded results can be categorized according to any of the three performance levels or as one colour-coded map. The geometry was translated into a mesh grid for simulation between 1 – 2 metres as an appropriate level of accuracy. A timestep of 10 minutes for the sun vectors was used to allow for accurate sub-hourly results and balance computation time, to use the simulation feedback in an iterative process. Sun altitudes and solar azimuth values in annexe tables in EN 17037 are used to filter in only those sun vectors that contribute to direct sunlight for standard compliance. New methods of assessment of solar access and solar envelopes have been proposed recently (de Luca et al., 2021), and are implemented in the plugin the 'Solar Envelope Tools' from Tallinn University of Technology. However, such workflows pre-determine the building shape and apply to already built-up areas. The objective of the proposed method is to explore how the performance of design options on 3D models, with extracted results in terms of façade area in square metres (or as percentages), can inform design decisions without prior restriction e.g., building distances, massing, program, window location and size, the layout of units (exposure or disposition on two levels) to reach a minimum or higher levels of sunlight provision for the buildings to be designed, as well as considering the impact on the existing buildings.

Daylight provision

Daylight simulations are performed with Ladybug Tools' Honeybee plugin, which connects to Radiance for point-in-time daylight factor, and annual daylight simulations. Visual scripting in Grasshopper is used to produce the results according to daylight metrics of EN 17037 and selected climate-based metrics.

In EN 17037, Daylight is considered adequate if a target illuminance (E_t) is reached across 50% of the reference plane and a minimum target illuminance ($E_{t,min}$) achieved respectively across 95% of the plane, categorized in three levels of recommendation that are given in **Table 1**.

Table 1. *Summary of EN 17037 reference values, and specific DF and E_t values for Finland.*

Area of assessment	Means of assessment	Level of recommendation		
		Minimum	Medium	High
Sunlight Provision	Daily Sunlight Exposure	≥ 1.5 h	≥ 3 h	≥ 4 h
Daylight Provision (Illuminance or corresponding DF), Finland values	Illuminance target	300 lux	500 lux	750 lux
	Daylight Factor target	2,2 %	3,7 %	5,6 %
	Illuminance minimum target	100 lux	300 lux	500 lux
	Daylight Factor minimum target	0,7 %	2,2 %	3,7 %
Quality of View out	Horizontal Sight Angle	≥ 14 °	≥ 28 °	≥ 54 °
	Outside distance of view	≥ 6 m	≥ 20 m	≥ 50 m
	No. Layers seen (Ground, Sky, Landscape)	1	2	3
Glare Protection	$DGP_{e<5\%}$	< 0.45	< 0.40	< 0.35

Method 1 of EN 17037 uses corresponding Daylight Factors determined by the internal illuminance and Ev,d,med of the local climate. Method 2 uses dynamic daylight provision of Illuminance levels for at least 2190 hours (i.e., half of the daylight hours of the year). Currently, and to our best knowledge, there is no software implementation available for calculating Method 2.

Climate based metrics such as spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) present in LEED are based on 'occupied hours' as described in IES-LM83 (2013). In addition, the Useful Daylight Illuminance (UDI), using the same occupied hours' schedule (8 am – 6 pm) will be presented in the results. Since daylight provision in EN 17037, is based on (1) local climate files, and (2) the same principle of concurring climate based metrics where illuminance levels are considered valid for at least half of the hours of the period considered, the results of each can be compared. Only the minimum level of recommendation, E_t of 300 lux, and $E_{t,min}$ of 100 lux is considered, as it provides (1) the best correlation with daylit area studies, and (2) for comparison with CBDM metrics. Corresponding Daylight Factors to Illuminance values for Finland are provided in **Table 2**. Both methods 1 and 2 in EN 17037 were used to compare the results with existing Climate Based Daylight metrics.

Case study for daylight metrics

An open-space office building in Helsinki (Finland) was used for comparing selected daylight metrics. The case study features core zones in the centre and collaborative spaces with glazed partitions around the core for daylight. Work desks in the open space are distributed around the perimeter. The building has cantilevered slabs and façade frame elements every 1 metre, at the outer part of the glazing and along all orientations. The first level of the buildings was subject to daylight simulations with Ladybug Tools' Honeybee plug-in in Grasshopper with a high-level setup, provided by Honeybee components. The space dimensions are 90.0 m in length, 25.0 m wide, and 3.4 m in height. Section B.3.1 of Calculation methods in Annex B of EN 17037, recommends reflectance values (Tvis) for main surfaces. **Table 3** reports the values utilized in the Honeybee daylight model. Model properties are within the ranges recommended in EN 17037.

View methodology

Numerous studies have been dedicated to the evaluation of the quality of views from windows and the correlation between daylight and visual comfort (C. Reinhart, 2018). Comprehensive frameworks for views and related metrics have been developed recently in research (Ko et al., 2021; Turan et al., 2020, 2021). Further research and limitations were identified in each study. The development of View metrics in EN 17037, green building standards and recent research need to be evaluated scientifically and integrated into architectural practice. The implementation in CAD and BIM tools or through Visual Programming remains underdeveloped. Currently, the Ladybug Tools plug-in (Version 1.4.0, 2022) for Grasshopper in Rhino offers a few components for simulating View types that are too generic for EN 17037 and the metrics of recent research. 'View Out' methods in EN 17037 refer to point-in-space assessments as presented in Annex C. The View method presented develops further on the framework of 'View Out'. Three algorithms are implemented in Grasshopper for computing the components of the View Out in EN 17037 that are (1) Horizontal Sight Angle, (2) Outside Distance of View and (3) Number of Layers Seen.

Ko defined three variables of views that are View content, view access, and view clarity (Ko et al., 2021). View content is determined as the 'layers seen'

Table 3. *Daylight surface properties.*

Element	Light Reflectance / Tvis	
	Honeybee – Radiance model value	EN 17037 Annex B recommended range of values
Ceiling	0,8	0,7 to 0,9
Interior Walls	0,5	0,5 to 0,8
Floor	0,2	0,2 to 0,4
Exterior Walls	0,35	0,2 to 0,4
Exterior Ground	0,2	0,2
Context	0,2	-
Exterior glazing	0,64	-

Table 2. *Extracted from EN 17037 Table A.3: Daylight Factor values for Finland to exceed illuminance level of 100, 300, 500 or 750 for a fraction of daylight hours* $F_{time,\%} = 50\%$.

Nation	Capital	Median External Diffuse Illuminance Ev,d,med	Geographical latitude φ [°]	DF ≥ 100 lux	DF ≥ 300 lux	DF ≥ 500 lux	DF ≥ 750 lux
Finland	Helsinki	13500 lux	60,32	0,7 %	2,2 %	3,7 %	5,6 %

in EN 17037 i.e., ground, sky, and landscape (built or natural). 'View access' is considered in the computation of each 'layer seen'. View access is defined as 'how much of the view can be seen through the window from the occupant's position' (Ko et al., 2021), and is captured in the implemented algorithm in the geometry-based computation of each 'layer seen'. 'View clarity' from the window is not considered in EN 17037 and neither in the computational method presented in the paper. The simulation is performed for a spatially distributed grid in the interior floorplan at seated eye-level 1.2 m above the floor. The definition of Outside Distance of the view in EN 17037 is given as "*distance from the inner surface of view opening to opposite major obstructions located in front of the opening*". Thus, the same level of performance would result for each point in space within the floorplan. The method proposed evaluates the view distance on basis of the 'position in space' and 'potential view directions'. The algorithm uses vector ray-tracing and measures the distances for each grid point to the ground and nature, or to all layers within a distance limit e.g., 100 m. An average result of the distances (remaining vectors that were not obstructed by the interior geometry) for each grid point is used.

Results

The computational methods are tested on real-world case studies in Helsinki. Simulations were performed during early and developed design iterations by the first author of the paper.

EN 17037 sunlight analysis for early design

The results are presented for a new development project with existing surrounding buildings in **Figure 1**. The colour-coded maps are for a default sunlight analysis in Ladybug, a 1.5 hours performance level, and an EN 17037 complete sunlight assessment. February 1st was chosen as the analysis period as it is more restricting than the 21st of March, and all performance levels in EN 1037 resulted in the facades of the case study. The simple model can be contoured with lines to guide the designer in relating the performance of the façade to the building level.

The areas corresponding to each level of performance are extracted from the simulation, in the unit of square metres, and as percentages, and represented in charts in **Figure 1**. Additionally, charts can be generated within Rhino for tracking the progress of design iterations with Grasshopper plugins such as "Conduit" and "Human UI".

CBDM results for open space office building

This part of the study presents a comprehensive review of climate based daylight metrics and EN 17037 daylight methods for an open space office building with openings on all facades and orientations in Helsinki, Finland. Daylight Autonomy (DA) in conjunction with Annual Sunlight Exposure (ASE) and UDI is shown in **Figure 2**. The contour lines representing 50% of the time for DA, the threshold of 300 lux, and the UDI range of 100-3000 lux range

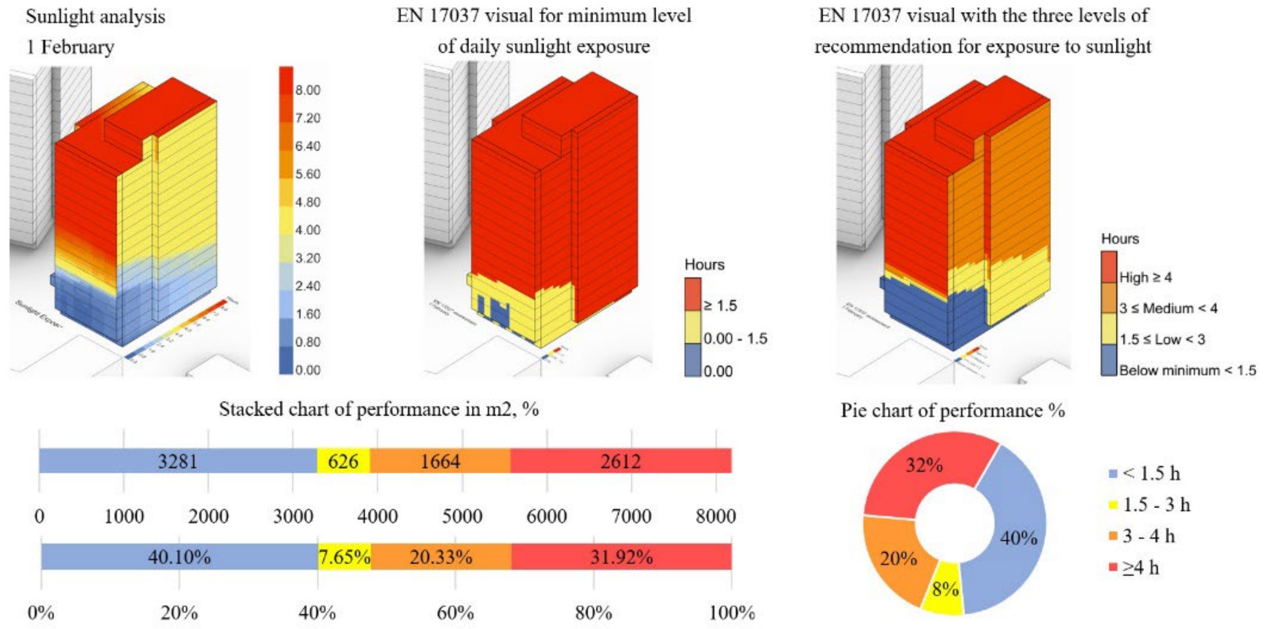

Figure 1. Left to right. Southeast views of colour-coded sunlight analysis, categorized based on EN 17037minimum level, categorized based on the three performance levels in EN1703. Charts with results.

are indicated. Spatial DA and UDI results are given. The colour-map is categorized in 10% steps for ease of comparing spatially the results of metrics.

Annual Sunlight Exposure (ASE) of at least 250 hours for more than 1000 lux of direct sun is presented and categorized every 250 hours up to 1000 hours, to show a higher level of granularity and visualize the differences between orientation exposures and the impact of the position in proximity to glazing.

Daylight Illuminances below 100 lux are considered insufficient (UDI_{low}) and when exceeding the useful range (UDI_{up}) are likely to produce visual or thermal discomfort, or both (Nabil & Mardaljevic, 2006). Contour lines of 10% and 20% of the time for UDI_{low} and UDI_{up} are shown in **Figure 2** for comparison of metrics. There is a 5% point difference between UDI_{up} of 27% and ASE of 32% across the space. While there are some differences between UDI_{up} and ASE, there is a similarity in the spatial distribution of results between $ASE_{>1000lux,1000h}$ to $UDI_{>3000lux,>20\%}$, and $ASE_{>1000lux,250h}$ to $UDI_{>3000lux,>10\%}$.

Comparison with EN 17037 daylight methods

Daylight Factor and Illuminance levels based on EN 17037 methods are simulated and presented. The design proposal fails to meet the requirements of EN 17037 based on the Daylight Factor. An "Option 2" of the Daylight Factor is calculated when a larger core area is not considered in the results, as indicated by a dashed rectangle in the right-side colour-map in **Figure 3**.

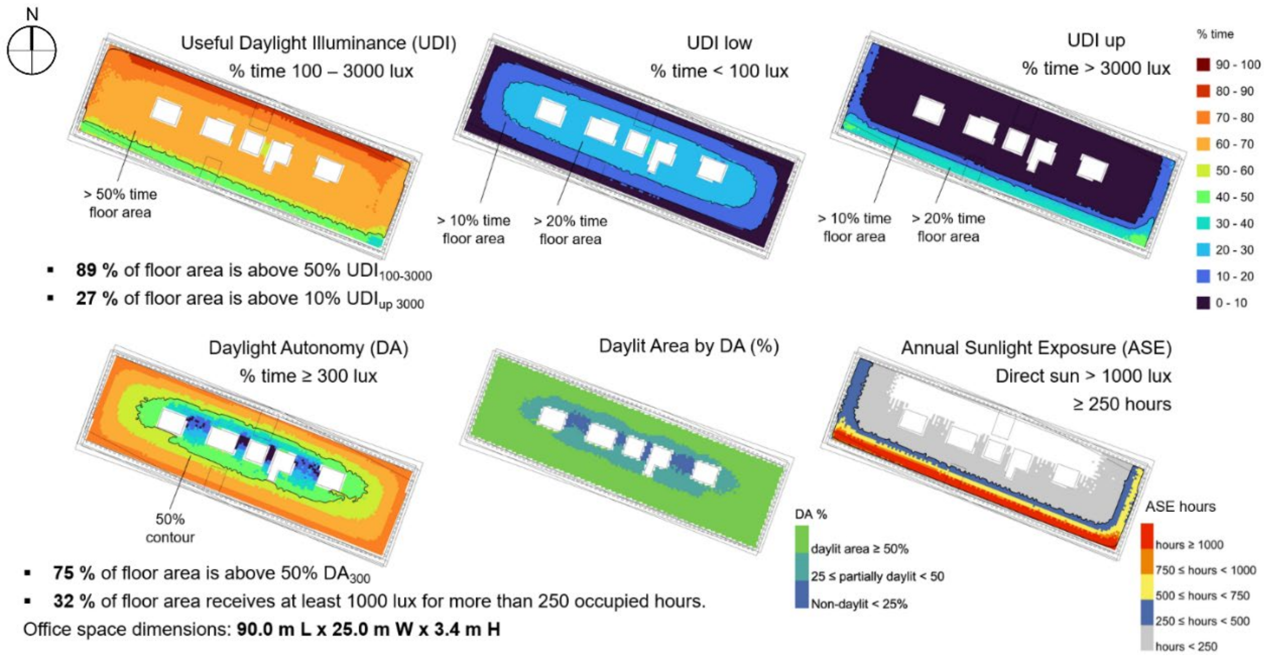

Figure 2. Climate Based Daylight metrics for an open space office building in Helsinki.

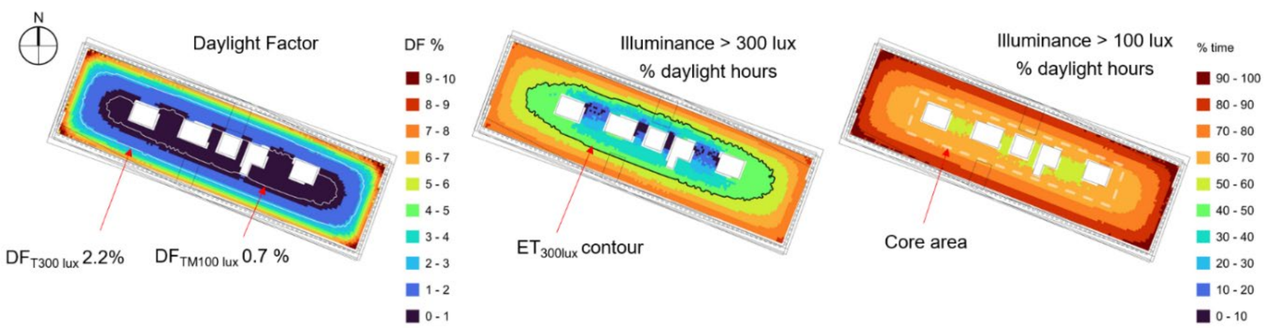

Figure 3. Left to right. Daylight Factor (target and minimum target), Illuminance levels of 300 lux, $F_{plane,50\%}$ and 100 lux $F_{plane,95\%}$ based on actual daylight hours as in method 2 for Daylight Provision in EN 17037.

The following differences are found:

- Spatial Daylight Autonomy ($DA_{300lux,50\%}$) of 75% versus a target Daylight Factor that is met for 38% of the reference plane. There is a 37% point difference for a target illuminance of 300 lux between sDA and DF (method 1, EN 17037).
- 63% of floor area is above Illuminance levels (method 2) of 300 lux. Compared to the Daylight Factor, there is a 25% point difference in spatial results.
- $sDA_{300lux,50\%}$ (based on occupied hours) results are higher by 12% points compared to the fraction of plane meeting Illuminance levels for half of the daylight hours as in EN 17037 method 2.

Additionally, a comparison of results between EN 17037, LEED, and BREEAM daylight metrics is given in **Table 4**. The WELL standard is not presented, as it is based on the IES LM-83-12 standard as in LEED, or using EN 17037 methods, with average sDA targets of 55% and 75% for regularly occupied spaces.

Quality Views

The method is tested on a master plan and shown for a unit of residential development with context buildings in Helsinki in **Figure 4**. The potential of incorporating view analysis early in the design process is presented. The location of the unit in the design and its context are shown in wireframe display mode in Rhino in **Figure 4**. 'View content' is composed of the "layers seen" as defined in EN 17037. The dimensionality from 1 to 3 levels can be extended by adding geometrical objects that account for the "quality of environmental information" in the computation of the View metric. Based on

Table 4. *Comparison of simulation results of EN 17037 daylight methods and selected standards.*

Daylight metric		Target value	DF, F_{plane} (option 1)	DF, F_{plane} (option 2)	Illuminance levels, F_{plane} (option 1)
EN 17037	E_t 300 lux, F_{plane}50%	≥ 2.2%	38%	50%	63%
	$E_{t\ min}$100 lux, F_{plane}95%	≥ 0.7%	81%	97%	100%
LEED v4.1 sDA300/50%		40%, 55%, 75%	-	-	75%
$UDI_{100\text{-}3000/50\%}$		-	-	-	89%
BREEAM INT NC v6 ADF, F_{plane} 80%		2.2%	2.4% (F_{plane} 100%)	2.9% (F_{plane} 100%)	-

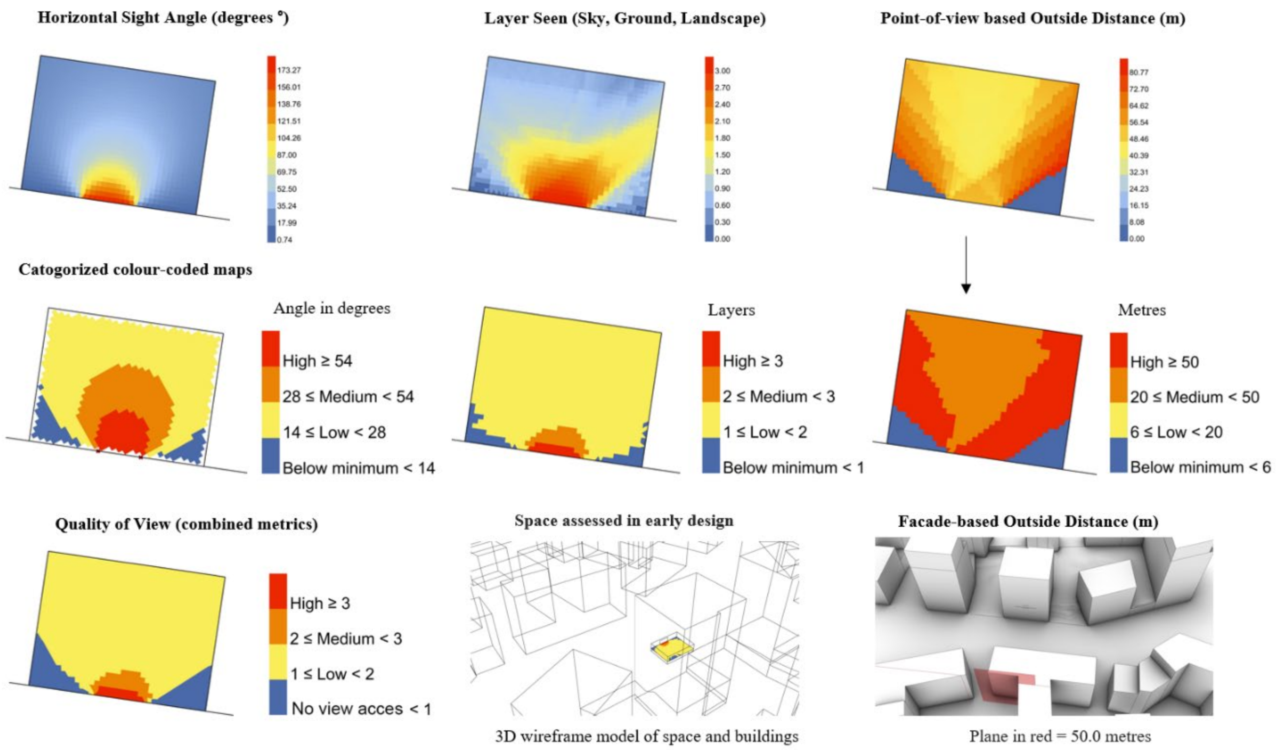

Figure 4. Spatially computed metrics for View Out in colour maps, categorized colour maps, and cumulative visualization of Quality Views developed from EN 17037.

real-world conditions, simple geometrical elements can be modelled to increase or reduce the score of the view.

The computation on a spatially distributed grid for the *Outside Distance* shows differences in the reference plane regarding the level of performance based on the position in space and view direction in the interior, in an urban setting with varying morphological features and building heights. The façade-based distance evaluated with a plane projection suggests there is only a medium level of performance per every floor as shown in **Figure 4**. It would influence to a greater extent the cumulative Quality Views assessment. When the performance of the "outside distance" metric is lower than the other two metrics, it would override the colouring and performance level of the total view evaluation. The viewpoint-based 'outside distance' is combined with the 'Layers Seen' and 'Horizontal Sight Angle' in one visualisation for communication purposes. However, the granularity of information from eacg metric is partially lost in the combined "Quality Views" evaluation in the case study.

The results can be further analysed by extracting the area (m^2) for each level of performance and deriving a "spatial metric" for the View. In addition, as in the Sunlight method, a stacked or pie chart with area in the unit of m^2 or % for each performance level can be used to predict the performance of a building when design variables change e.g., façade patterns, building layout, window size & locations, internal obstructions.

The developed method achieves the following:

- Translating EN 17037 View methods into *near real-time spatial assessment* in a design modelling environment.
- *View access* based on space geometry is embedded in the computation for each layer seen.
- Understand the implications of decisions early, how window size and location, shadings, and facade elements can influence access to views and its performance.
- The difference between *Point-of-view Outside Distance* versus *Façade-based Outside distance* is presented.
- Additional levels of performance are needed and can be added to the score for the **quality of the environmental information** (e.g., art, landmark, natural, water) with computational design tools.
- Layers Seen metric limitation is suggested e.g., Low-rise can have higher levels of three layers seen across the reference plane. Depending on urban morphology, lower floors could see the Ground layer and not Sky, while, higher floors could see Sky but not the Ground layer.
- Spatial metrics (% space) can be extracted from the results.

Discussion

This paper explores the potential of using the European Daylight Standard as a design tool rather than just an assessment method through its introduction to computational design workflows. The graphical methods and reference values of the standard are transformed into algorithms to automate parts of the process for evaluating projects, towards near real-time spatial assessments, that are communicated with colour-coded visuals in 3D models in a popular 3D modelling environment for architects such as Rhino. Novel computational methods with Sunlight, Daylight and Quality Views can help architects to achieve higher goals of Regenerative Design. Solar access requirements are present in many local regulations at European and International levels. CAD and BIM tools can visualize a 3D Sun Path, and shade the model, but lack the development of analysis features to evaluate the design or its surrounding context. Visual scripting in Grasshopper and Ladybug Tools plug-ins are used to develop design-based workflows for evaluating the performance to improve designs. An iterative design process, single or multi-objective optimization can be used.

The results of the Sunlight analysis can be used for improving the design according to the following:

- Improve masterplan e.g., distances between buildings, or adjust the shape of the designed building.
- Adjust program e.g., of building levels and internal layout of units/offices, core zones, and other functions.
- Allow for sunny/shaded open spaces and courtyards based on climate and season.
- Provide units with double exposure, or on two levels to reach the minimum or higher levels of sunlight recommendation on basis of the standard.
- Add rooms in the building layout that receive sunlight to units that could benefit from it.
- Add new/larger windows to units where low levels of sunlight result from the simulation.

Further research can explore the influence of climate, day of analysis, and simulation parameters in the evaluations of Sunlight performance.

Different Climate Based Daylight metrics inform the design in different ways. DA suggest the design is performing well along the perimeter for all exposures. UDI would suggest that the North façade has the highest daylight potential and that the South façade performs below the threshold 50% of the time, between 40-50%. $UDI_{<100lux,>20\%}$ can be an indicator of the need for integrative artificial lighting in the design.

ASE appears to be more detailed in representing differences due to orientation. However, UDI is the result of a single and easier simulation workflow. Since UDI_{up} results are comparable to ASE, further research could indicate its potential as a superseding metric of DA and ASE for standards and regulations.

The Daylight Factor method in EN 17037 would suggest the design does not meet the minimum level of performance in the standard. However, annual daylight metrics using occupied hours schedules or daylight hours indicate that the design is compliant. Relying solely on the Daylight Factor would suggest providing higher a Window-to-Wall ratio and light transmittance of glazing. Even in a Nordic climate with fewer sunshine hours, the Daylight Factor has a considerable difference in results from climate-based daylight metrics. Future studies can explore the influence of climate, shadings and their dynamic modelling in simulations.

New frameworks for Views take a holistic approach to a complex subject. However, fast and easy to use workflows are needed to increase adoption in by practitioners, going beyond traditional daylight performance and visual comfort studies. An overview of the three components of the "Quality Views" and a combined visualisation is recommended, to avoid bias from just one combined representation. A Spatial metric (% space) can inform the design. Having a myriad of real-world possibilities for "Views", further studies are needed to explore how this approach could be useful and to provide recommendation levels based on urban categories such as dense urban environments, low density, low-rise, high-rise, and suburban areas.

A critical review is needed to turn the results into actionable insights and avoid bias of metrics, and the identified limitations of metrics in this and previous studies. For example, is the condition of low-rises better in reality when it comes to views? The View quality depends on a wide range of real-world factors such as location, landmark or natural values, human preferences e.g., noise, privacy, thermal comfort, and something to gaze at.

Flexibility, adaptability and reuse of buildings is a topic of growing interest to transition towards a low carbon and circular built environment. During the pandemic, the nature of work changed, where more work could be done in-home settings. The following question arises. Is "daylight hours" better than the "occupied hours" method for annual daylight metrics if we are to think of new hybrid and flexible working hours, and adaptable buildings for the future?

Conclusions

New computational methods developed in line with the EN 17037 standard are proposed at both the urban and architectural scales to support the design process for sunlight provision, daylighting and quality views. Significant differences between current Climate Based Daylight metrics and both EN 17037 methods are presented, suggesting the need for a transition towards annual daylight simulations. The Quality Views on basis of the View Out method in EN 17037 is developed further with computational methods and results are presented for an early design case study in an urban context. The developed workflows can be currently performed in Rhino and Grasshopper. Visualizing colour-coded results in the 3D models is recommended to support an iterative and collaborative process. Simulations need not be performed in the end for building permit applications but for every design stage to make informed decisions. Parametric, computational and data-driven approaches have the potential to aid architects to explore the design with the performance and well-being evolving requirements in today's practice. ■

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References

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

Admission of Commercial Simulations for Energy Calculation and their Validation in Switzerland

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Introduction

Switzerland, as a non-EU country, is not obliged to implement Energy Performance of Buildings Directive of the European Union (EPBD). However, in order to eliminate technical trade impediments, the Swiss Association for Standardization (SNV) has been a full member of the European Center for Standardisation (CEN) for a long time. Therefore, the national implementation of European Standards, including those supporting the EPBD (EPB standards), is mandatory in Switzerland. For the construction sector, SNV has delegated all activities in respect of national and CEN standards to the Swiss Association of Engineers and Architects (SIA).

During the last decades of development of the EPB standards, SIA has been an active member of several of the relevant Technical Committees (TC's), including the participation of the author in CEN/TC 371 for the leadership and coordination of the work, responsible for the ventilation and cooling related part.

Standardisation and Energy Regulations

In Switzerland, the energy regulations are competence of the cantons, which leads essentially to 26 different energy regulations throughout the country. Although they have implemented a scheme for the coordination, the so called "sample cantonal energy regulations"

(MuKEn, [1]), this is only a recommendation for the cantons. It has a modular structure and includes one basic "mandatory" module and a collection of voluntary modules. The implementation in the different cantons is different depending on the specific legal basis. In some cases, law changes are necessary, which are discussed in cantonal parliaments and may be subject to referendums, in others decrees can e issued by the cantonal governments.

In the MuKEn and subsequently in the cantonal regulations, SIA standards are referenced wherever they find it suitable. Cantonal experts are also delegated in the SIA standardisation committees. However, not all intentions followed by the SIA are shared by the cantonal regulators. Also, the strategies and behaviour of the regulation bodies vary a lot.

Implementation of the CEN-EPB Standards

Although published already in 2017, the national implementation of the last generation of EPB standards in Switzerland has been completed only recently. The process of creating national elements and/or adopting national standards to comply with the European pendants is complicated and sometimes difficult, but has successfully been completed.

One key element of the implementation is the revised standard SIA 380:2022 "Basis for energy calculation of buildings", which refers to EN ISO 52000-1:2017 "Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures" and implements its basic method of energy balance and substantiates some national specifications. This standard also defines the use of monthly and hourly calculation methods. Whereas the monthly calculation is only admissible for heated only buildings or building parts, the hourly method is imposed for all other cases, but can be used for all buildings. It has to be noted that this is the standards view, not necessarily shared by the energy regulators (see above).

In parallel to the SIA 380 standard, a new standard for the hourly (dynamic) calculation has been developed, collecting all the information from different preceding standards or parts of them in one document and adapting it to the new CEN standards: SIA 380/2:2022 "Energy Calculations of Buildings – Dynamic Method for Determination of Needs, Power and Energy". It refers to a large extent to the CEN standards, but there is one essential deviation: it does not impose a specific method, but admits the use of any method and defines the requirements which these have to fulfil.

The CEN method as defined in the EPB standards is collected in a normative annex as the "standard calculation method". For the building part, this refers to EN ISO 52016-1:2017, with the exception of an own wall model [2] and a more detailed window/shading calculation [3]. For the technical building systems calculations is refers to the respective CEN Standards with only a few exceptions.

The Software Issue

For the first generation of EPB standards and their national implementations, an own software, providing an hourly calculation, had been developed and slowly found its acceptance both in the industry and with some of the regulation bodies: The "SIA TEC Tool". It was based on the EN ISO 13790:2008 and the technical system related standards.

The founding of an upgrade – essentially a new tool – to the new generation of standards turned out to be impossible. Furthermore, one of the initial reasons for an own software, i.e. the expected too small market for commercial tools proved to be wrong. Several other tools have evolved in the meantime.

In the industry, i.e. mainly in the HVAC design offices, there is a motion towards the use of building simulation software for the design (also supported by the increasing use of BIM, resulting in more precise design and respective investment costs). Therefore, these players also push for the use of their simulation tools for energy regulation compliance. In some cases, the regulators accept this, and consistently asked the standardisation body for a validation scheme rather than a new software.

The Validation Scheme

The most prominent condition for the acceptance of a calculation method in SIA 380/2 is to pass the required validation tests. These depend on the intended application of the respective method.

Therefore, a suite of 7 validation tests has been created. The intention of the tests is not only to show that the method provides acceptable results, but also that it covers the required processes of the respective area they cover.

Table 1 shows the matrix of the 7 tests and their embedding in the standards landscape. For the building envelope, international work has been executed for decades, and a part of this has penetrated the standards ▶

Table 1. *Test matrix.*

	Test	EPBD	Standards referenced	Object		
Nr	Verbal Characterisation	Module		Spatial	Technical	
					General	Specific
1	Basic building shell tests	M2-2	EN ISO 52016-1, chapter 7, table 27	Test cell EN ISO 52016-1, clause 7.2.2 (= ASHRAE 140)	--	
2	Type and control of solar protection	M2-8, M9-2	SIA 380/2:2022, clause 2.2.2.3; SIA 387/4:2017, clause 3.4.3	Like test 1, with adaptations (see last column)	--	Fabric screen and adjustable slat blinds
3	Lighting control	M2-7, M9-2	SIA 380/2:2022, clause 2.2.2.4; SIA 387/4:2017, clause 3.4.4	Like test 2	--	Specified lighting system
4	Single zone air conditioning system (air only)	M5-5, M5-6, M5-8	SN EN 16798-7, SN EN 16798-5-1	Example building, auditorium (no window), no heating/cooling emission system	Auditorium air conditioning system, air only	Single zone VAV system, CO_2 controlled; EN 16798-5-1: SYS_TYPE=SINGLE_ZONE; FAC_CTRL=DIRECT; Zone air temp. dependent supply air temp. control; heat recovery: flat plate; frost protection: bypass
5	Complex multi zone air conditioning system with heating coil, cooling coil and humidifier	M5-5, M5-6, M5-8	SN EN 16798-7, SN EN 16798-5-1	Example building, 1st + 2nd floor: 1 open space office, 2 meeting rooms 4 single offices 1 corner group office	Office air conditioning system	Multi-zone VAV system, CO_2 controlled; EN 16798-5-1: SYS_TYPE=MULTI_ZONE Outdoor air dependent supply air temp. control; Heat recovery: rotary heat exchanger
6	Staged ventilation system with pumped circuit heat recovery	M5-5, M5-6, M5-8	SN EN 16798-7, SN EN 16798-5-1	Example building, Restaurant and kitchen	Restaurant ventilation	3 stage air conditioning system; outdoor air dependent supply air temp. control; overflow from restaurant to kitchen (overpressure); heat recovery with pumped circuit, heating and cooling operation.
7	Heating and cooling emission, distribution, storage and generation	M3-5, M3-6, M3-7 M4-5, M4-6, M4-7, M3-8, M4-8	SN EN 16798-9 SN EN 15316-2, SN EN 15316-3, SN EN 15316-5, SN EN 16798-15 SIA 384/3 SN EN 16798-13	All zones from Tests 5 und 6, all ventilation systems from tests 4 to 6.	Cooling emission and distribution (Offices: chilled and heated ceilings, restaurant chilled ceilings) Heating emission and distribution Offices: chilled and heated ceilings, restaurant convectors) Cooling generation; heating generation; own electricity production (PV)	Distribution systems with water tank storage (techn. storage for operation time extension); heating and cooling generation: specific compression chiller/heat pump with dry heat rejection (acting as heat source in heating case); heating generation: bivalent with specific gas fired peak boiler; DHW use via given charging profile; distribution: simplified according to EN 16798-9, Tables 10 to 13:

		Technical systems area											Results		Remarks
		Ventilation			Cooling				Heating				Test	Diagnostic	
Variants	Numb. of Variants	Emission	Distribution	Generation	Emission	Distribution	Storage	Generation	Emission	Distribution	Storage	Generation			
													According to EN ISO 52016-1	--	
SIA 387/4, table 9	4												Solar heat gains; total solar transmission	Radiation on window pane; slat angle	Diagnostic cases for stepwise transfer from test 1: Climate Kloten New window Infiltration Utilisation SIA 2024 Fixed slat angles
SIA 387/4, table 10	12												Lighting energy	Transmitted daylight flow; daylight level on work pane	
	1	x		x	(x)				(x)				Volume flow rate; Supply air temperature; Zone air temperature; fan energy; heating coil energy; cooling coil energy	CO_2 concentration; zone operative temperature latent cooling coil energy	
FAN_CTRL: CONST_PRES / MIN_PRES; heat recovery: hygroscopic / non hygroscopic; humidifier: adiabatic / steam; combinations see sep. table	4	x	x	x	(x)				(x)				Volume flow rate; fan energy; heating coil energy; total cooling coil energy; latent cooling coil energy; total heat recovery; latent heat recovery; heat recovery auxiliary energy; humidification energy	Distribution and AHU leakage and heat losses; Supply air temp.; extract air temp. and humidity; CO_2 conc. (open space office); humidifier aux. energy	
	1	x	x	x	(x)				(x)				Volume flow rate; fan energy; heating coil energy; total cooling coil energy; total heat recovery (heating/cooling); heat recovery auxiliary energy	Latent cooling coil energy; supply air temp.; extract air temp.	
	1				x	x	x		x	x	x		Supplied electric energy for chiller; total extracted heat; auxiliary energy cooling generation; heat delivered from cooling generation to heating use; rejected heat; Supplied electric energy for heat pump; total supplied heat for heating and for DHW; Boiler energy use; auxiliary energy heating generation PV-generation	Electricity supplied from grid; self used PV electricity; exported PV electricity; Divers diagnosis parameters (temperatures, EER, COP)	Result can be seen as total building energy demand. Pre-calculated profiles for zone heating and cooling needs provided.

(ASHRAE 140 and especially EN ISO 52016-1). Therefore, little effort was put on this issue: reference to EN ISO 52016-1 is made, and these tests form test 1. For tests 2 and 3, the same "building" is used, however, a "localisation" suite of adjustments was introduced: local climate data, SIA standards building use data and contemporary glazing and infiltration. Test 2 then focuses on the solar heat gains through the window with two types of shading devices, one of them being blinds with adjustable slats and their control. Test 3 then is for the test of the different lighting control schemes in combination with the test 2 shading devices. The combinations are given in **Table 2**.

For tests 4 to 7, a synthetic example building has been defined (see **Figure 1**). This 3-storey building consists of several thermal zones with different uses and is tailored to the tests implemented on it. A text description as well as digital data such as DXF floor plans and an IFC model are provided.

Tests 4 to 6 all refer to different types of ventilation/air conditioning systems. This may be astonishing and suspect an unjustified emphasis on a specific topic. However, the variety of possible technical solutions in this area is very large, and specific issues wanted to be addressed in the 3 tests. For test 5, different combinations of settings are defined (**Table 3**).

Test 7, finally, is the collection of the energy supplied to and extracted from the ventilation systems from tests 4 to 6 and the thermal zones served by these, with the respective heating and cooling emission, distribution, storage and generation systems. Initially it was planned that this test would be based on the individual results from the candidate software. This was, however, given up to the benefit of pre-defined hourly profiles (originating from the EXCEL files), in order to minimise error propagation and enable the isolation of problems in the area really to be tested.

Also, the emission and distribution systems were simplified, due to their rather small impact, but also to the inability of different software packages to really detailed represent them. The focus is on the generation part, where the detailed technical information of a real heat pump, providing both heating and cooling service, was provided. The information, according to the component standards, especially EN 14825, is given, separately for heating and for cooling operation. So, it is left to the software user to decide how to implement the machine information, possibly by defining separate machines although in reality it is

Table 2. *Combinations for tests 2 and 3.*

Test		Solar protection type	Solar protection control type	Lighting control type
2A	3A	Fabric screen	–	1
	3B			2
	3C			3
	3D			4
	3E			5
	3F			6
2B	3G	Movable slat blinds	1	1
	3H		1	3
2C	3I		2	1
	3J		2	3
2D	3K		3	1
	3L		3	3

Table 3. *Combinations for test 5.*

Test	FAN-CTRL	Heat recovery	Humidifier
5A	MIN-PRES	hygroscopic	adiabatic
5B	CONST-PRES	hygroscopic	adiabatic
5C	CONST-PRES	non-hygroscopic	adiabatic
5D	CONST-PRES	non-hygroscopic	steam

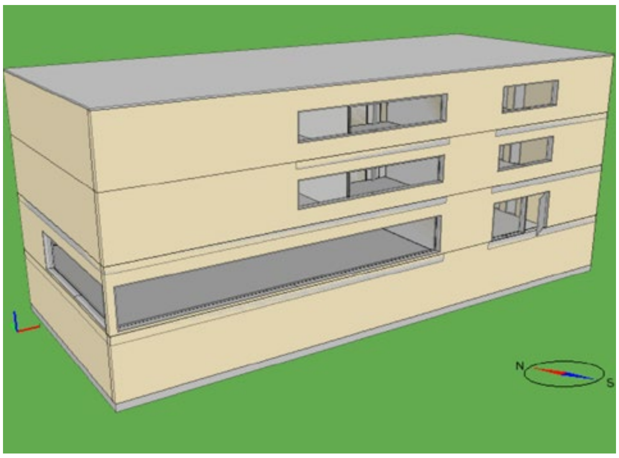

Figure 1. Isometric view of the example building.

only one. The key issue is to cover the cases where both services are provided at the same time. In order to be contemporary, the example building has also a PV production both on the roof and on the south façade (see **Figure 2**).

All 7 tests have been calculated with 4 different software packages: IDA-ICE (the market leader in Switzerland), Energy+, EDSL-TAS and the CEN and SIA spreadsheets. In respect of the latter, an own implementation of the EN ISO 52016-1, enriched with the necessary issues for the Swiss applications, was used for test 1. A special SIA test spreadsheet for the solar gain and lighting calculations was used for tests 2 and 3. For tests 4 to 6, the EN 16798-5-1 and -7 spreadsheets from EPB Center could be applied sequentially. For test 7, the spreadsheets to EN 16798-9 and -13 were applied again sequentially for the cooling part. For the heating part, again a slightly adopted EN 16798-9 spreadsheet was used rather than the one to EN 15316-1 (mostly for the reason of more familiarity to the user), combined with the EN 15316-4-2 spreadsheet for the heat pump. Some adaptions were made to some of these spreadsheets for data collection etc. This proved also the CEN spreadsheets to be fully applicable, and for many of the issues it turned out to generate reference results for the other software.

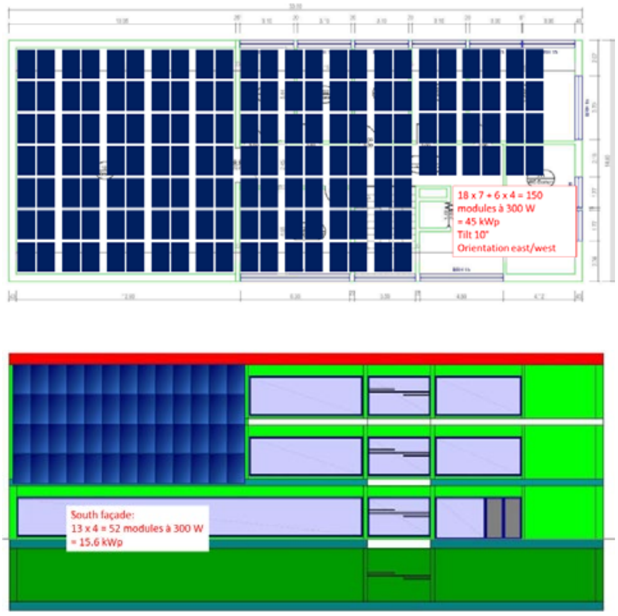

Figure 2. PV production layout on the roof and south façade of the example building.

The results of the 4 programs are used as reference results for the candidate programs. For each test, a specification (text description plus partly schematics in a pdf) an excel sheet is provided to fill in the results. This is protected, so only the parts for data entrance is accessible. The reference program results are used for the decision of "pass/fail" by two means: for the annual values, the average of the four +/- the max. difference of the reference program results defines the acceptable range. In a few cases, one of the reference programs has been excluded from this due to unacceptable deviations. For hourly results, graphical frequency distribution histograms are used, and the criterion is to be in the range of the four reference programs for all values (see **Figure 3** for an example).

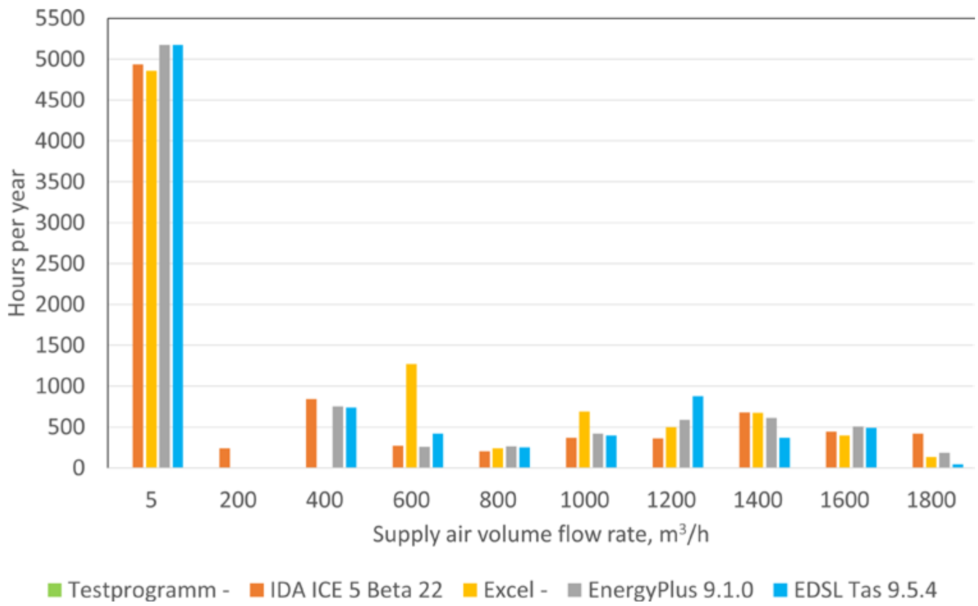

Figure 3. Example of a frequency distribution histogram of the supply volume flow rates of test 4. Note: There is a CO_2 control, except for EXCEL, which uses a work-around based on occupation.

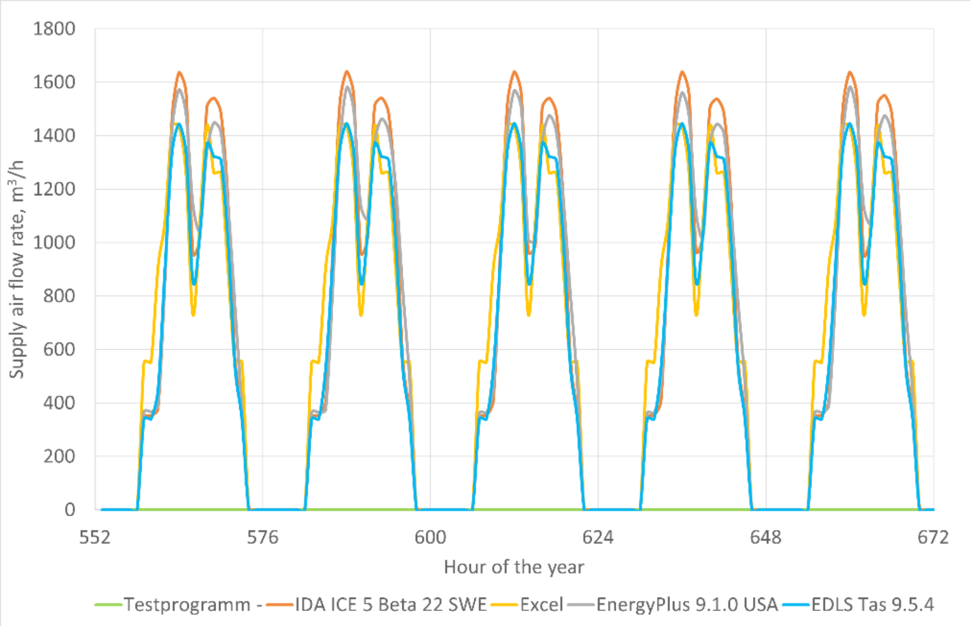

Figure 4. Example of a winter week plot of the supply volume flow rates of test 4. Note: This is only used for diagnosis purposes.

More reference results are shown in the data reporting and analysis sheets, which do not form part of the test criteria, but are given for diagnosis purposes. This includes frequency distributions, but also weekly plots for a winter and a summer week (see **Figure 4** for an example). No such course, however, is used as a test criterion (exception: test 1). For all four reference programs, "application reports" are also provided, where special issues for the implementation of the tests such as difficulties, special solutions and conscious deviations are reported.

Implementation

The document with the description of the test suite, the Technical Report SIA 4010 to the standard SIA 380/2, has been released for publication and will be published as per August 1. 2023. By that time, the tests will be "sharp", i.e. the specifications and the data reporting and analysis sheets will be published on the SIA home page. Several software vendors are already waiting for this moment. The documents for tests 1 to 6 are ready, the one for test 7 is still to be finished at the time of this report. Two reference programs still show unplausible results for some parts.

A technical panel will check the results, give feedback and also respond to questions during the test, where and FAQ document will result from. The test specifications have not been included in the TR SIA 4010 by intention, since from the experience with the reference programs, there might be modifications from further experience. ■

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A look back on building performance simulation

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This is a summary of my valedictory lecture 'Building Performance S(t)imulation' on April 21 2023 at Eindhoven University of Technology; video: https://youtu.be/aAG8EdVieH0 and booklet: https://research.tue.nl/en/publications/building-performance-stimulation

Keywords: EPB, Standards, Validation, Software, CEN, ISO

When I was a teenager, the Netherlands made a significant change in its energy source, switching from coal and city gas to natural gas. This switch led to an improvement of thermal comfort in homes, but it also resulted in higher fossil fuel consumption. However, concerns about the environment and need for energy savings soon arose, prompted by events like the 1973 energy crisis and the need to address climate change. These factors have motivated researchers and experts to focus on improving building performance and transitioning to renewable energy sources.

However, it's important to remember that energy use is just a means to achieve the real purpose of a building: to protect against external influences and provide a comfortable and healthy indoor environment. As awareness of health and well-being increases, there is a growing shift towards prioritizing indoor environmental quality rather than just energy-related performance.

The building sector faces various other challenges, such as involving multiple stakeholders, ensuring long-lasting and adaptable structures, and dealing with unique designs and construction processes. To overcome these challenges, innovative building solutions are required. These solutions need to be thoroughly analysed to understand how they can be optimized and integrated into existing or new buildings for long-term effectiveness.

The ultimate goal is to create sustainable built environments with zero-carbon emissions, where indoor environments are optimized for health, comfort, and productivity. Achieving this requires collaboration between different technical and non-technical disciplines.

From my perspective, building performance modelling and simulation can play a very efficient and effective role in this context [Hensen and Lamberts 2019].

Modelling involves creating simplified computer-based representations of real systems to focus on essential aspects of complex problems while excluding irrelevant details. Simulation, on the other hand, uses models to predict the behaviour of real systems in the future. Simulation is a powerful tool for analysis and understanding, although it does not directly generate solutions or answers.

Research and development of building performance simulation began in the 1960s, initially focusing on modelling and software features. However, attention has shifted towards improving the effectiveness of building performance simulation throughout the various stages of a building's life cycle. Let's introduce some applications we have been working on.

Building simulation allows to explore "wild" ideas such as dynamically adapting the thermal and optical properties of greenhouse covers based on weather and crop requirements. While it is not yet possible in the real world, simulations allow us to change these properties and evaluate their potential impact energy savings and increased crop growth.

Advances in material sciences offer opportunities for new building envelope technologies, such as vacuum insulation and phase change materials. Building performance simulation can help overcome challenges in the intermediate stages of research and development by providing insights into building integration issues and evaluating the performance of new materials. For example, smart energy glass is a technology that combines liquid crystalline materials with window integrated PV cells to create fast-switching, self-sufficient switchable glass. By regulating the amount of daylight and solar gains they transmit, absorb and reflect, these windows offer options for improving energy performance and comfort conditions.

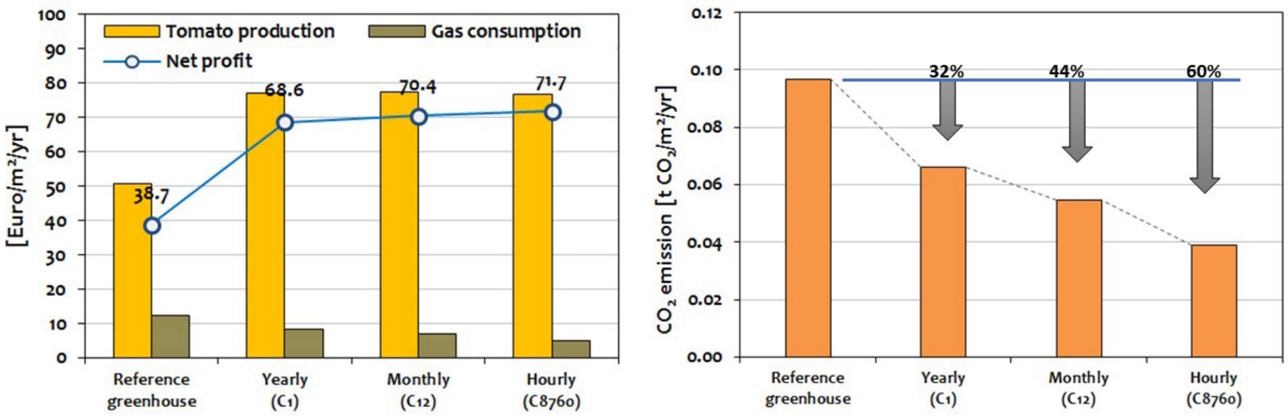

Figure 1. Predicted crop production, gas consumption and CO_2 emission for a generic reference greenhouse; one in which the optical and thermal properties are constant and optimized over the year for tomato production (C1) or where optical and thermal properties can change and are optimized per month (C12) or per hour (C8760). Costs and profit are based on 2015 prices. [Adapted from Lee et al. 2019]

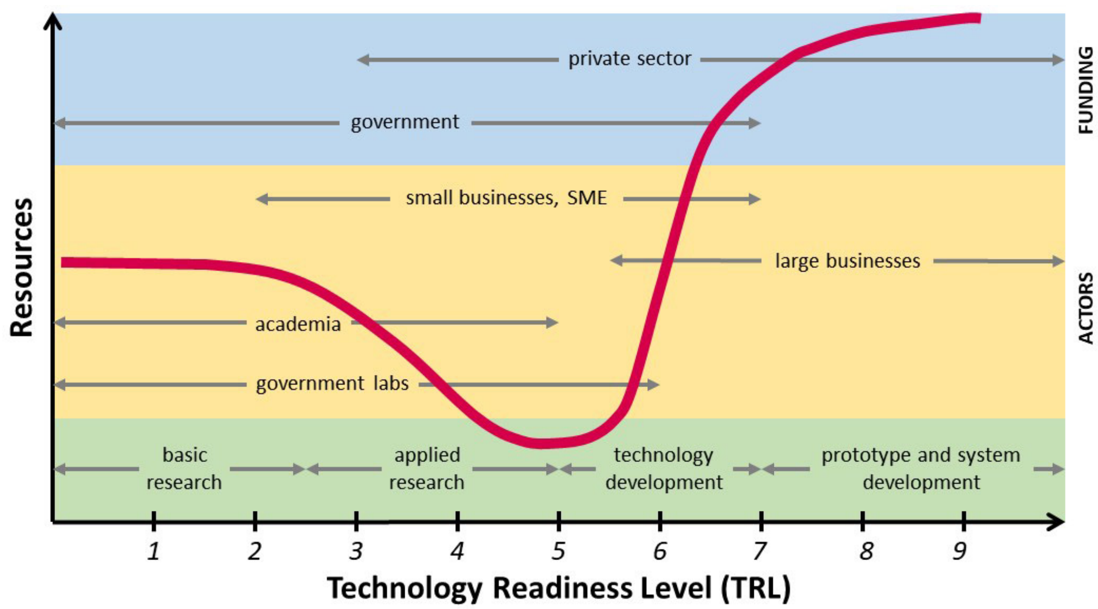

Figure 2. Availability of resources for new product development at various TRLs. Building simulation can help overcome the gap in the middle which is sometimes referred to as "The Valley of Death". [Loonen 2018]

In this case the use of simulations started during a very early R&D phase (TRL 2-3) when the technology was only available in the form of small-scale samples. We predicted whole-building performance in terms of comfort and energy saving potential under a range of operating conditions and building use scenarios. Based on this information, benchmarks were set and specific material-level development targets were outlined.

Building performance simulation is valuable when designers and engineers have doubts about certain (innovative) building design features. It can be used for risk analysis and optimization of mitigation measures. In that sense we have been involved in, for example, assessing the performance of double-skin facades, sizing appropriate air-conditioning systems for historical buildings, evaluating draft levels in underground train stations, and analysing indoor environments and condensation risks in unique structures like tropical zoo pavilions. Apart from risk analysis, the most common use in everyday practice is for checking compliance with building regulations.

A very interesting application is optimization under uncertainty, which is relevant in e.g. robust energy-efficient retrofitting of houses. Uncertainties in building operation and external factors such as occupant behaviour, climate change, energy prices, policy changes etc. impact future building performance, resulting in possible performance deviation during operation compared to the performance predicted in the design phase. The probability of occurrences of these uncertainties are usually unknown and, hence, scenarios are essential to assess the performance robustness of buildings. Therefore, a non-probabilistic scenario analysis, has been developed to identify robust designs. Maximum performance regret calculated using the minimax regret method is used as the measure of performance robustness. In this approach, the preferred robust design is based on optimal performance and performance robustness.

Consider the case of a 1992 single-family home that has to be converted to net zero-energy by adding extra insulation for demand reduction and PV panels for energy generation. The investment cost will depend on the insulation level and the number of PV panels.

The preferred solution depends on the viewpoint of the stakeholders. Assuming that home owners are very likely most interested in investment and operation costs, they would probably prefer the solution with not so much extra insulation but with a rather large number of PV panels. The government, however, is committed to putting CO_2 emission reduction policies in place. From the results it is clear that the solution with more insulation would be more effective in that context.

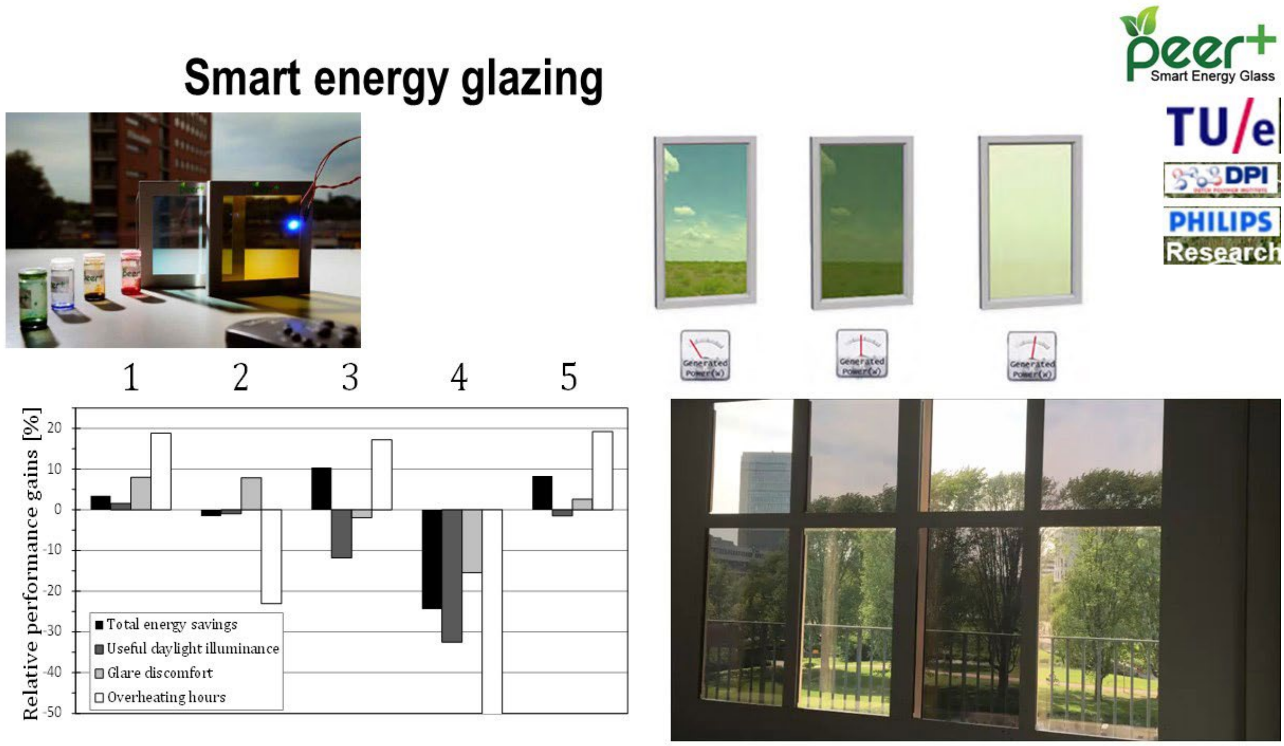

Figure 3. Smart energy glazing performance. Options 1-5 represent different control strategies. [Adapted from Loonen et al. 2014]

Building simulation is also very useful for supporting post-construction activities. By integrating computational and physical processes, cyber-physical systems enable testing and optimization of control strategies without disrupting real-world operations. Further development of this approach could lead to the creation of digital twins, which combine physical systems with digital copies to forecast the behaviour of real products in real time.

When it comes to optimizing building energy, there are significant differences between the design phase and the operational phase. Design choices can greatly impact predicted energy use, with a wide range of potential outcomes. Modifying a building after completion is challenging, whereas updating building energy management software is relatively easier.

During the design phase, we have to consider a vast range of design options, uncertain future conditions, and long-time horizons. Since new innovative solutions lack performance data, we rely on deterministic modelling approaches based on physics rather than data-driven methods.

Once a building is constructed and operational, real performance data becomes available. This data can be used for data-driven modelling and other artificial intelligence-based modelling and simulation approaches. The time horizon of interest is much shorter than during design (think of hours and days rather than decades). Use and boundary conditions are "known". Therefore, deviations between forecasted and real energy use are likely to be attributable to system faults or non-optimal operation. Hence, typical applications are fault detection and diagnostics, smart maintenance and control optimization.

Quality assurance is crucial for simulation-based decisions. The quality of simulation results depends in the first place on the correctness of the model and the input parameters; in other words, are the predicted numbers correct? Most of the time they are not, which results in the so-called performance gap. This difference

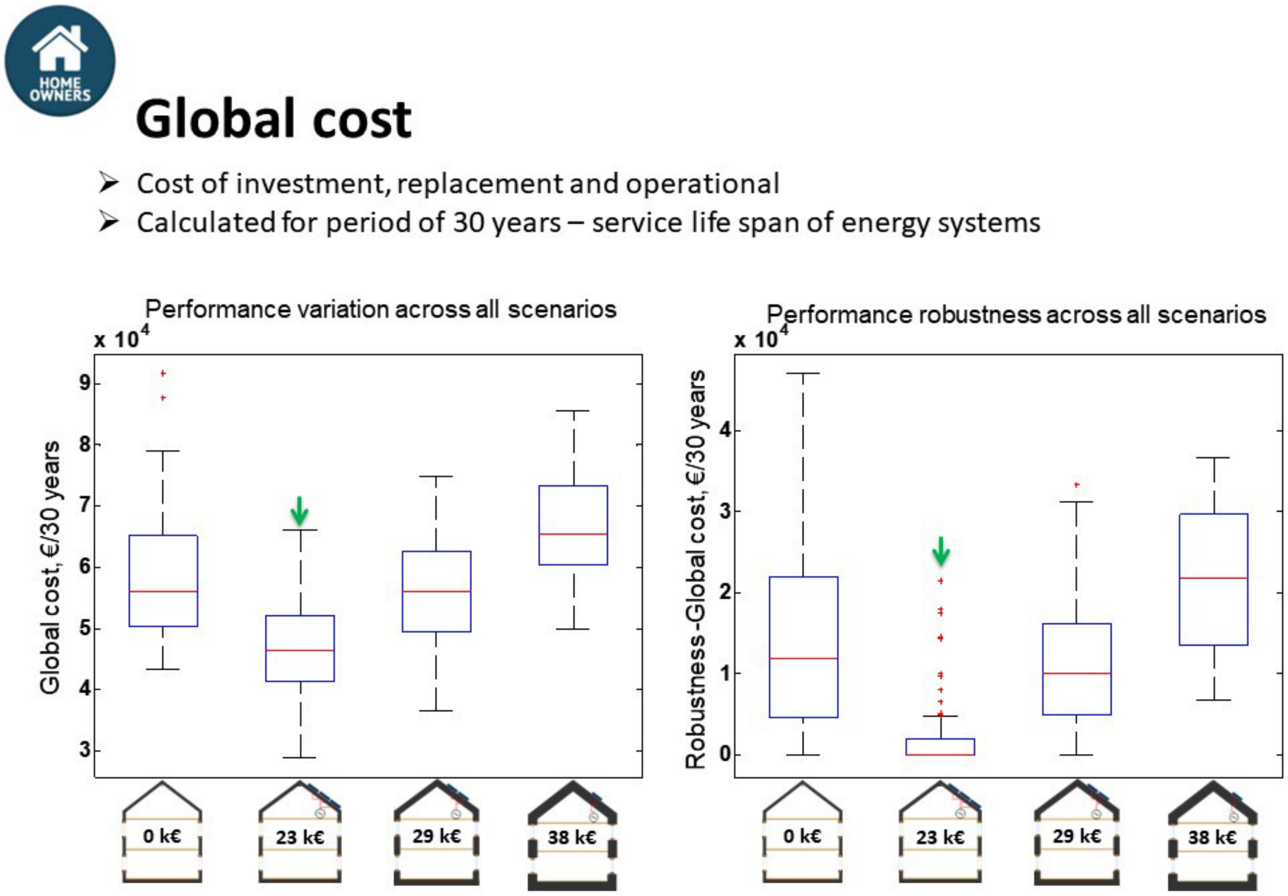

Figure 4. Predicted global cost for different renovation packages aiming at annual net zero-energy for a 1992 house assuming a wide range of occupant behaviour and climate change scenarios. The right-hand graph shows robustness in terms of regret (= performance difference between the solution considered and the best performing solution for a particular scenario). [Adapted from Kotireddy et al. 2018]

between predicted and real measured energy performance is caused by issues during the design phase (e.g. model limitations, input parameter assumptions); the construction and commissioning phase (e.g. construction flaws, differences between assumed and actual materials, components and systems); and the operation phase (e.g. systems not working properly and/or differences between assumed and actual building usage).

Energy label calculations mostly ignore these uncertainties. Labels are not meant to indicate future energy use and, therefore, should not be interpreted as such.

Since building energy simulation is now at the level where incorporation of uncertainty and sensitivity analysis is feasible, the results should always be presented with uncertainty ranges and preferably with sensitivity analysis outcomes as well.

The quality assurance of results for simulation-based decisions depends on much more than only the physical correctness of the model. The quality of the end result (i.e. the results to be communicated to decision makers) can only be "assured" when it is based on quality assurance during every step of a simulation study. This begins with the relevance and accuracy of the problem formulation.

The examples illustrated above are really based on different problems communicated by different stakeholders. Therefore, they need to be approached differently. It is not even always the best approach to use modelling and simulation – sometimes the problem can be solved by common sense or it would be better to use physical experiments.

It is crucial to start with validation, verification and testing in this initial phase and continue with it throughout the full life cycle of a simulation study. The procedures for doing this are known from other research fields (e.g. operations research) but they are not often used in our field. Since we have been teaching this to our students for many years now, it is hopefully only a matter of time before they become common practice.

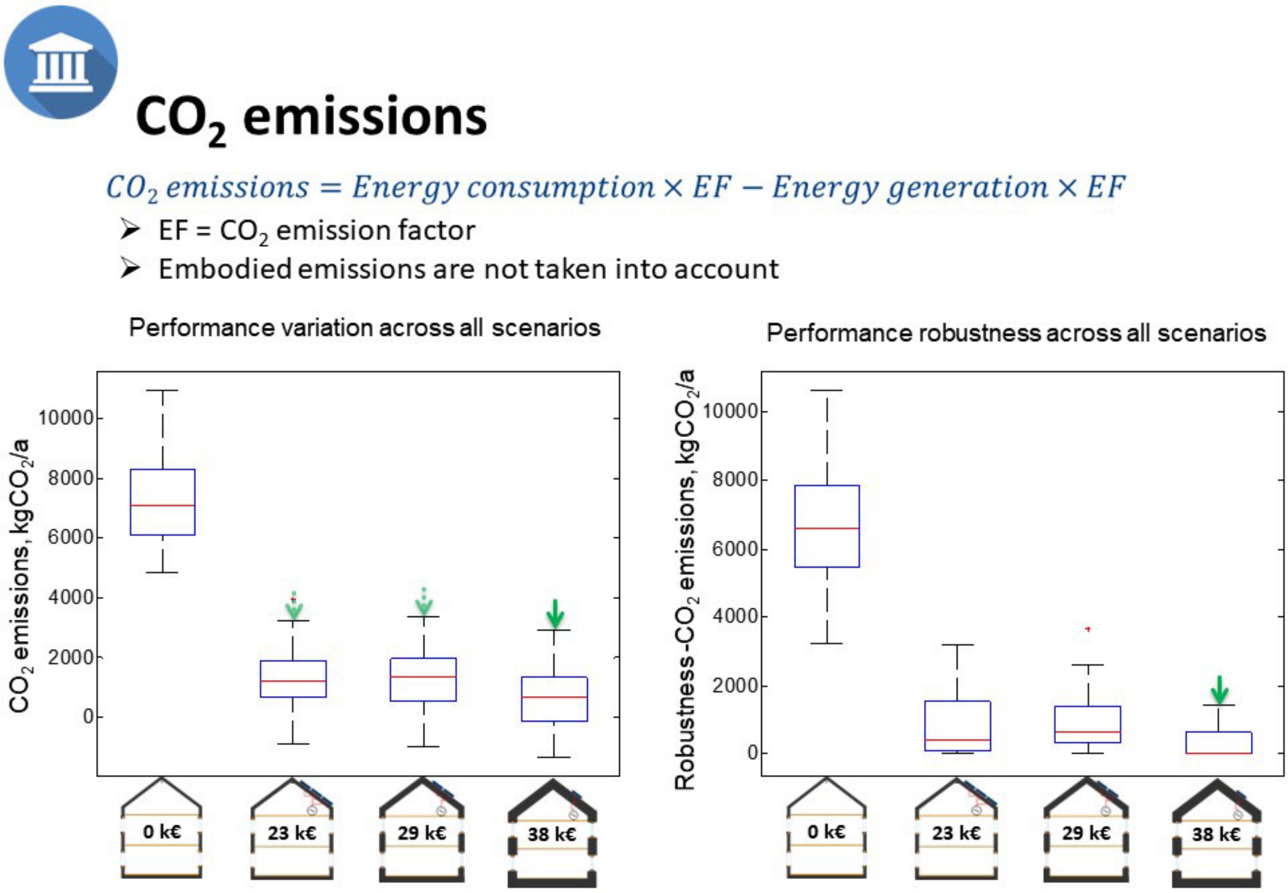

Figure 5. Predicted CO_2 emission for different renovation packages aiming at annual net zero-energy for a 1992 house assuming a wide range of occupant behaviour and climate change scenarios. The right-hand graph shows robustness in terms of regret (= performance difference between the solution considered and the best performing solution for a particular scenario). [Adapted from Kotireddy et al. 2018]

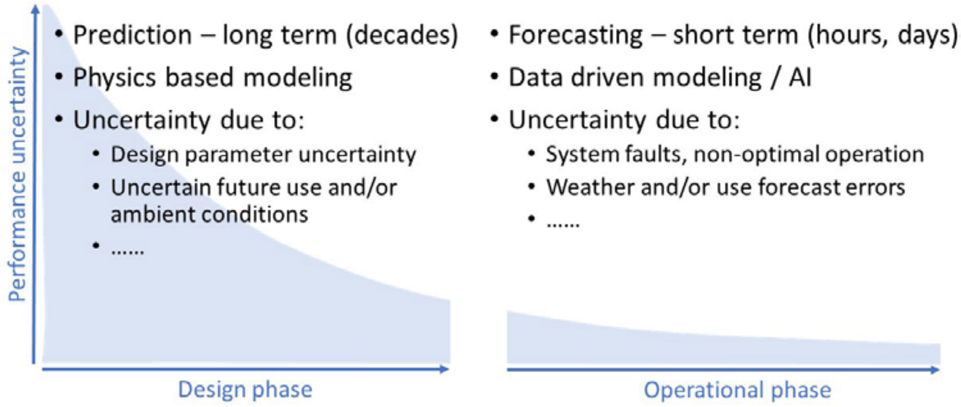

Figure 6. Main differences in performance uncertainty emanating from simulations in the design or operational phase of a building.

Thorough domain knowledge is paramount for assuring the quality of simulation results and conclusions. Nowadays, modelling and simulation are taught from the early education stages onwards. Therefore, our simulation courses and student projects can focus on specific building performance modelling and simulation skills along with knowledge about principles, assumptions, limitations, when to use and when not.

The ability to identify valid information from incorrect information is a very important skill to have. Credibility as a professional, hinges on the accuracy of the information they will use. Thus, learning how to assure the quality of simulation results is an overarching goal and very important, because poor quality or wrong information may have severe consequences for the built environment and human well-being.

The challenges faced by the built environment require intelligent individuals armed with appropriate knowledge and smart approaches. Building performance simulation is a vital tool in our pursuit of better buildings. I hope to have conveyed the significance of this field and the potential it holds for creating sustainable and efficient structures. ■

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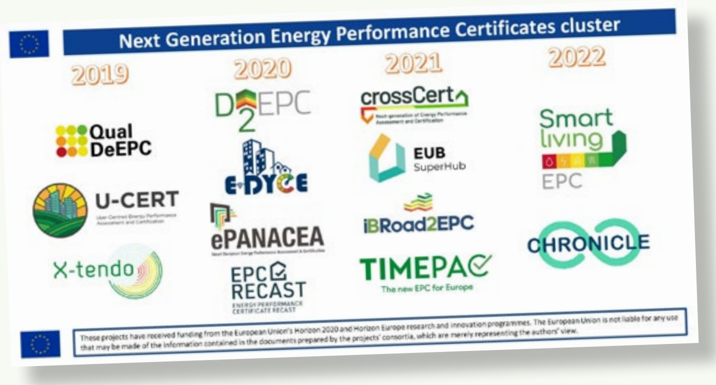
IEQ is in the scope of the EPBD

EPB experts' opinion
EPB Center & the Next Gen EPC cluster[1]

This opinion document is formulated for supporting the EPBD Recast Trialogue, keeping in mind the linchpin role of the CEN/ISO set of EPB standards in the transposition, implementation & monitoring of EPBD in EU's Member States

1. In a nutshell

- From the **technology neutral perspective of the CEN/ISO set of EPB (Energy Performance of Buildings)** the following reasons support the explicit inclusion of Indoor Environmental Quality (IEQ) in the EPBD:
- **Holistic Approach to Building Performance**: The EPB standards aim to provide a comprehensive framework for assessing and improving the energy performance of buildings. However, energy performance cannot be evaluated in isolation. Including IEQ requirements within the EPB standards would enable a more holistic approach to building performance, acknowledging the interdependence of energy efficiency, occupant comfort, and well-being.
- **Occupant-Centric Performance Evaluation**: The EPB standards currently focus primarily on technical aspects such as energy consumption and CO_2 emissions. By integrating IEQ requirements, the EPB standards would shift the focus towards occupant-centric performance evaluation. This would ensure that the indoor environment supports the needs, health, and well-being of building occupants, creating comfortable and healthy living and working spaces.
- **Performance Verification and Compliance**: The EPB standards provide a framework for verifying and assessing the compliance of buildings with energy performance requirements. By including IEQ requirements, the EPBD would establish criteria for evaluating and ensuring compliance with indoor environmental quality standards. This would enable better monitoring, enforcement, and accountability for building performance in terms of both energy efficiency and occupant well-being.
- **Synergies with Energy Efficiency Measures**: IEQ requirements and energy efficiency measures are mutually beneficial. Incorporating IEQ requirements in the EPB standards would enhance the



IEQ is in the scope of the EPBD – 4 July 2023 – EPB Center & Next Gen EPC cluster

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synergy between energy efficiency and indoor environmental quality. For example, optimizing ventilation systems can improve indoor air quality while reducing energy consumption. By integrating these requirements, the EPBD would promote integrated solutions that maximize energy efficiency while maintaining a healthy indoor environment.

- **Standardization and Harmonization**: Including IEQ requirements in the EPB standards would foster standardization and harmonization across the European Union. By establishing common guidelines and benchmarks for IEQ, the EPBD would facilitate consistency in building practices and regulations. This would improve the comparability of building performance across Member States and promote the exchange of best practices and knowledge-sharing.
- **Improved Data Collection and Performance Feedback**: Integrating IEQ requirements within the EPB standards would necessitate the collection of relevant data and information on indoor environmental parameters. This data can provide valuable insights into building performance and occupant satisfaction. By including IEQ in the EPBD, it would create a feedback loop for continuous improvement, allowing policymakers, designers, and building managers to optimize both energy performance and occupant comfort over time.
- **International Alignment and Collaboration**: The inclusion of IEQ requirements in the EPBD would push EU standards ahead of international initiatives and collaborations focused on indoor environmental quality. By harmonizing the global frameworks and exchanging knowledge and expertise, the European Union can contribute to the development of international best practices in assessing and improving IEQ.

2. Article 11a

The inclusion of Article 11a in the Energy Performance of Buildings Directive (EPBD) establishes a vital framework for the applicability and methodology of calculating Indoor Environmental Quality (IEQ) standards. By integrating this article, the importance of IEQ can effectively be addressed and healthy indoor climate within buildings can be promoted.

- **Integration of IEQ in EPBD**: The latest versions of the EPBD recast, including those endorsed by the EU Council, have already recognized the significance of IEQ and its association with healthy indoor conditions. The directive emphasizes the requirement for non-residential zero-emission buildings to be equipped with measuring and control devices to monitor and regulate indoor air quality. Furthermore, it encourages the installation of such devices in existing buildings during major renovations, where technically and economically feasible. The EPBD also highlights the need to optimize health, indoor air quality, and comfort levels defined by Member States when calculating energy needs and energy use. Supporting energy performance upgrades of existing buildings that contribute to achieving a healthy indoor environment is also encouraged.
- **Existing BACS Requirements**: The latest versions of the EPBD already include provisions for the installation of Building Automation and Control Systems (BACS) in both non-residential and residential buildings. These systems encompass IEQ sensors, further underlining the importance of monitoring and maintaining optimal indoor environmental conditions.
- **Energy Savings through IEQ Monitoring**: Implementing IEQ monitoring offers significant energy-saving opportunities. By actively controlling air exchange rates and avoiding the maldistribution of ventilation air, energy consumption can be optimized. Incorporating IEQ standards and monitoring devices ensures that energy efficiency measures are aligned with providing a healthy indoor environment.
- **IEQ Parameters for Energy Performance Calculations**: Defining specific requirements for IEQ parameters, as outlined in standards such as EN 16798-1, becomes essential for accurate energy performance calculations and system design. By incorporating these parameters into the methodology framework, the EPBD can provide comprehensive guidelines for achieving energy efficiency while safeguarding IEQ.

In conclusion, the inclusion of Article 11a in the EPBD signifies a crucial step towards recognizing

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and enhancing IEQ standards. By acknowledging the importance of IEQ, promoting monitoring and control systems, and incorporating specific parameters into energy performance calculations, the EPBD ensures the harmonious integration of energy efficiency and a healthy indoor environment.

3. Evidence-base from EU funded projects

3.1. ALDREN

The ALDREN project conducted a comprehensive analysis on the impact of renovation and non-energy benefits on market value. One of the key aspects explored in the study was the enhancement of Indoor Environmental Quality (IEQ) and its direct influence on market value, as well as its role in driving private sector engagement in renovation activities. Improved IEQ, encompassing health and well-being considerations, emerged as a vital component.

It is widely recognized that better IEQ significantly increases market value and serves as a compelling motivator for the private sector to invest in renovation projects. Therefore, it is crucial to incorporate IEQ indicators into energy renovation efforts and ensure their inclusion in Energy Performance Certificates (EPCs).

- The ALDREN project proposed a cost-effective thermal comfort score, derived from hourly energy calculations and the project also recommended the adoption of the TAIL (Thermal, Acoustic, Indoor air quality, Lighting) [**2**] approach, which involves dedicated measurements or simulations of various IEQ parameters tailored to specific cases, that should be incorporated into the standard EN 16798-1 and be considered as an output on par with the calculated energy requirements in EN ISO 52016-1.
- In the near future, a demonstration output of the IEQ score will be made accessible through the EN ISO 52016-1 spreadsheet, further emphasizing the significance of incorporating IEQ assessment alongside energy calculations.

The minimum IEQ level holds significant importance as an input parameter in assessing energy performance, both in terms of calculated and measured energy. Consequently, IEQ must be explicitly mentioned in the EPBD Recast.

- It is essential to always have knowledge of and report IEQ parameters connected with energy, such as thermal comfort, air exchange-carbon dioxide levels, daylighting, external acoustic levels, and pollution (which is considered for example in energy calculations in France).
- Without comprehensive information of the IEQ aspects, comparability of calculated values becomes challenging, and reliance on measured energy should be approached with caution.

Investigating and reporting IEQ alongside energy performance serves multiple purposes:

- Firstly, it allows for an assessment of whether improved energy efficiency ratings have been achieved at the expense of IEQ deterioration, for example, in buildings lacking cooling systems.
- Furthermore, it provides visibility to exemplary designs that utilize passive solutions and contribute to building climate change resilience.
- Reporting IEQ also helps prevent the risk of post-renovation IEQ deterioration due to factors like decreased air exchange rates or compromised solar factors.
- Lastly, it ensures the appropriate utilization of financial instruments and Minimum Energy Performance Standards (MEPS). It guards against misleading energy savings claims resulting from underheated or overheated buildings, where fictitious energy savings are reported due to a reduced IEQ level.
- **Above all**, in the context of calculating energy requirements for heating, cooling linked to indoor temperatures (as outlined in EN ISO 52016-1), a critical consideration is the need to assess whether improved energy ratings are attained without compromising Indoor Environmental Quality (IEQ). This is particularly pertinent in cases where cooling systems are absent, as it is crucial to ensure that enhancing energy efficiency does not result in a decline in IEQ standards.

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In summary, integrating IEQ into energy performance assessments is essential. It not only addresses the potential trade-offs between energy efficiency and IEQ but also showcases sustainable design practices, safeguards against post-renovation IEQ deterioration, and ensures the accuracy of financial instruments and MEPS. By embracing the consideration of IEQ alongside energy performance, holistic and responsible building practices are promoted that prioritize both energy efficiency and occupant well-being.

3.2. CHRONICLE

Energy performance of buildings and indoor environmental quality (IEQ) have significant co-benefits that merit addressing them simultaneously. Improved IEQ directly impacts occupants' health, comfort, and productivity. Parameters such as temperature, humidity, ventilation rates, and air quality play a vital role in creating a healthy and comfortable indoor environment.

Integrating energy performance and IEQ measures can result in long-term cost savings at building operation and renovation phases of existing buildings. By considering these factors together, we can create spaces that prioritize our health, well-being, and environmental sustainability through reductions in GHG emissions. Energy-efficient systems and practices can help to reduce energy consumption and operational costs, while optimized IEQ can potentially decrease healthcare expenses associated with poor indoor air quality. Energy efficiency measures, such as those related to heating, cooling and ventilation, may have direct

influence the comfort and IEQ of housing. Thus, addressing IEQ at a renovation phase is paramount to ensure healthy indoor conditions.

Increased innovation in the field of digitalization and digital monitoring of building performance as well as improved building automation systems will contribute to developing cost effective ways for assessing, monitoring and operating building performance both in energy efficiency as well as IEQ."

3.3. X-tendo

Although IEQ is essential, it is not yet covered by EPCs. However, there are methods ready to be applied to also assess, document and highlight IEQ in EPCs and thus communicate the co-benefit of IEQ.

Adequate levels of indoor air quality (IAQ), thermal comfort, lighting and acoustics in buildings are among the most important benefits and drivers especially for renovation, as they lead to improved health and comfort of the occupants. However, they are not currently covered by EPCs: this indicator allows to assess the levels of comfort in terms of Indoor Environmental Quality for a given building through reliable and evidence-based inputs.

X-tendo develops an assessment approach for calculation of Asset and Operational comfort rating, that is tested in buildings, and consists of a simplified checklist of systems and materials, measurements of temperature, relative humidity and CO_2-concentrations and survey of occupants' perception on aspects such as thermal comfort, indoor air quality, visual comfort and acoustics.

See: https://x-tendo.eu/toolboxes/comfort/.

3.4. crossCert

It has less to do with technical arguments, but an argument could be that indoor air quality as an indicator can be connected to the Indicator "Population Living in dwelling with presence of leak, damp and rot".

This indicator refers to the consequences of poor construction practices of dwellings and humid indoor conditions and can also be a consequence of an inability to keep the house adequately warm. Studying these two indicators together may provide a more complete picture of buildings where owners / tenants face energy poverty.

More on this: https://indicator.energypoverty.eu/modules/custom/epah_inidcator_frontend/pdfs/EPAH_Energy_Poverty_Indicators_Report_20221128.pdf#page=61

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Indoor air quality is a subject that has been receiving attention for some time in France:

- The National Commitment to the Environment Act of 12 July 2010 introduced the obligation to periodically monitor indoor air quality in certain establishments open to the public (ERP) where sensitive populations are present or exposed for long periods.
- Following feedback on the implementation of this monitoring since 2018, a review of the regulatory system has been undertaken as part of the 4th National Environmental Health Plan (PNSE 4).
- This revision also considers feedback from the health crisis linked to the SARS-CoV2 pandemic. This health crisis highlighted the importance of implementing an environmental strategy to control air quality in all public buildings. Controlling the rate of air renewal in premises by measuring CO_2-concentration has become a major challenge, as it helps to dilute and eliminate indoor pollutants, including airborne infectious agents. Furthermore, it has been scientifically established that an increase in CO_2 concentration is associated with a reduction in the cognitive performance of the occupants of the premises.

Here[3] is a link to the article listing the decrees and orders governing indoor air quality in France in buildings open to the public where sensitive populations are present or exposed for long periods.

3.5. U-CERT

U-CERT project had at heart the people, during its implementation activities. As the main takeaway message, having IEQ information in the EPC is relevant for building tenants and owners as it promotes health and well-being, enhances productivity, optimizes energy efficiency, ensures legal compliance, fosters transparency and accountability, and provides market differentiation. By considering IEQ alongside energy performance, tenants and owners can make more informed decisions and contribute to creating healthier and more sustainable built environments.

- **Health and Well-being**: IEQ factors, such as air quality, thermal comfort, lighting, and acoustics, significantly impact the health and well-being of occupants. By including IEQ information in the EPC, tenants and owners gain valuable insights into the indoor conditions of a building. This enables them to make informed decisions regarding the suitability of the space for occupancy and take necessary measures to improve the environment if needed.
- **Productivity and Performance**: Numerous studies have shown that a healthy and comfortable indoor environment has a direct positive impact on occupant productivity, cognitive function, and overall performance. By incorporating IEQ information in the EPC, tenants can identify spaces that promote productivity, while owners can showcase the quality of their buildings, attracting potential tenants and increasing occupancy rates.
- **Energy Efficiency Optimization**: IEQ and energy efficiency are closely interrelated. Including IEQ information in the EPC allows tenants and owners to understand the relationship between energy performance and indoor environment. This knowledge facilitates the optimization of energy consumption while ensuring a healthy and comfortable indoor setting. It encourages the adoption of energy-efficient technologies and practices that contribute to reduced energy bills, lower carbon emissions, and increased sustainability.
- **Legal Compliance**: Many jurisdictions and building standards are increasingly recognizing the importance of IEQ and its impact on occupants. Including IEQ information in the EPC aligns with legal requirements and regulations related to building performance and occupant health. It ensures compliance with existing guidelines, codes, and certifications, promoting responsible building practices and the well-being of occupants.
- **Transparency and Accountability**: Incorporating IEQ information in the EPC enhances transparency and accountability in the real estate market. Tenants gain access to comprehensive data on the indoor environment before committing to a lease, enabling them to make informed decisions. Owners, on the other hand, are motivated to maintain and improve the IEQ of their buildings to attract and retain tenants, thereby promoting responsible building management.

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- **Market Differentiation**: In today's competitive real estate market, including IEQ information in the EPC can provide a significant advantage to both tenants and owners. Tenants seeking healthy, comfortable, and productive spaces can easily identify buildings that prioritize IEQ, while owners can differentiate their properties by showcasing their commitment to providing high-quality indoor environments. This differentiation can lead to increased property value, tenant satisfaction, and a positive brand image.

More details can be found in the following deliverables of U-CERT project:

- D2.3 Report on users' perception on EPC scheme in U-CERT partner countries [4]
- D2.4 Building performance indicators based on measured data for holistic EPCs [5]
- D3.2 Proposed set of user-centred and effective overall and partial indicators, including SRI [6]
- U-CERT Certificate ■

Endnotes

[1] The following projects are part of the Next Gen EPC cluster: U-CERT (GA N. 839937), X-tendo (GA N. 845958), QualDeEPC (GA N.847100), ePANACEA (GA N.892421), D^2EPC (GA N.892984), EPC RECAST (GA N.893118), E-DYCE (GA N.893945), crossCert (GA N.101033778), EUB SuperHub (GA N.101033916), iBRoad2EPC (GA N.101033781),TIMEPAC (GA N.101033819), CHRONICLE (GA N. 101069722) and SmartLivingEPC (GA N.101069639). These projects have received funding from the European Union's Horizon 2020 and Horizon Europe research and innovation programmes. The European Union is not liable for any use that may be made of the information contained in the documents prepared by the projects' consortia, which are merely representing the authors' view.

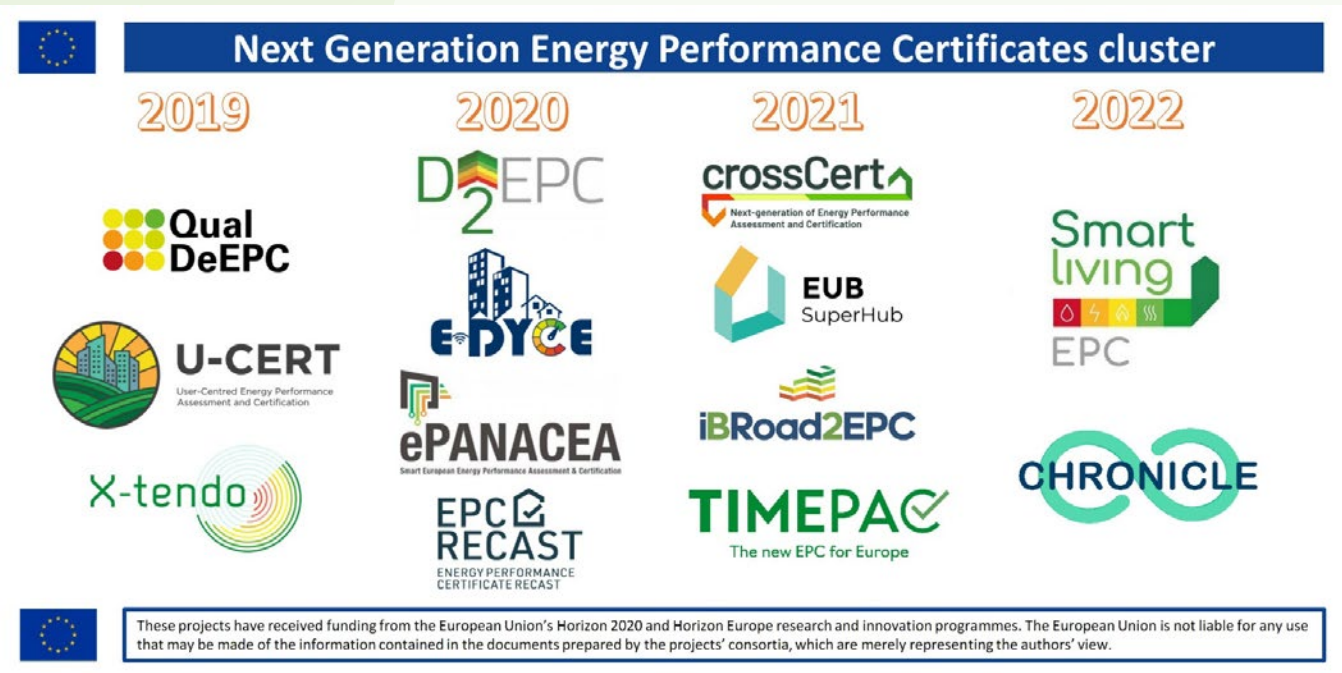
[2] https://www.rehva.eu/rehva-journal/chapter/tail-and-predictail-the-tools-for-rating-and-predicting-the-indoor-environmental-quality-in-buildings

[3] https://sante.gouv.fr/sante-et-environnement/batiments/article/surveillance-de-la-qualite-de-l-air-interieur-dans-les-etablissements-recevant

[4] https://u-certproject.eu/proceedings/epcertificates-people/

[5] https://u-certproject.eu/proceedings/indicators/

[6] https://u-certproject.eu/proceedings/u-cert-certificate-calculated-measured-indicators/



IEQ is in the scope of the EPBD – 4 July 2023 – EPB Center & Next Gen EPC cluster

Europe wins the HVAC World Student Competition!

Bas Turk (second on the right in the picture), the winner of the REHVA student competition, has triumphed once again by securing first place in the HVAC World Student Competition. Turk's exceptional work titled "Quantifying the potential of overheating countermeasures on a humanitarian shelter through measurements and building performance simulation" made a strong impression at the ASHRAE Annual Conference in Tampa, Florida.

Turk's journey began with his victory in the national competition organized by TVVL, the Dutch association for building services engineers. This success propelled him to the European level of the REHVA student competition, where his innovative research and dedication earned him the title in May, in Brussels.

Turk's research focused on addressing overheating issues in humanitarian shelters, an increasingly urgent concern due to climate change. Through meticulous measurements and building performance simulations, he quantified the potential impact of various countermeasures.

We would like to thank Eurovent Certita Certification for sponsoring this competition! Their support underscores their commitment to promoting excellence and recognizing exceptional achievements in the field. Through their sponsorship, Eurovent Certita Certification contributes to the development and advancement of the HVAC industry by encouraging talented individuals like Bas Turk to push boundaries and drive innovation in the field. ■

Proposed modifications and guidelines for implementation of Article 11a 'Indoor environmental quality' in EPBD draft

REHVA, Nordic Ventilation Group and EUROVENT launch common proposal on how to implement Indoor Environmental Quality (IEQ) requirements introduced by EPBD under revision. These new provisions added by the Commission's and Parliament's initiative, represent an important step forward to assure healthy and comfortable IEQ in buildings.

In this document, IEQ substance and requirements are explained just on few pages. It is shown which items need regulatory effort and which aspects can be left for technical guidance documents such as European standards or national technical guidance. Guidelines and examples are presented how an essential IEQ requirements can be implemented on national level. Also, some minor, but important changes are suggested to make Article 11a implementation technically and economically feasible.

Read the paper: https://www.rehva.eu/fileadmin/user_upload/2023/EPBD_IEQ_Guidance.pdf

Why IEQ is intrinsic to the EPBD

While the EPBD primarily focuses on reducing energy consumption and greenhouse gas emissions, it is crucial to highlight the significance of including Indoor Environmental Quality (IEQ) within its scope. IEQ refers to the conditions inside a building that affect occupants' health, comfort, and productivity.

Why IEQ should be considered an essential component of the EPBD?

- **Human Health and Well-being**: Buildings are where people spend a significant portion of their time, and poor indoor environmental conditions can have a detrimental impact on their health and well-being. Factors such as indoor air quality, thermal comfort, lighting, and acoustics directly influence occupants' physical health, productivity, cognitive abilities, and overall comfort. By including IEQ standards in the EPBD, policymakers can prioritize creating healthier indoor environments that promote well-being and reduce health risks.
- **Occupant Productivity**: Numerous studies have shown that improving IEQ can lead to increased occupant productivity and performance. Optimal indoor air quality, comfortable temperatures, appropriate lighting, and reduced noise levels positively affect cognitive abilities, concentration, focus, and overall job satisfaction.
- **Energy Efficiency and Building Performance**: Energy efficiency and IEQ are interconnected. Energy-efficient measures, such as better insulation, airtightness, and advanced HVAC systems, can improve both energy performance and IEQ. By integrating IEQ requirements into the EPBD, policymakers can ensure that energy-efficient measures are implemented in a manner that maintains or enhances indoor environmental conditions.
- **Sustainability and Long-Term Benefits**: Including IEQ within the EPBD promotes a more holistic and sustainable approach to building design, construction, and operation. By considering factors beyond energy consumption, such

as indoor air quality, thermal comfort, lighting comfort and acoustics, buildings can deliver long-term benefits in terms of occupant satisfaction, reduced sick leave, increased property value, and enhanced reputation.
- **Legal Compliance and Market Transformation**: Integrating IEQ into the EPBD ensures that building regulations and standards keep pace with evolving societal expectations and scientific knowledge. It sets a legal framework that obliges stakeholders to prioritize IEQ in building projects. By doing so, the EPBD can act as a catalyst for market transformation, encouraging innovation, research, and the development of new technologies and materials that improve both energy efficiency and IEQ.

In conclusion, incorporating IEQ within the scope of the EPBD is of utmost importance. By considering the indoor environmental conditions of buildings, policymakers can ensure that energy efficiency efforts go hand in hand with the well-being, productivity, and health of building occupants. The inclusion of IEQ enhances the overall effectiveness and long-term sustainability of the EPBD, contributing to healthier, more comfortable, and energy-efficient buildings throughout the European Union.

IEQ and EPB

The main function of buildings is to provide shelter from external environment. How well this is done (meaning the level of indoor environmental quality: especially in terms of indoor air quality, thermal comfort and lighting comfort), directly affects the energy performance of a building. If the building envelope is not specially design to address the IEQ issues:

- The better the air quality is inside a building the more energy is needed for indoor air replacement with outdoor air.
- Healthy and comfortable temperature ranges (with productivity and learning performance benefits) also need more heating and cooling energy than wider and uncomfortable temperature ranges (with less productivity and decreased learning performance).
- Daylighting use to increase the photobiological comfort may induce higher energy needs both for heating and cooling.

The level of IEQ has a direct impact on the energy performance of a building and it can be as high as a couple of energy performance classes (in the EPC).

- This alone makes it evident that the energy performance of a building cannot be specified without specifying at the same time the IEQ.
- In the situation of establishing a minimum standard for IEQ, cost-benefit analyses will make it salient and justified how far the IEQ should be improved depending on the building category e.g. calculated:
  - through increased productivity in workplace,
  - improved learning performance in schools,
  - reduced DALY**1** in residential buildings.

LEVEL(s)

The EU has established LEVEL(s) as the European framework for sustainable buildings [**2**], providing IEQ indicators in User Manual 3, under Macro-Objective 4: Healthy and comfortable spaces, where indicators 4.1 to 4.4 can be found for IAQ, thermal comfort, lighting and acoustics.

- Therefore, it is essential that IEQ indicators specified in LEVEL(s) are followed in the EPBD Recast, addressed in the amendment by the EP on Article 11a stating that national requirements shall be set according to measurable indicators based on those included in the LEVEL(s) framework.
- More specifically, regarding to numeric values, LEVEL(s) indicators 4.1[**3**] and 4.2[**4**] (IAQ and thermal comfort) refer to EN 16798-1:2019 standard (set of CEN/ISO EPB standards[**5**]) which uses Categories I to IV to describe IEQ level. For daylight in buildings, LEVEL(s) 4.3 refers to EN 17037:2018 specifying parameters which are categorised as Minimum, Medium and High.

This approach provides national flexibility, following the EU's principle of subsidiarity, to select suitable performance levels depending on local conditions and climate, by following one of specified categories. For instance, by following the normal level of Category II values specified in EN 16798-1:2019, will not only ensure avoiding adverse health effects but also improve comfort and well-being of occupants clearly above the minimum acceptable level.

Energy performance implications of IEQ indicators

Regarding the energy implications, the most essential IEQ indicators are related to IAQ and thermal comfort, but also lighting comfort and acoustic performance can have an important impact. In other words, to conduct meaningful energy calculation, target values for IEQ parameters shall be available.

Indoor Air Quality (IAQ)

IAQ deals with control of indoor air pollution that originates from both indoor and outdoor sources, and from the interaction of pollutants and oxidants from both of these [**6**].

- Indoor sources are building materials or cleaning products emitting volatile organic compounds [**7**,] and respiratory effluents and body odours emitted by humans themselves, but also emissions from combustion, cooking, products with fragrances and resuspending floor dust [**8**].
- Good IAQ requires controlling of indoor emission sources and concurrently reducing the entry of outdoor pollutants indoors which can be done by filtering of outdoor air pollutants and reducing infiltration.

To do this, the following minimum requirements are to be established to control IAQ:

- Source control must be applied for pollution sources from building materials and interior design through the use of low polluting building materials as defined in EN 16798-1:2019,
- Ventilation rates to maintain an acceptable level of pollutants in the indoor environment are to be specified according to EN 16798-1:2019 classification,
- To control particulate matter, ventilation with filters is one way of meeting the requirements in areas where the WHO limits [**9**] for outdoor air are exceeded. For non-residential buildings filters are specified in EN 16798-3. If no ventilation with filters is used, other measures need to be considered.

Thermal comfort

IEQ parameters for thermal comfort are specified in EN 16798-1:2019 standard. These include parameters for general thermal comfort and local thermal discomfort (draught, radiant temperature asymmetry, floor temperatures, vertical air temperature differences).

The minimum requirements in the regulation shall include at least room temperature [**10**] ranges for sedentary activities. Requirements may be split between non-residential and residential buildings where higher adaptation is possible.

Lighting comfort

While minimum requirements for visual comfort are established at the consensual level in the EN 12464-1:2021 according to the required visual task, the use of daylight as much as possible respect to artificial lighting has two positive effects: energy saving for lighting and increased photobiological comfort. EN 15193-1:2017 defines the methods for estimating the amount of energy required for lighting in buildings taking into account the effect of daylighting and introducing the daylight availability classes (none, low, medium, strong). EN 17037:2018 extends the concept to recommended minimum daylighting levels split in three classes (minimum, medium, and high). The minimum requirements in the regulation shall include a minimum daylighting level.

Further guidance and REHVA's commitment

Further guidance about how IEQ provisions can be straightforwardly implemented in national regulation is provided in the common IEQ guidance document co-prepared by REHVA, Nordic Ventilation Group and EUROVENT: Proposed modifications and guidelines for implementation of Article 11a 'Indoor environmental quality' in EPBD Recast [11].

REHVA fully supports transparent energy performance definitions including IEQ specification as currently proposed in Article 11a.

- We see that the current approach provided in Article 11a is straightforward to implement in national regulation with reasonable effort.
- It will avoid manipulation in energy calculations and energy performance certificates and will ensure that energy calculations and energy performance certificates would be realistic and will correspond to expected energy use in real operation that would support achievement of EPBD energy saving targets.

REHVA, as building professionals' organisation, remains committed to provide unconditioned and technology neutral support during the EPBD Recast Trialogue and the subsequent EPBD Recast transposition and implementation in the EU's Member States. ■

Endnotes

[1] https://www.who.int/data/gho/indicator-metadata-registry/imr-details/158

[2] https://environment.ec.europa.eu/topics/circular-economy/levels_en

[3] Dodd N., Donatello S. & Cordella.M., 2021. Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[4] Dodd N., Donatello S., & Cordella M., 2021. Level(s) indicator 4.2: Time outside of thermal comfort range user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[5] https://epb.center/epb-standards/

[6] Weschler, C. Chemistry in indoor environments: 20 years of research. Indoor Air 2011;21:205-218

[7] Harrison, P.; Crump, D.; Kephalopoulos, S.; Yu, C.; Däumling, C.; Rousselle, C. Harmonised regulation and labelling of product emissions–a new initiative by the european commission. Indoor and Built Environment 2011;20:581-583

[8] Qian, J.; Peccia, J.; Ferro, A.R. Walking-induced particle resuspension in indoor environments. Atmospheric Environment 2014;89:464-481

[9] WHO Global Air Quality Guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. Geneva, Europe; 2021c

[10] In EN 16798-1:2019 room temperature is specified as operative temperature that is calculated based on air temperature, mean radiant temperature and air velocity. In new and deeply renovated buildings, the operative temperature is almost equal to the air temperature.

[11] https://www.rehva.eu/fileadmin/user_upload/2023/EPBD_IEQ_Guidance.pdf

REHVA Brussels Summit

Join us in Brussels to discuss "Indoor Environmental Quality, Digitalization and Skills in the Decarbonization of Buildings" during the Brussels Summit 2023 (November 13-14).

Day 1: REHVA Standing Committee Meeting (13th November)

The first day of the Summit will focus on the internal activities of REHVA. During the Standing Committee Meeting, members will gather to discuss and address key issues and initiatives related to our organisation. This session provides an opportunity for REHVA members to actively engage in shaping the organization's agenda and strategies. The first day will end with a REHVA Reception and Dinner at the Thon Hotel.

Day 2: Policy Conference (14th November)

The second day of the Summit will feature the yearly Policy Conference. All policy instruments enabling and facilitating the clean energy transition in the building sector are falling into place in 2023 at EU level with the adoption of the Energy Efficiency Directive (EED), the Renewable Energy Directive (RED) and the Energy Performance of Buildings Directive (EPBD) as core elements of the 'fit for 55' package (designed to realise the EU Green Deal and more recently also REPowerEU).

The journey to bring the buildings related EU policy instruments to practice on the ground doesn't end here. The EU's Member States (MSs) need to adequately transpose, implement, enforce and monitor them while fostering and ensuring their practical application by skilled building professionals.

Furthermore **2023 is the European Year of Skills,** meant to promote upskilling and reskilling opportunities and EU funding possibilities, to support take-up, implementation and delivery on the ground. Without any coincidence, the EU Green Deal Industrial Plan presented in February 2023 has as third pillar "enhancing skills", at all levels and for all people, with inclusiveness of women and youth at the heart of the Plan.

Against this backdrop the session organizers, targeting foremost policy makers and at large the building sector stakeholders, drawn together some of the key institutional, professional, and business actors to foster EU-national coordination, at the fastest pace possible, for bridging the gap 'available-needed' professionals, with an emphasis also on Indoor Environmental Quality (IEQ) and Digitalisation:

- Policy and financing instruments as linchpin for the skills framework.
- Education, training, upskilling and reskilling.
- Best practices for designing effective training programmes.

The timing is nothing short of ideal for the EU level professional associations and their national member associations to step up and play a twofold game changing role for EU-national coordination:

- Support the adequate transposition of the EED, RED and EPBD in the EU's MSs while also future proofing the feasibility for practical implementation within the specific national contexts.
- Bridge the skilled building professionals' gap in collaboration with the national authorities, financing institutions and all concerned stakeholders of the building sector.

The day will end with a session held by MODERATE: Workshop with building professionals & EPB Expert (TBD).

This event is free of charge; however, **registration is mandatory**. Please take note that cancellation is also required. Fees might apply is you fail to cancel your registration at least 5 days prior to the conference. For any questions or cancellation requests, email info@rehva.eu.

Check out the DRAFT AGENDA

CIBSE TM68 Monitoring indoor environmental quality: A starter guide for building professionals

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VOLKAN DODA
Atelier Ten London Limited

The CIBSE Technical Memorandum 68 (TM68) on Monitoring Indoor Environmental Quality (CIBSE, 2022) provides building professionals with a primer on continuous IEQ monitoring by presenting a wholistic picture that includes delineating units and performance metrics, available instruments and sensors, practical sampling consideration and case studies for four principal IEQ aspects. Best practice for collecting and using data gathered from sensors and meters in and around buildings are suggested.

Keywords: Indoor environmental quality, IEQ sensors, Thermal comfort, Air quality, Luminous quality, Acoustic quality

1. Introduction

Europeans spend approximately 90% of their time indoors for work, study and living (EVIA, 2022), while nearly 40% of global energy demand is attributed to building sector (UNEP, 2022). The quality of living, health, productivity, and satisfaction of building occupants are generally correlated to the Indoor Environmental Quality (IEQ), which encapsulates four major environmental conditions, namely, thermal comfort, air quality, luminous quality, and acoustic quality (CIBSE, 2015). The average loss of human life expectancy due to particulate pollution alone is estimated to be 2.2 years (AQLI, 2022). Office users can be benefited from interventions in their working environment, in return for their enhanced health, comfort and productivity (Felgueiras et al., 2022). In the post-pandemic era, provision of good IEQ in indoor premises whilst minimizing energy consumption is vital for a return to normal life without sacrificing wellbeing and climate change aversion measures. This is where CIBSE's new TM68 fills a competence gap by equipping practitioners with guidance on the selection and implementation of tools and methods that can assist with improving thermal comfort, air quality, luminous quality, acoustic quality whilst supporting improvements in energy performance. The next section presents an overview for each of these aspects and they are summarized in **Figure 1to 4** for ease of reference.

2. Overview of IEQ monitoring considerations highlighted in TM68

2.1 Thermal comfort

Thermal comfort is defined as the *"condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation"* (ASHRAE, 2021). Thermal comfort is influenced by physical parameters listed in **Figure 1**, for example, air temperature, radiant temperature, air velocity and relative humidity, which can be measured and monitored by various sensors. Personal parameters, including metabolic rate and clothing insulation, are not directly measured and they can be referenced from guidelines and standards instead. The effect of the above factors on thermal comfort can be quantitatively evaluated by different performance metrics for naturally and mechanically ventilated buildings. Common instruments and sensors used for continuous monitoring are temperature probes, humidity probes and occupancy sensors. In addition to selecting appropriate sensors, several sampling issues should be considered. Frequency and granularity of data collection should be informed by the investigated variables and project specific requirements. Instruments should preferably be small to capture distinctive indoor climatic parameters and they should be mounted one meter away from the walls. Furthermore, capturing parameters for several consecutive summers can enable the investigation of longitudinal trends and the effect of year-to-year weather variations while a monitoring protocol should also be developed to define the function and location of sensors in various spaces.

2.2 Air quality

The inhalation of airborne pollutants in our environment can result in adverse health impacts, such as respiratory and cardiovascular diseases. Most of these pollutants are relevant to the concept of indoor air quality (IAQ). An acceptable IAQ can refer to "*air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction"* (ASHRAE, 2022). Common pollutants include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X) and volatile

<table>
<tr><th rowspan="2">Performance Metrics / Categories</th><th rowspan="2">Unit</th><th rowspan="2">Measurement Range</th><th rowspan="2">Accuracy Characterization</th><th colspan="2">Sampling Consideration</th><th rowspan="2">Commonly Used Instrument</th><th rowspan="2">Calibration</th></tr>
<tr><th>(General)</th><th>(Parameter Specified)</th></tr>
<tr><td rowspan="8">Mechanical Conditioned: PMV and PPD (ASHRAE Standard 55)

OR

Naturally Conditioned: Adaptive Model (CIBSE TM52/59, ASHRAE Standard 55)</td><td>Air Temperature, T_a [°C]</td><td>10 - 40°C</td><td>±0.2°C (Air)
±0.5°C (Draught)</td><td rowspan="6">• Define "Monitoring protocol" – capture representatives' environment
• Frequency: depend on the variable being investigated
• Able to capture periods of typical weather, ideally consecutive years
• Early monitoring may not be representative
• Parallel OA measurements</td><td>• Mean of 3 levels
- Ankle: 0.1 m
- Waist: 0.6 m / 1.1 m
- Head: 1.1 m / 1.7 m (Seated/Standing)
• Average from 3 to 15 mins
• Start when t > 1.5 Probe's response time</td><td>Thermometer</td><td>Temperature-controlled environments (hot baths, furnaces, 'dry-block' calibrators, …)</td></tr>
<tr><td>Mean Radiant Temperature, T_r [°C]</td><td>10 - 40°C</td><td>±1°C</td><td>20 - 30 mins response time</td><td>Black Globe Thermometer</td><td>N/A</td></tr>
<tr><td>Air Velocity, V_a [m/s]</td><td>0.05 – 2 m/s</td><td>±0.05°C (Air)
±0.05(1+V_a)°C (Draught)</td><td>N/A</td><td>Hot-sphere Anemometer (or Draught Probe)</td><td>Wind tunnels or wheels every 6 months</td></tr>
<tr><td>Relative Humidity, RH [%]</td><td>25 - 95%</td><td>±5%</td><td>Measured at centre height</td><td>Capacitive Humidity Sensor</td><td>Fixed-point humidity system</td></tr>
<tr><td>Occupancy</td><td>Up to 12 m (>130°)</td><td>Up to 98%</td><td>N/A</td><td>Passive Infrared</td><td>Not required</td></tr>
<tr><td>Operative Temperature, T_o [°C]</td><td colspan="2">N/A</td><td>• Measured at 0.6 m (seated) or 1.1 m (standing)
• H-value weighted average of T_a and T_r</td><td colspan="2">N/A</td></tr>
<tr><td>Metabolic Rate, M [met]</td><td colspan="6">Refer to Guidance and Tables in CIBSE Guide A, BS EN ISO 8996-2004, ASHRAE Standard 55-2020</td></tr>
<tr><td>Clothing Insulation, C [clo]</td><td colspan="6">Refer to Guidance and Tables in CIBSE Guide A, BS EN ISO 9920-2007, ASHRAE Standard 55-2020</td></tr>
</table>

Figure 1. Summary of Thermal Comfort in CIBSE TM68 Indoor Environmental Quality Monitoring (CIBSE, 2022).

organic compounds (VOC) as tabulated in **Figure 2**. Measurement of their concentration for IAQ assessments and monitoring in accordance with health-based guidelines requires different well-calibrated sensors and instruments. Particularly, CO_2 and total VOC (tVOC) are proxies used in the evaluation of ventilation and air quality. Short-term (less than one hour) and long-term (few days to few weeks) aggregated sampling can be used to assess the acute and chronic health risks respectively. In terms of sampling considerations, the recommendations are similar to those considered for thermal comfort. However, measurements in winter should be recorded with care as higher ambient pollutant concentration and lower ventilation rate during the heating season often result in the "worst case' conditions.

2.3 Luminous quality

The quality of the indoor luminous environment is generally monitored by the illuminance and luminance of the illuminated space. As there is no single definition of good luminous quality, it should be assessed by considering the light sources, use of building and other factors. The assessment of indoor luminous quality frequently emphasizes identification of sources of visual discomfort (or glare) and sufficiency of available light, in other words, whether the spot or average horizontal illuminance is sufficient to perform a specific task. **Figure 3** suggest common instruments shown as luxmeters and luminance sensors, which should be calibrated with reference to the angle of incidence and the photopic V(λ) curve for human eye sensitivity. For

Performance Metrics / Categories	Unit	Measurement Range	Accuracy Characterization	Sampling Consideration	Commonly Used Instrument	Calibration
Pollutant / Chemical Concentration	C [μg/m³], [ppm] or [ppb]	Refer to WHO Methods for Sampling and Analysis of Chemical Pollutants in Indoor Air 2020 and ISO 16000 Series	• No single classification system • Uncertainty estimates (Discontinuous sample): ±10 – 20 % • Compliance Checking - CO: ±15% - PM_x: ±25% - O_3 and NO_x: ±15%	• Measure at centre of representative rooms (5-10% of total space) - >1 m to any wall - 1-1.5 m above floor - OA measurement at the same story level - Avoid position near FA intake • Frequency - Short-term Aggregated: <60 mins - Long-term Aggregated: Few days to a number of weeks - Continuous/Real-time: Few hours to many months - At least 1 period in both heating and non-heating season	Miscellaneous	• Caution with software calibration • Co-locate sensor with accurate reference sensor • Review "raw" data for signs of drift or change in accuracy
Proxies of Air Quality	Carbon Dioxide (CO_2)					
	Total Volatile Organic Compound (TVOCs)					
	Condensation / Visible Mold					
Health-based Guideline	(Maximum concentration threshold averaged over a specified time period)	Refer to Table 9.1 and Figure 9.5 of CIBSE TM40 Health and Wellbeing in Building Services				

Figure 2. Summary of Air Quality in CIBSE TM68 Indoor Environmental Quality Monitoring (CIBSE, 2022).

Performance Metrics / Categories	Unit	Measurement Range	Accuracy Characterization	Sampling Consideration	Commonly Used Instrument	Calibration
Lighting Sufficiency: (1) Average Horizontal Illuminance (2) Daylight Factor or (3) Climate-based Daylight Modelling (CBDM) **Visual Discomfort:** Unified Glare Rating (UGR)	Luminous Intensity, I [cd]	Refer to CIBSE SLL Lighting Handbook 2018	N/A	• Minims the positions and FOV of a building occupant • Group position receiving similar light level • Time step = 10 – 15 mins or shorter • Weather resistant and able to record high outdoor illuminance values	N/A	
	Luminous Flux, Φ [lm]					
	Illuminance, E [lx]		Calibrate against the photopic V(λ) curve – Human eye sensitivity		Luxmeter	Standard lamp on the optical bench
	Luminance, L [cd/m²]				Luminance Meters or High Dynamic Range (HDR) Imaging	Laboratory reflectance tile
	Correlated Colour Temperature, CCT [°K]		N/A		N/A	
	Colour Rendering Index, CRI [-]					

Figure 3. Summary of Luminous Quality in CIBSE TM68 Indoor Environmental Quality Monitoring (CIBSE, 2022).

continuous monitoring, the lower price of luxmeters using illuminance sensors makes them more attractive than the luminance-based systems. The sensors should be located to mimic the field of view and eye level height of the space occupants. A typical measurement frequency in the range of 10 to 15 minutes is recommended, but this should also be informed by the time and weather conditions. Parallel outdoor measurements should be conducted in close proximity to the investigated indoor spaces. These outdoor sensors should be weather-resilient and able to capture high illuminance readings due to potential exposure to direct sunlight.

2.4 Acoustic quality

Acoustics quality of indoor spaces is assessed by room acoustics, sound insulation and sound level, in which the latter one dynamically reflects the indoor acoustic environment. It can be evaluated on the basis of acoustic criteria, users and purposes of the concerned spaces. Continuous sound level monitoring generally adopts the A-weighted equivalent continuous sound level over a defined period of time. Collection of 15-minute A-weighted equivalent sound level is recommended to capture temporal characteristic, based on which the 10th and 90th percentiles reveal the background noise levels. However, 1-to-2-minutes sampling is also advised for spaces with shorter functional time units, for example, a one-hour university lecture. The captured data can be aggregated over a day, week, or month for longitudinal analyses. Sound level meters (SLM) and low-cost acoustic sensor networks are commonly used to measure the sound level in the audible range of 20 to 20,000 Hz. The tolerance level of class 2 SLM can be referred to **Figure 4**. Meters and sensors should be located to capture the noise exposure of the representative users in the investigated space. Symmetric positioning or mounting of sensors less than 1 m away from sound-reflecting surfaces should be avoided.

3. Non-technical considerations of IEQ monitoring systems

Design, operation, and management of IEQ monitoring systems involves further non-technical considerations over the lifecycle of the system. **Figure 5** illustrates the overall decision-making process for selecting a continuous measurement system, which is similar to conventional engineering project workflow. Stakeholders of the project should establish realistic goals and expectations through communication with beneficiaries and delineating responsibilities among them. For example, combinations of required IEQ parameters, measurement locations and resolutions could be consolidated into a "wish-list", which facilitates the onward economic appraisal and vendor involvement. Ethical and privacy concerns should be addressed by complying with the relevant standards on data protection or equivalent regulation of the corresponding jurisdiction. A robust data management plan should cover essential elements including consent, transfer, storage, limiting usage and deletion of data. Risk assessment developed in consultation with cyber security specialists is also recommended to undergo scheduled test and review. For successful implementation, data-informed outcomes related to human wellbeing should place equal importance to both technical and non-technical considerations listed above.

Performance Metrics / Categories	Unit	Measurement Range	Accuracy Characterization	Sampling Consideration	Commonly Used Instrument	Calibration
Statics: Room Acoustics and Sound Insulation **Dynamic:** Sound Level	A-weighted equivalent continuous sound level over period T, $L_{Aeq,T}$ [dBA]	20 – 20,000 Hz audible range	Tolerance level (dB) for Class 2 SLM - 16 Hz: -∞, +5.5 - 20 Hz: ±3.5 - 1 kHz: ±1.4 - 10 kHz: -∞, +5.5 - 16 kHz: -∞, +6.0	• Provide noise exposure of the average user(s) • Distance between sensor and the nearest reflecting surfacing > 1 m • Avoid symmetric positioning • Frequency - Short Interval: $L_{Aeq,2min}$, $L_{Aeq,5min}$ - Long/Temporal Interval: $L_{Aeq,15min}$	Sound Level Meters (SLM) or Acoustic Sensor Network	Speaker-white noise generator (Fernandez-Prieto et al., 2020)

Figure 4. Summary of Acoustic Quality in CIBSE TM68 Indoor Environmental Quality Monitoring (CIBSE, 2022).

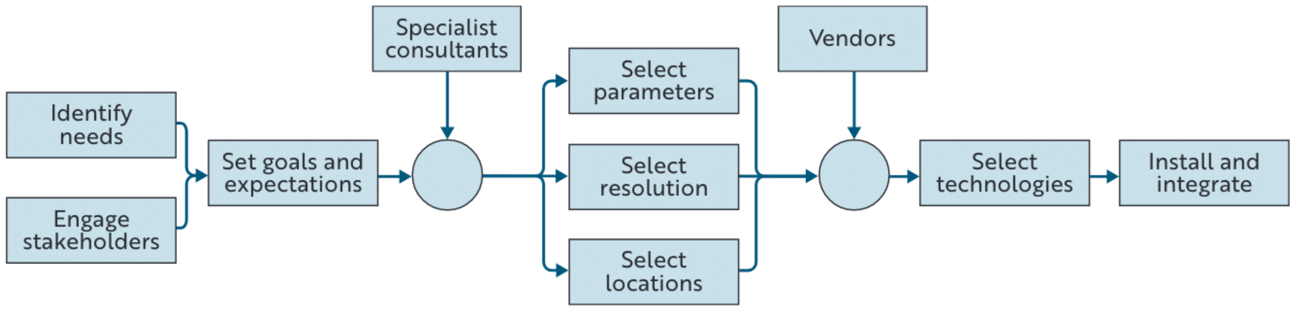

Figure 5. The decision-making process for selecting a continuous measurement system (CIBSE, 2022).

4. Further reading and opportunities

This article summarizes technical and non-technical considerations on continuous IEQ monitoring highlighted in CIBSE TM68. Key units and performance metrics, instruments and sensors, sampling considerations are briefly discussed for the four principal IEQ aspects. To retain holistic generality, building professionals are recommended to read the original TM68 in conjunction with the other relevant technical standards listed therein, as also summarized in figure 1a and 1b. Future works could be focused on the application in smart building design and engineering, such as assessing health implication for indoor environment in conjunction with building energy optimization through development of timeless digital twin platform. Productivity studies could be conducted through implementing these recommendations. ■

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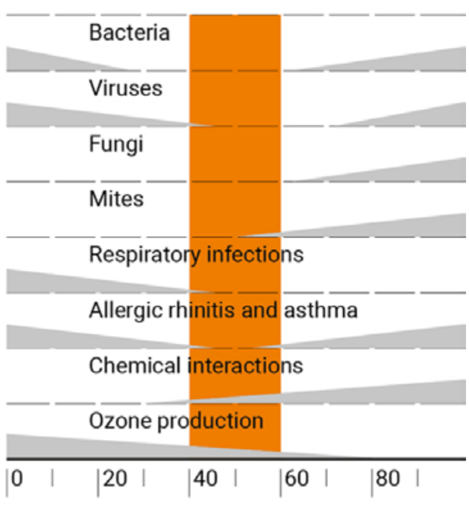
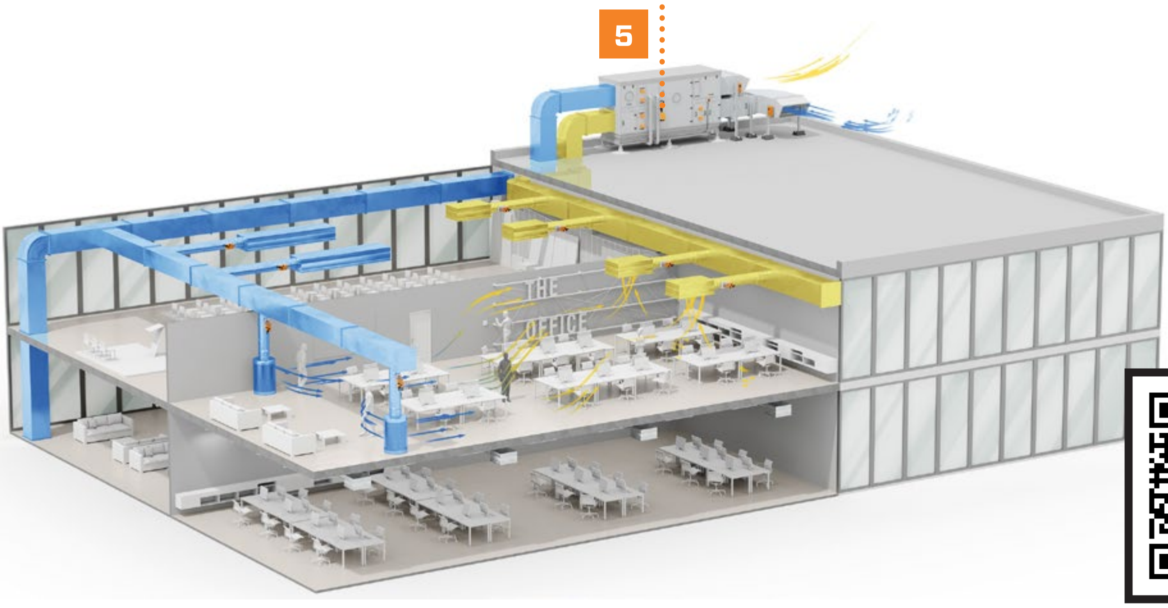


Source: Scotfield-Sterling-Diagram, Fachinstitut Gebäude-Klima e.V.



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