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D6.11 Report on living quality indicators before and after retrofit

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OUTPHIT – DEEP RETROFITS MADE FASTER, CHEAPER AND MORE RELIABLE
outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards. **outphit.eu**

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THE NEED FOR LIVING QUALITY INDICATORS FOR MONITORING THE SUCCESS OF DEEP RETROFIT MEASURES

Optimization and decision-making based on different indicators

The aim of the pre- and post-refurbishment monitoring in the outPHit project is, on the one hand, to monitor success and quality assurance regarding the expected increase in energy efficiency through the remediation measures. On the other hand, the measurement data should also be used to substantiate thermal comfort and indoor air quality parameters in the investigated project. Under the term “Living Quality” this evaluation serves as the second pillar of the Verified Performance scheme and offers opportunities to learn for future projects and planning. In the future, post-occupancy evaluations will also be carried out on this basis in order to assess the success of the measure during the building's operation. New buildings and renovations of residential and office buildings are primarily built or carried out with the aim of providing healthy and comfortable rooms, so the focus is on people in any case. The primary requirement is to ensure the minimum requirements for both comfort and health, and the aim is to achieve the highest possible level of fulfilment while at the same time complying with the energy efficiency criteria.

A comparative assessment regarding energy efficiency can easily be traced back to a single parameter even for different forms of energy (e.g., using primary energy or primary energy renewable PER). More challenging, however, is the quantitative assessment of health and comfort. Although there are also directional indicators for individual areas, the combination into a singular parameter seems difficult here since the individual indicators each concern fundamentally separate effects and thus cannot offset each other. For example, thermal comfort and indoor air quality represent separate assessments of occupied rooms, which are interdependent, but differ fundamentally both in their effects and in terms of measures to improve them.

Even if indicators can be unified in their unit through standardization, this does not mean that they can be directly combined into a single parameter. Scientifically correct is the clear presentation of all individual indicators, e.g., in the form of a radar or spider chart, the assessment is left to the observer for all individual indicators. On this basis, only queries regarding the complete avoidance of limit value exceedances or comparisons of variants can be carried out for decision-making if these differ in all indicators in a uniform direction in terms of improvement or deterioration. If, on the other hand, individual indicators indicate an improvement, others indicate a deterioration, a comparison of variants is no longer possible without transferring the individual indicators to a single parameter. This would require a scientifically justified weighting to be able to combine it into a meaningful common parameter. However, weighting can only be scientifically justified if it has been extensively validated in subject studies. However, such studies are extremely complex and extensive, especially for indicators with high user diversification, as explained in the following section.

In the field of thermal comfort, a scientifically valid single parameter could indeed be developed with the investigations of Fanger, but not by weighting but based on a comfort model and evaluation via a corresponding formula, which has even found its way into the internationally agreed standard ISO 7730.

Regarding health indicators, standardization is achieved via the unit DALY (disability-adjusted life years or disease-adjusted life years, WHO-definition see https://www.who.int/data/gho/indicator-metadata-registry/imr-details/158) for different health-adverse effects. But even this largely scientifically accepted assessment has weaknesses, e.g., DALYs are not able to consider comorbidities, i.e., diseases occurring simultaneously in the same patient.

Furthermore, EN 16798-1 ("Energy performance of buildings - Part 1: Indoor climate input parameters for the design and assessment of the energy performance of buildings in terms of indoor air quality, temperature, light and acoustics – Module M1-6") should be emphasized here, which defines the requirements for indoor air quality in connection with thermal indoor climate, indoor air quality, lighting, and acoustics. Parameters for indoor air quality are defined, which are used as the basis for system dimensioning in buildings and for energy efficiency calculations. At the same time, design criteria for local thermal discomfort factors such as draughts, air temperature differences and surface temperatures are described. EN 16798-1 applies when the criteria for indoor quality are determined by human use and not by production processes or similar [EN 16798-1].

Problem of user diversification with Living Quality Indicators (LQI)

Even if certain indicators can be recorded and scaled statistically and scientifically correct, their significance and statistical relevance when investigating smaller buildings with a limited number of people and not evenly statistically distributed characteristics of the persons in the building (age, gender, user behavior, etc.) is limited.

In the outPHit case study buildings CS22 in St. Johann/Austria, for example, the average age is higher compared to the average of the people in Austria, because many of the tenants have been living in the buildings for many years. If the indicators determined in these buildings are used for the quality assessment of the building envelope and building services, the evaluation result can be distorted due to the very special age structure of the residents. The results must therefore always be evaluated in relation to the individual case and allow only limited generalized comparisons.

Differentiation of the LQIs in relation to health and comfort

The term Living Quality Indicators (LQIs) in this context is related and restricted to indicators influenced directly or indirectly by the building envelope (external building elements) and building services (mainly heating, cooling and ventilation). In principle there is a fundamental difference between health and comfort related indicators, even if there is some overlap. Living in an environment with insufficient or borderline comfort conditions for a long time can end up in adverse health effects and long-term chronical diseases. If, for example, temperature and humidity data are to be evaluated not only for the statistical consideration of overheating frequencies and summer comfort, but also for the risk of deaths in times of extraordinary heat waves, completely different evaluation methods than those proposed in this document must be used.

Existing variation in IAQ assessment indicators

In Nearly-Zero-Energy-Building (NZEB), or Passive House/EnerPHit standard, high air tightness is required to keep thermal losses low. Therefore, efficient mechanical ventilation systems are required in this context to minimize risks of high humidity and air pollution on buildings and people. Indoor environmental quality (IEQ) is gaining importance. However, it is apparent that there is no universal consensus on the measurement, limitations of the assessment classes and weighting of individual categories for the assessment of IEQ [Heinzerling 2013, Han 2020]. Due to this variability in the evaluation procedure, many degrees of freedom lie with the evaluator for the building assessment.

Although indoor air quality (IAQ) parameters are measurable and have a proven influence on human well-being, there is currently no consensus on the quantitative description of measured variables and thus on the evaluation of energy improvement measures [Salis 2017]. IAQ parameters may include the CO_2 concentration and the concentration of particles and volatile organic compounds.

As a result, there are many indicators for assessing air quality, or indoor air quality (IAQ), e.g., EN 16798 ("Energy Performance of Buildings-Ventilation for Buildings-Part **3:** for Non-residential Buildings-Performance Requirements for Ventilation and Room-Conditioning Systems (Modules M5-1, M5-4)", 2017). The CO_2 concentration is used as an indicator of occupancy and thus as a basis for ventilation control. The CO_2 concentration also allows the calculation of air pollution [Persily 2017]. Accordingly, the CO_2-based occupancy information can also be used to make statements about the accumulation of other substances in the indoor air. For example, there are correlating effects between CO_2 concentration and certain gaseous compounds or bio-aerosols that affect IAQ [Lopez 2021]. Radar plots can additionally help to set focal points for the assessment. In this context, Lopez et al. identify the following indicators from literature, standards**,** and legal requirements for residential buildings (living rooms and bedrooms) during the heating season [Lopez 2021]:

- Mean CO_2 concentration - most common CO_2-based IAQ indicator (e.g. [Belmonte 2019]).
- Mean concentration above a threshold (EN 15665 "Ventilation of buildings - Determination of performance criteria for ventilation systems in residential buildings").
- Percentage of time spent in a defined concentration range (e.g., for high IAQ <750ppm, low IAQ >1200ppm), as defined in EN 13779 "Ventilation of

non-residential buildings - General principles and requirements for ventilation, air-conditioning and space cooling systems" and EN 15251 "Indoor climate input parameters for the design and assessment of energy performance of buildings - Indoor air quality, temperature, light and acoustics".

- Different types of cumulative exposures exceeding a defined threshold (e.g. [Guyot 2018]).
- ICONE air pollution index according to [Ribéron 2016].

[Han 2020] breaks down the assessment of air quality into two groups of metrics:

- Measurement of IAQ based on the concentration of one or more pollutants.
- Use of surrogate values such as CO_2 concentration and ventilation rate to assess air quality.

Accordingly, several indicators exist for IAQ assessment. An application of the identified indicators is applicable to the entire heating period as well as to exposure periods. However, the premise is occupant presence. In addition, it has been shown that the IAQ can turn out differently depending on the indicator selected under the same boundary conditions, since each indicator is different [Lopez 2021]. Therefore, a corresponding normalization of the results is required.

User-centered key performance indicators

Individual behaviors and preferences lead to different thermostat controls, manual ventilation of windows and shading devices [Hong 2016]. Occupants' habits thus have a major impact not only on indoor air quality (IAQ) [Lopez 2021], but also on energy demand [Hong 2017]. Existing indicators of building performance often neglect the interactions between occupants and the building [Han 2020]. These are mostly one-dimensional without consideration of IEQ (Indoor-Environmental-Quality) by humans [Mahdavi 2020]. Costs for measurement infrastructure and data protection aspects are cited as the main reasons for the lack of user-related metrics [Han 2020]. It further emerges that such user-related information can be very data-intensive. However, Han et al. argue that user-centered key performance indicators (KPIs) can not only improve building design and operation, but also quantify the impact of human-building interaction on energy demand and IEQ/IAQ. To move from existing KPI concepts on aggregated level to user-centered KPIs, the following challenges are posed [Han 2020]:

- KPI resolution by building type.
- Uniform scaling of KPIs
- Stronger quantification for performance quality assessments

Multi-objective optimization for energy efficiency and IAQ

Smart building systems aim to optimise the energy load on the grid while meeting the needs of occupants through distributed energy resources and advanced sensor and control technologies [Neukomm 2019]. In doing so, it proves crucial to quantify how changes would affect the indoor environment so as not to compromise occupant comfort and well-being [Han 2020]. One solution to this problem can be the use of Multiple Criteria Decision-Making (MCDM) methods.

In their work, Bakhtin et al. present an algorithm for solving a multi-criteria optimization problem. The algorithm uses a twofold separation of parameters and a combination of scanning with summarization and search point movement along the anti-gradient of the overall efficiency. Even though this algorithm was first applied in bridge construction, it can, in principle, be transferred to the building context. Thus, conflicting IAQ objectives (e.g., associated with high ventilation rates) can be optimized with energy objectives.

METRICS AND SENSORS FOR LIVING QUALITY INDICATORS

Selection of sensors in relation to comfort and health

According to ISO/DIS 7730, the analytical determination and interpretation of thermal comfort (PMV and PPD indices and local thermal comfort criteria) relies on the variables of the thermal field sorted by their importance:

- Radiative temperature θ_{rmt}
- Air temperature θ_a,
- relative air velocity v_{rel}
- Humidity p_a (water vapour partial pressure).

The influence of moisture is very small under normal living conditions. The air velocity is largely dependent on the room temperature and how much of the latent heat needs to be removed from the body to bring the body temperature back to its comfort setpoints.

Against this background, the influence of temperature is crucial. If air and radiation temperatures do not differ significantly (which they should not do in the interest of comfort constraints), both temperatures can be combined into a "perceived" or "operative temperature" θop as an arithmetic mean between radiation temperature and air temperature and the requirements can be formulated as requirements for this operative temperature. For rooms intended for the permanent residence of different people, the requirements for a high level of comfort (PPD < 6 %) are as follows:

Fluctuations of the operative temperature in space and time:
Δθop = ±0.8 K (max.)
Limitation of the risk of draughts to DR < 8 %:
vrel < 0.08 m/s
Radiation temperature asymmetry (ceiling/floor):
Δθr_ass < 5 K
Vertical air temperature difference between head and ankle in a sedentary person:
Δθ 1.1_0.1m < 2 K

The total amount of permitted changes in the operative temperature over time is also limited.

Regarding the draught risk (DR), strictly speaking, not only the absolute value of the air velocity but also the so-called degree of turbulence is considered. The latter can be determined from the dynamic course of the air velocity but requires a very high temporal resolution of both the sensor (low time constant) and the sampling rate. The effort for sensors, data acquisition and evaluation is therefore very high, but the influence of this quantity is low. An assessment on the safe side can therefore be made with the assumption of a high degree of turbulence and a simple air velocity measurement.

And even these can be dispensed with in buildings with a good thermal standard (high airtightness and surface temperatures), because then no significant air velocities are to be expected anyway. As the outPHit verification approach and case study buildings target the EnerPHit standard, good airtightness with a maximum $n_{50} \leqslant 1.0\ h^{-1}$ is ensured and validated systematically with pressurization and depressurization testing according to ISO 9972.

This does not hold for the unrefurbished condition of the building and temporary, simplified data acquisition with mobile data loggers. Still a full DR evaluation is dispensed with as it is regarded too complex and expensive, in favor of broad application at manageable cost.

It is nevertheless important to bear this simplification in mind in the comparison of data from unrefurbished and refurbished condition as the result is somewhat optimistic for the unrefurbished building, ignoring the draft risk.

Selection criteria for the sensors

The above paragraph describes a simplified method to assess thermal comfort without a draft risk evaluation. The method builds on time series of data for room temperature, relative humidity, and carbon dioxide concentration as indicators of indoor air quality and thermal comfort.

To arrive at reliable ratings based on this very limited set of parameters, however, the measuring uncertainty must not exceed narrow limits. For room temperature this is particularly significant also for the energy performance verification, cf. the outPHit D.6.5 Description of a certification scheme on "verified building performance”. Desired measuring uncertainties for each quantity are detailed there.

For practical use and easy deployment, a local data storage of data loggers was chosen as an appropriate method that requires no infrastructure in the first campaign, covering the unrefurbished condition of the building by spot checking in different places and flats for a couple of weeks each.

For long-term verification of energy performance and living quality a wireless system, based on IoT LoRa radio technology is used. Several manufacturers offer combined sensors for the three required parameters with specifications that come close enough to the desired quality and that can operate on battery power for at least two years. This time is usually sufficient to complete a performance

verification campaign. With a new set of batteries and a re-calibration the sensors are fit for reuse. The size of the sensor boxes is less than 100mm squared which makes installation easy and non-intrusive.
Data rate is 10 min intervals, which balances the desire for battery life and limited airtime within the wireless system with representation of dynamic developments in the observed quantities.

THE METHOD OF „RELATIVE THRESHOLD DEVIATION" RELATED TO LIVING QUALITY INDICATORS

Description and principle of Relative Threshold Deviation (RTD)

Performance indicators in terms of comfort as well as assessment of health parameters rely on well-defined ranges and categories by standards and guidelines. For example, the Indoor air quality is influenced and categorized by the concentration of gases and pollutants with individual target values and the range below, which is assumed to be unobjectionable.

In terms of the air quality parameters CO_2 and relative humidity, the impact on health and comfort is only relevant for hours with occupancy. Moreover, a distinction between the heating- and non-heating period can help to quantify the seasonal influence.

The principal definition of the so-called Relative Threshold Deviation (RTD) is as follows:

The measured parameters (CO_2, relative humidity etc.) are plotted for the evaluation period (e.g., 1. Dec. – 1. Mar.) and only for hours with occupancy as cumulative distribution function (sorted by size). The resulting area between threshold and cumulative distribution function is a measure for the duration *and* magnitude of the respective threshold deviation. It is equivalent to an area resulting from an (hypothetical) constant value above the threshold. For the parameter CO_2 it means, that having a concentration of 700 ppm during the entire evaluation period would be rated equally to having a concentration of 1600 ppm during 10% of the evaluation period. This integral absolute threshold deviation is then related to the maximum permissible threshold deviation, set by a limit value that should never be violated. The result is termed the relative threshold deviation (RTD) and abstracts the observed conditions from the particular parameter. A sum of RTD's from different quantitites may be calculated in order to represent more complex conditions as a single figure indicator. Note that the use of the area as an evaluation measure implies a linear weighting of duration and magnitude of a threshold exceedance. Ideally, a physiological derived weighting (not yet established) should be used. For more details refer to [Rojas 2015]. However, it is not valid to form sum parameters from adding comfort related and health related parameters, because those have a different scale.

APPLICATION OF THE RTD-METHOD ON THE LIVING QUALITY INDICATORS WITHIN THE OUTPHIT-PROJECT AND DATA BASE

Seasonal evaluation of LQIs

The typical usage of buildings in Europe varies between the seasons. While the windows are normally closed in the winter, the shoulder seasons and long periods of the summer invite opening them. This has a major impact on the average air change rate and hence the indoor air quality is also affected.

Old, existing buildings typically have inconsistent indoor air quality as the air change rate varies with the weather (wind, temperature difference) and user behaviour. There is a strong tendency to open windows only occasionally, for comfort reasons, which can lead to increased levels of indoor air relative humidity and carbon dioxide concentration. In many instances also moisture related problems persist, either from rising damp or critically low surface temperatures. Mould growth results and presents a potential health hazard as well as damages the building fabric components.

Buildings refurbished to the EnerPHit standard rely on mechanical ventilation with heat recovery (MVHR) in the winter, which ensures the air flow required for hygienic reasons at all times, independent of the weather. Moreover, high quality outdoor air filters remove dust, pollen, and fungal spores to a high degree. Moisture related problems are removed, rising damp stopped by adequate intervention and very low surface temperatures designed out by high levels of insulation and awareness of thermal bridge reduction.

It follows from the above that any evaluation of indoor Living Quality Indicators operates under fundamentally different boundary conditions in the summer versus in the winter and hence demands separating the assessment by the season. The appropriate definition of “summer” and “winter” however, differs by the local climate, and to some degree also by the properties of the building. This last effect may be illustrated by the example of a very well insulated building with much unshaded glazing towards the sun. In such a case the heating season will end particularly early, and windows may be opened more liberally early in the year as well.

In the design of any outPHit project a detailed energy balance model is set up with the Passive House Planning Package (PHPP, based on EN13790/ISO52016 monthly method). The calculation results can be used to derive the typical “summer” and “winter” periods, based on the climate data set, or even the specific time periods for a given year, if weather data is available from the Verified Performance monitoring.

Winter is represented by all months that contribute more than 1/100 to the annual space heating demand, while summer is either the remaining time (regions with mild summers) or, more specifically (in cooling climates) the time that contributes more than 1/1000 to the annual space cooling demand. As the PHPP data is available within the outPHit monitoring platform the information on the seasons can be used automatically.

SAMPLE EVALUATION OF THE IMPLEMENTATION AND ANALYSIS METHOD

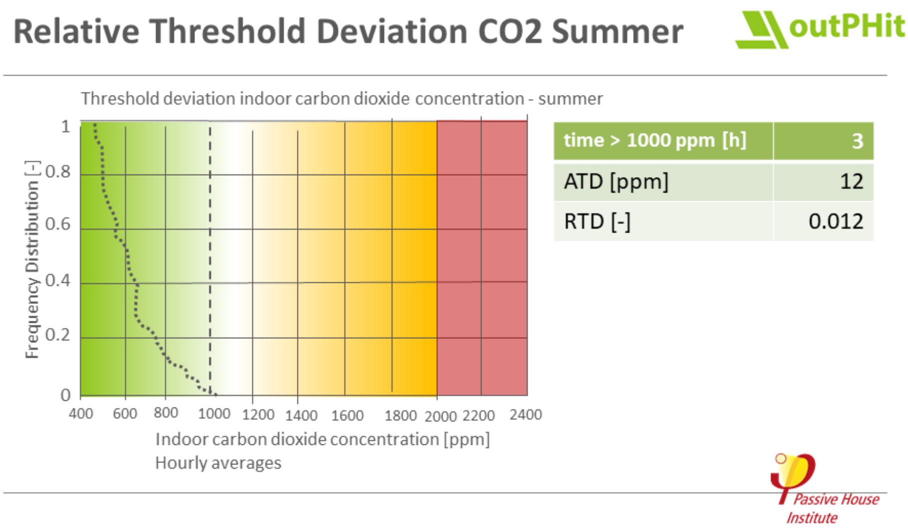
Assessment methodology using the Passive House as an example

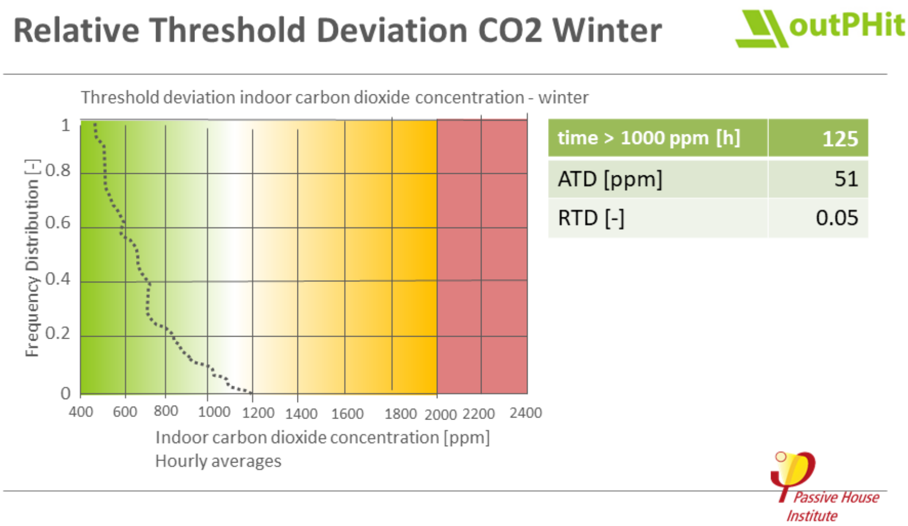
In [Ridley 2013] a long-term assessment of a passive house in London is presented. The performance was evaluated over a period of two years. To evaluate the building performance, room temperature, relative humidity (each in the living room, bedroom, bathroom, guest room) and the building-specific energy requirement were recorded every five minutes. In the case of the latter, the electrical energy was broken down by circuit (e.g., lighting, blinds, mechanical ventilation, and heat recovery). In addition, the entire electrical energy requirement, the gas requirement, and the water consumption were measured. To relate the performance in the building, a weather station recorded humidity, temperature, pressure, precipitation, and global solar radiation every five minutes. The performance evaluation of the building aimed for in [Ridley 2013] should also evaluate the forecast accuracy of PHPP, especially regarding the risk of overheating in summer and the forecast energy consumption. This turns out to be significant in outPHit since the serial renovation projects were evaluated according to the EnerPHit standard in the planning process via PHPP. Furthermore, analogous to [Ridley 2013], an evaluation of the renovation measure is to be carried out using pre- and post-monitoring of energy and indoor climate.

The results from the example project in London show that the CO_2 concentration is below 1000ppm in 78% of the cases and the requirements of EN 13779 according to IDA3 are met. In the bedroom area in particular, this value can be considered acceptable. [Bekö 2010] states that only 32% of naturally ventilated bedrooms achieved a CO_2 concentration below 1000ppm. The relative humidity did not fall below the limit value of 30%. The temperature profile proved to be largely stable. An average temperature of around 21.5°C was measured in the living room. In the bedroom, this is around 20°C. The stable temperature and low relative humidity indicate a low risk of mould. In summer, there were frequent excesses of 26°C in the living room (on average every 10 days). In winter, the living room temperature of 22.4°C was slightly higher than expected. In total, temperatures exceeded 25°C on 15% of the days [Ridley 2013]. The PHPP recommends that temperatures are only exceeded on 10% of the days. A slight increase can sometimes be attributed to low manual ventilation rates. The sample project meets the passive house standard limit of the heating requirement with 12.1kWh/m²a (specification: 15kWh/m²a) [Ridley 2013].

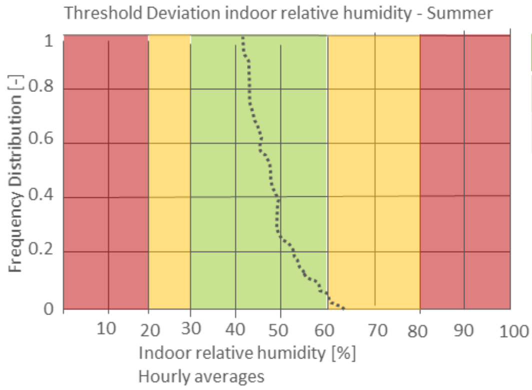
As shown in this study example, measured values for the indoor climate and energy requirements should also be used in the outPHit project to be able to evaluate the effectiveness of the measure.

Exemplary monitoring data are presented in the following subsection. As pointed out in the previous chapter (cf. The need for living quality indicators for monitoring the success of deep retrofit measures), radar plots can help to set priorities in the individual evaluation of individual pollutant variables (Fig. 2).





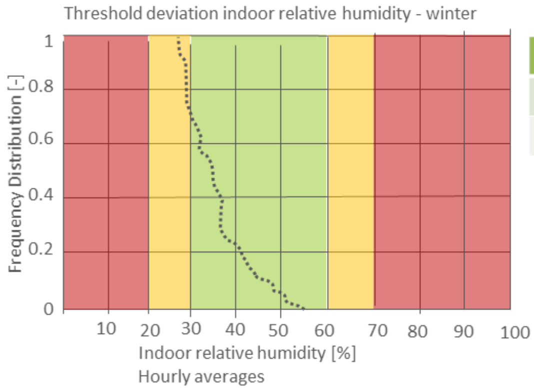
Relative Threshold Deviation rH Summer



time > 60 [%]	12
ATD [%]	0.01
RTD [-]	0.01

Passive House Institute

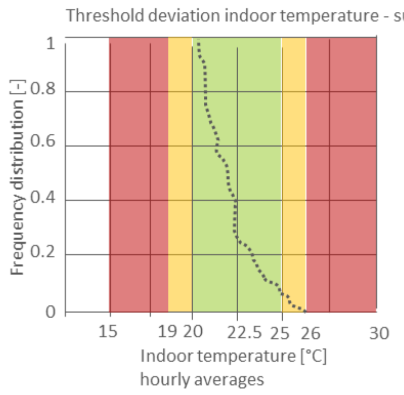
Relative Threshold Deviation rH Winter



time < 30 [%]	124
ATD [%]	2.00
RTD [-]	0.20

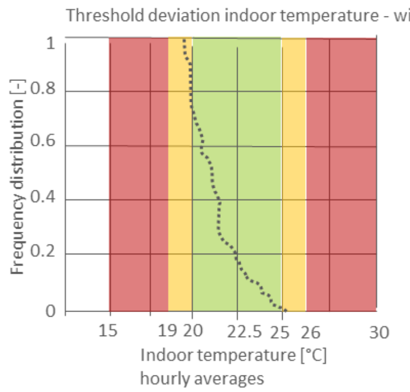
Passive House Institute

Relative Threshold Deviation Temp Summer



time > 25 [°C]	123
ATD [K]	0.20
RTD [-]	0.2

Relative Threshold Deviation Temp Winter



time < 20 [°C]	13
ATD [K]	0.15
RTD [-]	0.15

Fig. 1: Tentative representation of evaluation results from RTD method, to be implemented within the outPHit monitoring platform.

Microbiological assessment of indoor air, fungal spores

Indoor air quality in buildings is, among other factors, determined by the presence of mould spores. Particularly in old buildings with insufficient thermal insulation, rainwater leaking in or rising damp, the inner surfaces may offer sufficient humidity for mould to grow.

Airborne mould spores can present a health risk, depending on which species are present and to what amount, cf. [Maier 2021]. They are, however, not a problem per se, as such spores are ubiquitous in indoor and outdoor air, and a digestible substrate is also present nearly everywhere. Moreover, the presence of spores in outdoor air can vary greatly, depending on location, season, and weather. Hence, evaluating the situation in any given building is not straightforward. It will always involve (near) simultaneous sampling of indoor air and outdoor air, as a reference. Repeated tests are beneficial to distinguish noise from systematic pollution.

It follows that no simple quantitative scheme exists to rate the mould spore pollution observed in buildings in comparison to a definitive threshold. In critical cases expert assessment is called for to come up with a balanced evaluation.

Nevertheless, both WHO and the German Environmental Agency (UBA) suggest a simplified method for a first, coarse account [Seifert 2002]. It refers to the difference in number of colony forming units per sampled volume (CFU/m³) in outdoor air versus the respective indoor air count and yields a traffic light flag: green „insignificant“, orange „resample at a later time an intensify search on persistent increased concentration“, red „significant concentration search for cause immediately“.

The UBA guidance as per Table 8, p 47 in [Seifert 2002], shall be employed as a manageable outPHit indoor air quality evaluation. The table is quoted for convenience as follows.

Indoor air parameter	**Indoor source improbable**	**Indoor source cannot be ruled out** [1)]	**Indoor source probable** [2)]
Cladosporium as well as other genera of fungus that may reach increased concentration in outdoor air (e.g., sterile mycelia, yeasts, Alternaria, Botrytis)	If CFU/m³ of one genus in indoor air is below the 0.7 (to 1,0)- multiple of outdoor air $I_{typ\,=} \leq O_{typ\,O} \times 0{,}7\ (+0{,}3)$	If CFU/m³ of one genus in indoor air is below the 1.5 ± 0.5 - multiple of outdoor air $I_{typ\,=} \leq O_{typ\,O} \times 1.5\ (\pm 0{,}5)$	If CFU/m³ of one genus in indoor air is more than the 2 - multiple of outdoor air $I_{typ\,=} \leq O_{typ\,O} \times 2$
Sum of CFU of species untypical of outdoor air	If the difference of the CFU-sum indoor air minus outdoor air for species untypical of outdoor air is below 150 CFU/m³ $I_{\Sigma untyp\,O} \leq O_{\Sigma untyp\,O} + 150$	If the difference of the CFU-sum indoor air minus outdoor air for species untypical of outdoor air is below 500 CFU/m³ $I_{\Sigma untyp\,O} \leq O_{\Sigma untyp\,O} + 500$	If the difference of the CFU-sum indoor air minus outdoor air for species untypical of outdoor air exceeds 500 CFU/m³ $I_{\Sigma untyp\,O} > O_{\Sigma untyp\,O} + 500$
Single species untypical of outdoor air	If the difference of the indoor air minus outdoor air for **a single** species untypical of outdoor air is below 50 CFU/m³ $I_{\Sigma untyp\,O} \leq O_{\Sigma untyp\,O} + 50$	If the difference of the indoor air minus outdoor air for **a single** species untypical of outdoor air is below 100 CFU/m³ $I_{\Sigma untyp\,O} \leq O_{\Sigma untyp\,O} + 100$	If the difference of the indoor air minus outdoor air for **a single** species untypical of outdoor air exceeds 100 CFU/m³ $I_{\Sigma untyp\,O} > O_{\Sigma untyp\,O} + 100$

[1)] suggests further need to search for sources [2)] suggests immediate need to search for sources

The assessment is staggered in three sections.

It first compares those species that can typically reach high concentrations in outdoor air. If the concentration of outdoor air species in indoor air is smaller than 0.7...1.0 times the outdoor air a green flag is awarded, smaller than 1.5...2.0 yields an orange flag while greater than 2 times the outdoor air concentration is flagged red.

After that the sum of all CFU/m³ belonging to *genera* indicative of increased humidity in indoor environments are assessed for increased occurrence. If the indoor air count is less than the outdoor air count + 150 CFU/m³ a green flag is awarded, a count of up to outdoor air + 500 CFU/m³ yield orange while outdoor air counts + more than 500 CFU/m³ is flagged red.

As the third step, individual *species* within the former set of genera are scrutinized. For a green flag no individual species must exceed the outdoor air count + 50 CFU/m³. An increase over the outdoor air count of less than 100 CFU/m³ yields a yellow flag and more than outdoor air count + 100 CFU/m³ is flagged red.

Each of the three steps yields its traffic light flag. If all result in green, then with some confidence all is fine and the test passed. An orange flag suggests resampling and a red flag will call for immediate further action involving experts in the field.

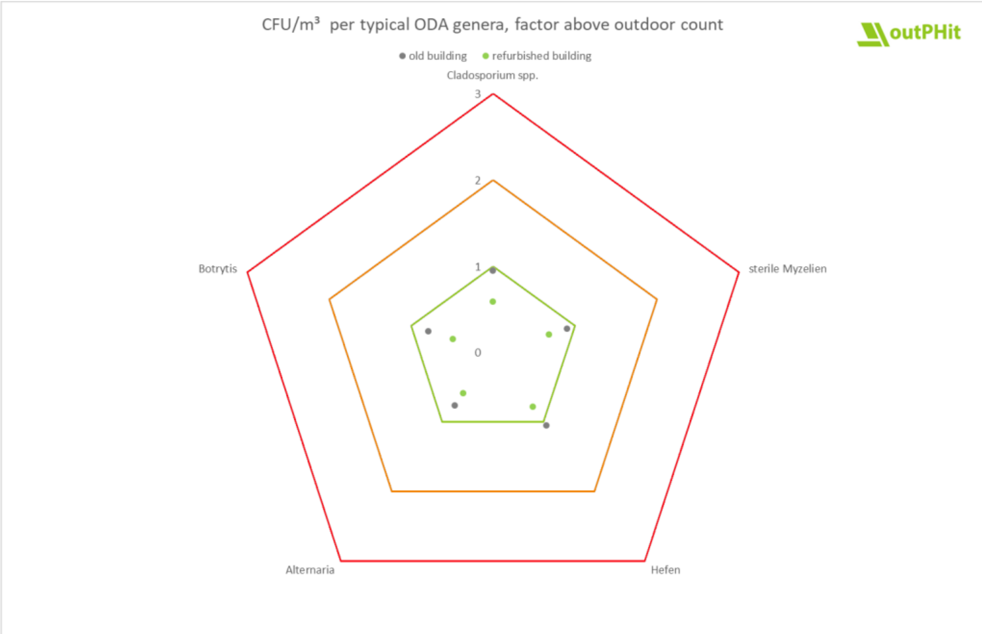
To implement this method for practical application, the outPHit monitoring platform requires a section on microbiological sampling results, tied to building, zone/flat and room as well as for outdoor air solely tied to the building. For each sampling date and all relevant genus and species there will be results in CFU/m³, while each species will be characterized by its critical increase over outdoor air and a flag on whether it is a typical outdoor air species.

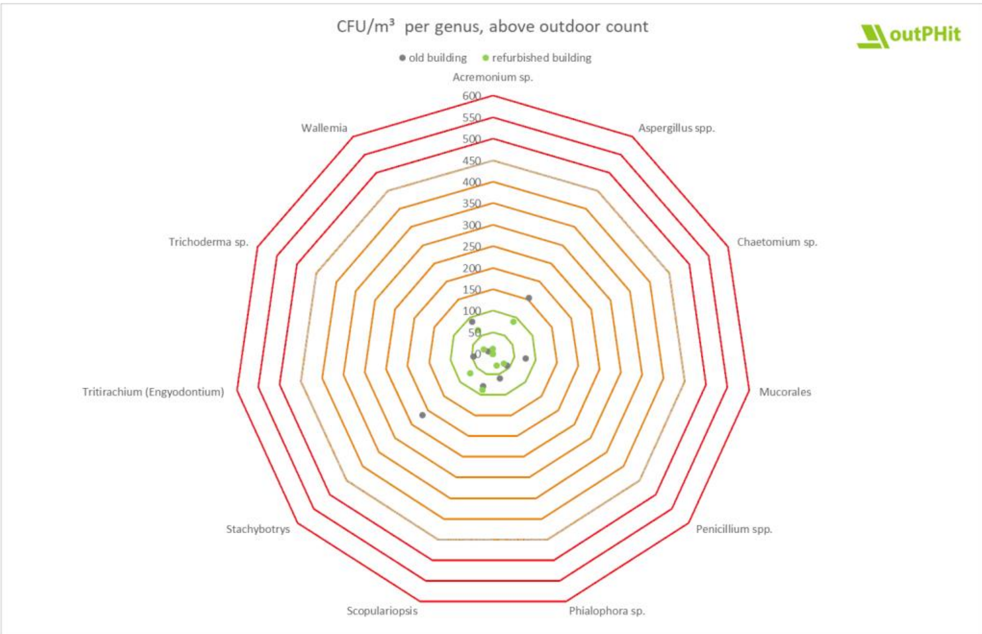
Based on this information a result sheet can be generated that states all species identified in the sample and add the traffic light rating with a suggestion on further action, if applicable. To provide a good overview at a glance radial charts (radar plots) for each assessment category are provided, with radial color coding according to the traffic light scheme.

A total rating is difficult to obtain, as a threat from one species cannot be offset by the uncritical situation with any other organism. Only if all green flags are awarded the overall situation may be categorized „Fungal spore assessment results without findings“.

Any orange flags are a pointer to further investigation and the message issued will be on the lines of „Fungal spore assessment results show some elevated concentrations. Further investigation advised. Repeat sampling. If results persist search for sources and involve experts.“

Any red flags trigger a prominent warning „Fungal spore assessment results evidence high concentrations. Immediate search for source advised, involve experts.“


CFU/m³ per typical ODA genera, factor above outdoor count
outPHit
old building
refurbished building
Cladosporium spp.
sterile Myzelien
Hefen
Alternaria
Botrytis
3
2
1
0


CFU/m³ per genus, above outdoor count
outPHit
old building
refurbished building
Acremonium sp.
Aspergillus spp.
Chaetomium sp.
Mucorales
Penicillium spp.
Phialophora sp.
Scopulariopsis
Stachybotrys
Tritirachium (Engyodontium)
Trichoderma sp.
Wallemia
600
550
500
450
400
350
300
250
200
150
100
50
0

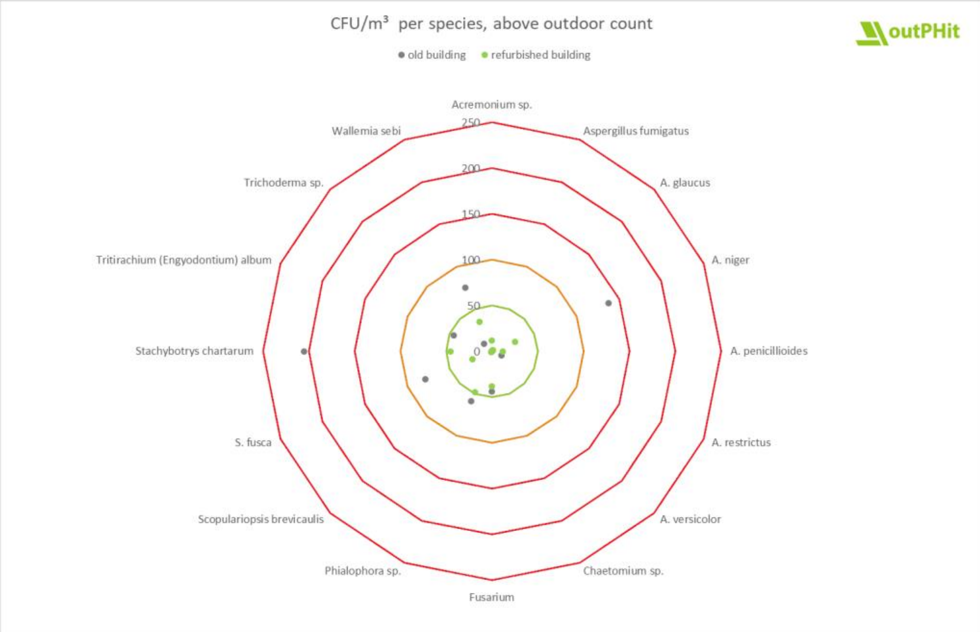


Fig. 2: Tentative representation of evaluation results from microbiological assessment to be implemented within the outPHit monitoring platform. The traffic light appraisal scheme according to WHO/UBA has been adopted.

RESULTS AND OUTLOOK

It turns out that the use of room climate parameters and energy requirements are suitable methods to evaluate both the effectiveness of the refurbishment measure regarding energy objectives (and thus the success of an EnerPHit standard) and about user-related target values (comfort and health). In this context, the Passive House Planning Package, PHPP, has proven to be a good indicator for calculating space heating requirements and the risk of overheating in summer [Ridley 2013]. However, the quality of living space is largely dependent on appropriate ventilation rates. To avoid dependencies on manual ventilation, (partially) automated ventilation is necessary. [Wilkinson 2009] highlights the health benefits of MVHR (mechanical ventilation with heat recovery) in this context. MVHR can reduce the risk of mold and minimize pollutants in the air and reduce accumulations of e.g., radon. The associated additional energy requirement is usually much lower than the energy savings from heating through improved building envelopes.

Performance gaps between forecast and actual performance cannot be ruled out. These are mainly due to mistakes in installation, deviations between planning and construction, deviating material properties and user behavior (cf. e.g. [Wingfield 2009]). For this reason, quality assurance measures along the value chain and subsequent evaluations are of great importance. In outPHit, this is to be ensured through pre- and post-monitoring and the associated analyses. When measuring, measurement accuracy, position, number, and measurement interval are of great importance. Depending on the progress of the project in the demo cases, a quantitative comparison of pre- and post-monitoring is sought in the follow-up report D6.12.

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