Assessment of Indoor Environmental Quality (IEQ) in offices and hotels undergoing deep energy renovation – The ALDREN Method


PAWEL WARGOCKI


CORINNE MANDIN


WENJUAN WEI


CARLOS ESPIGARES


JANA BENDZALOVA


OLIVIER GRESLOU


MATHIEU RIVALLAIN


JOHANN ZIRNGIBL

Energy renovation of the European building stock is crucial for achieving the reduction of CO_2 emissions. The emissions associated with the buildings are estimated to amount as much as 35% of the total CO_2 emissions. This action is essential in mitigating climate change and its effects. The conversion rate of building stock into environmentally friendly low-energy alternative is however still quite low in Europe and remains at the level not higher than 1% to 2% annually (Artola et al., 2016). This conversion rate cannot underpin the very ambitious targets set by the European Commission regarding the reduction of energy use and non-fossil fuel energy production, as well as the overall intention for quick decarbonization of building stock in Europe. The rate at which new buildings are erected cannot produce sufficiently high CO_2 reduction. Improving the energy performance of the existing buildings through their deep-energy renovation seems, therefore, at present to be the most efficient method for achieving decarbonization of building stock. The rate at which renovations are made must consequently be much higher than today.

Among different impediments of the low conversion rate of European building stock into buildings with low-energy use is the cost of performing the renovation and the long period for the return on the investments necessary to perform the renovation – there are financial benefits resulting from low energy use in buildings, but they are relatively low compared to investments required to improve the energy performance of a building. Additional justification and incentives for energy renovation of buildings, not only related to the environmental impact and energy use, are therefore required to boost the renovation rates far above the present low rates. Besides, straightforward and transparent procedures are required to support the energy renovation of buildings. They will secure that the intended energy savings are reached, that they are properly communicated and monetized and that no other risks exist that will limit the expected benefits from the renovation process.

To address the matters mentioned above the project ALDREN has been conceived and launched in 2017. The project was granted by the European Commission within the Horizon 2020 Programme (aldren.eu). ALDREN stands for "Alliance for Deep Energy Renovation". The main objective of ALDREN is to develop the operational methodology for advancing energy renovation of buildings; offices and hotels are the target buildings. The major elements (modules) of ALDREN methodology comprise the development of:

- a European harmonized energy performance rating, offering comparability and transparency across the EU;
- an energy performance verification protocol to enhance confidence ("you got what has been promised"), building value and management tools;
- a health and well-being assessment framework offering the integration of indoor air quality, comfort and health in the scope of deep energy renovation;
- and a method for financial valuation of both energy and non-energy benefits the latter comprising, for example, an increased building value or productivity in renovated buildings.

All these elements are embraced in the Building Passport and are additionally used to produce the Renovation Roadmap. They respectively collect and present all information regarding the energy performance of a building and energy renovation process, as well as provide recommendations and alternative solutions for the most effective, successful and financially healthy and beneficial energy renovation process. The elements of ALDREN methodology presented above are developed so that they can be used as stand-alone modules, but of course, the overall intention of ALDREN is that they are used together forming the so-called ALDREN method for deep-energy renovation. The method is expected to create a enough incentive to increase the rate at which renovations are carried out. Besides, this method is additionally expected to become a backbone of EVCS, the European Voluntary Certification Scheme, which has been proposed and considered by the Energy Performance of Building Directive (EPBD) (2010) as a market-driven vehicle to boost the energy renovations in the non-residential building sector entailing as much as 25% of the gross building floor area in Europe. Finally, it is believed that ALDREN method will become sufficiently attractive and straightforward so that it can be adopted partially or entirely by any other certification scheme already in use. The structure of ALDREN indicating the consolidation with EVCS is shown in **Figure 1**.

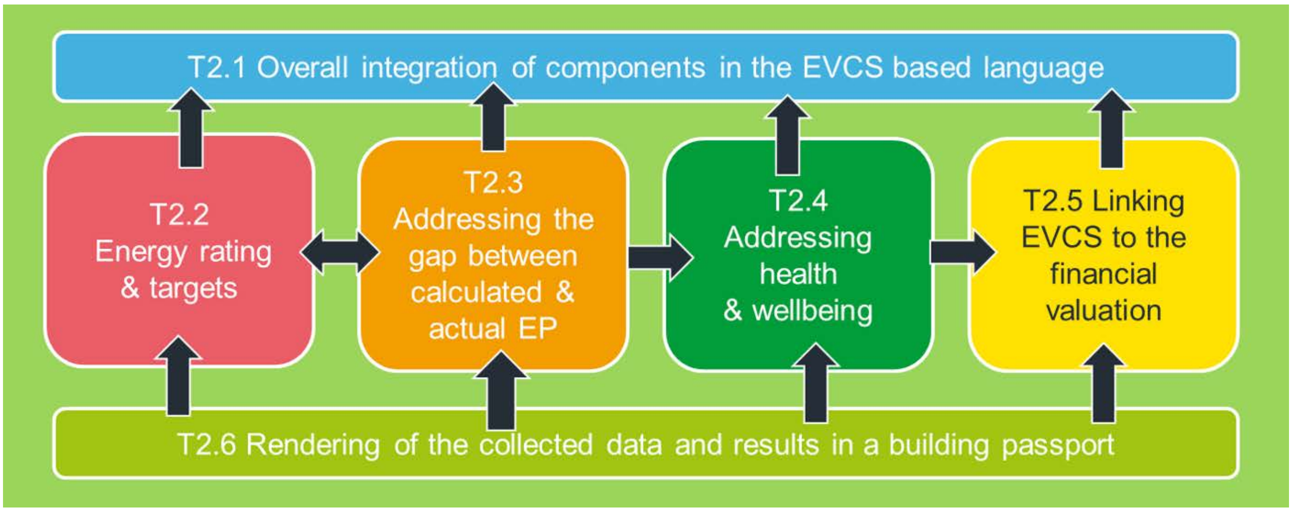

Figure 1. ALDREN in a nutshell, six tasks for consolidation and adaptation of an EVCS (European Voluntary Certification Scheme) based common language.

As indicated by the above bullet points, one of the elements of ALDREN method for the deep-energy renovation of offices and hotels is the development of a protocol for assessment of indoor environmental quality (IEQ) in building undergoing the energy renovation. One reason for the inclusion of this module in the ALDREN method is the direct requirement of EPBD (2010). EPBD is mandating that "*Member States should support energy performance upgrades of existing buildings that contribute to achieving a healthy indoor environment*" and that each long-term renovation strategy shall encompass "*an evidence-based estimate of expected energy savings and wider benefits such as those related to health, safety and air quality*". Another reason why the assessment of IEQ was included is that it allows estimating the potential additional benefits resulting from the renovation process that are not related to reduced energy use. They include among others the improved IEQ conditions in a building that has undergone energy renovation compared with the condition prior to renovation, improved well-being, comfort, health and productivity of building occupants, the increased market value of a building, lease renewal or time needed to lease the space, and alike. The subsequent economic benefits of these improvements are expected to be several times higher than those resulting from reduced energy (e.g., Wargocki and Seppanen, 2006). These additional benefits, often called non-energy benefits, create a powerful argument and incentive to perform energy renovation because their inclusion results in significantly lower pay-back times of the investments and because the resulting profits can be achieved much quicker and can be much higher than those that are associated only with lowering of energy use.

There are different protocols used to quantify IEQ in buildings including both the objective measurements of the components of IEQ, i.e., parameters describing the thermal, acoustic and luminous (visual) environment and air quality, and the subjective ratings of building occupants providing among others the information on their satisfaction with IEQ. However, no standard protocol exists describing, for example, the minimum number and type of measurements that need to be carried out to evaluate IEQ adequately in buildings. Consequently, rather than adopting one of the existing approaches for measuring IEQ, it has been decided that ALDREN should develop the protocol for assessing IEQ in buildings that undergo energy renovation with the focus on offices and hotels which are the target building typologies of ALDREN. This protocol should be applicable in buildings prior to and after the energy renovation is completed. It has additionally been decided that such protocol should not differ considerably from the measuring protocols that are already in use, especially it should not differ much from the protocols proposed by different schemes that are used for providing the sustainability certification of buildings; it was feared that too original and unconventional protocol might limit its use in practical applications. It was also decided that ALDREN protocol for IEQ measurements should only include objective measurements. Although subjective measurements have many advantages and provide information that cannot be obtained by the objective measurements, e.g., building occupants can express directly whether they are satisfied with IEQ or not, the use of subjective measurements was troublesome and ambiguous. An important argument justifying this opinion was that there is no standard questionnaire that can be proposed and applied for rating IEQ by building occupants. Another valid argument was that there are too many factors that can impact and/or modify the responses of occupants and that it is difficult to control them well and make the proper adjustments when the occupant ratings are analysed. Consequently, the ratings of IEQ made by occupants in different buildings may not be comparable, which would breach the original intentions and objectives of ALDREN.

To assist the process of developing the protocol for assessing IEQ in buildings undergoing energy renovation, the methods for assessing IEQ proposed by various certification schemes were examined and summarized. It was done mainly to learn which IEQ parameters are measured when buildings are given the sustainability certificate. An inventory of parameters used to characterize IEQ in different certification schemes was made (Wei et al., 2019), and some results are shown in **Table 1**. To make this inventory, thirteen green building (GB) certification schemes were examined, among which nine were European and four non-European ones. Because the ALDREN project is addressing the European building stock, the summary mainly focused on GB schemes developed in European countries because they were expected to accord with EU regulations, standards, climate and with European traditions for construction, building culture and heritage. Some GB schemes developed in non-European countries were also included in the summary because they are used globally, and thus also in Europe. Only the information available for public that could be retrieved from the documents posted on the certification schemes webpages was used to create this summary; the standards referred to by surveyed GBs were not examined. The focus was on indicators used to assess IEQ in offices and hotels. However, if no specific information for these types of buildings was provided, the indicators recommended for any types of buildings were retrieved from GB schemes.

Nineteen indicators characterizing thermal environment were identified. Among them, the most commonly used ones were Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), room operative temperature, room air relative humidity, and air speed. Twenty indicators characterizing acoustic environment were identified. Among them, the most commonly used ones were ambient noise and reverberation time. Thirty-nine indicators characterizing IAQ were identified. Among them, the most commonly used ones were ventilation rate and concentration of total volatile organic compounds (TVOC), formaldehyde, carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM10 and PM2.5), ozone, benzene, and radon. Twelve indicators characterizing luminous (visual) environment indicators were identified. Among them, the most commonly used ones were illuminance level, daylight factor, and spatial daylight autonomy.

The summary of IEQ indicators was used to select IEQ parameters that should be included in the protocol for assessing IEQ in buildings undergoing energy renovation that is proposed by ALDREN. Not all parameters listed in **Table 1** were selected, and this table does not include all parameters that were eventually included in the measuring protocol. The method for rating of IEQ in buildings proposed by ALDREN contains both the measuring protocol for the selected IEQ parameters as well as the rating of overall IEQ level using a new IEQ index called ALDREN TAIL index, in short TAIL. The measuring protocol and an index allow thus repeatability, comparability as well as similar standard rating metric, all originally called for in the proposed ALDREN method.

TAIL is shown in **Figure 2**. TAIL stands for the thermal (T), acoustic (A) and luminous (L) environment, and indoor air quality (I), the four cardinal components characterizing IEQ. Each component is assessed separately, and the quality of each component is provided by TAIL. The quality level is depicted by different colors, green standing for high quality, yellow for medium quality, orange for moderate quality, and red representing low quality. TAIL also provides information on the overall quality level of the indoor environment. This level depends on the quality of the four components of IEQ: T, A, I and L. The overall quality is expressed by the Roman numbers, I standing for high quality, II for medium quality, III for moderate quality,

Table 1. *IEQ indicators commonly used by Green Building certification schemes.*

IEQ indicator	Level(s)	HQE	OsmoZ	BREEAM	KLIMA	DGNB	LiderA	BES	ITACA	WELL	LEED	CASBEE	NABERS
Thermal environment													
PMV	x		x	x	x				x	x			x
PPD	x		x	x	x					x			
Air relative humidity					x	x	x	x				x	x
Operative temperature	x				x	x		x		x			
Air speed		x			x		x	x					x
Acoustic environment													
Ambient noise		x	x	x	x			x		x	x		x
Reverberation time	x	x	x	x		x		x		x	x		
Indoor air quality													
Ventilation rate	x	x	x	x		x		x	x	x	x	x	x
TVOC		x	x	x	x	x		x		x	x		x
Formaldehyde	x	x	x	x	x	x		x		x	x		x
CO_2	x		x		x			x		x	x		x
CO		x	x					x		x	x		x
PM_{10}	x	x	x							x	x		x
$PM_{2.5}$	x	x	x							x	x		
Ozone		x	x					x		x	x		
Visual (luminous) environment													
Illuminance level	x			x			x	x		x	x	x	
Daylight factor	x	x	x	x		x			x			x	
Spatial daylight autonomy	x	x	x							x	x		

and IV for low quality. These levels match the quality levels prescribed by the standard EN16798-1 (2019), one of the standards supporting EPBD (2010).

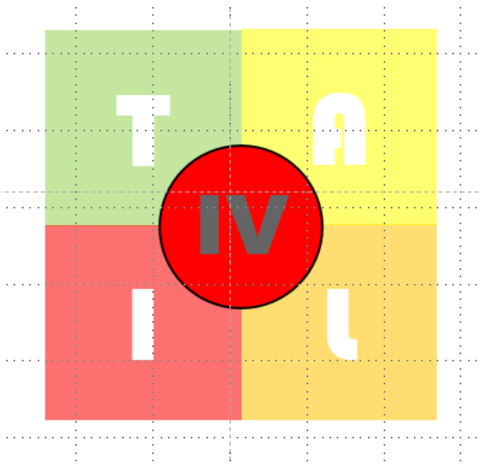

Figure 2. ALDREN TAIL index, in short TAIL.

The quality levels of the components of TAIL are determined by performing measurements of different parameters characterizing IEQ. Twelve parameters are selected: temperature for rating the quality level of T, sound level for A, ventilation rate, concentration of CO_2, formaldehyde, PM2,5, radon and benzene, relative humidity and visible mold level for I, and illuminance level and daylight factor for L. The measured values are compared with the reference values, and then their quality levels are determined. The reference values are set either to match the standard EN16798-1 (2019) or the WHO Air Quality Guidelines (2006, 2010). The detailed protocol for measuring the selected twelve parameters was developed, including the selection and a minimum number of measuring points, details regarding the accuracy of instrumentation, as well as analysis of measuring results.

Ten parameters used to characterize IEQ are measured. Visible mold is assessed by visual inspection, and the daylight factor is assessed by simulations. The protocol recommends the measurements and assessments in seasons with extreme conditions, which for most European regions comprises at least heating (winter) and non-heating (summer) season. Simulation of some IEQ parameters have been considered as a supplement or to replace the measurements. However, simulations require many assumptions, especially in the case when the original information regarding the construction materials used in the existing building undergoing renovation is unknown. Consequently, it was felt that performing measurements would provide a more accurate estimate of the actual IEQ level in a building. In addition to that, it is worth mentioning that many IEQ parameters simply cannot be simulated at present.

The measuring protocol and the index developed by ALDREN are currently subjected to testing and preliminary validation. Testing is made during pilot measurements carried out by ALDREN project in existing buildings that have undergone energy renovation. The index is reviewed by the project partners and different building stakeholders. Consequently, the index and the protocol presented in this article are not in their final version - they can still be revised and supplemented if the project continues its activity that is scheduled to end in the spring of 2020. There are few additional parameters considered for measurements and few protocol modifications, including the method for determining the overall IEQ level. ■

References

Artola I, et al. Boosting Building Renovation: What potential and value for Europe? Study for the Itre Committee of the European Parliament (2016) (http://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf)

EPBD (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 18(06), 2010.

Wargocki, P., & Seppänen, O. (2006). REHVA Guidebook no. 6, Indoor Climate and Productivity in Offices, How to integrate productivity in life cycle cost analysis of building services. Rehva.

Wen et al. (2019) Summary of indoor environmental quality indicators for hotels and offices – the basis of the IEQ indicators in ALDREN method, in the Press.

World Health Organization. (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: global update 2005: summary of risk assessment (No. WHO/SDE/PHE/OEH/06.02). Geneva: World Health Organization.

World Health Organization. (2010). WHO guidelines for indoor air quality: selected pollutants.