Evaluation results of combined labelling of dwellings located in different countries

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Abstract. In the TripleA-reno project, a new combined labelling scheme was developed for dwellings. The combined labelling includes the evaluation of the energy performance, indoor environmental quality and well-being of occupants in dwellings. In this paper, the method of the TripleA-reno combined labelling scheme, the necessary calculations and measurements and the labelling process are introduced. In the TripleA-reno project, the developed combined labelling was successfully applied to different demonstration cases. The main results and experiences of the combined labelling for four demonstration cases located in Hungary, the Netherlands, Spain and Italy are presented.

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1 Introduction

The TripleA-reno project has received funding from the European Union's H2020 Framework programme for coordination and support action under grant agreement no 784972. The overall project goal is to increase acceptance of - and facilitate decision making on - deep and nZEB renovation for consumers and end-users of residential buildings. To this end, the project is developing a user-centred platform that helps users in the decision-making, implementation, and even in-use phase of the renovation. As part of the project, the aim was to develop a combined labelling scheme for dwellings, which includes energy performance, indoor environmental and well-being indicators. These combined labelling indicators focus mainly on energy performance and comfort features of dwellings that can be changed by renovation.

2 Why is the combined labelling scheme necessary?

There are different demo cases in the project in several countries: condominium in Hungary, multifamily building in Spain, Slovenia and Italy, single-family dwellings in the Netherlands and a student house in Greece. In all cases, a thorough ethnography research [1] was carried out aimed at collecting user demands before starting any development. Currently, the lack of knowledge is a significant barrier to implement renovation projects. Occupants explained they do not have information on renovated buildings and they are interested in the energy savings, the experiences of the operation and the comfort. During a focus group interview, the representative of a building renovation company explained they made many renovation projects, but they neither have accurate data on the achieved energy saving, nor the enhanced comfort in the renovated buildings. This circumstance substantiated the need for the combined labelling scheme including energy, indoor environmental and well-being indicators, which can label dwellings, even before and after a renovation project. The approaches to establish a labelling scheme for residential buildings were already studied in 2011 by Franzitta et al. [2], but finally that Eco-label labelling scheme for residential buildings has not been implemented.

The renovation of building stock plays a major role in meeting the energy efficiency targets set in the EU Member States. The speed at which the building stock improves its energy performance can be expressed as the annual reduction of the total building stock's primary energy consumption. This weighted energy renovation rate is calculated to be about 1%. If this rate persists, the building sector will clearly and significantly fail to deliver its share of the overall need for primary energy reduction and, consequently, reduce greenhouse gas emissions [3]. The low renovation rate of the building sector is a problem in most of the Member States, for example, the article by Filippidou et al. [4] presents the problem of the Dutch non-profit housing sector, wherein have been many renovation improvements applied in the recent years, but these are too small to attain the ambitious national goal of the energy performance. The combined labelling can provide precise, evidence-based data on energy performance, indoor environmental quality and well-being, which could help decision making and increasing the number of deep renovation projects.

The essential indicators were gathered for combined labelling after studying the most widespread among the existing certification schemes, the Level(s) reporting framework and several EU projects. The obvious purpose was to develop a certification that focuses especially on dwellings and its characteristics and make the scheme as simplified as possible to ensure widespread support and easy usability.

As a result of the assessment, there is not an already available combined labelling scheme developed especially for dwellings, which presents the energy performance, indoor environmental quality and well-being indicators altogether. As for energy performance indicators, both the calculated and the measured energy consumption is worth to be presented in the combined labelling, which usually does not appear altogether in the existing certification schemes; however, there is some exception, for example, the ALDREN [5], but this project is developed especially for offices and hotels. The labelling of the qualitative parameters that influence the indoor environmental quality and well-being is also a novel evaluation, which has not been included in the existing schemes or partially appeared (e.g. evaluation of the temperature control strategy in the BREEAM certification scheme [6]). As for the labelling of well-being, the WELL building standard [7, 8, 9] obviously focuses on well-being aspects, but it does not label the energy performance of buildings. M.A. Ortiz et al. studied [10] the well-being and the interaction between influencing factors and concludes the energy use is a consequence of trying to attain homeostasis (comfort, neutral state, lack of stress). This means that people use energy to satisfy their needs and to achieve well-being. In line with this result, the TripleA-reno combined labelling focuses on end-users and informs them about the energy performance and well-being aspects of their homes. The well-being and IEQ indicators label the technical building systems' capabilities from well-being and IEQ point of view. However, in order to know what figures are realised in the analysed residential building or apartment, a series of on-site measurement of parameters that influence IEQ and well-being is also necessary. As Y. Al horr et al. [11] concludes, the building designs do not automatically guarantee the building will be comfortable and ensure occupant well-being. Monitoring the building and occupant performance during its operations is, therefore also necessary. With regards to the metering equipment, significant developments have been made in the recent past on miniaturisation, accuracy, robustness, data storage, ability to connect using multiple communication protocols, and the integration with the cloud, resulting in a range of available solutions [12], which helps the monitoring of buildings.

3 TripleA-reno combined labelling: energy performance, indoor environmental quality, well-being

The methodology used in the main existing certification schemes was reviewed, including regulations and standards, in order to determine the relevant indicators and requirements. As a result of the assessment, the TripleA-reno combined labelling scheme was developed, which includes the following indicators:

Table 1. Combined labelling indicators and main features

Indicators	Main features
Energy performance indicators	Both calculated and measured energy uses are presented.
Indoor environmental and well-being indicators	IEQ and well-being capability of the building and technical building systems.
Measured indoor environmental and well-being indicators	Based on measured figures, related to the specific dwelling and depend on occupant habits.

The labelling includes the most important energy performance, indoor environmental quality (IEQ) and well-being indicators for existing dwellings, so it does not examine other indicators that may hide the result. The first proposal of the TripleA-reno combined labelling scheme was presented in the 50th International HVAC&R Congress and Exhibition in Belgrade [13]. Then the combined labelling scheme was successfully applied to 14 demo cases in several European countries, and the scheme was improved according to the feedback of the demo case experts.

3.1 Energy performance indicators

The Energy Performance Certificate (EPC) has been introduced in EU countries according to the requirements of the EPBD. The EPC shows the characteristics of the building envelope and the HVAC systems and demonstrates the primary energy use of the building. The EPC is an objective assessment that helps end-users get information on energy efficiency; therefore, it makes sense to use energy efficiency class from national EPC as an energy performance indicator.

The calculated total primary energy use is included in the TripleA-reno labelling scheme. According to the EPBD, the primary energy consumption for dwellings takes into account only the energy consumption of heating, cooling, domestic hot water and ventilation. Household electricity (plug load) is not considered when primary energy consumption of different residential buildings or building units is compared, because there can be many differences between one and another dwellings' household appliances and their operation. However, from the end-user point of view, the calculated total primary energy consumption may be too difficult to understand; furthermore, there are significant differences among primary energy factors of different energy sources. Therefore, it makes sense to show the delivered energy use besides the total primary energy use.

Regarding the delivered energy use, both the calculated and the measured delivered energy use are included in the TripleA-reno labelling. The calculated delivered energy use is an objective way of evaluation of energy performance. However, the measured delivered energy is a very useful indicator, especially when somebody would like to monitor the energy consumption before and after a deep renovation or any kind of intervention, or if one needs to evaluate the occupant behaviour. The occupant behaviour has a significant effect on the energy consumption and even on the comfort, and therefore the measured energy consumption (and the measured comfort parameters) cannot be left out from the evaluation. Results obtained by Rouleau et al. [14] show great variability of energy consumption and thermal comfort for a given dwelling when different occupants are living in it, with a range of approximately 50%. The energy consumption monitoring can be implemented based on measurements from the power and gas meters (gas and electricity) and thermal flow meter for district heating/cooling or consumption bills (e.g. oil, biomass).

There are several types of building structures with different thermal transmittances (U-values) within a building, e.g. wall, roof, window. The area-weighted averaging is a simple mathematical technique for combining different amounts of various components into a single number. The area-weighted average thermal transmittance is included as an energy performance indicator in the TripleA-reno combined labelling because it is useful when comparing building structures before and after the renovation, or when one compares the energy characteristics of building structures of different buildings. The area-weighted average thermal transmittance regards only the above-ground structures. In most cases, the renovation includes the insulation of those building structures and not the floor insulation because the latter is very expensive in existing buildings.

The EPBD recast defines the nearly zero energy building, which means a building that has a very high energy performance, and the nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby [15]. The share of renewable energy use in the total primary energy use is essential information for occupants and also for experts, and therefore it is included in the TripleA-reno combined labelling. This indicator is very clear and can motivate end-users to use more renewable energy and protect the environment.

Table 2. Features of the energy performance indicators of TripleA-reno combined labelling

Nr.	Name, unit	Reference/ description	Source
1.1	Energy efficiency class [-]	Align with national energy performance certification (EPBD).	EPBD
1.2	Calculated total primary energy use, [kWh/m²a]	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.	Level(s)
1.3.1	Calculated delivered energy use (fuel), [kWh/m²a]	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.	Level(s)
1.3.2	Calculated delivered energy use (electricity), [kWh/m²a]	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.	Level(s)
1.3.3	Calculated delivered energy use (district energy), [kWh/m²a]	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.	Level(s)
1.3	Calculated delivered energy use, [kWh/m²a]	Sum of all calculated delivered energy use.	Level(s)
1.4.1	Measured delivered energy use (fuel), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	-
1.4.2	Measured delivered energy use (electricity), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	-
1.4.3	Measured delivered energy use (district energy), [kWh/m²a]	Based on measurement or energy bills. Energy consumption without any correction.	-
1.4	Measured delivered energy use, [kWh/m²a]	Sum of all measured energy use.	-
1.5	Share of renewable energy sources, [%]	Renewable primary energy use divided by total primary energy use: $RER_P = \frac{\sum E_{Pren}}{\sum E_{Ptot}}$	REHVA
1.6	Area weighted average thermal transmittance, [W/m²K]	Regarding the above-ground structures: $\overline{U} = \frac{\sum Ai * Ui}{\sum Ai}$	-

3.2 Well-being and IEQ indicators

The well-being and indoor environmental quality very much depend on the features of the technical building systems. The applied method, such as labelling qualitative parameters, is also used in the reviewed DGNB, the SRI, and the Openhouse rating system. In the developed TripleA-reno combined labelling, the well-being and IEQ indicators focus on the most critical features of the technical building systems, which on the one hand influence IEQ and occupant well-being in residential buildings, and on the other hand these can be improved by renovation.

The first indicator is control of the heating system, and the second is control of the cooling system. The heating/cooling systems’ appropriate control is very important for achieving thermal comfort and increasing occupant satisfaction. Occupants should be able to control the heating/cooling system in their homes in order to set the indoor temperature to the desired value. The room temperature control is better than an apartment or the whole building temperature control, because in the case of room temperature control, the occupants can set the indoor temperature according to their specific needs. In the case of central building control, the occupants only have limited influence on setting the indoor temperature. Besides the thermal comfort, occupant satisfaction and well-being are higher if the occupants can regulate the temperature in their home.

The third indicator is an essential indicator, which is supply air flow per person in the case of mechanical ventilation. Inadequate ventilation is a well-known potential factor for sick building syndrome. If the air change rate is inadequate, the concentration of indoor contaminants, such as CO_2 and VOC, will increase, which reduces the indoor air quality and occupants’ well-being and there are negative health implications. The evaluation of the fresh air flow rate is part of every reviewed labelling scheme and, of course, it is part of TripleA-reno combined labelling. In the case of natural ventilation, air change depends on the size and position of openings, which is part of designing a new building. Since TripleA-reno project focuses on existing buildings, where there is limited opportunity to change the size and position of windows, natural ventilation is not in the TripleA-reno labelling scope.

The fourth indicator is the air-tightness of windows and doors, which is not directly included in the reviewed labelling schemes. The low air-tightness of windows can cause local discomfort for occupants, especially during winter when draft can occur close to the openings, furthermore, low air-tightness increases infiltration, which results in higher heating and cooling energy consumption.

The exterior shading is the fifth indicator of the TripleA-reno combined labelling. The exterior shading can provide better thermal comfort, since the temperature of indoor spaces and the glass of windows will be limited, and on the other hand the same indoor temperature can be kept with lower energy use in the cooling season when using exterior shading.

Furthermore, the occupants are not so exposed to the weather conditions, and therefore the user satisfaction and well-being will be better.

Table 3. Well-being and IEQ indicator of TripleA-reno combined labelling

Nr.	Name, unit	Reference/ categories	Source
2.1	Control of the heating system	1. No heating system 2. No control 3. Central (building) temperature control 4. Apartment temperature control 5. Room temperature control	-
2.2	Control of the cooling system	1. No cooling system 2. No control 3. Central (building) temperature control 4. Apartment temperature control 5. Room temperature control	-
2.3	Supply air flow per person (in case of mechanical ventilation) [l/s, pers]	EN 16798-1 category I, II, III fresh air flow per number of occupants	Level(s)
2.4	Air-tightness of windows and doors	1.Poor air-tightness: warped, poorly fitted or unsealed windows and doors. 2.Medium air-tightness: windows and doors with well-fitted sealings. 3.Good air-tightness: factory-fitted shaped sealing profiles or certification document according to EN 12207 Class 4	-
2.5	Exterior shading [%]	Percentage of the windows with exterior shading. Windows are taken into account only from East to West.	-
2.6	Radiant heating and/or cooling system [%]	Radiant heating and/or cooling system (floor, wall, ceiling) operates in rooms at least 50% of the conditioned floor area	WELL
2.7	Radiant temperature asymmetry	Radiant temperature asymmetry meets ISO 7730 Category B requirement	ISO 7730

The radiant heating and cooling systems have the potential to provide better thermal comfort than conventional systems. The rating of the radiant heating and cooling system is adopted from the WELL labelling scheme. The sixth indicator of the TripleA-reno combined labelling provides information to the occupant about the radiant heating/cooling systems, whether radiant systems operate in rooms at least 50% of the conditioned floor area.

The evaluation of the radiant temperature asymmetry is included in most of the reviewed labelling scheme. The ISO 7730 standard defines the requirements of three different categories, from which category B is selected for TripleA-reno combined labelling because it is appropriate for existing buildings.

3.3 Measured well-being and IEQ indicators

The well-being and IEQ indicators presented in Section 3.2 provide feedback to the end-user about the technical building systems and its capabilities from well-being and IEQ point of view but does not provide information on what figures are realised in the analysed dwelling. Therefore on-site measurements are needed to evaluate the realised condition and provide information to the occupants on which parameters are good and which one should be improved.

TripleA-reno focuses on motivating the renovation of residential buildings; therefore, those essential parameters have been collected that significantly affect occupant well-being and IEQ in residential buildings and can thus be improved by renovation. The operative temperature, the relative humidity and the CO_2 concentration are the most important parameters that people are sensitive about. The measurement of these parameters is mandatory. The operative temperature and the CO_2 have to be compared to the categories of standard EN 16798-1. That category shall be selected from the standard for the labelling, where 85% of the measured data meets the category requirement. The relative humidity has to be in the comfort range, which is between 25 and 70 %RH.

The most common air contaminants, such as TVOC and formaldehyde, are taken into account in the TripleA-reno labelling. Building materials, furnishings, fabrics, cleaning products, personal care products and air fresheners can all emit volatile organic compounds (VOCs) into the indoor environment. Owing to VOCs' complexity, both the individual health effects on the human body can be different and vary greatly in certain cases. Long-term exposure to even low TVOC concentrations can lead to unspecific symptoms and reactions including perception unpleasant odours and tastes, runny nose and watery eyes, irritation of eyes/nose/throat, dry skin and itching, increased sensitivity to infections of the respiratory tract, neurotoxic symptoms (fatigue, headaches, reduced mental performance).

Formaldehyde (HCHO) can be released from the plastics, furniture, and adhesives in homes, which can be further concentrated in the living space during the winter. Formaldehyde is a colourless aldehyde gas and, similar to TVOC, even small quantities of formaldehyde in the room air may affect human health. The symptoms include concentration disorders, nervousness, headaches, dizziness, but also nausea, swelling of the mucosa, conjunctival irritations and lacrimation [16].

In the TripleA-reno labelling, the allowed concentration of TVOC as well-being limit was taken from WELL [7] and LEED [17] labelling schemes, and it is 500 µg/m³. However, the costly and complex laboratory analysis (ISO 16000-6) is not a requirement because the TVOC measurement is informative. The allowed concentration of formaldehyde was taken from WHO, and it is 100 µg/m³. The laboratory analysis (ISO 16000-3) is not a requirement because the formaldehyde measurement is informative. The allowed concentration of PM2.5 and PM10 was taken from WELL labelling scheme: PM2.5 = 15 µg/m³, PM10 = 50 µg/m3. The measurement can be implemented with a light-scattering airborne particle counter according to ISO 21501-4.

Table 4. Measured well-being and IEQ indicators of TripleA-reno combined labelling scheme

Nr.	Name, unit	Reference/ categories	Source
3.1	Operative temperature – heating* [°C]	Measured data compared to EN 16798-1 temperature ranges.	-
3.2	Operative temperature – cooling* [°C]	Measured data compared to EN 16798-1 temperature ranges.	-
3.3	Relative humidity of indoor air is between 25 % and 70 % [%RH]	Measured data compared to 25 to 70 %RH.	-
3.4	CO_2 concentration [ppm]	Measured data compared to EN 16798-1 categories.	-
3.5	TVOC [µg/m³]	Measured data compared to the limit (500 µg/m³)	Well-being limit adapted from WELL, LEED
3.6	Formaldehyde [ppb]	Measured data compared to the limit (100 µg/m³)	WHO
3.7	PM2,5 [µg/m³]	Measured data compared to the limit (15 µg/m³)	Well-being limit adapted from WELL
3.8	PM10 [µg/m³]	Measured data compared to the limit (50 µg/m³)	Well-being limit adapted from WELL

*During the site survey operative temperature in the heating season or the cooling season has to be measured according to the actual season.

3.4 Required measurements

The requirements of the measurements are summarised shortly in this section. The measurement place is the living room. The operative temperature, the relative humidity and the CO_2 concentration of indoor air should be measured for at least one week by 5-minute time series. The measured data of indoor temperature and CO_2 concentration has to be compared to the ranges of EN 16798-1 standard, while the relative humidity has to be compared to the comfort range that is from 25 to 70 %RH. The TVOC and the formaldehyde measurements should be completed two times on the spot, at the beginning and the end of one week measurements of temperature, relative humidity and CO_2 concentration. The measurement of PM2.5 and PM10 should also be completed two times on the spot, but it requires at least 30 minute-long measurements, at the beginning and the end of one week measurements of temperature, relative humidity and CO_2 concentration. During the evaluation of the measured figures, the category satisfied by at least 85% of the measured figures must be chosen.

3.5 Labelling

The energy performance indicators express the energy characteristic of the building, which contains the energy efficiency class, the calculated and the measured energy use, which are displayed to the end-user one by one. The energy efficiency class (A+, A, B, C, ...) of the analysed dwelling clearly conveys the energy efficiency of the current condition. The calculated figures, such as total primary energy use, delivered energy use per energy sources, measured energy use per energy sources, the share of RES and the area-weighted average thermal transmittance provide information on the main energy characteristics of the analysed dwelling.

Concerning the joint assessment of well-being and IEQ, the labelling output is one class to ensure easy understanding. However, the labelling presents not only the result (the achieved class) but all of the indicators with its gained and theoretical maximum points, which details the result and provides information on what should be improved. The steps of the labelling of the well-being and IEQ indicators are as follows:

1. Score calculating: the relevant well-being and IEQ indicators gain points according to Table 5 and Table 6 below.
2. Sum the gained scores of the relevant indicators.
3. Sum the theoretical maximum scores of the relevant indicators. These include maximum points for all the relevant indicators. For example, if there is no cooling system or mechanical ventilation system in the building, those will not be concerned when calculating maximum points that can be achieved.
4. Calculate the percentage of total gained points / total theoretical maximum points.

5. Labelling based on the calculated percentage of total and theoretical maximum points according to Table 7 below.

Table 5 below demonstrates the well-being and IEQ indicators scoring, Table 6 introduces the measured well-being and IEQ indicators, and Table 7 shows the labelling.

Table 5. Scoring of the well-being and IEQ indicators

Nr.	Name	Scores
2.1	Control of the heating system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
2.2	Control of the cooling system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
2.3	Supply air flow per person (in case of mechanical ventilation)	Fresh air flow per number of occupants meets EN 16798-1 category I, II: 20 points Fresh air flow per number of occupants meets EN 16798-1 category III: 10 points Less than EN 16798-1 category III: 0 points
2.4	Air-tightness of windows and doors	Good air-tightness: 10 points Medium air-tightness: 5 points Poor air-tightness: 0 point
2.5	Exterior shading	10 points for 100% of windows from East to West have exterior shading 9 points for 90%-99% 8 points for 80-89% 7 points for 70-79% 6 points for 60-69% 5 points for 50-59% 4 points for 40-49% 3 points for 30-39% 2 points for 20-29% 1 point for 10-19% 0 point for 0-9%
2.6	Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area	Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area: 10 points Radiant heating and/or cooling system operates in rooms less than 50% of the conditioned floor area: 0 points
2.7	Radiant temperature asymmetry	Radiant temperature asymmetry meets ISO 7730 Category A or B: 10 points Radiant temperature asymmetry meets ISO 7730 Category C or worse: 0 points

Table 6. Scoring of the measured well-being and IEQ indicators

Nr.	Name	Scores
3.1	Operative temperature – heating	30 points - EN 16798-1 Category II 15 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.2	Operative temperature – cooling	15 points - EN 16798-1 Category II 8 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.3	Relative humidity of indoor air is between 25 % and 70 %	5 points if RH is between 25 and 70 %RH
3.4	CO_2 concentration	20 points - EN 16798-1 Category II 10 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
3.5	TVOC	10 points - TVOC is under 500 μg/m³ 0 point - TVOC is 500 μg/m³ or more
3.6	Formaldehyde	10 points - Formaldehyde is under 100 μg/m³ 0 point - Formaldehyde is 100 μg/m³ or more
3.7	PM2,5	5 points if PM2.5 is under 15 μg/m³ 0 point if PM2.5 is 15 μg/m³ or more
3.8	PM10	5 points if PM10 is under 50 μg/m³ 0 point if PM10 is 50 μg/m³ or more

Table 7. Labelling results in the TripleA-reno combined labelling

Calculated percentage of total and theoretical maximum points	Labelling
90-100%	Excellent
80-89%	Good
60-79%	Acceptable
50-59%	Weak
0-49%	Very weak

3.6 Demonstration buildings

Validation of the developed combined labelling scheme on energy performance, IEQ and well-being was executed with real data of the TripleA-Reno project's demonstration buildings. The combined labelling template was applied to 14 dwellings in several European countries. The proposed combined labelling scheme was developed during the validation procedure according to the feedback from experts responsible for demonstration buildings. In the following sections, the main labelling results and experiences are presented for case studies located in Hungary, Italy, Spain and the Netherlands.

3.6.1 Case study, Hungary

The Hungarian demo building is located in Szigetszentmiklos, 30 km far from Budapest. The building was built in 1982 with prefabricated concrete panel construction technology. The building has a total of 60 apartments. The walls and the roof have a poor thermal characteristic. Most of the windows were replaced to new PVC framed windows. The building is connected to the district heating system, which provides thermal energy for heating and domestic hot water purposes. Within the building there is a 1-pipe heating system, the heating appliances are radiators equipped with a manual valve.

The energy efficiency class is "F" for two examined apartments, and "D" is for one analysed apartments. The wall and the roof of the building have very weak thermal insulation; therefore the area-weighted average thermal transmittance (1.09-1.23 W/m^2K), the delivered energy use (150-234 kWh/m^2a) and the primary energy consumption (159-243 kWh/m^2a) are high in the analysed dwellings. The renewable energy ratio is almost zero in the current condition. The building has central heating control which often results in overheating in some apartments, and the indoor temperature was even out of category III of the EN 16798-1 standard.

The well-being and IEQ indicators of the technical building systems were evaluated, and the result is weak for "apartment 1" and "apartment 2", and acceptable for "apartment 3". The main reason for the low level of well-being and IEQ performance of the technical building systems is the central building temperature control in the heating system; thus, the occupants cannot control the indoor temperature according to their specific needs. The better well-being and IEQ indicator in "apartment 3" is due to a local air conditioning system (split unit) in the living room, which has room temperature control; therefore, the occupant in this apartment is at least able to control the indoor temperature in the cooling season. The pilot building is an old building; therefore, there is no radiant heating or cooling system. These characteristics of the analysed dwellings provide little chance for the occupants to achieve well-being and create good indoor environmental quality in their homes. The central building control cannot provide adequate thermal comfort in all apartments. Typically, when the indoor temperature is good in apartments at the edge of the building, there can be overheating in the intermediate apartments without apartment or room control. The features mentioned above of the technical building system can trigger comfort complaints.

The measured well-being and IEQ indicator is acceptable for "apartment 2" and very weak for "apartment 1" and "apartment 3". During the measurement executed in the heating season, in "apartment 2" the measured operative temperature meets EN 16798-1 category II, however in "apartment 1" and "apartment 3" – which are on the edge of the building – it meets Category IV or worse. The temperature measurement was also executed in the apartments in the cooling season, and the indoor temperature of each apartment met the EN 16798-1 category III requirement. The measured CO_2 concentration was Category II in "apartment 1" and category III in the others. All these apartments have natural ventilation, which means the CO_2 concentration depends on how regularly and how much time the occupants open the windows. The relative humidity was out of the comfort range (25-70% RH) in each apartment. The TVOC was also measured in the apartments, and it did not fulfil the 500 $\mu g/m^3$ limit. The measured formaldehyde figures were well below the WHO limit (100 $\mu g/m^3$), except in "apartment 1". PM2.5 and PM10 figures were measured as well: in "apartment 2" the PM2.5 was under the limit, while PM10 was over the limit; in "apartment 1" and "apartment 3" neither PM2.5 nor PM10 was under the limit.

Based on the combined labelling, the thermal insulation of the walls and the roof is recommended, which results in less heating energy use and improves IEQ (operative temperature: indicator 3.1 and 3.2). Installing thermostatic valves on the radiators is recommended, ensuring room control of the heating system, reducing heating energy use, and improving thermal comfort (no more overheating) and well-being (automatic operation). Installing a thermal solar collector system for the whole building is suggested, which reduces the energy use of domestic hot water production and increases renewable energy ratio. There is natural ventilation in the building; therefore when the outdoor PM is high (vehicle traffic is stronger, traffic jam, solid fuel heating happens in the neighbourhood), the windows' opening should be avoided if possible.

3.6.2 Case study, Italy

The Italian demo building is located in Concordia Sagittaria, which is 60 km far from Venezia. The building was built between 1977 and 1978, and it is owned by ATER Venezia and hosts 21 apartments on four floors above ground. The external walls are made of a double layer of hollow bricks with thin thermal insulation. The heating system and the domestic hot water production are centralised: there is an oil-fired heating boiler, which provides thermal energy for heating and domestic hot water. The apartments have low performing window glasses and frames, and there is neither room thermostat, nor thermostatic radiator valves to control the indoor temperature.

The energy efficiency class is "F" or "G" for all the analysed apartments. The primary energy consumption (209-294 kWh/m^{2}a), the delivered energy use (123-173 kWh/m^{2}a) and the average thermal transmittance (1.12-1.66 W/m^{2}K) are significantly high. The reason for variable calculated figures is the different apartment's position inside the building. The measured delivered energy consumption is 20-25% higher than the calculated delivered energy use. This gap could be reasonably due to the central heating control that causes overheating in the apartments. Furthermore, the absence of thermostatic valves combined with the low energy performance of walls and windows increases this problem. The renewable energy ratio is zero in the current condition.

In all the surveyed dwellings the well-being IEQ indicators of the technical building systems highlighted a very weak performance, only the exterior shading indicator reaches the maximum score. The heating system has central temperature control; therefore, occupants cannot control the indoor temperature. This is one of the most frequent complaints reported by residents. Windows and doors have really poor air-tightness resulting in draughts and infiltrations, which caused evident plaster blooming and mould presence on the external walls. Finally, the Concordia building is an old building; therefore, there is no radiant floor, wall or ceiling heating/cooling system. These characteristics provide little chance for the occupants to achieve well-being and create good indoor environmental quality.

Operative temperature, relative humidity, and CO2 concentration were measured in four apartments in winter and summer. The operative temperature reaches only category III of EN-16798-1 standard in three apartments due to the central temperature control. The relative humidity was in the 25-70 %RH comfort range in three apartments, and it was out of the comfort range in one apartment. There is natural ventilation in the building; the measured CO_2 concentration was category II in two apartments and category III in the other two apartments. The windows' appropriate and regular opening results in better indoor air quality, which provides better labelling outcome.

The tender of the energy renovation project for the Concordia building is in progress; the design specifications are in line with the combined labelling assessment recommendations. The renovation includes the thermal insulation of the walls and the roof, which reduces energy use and improves thermal comfort. All windows and doors will be replaced with thermal break frames and low emission glasses. The oil boiler will be replaced to condensing gas boiler, improving the energy efficiency. The energy production will be supplemented by installing a photovoltaic system on the roof with 10 kW peak power. Thermostatic valves will be installed in the apartments in combination with the implementation of independent energy consumption accounting. The renovation project definitely improves both energy performance and comfort indicators.

3.6.3 Case study, Spain

The Spanish demo case is located in Almoradí, a medium-sized town close to the Alicante Mediterranean shore (Costa Blanca). The demo case involves five multifamily buildings built in 1982, and it is owned by the Regional Social Housing Company EVHA. The walls have poor energy performance. The apartments were initially constructed with wooden framed windows with single glass. There is electric heating in the rooms and air conditioning unit for heating and cooling in the living rooms. The passage of time, the lack of maintenance and the few economic resources of its inhabitants have resulted in a degraded building complex, with an unattractive and outdated image.

The energy efficiency class is "G" for the three examined apartments. The building walls have very weak thermal insulation; the original wood-frame windows also have poor energy efficiency; therefore, the area-weighted average thermal transmittance (1.09-2.08 W/m^{2}K), and the primary energy consumption (284-301 kWh/m^{2}a) are high in the analysed dwellings. The renewable energy ratio is zero in the current condition. The measured delivered energy consumption is lower than the calculated delivered energy consumption. The reason of this gap clearly turned out during the on-site visit and measurement, because the indoor temperature was even out of category IV of the EN 16798-1 standard in two apartments, i.e. the temperature and the occupant behaviour is significantly different from the standard user profile.

The well-being and IEQ indicators of the technical building systems were evaluated, and the results are acceptable. Indicators 2.1, 2.2 (control of heating, cooling system) and 2.5 (exterior shading) got the maximum scores, but for the 2.2, is to be noted that occupants installed local air conditioning split units only in their living rooms; therefore occupants can control the living room's indoor temperature in the cooling season. In all apartments, 100% of windows from East to West orientation have exterior shading, but the windows and the doors are old and neglected and have very poor air-tightness. The building is old, and there is no radiant heating or cooling system. These characteristics provide an acceptable chance for the occupants to achieve well-being and create good indoor environmental quality in their living rooms, but none in the rest of their homes.

The measured well-being and IEQ indicators were assessed, and the labelling result is acceptable (61-64%) for all the apartments. In "apartment 1" the measured operative temperature meets EN 16798-1 category III, while in "apartment 2" and "apartment 3" it meets category IV. All the apartments have and properly use, natural ventilation, resulting in adequate CO_2 concentration levels (EN 16798-1 category II). The relative humidity was most of the time within the comfort range. The TVOC was also measured in the apartments and exceeded the 500 µg/m³ limit in all of them. On the contrary, the measured formaldehyde figures were well below the WHO limit (100 µg/m³). PM2.5 and PM10 figures were measured as well and were under the limits for "apartment 2" and "apartment 3", while in "apartment 1" were over the limit, which can be explained due to the position of the apartment on the ground floor with a façade facing to a strong vehicle traffic road.

The thermal insulation of the walls and changing windows are recommended, which results in less cooling (and heating) energy use and will improve IEQ (Indicator 3.1 and 3.2, operative temperature). Sealing shutter boxes and perimeter of the windows will improve air-tightness. It is recommended that the home user have information on the indoor/outdoor conditions to make sound decisions regarding the on/off of their air conditioning equipment or open/close windows. Installing a thermal solar collector system for the whole building is suggested, which reduces the energy use of domestic hot water production and increases renewable energy ratio.

3.6.4 Case study, Netherlands

Two dwellings are assessed in the Netherlands, which are located in Eindhoven. Dwelling-1 is a typical Dutch style, 2-storeys, semi-detached house reflecting the architectural style of the 1930s, which is the era of its construction. The dwelling-2 is the second dwelling of a row house.

The energy efficiency class is "G" for dwelling-1, the calculated primary energy use is 413 kWh/m^{2}a, and the area-weighted average thermal transmittance is 1.48 W/m^{2}K, due to weak thermal insulation performance of walls and windows. The building structures of dwelling-2 have a bit better thermal performance that results in lower area-weighted average thermal transmittance (1.28 W/m^{2}K), while the primary energy consumption (145 kWh/m^{2}a) is much lower compared to dwelling-1 because heated dwellings surround it on two sides.

The well-being and IEQ indicators of the technical building systems were evaluated, and the results are weak for both surveyed dwellings. The main reasons for the low level of well-being and IEQ indicator are the heating system's central control, the low air-tightness of windows and doors and the lack of exterior shading.

Operative temperature, relative humidity and CO_2 concentration were measured both in winter and summer period. The operative temperature reaches category III of EN-16798-1 standard in both dwellings in the heating season due to the central temperature control. The operative temperature in the summer period got the worst result, i.e. category IV of EN-16798-1 standard in both dwellings. In dwelling-1, the relative humidity was in the comfort range; however, the CO_2 concentration meets only category III of standard 16798-1. In contrast, the relative humidity in dwelling-2 was out the comfort range, but the CO_2 concentration was category II of standard 16798-1.

The measured temperature, CO_2 concentration and relative humidity values provide "very weak" result in dwelling-1 and "weak" result in dwelling-2, which means occupants may have issues to ensure good indoor environmental quality in their homes.

Based on the combined labelling assessment, the thermal insulation of walls and changing windows are recommended, which reduces heating and cooling energy use and improves comfort.

In dwelling-1, it is recommended to install a CO_2 sensor and adapt the user behaviour by more often open windows to reduce the CO_2 concentration when the room is occupied by more than one person. In dwelling-1, the relative humidity should be reduced by installing an exhaust fan in the bathroom.

3.7 Conclusion

The TripleA-reno combined labelling scheme can inform people about the energy performance, IEQ and well-being of their homes. The energy performance indicators are essential to motivate occupants to renovate their homes. It has to be stressed out that, besides that calculated primary energy use, both calculated and measured delivered energy use are presented. The calculated delivered energy use is practical for objective comparison of different dwellings, while the measured delivered energy consumption is capable of presenting the realised energy performance especially before and after a renovation project and can also be useful to evaluate occupant behaviour.

Beyond the energy performance assessment, the evaluation of technical building systems in terms of well-being and IEQ can indicate which improvements are necessary to achieve better IEQ. If the rating of the technical building system provides a bad result, it does not always mean the actual indoor environmental quality is poor, but in such conditions, it is expected to be much more challenging to maintain good indoor environmental quality and well-being. The actual condition can be assessed with on-site measurements including temperature, relative humidity and indoor air pollutants. The TripleA-reno combined labelling is suitable for highlighting areas that need to be addressed to ensure better indoor environmental quality and well-being.

The excel template of the combined labelling can be downloaded via this link: https://triplea-reno.eu/wp-content/uploads/2020/09/Annex-1-TripleA-reno_Combined-labelling-template_v2.xlsx.

The TripleA-reno project team is developing the combined labelling web tool, which will be available also on the project website at https://triplea-reno.eu. This paper's authors hope the combined labelling will be successfully applied by building engineers, home energy auditors, and architect colleagues, who can inform homeowners, tenants, and investors about the energy performance, indoor environmental quality and well-being properties, and development opportunities of homes.

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