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Acoustic Classification of Buildings: Impact of Acoustic Performances of a High Energy-Efficient Building on Quality and Sustainability Indicators

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ABSTRACT

According to similar experiences of other countries, also Italian standards are defining procedures about acoustic classification of buildings, aiming at the determination of indoor acoustic comfort. Acoustic parameters influence building quality in different ways and amounts: the aim of the paper is to attest acoustic performances of buildings, taking into account different noise sources and people expectations. A voluntary certification model was proposed to assess indoor overall quality, which includes a specific Acoustic Performance index (AP) concerning human protection against noise into buildings. According to existing standards, noise measurements were carried out in order to assess acoustic performances of walls, façades, floors and systems in a high energy-efficient multifamily building as a case study. The paper shows a feasible approach to perform indoor acoustic comfort and to support sustainable buildings: a comparison was carried out between impact of acoustic performances on proposed assessment of building quality and on certification of building environmental sustainability introduced by law at regional level.

INTRODUCTION

As human activities at home, work or play impose to spend a long time of our lives into buildings, top indoor comfort must be guaranteed. Well-being condition comes from a combination of suitable thermal-hygrometric-microclimatic parameters, natural and artificial lighting, use of water and other resources, safety and technology, together with acoustic climate. High acoustic performances are unavoidable requirements which influence quality and value of buildings.

In the last years a real effort has been made and legislation has been revised, both at international and local level, to improve man protection from acoustic pollution and to promote effective ways in order to achieve building total quality and sustainability.

Together with the necessity to verify the respect of noise limits, it is important to quantify the impact of acoustic performances in the assessment of quality and environmental sustainability of buildings.

In this context, the paper shows the determination of the main acoustic parameters in a modern multifamily apartment building, performing excellent thermal insulation and energy saving. Experimental measurements were carried out in order to assess acoustic insulation of building elements and noise of systems concerning the case study. Waiting for the publication of national standard concerning acoustic classification of buildings in Italy, 2 different certification outlines were applied to the examined dwelling:

1. certification of building total quality BGP, proposed by CIRIAF (University of Perugia, Italy);
2. certification of building environmental sustainability, adopted by Umbria Region (Italy).

As a case study, Building Global Performance (BGP) certification was applied to a private flat in the above mentioned high energy-efficient building. Results were compared with outputs coming from certification of building environmental sustainability to determine respective impacts of acoustic performances.

The aim of the paper is to supply a contribution to the integrated assessment of factors influencing indoor quality, with particular attention to acoustic comfort into buildings, to enhance the satisfaction of the inhabitants by meeting their requirements.

ACOUSTIC CLASSIFICATION OF BUILDINGS: ITALIAN CONTEXT

Italian decree DPCM 5 December 1997

Acoustic performances of buildings in Italy are regulated by national decree DPCM 5 December 1997 [1], concerning airborne and impact sound insulation, noise levels coming from outside and from technical equipment. At present the decree is partially suspended as regards disputes between private citizens and its text is going to be updated.

DPCM 5 December 1997 imposes all over national territory the necessity to plan and design buildings in order to guarantee a fitting shield against noise and to achieve indoor acoustic well-being. Acoustic parameters influence the assessment of building quality in different ways and amounts: a suitable acoustic insulation improves life and stay into buildings and a correct planning can anticipate and solve deficiencies.

Italian standard project UNI U20001500

In many countries building regulations specify minimum requirements concerning acoustic conditions into dwellings. As complying with law limits does not necessarily guarantee satisfactory conditions for the occupants, several countries have introduced classification schemes, where classes represent different levels of acoustic comfort. Acoustic performances of buildings can be expressed as legal minimum requirements or, if available, as a specific class in a classification model, by specifying class criteria for different acoustic aspects [2].

Recently also Italian standard organization UNI has defined procedures about the acoustic classification of buildings, in order to assess and to improve indoor acoustic well-being. The outline of acoustic classification of buildings, proposed by UNI project of U20001500 Italian standard [3], introduces the classification both of single acoustic parameters, concerning building systems and acoustic insulation of façades, walls and floors, and of a final summary index as regards the whole apartment.

CERTIFICATION OF BUILDING OVERALL QUALITY BGP

Certification scheme and purpose

In 2007 Applied Physics Section of CIRIAF - University of Perugia (Italy) proposed an experimental model of building total certification, called BGP (Building Global Performance) [4]. BGP protocol was originally set in order to test the overall quality of an existing low performance flat: recently it has been updated according to the latest standards and regulations and it has been integrated, taking into account results obtained by implementations and applications.

The aim of BGP certification model is not to estimate only energy contributions of winter and summer air conditioning, warm water, ventilation, lighting system and renewable sources, but mainly to extend the assessment of a dwelling from energy efficiency to all fundamental factors playing a role in comfort.

Energy needed to condition indoor microclimate depends on building shell (opaque and transparent elements), heating/cooling systems and plant efficiency. Suitable artificial and natural lighting into buildings enhance indoor comfort: correct exposure to sun, medium illuminance according to visual tasks, limits for direct dazzle of light sources and fitting chromatic features of lamps are essential to provide comfortable lighting conditions. Attention must be paid also to water saving and to renewable energy sources, in order to encourage rational use of resources and to decrease costs and pollution (waste of water can be reduced by specific devices, such as systems for the recovery of rain water). Safety of systems is basic: a building can't be comfortable if it is unable to protect people from risks caused by dangerous plants. Electrical, gas and water systems must be provided with protection devices and automatic control stop in case of leaks. Safety of persons means also protection from outside: it can be upgraded by control, alarm and video-surveillance devices. Finally, available technology affects positively functionality and well-being into buildings by integration of services, automation and communication systems.

As an extension and an integration of building energy certification scheme to building overall performance, BGP index concerns all main aspects in an independent and objective way. Quality of buildings means an assessment of indoor overall comfort. Single contribution indicators were proposed and a global index was defined to classify new and existing buildings, referring to total performance: the paper shows the application of building global certification model to a private flat in a high energy-efficient building as a case study.

BGP certification provides for 6 indicators and 7 classes for each of them. Every class of performance is assigned a value from 0 (the lowest quality or class G) till 7 points (the highest quality or class A). Score derives from comparing in situ outcomes of specific parameter with a worth scale, which was assumed on the basis of standards and technical literature. BGP total index is calculated as the weighted mean of the 6 indicators: each of them is assigned a weight on the basis of objective criteria.

Assessments can be graphically represented as a quality "label", both for every single indicator and for BGP final index. If various assessments can be carried out as concerns the same indicator, the most critical value is considered cautiously.

Acoustic Performance index AP

The aim of the paper is to propose and show a scheme to attest acoustic comfort into buildings, taking into account protection from indoor and outdoor noise, use of rooms and people expectations. According to BGP code, acoustic quality of a building or of a building zone is expressed by AP index (Acoustic Performance) and it is defined by determining 7 categories of indoor acoustic well-being for every single acoustic requirement provided for by DPCM 5 December 1997: R'_w, $D_{2m,nT,w}$, $L'_{n,w}$, L_{ASmax} and L_{Aeq}. For each of these 5 parameters the limit established by decree for residential buildings was assumed as central value of the worth scale and the ranges for different classes were defined taking into account reasonably obtainable acoustic performances (Table 1).

Table 1. BGP: worth scale of acoustic requirements for residential buildings

Parameter	Class/Score						
	G/1	F/2	E/3	D/4	C/5	B/6	A/7
R'_w [dB]	≤44	45-47	48-49	50	51-52	53-55	≥56
$D_{2m,nT,w}$ [dB]	≤33	34-36	37-39	40	41	42	≥43
$L'_{n,w}$ [dB]	≥68	66-67	64-65	63	59-62	55-58	≤54
L_{ASmax} [dB(A)]	≥42	39-41	36-38	35	32-34	29-31	≤28
L_{Aeq} [dB(A)]	≥38	37	36	35	31-34	27-30	≤26

According to international and Italian standards, noise measurements must be carried out in order to evaluate acoustic performances of walls, façades, floors and systems into buildings.

In situ measurements have to be compared with class values fixed in Table 1 in order to assign every single acoustic parameter a score from 1 till 7. AP index of tested building unit corresponds to weighted average of scores obtained for each factor: adopted normalized weights are shown in Table 2, where $D_{2m,nT,w}$ is assigned a slightly higher impact and L_{Aeq} a slightly lower impact than other parameters.

Table 2. BGP: normalized weights assigned to acoustic parameters

Parameter	Weight
R'_w	0.20 (20%)
$D_{2m,nT,w}$	0.25 (25%)
$L'_{n,w}$	0.20 (20%)
L_{ASmax}	0.20 (20%)
L_{Aeq}	0.15 (15%)
AP	1.00 (100%)

The decision to assign $D_{2m,nT,w}$ an impact on overall Acoustic Performance a little higher than the one due to the other factors seems justified by the role of façade airborne insulation in the protection of indoor acoustic climate from external noise (transport, industry, human activities etc.): in addition, the certification of building environmental sustainability, adopted by Umbria Region, concentrates acoustic assessment on such requirement (see "Certification of building environmental sustainability" further on). As concerns building systems, it appears reasonable to consider noise effect of continuous services (such as Controlled Mechanical Ventilation) just a little lower than the one produced by discontinuous services (e.g. wc discharge), which is generally more annoying and less tolerable.

Finally calculated AP index is compared with limits reported in Table 3 in order to classify the acoustic quality of tested building.

Table 3. BGP: standardized worth scale of Acoustic Performance index AP for residential buildings

Parameter	Class						
	G	F	E	D	C	B	A
AP	<1.5	≥1.5 <2.5	≥2.5 <3.5	≥3.5 <4.5	≥4.5 < 5.5	≥5.5 <6.5	≥6.5

As the above mentioned acoustic certification of buildings, proposed by UNI U20001500 standard project [3], also AP module of BGP protocol introduces the classification of every specific acoustic parameter and of a final synthesis index. However, such a voluntary scheme privileges the check of the most critical noise conditions rather than the whole dwelling average values and prudently it establishes indoor acoustic comfort on the minimal performances of each requirement.

Overall quality index BGP

A new instrument for indoor quality certification was proposed: 6 indicators concerning Energy-Microclimate (EMP), Acoustic (AP), Lighting (LP), Water-Resources (WRP), Safety (SP) and Technology Performance (TP) were defined to determine Building Global Performance index.

BGP total quality index is calculated by giving a weight to the 6 indicators describing building performances. In order to assign every single index the fitting and consistent weight, different criteria were examined and it was preferred the one based on costs, which seems to assure the greatest objectivity. Therefore weights were determined on the basis of cost analysis.

According to Italian market general data, average costs to be supported, to equip buildings with materials and devices which can guarantee high performances, were estimated in about 54% of total costs of plant design and installation. Normalized weights given to all different indicators were obtained by comparing single contributions to total percentage of 54% (Table 4).

Table 4. BGP: normalized weights assigned to single indicators and final index

Index	Contribution	Cost/Total	Weight
EMP	Energy efficiency, thermal insulation, microclimate	25%	0.46 (46%)
AP	Acoustic insulation of components and systems	10%	0.19 (19%)
LP	Natural light and artificial lighting system design	2%	0.04 (4%)
WRP	Water and other resources saving equipment	6%	0.11 (11%)
SP	Safety devices for man and systems	5%	0.09 (9%)
TP	Technological devices improving indoor life	6%	0.11 (11%)
BGP	Indoor overall quality performance	54%	1.00 (100%)

The rate of every performance was gained on the basis of medium cost analysis: expense necessary to obtain the excellence of performance was compared with total costs of equipment and then normalized to total percentage. Acoustic insulation fee was calculated equal to 10% of total costs of building systems: therefore, referring to total expense for optimization (54%), Acoustic Performance index affects BGP total quality index for about 19%.

CERTIFICATION OF BUILDING ENVIRONMENTAL SUSTAINABILITY IN UMBRIA REGION (ITALY)

By Regional Law 18 November 2008 n. 17 and relevant Technical Disciplinary, Umbria Region (Italy) adopted the certification of building environmental sustainability.

Certification is optional for private citizens and it is compulsory for public organizations: 22 specification cards of Italian ITACA protocol, concerning the assessment of energy and environment building quality, were adapted to local context. Scores obtained in every single card, from –1 to +5 (according to a scale ranging from "sufficient" to "very good"), must be balanced in compliance with weights given to different contributions, then they have to be added to determine the performance of specific assessment areas. The sum of values represents building total performance in hundredth parts and it identifies the class of environmental sustainability referring to certification scale (Table 5).

Table 5. Umbria Region: classification of building environmental sustainability

Class	D	C	B	A	A+
Score [/100]	< 40	40-54	55-69	70-84	85-100

Source: (ARPA Umbria, 2009)

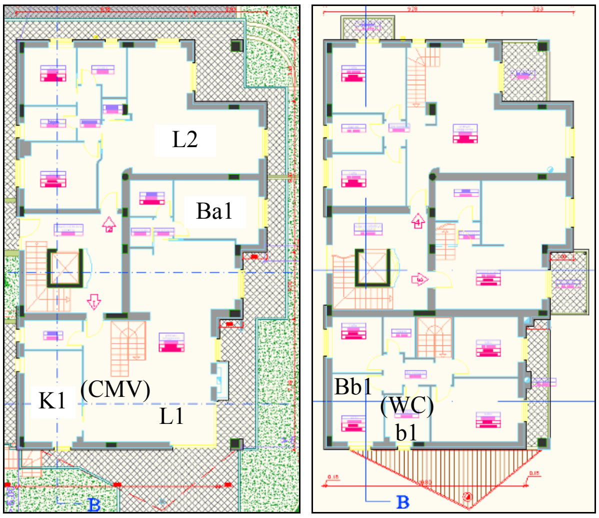
Environmental requirements of dwellings are determined according to 5 assessment areas: "Quality of site", "Consumption of resources", "Environmental impacts", "Indoor quality" and "Quality of service". Umbria Region classification assigned a weight of 15,76% to "Indoor quality": this area evaluates comfort into buildings by 4 assessment cards concerning ventilation, air temperature, natural lighting and acoustic insulation of building shell. As each of these 4 parameters concurs to determine indoor well-being with the same rate (25%), incidence of acoustic insulation on final result equals only to 3,94%. In addition, in Umbria Region certification the impact of acoustic performances on building environmental sustainability is limited to the calculation of façade airborne noise insulation (only $D_{2m,nT,w}$ parameter).

CASE STUDY

Building main features

As a validation of BGP index, overall quality certification model was applied to a modern building, called "Annamaria Residence", in the Municipality of Perugia (Umbria Region, Italy): case study is the first multifamily apartment building in Umbria Region to be certified "KlimaHouse class A" for very high energy efficiency.

Based on in situ measurements, assessment regarded flat n. 1, developing on two levels (Figure 1). The private flat was assumed as a case study: an example of total quality certification was given and then it was compared with results provided by Umbria Region certification of building environmental sustainability.



Source: (Gallano s.r.l., 2009)

Figure 1. Case study: plans of 1st level (left) and 2nd level (right)

The flat has a volume of 476,3 m^3 and a surface of 176,4 m^2. External walls are 47 cm thick (1 cm external and 2 cm internal plaster, 14 cm EPS external layer and 30 cm bricks). The walls that separate the examined dwelling from the adjacent ones are 42 cm thick (internal 25 cm expanded clay blocks and 2 external layers of 6 cm bricks separated by 1 cm of mortar; 1,5 cm coat of plaster on each side). Floor thickness ranges from 47.3 cm (internal floor) to 53 cm (building shell) and ventilated wood roof is 29.6 cm thick.

Heating and cooling pavement system is fed by a collective central boiler, having separated accountings. Indoor microclimate is regulated also by a Controlled Mechanical Ventilation system (CMV). As concerns energy efficiency of building shell, annual specific consumption of primary energy for heating the hole multifamily apartment building was estimated in about 16 kWh/m^2year.

Acoustic Performance index AP: measurements and calculations

Measurement methodology for in situ determination of acoustic parameters was consistent with UNI EN ISO 140 series and UNI EN ISO 717 series technical standards. Noise levels due to building plants and services were determined according to UNI EN ISO 16032 and UNI 8199 Italian standards.

Employed measurement equipment consisted of a sound level meter 01dB Solo, a 2 channel acquisition unit and frequency analyzer 01dB Symphonie, a dodecahedral noise source, a remote tapping machine, a loudspeaker having directional emission, transducers and accessories: all instruments respected requirements of class 1 complying with EN, IEC and CEI standards. Data were collected and processed by software 01dB BATI.

Significant acoustic case studies were selected and analysed:

1. airborne noise transmission loss of the wall between a livingroom (L2) and a bedroom (Ba1; Figure 2);

2. airborne noise difference of the façade in the kitchen (K1; Figure 3);

3. impact noise level of the floor between a bedroom on the upper level (Bb1) and the kitchen on the lower level (K1; Figure 4);

4. A-weighted maximum sound pressure level (S-time weighting), produced by a wc discharge (discontinuously working system, bathroom on the upper level b1) into the most disturbed room below, i.e. the kitchen (K1; Figure 5);

5. A-weighted continuous equivalent sound pressure level produced by Controlled Mechanical Ventilation (CMV, continuously working system) into the livingroom (L1; Figure 6).

Figure 2. Case study: in situ measurement of weighted sound reduction index of partitions between rooms R'_w

Figure 3. Case study: in situ measurement of weighted standardized sound level difference of façades $D_{2m,nT,w}$

Figure 4. Case study: in situ measurement of weighted normalized impact sound pressure level of floors $L'_{n,w}$

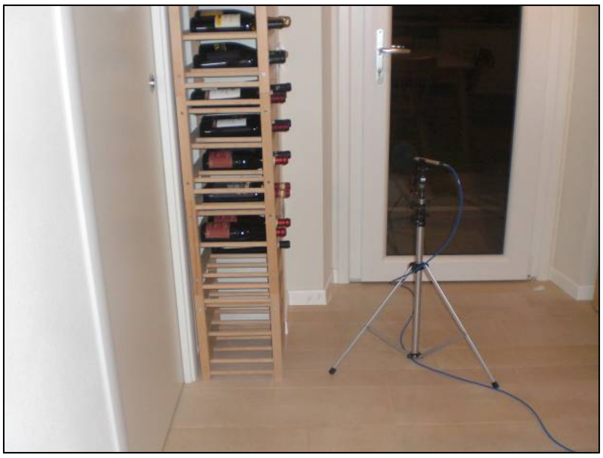


Figure 5. Case study: in situ measurement of noise level L_{ASmax} produced by wc discharge into the most disturbed room beneath (kitchen K1)

Figure 6. Case study: in situ measurement of noise level L_{Aeq} produced by CMV system into livingroom L1 (position microphone-air vents)

Measurement contexts and results are shown in Table 6: referring to proposed worth scale (Table 1), for tested flat AP index obtained 5.5 points on 7 (high Acoustic Performance, B class), equivalent to 78.6/100. A graphic representation of acoustic quality certification as a label is reported in Figure 7.

Overall quality BGP index calculation

Case study surveys and measurements concerned all of the 6 indicators introduced in order to describe indoor comfort.

Table 6. BGP, case study: assessment of Acoustic Performance index AP

Parameter	Rooms and Systems	Measured Value	Class/ Score	Weight	Weighted Score/Cl.
R'_w	L2 vs Ba1	51 dB	C/5	0.20	1.00
$D_{2m,nT,w}$	K1	41 dB	C/5	0.25	1.25
$L'_{n,w}$	Bb1 vs K1	58 dB	B/6	0.20	1.20
L_{ASmax}	WCb1 vs K1	34 dB(A)	C/5	0.20	1.00
L_{Aeq}	CMV vs L1	21 dB(A)	A/7	0.15	1.05
AP				1.00	5.50/B

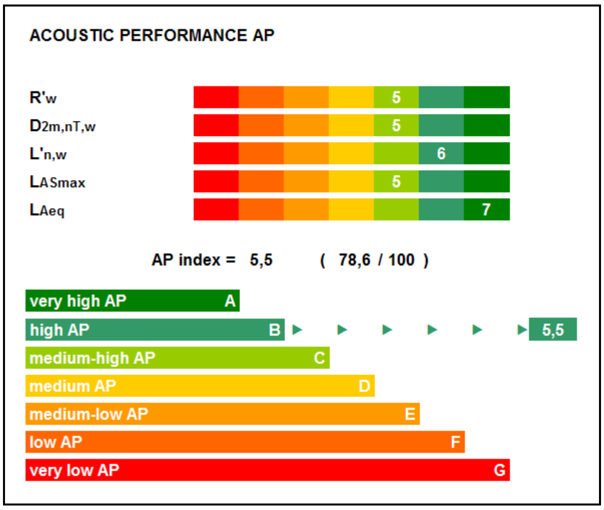


Figure 7. BGP, case study: graphic representation of Acoustic Performance index AP certification as a label

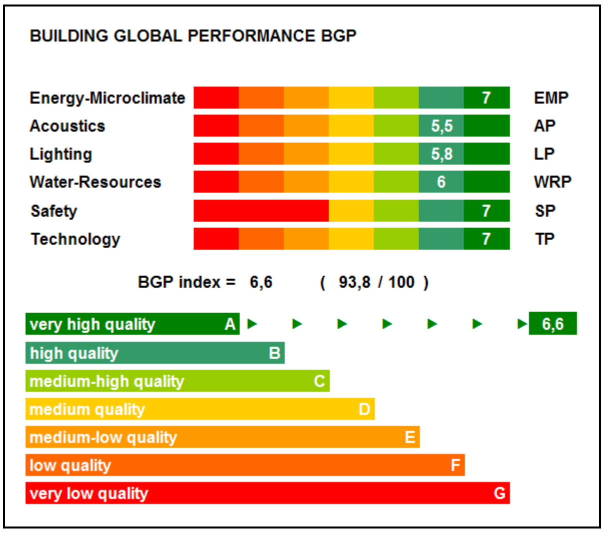


Figure 8. BGP, case study: graphic representation of Acoustic Performance index AP certification as a label

Required input data were processed to calculate BGP index. Each single indicator was multiplied by the corresponding weight, as reported in Table 4, and results were added to obtain total performance. The calculation gives back the values of all indicators as a certificate (Figure 8): case study BGP index performs a value equal to 6.6 points on 7, equivalent to 93,8/100, and it reaches class A (very high overall quality), in tune with the appraisal of the occupants.

Umbria Region environmental sustainability

Umbria Region certification of building environmental sustainability provides for filling 22 technical cards, where the determination of indoor acoustic well-being is limited to verify the acoustic insulation of building shell by means of provisional assessment, according to standard UNI EN 12354-3. As in situ measurements were carried out on a critical partition (kitchen façade), available result was preferred to predictive calculation: being $D_{2m,nT,w}$ equal to 41 dB the certification shows a sufficient performance and it supplies a score equal to 0.

Due also to low rate assigned to acoustic insulation on final assessment of environmental sustainability (only 3,94%), in Umbria Region classification the effect of acoustic performances on case study environmental sustainability is practically negligible. This certification scheme takes into account only acoustic performance of building shell as regards outdoor environment; on the contrary, it excludes the calculation of sound transmission loss of internal walls between rooms, impact sound pressure level of floors and noise produced by building systems, both continuosly and discontinuously working.

Total performance of case study environmental sustainability, according to Umbria Region certification model, is 52.05/100 points (class C, as reported in Table 5).

CONCLUSIONS

The aim of building certification is to estimate and to compare performances, making them part of the assessment together with dimensional, economic and aesthetic considerations, thus pursuing high quality and sustainability in buildings.

The paper shows different approaches in order to extend classification concept also to acoustic requirements of buildings, which contribute to indoor comfort. Acoustic performances of a high energy-efficient building were studied to assess their effects on sustainabilty and quality indicators.

Voluntary certification model BGP, by means of Acoustic Performance module, checks main acoustic parameters referring to the most precautionary conditions. Adopted worth scale limits are in good compliance with the ones provided for by UNI project of Italian standard U20001500, dealing with acoustic classification of buildings [3]. The application of BGP protocol to the case study highlights that Acoustic Performance class coincides with overal quality BGP category (class B, weight: 19%): they are in tune with the assessment of inhabitants and they differs just for one rank from KlimaHouse energy certification (class A).

In Umbria Region certification of building environmental sustainability the impact of case stady acoustic performances is limited to the assessment of only one parameter ($D_{2m,nT,w}$) which represents building shell acoustic insulation from outdoor noise: however, it seems to be almost insignificant, being its weight modest (3,94% on final score). Results show that high performances of energy saving generally are not sufficient to guarantee equivalent levels of environmental quality: in fact many aspects taken into account by Umbria Region protocol (such as urbanization of site and access to public transportation) regard not only the "building system" but also and particularly the context in which it is located. Therefore the case study obtains a sufficient environmental sustainable performance (class C) in Umbria Region certification, 2 classes lower than energy certification.

The paper shows the first complete application of proposed renewed BGP index to all performances of indoor quality in a modern apartment building. Based on experimental results, introduced indicators seem to work efficiently: additional tests will be carried out in other buildings to achieve the full validation of BGP certification model.

Differences among obtained outputs are due mainly to methodologies of calculation and to contributions to be considered. Weights in BGP model were assigned to indicators depending on average cost analysis: a combination with further evaluations may improve certification outline. The assessment could be integrated with other peculiar features, to test existing buildings and to evaluate new buildings according to standards.

Generally high performances increase building cost but lower consumption and higher comfort amortize initial investment. Integrated experimental tests are being carried out to achieve high levels of energy efficiency together with indoor quality and environmental sustainability [5], [6]. Also energetic and environmental certification of products can be taken into account to optimize the selection of building elements, by comparison of samples providing the same acoustic characteristics on the basis of certified performances of materials. Multi-criteria analysis of data concerning measured acoustic parameters, calculated energy demand and predicted CO_2 emissions of building materials during life cycle (LCA [6], [7], [8]) can improve the assessment of AP and BGP indicators according to objective standards, to classify examined case study integrating acoustic, environmental and quality performances.

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