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Application of the LEED PRM to an Italian existing building

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Abstract

ANSI/ASHRAE/IESNA 90.1 Energy Standard for Buildings except Low-Rise Residential Buildings is the benchmark code of U.S. local regulations. In addition to provide a set of minimum mandatory requirements for energy-using components (prescriptive approach), the standard includes in the Appendix G a more flexible path to attest performances significantly better than code minimum (performance-based approach). With regard to this approach, a procedure to establish the proposed building performance by quantifying the energy savings above an annual baseline energy consumption is defined as Performance Rating Method and used within the Leadership in Energy and Environmental Design (LEED) Protocol.

This paper applies the U.S. performance-based approach to the global energy efficiency goal within the prescriptive-oriented Italian framework. In particular, the Performance Rating Method – partially customized to the Italian context by GBC Italia® and in compliance with LEED Italia requirements – has been applied to an Italian case study in order to highlight strengths and weaknesses correlated to a steady adoption of the performance approach in Italian energy policies. The proposed building performance of the case study has been evaluated throughout a dynamic simulation analysis carried out by means of the EnergyPlus code.

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Keywords: Standard 90.1-2007; performance-based approach; LEED; energy perfomance optimization; adaptability;

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1. Introduction

It is widely recognized that approximately 24% of world total energy consumption is attributable to the building sector, whose impact rises up to 40% in developed countries [1]. For this reason most of current codes, standards

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and laws are building energy efficiency oriented, aiming to low energy buildings. The regulatory framework can follow prescriptive and/or performance compliance paths. According to the prescriptive approach, the selection of building design components is bound by a list of low-level requirements to be met [2]. Criticism around this prescriptive way of approaching energy demand regulation has risen due to the impossibility of exploring innovative solutions [3]. Attempts to prioritize global goals have focused on performances rather than on requisites [2]. On the other hand, with regard to performance-based approaches, prescriptions can be traded-off. More elastic paths, which by-pass prearranged solutions to improve the overall energy performance, are thus adopted.

In order to optimize the building energy behavior in an integrated way, performance simulation models have been incorporating into code compliance tools [4]. European Standard ISO 13790:2008 provides detailed simulation methods to calculate buildings annual energy uses for space heating and cooling. A further step in building energy standards is expected to be the optimal level at which the energy performance coincides with the lowest cost throughout the estimated economic building lifecycle [2], [5], [6].

In addition to prescriptive and performance regulatory paths for code compliance, over the last two decades 'beyond-code' voluntary schemes have been developing aimed to certify buildings impact on environment and human health. Currently the two most widely recognized environmental assessment methods are the Building Research Establishment Environmental Assessment Methodology (BREEAM) – the longest established – and Leadership in Energy and Environmental Design (LEED) [7], [8].

However other green building rating systems such as HQE (France), DGNB Certification System (Germany) and CASBEE (Japan) have been developed. Generally the rating of buildings environment sustainability is based on several parameters, such as site selection, water management, energy consumption and indoor air quality. In particular, within LEED 2009 for New Construction and Major Renovations [9], 5 main environmental categories define the certification rating system (Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR) and Indoor Environmental Quality (IEQ)) along with 2 additional ones (Innovation in Design (ID) and Regional Priority (RP)). Within each category a maximum number of points can be achieved and different levels of LEED certification can be obtained. LEED points are awarded on a 100+10 bonus point scale. Base level requires a total score between 40 and 49 points; Silver: 50–59 points; Gold: 60–79 points; Platinum: 80 and above.

At state-of-the-art an European common and universal approach to building energy efficiency has not been defined yet. Lack of harmonized visions leads some EU countries to list low-level requirements. Some choose to definitely replace the prescriptive approach with global energy efficiency goals, while others still perseverate in enacting independent demand-efficiency prescriptions without adopting performance paths [2]. In contrast, American energy policies are oriented to reconcile performance and prescriptive approaches. For instance Standard ASHRAE/ANSI/IESNA 90.1-2007 (Std 90.1) [10] provides minimum requirements for code compliance, by prescribing a set of low-level energy-efficiency requirements for the design and construction of new and renovated commercial buildings. Moreover, within Appendix G of Std 90.1, the Performance Rating Method (PRM) sets a performance-based compliance path whose flexibility is the boundary condition for exceeding the requirements of Std 90.1. The proposed building resulting from PRM is compared to a code-compliant reference building by means of dynamic simulation. PRM is also included in LEED.

This paper evaluates the applicability of U.S. PRM outside its geographic framework. In particular it shows its application as partly customized by GBC Italia, in order to point out strengths and weaknesses related to the coexistence of the Italian prescriptive requirements with a more flexible, pragmatic and market-oriented, performance-based approach to fulfill the global energy efficiency goal. The assessment of the building energy performance, according to the EA category, has been applied to an Italian case study. EA Prerequisite 2 "Minimum Energy Performance" and EA Credit 1 "Optimize Energy Performance" were considered. The energy performance of the selected case study, referred to as proposed building, was compared to the energy performance of a reference building, called baseline building. Energy cost savings are assessed by means of the dynamic simulation program EnergyPlus.

2. ASHRAE Standard 90.1 and the Performance Rating Method

2.1. ASHRAE Standard 90.1

Std 90.1 provides a set of minimum energy-efficiency requirements for the design and construction of new and renovated commercial buildings [10]. The building requirements are provided within several technical sections (“Building Envelope”, “Heating, Ventilating, and Air Conditioning”, “Service Water Heating”, “Power”, “Lighting”, “Other Equipment”). The Informative Appendix G of Std 90.1 reports PRM as a procedure to assess the energy performance of buildings that go beyond the minimum energy efficiency levels required by the standard. The PRM is not a part of the standard, since it does not supply requirements for conformance; it is a revised version of the Energy Cost Budget Method (Section 11), which is presented as an alternative compliance path to the standard. The PRM is a calculation procedure aimed to quantify the percentage improvement of the annual energy cost of the proposed design (proposed building performance) over the annual energy cost of a reference building (baseline building performance). The improved performance is calculated as follows:

$$Percentage\,improvement = 100.\frac{BaselineBuildingPerfomance - \Pr oposedBuildingPerformance}{BaselineBuildingPerformance} \tag{1}$$

The baseline building performance represents the average annual energy cost of four dynamic simulations of a reference building, rotated at 0, 90, 180 and 270 degrees. For the characterization of the baseline building, reference parameters are applied to the case study. This approach concerns the building envelope definition as well as the building system.

The applicability of performance-based paths to energy efficiency regulation, following the U.S. approach, has been evaluated worldwide in various countries, such as fast-developing countries like China and Brazil. For instance ASHRAE Standard 90.1-2004 [11] has been taken as reference by [12] to identify weaknesses in code stringency in the Chinese Design Standard for Energy Efficiency of Public Buildings GB50189-2005 [13]. Hong highlighted sensible aspects of the U.S. standard to be integrated within the Chinese standard, looking forward to a whole building energy performance method [12]. Moreover Standard GB50189-2005 in analogy with the PRM approach, takes as a reference the energy consumptions of typical Chinese public building [12]. However the benchmark building has been questioned since based on obsolete 1980s living standards and a reference building, representative of 2000–2004 average baselines, has been evaluated as more adequate [14].

Furthermore, a recent focus on LEED applicability in China has been carried out [15] assessing the energy performance of two Chinese office buildings in compliance with LEED for New Construction and Major Renovations (NC) 2.2 requirements on EAc1 Optimize Energy Performance. In particular Standard 90.1-2004 PRM was not customized to the Chinese framework but used as a basis for comparison for the China Code building [15]. On the other hand, with regard to Brazil, the new code “Quality Technical Regulation for Energy Efficiency in Public, Commercial and Service Buildings” - RTQ-C has been based on ASHRAE 90.1 framework [16] providing a dual prescriptive/performance-based approach to label the buildings energy efficiency.

LEED adaptability outside the U.S. can be considered as a key aspect. Over the last decade, USGBC’s LEED has been adapted to the Canadian and Indian local scales. In 2004 the Canada Green Building Council aligned LEED Canada for New Construction and Major Renovations 1.0 [17] with USGBC’s LEED-NC 2.1. In October 2006 the Indian Green Building Council launched LEED India version 1.0 [18]; the latest LEED India rating programme is currently LEED 2011 for India-NC. Moreover, in April 2010, LEED Italia New Construction and Renovations 2009 has been launched by GBC Italia [19]. Actually a similar effort to develop tailored assessment tools already characterised the Italian context, where an SBMethod-based rating system known as Protocollo ITACA has been carried on in order to compare a building’s life cycle with benchmarks representatives of current Italian building practices.

This critical review of the academic literature provides an insight into state-of-the-art performance-based approaches to energy regulation – symptomatic of the on-going shift from prescriptive to performance-based design guidelines. However, up-to-date, a critical application of PRM, in compliance with LEED, within EU members state framework – the focus of this paper – has not been properly analysed yet.

2.2. Italian customization of the Performance Rating Method

In order to evaluate the building energy performance, Std 90.1 PRM has been applied to an Italian case study, in compliance with GBC Italia requirements. In particular, protocol LEED Italia New Construction and Renovations 2009 has been taken as a reference. It should be noted that the selected case study did not strive in view of achieving a LEED certification. It was thus designed in compliance with the Italian standards but without adopting Std 90.1.

LEED Italia New Construction and Renovations 2009 provides two compliance path options to satisfy EA Prerequisite 2 and EA Credit 1. The first one is a prescriptive compliance path, based on the Italian prescriptive requirements. The second option represents a whole building energy simulation path based on a dynamic simulation model. EA Prerequisite 2 is mandatory and no points are awarded. In EA Credit 1, points can be gained depending on the energy saving obtained. A simplified procedure can bring from 1 up to 3 points maximum, whereas a whole building energy simulation based approach can bring from 1 up to 19 points. In this paper the whole building energy simulation path was followed. The percentage performance improvement of the case study has been calculated according to the PRM reported in the Appendix G of Std 90.1, partly customized to the Italian framework as required by GBC Italia (Table 1). According to LEED Italia, even thought 90.1 mandatory provisions should be respected, the Italian energy performance mandatory provisions are not replaced.

Table 1. Customization of Std 90.1 mandatory provisions according to LEED Italia New Construction and Renovations 2009

ASHRAE Mandatory Provisions	Adjustments and integrations according to LEED Italia New Construction and Renovations 2009
5.4 Building Envelope	Compliance requirements differ on the basis of the climate zones. In Table B-3 of Std 90., Italy is associated to a unique climate zone (zone 4). Nevertheless LEED Italia subdivides Italy into two climate zones: Zone 4a (Northern Italy) and Zone 3a (Central and Southern Italy). New buildings must comply with maximum U-values provided at points 2, 3 and 4 in the Attachment C of the Italian Legislative Decree 192/2005, as modified and integrated by Legislative Decree 311/2006 and Decree of the President of the Republic 59/09 or in accordance with more restrictive Regional Laws. In case different envelope performance baseline parameters are provided in Standard 90.1-2007 and Italian code tools, most stringent values are selected. Insulation mandatory provisions (5.4.1) are replaced with Italian National Standards Body (UNI) requirements on insulation products (e.g. UNI EN 13162 (UNI EN, 2009a): mineral wools; UNI EN 13163 (UNI EN, 2009b): expanded polystyrene etc.) Fenestration and doors mandatory provisions (5.4.3.2) are replaced with minimum permeability class 4 requirements in conformity with UNI EN 12207:2000 (UNI EN, 2000).
6.4 Heating, Ventilating and Air Conditioning	ASHRAE mandatory provisions are limited to ventilation and air conditioning systems. Heating systems must comply with Italian prescriptive requirements. Heating source energy consumption, calculated according to parts 1 and 2 of UNI/TS 11300:2008, is set below the baseline energy performance parameter (so called EP2010) fixed at point 1 of the Attachment C of the Italian Legislative Decree 192/2005 or the corresponding Regional value when more restrictive; Average equipment efficiencies, calculated according to UNI/TS 11300-2:2008, exceed the baseline values provided at point 5 of the Attachment C of the Italian Legislative Decree 192/2005; Boilers carry a 4 stars label (****) according to the Decree of the President of the Republic No. 660; Insulation covering pipes complies with requirements reported in the Attachment B of the Decree of the President of the Republic 551/'99. In case different HVAC systems and operations baseline parameters are provided in Standard 90.1-2007 and Italian code tools, most stringent values are selected.
7.4 Service Water Heating	According to UNI/TS 11300:2008, service water heating requirements provide that: - SWH source energy consumption does not exceed 18 kWh/(m2year) or lower regional limits; - average equipment efficiencies, calculated according to UNI/TS 11300-2:2008 (UNI/TS, 2008b), exceed the baseline values provided at point 5 of the Attachment C of the Italian Legislative Decree 192/2005 (The Italian Government, 2005); - boilers carry a 4 stars label (****) according to the Decree of the President of the Republic No. 660 (EU 92/42) (The President of the Republic, 1996; EU, 1992). These requirements replace the corresponding Std 90.1 Section.

3. Case study

3.1. Building model

The case study is a social housing complex, composed by a renovated historical 5-storey plus-basement building and by a more recent 3-storey building in Turin. The building complex combines residential units (13 studio apartments and 14 two-room flats) and commercial areas (a small office, retail units and a café/restaurant) in addition to wide common spaces.

Table 2. Building envelope and general data (* the value is referred to the existing envelope, which according to the PRM reflects conditions before renovation)

Use	Building general Data	
Type	Renovation	
Building use	Residential and commercial	
Location	Turin	
HDD	2617 °C/day	
Gross building area	2465 m^2	
Wall area	1793 m^2	
Window area	292 m^2	
Roof area	723 m^2	
Opaque envelope	Proposed building (U value – W/m^{2}K)	Baseline building (U value – W/m^{2}K)
External walls	0.28 / 0.29	1.80*
	0.30 / 0.36 / 0.27	0.33
Basement walls	0.28 / 0.31	1.80*
Walls on adjacent building	0.89	1.10*
Roof	0.21 / 0.39	0.52* / 0.27
U_g	2.20	6.00* / 2.00

The building is characterized by an L-shape plan oriented on the SE-NW axes, with a partially unconditioned basement. The ratio of the transparent area to the opaque envelope area amounts to 16%. Due to different construction ages of the building portions, the building construction is not homogenous; the 5-storeys building is based on load-bearing masonry, whereas the 3-storeys building has a reinforced concrete structure. Technological and materials choices are set with a view to cost-effectiveness and energy efficiency principles in compliance with Italian mandatory requirements. The roof is pitched, tiled and insulated. Building envelope transparent components are low-emission double-glazing windows with thermal break frames. The east façade is mainly equipped with external fixed shading devices; windows in other orientations are simply supplied with movable internal blinds.

Table 2 reports general, geometrical and envelope data for the proposed and baseline building. In particular in the table various U-factors are listed for the opaque elements. Different U-values were thus associated to the building envelope depending on the façade considered. The case study was designed in order to comply only with Italian prescriptions. Therefore the U-factors of some building envelope components proved to be not compliant with more stringent requirements of the Std 90.1.

The building system consists of a gas boiler with hot water terminals and a direct expansion cooling system – except for the office which has a chilled water fan coil; since no cooling system serves the residential areas, according to Std 90.1, the same DX cooling type used for the baseline building has been applied to the proposed residential units. With regard to the HVAC system, the baseline residential areas are served by a packaged terminal air conditioner (PTAC) with a hot water fossil fuel boiler and hot water coils. For non-residential zones, the baseline

HVAC system is a packaged rooftop air conditioner (PSZ-AC) serving each thermal zone with a fossil fuel furnace. Both HVAC baseline systems have a direct expansion cooling system and fans providing a constant volume of air. Domestic hot-water systems, limited to the residential units and the restaurant, are the same for proposed and baseline building. Residential units are equipped with an instantaneous water heater with a 1500-liter storage tank, while the restaurant is served by a 200-liters water heater. The case-study is also equipped with a 3 kWp photovoltaic (PV) power plant and 30 m^2 of solar collectors. In compliance with Section G2.4 of Std 90.1, on-site renewable solar collectors are not included in the proposed building performance and have been modeled apart within the EnergyPlus environment.

3.2. Modeling assumptions

The case study has been modelled into two main unconditioned thermal zones and several conditioned thermal zones for commercial and residential areas. In particular the unconditioned zones were distinguished into an access area for each floor and a part of the basement. The other zones were defined as residential (one for each of the four residential storeys) and commercial (retail, office, restaurant kitchen and dining room, a common area). Figure 1 shows the building models thermal zones.

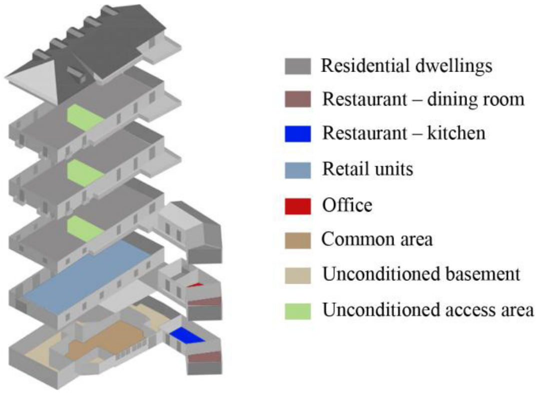

Fig. 1. Axonometric view of the case study

The typical meteorological year (TMY) of Turin (north-western Italy), characterized by a continental climate with cold-dry winters and hot-humid summers, has been used for the simulation.

With regard to the building operation, different schedules have been defined and applied to the thermal zones depending on the main use. Power densities for each main zone are listed in Table 3. Considered site to source conversion factors amount to 2.174 for electricity and 1.00 for natural gas. Energy costs related to the energy consumptions estimated by means of dynamic simulation have been assumed as equal to 0.17 €/kWh$_{el}$ for electricity unit price and 0.08 €/kWh$_{th}$ for natural gas tariff.

Table 3. Building operation main data

Use	Lighting power density [W/m^2]	Electrical equipment [W/m^2]	People [pers/m^2]
Residential units	4	5	41 total
Restaurant – dining room	15	60	0.60
Restaurant – kitchen	13	377	7.50 total
Retail units	16		0.10
Point of sail		22	
Back space		8	

Core		3	
Office	11	11	0.06
Common area	14	8	0.30
Unconditioned basement	6	12	0.10
Unconditioned access area	5		
External area – court	2		
External area – access balconies	11		

4. Results

With an energy performance index (the percentage ratio of the proposed building performance to the baseline building performance) amounting to 15%, the case study complies with LEED EA Prerequisite 2, which requires at least a 5% improvement for major renovations to existing buildings, and gathers 4 points in EA Credit 1 Optimize Energy Performance. The final score is significantly influenced by the boundary conditions that subtend the application of the Performance Rating Method to a retrofit project. Since the baseline building design reflects the existing conditions of the envelope, a higher spread between baseline and proposed building performance resulted facilitated. A summary of the outcomes from the PRM application to the selected case study is pictured in Figure 2.

Electric energy consumption of the proposed building is slightly higher (6%) than that of the baseline building. This is mainly attributable to the higher space cooling demand caused by an increase of the building envelope thermal insulation included in the retrofit design actions. Moreover, while in the proposed building pumps serve all the thermal zones, in the baseline building they run only in the residences. No automatic or programmable daylight control has been set, consequently there isn't a significant variation in the interior lighting energy consumption from the proposed to the baseline building; furthermore also exterior building lighting and electrical equipment do not change. On the other hand, as expected, increasing insulation leads to high energy savings (49%) in the space heating demand. In addition, the photovoltaic and solar thermal systems, supplying respectively about 2% of the electricity and 66% of the thermal energy demand for SWH, approximately cover 3% of the building overall energy demand. In conclusion, a 15% improvement in the proposed building performance over the baseline building performance has been assessed.

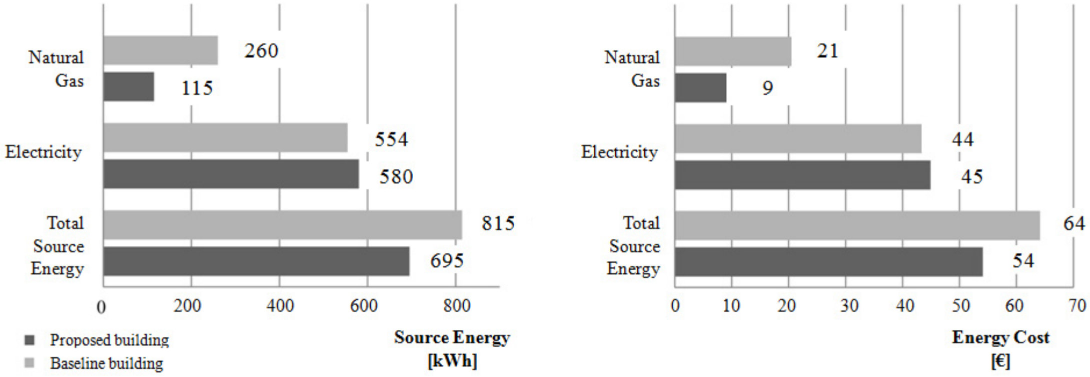

Fig. 2. Results: baseline and proposed building energy consumptions and costs

5. Conclusions

From the growing body of green buildings literature clearly emerges an on-going effort to understand barriers and drivers currently facing LEED performance-based approach applicability outside the U.S.. In this study the U.S. performance-based rating method has been applied within the Italian framework.

In particular this study was aimed to the application of U.S. Std 90.1 PRM to an Italian case study in order to assess its energy performance. PRM used was in compliance with the customization carried out by GBC Italia in frame of LEED Italia New Construction and Renovations 2009. The whole building energy simulation path, as presented in LEED EA Credit 1 “Optimize Energy Performance”, has been followed for the case study energy assessment.

The application of the rating method to the case study – which gathered 4 LEED points attesting a 15% improvement over the baseline performance – led to acquiring a critical consciousness around strengths and weaknesses related to a potential adoption of the Performance Rating Method within the Italian context.

Following up European Directive 2002/91/EC [20], implemented within a relatively close time span, Italian policies on energy performance issues converged towards a vertical subsidiary approach where the regional levels can directly acknowledge EU directives, resulting in a non-homogenous setting out of the matter. Italian scenario is marked by evident similarities with the U.S. framework, where the adoption of building energy codes falls under the states and local jurisdictions. An official recognition by Italian authorities on performance-based paths as approach to be used to attest performances that significantly go beyond the prescriptive minimum requirements, would represent a way, on the basis of the American best practices, to pour well-defined boundary conditions – and therefore uniformity – to reach and catalyze virtuous energy performances. This path could for instance be undertaken by energy efficiency incentive programs based on energy modeling results to provide financial funds or tax deductions.

Furthermore an effective assessment method would create a common language constructing dialogue among different stakeholders, not only the design team [21]. In a context of cost optimality [6] the adoption of an energy-costs based method would provide the commissioning and the occupants with a guideline for comparing the estimated typical annual energy costs associated to the standard operations of the building with benchmark code-compliant values [5]. The focus on practical economic aspects such as utility bills, directly comprehensible also by non-experts, would hopefully lead the Italian real estate market – basically still insensible to energy performance issues – to monetizing energy savings as concrete tangible benefits to be showcased.

More generally, the continuous maintenance policy of Std 90.1, represents a benchmark hopefully extensible to the Italian energy codes with the aim of disposing of prompt and receptive requirements on the basis of certain deadlines, for an evolving interpretation of the multiple and changing tensions underpinning market transformations. Effective working methodologies covering different parts of design and comparing alternative solutions would on the other hand be an asset for building professionals [22]-[24].

According to current credit achievement rates for EA 1, the operational energy averagely saved worldwide amounts to 26%, but peaks exceeding 40% have been sometimes reached [25]. In addition to give evidence to the technical potentials and the economic feasibility of green buildings, these numbers denote the flexibility of a rating system which remains accessible to outsiders whilst rewarding outstanding performances. However, drawbacks could affect the main logic on which the performance rating method is built. “Anchoring” cognitive bias – the unconscious propensity to be influenced by pre-set values regardless of their relevance [26] – influencing the energy performance goals set by rating systems has been proven. Basically, anchoring the energy saving targets to relatively low percentages would indirectly lead to fulfill lower energy performances than what could actually be the technological and economic convenience [27]. Higher energy performance goals i.e. net-zero energy consumption, could therefore be awarded with the maximum score in order to avoid to inhibit ambitious but realistic and feasible energy performances within the Italian framework.

Other improvements concern the Italian transposition of a rating system definitely American centric. In particular the subdivision of the Italian territories only into two climate zones (matched with correlated requirements) appears to be an excessively simplistic assumption. A central aspect can thus regard a greater integration of the Italian specificities within the PRM framework, in view of implementing nationwide energetic and environmental goals.

To draw a conclusion, an official adoption of an Italian-contextualized rating method would represent a starting key point for leveling the fragmented national landscape in energy efficiency regulation. It will help to reduce the mismatch between certified and real energy performances and costs.

Further studies will concern the application of PRM, in compliance with LEED Italia protocol, in order to evaluate a new construction case study, with the aim of gaining an exhaustive picture of the theoretical and applicative principles underlying the PRM.

References

[1] Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy Build 2008; 40:394-398.

[2] Pérez-Lombard L, Ortiz J, Coronel JF, Maestre IR. A review of HVAC systems requirements in building energy regulations. Energy Build 2011; 43:255–268.

[3] Hamza N, Greenwood D. Energy conservation regulations: impacts on design and procurement of low energy buildings. Build Environ 2009; 44:929–936.

[4] Reichard G, Papamichael K. Decision-making through performance simulation and code compliance from the early schematic phases of building design. Autom Constr 2005; 14:173–180.

[5] Corgnati SP, Fabrizio E, Filippi M, Monetti V. Reference buildings for cost optimal analysis: Method of definition and application. Appl Energy 2013; 102:983–993.

[6] EU. Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast). Official Journal of the European Union; 2010.

[7] Cole RJ, Valdebenito MJ. The importation of building environmental certification systems: international usages of BREEAM and LEED. Build Res Inf 2013; 41:662-676.

[8] Yu CWF, Kim JT. Building environmental assessment schemes for rating of IAQ in sustainable buildings. Indoor Built Environ 2011; 20:5–15.

[9] U.S. Green Building Council (USGBC). LEED 2009 for New Construction & Major Renovations (Updated July 2012). U.S. Green Building Council; 2009.

[10] ASHRAE. ASHRAE Standard 90.1-2007. Energy Standard for Buildings Except Low-Rise Residential Buildings (SI Edition). Atlanta, GA: ASHRAE; 2007.

[11] ASHRAE. ASHRAE Standard 90.1-2004. Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: ASHRAE; 2004.

[12] Hong T. A close look at the China Design Standard for Energy Efficiency of Public Buildings. Energy Build 2009; 41:426–435.

[13] China Architecture and Building Press. The People's Republic of China National Standard GB 50189-2005, Design Standard for Energy Efficiency of Public Buildings with Explanation. China Architecture and Building Press, 2005.

[14] Jiang P. Analysis of national and local energy-efficiency design standards in the public building sector in China. Energy Sustain Dev 2011; 15:443–450.

[15] Pan Y, Yin R, Huang Z. Energy modelling of two office buildings with data center for green building design. Energy Build 2008; 40:1145–1152.

[16] Amorim CND, Cintra MS, Silva CF, Fernandes JT, Sudbrack LO. Energy efficiency code in Brazil: experiences in the first public building labeled in Brasilia. In: the Fourth National Conference of IBPSA-USA, New York; 2010.

[17] Canada Green Building Council. LEED for New Construction & Major Renovations Version 1.0. Canada Green Building Council; 2004.

[18] Indian Green Building Council. LEED-INDIA-NC Abridged Version 1.0. Indian Green Building Council; 2007.

[19] http://www.gbcitalia.org.

[20] EU. Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings. Official Journal of the European Communities, 2002.

[21] Cole RJ. Building environmental assessment methods: redefining intentions and roles. Build Res Inf 2005; 35:455–467.

[22] Bayraktar M, Fabrizio E, Perino M. The «Extended Building Energy Hub»: a new method for the simultaneous optimization of energy demand and energy supply in buildings. HVAC&R Res 2012; 18(1-2):67–87.

[23] Fabrizio E, Filippi M, Virgone J. An hourly modelling framework for the assessment of energy sources exploitation and energy converters selection and sizing in buildings. Energy Build 2009; 41(10):1037-1050.

[24] Fabrizio E, Filippi M, Virgone J. Trade-off between environmental and economic objectives in the optimization of multi-energy systems. Build Simul 2009; 2(1):29-40.

[25] Todd JA, Pyke C, Tufts R. Implications of trends in LEED usage: rating system design and market transformation. Build Res Inf 2013; 41(4):384-400.

[26] Jacowitz KE, Kahneman D. Measures of anchoring in estimation tasks. Pers Soc Psychol Bull 1995; 21:1161–1166.

[27] Klotz L, Mack D, Klapthor B, Tunstall C, Harrison J. Unintended anchors: Building rating systems and energy performance goals for U.S. buildings. Energy Policy 2010; 38:3557–3566.