Chapter 2
Review and State of the Art on Methodologies of Buildings' Energy-Efficiency Classification

2.1 Introduction

The term building energy classification encompasses any procedure that allows the determination of the quality of a building (in terms of energy use) in comparison with others. In this chapter, the previous works in the field of building energy benchmarking, energy rating, and labeling in the context of building energy classification are investigated.

2.2 Review on Building Energy-Efficiency Benchmarking Methods

Originally, the word benchmark was used exclusively in topography to precisely define a reference point in terrain or geological analysis. In the 1970s, some companies developed benchmarking tools to allow comparison of key production parameters and thus to check whether improved processes enhanced their performance (Nikolaou et al. 2011).

In the 1990s, the term building energy benchmarking started to be used to refer to the comparison of energy use in buildings of similar characteristics. Some authors like Federspiel et al. (2002) distinguish benchmarking from base lining. According to various authors, benchmarking generally includes a comparison of energy performance with other buildings, while base lining generally involves a comparison of past energy performance of a single building with current energy performance.

Benchmarking models developed from energy-efficiency indicators are valuable tools for both governmental and private sectors in managing energy consumption.

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Some governments have used these tools to formulate policies for the efficient use of energy in buildings.

The energy performance metric plays a key role for energy benchmarking of buildings (also known as energy-efficiency indicators). The most common performance metric for whole building energy consumption is Energy Performance Indicator (EPI) or Energy Use Intensity (EUI).

Benchmarking, it consists of a comparison of the EPI or EUI of a building with a sample of similar buildings or with the best-practice building. A common EPI or EUI used for many building types is annual energy use normalized with floor area but others such as energy per worker or energy per bed may also be used. Energy services companies use the EPI as a starting point in energy audits and assess saving opportunities by comparing with existing references (benchmarks) of average (typical), above average (good), and excellent (best) practice. At the design stage, energy performance indices for different designs are of great use when choosing suitable technologies, particularly if benchmarks for similar buildings are available. Last but not least, governments consider benchmarking in the early conception, development, and implementation of energy-efficiency policies within the building sector.

The Normalized Performance Indicator (NPI) (Zmeureanu and Fazio 1992) developed for office buildings in the United Kingdom, takes into account the heating energy, building size, operating hours, internal temperature, and wind exposure.

Typically, energy-efficiency indicators for commercial buildings can be obtained by normalizing the energy use with floor area and/or operational hours. For instance, Filippìn (2000) used a sample of energy consumption data and the floor area to calculate the Energy Use Intensity (EUI), i.e., kWh/ft^2 or MJ/m^2, for school buildings in central Argentina. The calculated EUIs were then ranked as a benchmark table. This simple floor-area-normalized EUI is often used for judging the energy use performance of a commercial building.

Also, Casals (2006) noted that energy intensity was an appropriate indicator for adoption in energy regulations. However, he emphasized that an appropriate indicator should comply with the regulation objectives. He also described energy intensity as a quantitative indicator that should be adopted in many regulation schemes that still use steady-state heat transfer coefficients, such as the Spanish regulation.

On the other hand, Monts and Blissett (1982) discussed the limitations of using the simple normalized EUI for commercial buildings. It is plausible that other factors (such as an HVAC system) may cause the energy use in specific buildings to be higher (or lower) than that in their peers.

Sharp also made the same argument that such a simple normalized EUI was not good enough for a credible energy consumption performance rating. To account for the effect of other factors that affect energy consumption, benchmarks were developed using a multivariate linear regression approach to correlate other factors representing some important characteristics of buildings with EUI. Moreover, Sharp argued that the mean EUI can be a poor benchmark as distributions of indicators are generally skewed. Hence, Sharp used the standard errors of the resulting regression model to establish the distributional benchmark table, which was considered more reliable as it masked the effect of outliners. The benchmarking process of a specific building makes use of the "best-fitted" regression model to calculate the predicted EUI. With this predicted EUI, a distributional benchmark table (percentile table) is calculated by means of the distribution of standard errors. The actual EUI can be compared with the benchmark table for the benchmark score (Sharp 1996).

Another common benchmarking method is based on the distribution of residuals of the regression model, in contrast to the approach based on the standard error distribution in Sharp's method. The residual is the difference between the actual EUI and the predicted EUI. Hence, the residuals are treated as measures of inefficiency. For a given building to be benchmarked, if the actual EUI is less than the predicted EUI (negative residual), it means that the building uses less energy than other similar buildings. Moreover, the distribution of sample residuals from the regression model can be used to construct the corresponding benchmark table. Lovell-Smith and Baldwin (1998) used this approach where the residuals were not obtained from the regression model. However, they used the mean EUI from the sample as the predicted EUI without considering the normalization of other significant factors. Obviously, this kind of benchmark table does not provide a physical measure. Sharp in his proposed method uses the actual EUI distribution instead.

In the literature energy-efficiency benchmarking methods are also categorized according to the purpose. According to Kinney and Piette (2002) they are used for two fundamental purposes:

- To identify if a building's energy performance is good, average, or poor with respect to other buildings of its type. This is a robust indicator of whether the building should be prioritized for action. For this purpose, empirical benchmarks derived from energy statistics for the stock (or analysis of the stock) are applicable.
- To identify if a building's energy performance matches its potential and if not by how much it might be improved cost-effectively. For this purpose a realistic model of the building and its systems is theoretically more applicable.

Empirical benchmarks fall into two categories: (a) the conventional type is obtained from bulk statistical data, often corrected for climate, (b) less common but more insightful are parameterized benchmarks which set criterion (good practice) and normative (typical) standards for each energy use of the building.

Model-based benchmarking calculates benchmarks based on an idealized model of building performance. Models have the advantage that they can be tweaked to account for a wide range of factors that contribute to variation in energy use. They can also be used to generate targets and compare design alternatives and retrofit scenarios. They offer detailed information and a wide variety of outputs; however, it may require a great number of inputs, skilled users, and a significant amount of time to gather and input the necessary data, all of which can make the process expensive.

The benchmarking techniques are divided into four categories: Statistical Analysis Benchmarking (also known as Regression Model-Based), Points-Based

Rating Systems, Simulation Model-Based Benchmarking, and Hierarchical and End-Use Metrics.

The statistical analysis consists of collecting the survey data and comparing one unit with the others. Chung et al. (2006) used multiple regression analysis to build a benchmark table by investigating the relationship between EUIs and the explanatory factors. In that study, the most significant factors were found to be the building age, operating hours, floor area, number of consumers, and a subjective qualitative description of user behavior and maintenance.

Simulation Model-Based Benchmarking sets up a mathematical model to calculate theoretical energy consumption and makes a comparison between theoretical energy consumption and observed energy consumption in order to evaluate the performance of energy consumption. Federspiel et al. (2002) used numerical software to construct the minimum Energy Usage Intensity (EUI) for laboratories and compared this with observed EUI of the evaluated building.

Carriere et al. (1999) implemented DOE-2 simulation software to study the energy-saving potential of large buildings. The simulation method used factors including the properties of building construction material, the energy efficiency of related energy-consuming equipments (such as air conditioners, lights, etc.), and the usage period to calculate the theoretical energy consumption of the building.

Points-Based Rating Systems, including the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating System, do not allow comparisons against other buildings, rather they provide standards and guidelines to measure how efficient and environmentally friendly a facility is and compare it to best-practice standards. An LEED score is made up for credits assigned for satisfying different criteria including energy efficiency and other environmental factors.

Hierarchical and End-Use Metrics refers to the generation of benchmarks that link energy use to climate and functional requirements. This method is useful for accounting for more of the differences in features affecting energy use.

Many authors have investigated the crucial parameters according to their effect to the energy consumption that have to be taken into account during energy benchmarking methods adoption.

For instance, Lam et al. (1997) analyzed several characteristics relevant to energy consumption through parametric simulations, developing equations to predict the electricity consumption of commercial buildings in Hong Kong. The statistical analysis indicated Shading Coefficient (SC) and Window to Wall Ratio (WWR) as significant envelope variables, excluding variables such as floor to floor height and number of storeys.

In Brazil, Signor et al. (2001) developed multivariable regression equations for office buildings based on the work of Lam et al. (1997), but using two building volume indicators: facade area divided by total floor area (to represent shape), and roof area divided by total floor area (to represent number of storeys). The equations focused on the envelope parameters: WWR, SC, projection factor of horizontal solar protection, thermal transmittance, U-value, and solar absorptance of the roof. The U-value of the external walls was also analyzed, but it was excluded from the equation due to its nonlinearity, while solar absorptance of the external walls was excluded due to its low significance indicated by the simulation results. The final result was annual electricity consumption by area (or annual energy intensity).

Backer and Paciuk (2002) reported a study in 2002, which investigated the impact of night ventilation and precooling on peak cooling demand for an office building in coastal region of Israel.

In another research, Olofsson et al. (2009) used Partial Least Squares (PLS) to latent structures method to model different energy performance measures, such as the use of energy for heating, electricity used to operate the building technical system, the building total heat loss coefficient, and the use of domestic cold water, in order to enable energy benchmarks. The PLS model was investigated for both the total annual use and the annual use normalized to the available floor area.

Carlo and Lamberts (2008) in their research adopted criteria to evaluate the envelope efficiency level, focusing on the development of a regression equation which provides an electricity consumption indicator. The envelope label is divided into five efficiency levels, from A (more efficient) to E (less efficient), identified according to the electricity consumption indicator. The linear regression equation considers variables such as window to wall ratio (WWR), solar protection angles, building volume indicators, and the roof U-value. The U-value of the walls was excluded from the equation due to its nonlinearity. Its relation with electricity consumption depends on internal gains, exterior temperatures, building size, and thermal capacity of the walls and could not be described by a linear regression equation. The envelope efficiency label is obtained by the comparison of the electricity consumption indicator of the proposed building with the electricity consumption indicators of two other building envelopes presented.

It is worth noted that there are significant surveys focusing on this topic in Greece. Papadopoulos et al. (2002) after a monitoring survey determined the buildings' energy consumption factors, which are the building size, their surface to heated volume ratio, the thermal insulation, and the type and condition of the heating system. In that study the authors also determined the potential and feasibility of energy-saving renovation measures.

Daskalaki and Santamouris (2002) reported another study in the same year which investigated the energy conservation potential of office buildings in five climatic zones in Europe for different passive retrofit scenarios.

A. Papadopoulos and other authors in a more recent research have investigated the role of HVAC Systems in the energy and environmental efficiency of Greek buildings. Papadopoulos et al. in (2008) research investigated the energy, economic, and environmental performance of heating systems in Greek buildings. Papakostas and Papadopoulos in (2004) discussed the impact of the relation between indoor and outdoor conditions on the ventilation loads of buildings. Also, Avgelis and Papadopoulos in (2009) developed a method for choosing and managing in the best possible way Heating, Ventilating, and Air-Conditioning (HVAC) systems in new and existing buildings. The method utilizes a combination of two analysis' tools, the multi-criteria decision-making and the building simulation toward the direction of a holistic assessment of HVAC systems. In order to evaluate the method, a series of HVAC systems are considered for installing in an office building and the multi-criteria method Electre III is applied for their selection. The results show that the proposed model allows the classification of alternative technical solutions concerning the HVAC's design, taking into consideration economic, energy, and environmental criteria as well as criteria of users' satisfaction.

Karatasou et al. (2006) presented an approach for modeling and predicting hourly building loads using feed forward neural networks where not only the inputs selection, but also the structure of the network is systematically treated. Also in this research the importance of input parameters (energy consumption factors) investigation is outlined. The authors indicated that some of the environmental variables such as the ambient temperature and the solar radiation are important while others such as the wind velocity or humidity can be omitted.

Database information availability is a different crucial issue. The knowledge of building stock energy data of a country is a very significant tool for energy benchmarks establishment. Gathering energy information to populate a database with a representative sample of the building stock is not only expensive but also technically complex. It is not surprising that only a few nations have undertaken this task to date. Usually, information is collected on-site from building owners, tenants, facility managers, etc.

An outstanding example is the US Energy Information Administration (EIA) database and the later surveys for both the residential sector (EIA, RECS 2001) and commercial buildings (EIA, CBECS 2003).

Different data collection methods for energy benchmark procedures are found in the literature (Jones et al. 2000; Hernandez et al. 2008). Santamouris et al. (2007) have collected energy consumption data through energy audits performed in 320 schools in Greece. Argiriou et al. (1994) developed specific questionnaires to perform surveys for office buildings and hospitals' energy use and indoor air quality. DATAMINE project (2007) provides the necessary platform to gather building energy data extracted by the energy performance certification procedure.

At European level, the unavailability of building energy use databases has restricted the development of benchmarking tools. Recently, the European projects Euroclass (Santamouris 2005), Europrosper (2004), EPlabel (2007), and ENPER-EXIST (2007) have studied the complexity associated with the elaboration of a database of building energy consumptions in Europe and with identifying suitable reference levels as intermediate steps for the development of an energy performance certificate for existing buildings.

Lompbard et al. (2009) proposes a different approach to database generation based on the application of building energy simulation to a variety of building types for a range of energy parameters (parametric benchmarking). The author claims that careful selection of building types and calculation methods is critical to the validity of the database. Another added constraint is the need to customize building envelopes and HVAC sizing for each climate and system type. An advantage is the possibility of covering a wide range of building energy consumption characteristics with a suitable selection and variation of the energy parameters. Additionally, energy simulation provides a wider range of energy outputs for future comparisons.

The core of benchmarking process is the comparative analysis. A subset of comparable buildings could be obtained by filtering the database against similarity parameters. This is called the "comparison scenario". Energy intensity frequency distribution curves for that scenario enables determination of a percentile ranking, percentage of buildings with better (or worse) energy performance. Programs such as Energy Star (1992) score from 1 to 100, based on models and normalization methods of statistical analysis applied to the EIA database. To obtain a certificate (Energy Star Label) the building must achieve a minimum of 75 points, equivalent to belonging to the quartile of better energy efficiency. Other tools such as Cal-Arch (2003) do not offer any score but represent the energy intensity frequency distribution curve and the relative position of the actual building.

CEN Standard EN ISO 15217 "Energy performance of buildings—Methods for expressing energy performance and for energy certification of buildings" proposes procedures to define reference values and benchmarks. In this standard the global indicator of energy performance for a whole building is measured by an indicator's value that is expressed (EP) by the weighted sum of a building's delivered energy:

$$\mathrm{EP}_{\mathrm{period}} = \sum_{i=1}^{n} \text{delivered Energy}_i$$

where i = 1,2, … *n* declares the months of a period (heating/cooling).

The energy performance (EP) indicators should be based on two types of ratings according to EN 15203/15315. These types of ratings are "standard calculated" and "measured energy" rating that is described in the following paragraph. EP can represent Primary Energy of a building, Carbon Dioxide Emissions, and Net Delivered Energy defined by national policies (e.g., delivered energy).

Referring to EP requirements, there are two ways of expressing them:

(a) Global EP requirement based on an asset rating. This should be an upper limit value of one of the following indicators:

- Delivered energy.
- Primary energy.
- CO_2 emissions.

The requirement can be written: $\mathrm{EP} \leq \mathrm{EP}_r$ where EP is the performance indicator and EP_r is the value which defines the requirement.

(b) Specific requirement is based on:

- Energy use for one specific purpose (e.g., heating, cooling, and lighting).
- Building's characteristics or of its systems installed considered as a whole.
- Building envelope's characteristics or system components.

Reference values and benchmarks are used to compare the energy performance of a given building to the energy performance of similar buildings in terms of building use (e.g., apartment blocks, offices, hospitals).

The standard establishes three types of benchmarks:

- Rr: Energy performance regulation reference/benchmark.
- Rs: Building stock reference/benchmark, which represents the energy performance reached approximately 50 % of the national or regional building stock.
- R_0: Zero energy reference/benchmark, which corresponds to a building that produces as much energy as it uses.

According to standard the use of energy considered when defining the reference values/benchmarks shall be the same as the use of energy considered when establishing the rating. If the rating used is an asset rating, the reference will be obtained with the same assumptions as the asset rating regarding use patterns and internal and external climate.

2.3 Review on Energy Rating Methodologies

"Rating" is perhaps the most confusing term within this framework, as it is indistinctly used to refer to the building energy classification (the rating system), its application (the action of rating), and its final result (the rating figure) (Lombard et al. 2009).

According to literature the most common rating method is to normalize energy use with respect to building size, the annual energy use being divided by the heated floor area or by volume.

In general, the expression energy rating system (ERS) may be used as a synonym of energy classification, that is, a method for assessing energy quality. Examples can be found in both the Home Energy Rating System (HERS) of the Energy Star program and the US Green Building Council Leadership in Energy and Environmental Design (LEED) building rating system (LEED-NC 2005). HERS measures and rates the relative energy efficiency of any house, regardless of its age, location, construction type, or fuel use. The rating evaluates the performance of the thermal envelope, glazing strategies, siting, HVAC systems, and other criteria. HERS calculations include estimates of annual energy performance and costs and can provide insight into cost-effective, cost-efficiency improvements (HERS 2000). According to HERS, dwellings are subject to a standard simulation test for energy rating proposes with standard assumptions including: typical weather for building's location and standard occupant behavior (thermostat set points, hot water usage, personal appliances usage, etc.). The drawback for using this "universal" rating tool is that, for a project where the above factors are different from the standard assumptions, the resulting design is likely to be far from optimum when judged by the normal criteria.

Stein (1997) while examining the accuracy of HERS found also that the case studies demonstrated that is more difficult to accurately predict energy use in mild climates than in more severe climates.

Also, Stein and Meier (2000) are more precise in the Energy Rating System definition: "a method for the assessment of predicted energy use under standard conditions and its potential for improvement" and usual output (energy use prediction, rating score based on a comparison with a reference building and a list of improvements).

Like HERS, energy rating of commercial buildings operates in several countries. ASHRAE Standard 90.1 (1989) which incorporates the Building Energy Cost Budget Method is used as the basis for Commercial Energy Codes in several states in the US. The method involves the use of an energy simulation program to estimate the performance of the proposed building compared to a prototype or reference building. The reference building approach is to be used when a prototype building description is not relevant for the proposed design. The method is intended "only for the purpose of demonstrating design compliance". Input parameters for the prototype or reference buildings are suggested by the standard, based on the type of the proposed building. The suggested input parameters include the quantity/density and schedules of the occupancy, light, HVAC, water, HVAC system types, and the thermostat settings. It is also suggested that the prescriptive values for code compliance be used for the reference building's envelope's thermal properties. The performance of the proposed building is compared to that of the prototype or reference building in terms of the predicted annual energy cost. Although this methodology is more comprehensive than the most energy rating schemes for residential buildings it also, however, poses limitations for the designer. First, since the criteria used are annual energy cost, nothing is known of other possible aims, such as the CO_2 emission and life-cycle costs. Another limitation is that it does not take into account the building location in suggesting the thermostat settings and HVAC systems.

Fels (1986) presents the Princeton Scorekeeping Method (PRISM), where he uses the well-known linear relationship called energy signature, between heating energy use and outdoor temperature. Zmeureanu (1992) further developed this normalization method, to analyze utility bills collected in heated or cooled buildings.

Within the framework of Directive 2002/91, energy rating means the evaluation of the building energy performance. In the standard EN 15603 (2008) CEN proposes two types of ratings: (1) calculated ratings, based on computer calculations to predict energy used by a building for HVAC systems, domestic hot water, and lighting and (2) measured (or operational) ratings, based on real metering on-site. Calculated ratings are subdivided into standard (also called asset) and tailored ratings. The asset ratings use the calculation procedure within standard usage patterns and climatic conditions not to depend on occupant behavior, actual weather and indoor conditions, and are designed to rate the building and not the occupant. Asset ratings can be shaped to buildings during the design process (as designed), new buildings (as built), or to existing buildings. For the latter, when calculated under actual conditions (different to standard usage patterns) the rating becomes a tailored rating. In this sense, most of the American ERS are asset ratings for new or existing buildings, while benchmarking tools are normally based on measured ratings applicable only to existing buildings. Definition details for each rating are shown in Table 2.1.

Table 2.1 Definition of energy ratings according to CEN Standard

Name		Input data			Utility or purpose
		Use	Climate	Building	
Calculated	Design	Standard	Standard	Design	Building permit, certificate under conditions
	Standard	Standard	Standard	Actual	Energy performance certificate, regulation
	Tailored	Depending on purpose		Actual	Optimization, validation, retrofit planning
Measured	Operational	Actual	Actual	Actual	Energy performance certificate, regulation

While the schemes described above deal with site energy consumption (or energy costs) as a single rating criterion, some authors propose multi-criteria assessment of building performance. Soebarto and Williamson (2001) developed a building performance assessment methodology and tool based on multi-criteria decision-making approach where the performance of the building is always compared to a reference building. The criteria include energy use, indoor air quality, thermal comfort, operating plan load, costs, and other environmental degradation, e.g., using nuclear fuel, atmospheric pollution, etc.

In addition, within the framework of the European Joule–Thermie OFFICE project, Roulet et al. (2002) developed a multi-criteria rating method (ORME) for office buildings. This method is based on a rating method that uses principal component analysis and aims to qualify and sort various retrofitting scenarios based on energy use and thermal comfort condition. The result of the rating method is a single indicator that combines energy and comfort parameters. This score globally characterizes the performance of the building under defined conditions regarding the parameters: energy use for heating, cooling, and other appliances, impact on external environment, indoor environment quality and cost. ORME also includes a ranking method that uses partial aggregation techniques and purposes to rank buildings or retrofitting scenarios according to their performance with regard to several aspects. It requires a list of criteria along with an assignment of weight to each of them and allows the user to provide his scale of values.

Several schemes also exist attempting to combine other environmental factors into a single rating score (Yang et al. 2011a, b). Examples include the BREEAM technique (Prior 1993) introduced in the UK in 1990 as a voluntary environmental assessment scheme intended to encourage building owners and operators to adopt "green" practices. The scheme provides a tool and authoritative assessment procedures for quantitative evaluation of the environmental impacts of a building. The evaluation relates to a number of broad issues including, operational energy use and CO_2 emission, sick building syndrome, pollutants released during fire, embodied energy, radon emissions, and the life-cycle use of the building. Credit points are accumulated against the various performance requirements. These are summed to a total score to define Fair, Good, Very Good, and Excellent overall performance, with additional requirements of having attained minimum scores in the three performance categories: Global/Resources, Local, and Indoor.

The building energy and environmental assessment method (BE_2AM,) was developed within the THERMIE program. The aim is to provide a common and recognized system of assessing, at the design stage, the energy and environmental impact of buildings across Europe. BE_2AM has three components: (i) Life-cycle analysis of energy in use and embodied energy, (ii) Environmental preference for materials, and (iii) Environmental design opportunities. The rating performance is obtained by comparison with the performance of two reference buildings that comply with local standards. An overall credit rating can be defined as a linear combination of the three credit factors.

Also, LEED (1998) works in a similar way. Applicant buildings must satisfy a number of performance prerequisites and obtain a number of performance credit points to qualify for Bronze, Silver, Gold, or Platinum certification.

An international initiative, initially involving the input of teams representing 14 countries, was established to investigate the development of a comprehensive building environmental assessment methodology. The project titled Green Building Challenge 98 (GBC) was lead by representatives from Canada. The overall goal of GBC 98 was to "develop, test, and demonstrate an improved method of measuring building performance" (Larson and Cole 1998). The project reconciled the work of many around the world and a so-called "second-generation" framework for assessing energy and environmental performance was developed during the process. The method is embedded in a computer tool GBTool (Anon 1998). The work has been extended for GBC2000.

2.4 Review on Energy Labeling Methods

It was in the early 1990s when the EU introduced energy labeling with a double objective: to inform consumers about the energy performance of energy-consuming devices and to promote energy savings and energy efficiency. Following the success of its application to domestic appliances (Directive 92/75 1992), energy labeling was extended to buildings a decade later (Directive 2002/91/EC 2002).

Building energy labeling, consisting of assigning an energy performance class or label to the building, requires the development of a scale related to a Labeling Index (LI). The choice of the comparison scenario is a key issue for the scale definition.

If there are enough comparable buildings, statistical analysis of the EPI through the cumulative frequency distribution curve allows the use of the percentile as an indicator of the energy position. At this point, labeling is equivalent to assigning percentile intervals (bands) to energy classes. According to Lombard et al. (2009), by normalizing the EPI distribution of cumulative frequencies using an average value such us the percentile of 50 % (EPI_{50}) the labeling index could be defined as:

$$\mathrm{LI} = \frac{\mathrm{EPI}}{\mathrm{EPI}_{50}}$$

The scale is defined by fixing the transition values between classes.

As it has been described, standard EN 15217 describes a procedure to define limits between classes based on two references: building regulations and building stock. The first is the overall minimum efficiency requirement set by the regulation as a maximum limit for the energy performance index ($\mathrm{EPI} < \mathrm{EPI}_R$). The second reference corresponds to the energy performance reached by 50 % of the building stock (EPI_S). If the EPI is normalized by the stock reference, the label index for the regulation reference is:

$$\mathrm{LI}_R = \frac{\mathrm{EPI}_R}{\mathrm{EPI}_S} = a$$

According to this methodology CEN scale situates the regulations reference on the boundary between B and C and the stock reference on the boundary between D and E (Table 2.2).

Lombard et al. (2009) comments that CEN scale suffers from a lack of sensitivity since every new building must comply with the regulation and would be labeled B or A depending on the saving percentage ahead regulations reference.

Another labeling method is the self-reference method that should be used when the comparison with other buildings is not feasible and the only valid reference is set by a Reference Building (RB) generated from the actual building once a set of standard rules are applied. In this case, energy performance comparison must be done on the basis of a labeling index showing the saving percentage in relation to the self-reference:

$$\mathrm{LI}_{\mathrm{SR}} = \frac{\mathrm{EPI}}{\mathrm{EPI}_{\mathrm{RB}}}$$

The latter approach does not require a database for the comparison, nor a statistical analysis of the building stock comparison scenario. However, bands must be adjusted for the scale to be sensitive enough for improvement measures.

Criteria to set the scale are subjective and, perhaps, closer to policy decisions than to technical analysis. Thus, there is great disparity between different scales. A key issue is the level of definition or number of classes, with examples such as the 13 bands (A–M) Danish system and the Australian 5 stars system.

Table 2.2 Limits between classes for the scale proposed by CEN

$\mathrm{LI}_{\mathrm{AB}}$	$\mathrm{LI}_{\mathrm{BC}}$	$\mathrm{LI}_{\mathrm{CD}}$	$\mathrm{LI}_{\mathrm{DE}}$	$\mathrm{LI}_{\mathrm{EF}}$	$\mathrm{LI}_{\mathrm{FG}}$
0.5α	α	0.5(α + 1)	1	1.25	1.5

The CEN's scale reference is set by the regulations, while the BREEAM for office certification and the American LEED-NC propose different self-reference buildings. The latter, rewards with up to 10 points (from a total of 69) if the running costs of the building are below the reference established in Annex G of ASHRAE 90.1.

2.5 Review on Integrated Building Energy Classification Methods

In the literature there are some significant researches that investigate integrated classification methods including the building energy database, the benchmarking method, the building energy performance evaluation, and the energy boundaries (classes) definition.

Hernandez et al. (2008) in their research present a methodology to develop energy benchmarks and rating systems for classifying the Irish Primary schools. The benchmarking building dataset (46 school buildings) was adopted in detail in terms of building and energy consumption data questionnaires distribution and collection. Having comparison benchmarks for reference stock buildings and reference regulation buildings and applying the building energy performance classification method proposed in EN 15217 (2007) the authors rate a sample school building according to asset and operational rating method, in order to compare these two methods that have been proposed by CEN Standard (EN 15203 2007). The authors conclude that measured rating represents the actual use of building, while asset rating has the benefit of retrofit scenarios investigation. They also remark that both rating approaches require considerable efforts in data collection and data analysis and they propose, in terms of future prospects of their research, that rating methods should somehow take into account of indoor environment issues.

Santamouris et al. (2007) in their research propose an energy classification technique based on intelligent clustering technique. The benchmarking building dataset consists of collected energy data from 320 school buildings from almost all geographic departments of the country. First, the energy benchmarks regarding the heating, electricity, and total energy consumption based on equal frequency rating procedures are defined (i.e., typical school building—50 % of the stock, best-practice school building—25 % of the stock) leading to a four-class rating. At the next step a five-class rating for heating and total energy consumption is obtained with the application of fuzzy clustering techniques. The proposed method presents important advantages compared to the frequency rating procedures: it offers more robust classes avoiding problems of unbalanced classification, while it considers in a more concise way the common characteristics of the buildings and classify them according to existing similarities.

Lee and Lee (2009) investigate the application of data envelopment analysis (DEA) to classify government office buildings in Taiwan. The benchmarking building dataset consists of collected energy data from 47 office buildings. According to the proposed method the overall building energy efficiency is influenced by scale factors and management factors and then has the effect of scale factors removed to focus on the performance of management factors that may provide an optional indicator to refine the traditional focus on energy consumption per unit floor area. The scale factors for climate-adjusted building energy consumption after regression analysis are floor area and the number of occupants. The overall energy efficiency is divided into scale efficiency and pure technical efficiency. The pure technical efficiency, calculated by comparing climate-adjusted energy consumption under the same scale, can be expected to represent the effect of management performance. The proposed method leads to a four-class rating system where the buildings are classified according to their management performance.

Barelli et al. (2009) propose an energy building classification procedure where the corrected energy demand, separately for heating and cooling, is determined independently of buildings location and directly comparable to a standard seasonal performance scale, defined on the entire territory of application. The proposed corrective procedure allows comparing the construction quality of real buildings without taking into account their localization, in order to obtain a homogeneous criterion of evaluation at national level.

By summarizing the research work performed so far in the buildings' classification sector, the following points are revealed:

- The knowledge of building stock energy data of a country is a very significant tool for energy benchmarks establishment, energy rating procedures, and energy classes' determination, according to the Directive 2002/91/EC and its implementation in EU member states. The lack of building energy databases in many EU Countries, including Greece, and the difficulties of collecting them through audits lead to the investigation of other potential solutions. A different approach to a database creation is the generation of representative building datasets based on the application of building simulation for a range of energy parameters, such as the building use, building size, constructional characteristics, operational characteristics, and climatic conditions. Up to now, the author dealing with building database creation has found no research work that creates large simulated building datasets for energy and thermal comfort benchmarking.
- A detailed building simulation model which provides, with relative accuracy, building performance indicators at hourly and yearly base, such as energy use demand, energy consumption for heating, cooling, ventilation, electric lighting, appliances and hot water, thermal comfort indicators such as indoor temperature, humidity, PMV, PPD etc., is a core tool for energy and thermal comfort rating, validated building datasets creation, benchmarking and classification.
- Several rating and classification schemes and standards combine indoor environmental performance with building energy performance. These schemes, apart from the building's energy consumption, take into account environmental parameters such as thermal and visual comfort, indoor air quality and noise level (Wong and Mui 2009) in order to establish environmental benchmarks for

buildings. These classifications are based on expensive and time-consuming methods and processes such as operational rating results, measurements of environmental parameters, building monitoring, building indoor environment management system application (Kolokotsa et al. 2005), and building audits. The energy performance calculation tools that have incorporated environmental parameters calculation methods have to be generalized in order to create simulated datasets that include not only energy data but also indoor environmental data of buildings, providing thus easier methods for environmental benchmarks establishment and boundaries determination for each building type at national or/and global level.

- Up to now the various techniques that have been proposed to develop classification schemes (Santamouris 2001) define energy classes based on the cumulative frequency distribution of the energy consumption of the buildings stock. Such a classification requires that the used sample of building energy data strictly follows a normal distribution, condition which rarely applies given the large variety of the buildings' characteristics. To this direction, Santamouris et al. (2007) in their research propose an energy classification technique based on intelligent clustering technique. The proposed method presents important advantages compared to the frequency rating procedures: it offers more robust classes avoiding problems of unbalanced classification, while it considers the common characteristics of the buildings in a more concise way and classifies them according to existing similarities. The outcomes of this research encourage the investigation of applying various clustering techniques, such as hierarchical, K-Means, Gaussian Mixture Models, Fuzzy and Neural clustering algorithms, to large building datasets for establishing buildings' performance benchmarks and boundaries toward an integrated classification scheme for Greek, Romanian, and Balkan office building sectors. The establishment of these classifications will permit the comparison of similar buildings in terms of their energy consumption and indoor environment quality.

In the framework of this book and in Nikolaou et al. 2012, an integrated classification method including the building energy performance evaluation method, the building stock database creation, the benchmarking process, the energy boundaries definition, and building efficiency improvement methods recommendations, is developed and proposed for office building sector (Fig. 2.1).

The characteristics of the proposed classification scheme are:

- The investigation of the office building characteristics through small audits. Case studies office buildings located in Athens have been audited by the authors

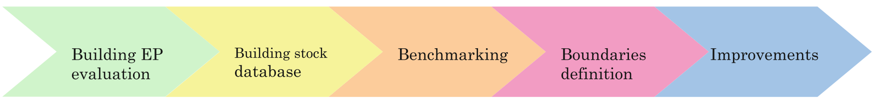

Fig. 2.1 The steps of the integrated building classification method

via detailed questionnaires distribution and many in situ measurements with the aim of collecting individual details on the construction, activities, energy uses, and energy bills.

- The installation of a Building Management System (BMS) in an office building in Athens in order to conduct a detailed energy and environmental audit. The measured variables such as the indoor air temperature, the relative humidity, the CO_2 concentration, and the energy consumption for heating, cooling, and ventilation will be the tool for the (measured) operational rating procedure of the office building.
- The creation of a detailed office building simulation model, validated initially through the small audits and then through the detailed energy audit. The main aims of this simulation model are to approximate reality at a higher degree, since the study is based on the hourly measurements, to provide a reliable tool for calculated (asset) rating of office buildings and to constitute the starting point for a generalized energy rating model for large simulated building datasets creation.
- The principles of the creation of large virtual building datasets of office buildings based on the application of building simulation for a range of energy parameters, such as building use, building size, constructional characteristics, operational characteristics, and climatic conditions. Therefore, the proposed methodology overcomes the difficulties and time required for collecting building constructional properties and energy bills data by creating them virtually, taking into account all the parameters that may affect the energy performance and indoor thermal comfort. Moreover, the proposed method provides flexibility and expandability on building datasets' characteristics, sample size, and climatic conditions according to the relevant research scope. The large amount of the output data can be employed for energy and thermal comfort benchmarking, classification, sensitivity analysis, neural network training, and eventually for any process that demands a significant number of building data.
- The investigation of the application of available clustering techniques, such as Hierarchical, K-Means, Gaussian Mixture Models, Fuzzy, and Neural clustering algorithms to the simulated office building dataset toward the establishment of benchmarks and classifications for office buildings. Using appropriate indices and criteria such as validity indexes the present thesis focuses on the selection of the best classification algorithm. The energy and thermal comfort classes that will be produced by the selected method will be compared to the equal frequency distribution methods and the CEN proposed methodology.
- The final classification results will be used for parametric study and detailed investigation of common buildings' characteristics (constructional and operational) in each rating class in order to provide with a tool for adopting improvement recommendations for office buildings' energy efficiency.

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