Energy assessment in town planning: urban energy maps

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Abstract

The paper describes an analytical procedure which allows the characterization of the energy performance of new and existing buildings, in a large urban context, through Geographic Information Systems (GIS). The methodology tries to codify a new process of integrated urban planning, aimed at identifying and designing energy efficient new buildings and the refurbishment of existing ones, for sustainable urban development and growth. The multidisciplinary of various boundary conditions, within an incomplete/unapplied legislative framework about building energy efficiency, makes a very interesting scientific study regarding the sustainability of town planning and urban retrofit, guaranteeing: environmental stewardship and economic development targets; global goals of an environmental sustainability; introduction of procedures for a global view of the construction process that has to be declined in each local context for focused territorial planning. Therefore, the paper suggests a geo-referenced model, through which it will be possible to determine the energy consumption of each building and then to support the management of territorial transformations. The new methodological approach has been applied to the historical center of Benevento. With reference to each building, the energy demand was determined by crossing census data, (ISTAT/ENEA) and the results of predictive physical correlations, with thermo-physical properties, cooling/heating needs and energy requests. The achieved results and their reliability allowed us to obtain "urban-energy maps" (MEU), which represent an important tool for advanced energy planning, in terms of both territorial control and evaluation of the energy retrofit potential.
Keywords: inner city, energy audit, energy retrofit, GIS, sustainable urban development.

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1 Introduction: building and urban sustainability

The current dependence of the global energy system by fossil primary sources (burned to satisfy about 80% of the overall needs), is the leading cause of polluting emissions that are altering dangerously the climate on the planet. In Italy, the energy balance of 2009, published by the Ministry of Economic Development, shows that the civil sector accounts about 35% of total demand, which corresponds to an increase in emissions around +17% compared to 2002. Moreover about 60% of the energy consumption in the civil sector is due to the residential one, which is mainly related to the energy requirements for the heating and the cooling [1].

New European energy policy cannot ignore that the annual energy requirements of domestic consumption account for approximately one third of total EU energy consumption. This led to the adoption of European Directive 2002/91/EC (Energy performance of Building Directive – EPBD), to improve energy efficiency in buildings, then updated by the European Directive 2010/31/EC [2].

The Italian Government receipted the Directive 91/2002/EC through the Italian Legislative Decree n. 19272005 (Implementation of Directive 2002/91/EC on the energy performance of buildings) [3], which has been reviewed and improved by the Decree 2006/311. Currently, the definite asset of the Italian energy legislation is reported in the Italian Presidential Decree 59/2009 and in the Ministerial Decree 26.06.2009 [4].

Moreover, in order to reduce the impact of the civil sector, in Italy it is essential acting on existing buildings, since there is a low building turnover rate (i.e., less than 1% yearly). This happens because a significant portion of the building stock (approximately 40%) was built before of the first laws on energy savings.

Therefore, tools developed to monitor the quality of the existing buildings and to design energy efficient new buildings and refurbishments of existing ones are required, above all in large urban contexts.

2 GIS: tool of visualization and support in determining the energy performance of buildings

Starting from the theory of the "Ecourbanistica" (i.e., Ecotownplanning) [5] and from the systemic approach [6] to the city, an urban structure may be interpreted as a complex dynamic system [7] in which you can find, among others, several sub-systems [5]:

- the physical system which consists of all urban spaces (houses, streets, and squares), inside which activities take over and networks where flow the communications (physic, energetic, telecommunication, etc.)
- the functional system including all urban activities (functions) and the relations among these;
- the socio-anthropic system which is composed by the urban community: the citizens and relationships among them.

This interpretation of urban phenomena allows the basic elements for designing an environment of representation and knowledge development. About this, by using the Geographic Information System (GIS), it is possible to work out an information models of territory, structured according to levels that can be filled through geo-referenced data regarding the city. Therefore, GIS is a cognitive ideal support for structuring a “model” of the city in which the buildings are the basic entity to which to associate the informationi [8].

The prerogative of GIS is the georeferencing, i.e. “the process of applying a coordinate system to a given object with its layer of data on a map”. Each object is positioned in an appropriate coordinate system, through its association to a geometric entity suitable for the representation (point, line or polygon) [9].

This digital tool becomes an fundamental support for analysis and management of the town. Indeed, the creation of a Geographic Information System, which collects all the spatial data (in graphical and alphanumeric form) and allows their elaboration, is an essential tool for an advanced energy planning, in terms of both territorial control and evaluation of energy retrofit potential [10].

Moreover, this digital ambient is particularly suitable for the storage of individual building’s data and the consequent determination of the energy performance of buildings.

The potential of georeferencing process and related technology can be help greatly in the management and analysis of large volumes of data, allowing for better understanding the urban transformations and the modifications induced by selected interventions.

3 The energy performance of buildings characterizing large urban contexts: methodology and its application to the historical center of Benevento

As said, the use of GIS allows acquisition, archiving, analysis and geo-referenced visualization of levels related to the data considered necessary for the characterization of urban land, identifying the most critical points and the potential of targeted energy-retrofit interventions.

Moving from these potential, this paper intends to describe the energy characterization of over 500 buildings in the historical center of the Italian town of Benevento (Campania).

The characterization methodology presented can be divided in two main steps that will be described:

1. audit of the historical center and determination of building types;
2. determination of energy demand and of the energy class of each building.

3.1 Audit of the historical center and determination of building types

When the final purpose is a standard evaluation of the building energy performances, e.g. in order to compare the energy performances of a particular building compared to benchmark values or to plan the energy retrofit of the building stock, the level of deepening and realibility of the analysis are linked to number and quality of data characterizing the building.

Therefore, the first phase of work was the direct detection of the major characteristics of the buildings through a census. The obtained values were entered into an electronic spreadsheets for further processing, as below listed:

- the kind of use.
- the number of floors.
- the construction period.
- the number of contiguity with other buildings.
- the indoor liveableness.

The first chart shows the percentage distribution for the building's number of floors and it is noted that, since this is an historic center, the heights are quite proportionate and about 80% of the buildings has between two and three floors.

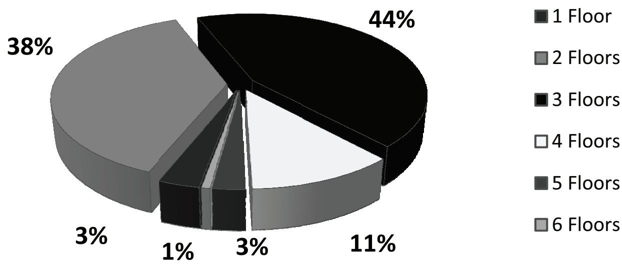

Figure 1: Percentage distribution for the building's number of floors.

Figure 2 shows that the highest percentages, as regards the kind of use, competes to residential function (→ 52%), and residential-commercial one (→ 23%).

The census data showed that 95% of buildings were made of load bearing walls, while the remaining has reinforced concrete structures. This estimation is crucial to determine the thermo-physical properties and the average height of each building.

Indeed, acording to data published in the Official Bulletin of the Campania Region n. 27, "Proposal for a Regional Environmental Energy Plan of Campania and the initiation of consultation activities, environmental assessment, and drafting of the Action Plan for Energy and the "environment", the building's average height was estimated as a weighted mean between height of masonry buildings (→ 4 meters/floor) and of reinforced concrete ones (→ 3 meters /floor). Obviously, the data refer to a single-floor building. Since in the case study the number of masonry buildings is much higher than those of reinforced concrete, it has been set an average height of 4 meters for all buildings.

Crossing the census data and the most common building types in Campania, derived from data on seismic vulnerability of the regions, it has been considered for the masonry a transmittance value of 0.75 W/m^2K, while for concrete buildings a value of 0.94 W/m^2K has been used.

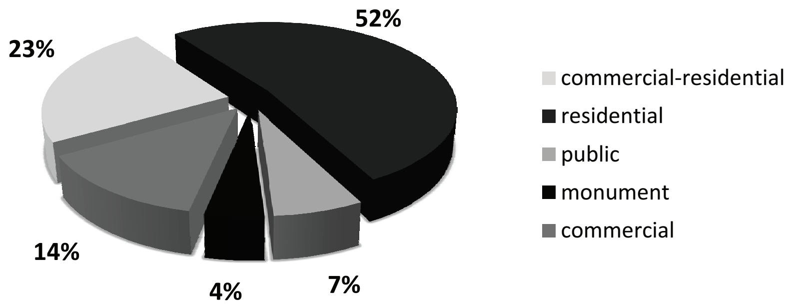

Figure 2: Percentage distribution of kind of use.

Considering the building type and the construction period, it is assumed that all building have a mixed basement slab, and the thermal transmittance was taken as to 1.04 W/m^{2}K.

The assessments of the above study indicate that almost all buildings have been interested by the replacement of single glass windows with double glazed ones. Therefore the value assumed for the transmittance is 3.0 W/m^{2}K [11].
For its importance, determination of the "surface to volume ratio" (S/V) has been particularly accurate. By definition, this parameter expresses the relationship between all dispersing surface and heated or cooled volume.

Specifically, the volume has been obtained by the product between the average height of the building and the surface area, achieved starting from the ISTAT census of 2001 and from the floors number inferred. Instead, the total dispersing surface has been estimated through knowledge of building height, surface of basements, perimeter and number of contiguities related to the number of floors of adjacent buildings [12]. For instance, the calculation for two adjoining buildings, generically defined "build1" and "build2", respectively of two and three floors, is reported in figure 3.

The dispersing surface of "build2" (i.e., Sd2) has been calculated as reported in equation (1).

$$Sd2 = (2 * Sc) + (P * h) - (Cc * P * h/4) \quad (1)$$

where:

- Sc2 is the surface area of the building
- P is its perimeter;
- h is its height;
- Cc is the contiguity coefficient that is related to the number of buildings in contact with the examined one.

In this case, surface of basement and roof (2*Sc) have been added to the vertical envelope surfaces (P*h); then, the surfaces adiacent to the buisling 1 have subtracted (CC*P*h/4).

Geometrically, the building was considered consisting of eight lateral sides, and to gain the true value of the dispersing surfaces, the contact surfaces (in this case two), were divided by the total ones (eight). This procedure has been applied to each building, and we have obtained all S/V ratios.

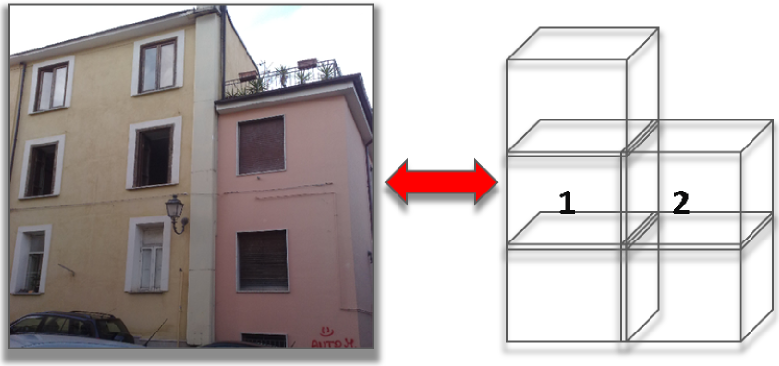

Figure 3: Real and exemplificative picture of the two adjacent buildings.

3.2 Determination of building energy demand and of the class for energy efficiency

The Guidelines for the Building's Energy Certification (→ Italian Ministerial Decree 26/06/09) and the standard UNI/TS 11300-1 define several kinds of building's energy ratings, depending on the required level of deepening.
In particular, in this paper, the methodology of standard evaluation (i.e., the "asset rating" of the building energy performances) has been applied, in order to obtain the building energy class.

This kind of evaluation starts from the input data provided into the technical documentation of the building design, from numerical-physical evaluations and from typical boundary conditions. Therefore, it is considered an indoor air set point temperature equal to 20 °C and a length of the heating season such as established by the Italian Presidential Decree 412/93 [13]. Table 1 shows the main data for Benevento.

Table 1: Climatic data and heating period of Benevento.

Climatic zone	Degrees Day	Daily hours of heating	Heating period
C	1'316	10	15/11 - 31/03

Table 2: Values of the energy efficiency ratio of heating sub-systems.

Sub- system	Not-refurbished building	Refurbished building
Equipment for the heat emission into the indoor environment	0.95	0.93
Control devices	0.93	0.93
Distribution of the heated fluid devices	0.88	0.99
Generation equipment	0.90	0.93

According to the normative, the primary energy need for the winter air conditioning can be calculated as the ratio between the energy requirement for the winter heating and the overall seasonal energy efficiency of the heating systems.

The thermo-physical properties, outlined above, allow the evaluation of energy losses due to the thermal dispersions for transmission, assuming that the windows occupy about 15% of the vertical surface.

With regard to heat transferred for ventilation, the fresh air value (ACH = Volumetric Air Change per hour), assigned to the airflow rate, was chosen according to the kind of use: commercial-residential, ACH = 0.7; residential, ACH = 0.4; public-commercial, n = ACH; monument, ACH = 0.3.

For the determination of the endogenous heat gains input was made reference to prospect n. 8 of the UNI/TS 11300-1, so it has been assumed [14]:

- Commercial-residential buildings → Q_{end} = 12 W/m^2, by an average value;
- Residential buildings → Q_{end} = 16 W/m^2, estimated according to expected loads;
- Public-commercial buildings → Q_{end} = 10 W/m^2, from an average between bars, restaurants, offices, hotels and schools, with 70% of the weight taken from bars and restaurants.
- Monument → Q_{end} = 6 W/m^2, by an average value among churches, museums and libraries.

About the energy performances of the heating appliance, in the Italian standard UNI/TS 11300-2, the heating system has been divided in several sub-systems. The global system efficiency can be defined as the product of the efficiency ratios characterizing each sub-system. Input data are reported in table 2 [15].

By attributing these value to each sub-system, and considering about 50% of possible interventions of refurbishment, the final result is an overall seasonal energy efficiency ratio of the heating system equal to 0.75.

The global mean value obtained was compared with the ISTAT data to estimate the reliability of the results.

To obtain the whole energy consumption for the town of Benevento, the starting point is the energy requirement for the winter heating (ktoe), published in “Energy and Environment Report” ENEA, 2007/2008. The values are updated to 2005, and these are the sum of all uses in the residential sector.

By normalizing this demand to the surface area (m^2) of buildings occupied, we obtain the average winter demand in Campania, expressed in kWh/m^{2}year [16].

Table 3: Energy requirement for the winter heating in Campania (ENEA).

Energy requirement	Occupied surface area	Energy consumption
878 (ktep)	168'269'939 (m^2)	60,82 (kWh/m^2 year)
10184 (GWh)		

Evaluating the weight that the province of Benevento has on regional consumption, according to PEAR’s data, there is an assumed average need of 83.15 kWh/m^{2}year.

Since the average primary energy need for the winter air conditioning, obtained by applying the methodology previously exposed to all buildings o, is equal to 80.97 kWh/m^2 year, there is a difference of only 3 percentage points. This value exalts the consistency of the analysis made.

Table 4: Percentage deviation of the energy requirement for the heating.

Investigated Building	Calculated value (kWh/m^2 year)	Energy bills (kWh/m^2 year)	Percentage differences
R-cost	102.8	95.4	≈ 7%
Palazzo San Domenico	115.5	167.0	≈ 44%
Palazzo Bosco Lucarelli	128.1	138.1	≈ 8%
Palazzo Giannone	130.1	142.1	≈ 8%

As further comparison, the calculated values were compared to real ones of four buildings for which the the energy requirement for the winter heating was derived from their energetic bills; the percentage deviation is shown in table 4.

The comparison shows that, for three buildings, there is an excellent convergence. Instead the building with the largest variance allows to highlight that a global methodological approach and simplified doesn't take account of particular conditions present in both structure and in the kind of use of buildings.

3.3 The energy quality of the historic center of Benevento

With reference to the case-study here presented, starting by the Italian scheme that builds the different classes starting by the admitted limit value of the energy performance index (e.g., EPi, the primary energy request for the winter air-conditioning), the energy certification of each building has been prepared and synthetically shown in figure 4.

The chart shows that 280 buildings have an energy label expressing an energy class F (48.87%), and for remaining 293 an energy class G (51.13%) is achieved (figure 4).

Therefore, the historical center of Benevento is characterized by a building stock quite unsatisfactory under the energy efficiency point of view, mirror of a not unlike reality on national scale.

The outcomes reported in figure 4 and the following maps (figures 5 and 6) provide information useful for a pre-analysis aimed to evaluate the potential energy saving of several energy-retrofit measures. Indeed, a geo-referenced model allows to identify quickly the position of buildings characterized by higher energy needs and the energy class, in order to define appropriate strategies.

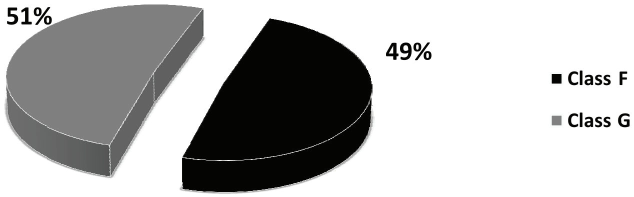

Figure 4: Energy class of buildings, according to Decree 26/06/2009.

4 The urban-energy maps: innovative elements for sustainable urban development and growth

Since the GIS is the merging of cartography, statistical analysis, and database technology, through this tool it is possible to generate a digital map of a town and manipulate all geo-referenced interested data (see figures 5 and 6).

With reference to case study, after to have developed a digital cartographic base of Benevento historical center, it was necessary to connect the geo-referenced territorial dataset with the table which was structured through the information known about every individual building and the calculated energy parameters. In this way, through "queries" to the system, it is then possible to obtain the maps relating to the energy performance of the building but also to other key parameters to help reach provincial target of sustainability. So it is clear that the urban energy maps are an important tool for an advanced and participated energy planning with which the sustainability could become a value diffused.

For example, the figures below show maps to the primary energy need for the winter air conditioning and for energy class of buildings.

Since the created database is very rich of information, it will be possible to work out maps for all other useful characteristics and performances, and determine the priorities for action.

These maps allow an immediate interpreqtation of the geometric and thermo-physical characteristics for the existing building stock, but also to quantify the relationship between energy need and demographic variables, as well as the distribution of inefficiencies.

Starting from the collected information, the following benefits can be marked in the management of the building stock:

- the possibility to easily verify characteristics of buildings in real-time;
- the ability to query the system and thus support the evaluation of multiple aspects of a building by combining together several variables;
- the possibility for the authorities to identify and control energy saving strategies and to inform citizens of the energy performance of their building, initiating a new social ethic of sustainable urban development.

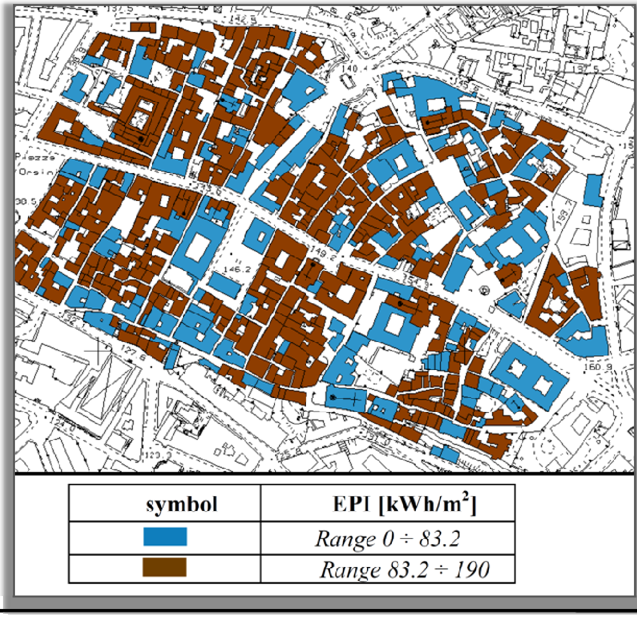

Figure 5: Urban energy map of the Benevento: winter heating performances.

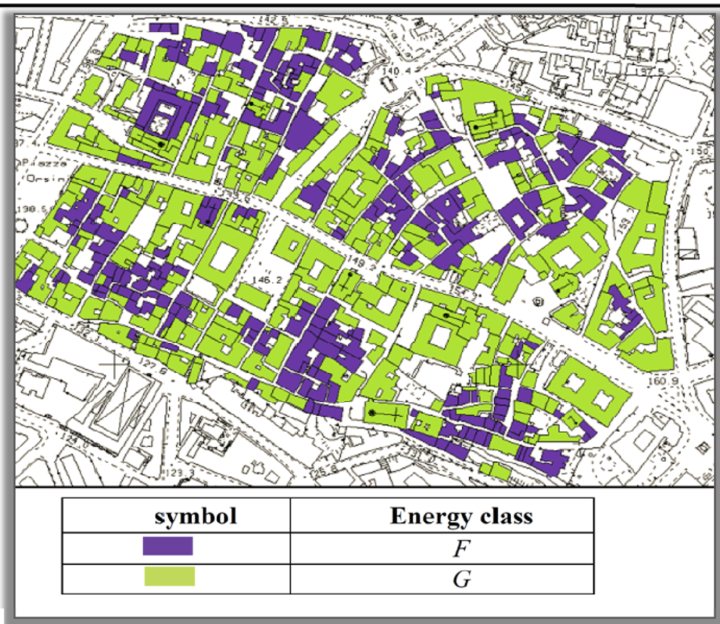

Figure 6: Urban energy map of the Benevento: energy label.

5 Conclusions

The manuscript tries to clarify that the urban-energy maps are a powerful base for the territorial managment because these tools can help the planners and steer a growth inspired to the more general goal of a sustainable urban development. Summarizing, the achieved results and their mapping are the starting point for studying the effect of some selected energy-retrofit interventions. Their analysis allows to obtain new maps showing the improvements made and the new values of the energy performance indexes.

Therefore, by using the Geographic Information System and with appropriate government strategies, it is possible a new integrated town planning so that the sustainability could become a value diffused.

As regards the carried out research, currently the authors of this paper are involved in the study of further expansion of the geo-referenced database by adding the energy requirements in summer time. In particular, with reference to some Italian latitudes, the evaluation of the summery building's thermal needs is particularly significant, in order to provide the summer cooling energy performances and, thus, identify the most adapted retrofit actions.

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