Chapter 8
Methods and Tools for Urban Energy Planning

Giuliano Dall'O' and Simone Ferrari

Abstract Cities are responsible for around 70% of global energy demand and are considered as having a crucial role in effective abatement of global energy consumptions. The topic is largely discussed in available literature, which reveals the great diversity of applied approaches and the necessity to move towards the concept of smart energy systems, focussing on synergies among different energy sectors. However, considering the large share of responsibility of the building sector, this chapter focussed on related energy demand assessment. After an initial introduction, which spotlights the most complex elements, the chapter presents some methods of analysis to evaluate the energy performance of the existing building stocks. Subsequently an overview is presented of the methods and tools for determining the energy demand of buildings within urban energy planning, paying particular attention to those that rely on hourly profiles. The assessment of hourly energy demand of the existing building stock, as well as the prediction of its variation due to energy efficiency measures, are fundamental activities for planning strategies of distributed generation, district heating and/or cooling networks, renewables integration, energy storages, etc., all necessary in moving towards smart energy districts.

8.1 Methods for Estimating the Energy Performance of Existing Building Stock

In the sustainable planning of a city or a community, the energy retrofit of the existing building stock represents a strategic goal if important greenhouse gas reduction results are to be achieved. The energy analysis of all the buildings in a city or a neighbourhood, however, is by no means easy since the information available on

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the thermal-physical characteristics of the buildings and about the management and control of the associated plants and services installed are mostly unknown.

A classic energy audit methodology cannot be applied because it would be too expensive and time-consuming. On the other hand, knowledge of energy quality is essential because it allows the urban or the energy planner to define the current situation (baseline) and to plan strategies for energy retrofit actions evaluating the technical-economic aspects and the possible barriers to be overcome.

An understanding of the energy performance in buildings in a whole city or an entire district is important for sustainable energy planning strategies that accelerate the energy renovation process in existing buildings that are not energy efficient.

Researchers from the Department of Architecture, Built Environment and Construction Engineering (ABC) of the Milan Polytechnic worked on the subject of the energy assessment of existing building stocks. In the following sections the results of two research studies on this topic will be presented and discussed, becoming methodological approaches.

8.1.1 A Methodology for Energy Performance Classification of Buildings at Urban Scale

A methodology for energy performance classification of buildings on an urban scale, largely based on information which is already available on building stock (i.e., cartographic documentation, thematic maps, geometric data and others) was proposed in the study of Dall'O' et al. (2011). Data regarding the energy performance of buildings were collected using energy audits on sample buildings, which were selected using a statistical approach. Using the tools in a Geographic Information System (GIS) platform, the integration of two data sources allowed for a low cost, comprehensive framework of the energy performance of buildings in Carugate, a small town located in the Lombardy region of northern Italy. The methodology is outlined in the flowchart in Fig. 8.1.

This documentation retrieval phase includes the collection of all information that may be useful for analysis, for example, site maps, aerial photogrammetric surveys and building cadastral data. Internet is a very useful source that contains a large amount of information, if the maps are sufficiently updated, tools as Google Maps® very useful, particularly for detecting the status of the buildings' roofs.

The management of the energy characteristics data of buildings is based on a GIS platform. Many municipal technical departments already have a GIS platform, and in these situations, the work is easier because it is then sufficient to integrate additional information in the same platform.

In some cases, the basic digital map must be corrected, for example, when completing the boundary lines or closing the polylines of each building. GIS implementation involves the creation of a database. The elementary object is the building, which is

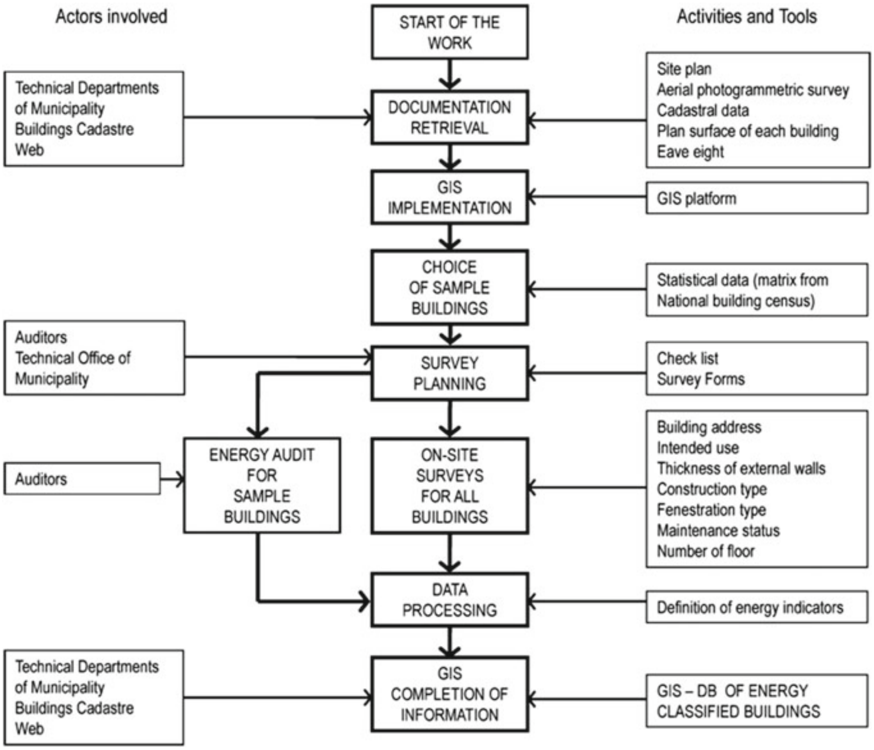


Fig. 8.1 Flowchart of the methodology for the energy performance classification of the buildings (Dall'O' et al. 2011)

associated with a record. The fields of each record define the attributes of a building's characteristics (e.g., area, volume, the condition of the facilities and energy performance). Each building is identified by a code that must be defined at this stage.

From the statistical data of the population census, it is possible to obtain information on existing building stock to define a matrix of the "number of apartments per building/construction period". From this matrix, it is possible to define the characteristics of the buildings to be identified within the building stock (sample buildings representative of each construction period) and to perform a detailed investigation with a specific energy audit.

The purpose of survey planning is to efficiently and effectively plan the next phase of an on-site survey. Checklists and survey forms must be prepared to facilitate the survey. All the paths of the auditors must be planned to limit unnecessary footwork on the streets. Proper planning reduces the time required while maintaining high quality results. In many cases the mapping of buildings from the outside can be facilitated using the Google Maps® "Street-view" function. The purpose of this activity is to obtain all of the information that is needed to complete the framework of the status of the building stock from an energy efficiency and conservation perspective.

The next phase involves the selection of some representative buildings on which to perform a detailed energy audit. The scope of these audits is to calculate the primary energy needs for winter heating (EP_H) expressed in kWh/m^2 per year: calculations must be performed using the calculation method that has been adopted locally for energy certification. The choice of the number of samples for the energy audits of the buildings must be made on the basis of the existing building stock. To this end the national census is a useful source that provides data on buildings and houses. In this case study, considering that in Carugate there are 1320 buildings, the total number of sample buildings, 93, is approximately 7% of the entire building stock. Energy audits are not necessary if the municipality has a large number of energy certifications in hand.

The EP_H data for the sample buildings are initially divided up into groups of construction periods: in the case under study seven construction periods (before 1919, 1919–1945, 1946–1960, 1961–1980, 1981–2002, 2003–2006, 2007–2010) were considered.

The correlation between the shape coefficient, or S/V ratio and EP_H must be calculated to obtain a linear function between the shape coefficient of the building S/V and EP_H. In the calculation phase, it is important to verify that the coefficient of determination R^2 of each line is acceptable (values are considered acceptable if R^2 is greater than 0.75). Figure 8.2 shows the regression lines that relate the EP_H to the S/V ratio for different construction periods.

The equations of the regression lines were the used to complete the information in the database of the GIS platform. Data on the energy performance (EP_H) of each building were obtained automatically by the software using the calculation function

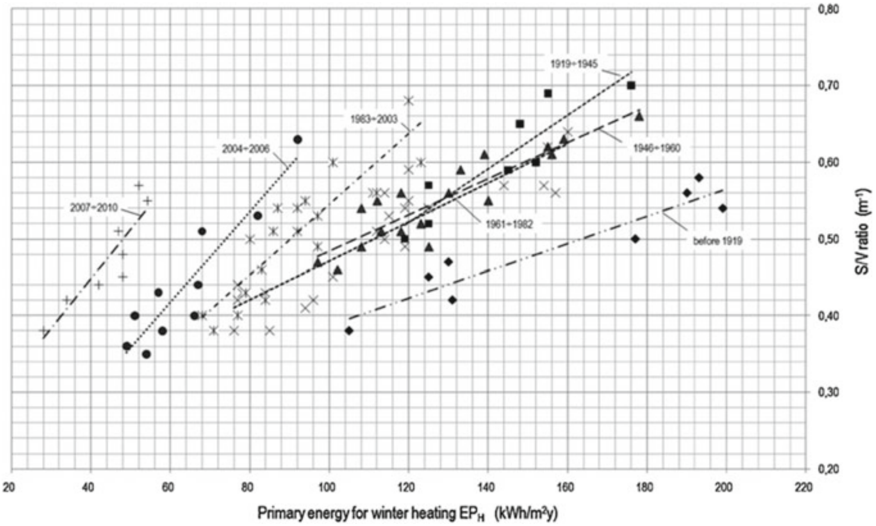


Fig. 8.2 Regression lines that relate the EP_H to S/V ratio for different construction periods (Dall'O' et al. 2011)

tools which employ the equations derived on the basis of the energy audits of a sample of the buildings, functions of the construction period and the S/V ratio (construction periods and S/V ratio were information already available in the database).

Once all of the data are included in the GIS platform, the technical department of the municipality/local authority uses a tool that is capable of performing a large number of territorial energy management and planning functions.

Some examples of its potential uses are listed hereunder:

- estimation of the energy class of existing buildings that can be updated with the official implementation of energy certificates;
- monitoring of estimated energy consumption and verification of any reductions in energy consumption and consequentially of CO_2 emissions due to improvements in energy efficiency and/or use of renewable energy sources (solar thermal, solar PV);
- real-time verification of the results obtained from the implementation strategies to improve the energy performance of buildings or to promote renewable energy (the platform is able to man-age the different scenarios in a selective way by considering, for example, interventions beginning with the most inefficient buildings or from buildings belonging to a certain class of construction period);
- informing the general public of the local area through a web interface about the energy quality of their buildings and encouraging them to perform energy audits in some cases.

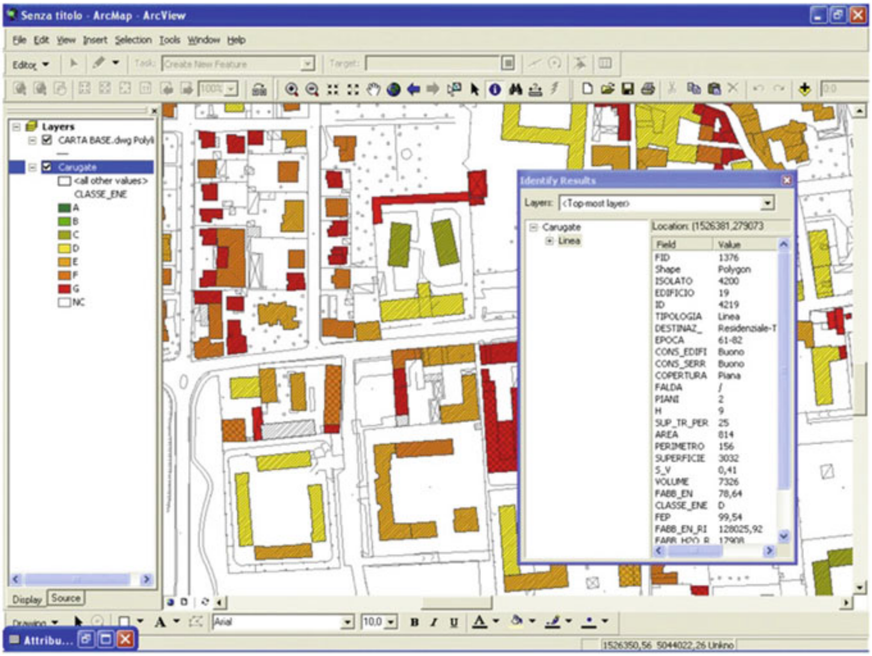
A GIS platform greatly improves the user interface through the display of graphical tools. In Fig. 8.3, for example, buildings are associated with a colour depending on their estimated energy class.

By browsing on the digital map, it is possible to query the database selectively, for example, for the assessment the energy performance of buildings for a certain construction period or for a selected area of the territory. It is also possible acquire information about a single building.

The methodology was validated by comparing the consumption data from all the residential sectors, which was calculated by the software, with those derived indirectly from the conventional energy (natural gas in this study) which was actually consumed. Data on natural gas usage were provided by the local gas utility.

8.1.2 Indicators for Energy Planning from Energy Certification Database

Energy certification of buildings, mandatory under the European Directive EPBD (EC 2002) provides interesting data on the thermo-physical properties and geometry of existing buildings. Although the energy certificate is intended to provide the characteristics of individual buildings, thereby stimulating the real estate market towards ever better energy performance, data management of the certificates issued over time,



Location: (1526381,279073

Field	Value
FID	1376
Shape	Polygon
ISOLATO	4200
EDIFICIO	19
ID	4219
TIPOLOGIA	Linea
DESTINAZ_	Residenziale-T
EPOCA	61-82
CONS_EDIFI	Buono
CONS_SERR	Buono
COPERTURA	Piana
FALDA	/
PIANI	2
H	9
SUP_TR_PER	25
AREA	814
PERIMETRO	156
SUPERFICIE	3032
S_V	0,41
VOLUME	7326
FABB_EN	78,64
CLASSE_ENE	D
FEP	99,54
FABB_EN_RI	128025,92

Fig. 8.3 User interface of the GIS platform when the database was complete (Dall'O' et al. 2011)

using a national or regional energy cadastre, makes available a data base which is useful for energy planning in the building sector.

The use of the data provided by the energy certification of buildings to obtain energy performance indicators related to the existing building stock was the objective of a study carried out by Dall'O' et al. (2015).

This document is based on the results of a benchmarking study of the Lombardy Region, northern Italy. By integrating data from the energy cadastre (175,778 energy certificates) with the statistical data obtained from the national census, indicators were obtained on the energy performance of existing buildings.

The energy indicators obtained, characterised by building type and construction period, normalized as a function of Degree-Days, became an effective tool for energy planning at local and regional scales. In the specific case, the energy indicators have been used to estimate the potential for energy retrofitting of existing buildings in the Lombardy Region. The same indicators could be used by municipalities/local authorities for energy planning at the municipal or district level.

In Lombardy Region the energy certification procedure requires that the energy assessor, registered in the regional professional register of energy assessors, must transfer the entire set of the data contained in a single Energy Performance Certificate (EPC) into the regional cadastre, automatically: in this way the energy certificate database is updated in real time.

In order to promote transparency of the activities of all regional public administration, the Lombardy Region, as of 2013, has released the data on the EPCs. Relevant data of each EPC can be read on-line by any citizen. Alternatively, the entire database of energy certificates can be downloaded in order to allow off-line processing.

Table 8.1 shows the available data: these refer to the main characteristics of the energy certificates.

The published database does not contain all the characteristics of the buildings but only the main ones; however these are sufficient for the purposes of the study.

Table 8.1 Structure of the database of the EPC cadastre in Lombardy Region (Dall'O' et al. 2015)

Symbol	Field description	Units
EPC #	Energy Performance Certificate Code	–
A_{ID}	Energy assessor ID number	–
Loc	Location (municipality)	–
DD_W	Winter standard Degree-Days	°C
BT	Building type (e.g. residential, school, office, etc.)	–
CY	Construction year	–
A_g	Gross floor area	m^2
A_n	Net floor area	m^2
V_g	Gross volume	m^3
V_n	Net volume	m^3
S	Dispersant surface	m^2
GO_R	Glass surface/opaque surface ratio	–
U_e	Average *U*-value of the building envelope	$W/m^2\ K$
U_r	Average *U*-value of the roofing	$W/m^2\ K$
U_w	Average *U*-value of the windows	$W/m^2\ K$
U_b	Average *U*-value of the basement	$W/m^2\ K$
EC	Energy class (ranging from A+ to G)	
ET_H	Heat demand indicator	$kWh/m^2\ y$
EP_H	Primary energy indicator	$kWh/m^2\ y$
Vent	Ventilation type (e.g. natural, mechanical, etc.)	–
AC	Air changes	1/h
P	Boiler capacity	W
HT	Heating system (e.g. boiler, heat pump, CHP, etc.)	–
Ft	Fuel type (e.g. gas, oil, etc.)	–
SPV	Solar PV system type (e.g. monocrystalline silicon, amorphous silicon, etc.)	–
PV	Solar PV surface	m^2
STH	Solar thermal type (e.g. flat plate, vacuum, etc.)	–
TH	Solar thermal surface	m^2

Table 8.2 List of the parameters used to filter the data contained in the energy cadastre in Lombardy Region (Dall'O' et al. 2015)

Parameter description	Unreliability of the parameter
Net floor surface (A_n)	$A_n < 50\ m^2$
Net volume (V_n)	$A_n < 120\ m^3$
Ratio of dispersant surface and heated volume (S/V_g)	$S/V_g < 0.2$ or $S/V_g > 1.5$
Calculated average height (V_n/A_n)	<2.4 m or >6 m
U-values for opaque surfaces	$U < 0.15\ W/m^2\ K$ or $U > 2.60\ W/m^2\ K$
U-values for transparent surfaces	$U < 0.8\ W/m^2\ K$ or $U > 6.00\ W/m^2\ K$
Heat demand indicator/primary energy indicator (ET_H/EP_H)	<0.5 or >1.5

EPCs of buildings allowed the Lombardy Region to acquire a considerable amount of information about the housing stock: at the date of the study (September 15, 2013) the total number of registered EPCs, referred to the residential sector, amounted to 1.154610.[1]

A first analysis of the database of the energy cadastre made it possible to delete records corresponding to the buildings in which the data fields were incomplete, after this data-cleaning process, the number of EPCs was reduced to 850,970.

The EPCs in the database refer to certifications that may relate to entire buildings or individual flats. The objective of the study, however, was to define the characteristics of entire buildings. In order to achieve this goal, only records in which all surfaces of the building envelope (roofs, walls, basement) had a value greater than 0 were selected. After this processing it was found that of the entire archive the certifications that refer to complete buildings are 233,212.

The platform of the energy cadastre of the Lombardy Region does not verify the consistency of the data contained in the downloaded EPCs. For this reason it was necessary to clean up the database by removing all records that contain obvious errors. The EPCs were then filtered, based on the criteria defined in Table 8.2.

The EPCs which proved compliant, and suitable for the purpose, were reduced to 175,778, a value which nonetheless represents a large amount of available data.

The next step was the definition of a reference matrix.

The Italian national census classifies existing buildings on the basis of two parameters of interest: construction period and number of flats per building.

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[1] The According to ISTAT, the Italian national census of population and housing (accessed on September 2019), in Lombardy there are about 4,827,000 apartments; considering that in the energy cadastre of Lombardy Region (accessed on September 2019) there are about 2,067,000 EPCs, 43% of the existing residential building stock is certificated.

Table 8.3 Matrix used for the classification of buildings

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	>31
<1930						
1930–1945						
1946–1960						
1961–1976						
1977–1992						
1993–2006						
After 2006						

The construction period can be reasonably related to the construction technology involved, while the number of apartments per building determines the size of the building and the S/V ratio.

Concerning the first parameter, the buildings were divided into 7 classes: the construction period is one of the items of information contained in the EPCs database and therefore readily available. The clustering according to the six classes, starting from the EPCs of the energy cadastre, was possible because the field "number of flats per building" was available for each EPC.

Table 8.3 shows the matrix used for the building classification in accordance with the chosen parameters. The matrix that has emerged consists of $7 \times 6 = 42$ cells. The choice of this matrix is important because it is compatible with the data available via the national census and, as shall be seen later, allows the creation of interesting synergies between the energy cadastre and the database of the national census.

Starting from the data of EPCs one can define, for each of the cells of the matrix, three types of representative buildings:

- buildings which preserve their original energy performance;
- buildings which have been partially retrofitted to improve their energetics (replacement of windows).
- buildings which have undergone a complete energy retrofit (replacement of windows and building envelope insulation).

The possibility of obtaining three matrices is very useful since it allows one to test the potential for improving energy performance.

Figure 8.4 shows the flow diagram of the procedure used to define the representative buildings. The definition of the representative buildings within each cell was made, in each step, using a recursive procedure with analysis of frequencies on the basis of indicators in order to select the really significant samples, eliminating those characterised by the parameter values which are least recurrent. The analysis was performed for each of the 42 cells of the matrix and was therefore quite complex.

The first filter of the selection concerns the indicator of the quality of the building envelope, expressed by an average *U*-value. The second selection concerns the energy performance of the transparent surfaces of the building envelope. At this stage three

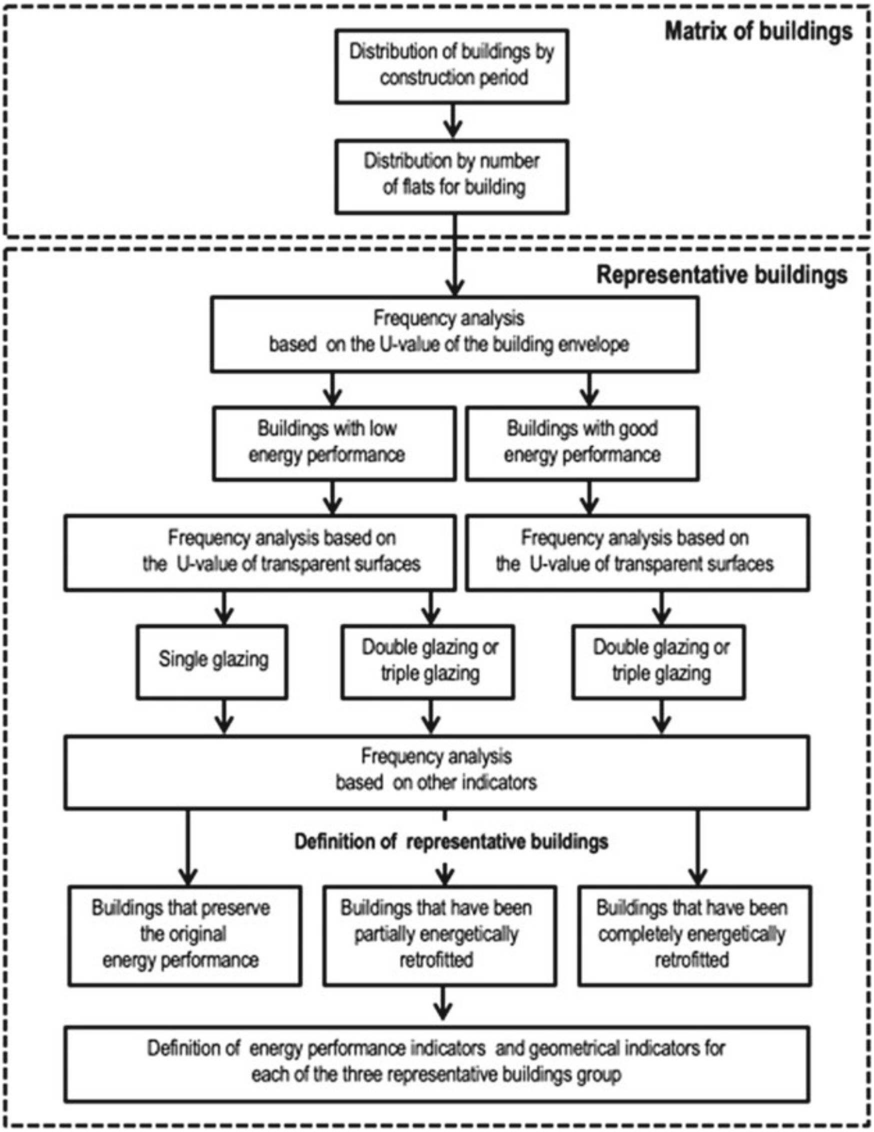

Fig. 8.4 Diagram of the procedure for the definition of the representative buildings within each cell of the matrix of Table 8.3 (Dall'O' et al. 2015)

classes of buildings are highlighted: buildings which preserve their original energy performance, buildings that have been partially retrofitted to improve their energetics (window replacement) and buildings that have undergone a complete energy retrofit (replacement of windows and building envelope insulation).

However the definition of the representative buildings which then constitute the final matrices do require additional steps, through filtering based upon other indicators e.g. the average *U*-value of the roof, the average *U*-value of the basement, ET_{H} (specific heat required by the building for space heating during the winter season), EP_{H}, the ratio between the heating capacity and the net floor surface, the overall average efficiency of the heating system (expressed as $\mathrm{ET}_{\mathrm{H}}/\mathrm{EP}_{\mathrm{H}}$) and the S/V ratio.

The identification of the representative buildings within the single cells of the matrix used allow the extrapolation of a series of useful items of information to characterise, from the energy point of view, the residential buildings of the existing building stock of the Lombardy Region.

The final result of this statistical analysis is represented by sets of three matrices: the values reported in the matrixes of Table 8.4, for example, define the representative statistical values of EP_{H}, expressed in kWh/m^2 year, for each cell of the used matrix.

Analogous matrices define other parameters, both energy and geometric performance of representative buildings, including:

Matrix $\mathrm{M1}_{1,2,3}$	Average *U*-value (W/m^2 K) of the opaque vertical envelope;
Matrix $\mathrm{M2}_{1,2,3}$	Average *U*-value (W/m^2 K) of the transparent surfaces;
Matrix $\mathrm{M3}_{1,2,3}$	Average *U*-value (W/m^2 K) of the roofs;
Matrix $\mathrm{M4}_{1,2,3}$	Ratio between the opaque surfaces of the vertical building envelopes and the net floor area;
Matrix $\mathrm{M5}_{1,2,3}$	Ratio between the transparent surfaces of the vertical building envelopes and the net floor area;
Matrix $\mathrm{M6}_{1,2,3}$	Ratio between the roofs surfaces and the net floor area,

where the subscripts of matrices 1, 2 and 3 indicate the three situations examined: (1) buildings which preserve their original energy performance, (2) buildings that have been partially retrofitted to improve energetics and (3) buildings that have undergone a complete energy retrofit.

The indicators derived from the analysis of the database of the energy cadastre of the EPCs in Lombardy Region can be used in the form of matrix, in the context of energy planning, both at regional and local level (town/city level).

The starting point for further processing is the availability of a matrix (construction period – number of flats per building) in which each cell is given the value of the total net area of the existing building stock: in the case of Italy, this matrix can be derived from the data of the national census. The structure of the matrix, and consequently the number of cells over which the existing building stock is divided, depends upon the availability of data and can be adapted accordingly.

Having available the matrix that defines the net floor areas, which can be denominated the "M0" matrix, and the matrices with the indicators described above, the calculations are simple and can be performed using a spreadsheet, via normal operations of addition, subtraction, multiplication and division between cells.

When the Lombardy Region updated its Regional Energy and Environmental Plan, for the evaluation of the potential for energy savings in the residential sector, it used this method, based on statistical data of the existing building stock.

Table 8.4 Average value of EP_H (kWh/m^2 y) for the representative buildings, broken down by period of construction, number of flats per building and conservation status (Dall'O' et al. 2015)

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	>31
Buildings that preserve their original energy performance						
<1930	342	358	236	206	227	202
1930–1945	382	380	287	246	221	267
1946–1960	386	364	282	236	212	198
1961–1976	381	340	263	235	202	192
1977–1992	302	298	270	215	199	206
1993–2006	142	138	124	123	100	111
After 2006	57	52	44	40	35	34
Buildings that have been partially retrofitted to improve energetics						
<1930	311	289	224	201	169	177
1930–1945	332	324	224	187	162	160
1946–1960	330	282	253	218	161	162
1961–1976	300	309	222	197	184	158
1977–1992	237	229	217	165	164	163
1993–2006	–	–	–	–	–	–
After 2006	–	–	–	–	–	–
Buildings that have undergone complete energy retrofit						
<1930	90	68	54	56	54	94
1930–1945	76	70	62	46	53	91
1946–1960	98	93	63	52	85	110
1961–1976	95	95	89	93	79	98
1977–1992	90	88	83	96	109	95
1993–2006	–	–	–	–	–	–
After 2006	–	–	–	–	–	–

A limitation of the proposed method lies in the fact that all the energy assessments are based on a theoretical calculation: in fact the energy performances calculated for the preparation of EPCs refer to the technical standards applicable and take account of a standard use of the building. In other words, the real energy consumption of buildings can be different from the theoretical one and consequently even the potential for savings may be different.

In order to bring the assessments of potential savings calculated on the basis of the needs arising from standardized algorithms, related to energy certification, into line with actual consumption measured on buildings of the residential sector, it is necessary to define the relationship between the two variables involved. The Lombardy Region has estimated that the theoretical consumption for space heating in the residential sector is 27% higher than that actually observed. Therefore in its analysis it has taken account of this corrective index.

The innovative element of this study lies in the fact that the characterisation of the building stock does not require field investigations across the territory, measurements nor energy audits but is rather based upon existing information which is already available; this being that of the energy certificates registered in the databases.

8.1.3 Application of Neural Network for Evaluating Energy Performance of Buildings

A further piece of research directed by Khayatian et al. (2016) evaluates the possibility of calculating the energy performance of existing buildings using the database of the energy register containing the EPCs with a different approach to that described in the previous paragraph.

The objective of the study was to fit an estimator to the Calculation software used for estimating the energy performance of building for EPC purposes, by benefiting from the large number of energy certificates that are available online.

Due to the complexity of the calculation procedure, a black-box approach using Artificial Neural Networks (ANN) was adopted for replicating the relation between the input parameters and the respective ET_H value. Several combinations of inputs were tested for defining the most suitable implementation of features. It was observed that using 12 features (Table 8.5) was sufficient for successfully predicting the ET_H value (specific heat required by the building for space heating during the winter season) with an acceptable margin of error. Meanwhile, small abnormalities were observed in the overall performance of the network. Initial investigations on the predicted values revealed that the observed abnormalities were related to defective input data.

Further explorations were also conducted in order to outline the most important factors which affect the model's performance. It was observed that the model consisted of sufficient number of samples, yet additional features were required for obtaining a greater accuracy. A sequence of 100 models were trained due to the stochastic weight initialisation in training ANNs. In order to evaluate each entry, a Gaussian distribution of 100 predictions were created based on the trained models. This approach provided a probability of occurrence for each certificate rather than

Table 8.5 Average classification of utilized features (Khayatian et al. 2016)

Category	Features
Direct	Degree days, net volume, net floor area, dispersant surface, opaque to glazed ratio, year of construction, thermal conductivity (walls, windows, roof, basement)
Derived	Average floor height, opaque surface area, glazed surface area, construction period, non-linear features

a definitive statement. As a consequence, the procedure of monitoring each entry is prioritised based on its level of reliability i.e. probability of occurrence. Such approach may be replicated for similar EPC datasets with comparable data. Final results indicated that 95 ± 3% of entries fall within the limits, so the proposed tool is reliable.

The application of machine learning in building energy estimation provides the opportunity to extract predictions in a rapid manner. Therefore, the methodology can also be used as an easy tool to support energy planning on a territorial scale.

8.2 Methods for Estimating Buildings Energy Demand at District Level

In the framework of distributed energy planning, evaluating reliable energy profiles of different sectors has a prominent role. At the same time, it is a quite challenging task, since the availability of actual energy profiles is not common.

For guiding stakeholders involved in local smart energy planning to choose the proper method for assessing the buildings energy demand, Ferrari et al. (2019a) surveyed 70 studies, adopting different methods including some case-study applications and identifying those adopting hourly energy profiles.

From the methodological perspective, a set of criteria for classifying the selected contributions was defined and, as final results, tables summarizing the characteristics of the principal methods and a selection of studies providing directly usable energy profiles were reported. Broadly speaking, this piece of research demonstrates that the potential replicability of analysed methods is constrained to the availability of datasets and, more particularly, underlines the necessity of defining reliable hourly energy profiles in order to develop accurate energy scenarios. The principal findings of the research are reported in the following.

In the context of review articles on methods for buildings energy demand estimation, the study of Swan and Ugursal (2009) is one of the most exhaustive. They made a first broad distinction between:

- Top-down methods, whose output data are estimated based on aggregated input data through econometric or technological correlations;
- Bottom-up methods, based on use of subordinated input data and highly detailed and reliable calculations.

Starting from the methodological classification reported in the aforementioned article (Swan and Ugursal 2009), investigated studies have been classified hereunder, consistently with the main scope of this research, first according to the time resolution of used energy demand data and then, to the adopted data source/estimation method, as follows (Fig. 8.5):

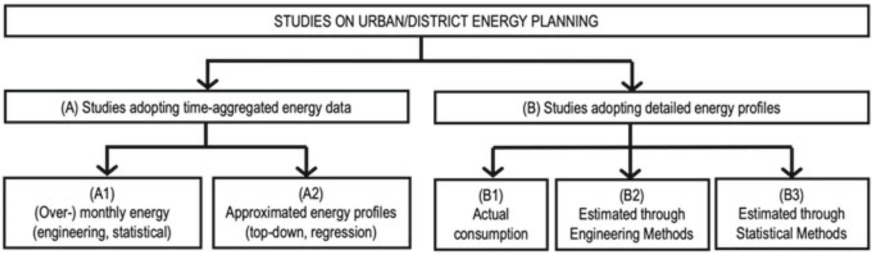

Fig. 8.5 Scheme of adopted classification. Adapted from Ferrari et al. (2019a)

- Studies adopting time-aggregated energy data, as:
  - Over-monthly energy data;
  - Approximated energy profiles;
- Studies adopting detailed energy profiles, as:
  - Actual consumption profiles;
  - Energy profiles estimated through engineering methods
  - Energy profiles estimated through statistical methods.

Following, all identified methodological categories are outlined, discussed and compared.

8.2.1 Studies Adopting Time-Aggregated Energy Data (A)

Studies adopting (over-)monthly energy data (A1). In some studies, the annual or monthly energy demand was calculated, either based on engineering or statistical methods, for assessing the balance of the potential energy supply with the energy loads. Although such approach is typical of truly early stage first analysis, it clearly returns highly approximated outcomes which can be substantially far away from more detailed results.

Documented experience referred to engineering methods revealed assessments of energy consumptions for buildings according to local monthly based calculation procedure, or by means of commercial building energy simulations, assuming single thermal zones and retrieving properties from direct survey, statistical and commercial data and software libraries, or via a simplified steady-state calculation procedure.

Documented experience based on statistical methods revealed energy consumptions estimated thanks to statistical data on population and/or buildings characteristics, or through correlations with weather data (e.g. energy signature (CEN 2008).

Studies adopting approximated energy profiles (A2). In order to provide more accurate energy assessments while coping with serious lack of data, some studies adopted procedures for deriving approximated profiles from top-level data, thanks to correlations with weather data, building use category or typology consistency.

Top-down approaches were used to proportionally derive hourly profiles at local level from spatially aggregated hourly profiles. In one case the energy demand hourly profiles for a town have been derived by scaling-down the previously determined national hourly profiles to the consumptions reported in the municipal energy balance, and then adjusted to take into account the local climatic conditions and a future scenario. Similarly, in another case the measured national profile was scaled-down to the annual energy consumption of the town. For two case studies the lower scale profiles were defined from the available overall urban hourly energy data, based on the distance from the urban centre (i.e. urban texture) and on the different end-use energy sector.

Finer data can be derived also from temporally aggregated data, by means of regression. Starting data to be regressed can be obtained by means of statistical data or simplified calculation procedures (e.g. steady state or quasi-steady state procedures, calculation based on total installed power of electrical appliances, etc.).

Regarding the time resolution of approximated energy profiles, regressions were carried out in some case from annual/monthly data into daily, over-hourly or hourly ones while in other cases from daily data to hourly and from regional hourly to local hourly.

8.2.2 Studies Adopting Detailed Energy Profiles (B)

Studies adopting actual energy consumption profiles (B1). For the accurate estimation of energy fluxes, the availability of actual hourly based energy consumptions for the investigated case study is of course the optimal condition. Hourly data can be generally retrieved by monitoring campaigns in delimited areas, such as a University campus, or provided by electricity distribution utilities or operators of district heating networks.

Studies adopting energy profiles estimated through Engineering Methods (B2). The adoption of engineering methods to assess the energy demand of buildings enables one to have very accurate estimations, when based on dynamic energy simulation. Despite this, detailed building energy simulations on urban scale could not always be justifiable in terms of the time necessary, owing to the required level of detail and quantity of information. Hence simplifications in the calculation methods or in the number and complexity of the modelled buildings are often adopted.

This can be achieved by simulating "Representative buildings" (Ferrari and Zanotto 2016a), Building Archetypes or samples, representative of the considered building stock, adopting simplified calculation procedures for deriving buildings thermal energy profiles such as the EN ISO 13790 simplified hourly method (ISO 2008).

More accurate estimations of thermal energy profiles can be carried out by means of detailed dynamic building energy simulation tools, such as TRNSYS (Klein et al.

2014), EnergyPlus (DOE 2018), ESP-r (http://www.esru.strath.ac.uk/Programs/ESP-r.htm), etc.

Studies adopting hourly energy profiles estimated through Statistical Methods (B3). Statistical methods include a wide range of techniques.

Space heating and cooling, domestic hot water (DHW) and electricity consumption profiles can be determined based upon statistical analysis of data from direct surveys and measurements on buildings representative of different typologies and/or uses in order to determine, through probability distribution function, regression analysis or Machine Learning methods, hourly energy profiles of the stock being considered.

The latter methods are increasingly adopted for forecasting energy loads due to the ability of learning from past behavior so returning in most robust outcomes.

8.2.3 Discussion and Conclusion

For accomplishing reliable distributed energy planning, the adoption of detailed energy demand profiles is essential. However there is a general unavailability of detailed consumption profiles at local level.

From the research article (Ferrari et al. 2019a) the Authors saw that those studies relying on time aggregated energy data (A) often lead to a very much approximated estimation.

In fact, the adoption of seasonal energy data (A1) is responsible for the neglect of energy fluctuations which are in fact relevant when planning smart and RES (Renewable energy sources) integrated energy systems, including assessment of storage systems. Moreover, approximated energy profiles (A2) derived from spatially aggregated data through top-down approach, by placing on the same level a small community and a Country, or from temporally aggregated data derived from regressions based on the outdoor temperatures, neglecting other weather parameters, such as the solar radiation (Ferrari and Zanotto 2016b), or building usage patterns (which are usually responsible for a more variable profile), can be also critical.

Regarding the studies adopting detailed energy profiles (B), apart from those cases where actual consumption profiles are available (B1), robust methods for the estimation of reliable profiles, being either engineering-based (B2) or statistical-based (B3), must be chosen.

For reducing the computational effort of engineering modelling, the clustering of a building stock in a series of representative buildings is a well-established approach that allows, if combined with accurate dynamic energy simulations, an acceptable approximation of the energy evaluations to be maintained (Ferrari and Zagarella 2016). However, a critical point of these studies could be the assumption of standard values of the building usage patterns instead of an accurate assessment (Ferrari and Zanotto 2016c). Studies adopting distributions, which are based on a statistical approach but as detailed as those from engineering methods, could be a way to overcome this issue.

Among the statistical methods, those which are based on machine learning enable one to make reliable estimates from uncertain data and even reduce computational effort, overcoming the limitations of the basic statistical correlations. However the adoption of statistical methods relies on measured/simulated data which are not everywhere accessible.

8.3 Tools for Urban Energy Planning

For low carbon district/urban energy planning, several computational tools have been developed although guidelines for a more diffuse use in common planning, outside the academic ambit are needed. Ferrari et al. (2019b) assessed 17 selected easy-access and well documented tools based on: analysis type, operation spatial scale, output time scale, use and licence.

General information, functionalities, structure, graphic user interface, required input data and outputs were described. A plenty of information was provided on the data quality and level of details and the related constraints to implement an energy system analysis. The possible final user of the above mentioned research is guided in choosing the tool based on the related outputs and potentialities, but also on available data for a given context and the required skills.

Based on the above mentioned research, this sub-chapter focuses on the tools liable to be used outside the academic environment (i.e. by public administrations, urban energy planners). Hence, nine tools having user-friendly interface have been examined, as classified in Fig. 8.6, according to: time resolution of outputs (i.e. over-hourly based or sub/hourly based outputs), and kind of licence (i.e. subject to payment or free of charge). As a result, *coverage is given to* 3 tools that report over-hourly output data of energy demand-supply, and so can be adopted at very early stage of urban energy planning, and 6 tools that enable energy calculations on at least an hourly base, which is essential for modelling the detailed interactions among variable energy fluxes at urban level.

The general information on the nine user-friendly tools are reported in the following sections: the descriptions of the six hourly-based tools have been treated in greater detail.

8.3.1 User-Friendly Tools with Over-Hourly Based Outputs

District-ECA was developed by the Fraunhofer Institute for Building Physics with the IEA-ECBCS Annex 51 partners for supporting those operators who are active in the first-stage of planning energy-efficient districts, for quickly evaluating the effects on both the supply and the demand sides strategies. The software is freely downloadable after making a preliminary registration and comprises a set of tools with

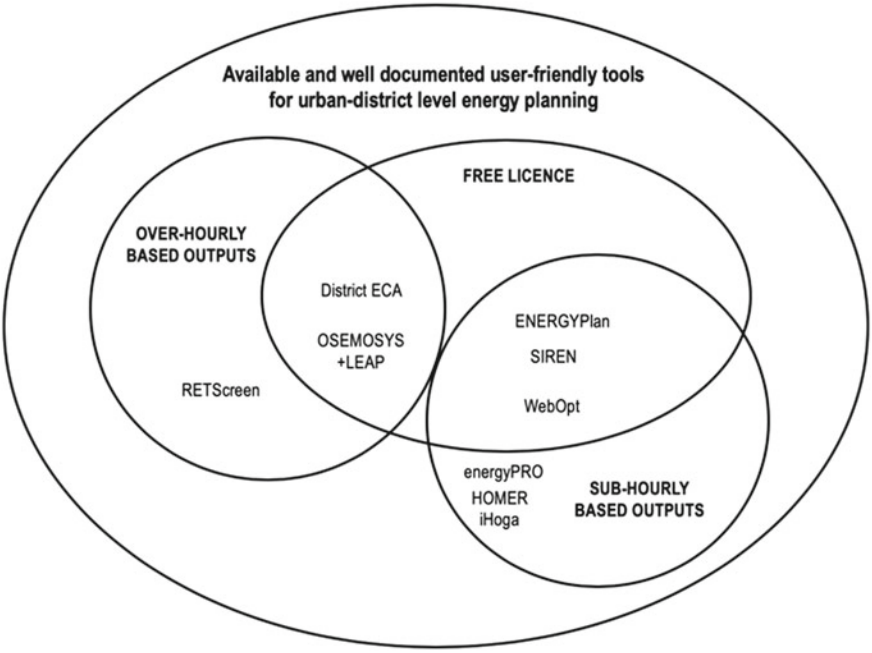

Fig. 8.6 Scheme of the method adopted for the classification of the tools. Adapted from Ferrari et al. (2019b)

miscellaneous scopes[2] (Fraunhofer Institute of Buildings 2013). The main core is an easy-to-use tool (i.e. Energy Assessment of Districts) for accomplishing a monthly based assessment of energy balance and related emissions of a district. A single building modelling of related envelope and systems should be done, the technologies provided mainly refer to space heating, weather data and typical solutions are constrained to IEA-ECBCS Annex 51 participating Countries.

OSeMOSYS (Open Source Energy MOdeling SYStem) is an open source modelling tool for long-term energy assessment and planning[3] (Howells et al. 2011). Its most common graphic user interface (GUI) is the commercial software LEAP maintained at the Stockholm Environment Institute[4] and referred as a decision support software, enabling users in extensive data management and reporting, assessing medium/long-term scenarios including changes in energy use, related emissions, resources deployment, for any economic sector. Most of its calculations occur on an annual time-step, while the time horizon is unlimited.

Since it is a very general-purpose tool, required input data broadly depend upon the case study (e.g. top-down, bottom-up, economic, social data, etc.).

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[2] https://www.district-eca.com/index.php?lang=en. Accessed 27 September, 2019.

[3] http://www.osemosys.org/. Accessed 27 September, 2019.

[4] https://www.energycommunity.org/default.asp?action=home. Accessed 27 September, 2019.

So far as energy related data are concerned: annual values for demand and production, eventually by sector and fuel, are required; additionally, costs of systems and energy, system efficiencies and capacities, energy profiles, emission factors, interest and inflation rates can be indicated.

RETScreen[5] (Minister of Natural Resources of Canada 1997) is a commercial tool developed at the Natural Resources Canada department of the Government of Canada as a clean energy management software system. Currently, it consists of an Excel-based software package and a Windows-based one. It is possible to model systems of any scale, developing different scenarios (buildings envelope and systems energy efficiency measures, various electricity and thermal energy supply plants, integration of RES, etc.).

Required information includes: general data and settings on calculation, climatic location, type of project, sector, system features such as capacity, delivered energy, efficiency. In addition, CO_2 emissions per each fuel and financial data (e.g. inflation rate, lifetime, debt ratio range, initial costs, incentive and grants, annual Operation and Maintenance (O&M) and fuel costs) can be inserted.

8.3.2 User-Friendly Tools with Hourly or Sub-hourly Based Outputs

EnergyPRO, is a commercial tool developed by the Danish company EMD International A/S for accomplishing techno-economic analysis and optimisation of energy projects with a combined supply of electricity and thermal energy from a multiplicity of different energy producing units[6] (EMD 2017).

It is typically used for analysing scenarios including district heating (DH), CHP, combined cooling, heat and power (CCHP), but can be also used for projects including geothermal energy, solar collectors, PV, wind farms, hydro pumping stations, storage systems.

The user should select the type of assessment among: Design, with emphasis on energy conversion and operation payments for one-year calculations, Finance for multi-years investment analysis, Account, for a more detailed economic assessment, Operation, for optimizing the operation on a daily period. The user can provide information on external conditions by adding data, i.e. loads and energy prices, as time series. It is possible to assess regional level scenarios by defining more interconnected distributed production sites.

When describing the energy exchange among the possible sites, required information includes: the start and end site, the transmission direction, the energy service (heat, process heat, cooling), and the transmission capacity and loss which can be defined by functions or time series. The calorific value of fuels with related units of

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[5] http://www.nrcan.gc.ca/energy/software-tools/7465. Accessed 27 September, 2019.

[6] http://www.emd.dk. Accessed 27 September, 2019.

measurement, eventually the maximum usable amount of the fuel storage, the offered fuel to production units per each month can also be indicated.

An unlimited number of demands per each service (heat, process heat, electricity and cooling) can be defined. In the tool library, arbitrary profiles and, specifically for the German context, profiles from national standards of electric and thermal energy are included. Otherwise, it is possible for the user to specify his/her own data both as annual or time-series (i.e. hourly or sub-hourly based) amounts, both as fixed values or dependent upon weather data (i.e. average ambient temperatures) and with year-to-year variations by adding a defined fixed or variable index for specifying the time series development over the years in question. So far as energy supply is concerned, the included units are: recovery of rejected heat, CHP, electric boiler, absorption/electric chiller, heat pump, flat plate/evacuated tubes solar collector, PV, wind farms and storage systems. Usually required data, depending on the single technology, are: capacity, production, fuel, power curve, inlet and outlet temperatures, if the operation is dependent on another unit, charging/discharging power; height difference of hydro-pumping storage reservoirs, dimensions and technical features, etc. The operation strategy, except for a user-defined one, is basically driven by a minimisation of net present cost (NPC) through assigning levels of priority to production units. Emissions of CO_2, NOx and SO_2 per unit of mass can be defined. It is possible to define the electricity market, choosing between fixed tariff and spot market.

HOMER is a commercial tool developed at the U.S. National Renewable Energy Laboratory to assist in the design of micropower systems and to facilitate the comparison of power generation technologies across a wide range of applications (HOMER Energy 2016).

The software can perform three assessments: simulation, to model hourly the micropower system behaviour and determine the techno-economic feasibility over its operating lifetime; optimisation, to simulate different system configurations in search of the one that satisfies the technical constraints at the minimum NPC; sensitivity analysis, to evaluate the impact on the optimisations results of changes in the input parameters even in a long-term perspective.

First, the climatic zone of the context under study must be specified, in order to determine the RES availability. Thereafter four types of energy load are considered: the primary load, i.e. electricity demand, the deferrable load, i.e. a demand for electricity that can be met at any chosen time within a certain time interval (e.g. water pumps, ice makers, and battery-charging stations), the thermal load, the hydrogen load. Primary, thermal and hydrogen loads must be defined by indicating average daily values of energy and power, a peak power and a daily hourly schedule.

The profiles can be modified either by introducing some weekly/monthly variations or adding a percentage of disturbance which will randomly change the curve. The tool includes some default arbitrary hourly profiles, which are the same for each energy service but differ per end-use sector.

Otherwise it is suggested to use external datasets mainly referring to US context or, if possible, by importing one's own hourly data.

There is a wide library of supply/conversion/storage units, but others can be created by the user. Generally speaking, the required information includes: system capacity, the plant lifetime, the unit costs of investment, of replacement and operation and management with related frequency, and whether the electric current is alternating or direct. Fuels can be defined based on the library or by inserting the type, unit prices, calorific value, GHG emissions for each substance.

In case of modelling RES-based systems, other data, regarding the efficiencies and technical characteristics of supply systems as well as average monthly availability of resources, are required. Once the energy system has been modelled, the user must define the settings of the system assessment and optimisation. The required economic parameters are: nominal discount rate, expected inflation rate, project lifetime, system fixed capital and operation and maintenance (O&M) costs, capacity shortage penalty, and currency.

For the definition of optimisation constraints, maximum annual capacity shortage, minimum RES fraction and operative reserve as a percentage of load or RES output, are required. Possible economic penalties and annual limits of GHG emissions production can be set. The principal outputs, both in tabular and graphic form, are the total and annually cash flows by component and either per NPC or annualised costs, details about the electricity production and consumption, per component and load types, annual emissions of pollutants, possible ranking of developed scenarios according to NPC and/or related to sensitivity analysis.

iHoga (Improved Hybrid Optimization by Genetic Algorithm), developed at the University of Zaragoza, is a commercial software for the simulation and optimisation of hybrid stand-alone systems of electric power generation based on RES[7] (Dufo-López 2017). An educational version can be freely downloaded, although the lack of several functionalities and some computer-related requirements (i.e. internet connection and Windows version up to 8) widely limit its use, so it has not been taken into account for this review.

The expected load consumption of alternating/direct electric current, hydrogen and/or water has to be defined, by either adopting monthly average values or selecting default profiles to which one eventually applies a percentage of random variation. Included profiles come from literature and case studies of stand-alone systems. Alternatively the user's own time-step based profiles can be adopted by importing files with rows of data referring to hourly power, mass flow rate for hydrogen and volume flow rate for the water. There is the facility to indicate data on solar irradiation, wind and hydrogen either as average monthly values from NASA or as own time-step-based files.

The simulation time step, between a minute and an hour, and time horizon must be chosen and in the case of the lifetime of the whole system, the user has to choose between a mono-objective (based on NPV minimisation) and a multi-objective optimisation (based on minimisation of NPV, equivalent CO_2 emissions or unmet energy load) otherwise more advanced alternatives can be defined.

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[7] https://ihoga.software.informer.com. Accessed 27 September, 2019.

Regarding financial data, the nominal interest rate, the expected annual inflation rate, the system lifetime/assessment period, the currency, the installation costs and variable initial cost, as both the fixed cost and its percentage to initial cost must be entered. Total cost of the different solutions and CO_2 emissions are represented graphically.

EnergyPLAN is a freeware deterministic software developed at Department of Development and Planning at Aalborg University, for assisting the design of national energy planning strategies on the basis of technical and economic analyses. It is downloadable by means of preliminary registration[8] (Lund 2017).

It has been used in several scientific studies, both academic and not (Connolly et al. 2015). Two alternative analysis can be performed: technical simulation, for balancing either thermal or electric energy fluxes, and market-economic simulation, for assessing the system feasibility on the basis of annual costs. Electricity, heating, cooling, industrial and fuel, transport, water consumptions can be modelled; for all of them, the necessary input data are the total annual energy requirements and related hourly distributions.

The hourly distribution is the energy consumption profile for a leap year, where each value is normalized to the maximum hourly value. In the library, energy demand distributions are included at town level, which usually come from utility companies for some contexts which have been investigated, and at national level, coming from energy balance or STRATEGO project (Connolly et al. 2015). Additionally, the efficiencies of the heating and cooling production units must be specified; the contribution from solar thermal energy, by entering the capacity of the heat storage, given in days of average heat demand, and the share of consumers having installed solar thermal collectors, with the related total annual production and hourly distribution, can be modelled as well as, when existing, a flexible share for the electricity consumption.

The supply side is separately modelled with reference to the energy service (i.e. heat and electricity, electricity only, heat only, thermal plant fuel distribution, waste, liquid and gaseous fuels) for whose plants the annual production and/or capacity, the operation efficiencies and the production hourly distribution are required; in the particular case of more than one DH demand, the data must be reported for each defined group.

Moreover, the carbon dioxide content by kilogram of fuel can be inserted. For the performance of a market-economic analysis the user is required to insert the interest rate, and, for each plant unit, the investment cost, the lifetime and the percentage shares of fixed operation and maintenance costs (in order to permit the software to calculate the annual amount).

In the additional subsection, as suggested in the manual, other costs can be indicated, such as those referred to the retrofitting of buildings. Hourly energy balances, annual/monthly fuel consumptions, CO_2 emissions and costs of the defined system are provided as outputs, which can be exported in an excel sheet while charts of hourly fluxes can be also plotted.

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[8] http://www.energyplan.eu/. Accessed 27 September, 2019.

SIREN (SEN Integrated Renewable Energy Network) Modelling Toolkit is a freeware tool developed at the Australian not-for-profit organization called Sustainable Energy Now team and is currently freely distributed as a beta version.[9] The software's goal is used to calculate energy generation for renewable energy power stations and developing electricity long-term scenarios. In detail, it aims to determine the optimal locations to access RES, minimise grid connection costs and meet the varying demand on the grid, while achieving the best in terms of efficiency, cost effectiveness and energy security.

The whole software is made of a geo-referenced tool (SIREN), an energy calculation tool (SAM Power Models), provided by the National Renewable Energy Laboratory, and a set of Excel worksheets for the energy system optimisation (Power Balance tool).

The project area can be defined based on coordinates and the related imported satellite image. The satellite maps are used for visualizing, locating and modelling both the existing electricity network and the new RES plants. Apart for Australia territory for which default data are available, the hourly weather and electricity loads data and, possibly, the existing geo-referenced electric network layout must be imported. Possible supply technologies are: biomass, PV (fixed, tracking or rooftop), geothermal, solar thermal, wind, hydro and wave.

Required data are: location, power capacity, area, capital, operation and maintenance costs, hourly power production and, in the specific cases of wind farms and PV, respectively the type, the rotor diameter and the number of turbines and the orientation of the panels.

Connecting lines must be specified with regard to type, cost and maximum carrying capacity. By means of the SAM Power Models, hourly electricity balance is reported and exported to the Power Balance tool, which quantifies and cost-optimises the various amounts of storage and generation technologies for completely balancing the system; finally, CO_2 emissions can be calculated as outputs.

WebOpt stands for Distributed Energy Resources Web Optimization Service and is the freeware academic online version, accessible through preliminary registration[10] (Stadler et al. 2013), of the Distributed Energy Resources Customer Adoption Model (DER-CAM) software, developed at the Berkeley Lab. Even if, compared to DER-CAM software, the browser-based version is more limited and has also been less frequently adopted in existing studies it is a quite complete tool, able to assess an integrated energy system. WebOpt permits the modelling and optimisation of energy scenarios as a function of the criteria of economic costs and/or carbon dioxide emissions.

Three alternative optimisation strategies can be achieved: a cost minimisation; a CO_2 emissions minimisation or a multi-objective analysis (i.e. CO_2 minimization with cost constraint, for which it is required to fix a maximum allowable energy cost for purchasing electricity from the grid). Hourly energy loads for electricity,

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[9] http://www.sen.asn.au/modelling_overview. Accessed 27 September, 2019.

[10] https://building-microgrid.lbl.gov/projects/distributed-energy-resources-web. Accessed 27 September, 2019.

electrically powered cooling, electrically powered refrigeration, space heating, water heating and/or natural gas should be imported as normalized profiles to 1 GWh.

They can be inserted using one building default profile, suggested for first analysis, or copying and pasting in each cell the user-defined data or selecting one profile from the ASHRAE U.S. Climate Regions. While, if the user-defined load data are entered, there is a requirement for a monthly average hourly value, the typical hourly based weekly profile, differing if possible between working and weekend days, and the peak. Specifically, the cooling and the refrigeration loads are always expressed in the electricity consumed by an electric chiller with a coefficient of performance of 4.5.

There is the possibility of modelling in detail the energy costs of electricity and natural gas, with options on indicating: differences of cost on a seasonal/monthly base, costs fixed and variable part, different time of use. System investment and O&M costs, lifetime and maintenance periods, efficiencies and capacity must be defined. The percentage of schedulable load, the solar radiation daily profile and the carbon dioxide emissions per energy unit are additional items that can be defined. In Information on total annual costs, payback time, installed plants capacities, the detailed hourly energy profile are provided as results of the simulation.

8.3.3 Discussion and Conclusion

For supporting the decision-makers in urban distributed energy planning, several tools are available today. From the work of Ferrari et al. (2019b), nine user-friendly tools for the development of RES integrated energy scenarios in urban contexts have been selected and their main features have been reported in this chapter.

Previous studies have shown that several differences characterise the available tools, so it is not possible to identify an optimal one valid for any situation, but the choice strictly depends upon the specific goals of the project.

In particular, for modelling the interactions among variable energy fluxes and for evaluating the effects of several energy supply units, it is essential to adopt tools with at least hourly-based outputs.

In this regard, concerning the 6 sub/hourly-based tools described in this chapter, the following commentary can be added: iHoga and energyPRO can run with time-steps until 1 min. In addition, very easy employment of Homer, EnergyPLAN and WebOpt has been observed but the online use of the last mentioned has the drawbacks of slowness and limited basic functions (e.g. copy and paste, lack of shortcuts).

In general terms their use is facilitated by their excellent support platforms, including video-tutorials, lists of related publications, user manuals and sometimes guides on required data resources; among these tools, energyPRO, Homer and Energy-PLAN benefit from the most complete training material. Of additional value is the integration with spatial representation, i.e. georeferenced satellite maps in SIREN or network graphical representation in energyPRO and iHOGA, which allow one to spatially analyse the energy fluxes, optimally locate RES plants, estimate distributed network losses, etc.

There is the possibility of modelling and comparing more than one scenarios at time but only when using Homer, SIREN and WebOpt. Regarding default loads, all tools foresee the possibility of importing one's own timeseries for specific case studies, which is also the option most encouraged. Otherwise, default profiles are either of an arbitrary form or constrained to specific contexts.

Some tools are more appropriate for assessing the electrical energy sector, i.e. HOMER, iHoga, SIREN. Accordingly, in HOMER, modelling thermal energy depends on preliminary modelling of the electrical energy involved; however, it is able to consider up to two thermal loads, with some heating supply components, while no plant for space cooling is specifically included. In contrast, other tools are able to model more sectors, thereby enabling the user to assess integration and flexibility in urban energy systems.

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