Building-Stock Analysis for the Definition of an Energy Renovation Scenario on the Urban Scale

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Abstract This paper describes the enhanced typology approach we developed as an operative tool for building-stock analysis and its implementation in two case studies. It is based on the outcomes of the IEE Project Tabula, which introduced the classification of residential constructions in reference typologies according to the architectural features and the construction period. These typologies compose the matrix, representing the whole building stock of a territory. The enhanced approach described in this paper is focused on analysis on the urban and inter-municipal levels, and enables estimations of the overall energy demand of the constructions, while associating with each real building the energy performance as calculated for the relative reference typology. Starting from the analysis of building stock, we developed renovation strategies with different levels of interventions (i.e., base, standard, and advanced) for the representative building typologies. Accordingly, we foresaw several energy-saving scenarios considering different renovation rates and levels of intervention for the building typologies, and we identified the most cost-effective renovation strategy on the whole building-stock level. The implementation of the approach on the urban level provides a general overview of the main energy-consuming typologies, identifying the buildings' needs for renovation and the potential savings. In this regard, the results could constitute effective support for defining tailored policies. We applied the approach within two preparatory studies to develop an integrated energy strategy on the inter-municipal

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level: the Rotaliana-Königsberg Valley Community and the Passiria Valley. The paper presents the main results of these applications, highlighting the different strategies for the data collection and approaches for the definition of the typologies according to the available sources of information and the main features of the building stock.

1 Introduction

In recent years, in order to reach the EU-target of reducing the GHG emissions to 20 % before 2020, several actions have been started on different scales (Atanasiu et al. 2013; I. E. Agency 2008). In particular, on the urban and regional levels, the Covenant of Majors proposed in 2010 the Sustainable Energy Action Plan (SEAP) (European Commission 2010), as a tool to promote energy-saving policies and measures to reduced GHG emissions by end users. Given that buildings account for 40 % of EU-energy consumption, they represent a strategic sector to be addressed in a SEAP, which can also promote specific measures to foster the building renovation process on urban level, both for public and private buildings. Nevertheless, in order to estimate reliably energy consumption of the building stock, to define energy saving potential and performance targets, and to determine robust technology renovation actions, detailed data as well as consistent and replicable methodological approach are needed.

In this regards, EURAC has started an internal research line intended to define renovation scenarios at building-stock level to develop strategies for both private and public single-owners and multiple owners. In particular, this paper is focused on the approach developed for the definition of scenarios for multiple-owners of building stock, represented by residential buildings.

There are several methods to evaluate the performance of a large number of buildings in order to define robust energy-conservation measures, and they can be classified into two main categories: on the one hand, the top-down approaches that enable determination of the energy performance of each building, starting from aggregated data and finding a relationship between statistical information on the features of the construction and the related consumption (Bentzen and Engsted 2001; Mastrucci et al. 2014). On the other hand, bottom-up approaches define the overall performance of stock starting from the evaluation on the single-building level. The information can be deduced through official statistics on actual consumption or by using energy performance certificates (Mangold et al. 2015) or through an engineering-based approach, defining the numerical model of a set of reference buildings representative of a whole building stock (Filogamo et al. 2014).

The approach adopting reference buildings to both scenarios on the national (Sartori et al., Dascalaki et al.) and urban scale (Caputo et al. 2013; Galante and Torri 2012) is the one most often applied. The method developed by EURAC is based on the typology approach defined within the IEE Project TABULA (Ballarini et al. 2011), which introduced the criteria for the definition of a set of reference buildings representative of building stocks on the national level.

Starting from those achievements, we developed a practical method, focused on the urban scale, to provide an operative tool for the definition of effective renovation strategies on the urban level. Therefore, the level of detail for the definition of the reference buildings is increased, and we introduced a structured and manageable approach for the data collection exploiting the information from different sources available for the territory (GIS maps, local statistics, on-site survey, and questionnaires). The data collection is preparatory for defining the baseline of energy consumption and the possible renovation scenarios, tailored on the specific needs of the local building stock, with an estimation of the potential saving on the urban level supported with the use of a GIS software.

The following sections present a detailed overview of the activities and assumptions for each phase of the typology approach considering the particular issues of the residential building stock. Moreover, the paper presents and discusses the main results of the building stock analysis approach to two case studies: the Rotaliana-Königsberg Valley Community and the Passiria Valley.

2 The Typology Approach

The building-stock analysis enables us to identify the most energy-consuming typologies and to define effective renovation strategies, so it represents a strategic support for a public authority to define policies and incentives for building renovation. In fact, starting from the definition of the baseline scenario for the energy consumption at large scale, we propose different tailored renovation packages for the identified target buildings and to evaluate the energy saving potential on the urban, regional or territorial level.

The typology approach encompasses four principal steps:

- definition of reference buildings;
- energy-demand modelling and baseline scenario;
- renovation packages: elaboration of strategies to renovate the identified reference buildings;
- renovation scenarios: definition of the targets after the implementation of the renovation packages and elaboration of different scenarios to assess the energy saving potential.

2.1   Definition of Reference Buildings

Following the approach developed within the IEE project TABULA (Tabula project team 2012), the aim of the first phase is to define the typology matrix that includes the set of reference buildings for the analyzed building stock. The choice of the base parameters for the definition of the matrix might vary with the scope of the evaluation and on the kind of buildings the analysis focuses on. For the residential constructions, which present homogeneous features in terms of thermal zone, indoor temperatures, internal loads and occupancy time, the two variables adopted (Ballarini et al. 2011; Filogamo et al. 2014) that also represent the axes of the matrix are:

- the *building-age class*, which affects the construction features (envelope and HVAC system); and
- the *building category*, which determines the geometry of the buildings.

In particular, the definition of the age classes should reflect the changes of construction methods over the last decades in the territory: the introduction of new building materials and techniques (e.g. reinforced concrete, prefabrication), the availability and costs of energy resources, as well as the definition of specific policies on energy savings that affect the architecture of buildings and the thermal features of the envelope. Therefore, the definition of the age classes is the key issue for an accurate determination of the baseline scenario, as well as to propose appropriate renovation strategies. For example, after World War II, buildings in Central Europe have been constructed mainly cost-effectively and quickly with the available material on-site. For that reason, buildings of this construction period usually do not meet the present requirements of thermal and acoustic insulation (Amtmann and Altmann-Mavaddat 2014). Another important milestone for the energy policies is the oil crises of the seventies, when energy conservation was becoming an important issue. Gradually reducing the maximum permitted limits for the heat loss, through legislation, influences the energy efficiency of the building envelope and thus the design and materials used. Therefore, the defined age classes should reflect mainly: evolution of policies, construction material and techniques innovation and historic events which effects on energy issues.

The second main variable, the building category, enables us to define the geometry of the constructions in order to determine heat losses through the thermal envelope (i.e. roof/top floor, external walls, windows, baseplate/basement ceiling) as well as the relation between surface of the thermal envelope and heated volume (surface-to-volume ratio), which is strongly connected to the specific-energy demand.

According to these two variables, the entire building stock is divided into different building categories which have similar characteristics in term of architectonical features such as size, shape, dimensions, surface-to-volume ratio and other energy relevant properties like the number of floors of housing units, presence of balconies, external or internal staircase, etc. Each reference building is described by a data set, containing all energy relevant information: geometry, thermal characteristics and building services.

The data collection phase is crucial for the determination of the building categories; in this regards, we decided to adopt firstly an on-site survey in the relevant area, in order to identify the main building features and typical construction methods. During the survey, a vast majority of buildings is photographed and, by means of a GPS, the images are georeferenced and integrated into the GIS map. In this way, it is possible to locate the images, to identify the documented buildings and to start the process of cataloguing and analyzing buildings according to their dimensional characteristics and architectural features. The photographic campaign enables on the one hand, to have a general overview of the building stock, and on the other hand, to collect and store specific information on the construction features (e.g. material used, amount of overhang, balconies, roof type, etc.) and the state of conservation.

According to the information gained during this process, it is possible to establish preliminary rough dimensional thresholds that determine the main building categories typical for the area of investigation (e.g. single-family house, semi-detached house, multifamily house, terraced house, block etc.). Table 1 reports the preliminary dimensional ranges adopted for Case Study 1 (described in more detail in Sect. 2.1).

Besides the on-site investigation, it is crucial to collect all useful energy relevant data about the buildings from statistical databases (such as national or regional institutes for statistics, historical maps, and development plans of municipalities), questionnaires for the users and, above all, to extract information from maps provided by GIS data sources/geoportals. In particular, in order to properly describe a building stock, five key parameters for each building are needed from the GIS database:

- the covered or built-up area
- the average building height (ideally including both the eaves and ridge height)
- the perimeter
- the building age
- the heritage-related legislation

**Table 1** Building category and preliminary dimensional thresholds

Building category	Dimensional range
One/two-family house	Buildings with 1–2 floors (+0.5 for attic floor), with 1–2 housing units, mainly with saddle roof
Agglomerates/terraced house	<3 floors, apartments adjacent to others housing units, agglomerates/accumulation in historic centers, terraced houses
Small multi-family house	Building with 2–4 floors, <10 housing units
Large multi-family house	Building with 2–4 floors, >10 housing units
Block	>4 floors, high number of housing units and compact design (low shape ratio)

Starting from these base parameters, a series of other relevant data can be ideally recognized from the map, such as adiabatic-not-adiabatic walls, roof shape and orientation (for the integration of solar energy) or data that can be deduced, such as: net base area, net-floor area, net heated-floor area, gross-floor area, number of inhabitants and housing units, gross volume, heated volume, number of floors, surfaces of the thermal envelope (vertical: exterior walls; horizontal: baseplate/basement ceiling or roof/top floor ceiling), window surfaces, and shape ratio.

After the creation of a thematic map, integrating all relevant data from different sources into one GIS map, for each examined building we obtain a polygon feature linked to a series of data. From the data of the geographical map, a table is generated (1 building/1 row) and is subjected to a process of statistical analysis. The building stock can be divided into the identified age classes and, for each of them, a series of definitive thresholds for geometric characteristics are defined to fix the building categories.

The result is the division of the building stock into different typologies according to the two main variables: age class and building category. This information can be reimported into the GIS software and can be illustrated on the thematic map as shown in Fig. 1.

The key step of this first phase is the definition of the reference buildings that will be assumed as representative of each typology in terms of building features and thermal properties. According to the availability of data, it is possible to adopt three kind of references, with different levels of detail:
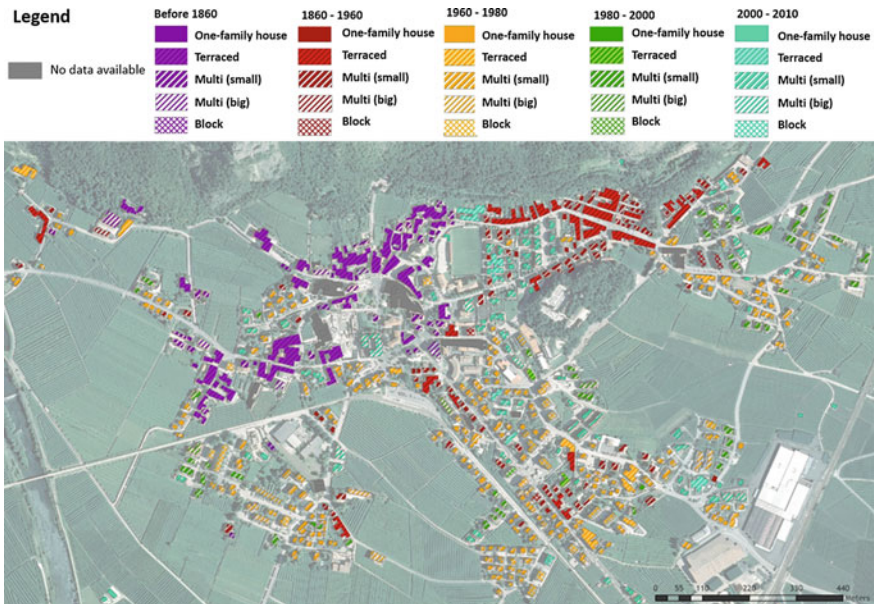
Fig. 1 Illustration of building typologies in the geographical map

- a real exemplary building defined according to on-site survey (*qualitative approach*)
- a real exemplary building that is close to the median geometrical features of each typology (*quantitative approach*)
- a model building that represents the median values of all the geometrical features (*detailed approach*)

Coupled to the geometrical features, for each reference building the thermal properties and the features of the HVAC system have to be determined. In particular, the properties of the envelope are deduced from catalogues of typical national or regional construction materials and methods (i.e. TABULA or AlpHouse project, UNI 11300, technical guidelines of regional energy certification etc.). In order to increase the reliability of the analysis, the results from literature research should be compared with former architects' drawings and on-site spot investigations of the reference buildings.

The data on the technical building systems for heat production, distribution and radiation are deduced as well from databases for existing heating plants. The assigned values, e.g. boiler efficiency, are dependent on the year of construction of the building and the building typology (UNI TS 11300-2 2014). For heat generation we usually choose the technology and energy source with the highest use, according to the respective building age and category in the area.

2.2 Baseline Simulation

The aim of the reference building definition is to determine a so-called "baseline" scenario that offers a picture of the current energy consumptions of the building stock. In this regard, it is possible to collect the actual energy consumption of the buildings or/and to evaluate the energy performance through energy simulations. The level of detail of the simulation determines the reliability of the analysis, nevertheless, the more detailed the simulations, the more time-consuming is the analysis. As an effective compromise, in order to evaluate the energy demand for heating, domestic hot water (DHW) and cooling, we adopted a steady-state energy balance according to the norm EN 832 which is based on a monthly method.

In order to determine the total energy consumption of the buildings in the investigated area, the calculated specific energy demand of the single building typologies (in $kWh/(m^2a)$) is projected to all the existing buildings (based on the calculated heated net surface), according to the age class and to the category of each building. The result is the illustration of the actual energy consumptions of the whole building stock according to all building categories in the different age classes. The knowledge of the trend and distribution of energy consumptions over the building stock is an essential basis and starting point to define effective energy-saving strategies, to identify most energy-consuming typologies and to develop tailored renovation measures.

The final step is the validation of the baseline scenario according to either actual consumption collected on building-stock level or specific consumption for the reference buildings (if real buildings are assumed as reference buildings, the validation for the performances of the specific building typology can be carried out applying the M&V Protocol or the IPMVP Protocol).

Although the validation represents an important step for the reliability of the baseline scenario and is crucial for an effective definition of the energy conservation measures and the potential energy savings, the lack of detailed and structured information usually does not allow proper completion of this phase.

2.3 Renovation Measures

The renovation packages include both improvements of the thermal envelope (insulation of facades, roof and baseplate, replacement of windows, improvement of air infiltration rate, etc.) and of the building services (replacement of boiler and increased efficiency of the plants). The aim is to reduce energy consumption and costs as well as CO_2 emissions, while improving the quality of comfort at least to comply with the legal minimum standard.

In particular, a set of different renovation packages tailored to the specific needs of the building typologies and to the current local standards are elaborated aiming to improve the thermal envelope and the building services.

As a general approach, we distinguish between interventions tailored to the requirements of historic buildings and renovation measures for non-historic buildings. Therefore, the proposed renovation packages vary according to the preservation requirements (listed buildings and protection of historic ensembles) present in the territory that have an impact on energy efficiency measures. These are the three different renovation sets that have been developed:

"**Conservative renovation**": minimal invasive renovation for listed historic ensembles under preservation order.

"**Standard**": renovation of the building elements to meet the minimum values required by law for the related climate zone.

"**Advanced**": renovation towards the nZEB target.

The information on the land-use plan of the municipalities and communities enables us to identify how many buildings are subjected to what kind of preservation constraints. Consequently, it is possible to attribute the different renovation packages and to perform the calculation of the potential energy savings for the building stock in the whole area.

The calculation of energy consumption "after-renovation" is performed for each reference building. To assess the impact of the renovation measures, the primary energy demand of the existing building is compared to the results of the renovation variants. Starting from the possible energy savings that can be obtained, the pay-back period for the renovation packages is evaluated in relation to each building typology.

2.4   Energy Saving Potential and Target Setting

Starting from the specific energy saving associated with each renovation package for the building typologies, the evaluation of the saving potential on the building-stock level requires assumption of a reliable annual renovation rate in a certain time frame (e.g. 20 years), in order to establish which is the surface which undergoes renovation each year. This value represents a strategic parameter that is affected by the renovation policies on national and local levels, thus usually a series of energy saving scenarios adopting different renovation rates on the building-stock level have to be performed to provide a comprehensive evaluation.

In particular, one of the scenario aims to evaluate the total percentage of energy savings achievable with the current average renovation rate of the last 20 years in the territory. A second scenario considers an increased and desirable rate of 3 %, which would correspond to the minimum value recommended by the campaign "Renovate Europe" at European level, to attain by 2030 the energy savings specified in the EU directive 2012/27/EU. When performing the scenarios, as described above, we assigned to the listed buildings the respective adequate renovation packages depending on the preservation regulations, while to the non-historical building we applied either the "Standard" or the "Advanced" package. Results show different percentages of energy-saving potential according to different renovation rates within a predetermined time frame. The elaboration represents the basis to formulate energy-saving targets in order to estimate reliably and adequately the renovation rates and to orient the energy-saving policies on the local level.

3   Results of the Building-Stock Energy Analysis

The enhanced typology approach was implemented in two areas in northern Italy: the Valley Community Rotaliana-Königsberg and the Passiria Valley.

3.1   Case Study 1: Rotaliana-Königsberg

Rotaliana-Königsberg is an Alpine valley located in northern Italy. The Community includes eight municipalities (Faedo, Lavis, Mezzocorona, Mezzolombardo, Nave San Rocco, Roverè della Luna, San Michele and Zambana) and forms a geographical unit oriented north-south along the bottom of the Adige valley. Data sources for the energy analysis of residential buildings and the consequent estimation of the potential energy savings were: municipality, community, Province of Trento and Department of Civil Environmental and Mechanical Engineering of the University of Trento.

3.1.1 Data Collection

Two different shapefiles were available for the investigated area: one from the geoportal of the province, with information on the building size, in terms of covered area, building height and perimeter; and another one elaborated by the University of Trento with information on the construction period. In addition, an on-site visit was conducted intended to capture typical building dimensions, particular architectonic features and building methods and to determine the prevailing building categories in the district. At the same time, a vast majority of building was photographically documented from the outside. Information about the preservation regulations have been collected manually from the land-use plan of the municipalities (% of listed building and ensembles under protection). The physical parameters or, respectively, the typical component assembly were taken from catalogues of national and regional building methods, as well as in part from the typology brochure of Italy from the TABULA project (Corrado et al. 2014), and not verified on-site. The information from the two shapefiles on building geometry and building age, as well as the images (by means of GPS), were integrated into one thematic map, which contained a relatively high level of information on every building and represented therefore a good starting point for the categorization of buildings and baseline calculation. In this case, the data on the actual energy consumption of the building stock are not available, and so it was not possible to validate the analysis.

3.1.2 Building-Stock Analysis/Typology Matrix

The building stock of the Rotaliana-Königsberg territory totals about 3,830 residential buildings and the analytical work considered 3,690 constructions, or about 96.5 % of the total stock. The analysis shows that almost 40 % of the analyzed residential buildings were built between 1960 and 1980, during the so-called Italian "construction boom".

Due to the results of the on-site inspection and the subsequent analysis of the catalogued photos, five building categories have been roughly determined; the prevailing building types in the area are: one/two-family dwellings, small and large multifamily houses, terraced houses/agglomerates and housing blocks. The building classes were then extracted from the whole building stock, by splitting up the statistical building data into a series of specific thresholds describing the characteristic dimensions and proportions.

For the definition of the reference buildings, we calculated a fictitious median building from the geometric data of every building category. The available data on construction periods enabled us to define five building age classes taking into account: two periods before and after the use of reinforced concrete (respectively <1860 and 1860–1960); and three periods, from 1960 and later, that reflect the introduction of the national legislations for energy efficiency in buildings (1960–1980, 1980–2000, >2000). Figure 2 shows the resulting typology matrix with the 25 reference buildings defined for the district.
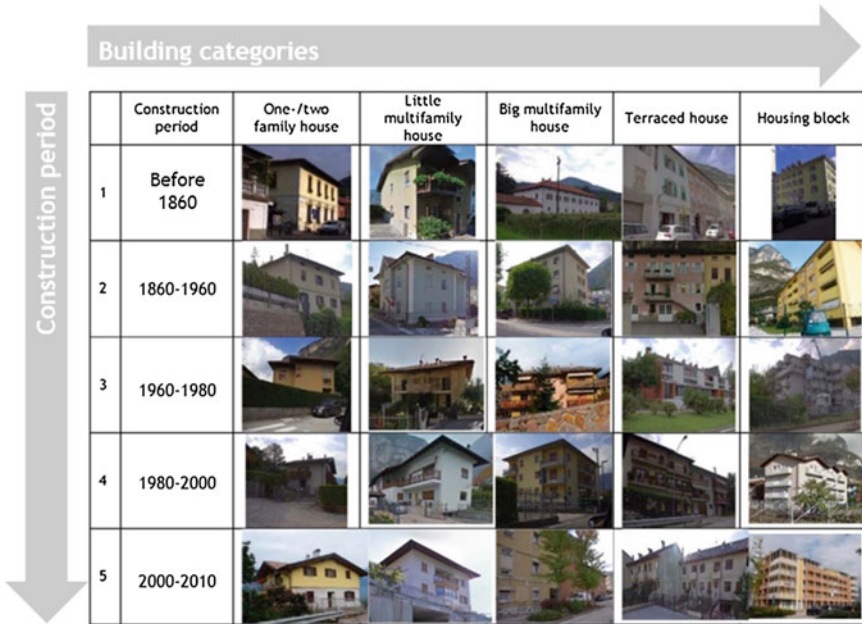
Fig. 2 Exemplary building typology matrix, indicating the two base parameters

The quantitative analysis show that most buildings of all typologies were built between 1960 and 1980. At around 1,100, the number of small multi-family houses stands out compared to the other typologies in all the age classes, but especially between 1960 and 1980, followed by the one/two-family houses of the same age class with approximately 220. The typology with the lowest number of buildings over all construction periods is the apartment block. The number of agglomerates/detached houses was constantly decreasing over the years. The total heated surface confirms the main trend: over all periods, the small multi-family house represents the largest fraction of the whole surface, here followed in the first age class (before 1860) by the agglomerates of the historic city centers. The largest part (around 700,000 m^2) of the heated surface was built from 1960 until 1980, but also the historic building surface totals around 510,000 m^2, while the remaining three age classes total around 300,000 m^2 each.

3.1.3 Renovation Measures

Due to the large portion of historic buildings, it was necessary to develop a tailored renovation package that addresses the special requirements of listed buildings and historic ensembles under preservation order. Following the renovation criteria of the Province of Trento that distinguishes between "Restoration" and "Conservative renovation", we developed solutions that have no impact on the aesthetic of the

buildings (especially from outside). For listed buildings, we propose a minimum insulation of the roof and the installation of a new boiler, while, for less protected ensembles, we propose the insulation of roof/top floor ceiling and baseplate/basement ceiling, interior insulation of outer walls, enhancement of existing windows by implementing double glazing and improving their airtightness, and a new heating boiler.

For the large remaining part of multifamily houses from the 1960 until 2000, besides the standard solution, we proposed an advanced renovation package, which foresees approaching the target nZEB. In particular, special focus is devoted to large-dimension residential buildings like the multifamily houses and blocks that would have a higher impact on the energy savings at stock level. Furthermore, high energy-efficient solutions for the compact and standardized architecture of those multifamily houses and blocks from the last decades can be more replicable, cost-efficient and easier to apply. In detail we propose as "standard" package: renovation of the building elements to meet the minimum values required by law for the related climate zone by means of adding medium insulation to the whole building envelope, replacement of windows (double glazing), improvement of airtightness and installation of a new heating boiler. As "advanced" package: the same as standard, but increased energy efficiency of the components of the thermal envelope, e.g. triple glazing and the installation of a ventilation system with heat recovery (see Table 2).

Table 2 Detailed parameters of the four renovation packages

Refurbishment measures	Restoration	Conservative Renovation	Standard	Advanced
Thermal envelope	U-values (W/m^{2}K)	U-values (W/m^{2}K)	U-values (W/m^{2}K)	U-values (W/m^{2}K)
Insulation of exterior walls	–	0.38	0.34	0.16
Insulation of roof/top floor ceiling	0.43	0.22	0.30	0.17
Insulation of baseplate/basement ceiling	–	0.33	0.33	0.22
Replacement of windows	–	Glazing: 1.20 (g-value = 0.60)	Glazing: 1.70 (g-value = 0.7) Frame: 1.60	Glazing: 1.10 (g-value = 0.56) Frame: 1.00
Airtightness	n50 (h^{-1})	n50 (h^{-1})	n50 (h^{-1})	n50 (h^{-1})
Air change rate at press. test	2.0	1.5	1.5	0.6
Building services	Boiler efficiency normal output	Boiler efficiency normal output	Boiler efficiency normal output	Boiler efficiency normal output
Replacement of boiler (higher efficiency)	99 % (condensing boiler)	99 % (condensing boiler)	99 % (condensing boiler)	99 % (condensing boiler)
Installation of a controlled ventilation system with HR	–	Heat recovery efficiency 85 % 0.35 Wh/m^3	–	Heat recovery efficiency 85 % 0.35 Wh/m^3

3.1.4 Main Results: Baseline and Renovation Scenarios

Considering the baseline scenario, the results of the analysis show that the single-detached buildings (one or two-family) present the highest specific primary-energy demand for heating and hot water (EP_{gl}) over all building periods. This is due to the higher surface-to-volume ratio, the relationship between surface of the thermal envelope and the heated building volume, compared to the other building typologies.

The average specific EP_{gl} of the building stock is around 215 kWh/(m^{2}a); whereas the lowest value is associated with the housing blocks of the recent construction period (2000–2010) accounting for 88 kWh/(m^{2}a), while the highest EPgl value is calculated for one/two-family houses built from before 1860—with 490 kWh/(m^{2}a).

Considering the total primary energy demand (MWh/year) for the building stock, the constructions of the age class 1960–1980 have the highest energy needs. Among them, the small multi-family houses are the highest consuming since this is the most frequent typology in the analyzed territory. The total primary energy demand of the whole district is 465,515 MWh/a, where of the small multi-family houses from 1960–1980 contribute for 128,213 MWh/a, which represents the 28 % of the total (Fig. 3).

One result from the energy simulations was that the potential savings of primary energy are greater for buildings built before 1980. In fact, for these buildings, thanks to an advanced refurbishment, the energy need would be reduced to a tenth of the current one. The payback time of refurbishment interventions, which was determined by a simple balance between the investment costs per intervention and the annually saved energy costs (calculated with the actual stable energy unit price), showed that typologies which are more compact (blocks of flats, big multi-family

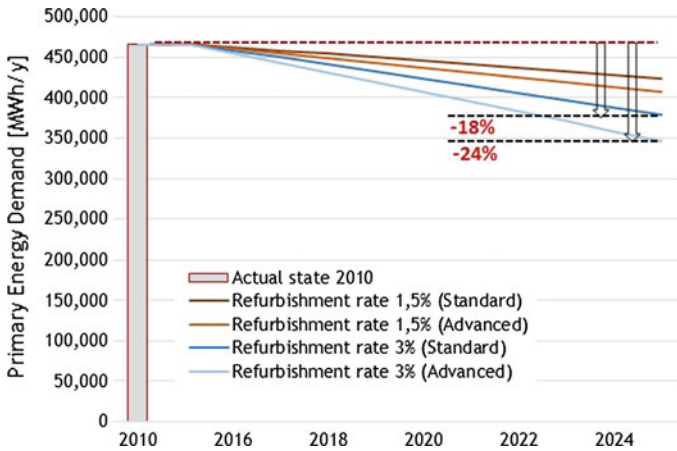Fig. 3 Primary energy demand for heating by building typologies and age classes before renovation
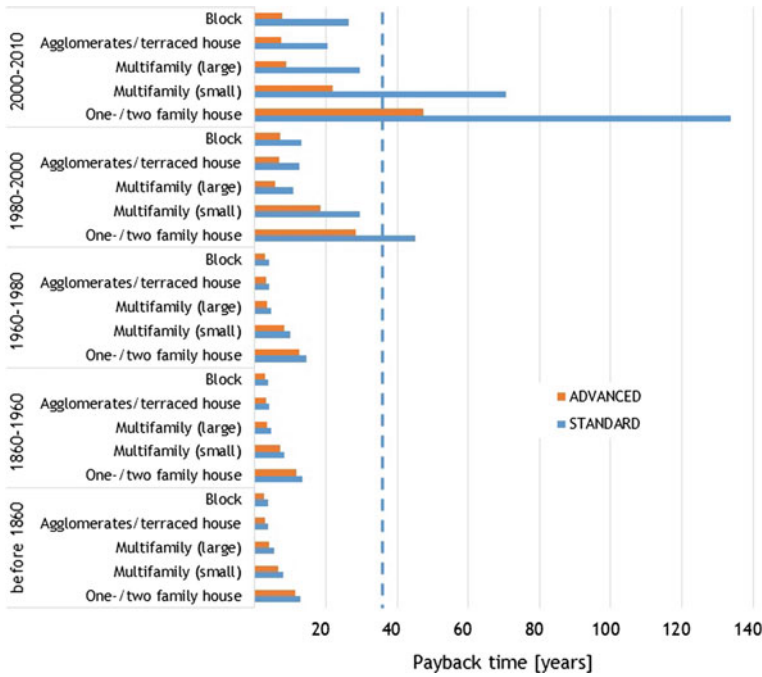
Fig. 4 Payback time by building typologies and age classes

buildings) and generally buildings built before 1980 have a lower payback time and therefore more benefits (Fig. 4). In the scenario with an annual refurbishment of 3 % of the existing residential buildings, by 2025 the total demand of primary energy would be reduced by almost 20 % with standard interventions and by 24 % with advanced refurbishment actions (Fig. 5). Due to their large number and diffusion, the small multi-family buildings would remain the typology with the highest impact on energy savings (Fig. 6).

## 3.2 Case Study 2: The Passiria Valley

The Passiria valley is a left tributary of the Adige, between the Alps of the Ötztal on west side and the Alps of Sarntal on the east side. For the sustainable-energy action plan (SEAP), in particular, the residential building stock of the municipalities of St. Leonhard, St. Martin and Moos were investigated. Data sources for the energy analysis of residential buildings and the consequent estimation of the potential energy savings were: municipalities, community, the Province of Bolzano, databases of national and regional institute of statistics (ISTAT and ASTAT), and questionnaires to the inhabitants.

Fig. 5 Trend of primary energy demand for heating and hot-water generation according to different annual renovation rates (1.5 and 3 %) from 2010 until 2025

3.2.1 Data Collection

The two shapefiles, provided by the Consortium of Municipalities in the Province of Bolzano, included on one hand a polygon feature for every residential building and on the other hand shapefiles for all listed buildings. There was no more specific georeferenced data available with regard to additional geometric parameters or especially to the construction age. To complete the geometrical data of building typologies, the covered area and perimeter could be deduced from the shapefile of the GIS map, while the height was calculated from the number of floors (from photos) multiplied by an estimated floor height. It was not possible to gain information on the building periods from historic development plans archived by building authorities. Therefore, in order to obtain more energy relevant information, a detailed on-site inspection accompanied by photographic documentation of 80–90 % of the whole building stock was conducted, besides a survey amongst the inhabitants of residential buildings. The survey was answered by 189 households, which represented 6 % of the total of dwellings in the three municipalities. It showed that almost 70 % of the surveyed households live in brick buildings, 75 % use combined generation (heating and DHW) and that methane, together with biomass, are the most used fuels. Due to the low participation in the survey however and some clear discrepancies with the data from the national institute for statistics, the results of the survey were only used, together with literature, for the description of the reference buildings, but not for the inventory of each building typology and age. On the district level, data from the national institute for statistics
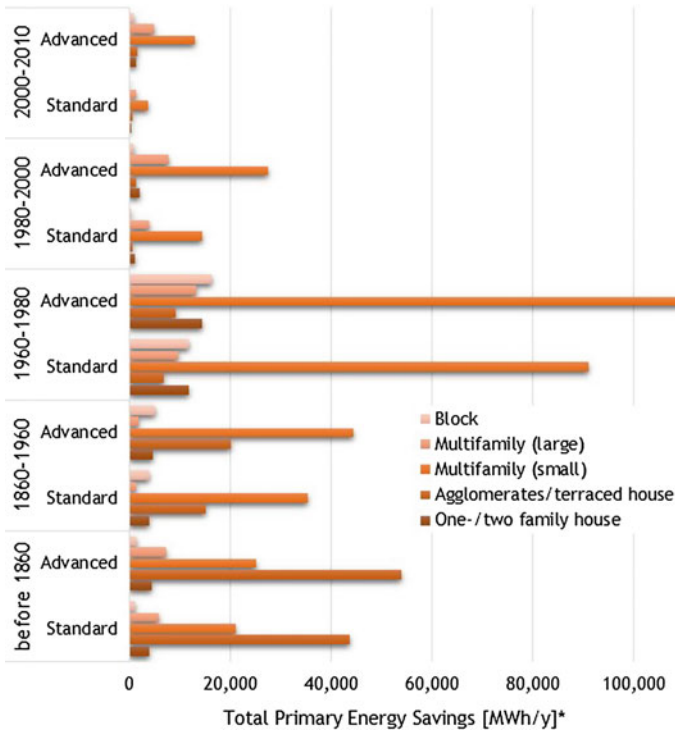
*The energy savings of "Restoration" and "Conservative Renovation" are included both in "Standard" and "Advanced".

Fig. 6 Possible total primary energy savings after renovation according to building typologies and age classes

(ISTAT) was collected regarding number of dwellings per municipality, useful floor area, number of floors above ground, building material, type of fuel etc., as well as from the provincial statistics institute (ASTAT) concerning total the number of buildings and number of buildings by dwelling types. Besides ISTAT information about building materials and methods, data was taken from regional and national catalogues for typical component assemblies, especially from the project AlpHouse (Benedetti et al. 2013) and, in parts, from the typology brochure of Italy from the TABULA project (Corrado et al. 2014), but not verified on-site. Data on real consumption was provided by the energy suppliers and from a study on biomass use; nevertheless it was not adoptable for the typology approach since it was not structured, e.g. by the municipalities (three in this case).
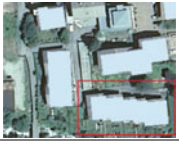
3.2.2 Building Stock Analysis/Typology Matrix

According to the data of ASTAT, the residential-building stock of the three municipalities included, in the reference year 2010, a total of 1,691 buildings. 55.4 % of the residential buildings were constructed in the period from 1946–1991, which reflects the construction boom in Italy of the 60s–70s. The existing buildings from before World War II made up around 24 %. The percentage of buildings that have been built between 1992 and 2005 is about 17 %, which is comparatively high and approximately proportional to the period after the World War II (1946–1991). The distribution of the buildings in the different age classes is very similar for all municipalities.

According to the available data, only three typical building types were defined after a qualitative analysis of the documented buildings in terms of their dimensions and architectonical features. The investigated area consists of relatively small villages with a majority of small constructions, like one/two-family houses, semi-detached houses and a minority of (small-sized) multi-family houses. From the catalogued buildings for each category, one real building was selected, representative for the entire category in terms of size and proportions. The real building was recognized in the GIS map, and the geometric data was taken from the shapefile. The four building periods divide the building stock into constructions before World War II and after, until the introduction of the national laws beginning in 1991 (Italian Law n. 10/1991) and beginning in 2006 (311/2006) that required the enhanced use of thermal insulation. Table 3 show the resulting typology matrix with the 12 reference buildings defined for the district.

The distribution of the three building categories (one/two-family house, detached and multi-family house) over the four construction phases was determined from the photo documentation of the buildings. The total number of multi-family houses was

Table 3 Building typology matrix of case study 2

	Age class	One/two-family house	Multi-family house	Detached house
1	Before 1945			
2	1946–1991			
3	1992–2005			
4	2006–2010			

taken from ASTAT data (buildings with more than three units). A look at the development of the building stock related to building categories and age classes shows that the building type one/two-family-house of the construction period from 1946–1991 occurs most frequently and clearly stands out from the total number of buildings. According to statistical data, the total heated net area of the building stock is 300,685 m^2: 123,178 m^2 in St. Martin, 107,203 m^2 in St. Leonhard and 70,304 m^2 in Moos.

3.2.3 Renovation Measures

The proposed renovation packages for older one/two-family houses of the district were based on the specific interventions developed especially for historic envelopes typical for the Alpine space within the project Alphouse (Benedetti et al. 2013). To respond to the different requirements of listed and non-listed buildings, but also to consider different amounts of investment costs, three renovation packages were elaborated: A "base", a "standard" and an "advanced" refurbishment package. The base renovation foresees minimal invasive interventions (roof/top floor insulation and installation of a new heating boiler), the standard package respects again the minimum values required by law for the related climate zone and the advanced renovation anticipates the high-energy efficiency refurbishment towards the low-energy standard.

3.2.4 Main Results

Due to the fact that the municipality of Moos belongs to a colder climate zone because of its higher altitude above sea level, the specific primary energy needs for heating and domestic hot water of the building typologies tend to be higher than in the lower situated municipalities of St. Leonhard and St. Martin. In fact, the average primary energy demand of buildings in Moos was 291 kWh/(m^{2}a), while for buildings in St. Leonhard and St. Martin it was 254 kWh/(m^{2}a). The building type one/two-family house has, despite similar characteristics of the thermal envelope in the whole district and over all construction periods, the highest energy demand, especially in the first age class, before 1945, with 489 kWh/(m^{2}a). This is again due to the comparatively high surface-volume ratio. On the other hand, the multifamily and the terraced houses, which are characterized by a higher compactness, show reduced energy needs, especially the terraced houses from the most recent construction period (2006–2010) with 84 kWh/(m^{2}a).

Due to the lack of sufficient data, the net heated floor area distribution per building category and age class was estimated proportionally: the product of the number of buildings per building category and age class and the related typical net heated surface produced the percentage of one building typology of the total net heated area of the district. According to that, the one/two-family house of the second construction period (1946–1991) has the highest impact on energy consumption, with a share of around 35 %, followed by the same building type of the first age class (from before 1945), with around 19 %.

Applying the three renovation packages to the reference buildings, we can see, that with a "base" refurbishment which foresees insulation of the roof and installation of a new heating boiler, already one third of energy savings can be achieved at least for buildings of the first two age classes. In general, in both of these construction periods (before 1945 and 1946–1991), the highest energy savings can be achieved: through realization of the high energy efficient refurbishment, energy consumption can be reduced by factor 10. Regarding the payback time of refurbishment interventions, buildings built before 1991 have significantly lower amortization periods (Fig. 7).

Renovating 3 % of the buildings per year until 2020, with standard interventions, would reduce the energy demand by 15 % compared to current energy needs. Considering advanced interventions (toward the target of the low-energy standard) with the same annual rate, the final energy demand would be reduced by 18 % compared to the current one (Fig. 8).
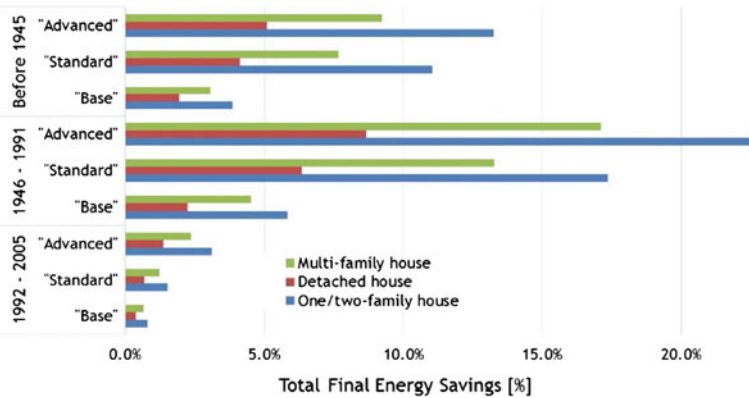
Payback-time of interventions								
	Before 1945			1946-1991			1992-2005		
Payback-time [years]	Base	Standard	Advanced	Base	Standard	Advanced	Base	Standard	Advanced
One/two-family house	6.4	9.1	9.0	7.8	12.0	11.0	19.8	>30	23.3
Multi-family house	7.3	12.2	12.1	8.7	14.9	13.9	21.8	>30	29.4
Detached house	6.8	10.6	10.1	7.8	12.6	11.4	21.4	>30	22.9

Fig. 7 Possible energy savings after renovation and payback time of interventions according to building typologies and age classes
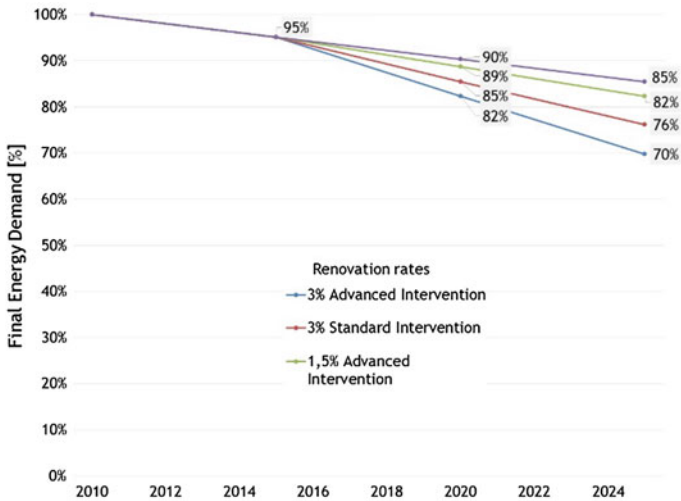
Fig. 8 Trend of final energy demand for heating and hot water generation according to different annual renovation rates (1.5 and 3 %) from 2010 until 2025

4 Conclusions

The paper shows that the developed methodology has a great potential both in considering the investigation phase, which enables us to have a general overview on the building stock, as well as in identifying the main needs of renovation and which are the sectors with the most energy consumption to be addressed by energy conservation measures. The results obtained show very well the possible energy reduction for every building typology combined with the information on which measures for what building type are cost-effective and which interventions on what building type have the highest impact on energy savings. The enhanced-with-GIS typology approach can therefore support public authorities during the decision-making process to choose among priorities and to define policies and incentives for building renovation, as well as to set precise energy targets within a specific time frame.

Nevertheless, the quality of the results is affected to a large extent by the availability of data on the urban level, in terms of georeferenced information on building geometry and construction period, as well as by the availability of energy consumption data. Even if GIS data are available from different sources, it is often not possible to integrate them because the shapefiles are not overlapping. The other main critical point is that often there is a lack of structured and detailed information on real energy consumption. If it is not possible to compare the simulated energy consumptions with real consumptions, the analysis cannot be validated. Energy consumptions in reality might be lower as the simulated ones, since the simulation foresees a standard temperature of 20° for the whole heated surface over all the

time. Consequently, total energy savings might be reduced and the analysis may produce misleading results. Therefore, public authorities and energy suppliers are in demand to provide structured and interoperable data.

In general, the level of detail of the survey depends strongly on the specific question or on the specific target of the investigation. The more detailed the preceding inventory, the more accurate and reliable the results, but also the more time-consuming. At the beginning of the building stock analysis, the concrete question for the relevant district has to be clarified and the methodology has to be tailored to the specific conditions and the data availability. In any case, this methodology can be adapted and extended to the central issue of the investigation area: other energy types in terms of electric energy consumption or energy consumption for cooling can be considered; energy calculations can be done with dynamic energy simulations programs; and the integration of renewable energy production on-site can be taken into account in the energy balance. Also, the cost-benefit calculation can be enlarged and made more detailed, considering already existing subsidies and maintenance actions.

However, this methodology is a tool for preliminary estimates: already a quite rough investigation based on sufficient input data can provide effective renovation measures, identify intervention areas and deliver a useful and reliable estimation of energy saving potential, thanks to the enhanced-with-GIS typology approach.

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