Energy Audit of two Apartment Buildings in Cagliari using Energy Simulation

Graduation Thesis by Carla Vargiu and Luisa Zedda, Master in Green Building and Energy Efficiency

This thesis focuses on the thermal and energy behaviour of two existing apartment buildings located in Cagliari. An energy audit has been performed to identify energy saving opportunities and to assess economic and environmental benefits. Both buildings were built in the 1970's and 1980's, with simple volumes and similar construction characteristics. They are the first two case studies in Sardinia included by GBC Italy in its LEED protocol for apartment blocks.

The dynamic simulation calculation tool *DesignBuilder* with *EnergyPlus* as calculation engine, has been used for the appraisal of buildings' energy performance and the definition of energy profiles.
Audit data on user profiles and buildings' envelope and plant system have been used to define real performances of the two buildings. Calibrating the model on real performances data allowed to elaborate several retrofit strategies, and then choose between them the optimal solutions, taking into account economic and environmental benefits, effects on comfort, architectural quality, legal obligations and the actions' coherence with the context.

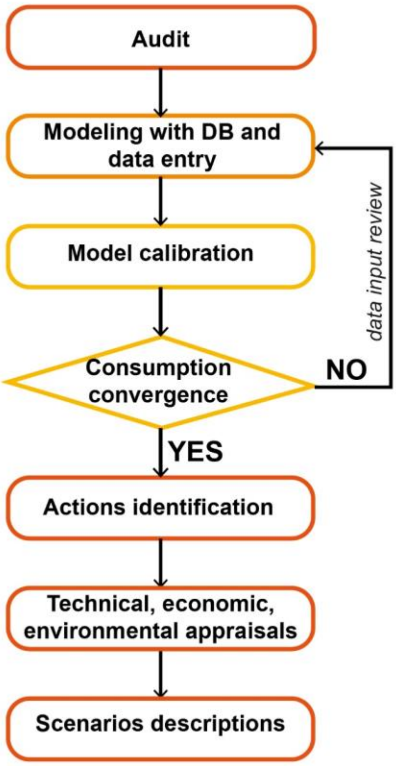


Figure 1: Project Processes

Case studies

The subjects of the study are two apartment buildings representative of Sardinian architecture of the seventies. To simplify the research and allow a reliable comparison, buildings were selected with simple volumes and similar features by type, period of construction, context, materials and construction techniques.

Block A is made up of two blocks of regular and almost rectangular shape with a pitched roof; orthogonal to one another enclose a courtyard facing south-east. It is divided into several levels: basement (with garages, cellars and boiler room), five floors above ground and a penthouse with warehouses. The ground floor is made up of offices and 18 apartments are distributed over the 4 floors above. All calculations and simulations focused only on the residential part in order to be able to make comparisons with the other case study.

Block B comprises a basement (with cellars and garages), a pilotis floor used as parking for cars and five floors above ground with 18 apartments and a penthouse.
In both cases the structure is made of solid concrete skeleton, rubble-filled walls vertical walls and hollow-core concrete roofs. Windows are single glazed wooden frames and shielded by shutters and integrated blinds.

In general the building envelope is not well insulated and thermal bridges due both to textural discontinuities are an issue.

Heating, in both cases, is provided by a centralized heating system with oil-fired boilers and traditional cast-iron radiators. Domestic hot water is produced independently from each apartment by electric heaters. Some apartments are equipped with autonomous systems for summer cooling through air-to-air heat pumps.

Lighting is provided almost entirely by fluorescent luminaires.

Figure 2: Block A

Figure 3: Block B

Audit phase

The Audit phase was carried out according to the procedure defined by the UNI CEI EN 16247 and processing collected data through the use of dynamic simulation of the building-plant system in order to determine the energy performance before and after the interventions in greater detail.

Data on electricity consumption and heating oil were provided by the Administration Condominium.

The estimate of private consumption and the distribution across the various services (domestic hot water, heating, cooling, lighting, forced use) was calculated from:

- application of the UNI 11300-2 for calculating domestic hot water needs;
- diesel consumption bills for heating;
- number, type and operating time of heat pumps installed;
- regional and national studies (eg.: ENEA);
- number, type and operating time of household appliances;
- meter readings carried out for 14 consecutive days at the same hour for electric consumption;
- answers to the questionnaires to the owners of apartments.

Modeling with DesignBuilder

DesignBuilder was used to model the geometry of the apartment buildings and the urban context in which they are located. All external obstacles that shade the study buildings were included. All building blocks were zoned so as to define different areas with different conditions of HVAC, lighting, orientation and use. On each floor a zone was created for each apartment and a zone for the stairwell.

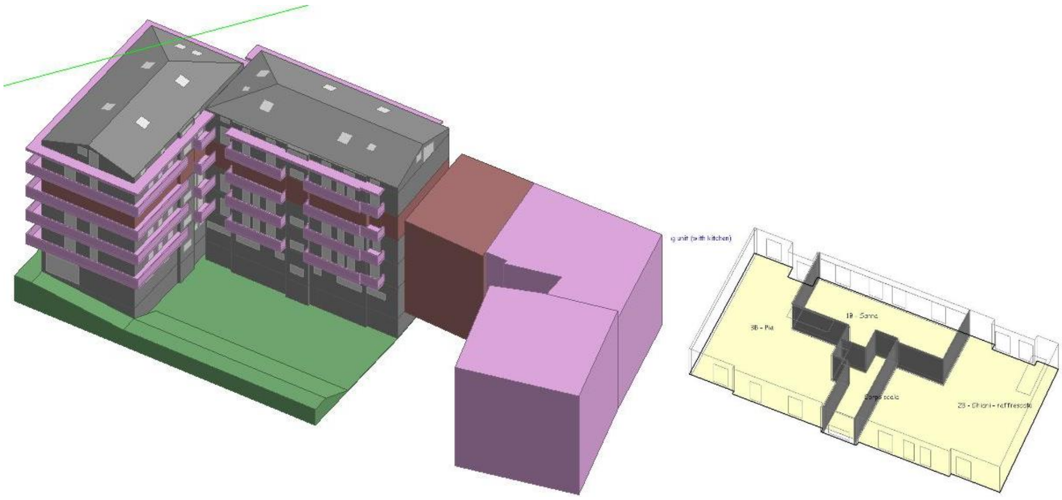


Figure 4: Block A model and zoning

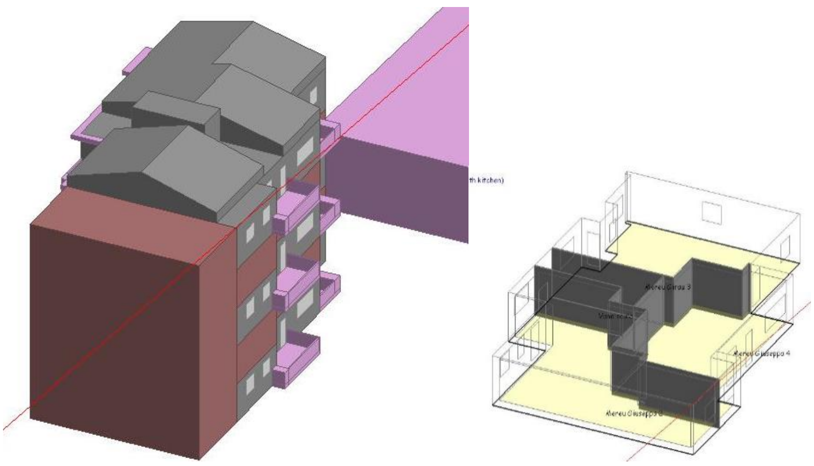


Figure 5: Block B model and zoning

Thermal bridges were not included to avoid creating overly complex models that would involve excessive modeling and simulation time and resources during calibration.

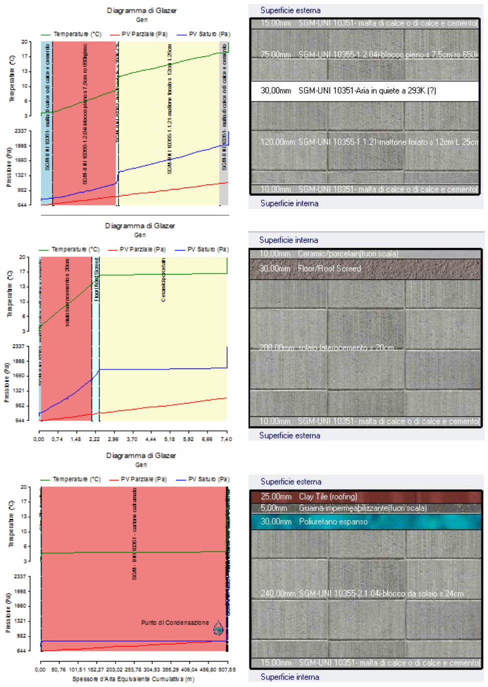


Figure 6. Envelope layers

COMPONENTS	TRANSMITTANCE [W/m^{2}K]
rubble-filled walls	1,033
intermediate roof	1,72
Rooftop	1,88
windows frame	5,80
windows glass	3,63

Model Calibration

At the end of the audit phase a Baseline Model was developed for each of the two case studies. The final model was obtained by calibration through multiple software interactions and by adjusting input parameters and generates results that are very similar to the audit data. The Baseline Model has been used to benchmark several interventions and to evaluate the pros and cons of each one.

Resident’s energy consumption can be modelled in DesignBuilder using the “*Utilization 7/12 Schedule*” functionality: utilization programs with the HVAC feature have been created for each utility (as DHW production, heating and cooling system).

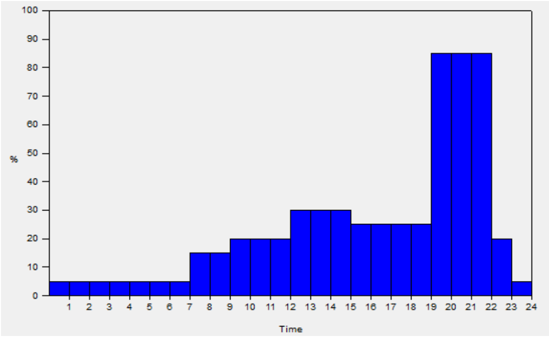


Figure 7: Example 7-12 schedule "Office Equipment"

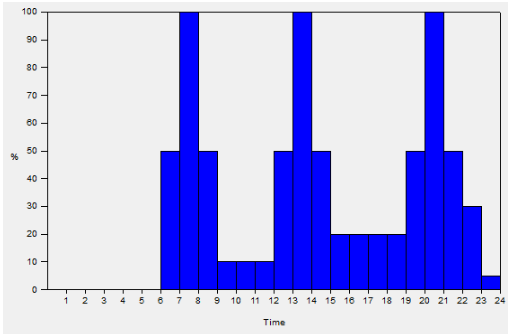


Figure 8: Example 7-12 schedule "DHW"

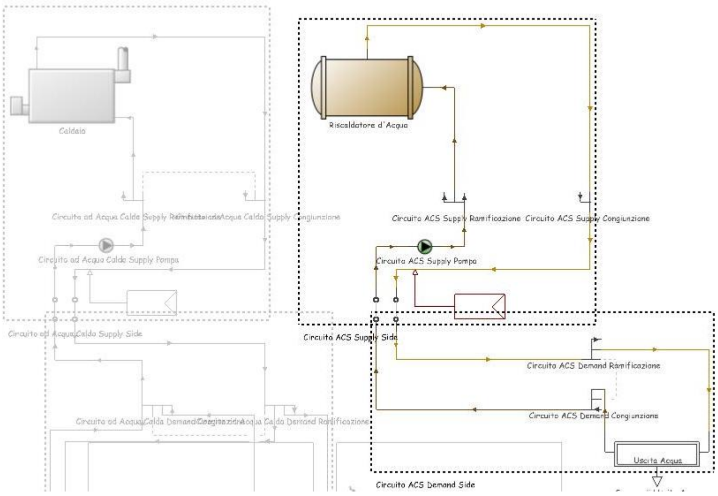


Figure 9: HVAC Detailed (DHW)

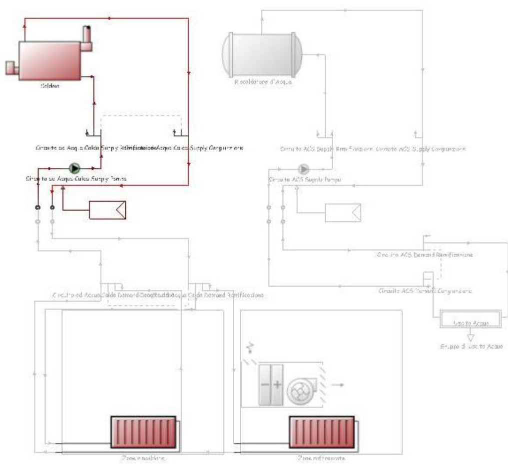
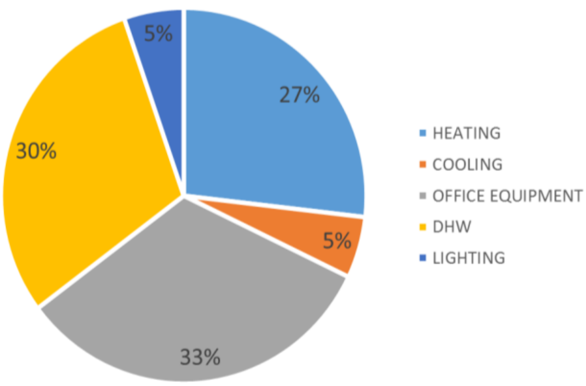


Figure 10: HVAC Detailed (heating)

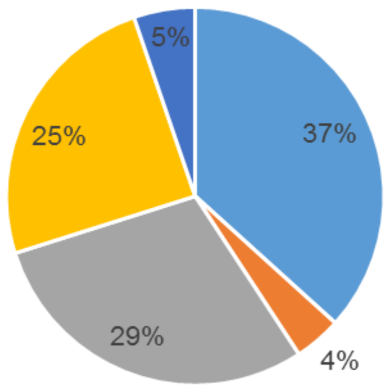
Table 1: Comparison between audit data and the baseline model

BLOCK A	DHW	OFFICE EQUIPMENT	LIGHTING	COOLING	HEATING
AUDIT	30.537	33.288	5.950	5.400	26.916
BASELINE	30.487	33.781	5.847	5.490	27.189

BLOCK B	DHW	OFFICE EQUIPMENT	LIGHTING	COOLING	HEATING
AUDIT	24.608	29.372	5.250	4.050	36.680
BASELINE	23.469	29.215	5.470	4.096	36.704



Graphic 1: Block A. Annual consumption



Graphic 2: Block B. Annual consumption

Energy optimization solutions

The first objective was to reduce energy use by reducing energy consumptions and costs.
To answer the remaining questions have identified measures that take account of different needs, such as: use of technology more efficient and renewable that minimize power consumption, environmental impacts and dependence on the electricity grid; consistent with the architectural appearance of the building and with the context; safety, comfort and quality of life; technical and economic feasibility.

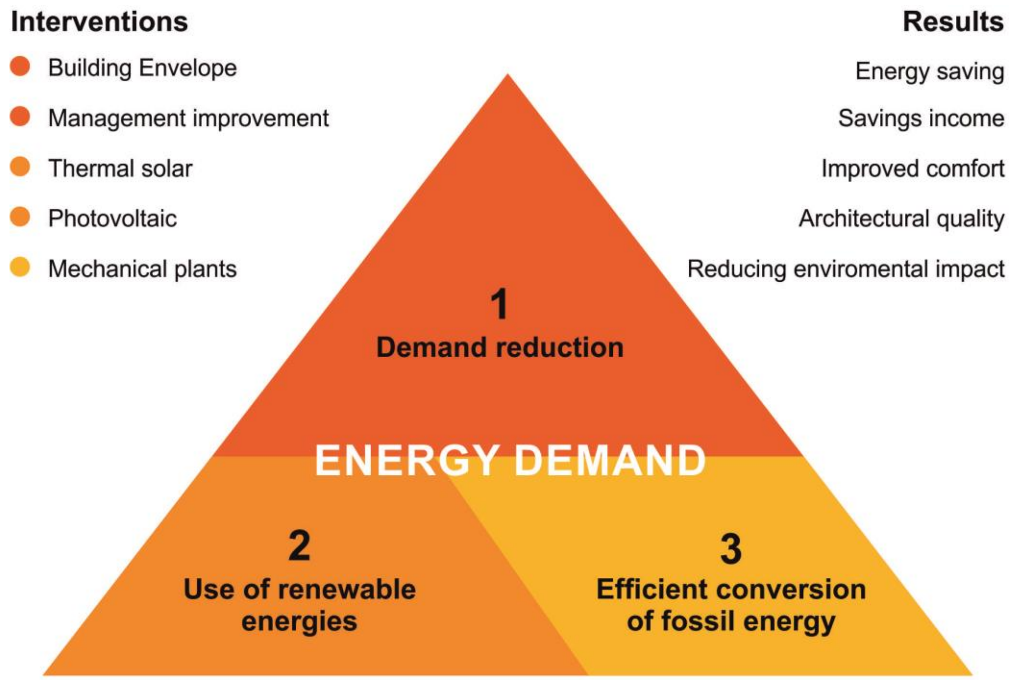


Figure 11: Summary table of the principles that have determined the choice of the energy efficiency solutions

The most effective solutions are based on those interventions:

- BUILDING ENVELOPE
    - Matt:
        - External thermal insulation in vertical walls.
        - Insulated roof and breezy.
    - Transparent:
        - aluminum window frames with a thermal break and double glazing low emissivity
        - aluminum window frames with a thermal break and solar control glass
- MECHANICAL PLANTS
    - DHW production. Replace electric boilers with:
        - Gas boilers.
        - Water heaters to heat pump.
    - Heating system:
        - New generation boiler.
        - Condensing boiler.
        - Thermoregulation and heat accounting.
    - Cooling system: more efficient air to air heat pumps.
    - Electricity consumption:
        - Replacement of existing light bulbs with other LED.
        - Replacement of the most energy-consuming appliances with more efficient ones.
- RENEWABLE ENERGY

- Autonomous solar heating system with forced circulation for production of DHW.
- PV system with and without energy accumulation.

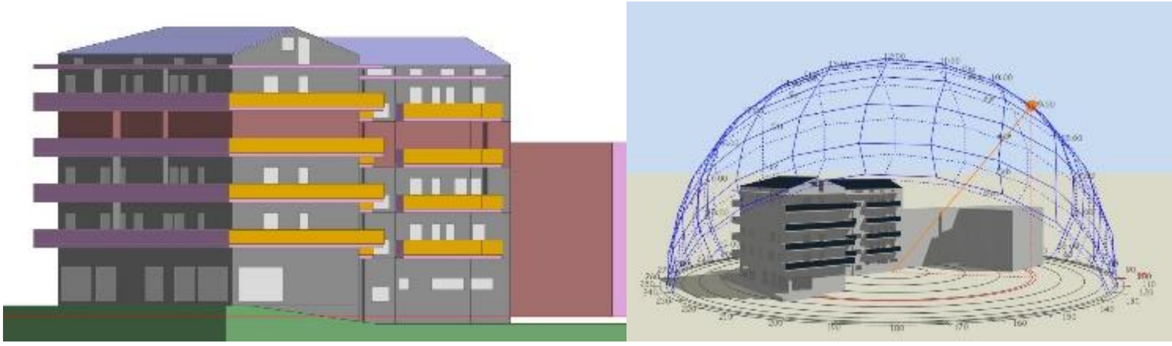


Figure 12: Block A. Model with solar collectors and solar diagram

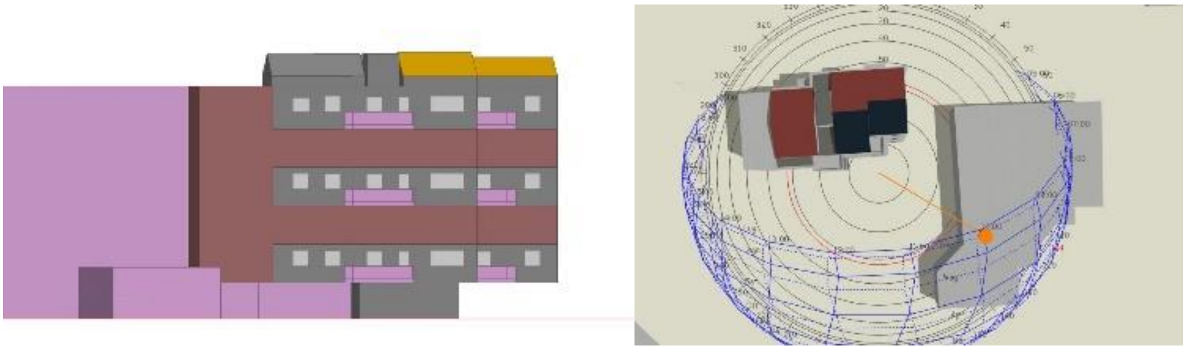


Figure 13: Block B. Model with solar collectors and solar diagram

- MANAGEMENT IMPROVEMENT:
  - Production of DHW (water saving).
  - Heating and cooling.
  - Electricity consumation.
  - ESCo tool.

As audit data showed both buildings having same issues (INVOLUCRO not performing, inefficient IMPIANTI, extensive use of fossil fuels, energy wastage), optimization solutions are similar for both buildings.

Economic, environmental and technical assessment

Every solution has been evaluated from the economic, environmental and technical points of view.

- ECONOMIC

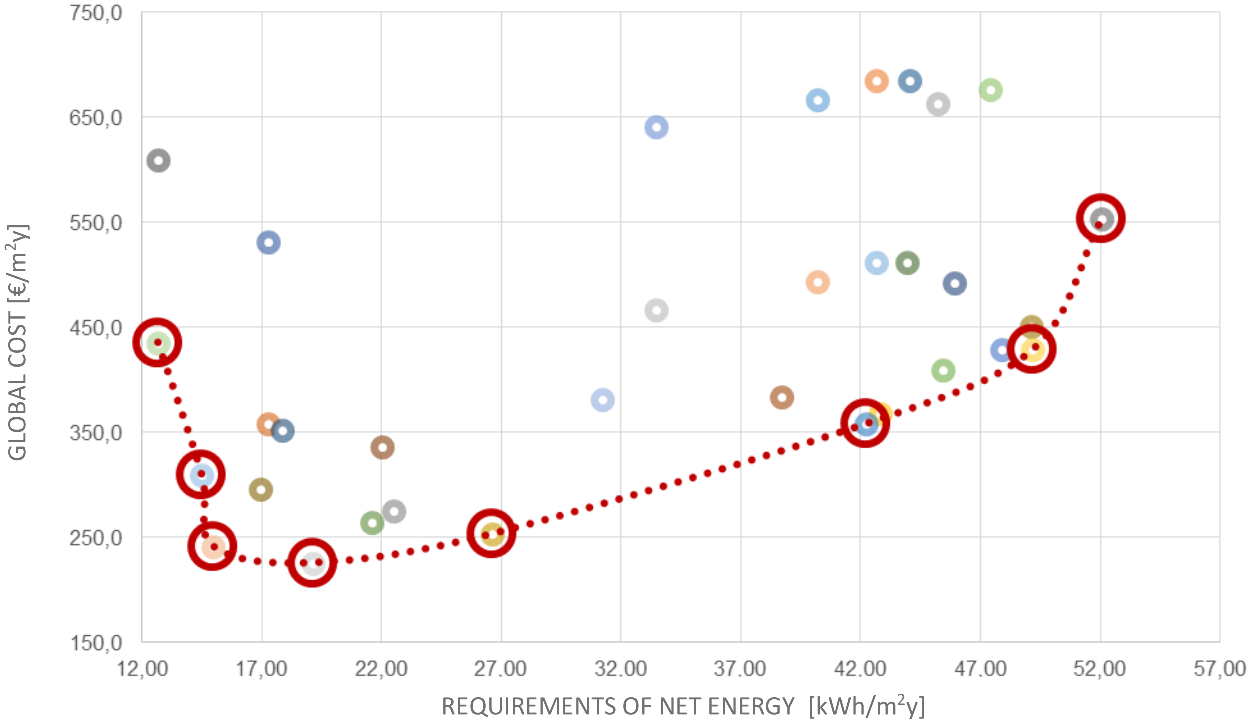
  A cashflow has been defined for each solution taking in consideration: energy price, annual energy savings, initial investment costs, operational costs, subsidies. KPIs have been associated to each solution: NPV (net present value), IP (profit ratio), PBT (pay back time) and IRR (internal rate of return).
- ENVIROMENTAL

  Energy savings allowed CO_2 emissions reduction: the reduction was estimated using standard emission factors of commonly used fuels.
- TECHNICAL

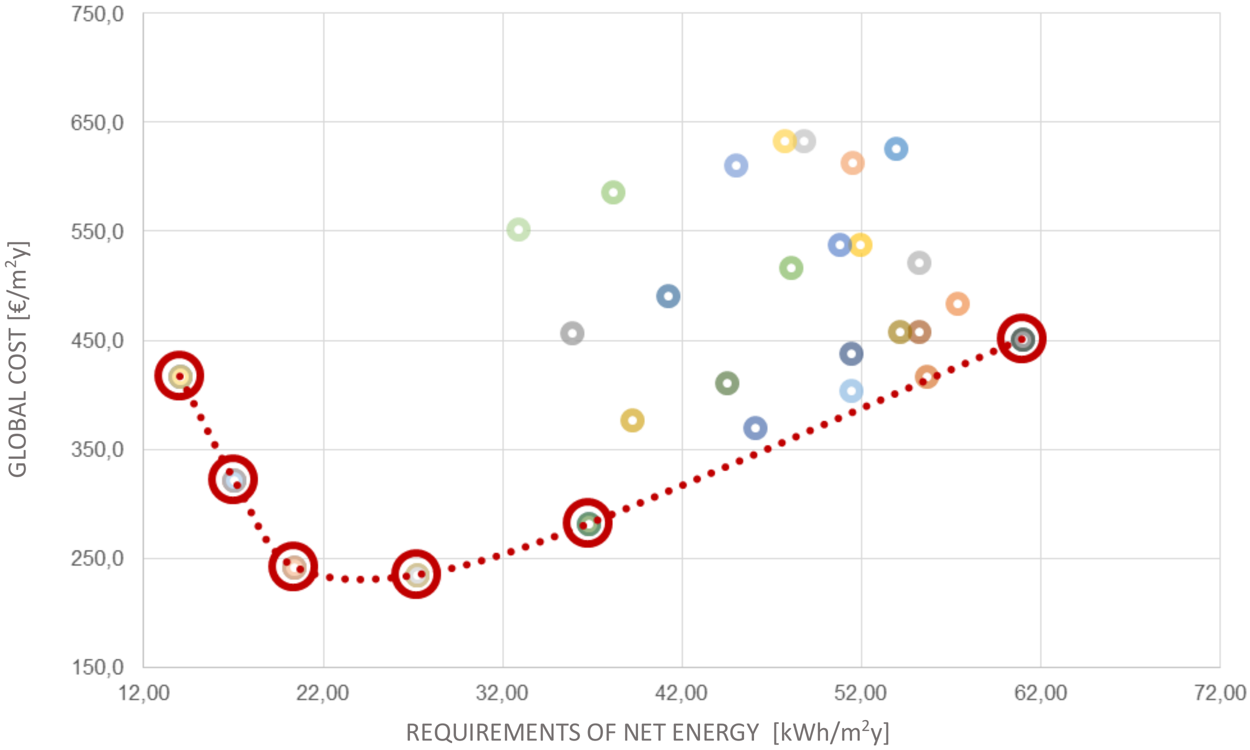
  The following factors have been taken in consideration: technical feasibility, consistent with the building and the environment, improvement of hygrothermal comfort, reducing dependence on fossil fuels, regulatory constraints.

Scenarios' details

Using *Global costs methodology*, solutions have been combined in several scenarios (38 for Block A, 28 for block B). Each scenario includes a cost chart, which relates energy needs (kWh/m^2) to global costs (€/m^2). For each case study an optimal cost curve has been identified: this curve is the union of optimal scenarios that minimize costs while offering the best energy savings.



Graphic 3: Block A. Interval of the optimal level of costs

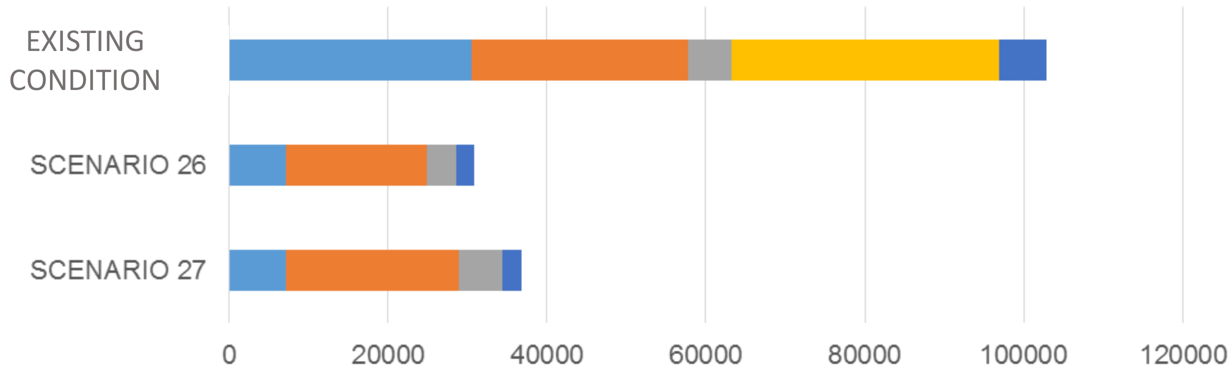


Graphic 4: Block B. Interval of the optimal level of costs

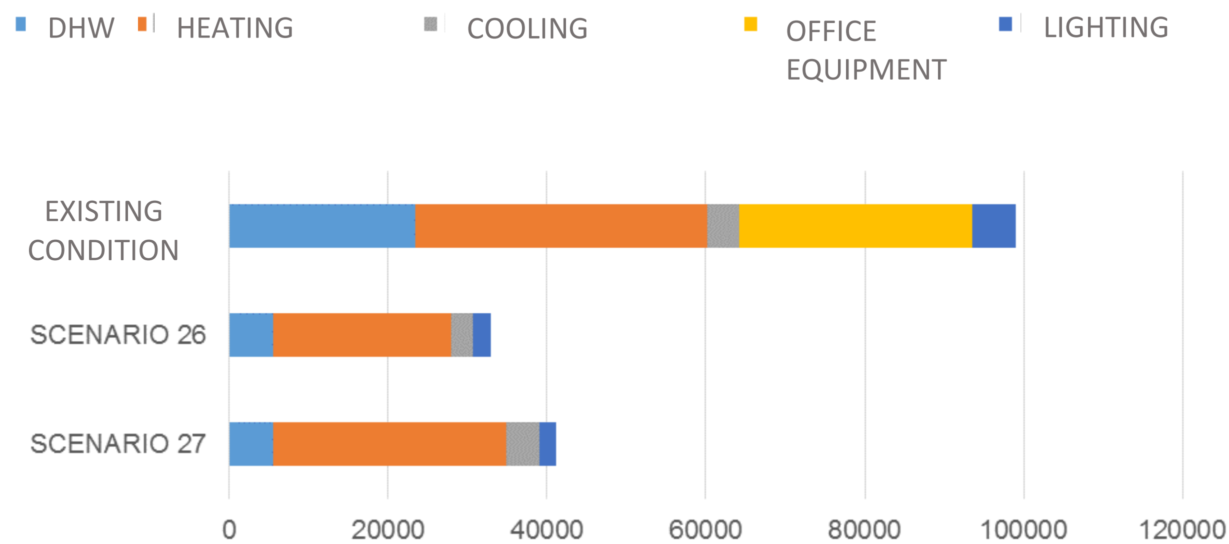
Best scenarios are obtained with the following interventions:

• SCENARIO 26: installation of heat pump for DHW production, thermoregulation and heat accounting, replacement of existing boilers with other new more efficient generation, replacement of the cooling system with high efficiency heat pumps, replacing fluorescent light bulbs with LED, replacement of major appliances and installation of PV system with energy storage;

• SCENARIO 27: installation of heat pump for DHW production, thermoregulation and heat accounting, replacing fluorescent light bulbs with other LED, replacement of major appliances and installation of PV system with energy accumulation.



Graphic 5: Block A. Comparison betweeen existing condition and two optimal scenarios



Graphic 6: Block B. Comparison betweeen existing condition and two optimal scenarios

Results

The most important result of the study is the demonstration of the potential impact of energy retrofit analysis. The study was done on buildings representative of national and regional context: functionally, structurally, energetically and technologically old. Energy retrofit analysis is a methodology that on the base of audit data is able to elaborate multiple information on buildings' state of art and on its occupant energy consumption rates, and using dynamic simulations and economic, environmental and technical evaluations, providing retrofit advice that allow:

- Reduction in consumption.
- Energy savings.
- Greenhouse emissions reduction.
- Home comfort improvement.

This study is not extensive enough to elaborate a theory and solutions for buildings and apartments in Cagliari. Its main scope is to create a framework and a strategy that can be applied to other case studies.
In order to create a local and regional energetic framework, data on other buildings should be collected and organized in a dedicated database.

The applied methodology has some limits, the biggest of which is the accessibility to some key information, related to energy consumptions - uncooperative building occupants who couldn't see any immediate advantage on the study. This is due to a lack of interest in the environmental cause, and low confidence in energy savings solutions.

The needs and priorities of people living in the buildings were not part of input data, and had to be replaced by some hypotheses. Also, the lack of cooperation caused some delays and slowed down the process.
Our hope is that this work can be used as a pilot, contributing to lower these barriers, so that in the future the same methodology could be applied with more benefits for all the stakeholders.

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