Aerial thermography applications for energy conservation and retrofit of urban heritage

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Abstract
Cities are the main responsible for energy consumption and greenhouse gas emissions in Europe, with the European Union playing a key role in policy-making to address this issue by enhancing the current energy performance class. In this process it is to be acknowledged that restrictions on cultural heritage can obstruct the renovation process by preventing transformations, thus requiring policymakers to find a trade-off which balances conservation and energy retrofit targets.

Infrared thermography can support the assessment process on multiple scales. By crossing estimated data on indoor temperatures and thermographic images it is possible to define the thermal dispersion of the building envelope, then correlating it to the energy performance class for planning interventions.

A real application on a district in Turin, Italy, is presented. It aimed at creating a hybrid Urban Building Energy Model based on aerial thermographic images and statistical data gathered through the Energy Performance Certificates and the national population census. The current state was defined before comparing two alternative renovation scenarios which considered alternative energy performance parameters and energy supply options. Specific insights can be produced on protected assets of the district area, thus enabling conclusions targeting an optimal trade-off between conservation and renovation.

Keywords: aerial thermography, remote sensing, energy performance, EPBD, energy renovation, urban energy modeling.

Introduction

Energy demand and emissions are strongly associated with cities, with these likely to further increase due to growing urbanization. At European level, the fit for 55 package targets a 80-95% reduction of GHG emissions by 2050 through 13 proposals, among which there is the revision of the Renewable Energy Directive, Energy Efficiency Directive and Energy Performance of Buildings Directive EPBD [COM/2021/802]. Especially the last two put the accent on the need for extensive energy classification, giving new light to this subject, due to the new minimum energy performance requirements that are expressed in terms of minimum energy class. In particular, energy performance class D must be reached for all buildings by 2035, while eliminating the building sector dependency on fossil fuels and relying on renewable energy sources.

The discussion generated from European policies highlighted the need for tools supporting energy assessments and planning. Geographic Information System (GIS) is able to overlap several layers for the understanding of complex phenomena. In the energy sector, it is used to create Urban Building Energy Models. UBEM's main weakness is the use of archetypes, with bottom-up physics approach being too expensive due to the extensive data gathering needed. Aerial thermography is a non-destructive, non-invasive technique that have great potential to solve this problem by providing data on a wide portion of the building stock, including dense urban areas that are recognized as cultural heritage.

In the context of energy assessment and planning, architectural heritage is often seen as an obstacle due to the constraints imposed by preservation authorities, that may occur both for monitoring campaigns and retrofit intervention. In particular, the need to preserve the current aspect often results in the impossibility to meet the EU objective and reduce energy demand through external envelope insulation, thus requiring dedicated design of other plant-based energy strategies based on detailed energy assessment of each building.

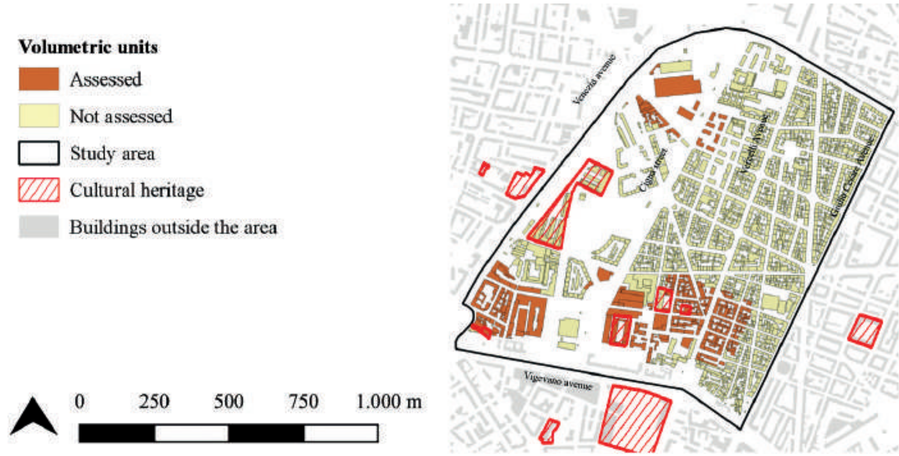

Fig. 1 Definition of the study area.

The study area

The analysed sample is located in the *Barriera di Milano* district, in Turin. This area has been one of the major expansion areas during the economic boom of the post-war period. In particular, multiple factories were located in the nearby, resulting in a pressing housing and services demand. Cheap housing was realised in the district, resulting in a building stock which nowadays proves to be crumbling or in the need for extensive renovations. Moreover, the dismission of historic factories – moved outside the cities or to other countries – in the Nineties left a considerable heritage in terms of volumes and value. The 1995 Turin masterplan fostered the regeneration of dismissed shopfloors and the area is now characterised also by malls and museums hosted in former production plants. The quality and results of such renovations, however, are still to be evaluated.

Nevertheless, minor heritage is still present and preserved by the Authority for Cultural Heritage, as shown in Fig. 1. It is the case of a wing of the former INCET factory – closed in 1968 – and of two schools realised between the end of XIX and the beginning of XX century.

Nevertheless, the historical urban structure has been kept, with a strong functional heterogeneity. The inner part is dense and designated to residences, while the main shopping areas and services are located on the boundaries of the study area. Such boundaries are now represented by the mobility infrastructures which used to serve the factories. In particular, it is the case of the former railway, a part of which is now the "backbone" of the interventions deriving from the 1995 plan.

Dataset acquisition

For this study, remotely sensed pictures were the key input. The evaluation of the thermal energy demand was carried out by observing values registered by a FLIR A8581 MWIR HD thermographic camera on 9/1/2022, which registers the bands with wavelength comprised between 3 and 5 μm and returns the surface temperature with a ±1°C accuracy. The pictures (example in Fig. 2) have a nadiral perspective and they were orthorectified, so the roofs only are visible. Moreover, the acquisition was performed during the day, with the results flawed by solar radiation and shading effect.

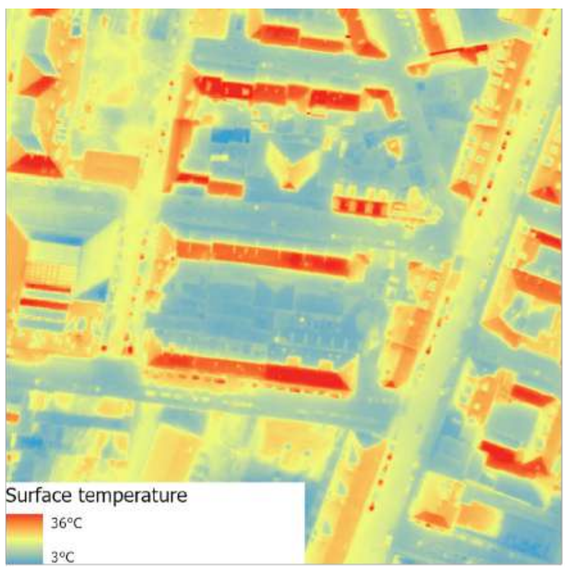

Fig. 2 Example of the acquired thermographic images.

To make them usable, thermographic pictures were georeferenced. The whole process was carried out in ArcGIS Pro by ESRI, in two phases: (i) scaling and rotating the picture for a first fit; (ii) definition of Ground Control Points for refining the georeferencing. The five images – covering approximately 0.35 km^2 – are located with a forward error equal to 0.941, equal to an inverse error of 1.412.

A LiDAR sensor was coupled to the camera during the survey for the TerraItaly™ Metro HD project, acquiring on average 8 points/m^2. Thanks to it, it was possible to realise a Digital Surface Model with a 0.5 m cell size, making it possible to compute geometries with a high accuracy. The DSM was one of the principal inputs for assessing the photovoltaic potential of the area.

The calculated data were referred to the volumetric units, assumed to be the minimum unit of analysis. The vector file containing the units is part of the technical map of the City of Turin, available on the Geoportal. The same source publishes the vector file of all protected buildings.

Determination of energy performance

Based the outer surface temperature obtained through thermography, it was possible to correlate the observed thermal dispersion to the actual energy performance of all buildings in the area. This was done by gathering the available Energy Performance Certificates, reporting calculated data on the energy consumption for space heating and cooling, and then extending the so-determined energy performance to buildings with similar thermal dispersion.

The most energy-intensive units are the biggest ones, especially former industrial buildings. On the other hand, reconverted buildings in the Western part of the study area are among the best performing. The historical buildings considered show low performing values, being classified in E or lower classes. In particular, two units pertaining to the primary school are classified in the worst class, G. As for the former industrial building, only one unit is falling in class G, but the huge footprint makes it the most consuming building among the three protected.

As for the total energy demand, electricity consumption are negligible due to the inclusion of residential needs only, equal to 9%. The average building can be classified as class E, based on a consumption of 155 kWh/m^2.

Determination of photovoltaic potential

Photovoltaic technologies are the most diffused in cities, thanks to the possibility to install modules integrated in roofs. Despite the mentioned problem of the potential impossibility to install photovoltaic panels on some roofs of architectural heritage, it is possible to identify available roofs and foresee collaboration forms, towards Renewable Energy Communities. Therefore, the photovoltaic potential of the available roofs in the studied area was calculated though the Suri equation (1):

$$PV_{potential} = PR * \eta * surface * Solar\ energy\ [kWh/year] \qquad (1)$$

where the Performance Ratio PR – assumed to be 75% – estimates the efficiency of the system, including potential leaks; the conversion efficiency η (set to 18.4% for polycrystalline cells, according to Green et al.) returns the share of solar energy converted into electricity by different technologies of photovoltaic modules; the surface is assumed to be 40% of the footprint of each unit, with this share correcting the inclination and presence of obstacles. Concerning the detailed calculation of solar energy, it was assessed through the "Area solar radiation" tool in ArcGIS Pro, whose inputs were set in order to reduce the elaboration time while keeping the accuracy.

Two crucial parameters are the two pertaining the radiation – diffuse ratio and transmissivity. The former is calculated through an online tool by the European Commission – PVGIS – while the latter requires further calculations on the data extracted from the same source.

With these parameters, the process takes approximately one hour for 0.7 km^2 (two hours to process the whole area). Each building was assigned a production value by converting the raster output of the "Area solar radiation" tool to points and spatially join them to the volumetric units dataset – using the values of the closest point to the centroid of the unit.

From this it derives a yearly producibility of 8.8 GWh, with differences deriving mainly from the dimensioning of the systems – and therefore from the roof areas – with all buildings producing more than 120 MWh/year having panels for at least 480 m^2.

Nearly half of the volumetric units can self-produce their electricity need, with 15% of the total potentially producing twice the demand. 83.2% of the demand can be produced in the district, with a resulting need to produce collaboration forms which maximise benefits for the community.

Renovation scenarios

To test the method described above, two alternative renovation scenarios were elaborated by changing some of the relevant input parameters, such as energy performance class and energy supply option.

First, savings were assessed in terms of primary energy. In Fig. 3 all the different configurations are compared. It emerges that natural gas boilers (G) – which are currently used – cause the highest consumptions, while

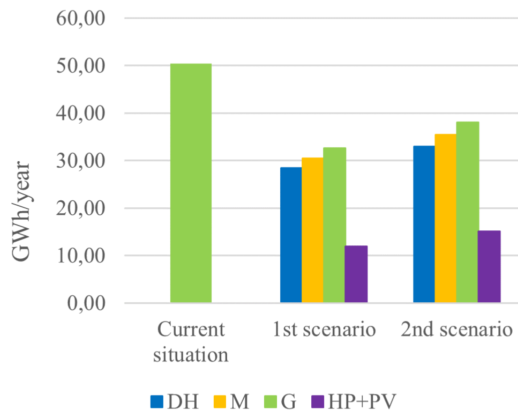

Fig. 3 Primary energy consumption.

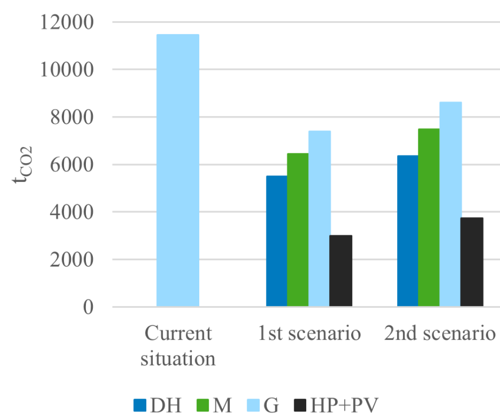

Fig. 4 CO_2 emissions.

the installation of heating pumps – with the demand partially covered by photovoltaic panels – (HP+PV) would half the energy need. Nevertheless, keeping this supply option it would be possible to cut the CO_2 emissions (Fig. 4) by 2829 tonnes in the second scenario. District heating (DH), whose implementation in the district is likely in the near future, reduces consumptions by a further 15% compared to natural gas boilers. The mixed scenario (M), with thermal consumptions provided by gas boilers and district heating for 50% each, is an average between the two.

The second scenario can be seen as a first step towards the implementation of the optimum one. The additional retrofit would result in energy savings comprised between 14% and 21% without the need to change the energy supply option, with additional benefits moving from natural gas boilers to district heating too – 25%. As for carbon emissions, savings are increased by 10% when transitioning to district heating from gas boilers, 6% in the case of stopping with a mixed scenario.

Conclusions

This research aims to create a simple but reliable method to assess energy consumption and production from RESs, with the possibility to use it to compare alternative renovation scenarios considering the boundaries of architectural heritage and their identified technical constraints. It emerged a need for extensive and reliable data as input, but also the possibility to quickly evaluate savings in terms of primary energy and prevented emissions.

The used dataset resulted in some limitations. In particular, the nadiral perspective of thermographic pictures caused the impossibility to assess the thermal dispersion of the facades, with roofs being also affected by incident solar radiation flawing the results. Moreover, the adopted temporal resolution for the two example retrofit scenarios – yearly – is suitable for a suitability analysis, while it requires additional calculations for defining precisely the potential benefits.

Still, the main aspect to be tackled, considering limitations emerging from the need to preserve the architectural heritage and the different characteristics of the urban structure – making some interventions more suitable than others in the medium term – is the realization of Energy Communities, which empower the community and enact a virtuous cycle of economic and environmental benefits. The two scenarios – properly deepened in terms of requirements – can be used for setting a roadmap towards the implementation of Energy Communities, with this tool being a support to respect the dimensioning requirements.

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