Data Article

Data on roof renovation and photovoltaic energy production including energy storage in existing residential buildings

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ABSTRACT

This data article refers to the paper "Optimizing photovoltaic electric generation and roof insulation in existing residential buildings" [1].

The reported data deal with roof retrofit in different types of existing residential buildings (single-family, multi-family and apartment complex) located in Milan (Northern Italy). The study focus on the optimization of envelope insulation and photovoltaic (PV) energy production associated with different building geometries, initial insulation level, roof constructions, and materials.

The data linked within this article relate to the modelled building energy consumption, renewable production, potential energy savings, and costs. Data refer to two main scenarios: refurbishment (roof in need of replacement and insulation) and re-roofing (energy intervention for roof improvement). Data allow to visualize energy consumption before and after the optimization, selected insulation level and material, costs and PV renewable production (with and without energy storage). The reduction of energy consumption can be visualized for each building type and scenario. Further data is available on CO₂ emissions, envelope, materials, and systems.
Specification Table

| Subject                  | Energy.                                      |
|--------------------------|----------------------------------------------|
| Specific subject area    | Energy retrofit of the roof.                 |
| Type of data             | Building simulation file.                    |
| How data were acquired   | Data were processed using the BEopt tool.    |
| Data format              | BEopt                                       |
| Parameters for data collection | Data of performance calculations and dynamic simulation modelling of existing residential buildings. |
| Description of the data collection | Data collected from different sources for the model set up (e.g. weather data files, Eurostat cost data, market surveys, literature, available information on technological measures, Standards), then processed by BEopt. |
| Data source location     | Table 1, Table 2, Table 3 of [1] summarize the primary data sources used. |
| Data accessibility       | Data are provided in supplementary materials directly with this article. |
| Related research article | Delia D’Agostino, Danny Parker, Paco Melià, Giovanni Dotelli, “Optimizing photovoltaic electric generation and roof insulation in existing residential buildings”, Energy and Buildings, 255 (2022) 111652, https://doi.org/10.1016/j.enbuild.2021.111652. |

Value of the Data

- The data provide quantitative information on roof retrofit in different existing building prototypes;
- The data show modelled energy consumption, optimal insulation level, renewable production, primary energy savings, and costs;
- Energy and economic data related to different retrofit options and PV production guide how to optimize roof retrofit;
- The data can be useful for the development of specific measures and incentives related to roof, comparison with other building types, other retrofit intervention, or further analysis.
- The data support the Green Deal and the Renovation Wave initiative to boost renovation at European level [2].

1. Data Description

The data provided in this paper are the developed file that documents the modeling process supporting the research. To optimize roof insulation and determining the cost-effectiveness of installing PV (with and without energy storage) in different building prototypes, a simulation-based optimization model has been developed. The methodology and the research assumptions are reported in Section 2 of [1]. A total of 120 simulations (40 per building type) were carried out for three baseline building prototypes (single-family, multi-family, apartment complex). Both pre- and post-intervention consumption is based on simulation. Pre-intervention consumption was compared to typical consumption as evaluated by the Danish Building Institute and Ecofys described in Section 4.1 of paper [1]. Once we had good agreement, we simulated buildings as if they were all electric as this will be the direction of the housing energy supply in the future. The modelled building prototypes and its main properties are detailed in Section 2.2 of [1], while roof characteristics are in Section 2.3 of [1]. The economic parameters and assumptions are in Section 2.4 of [1].
Table 1
Climate in Milan: monthly mean temperature, relative humidity, sunshine hours, precipitation.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Temperature (°C) | 5.9 | 9.0 | 14.3 | 17.4 | 22.3 | 26.2 | 29.2 | 28.5 | 24.4 | 17.8 | 10.7 | 6.4 |
| Relative humidity (%) | 86.0 | 78.0 | 71.0 | 75.0 | 72.0 | 71.0 | 71.0 | 72.0 | 74.0 | 81.0 | 85.0 | 86.0 |
| Sunshine (hours) | 58.9 | 96.1 | 151.9 | 177.0 | 210.8 | 243.0 | 285.2 | 251.1 | 186.0 | 130.2 | 66.0 | 58.9 |
| Precipitation (mm) | 58.7 | 49.2 | 65.0 | 75.5 | 95.5 | 66.7 | 66.8 | 88.8 | 93.1 | 122.4 | 76.7 | 61.7 |

Fig. 1. Data for the Milan case from BEopt/EnergyPlus simulation showing predicted energy use for each evaluated insulation increment in the multi-family building. Colors represent different energy end-uses. Heating (red), cooling (blue) and associated fans are the end uses that are strongly impacted. Point 1 is no insulation. Point 2 is a low insulation (0.80 W/m²K), Point 3 is a medium level (0.60 W/m²K) and 4, 5 and 6 are high (0.35 W/m²K), very high (0.20 W/m²K) and extra high levels (0.15 W/m²K). Raw data from this figure are attached to the paper.

The shared data are the building simulations files carried out using the software BEopt. These data detect the optimal building retrofit design considering different level of insulation, materials, costs, PV energy production, with and without energy storage. Data refer to existing residential buildings and include the main building characteristics (efficiency measures, envelope, systems, technologies, lighting, renewables).

As detailed in [3], BEopt is a widely-recognized optimization software that implements a sequential search technique to optimize the building design starting from a base configuration. It has the EnergyPlus and TRNSYS engines to perform the dynamic simulations of the building. In more details, EnergyPlus calculates hourly household needs (heating, cooling, water heating and appliance), while TRNSYS estimates the renewable energy production.

Hourly Typical Meteorological Year (TMY) data files has been included in the model for the city of Milan for the period 2004-2018. Table 1 shows average monthly mean temperature, relative humidity, and precipitation and sunshine hours along the year for Milan.

For the baseline building, provided data include selected energy efficient measures, related to envelope, appliances and systems. This comprises technical features as well as life expectancy, operation, maintenance, and replacement costs [4]. Incremental and cumulative costs can be visualized as well. The shared data include both the model input and output.

Provided data allow the identification of the cost-optimal insulation level within the cost-optimal curve that reports global costs (€/m²) and energy consumption (kWh/m²y).

Data outputs can be visualized from the provided material in different forms: energy consumption, savings, costs and renewable production. An example of energy data visualization across insulation levels is shown in Fig. 1. The data reported in the figure are made available as hourly data in the provided Excel spreadsheet where the following columns are reported: Base (kWh), Insulated (kWh) and PV (kWh). Data relate the final energy use in the building at each iteration for the different energy uses (e.g. heating, cooling, hot water). In the output section, all consumption are available from the starting building configuration.
Table 2
Optimized insulation levels and PV outputs by building type.

| Building prototype | Parameter                      | No Existing Insulation | Low Existing Insulation |
|--------------------|--------------------------------|------------------------|-------------------------|
|                    |                                | Refurbish | Re-roof | Refurbish | Re-roof |
| Single-family       | Optimal Insulation (W/m²K)     | 0.20       | 0.20    | 0.20      | 0.20    |
|                    | (Very high level)              |           |         |           |         |
|                    | Pre- intervention (kWh)        | 11867     | 11867   | 10589     | 10589   |
|                    | Post-intervention (kWh)        | 9853      | 9853    | 9853      | 9853    |
|                    | Rooftop PV (kWh)               | 7488      | 7488    | 7488      | 7488    |
| Multi-family        | Pre-intervention (kWh/m²)      | 98.9      | 98.9    | 88.2      | 88.2    |
|                    | Post-intervention (kWh/m²)     | 19.7      | 19.7    | 19.7      | 19.7    |
|                    | Primary Energy savings (%)     | 80.1      | 80.1    | 77.7      | 77.7    |
|                    | CO₂ Reduction (t/year)         | 4.6       | 4.0     | 4.0       | 4.0     |
|                    | Incremental cost (€)           | 13010     | 15908   | 12740     | 15638   |
|                    | Annual cost pre – intervention (€) | 3066   | 3066    | 2812      | 2812    |
|                    | Annual cost post-intervention (€) | 1516   | 1629    | 1527      | 1640    |
|                    | Optimal Insulation (W/m²K)     | 0.20      | 0.20    | 0.20      | 0.20    |
|                    | (Very high level)              |           |         |           |         |
|                    | Pre- intervention (kWh)        | 75451     | 75451   | 68441     | 68441   |
|                    | Post-intervention (kWh)        | 64379     | 64379   | 64377     | 64377   |
|                    | Rooftop PV (kWh)               | 37462     | 37462   | 37462     | 37462   |
|                    | Pre-intervention (kWh/m²)      | 78.9      | 78.9    | 71.6      | 71.6    |
|                    | Post-intervention (kWh/m²)     | 28.2      | 28.2    | 28.2      | 28.2    |
|                    | Primary Energy savings (%)     | 64.3      | 64.3    | 60.7      | 60.7    |
|                    | Incremental Cost (€)           | 59078     | 74780   | 57613     | 72955   |
|                    | CO₂ Reduction (t/year)         | 23.7      | 23.7    | 20.3      | 20.3    |
|                    | Annual Cost Pre – intervention (€) | 20330  | 20330   | 18962     | 18962   |
|                    | Annual Cost Post-intervention (€) | 11022  | 13328   | 11003     | 11742   |
|                    | Optimal Insulation (W/m²K)     | 0.35      | 0.35    | 0.35      | 0.35    |
|                    | (High level)                   |           |         |           |         |
| Apartment Complex  | Pre- intervention (kWh)        | 295991    | 295991  | 278936    | 278936  |
|                    | Post-intervention (kWh)        | 272817    | 272817  | 272817    | 272817  |
|                    | Rooftop PV (kWh)               | 146674    | 146674  | 146674    | 146674  |
|                    | Post-intervention (kWh/m²)     | 73.0      | 73.0    | 68.8      | 68.8    |
|                    | Post-intervention (kWh/m²)     | 31.1      | 31.1    | 31.1      | 31.1    |
|                    | Primary Energy savings (%)     | 57.4      | 57.4    | 54.8      | 54.8    |
|                    | CO₂ Reduction (t/year)         | 83.1      | 83.1    | 74.7      | 74.7    |
|                    | Incremental Cost (€)           | 268842    | 309214  | 257774    | 298146  |
|                    | Annual Cost Pre – intervention (€) | 76554  | 76554   | 72342     | 72342   |
|                    | Annual Cost Post-intervention (€) | 45376  | 46945   | 45018     | 46857   |

2. Experimental Design, Materials and Methods

Table 2 summarizes the data of the optimization modelling carried out for each building and roof type, and PV (with and without energy storage) (Table 1 – Table 4 of [1]). They are provided for each scenario (refurbishment and re-roofing), building type and initial insulation level (no or low insulation). For each building type, the table indicates the optimal insulation level identified by the algorithm, the amount of energy consumed pre- and post- intervention, the energy output of the PV system, the reduction in CO₂, the incremental costs, and the annual costs pre- and post- intervention. These values are normalized per building floor area and per occupant.

Table 3 reports the results of the building prototypes and scenarios that include PV systems with electrical storage. The Table indicates energy savings, costs and optimal insulation in the two scenarios, as in Table 1 but including the electrical storage. The installed electrical storage was 4 kWstorage/kW PV. This is detailed in Section 4.3 and Table 4 of paper [1]. Storage is 24 kWh for a 6 kW PV system on residential building and scales with the installed PV on the other
Table 3
Insulation optimization and PV with energy storage.

| Building prototype | Parameter                              | Refurbish (€) | Re-roof (€) | Refurbish (€) | Re-roof (€) |
|--------------------|----------------------------------------|---------------|------------|---------------|------------|
| **Single Family**  | Optimal Insulation (W/m²K)            | 0.15 (Extra high level) | 0.15 (Extra high level) | 0.15 (Extra high level) | 0.15 (Extra high level) |
|                    | Pre- intervention (kWh)                | 11867         | 11867      | 10589         | 10589      |
|                    | Post-intervention (kWh)                | 9780          | 9780       | 9780          | 9780       |
|                    | Rooftop PV (kWh)                       | 7222          | 7222       | 7222          | 7222       |
|                    | Pre-intervention (kWh/m²)              | 98.9          | 98.9       | 88.2          | 88.2       |
|                    | Post-intervention (kWh/m²)             | 21.3          | 21.3       | 21.3          | 21.3       |
|                    | Primary Energy savings (%)             | 78.4          | 78.4       | 75.8          | 75.8       |
|                    | CO₂ Reduction (t/year)                 | 4.6           | 4.6        | 3.9           | 3.9        |
|                    | Incremental Cost (€)                   | 33637         | 36536      | 33367         | 36265      |
|                    | Annual Cost Pre – intervention (€)     | 3066          | 3066       | 2812          | 2812       |
|                    | Annual Cost Post-intervention (€)      | 3629          | 3742       | 3640          | 3753       |
| **Multi-family**   | Optimal Insulation (W/m²K)            | 0.20 (Very high level) | 0.20 (Very high level) | 0.20 (Very high level) | 0.20 (Very high level) |
|                    | Pre- intervention (kWh)                | 75451         | 75451      | 68441         | 68441      |
|                    | Post-intervention (kWh)                | 64379         | 64379      | 64379         | 64379      |
|                    | Rooftop PV (kWh)                       | 36571         | 36571      | 36571         | 36571      |
|                    | Pre-intervention (kWh/m²)              | 78.9          | 78.9       | 71.6          | 71.6       |
|                    | Post-intervention (kWh/m²)             | 29.1          | 29.1       | 29.1          | 29.1       |
|                    | Primary Energy savings (%)             | 63.1%         | 63.1%      | 59.4%         | 59.4%      |
|                    | Incremental Cost (€)                   | 149110        | 165062     | 147645        | 163347     |
|                    | CO₂ Reduction (t/year)                 | 23.3          | 23.3       | 19.9          | 19.9       |
|                    | Annual Cost Pre – intervention (€)     | 20330         | 20330      | 18962         | 18962      |
|                    | Annual Cost Post-intervention (€)      | 18704         | 19315      | 18716         | 19326      |
| **Apartment Complex** | Optimal Insulation (W/m²K)            | 0.20 (Very high level) | 0.20 (Very high level) | 0.20 (Very high level) | 0.20 (Very high level) |
|                    | Pre- intervention (kWh)                | 295991        | 295991     | 278936        | 278936     |
|                    | Post-intervention (kWh)                | 270293        | 270293     | 270293        | 270293     |
|                    | Rooftop PV (kWh)                       | 143186        | 143186     | 143186        | 143186     |
|                    | Pre-intervention (kWh/m²)              | 73.0          | 73.0       | 68.8          | 68.8       |
|                    | Post-intervention (kWh/m²)             | 31.3          | 31.3       | 31.3          | 31.3       |
|                    | Primary Energy savings (%)             | 57.1          | 57.1       | 54.4          | 54.4       |
|                    | CO₂ Reduction (t/year)                 | 82.6          | 82.6       | 74.2          | 74.2       |
|                    | Incremental Cost (€)                   | 705225        | 745597     | 694156        | 734528     |
|                    | Annual Cost Pre – intervention (€)     | 76554         | 76554      | 72342         | 72342      |
|                    | Annual Cost Post-intervention (€)      | 80683         | 82252      | 80325         | 81893      |

systems [5–7]. This is larger than might be considered for non-electric buildings [8–10], but this level was deemed necessary for effective daily storage for the transformation of heating and water heating from natural gas to electric systems [5–13].

Fig. 2 shows an illustration of the data that can be visualized for the insulation optimization process related to the multi-family building. On the x-axis are the analyzed insulation levels from no insulation to extremely high insulation. The y-axis shows simulated kWh per year for heating (red) and cooling (blue) as well as the produced savings at each level (yellow). On the right axis are the total annual costs of the refurbishment investment and energy costs. The very high insulation level (0.20 W/m²K) is identified as the optimal least cost increment as detailed in [1].

**Ethics Statements**

No ethics fields involved.
Fig. 2. Illustration of insulation optimization for multi-family building in Milan (figure based on data in Table 1).

Credit Author Statement

Work plan: Delia D’Agostino: Simulations and result analysis, Writing, Revision; Danny Parker: Simulations and result analysis, Writing, Revision; Paco Melià: Revision, Giovanni Dotelli: Revision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2022.107874.

References

[1] Delia D’Agostino, Danny Parker, Paco Melià, Giovanni Dotelli, Optimizing photovoltaic electric generation and roof insulation in existing residential buildings, Energy Build. 255 (2022) 111652, doi:10.1016/j.enbuild.2021.111652.
[2] Regulation 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, L 328/1.
[3] D. D’Agostino, D. Parker, A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe, Energy 149 (2018) 814–829.
D’Agostino Delia, Cuniberti Barbara, Bertoldi Paolo, Energy consumption and efficiency technology measures in European non-residential buildings, Energy Build. 153 (2017) 72–86, doi:10.1016/j.enbuild.2017.07.062.

[5] Delia D’Agostino, Danny Parker, Ilenia Epifani, Dru Crawley, Linda Lawrie, How will future climate impact the design and performance of nearly zero energy buildings (NZEBs)? Energy 240 (2022) 122479, doi:10.1016/j.energy.2021.122479.

[6] Delia D’Agostino, Sofia Tzeiranaki, Paolo Zangheri, Paolo Bertoldi, Assessing Nearly Zero Energy Buildings (NZEBs) development in Europe, Energy Strategy Reviews 36 (2021) 100680, doi:10.1016/j.esr.2021.100680.

[7] Delia D’Agostino, Sofia Tzeiranaki, Paolo Zangheri, Paolo Bertoldi, Data on nearly energy buildings (NZEBs) projects and best practices in Europe, Data in Brief 39 (2021) 107641, doi: 10.1016/j.dib.2021.107641.

[8] Delia D’Agostino, Livio Mazzarella, Data on energy consumption and Nearly zero energy buildings (NZEBs) in Europe, Data in Brief 21 (2018) 2470–2474, doi:10.1016/j.dib.2018.11.094.

[9] Delia D’Agostino, Danny Parker, Data on cost-optimal Nearly Zero Energy Buildings (NZEBs) across Europe, Data in Brief 17 (2018) 1168–1174, doi:10.1016/j.dib.2018.02.038.

[10] Delia D’Agostino, Ilaria Zacà, Cristina Baglivo, Paolo Congedo, Economic and thermal evaluation of different uses of an existing structure in a warm climate, Energies (2017), doi:10.3390/en10050658.

[11] Delia D’Agostino, Barbara Cuniberti, Paolo Bertoldi, Data on European non-residential buildings, Data in Brief 14 (2017) 759–762, doi:10.1016/j.dib.2017.08.043.

[12] Marina Economidou, Valeria Todeschi, Paolo Bertoldi, Delia D’Agostino, Paolo Zangheri, Luca Castellazzi, Review of 50 years of EU energy efficiency policies for buildings, Energy and Buildings 225 (2020) 110322, doi:10.1016/j.enbuild.2020.110322.

[13] Paolo Congedo, Cristina Baglivo, Ilaria Zacà, Delta D’Agostino, High performance solutions and data for nZEBs offices located in warm climates, Data in Brief (2015) 502–505, doi:10.1016/j.dib.2015.09.041.