

A data-driven energy analysis framework to support energy efficiency of the Telecommunication sector

April 30, 2025

The energy efficiency for the building sector is an urgent topic to be addressed to meet the sustainability goals, reduce emissions and energy consumption, and improve companies' competitiveness by lowering operational costs. Considering the most important areas of potential improvement identified for existing buildings and building operations, the present work identifies 5 aims to support the energy transition for industrial buildings: *i)* **benchmarking** of buildings to enhance comparison and energy performance ranking, *ii)* the design of an easily-to-adopt tool for non-intrusive **energy audit**, *iii)* training robust and accurate short-term **forecasting** algorithms, *iv)* the design of **control charts** to support energy managers in the perspective of optimal operation of buildings, and *v)* the design of proper tools for energy savings or waste **accounting**. To achieve these goals, a pipeline is presented, where the outcomes from each one of the tasks are exploited and integrated into the others to finally create a coherent and complete framework for energy analysis. Considering the recent widespread use of data monitoring, the framework employs a data-driven approach. For computational purposes, the most recent developments regarding Machine Learning algorithms are a fundamental part of the present work. Many different algorithms are deployed for the different tasks of the present work, both pertaining to supervised and unsupervised learning. In many cases, additional contributions to the State of the Art are proposed to overcome the current limitations of the methods. In particular: the employment of clustering on representative periodical profiles is proposed to obtain reference buildings' groups for benchmarking; the adoption of neural networks is proposed to estimate Energy Signatures of buildings; and a semi-parametric ensemble model is proposed for forecasting and for later deployment in the CUSUM-based control charts. The methodology has been tested on a comprehensive set of data, which include both real-world data and simulated data. In particular, the data from around 2000 real buildings has been employed. Moreover, a simulator has been designed for synthetic data creation, allowing the simulation of several abnormal events. The results achieved in the different stages of the methodology include, among the others: the neural network-based Energy Signature model

was able to achieve R^2 of 0.849, accurately detecting the presence of multiple cooling regimes and allowing the extraction of some characteristic parameters of buildings; the semi-parametric forecasting model achieved a mean absolute percentage error of 3.10% and a determination coefficient of 0.905 for electrical load non-autoregressive prediction, while preserving the physics-grounding and thus the interpretability of the parametric model; the control charts allowed the detection of 95% of the abnormal events, whose early detection could reduce the associated energy wastes by up to 90%. For these reasons, the present work aspires to real-world deployment, to support energy managers for optimal building operation and in the decision-making process regarding energy-retrofit actions.