

# Summary

Urban energy consumption has been steadily increasing, driven by higher urbanization and living standards. Improved predictive tools must therefore be developed to forecast urban building energy consumption during both the design phase and for existing buildings, enabling effective management of energy demand and peak loads. However, buildings are not isolated units within cities, they exist as part of a complex urban context. Urban Building Energy Modeling (UBEM) addresses this issue by treating buildings as territorial units influenced by urban factors such as building density, urban canyon geometry, building orientation, and local climate conditions.

This thesis improves UBEM which is based on an hourly process-driven approach that models the three thermodynamic systems of a building: opaque envelope, transparent envelope, and the internal zone. To further improve this UBEM, infiltration rates due to natural ventilation have been implemented using building-specific, hourly air change rates (ACRs) rather than conventional fixed values. A three-zone lumped-parameter model (3ZLPM) was improved and solved with mathematical refinements completed during a collaboration with the Indoor Air Quality and Ventilation Group at the National Institute of Standards and Technology in Gaithersburg/USA. This computational efficiency enabled application at the urban scale. In this 3ZLPM, each building is represented by three interconnected zones: zone "a" (lower level of a building's apartments: lower half), zone "b" (upper level of a building's apartments: upper half), and zone "c" (vertical shaft connecting both zones). The leakage characteristics for airflow infiltration elements are obtained from standard building databases and literature based on building construction period and materials used.

Moreover, localized boundary conditions were developed to consider local climate conditions and morphology effects. The hourly outdoor air temperature was corrected using the Urban Weather Generator (UWG) tool for each analyzed

neighborhood. While the wind speed on building's façade was corrected using the Urban Multi-scale Environmental Predictor (UMEP) plugin within the Geographic Information System (QGIS) software, which provides aerodynamic and morphometric parameters that describe the surrounding roughness elements, and local wind dynamics at specified wind direction intervals, i.e., 30°. The obtained parameters were used in different canyon-scale wind speed correction algorithms. Rather than relying solely on weather station data, the methodology provides corrected wind speeds specific to each façade and leakage element at different heights, resulting in morphology-aware dynamic pressures that drive infiltration. The developed methodology for boundary condition identification was further evaluated in contrasting urban contexts, Turin (medium-high density) and New York City (high density), demonstrating its applicability across different climates and urban characteristics.

After the validation of the 3ZLPM with the defined boundary conditions, the resulting hourly varying building- and climate- specific ACR are used to enhance the UBEM by testing the model with both fixed ACR scenarios and hourly varying ones. The results showed considerable improvement compared to fixed ACR values. The application of this methodology to 27 residential buildings in Turin, having measured hourly energy consumption for space heating, showed that 67% of the analyzed buildings had improvements higher than 20% in daily prediction accuracy, with 10 buildings achieving improvements greater than 50% during the coldest months when utilizing building-specific ACR compared to fixed values.

The improved energy prediction allows an enhanced assessment of energy demand within dense urban environments to support the evaluation of various local climate conditions. This would directly contribute to achieve EU and national energy efficiency and decarbonization targets. This includes Italy's National Energy and Climate Plan objective for reducing primary and final energy consumption through improved energy performance and renovations.

The presented methodology in this thesis is currently being implemented as an experimental QGIS plugin with two main components that are integrated: a physics-based hourly UBEM module and an hourly varying building and climate specific infiltration module. This implementation, which will be open-source, provides urban planners, energy analysts, architects, and policymakers a robust and flexible tool for energy modeling in dense urban areas.