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EXTENDED ABSTRACTS

A Scalable Geospatial Simulation Framework for Assessing Thermal Energy Storage–Based Self-Sufficiency of the Swiss Residential Building Stock

Summary

This study develops and formalises a scalable geospatial simulation framework for assessing thermal energy storage–based self-sufficiency (TSS) of residential buildings. The framework integrates building-level geodata, roof-segment-based photovoltaic modelling, terrain-induced shading, site-specific meteorological inputs, and temperature-dependent load profiling into a consistent storage model. In contrast to profile-based approaches, all inputs are generated geospatially for each building. A controlled demonstration across six municipalities with identical total living space and fixed TES sizing (1.5 % of building volume) yields TSS values between 20 % and 93 %, illustrating the framework's ability to resolve structural and topographic heterogeneity. The approach enables spatially resolved building-stock assessment from individual buildings to national scale.

Keywords: Thermal self-sufficiency, thermal energy storage, photovoltaic, building stock modelling, GIS-based simulation

Field of application for the findings: Geospatial energy system modelling, building-stock assessment, solar-assisted heating systems, spatial energy planning, national decarbonisation analysis.

Addressed audience: Researchers in solar energy systems, building energy modelling and thermal energy storag; energy system modellers; professionals in spatial energy planning and policy assessment.

1. Introduction

Thermal energy storage (TES) plays a central role in the decarbonisation of heat supply in the building sector (Cabeza, 2021). In combination with PV systems and heat pumps, TES enables temporal shifting of locally generated renewable energy to meet space heating and domestic hot water demand. Thermal self-sufficiency (TSS) quantifies the share of heat demand covered by local generation and storage and serves as an evaluation metric for TES systems. Lüchinger et al., (2024) formalise TSS and propose a technology-agnostic estimation approach based on standardised hourly profiles, suggesting its application to larger building datasets. However, building-level modelling that incorporates real roof geometries, terrain-induced shading, and site-specific meteorological conditions remains unaddressed. In topographically heterogeneous regions such as Switzerland, these factors lead to substantial differences in PV generation and achievable TSS. A georeferenced and scalable methodology for building-level TSS assessment therefore remains lacking. This study develops and formalises a GIS-coupled simulation framework for spatially resolved TSS assessment. The contribution lies in the integration of geospatial building data, physically resolved PV modelling, terrain-aware shading, and hourly load profiling into a scalable storage-based TSS framework, enabling analysis from individual buildings to national scale.

2. Methodological Approach

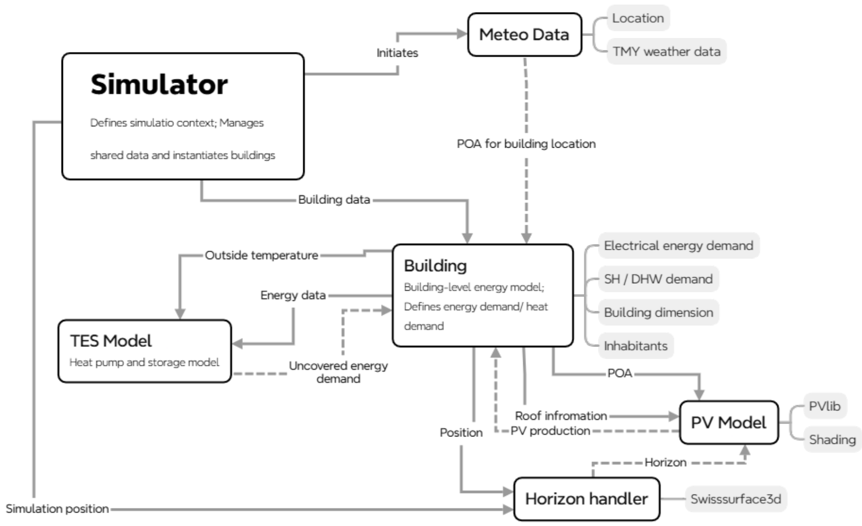

Figure 1: Overall architecture of the geospatially explicit TSS simulation framework. Building-specific data from the Swiss building register, roof-segment-based PV modelling, terrain-aware shading, and site-specific meteorological inputs are combined to generate hourly time series of electricity and heat demand as well as PV production. These inputs are provided to the TES model to compute storage operation and building-level TSS.

The presented framework builds directly on the TSS model by Lüchinger et al. (2024) and adopts its formulation for surplus heat calculation, storage operation, and TSS. The original model requires hourly time series of PV generation, space heating and domestic hot water demand (SH/DHW), household electricity demand, and ambient temperature. In contrast to the reference approach, the framework generates all required inputs geospatially for each residential building in Switzerland, replacing standardised profiles with physically resolved and spatially explicit data. The overall architecture is shown in Figure 1. Building data are obtained from the Swiss Register of Buildings and Dwellings, providing location and usage parameters. PV generation is simulated per roof segment based on real geometries. Hourly Typical Meteorological Years (TMY) provide climate data, and terrain-induced shading is derived from digital elevation models. Space heating profiles are derived temperature-dependently from public building data and weather information following Schneeberger et al., (2025), combining annual demand with hourly disaggregation via Heating Degree Hours. Electricity load and domestic hot water profiles are incorporated consistently with building attributes. The resulting hourly time series are integrated into the heat pump and storage model. TSS is computed per building based on uncovered heat demand. Multiple buildings are aggregated by summing time series and evaluated using the same modelling logic.

3. Preliminary Results

The developed framework enables, for the first time, building-level simulation of photovoltaic generation, heat pump operation, and thermal storage for all residential buildings in Switzerland. For each building, complete hourly time series are generated and integrated into the TSS model, allowing the potential thermal self-sufficiency to be determined under consistent system assumptions. To demonstrate the methodological functionality and spatial resolution capability, six reference municipalities are considered. These municipalities exhibit identical total residential floor areas and differ primarily in topographic location and terrain shading. The storage capacity is set to 1.5% of the respective building volume in all cases. The resulting average storage volumes range between 12.0 m³ and 18.1 m³ depending on the municipality. Figure 2 presents the building-level distribution of TSS across the six municipalities. The resulting TSS values range from 20% to 93%, illustrating the framework's ability to resolve spatial heterogeneity under identical system assumptions. The individual TSS values of all residential buildings in each municipality are shown.

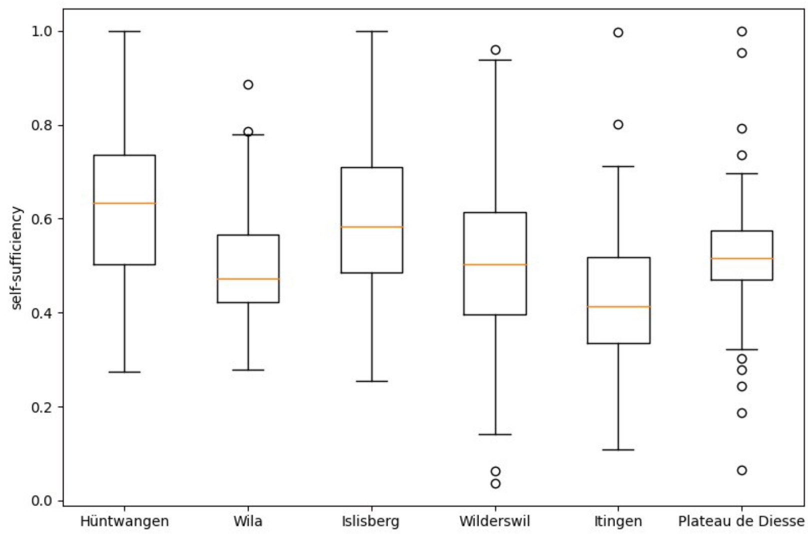

Figure 2: Building-specific distribution of TSS in six reference municipalities with identical total living space and storage capacity of 1.5% of the building volume. The differences in median values illustrate the influence of topography and terrain shading on the achievable TSS.

4. Outlook

The present study introduces the methodological framework and initial demonstration results and establishes the basis for a nationwide, building-level assessment of thermal energy storage using the TSS indicator. The developed approach provides a methodological basis for analysing structural influences such as topography, building typology, and storage size. The subsequent sections validate the framework comprehensively to assess the robustness and consistency of the building-level simulation. Future work applies the framework to the complete Swiss residential building stock and evaluates its robustness and scalability under different system configurations.

5. References

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6. Appendix

Table 1: List of Abbreviations

Definition	Abbreviation
Domestic hot water	DHW
Space heating	SH
Thermal energy storage	TES
Typical Meteorological Years	TMY
Thermal Self-Sufficiency	TSS