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Towards Optimal Building Retrofits: A Multi-Objective Optimisation Framework Using Genetic Algorithms and EnergyPlus

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Abstract The decarbonisation of the building sector requires the identification of optimal retrofit strategies that balance energy efficiency, cost, and indoor comfort. This paper presents the conceptual design of an integrated simulation pipeline that couples Genetic Algorithms (GAs) with dynamic building performance simulations. The tool will leverage EnergyPlus for energy and comfort simulations, while multi-objective optimisation will be conducted using NSGA-II and NSGA-III algorithms. Key inputs include the building model, a microclimate-adjusted weather file, user-defined objectives, and a set of possible retrofit measures. A novel feature of the pipeline is the dynamic adjustment of objective functions based on stakeholder preferences, ensuring that outputs are aligned with user priorities. Following simulation and optimisation, the Pareto-optimal retrofit scenarios will be ranked through a Multi-Criteria Decision Support System (MDSS), providing tailored recommendations. The proposed pipeline aims to deliver an effective, user-centric decision-making framework to support engineers, consultants, advanced homeowners, and policymakers in achieving sustainable building upgrades.

Keywords: *Multi-objective optimization, Building retrofit, EnergyPlus, Microclimate weather data*

1. Introduction

Improving the energy performance of existing buildings is a critical priority for achieving climate goals and enhancing occupant well-being (*Energy Performance of Buildings Directive*, n.d.; *Revised Energy Performance of Buildings Directive (EPBD)*, n.d.). Retrofit interventions often involve multiple, conflicting objectives, including minimising energy consumption, reducing retrofit costs, improving indoor comfort, and enhancing economic returns (Alexakis et al., 2025). To address these challenges, the application of multi-objective optimisation algorithms combined with detailed building performance simulations has gained increasing attention(Kamel & Memari, 2022).

This paper introduces a simulation pipeline under development as part of a doctoral research project, designed to identify optimal retrofit strategies for individual buildings. The pipeline integrates multi-objective Genetic Algorithms (specifically NSGA-II and NSGA-III) with EnergyPlus simulation models, enabling the exploration of trade-offs among competing retrofit objectives.

The novelty of the proposed pipeline lies in two main features. Firstly, objective functions are dynamically defined based on stakeholder inputs, allowing the tool to reflect diverse priorities, such as energy savings, economic feasibility, or comfort improvements. Secondly, the pipeline utilises microclimate-specific weather data rather than standardised datasets, providing more accurate representations of local environmental conditions.

Users, including engineers, retrofit consultants, informed building owners, and policymakers, will provide the building model (in IDF format), select relevant retrofit actions, and prioritise objectives through an intuitive User Interface (UI). The optimisation process will generate a Pareto front of solutions, which will subsequently be ranked by a Multi-Criteria Decision Support System (MDSS) adjusted according to user-defined criteria. This approach aims to offer a flexible, effective decision-support tool to accelerate high-quality, stakeholder-centred building retrofits.

2. Methodology

The proposed pipeline is structured around four core components: data input and pre-processing, simulation and optimisation, post-processing, and decision support.

2.1 Input Data and User Configuration

Users provide the building geometry and systems model in IDF format, alongside a microclimate-specific weather file reflecting local climatic conditions. Retrofit measures are

selected from a predefined catalogue, encompassing options such as insulation upgrades, window replacements, and system efficiencies. Furthermore, users define their optimisation objectives, choosing among minimising energy consumption, minimising retrofit cost, maximising indoor comfort, and maximising return on investment. Objective priorities are dynamically configured, enabling the pipeline to adapt to stakeholder-specific requirements.

2.2 Simulation and Optimisation

The pipeline integrates EnergyPlus to perform dynamic thermal simulations of candidate retrofit configurations. Optimisation is achieved using multi-objective Genetic Algorithms, specifically NSGA-II and NSGA-III. NSGA-II is employed for problems involving two or three objectives, while NSGA-III is applied to cases with four or more objectives. Each individual solution within the population represents a unique combination of retrofit actions. Performance indicators, corresponding to the defined objectives, are calculated for each candidate through EnergyPlus simulation outputs.

2.3 Post-Processing and Multi-Criteria Decision Support

Following the optimisation process, a Pareto front of non-dominated retrofit scenarios is generated. To assist users in selecting a preferred solution, the pipeline includes a Multi-Criteria Decision Support System (MDSS). Prior to the simulations, users configure the MDSS to assign weights or preferences to the various objectives. Post-optimisation, the MDSS ranks the Pareto-optimal solutions accordingly, presenting the five highest-ranked scenarios with their associated performance indicators.

2.4 Automation and Flexibility

The entire process, from input configuration through simulation, optimisation, and decision support, is automated within the pipeline. However, flexibility is maintained through user interactions at the initial setup phase and during the MDSS configuration. This design ensures a balance between computational efficiency and stakeholder customisation.

3. Expected Impact and Novelty

The proposed simulation pipeline offers a significant advancement over conventional retrofit optimisation approaches. Traditional methods often rely on fixed objective functions and standardised weather data, limiting the adaptability and realism of the results. In contrast, this pipeline dynamically configures objectives based on stakeholder input and utilises microclimate-adjusted weather files, ensuring that retrofit strategies are both user-centred and context-specific.

By integrating NSGA-II and NSGA-III algorithms with EnergyPlus simulations, the pipeline enables a thorough exploration of the trade-offs between energy, cost, comfort, and environmental impact. The inclusion of a Multi-Criteria Decision Support System further enhances decision-making by translating complex optimisation outputs into a manageable and prioritised set of retrofit options.

Ultimately, the tool is expected to support engineers, retrofit consultants, advanced homeowners, and policymakers in achieving more effective, tailored, and sustainable building upgrades. In addition, the modular and flexible design of the pipeline allows for future expansions, including the integration of additional objectives, renewable energy systems, or resilience metrics.

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References

Alexakis, K., Benekis, V., Kokkinakos, P., & Askounis, D. (2025). Genetic algorithm-based multi-objective optimisation for energy-efficient building retrofitting: A systematic review. *Energy and Buildings*, *328*, 115216. https://doi.org/10.1016/J.ENBUILD.2024.115216

Energy Performance of Buildings Directive. (n.d.). Retrieved October 8, 2024, from https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

Kamel, E., & Memari, A. M. (2022). Residential Building Envelope Energy Retrofit Methods, Simulation Tools, and Example Projects: A Review of the Literature. *Buildings 2022, Vol. 12, Page 954*, *12*(7), 954. https://doi.org/10.3390/BUILDINGS12070954

Revised Energy Performance of Buildings Directive (EPBD). (n.d.). Retrieved October 8, 2024, from https://ec.europa.eu/commission/presscorner/detail/en/qanda_24_1966