SHERLOCK CASE STUDY #3

COUNTY WESTMEATH CASE STUDY RETROFITTING MULLINGAR WITH MACHINE LEARNING INSIGHTS

Prepared by :

BEHNAM MOHSENI-GHARYEHSAFAA, PIETRO LUIGI DESOLEA, FABIANO PALLONETTO

Maynooth University National University of Ireland Maynooth

SHERLOCK

Co-funded by the European Union

Table of Content

Introduction

Cities across Europe are working to reduce energy use, cut emissions, and modernise buildings as part of the shift toward smarter and more sustainable urban environments. One of the biggest challenges is deciding how to retrofit large numbers of buildings efficiently. Conventional engineering simulations can take many hours for even a single building — making city-wide planning slow and expensive.

This case study focuses on Mullingar, **a town in County Westmeath, Ireland,** where more than 6,000 buildings of different types (homes, shops, public services, cultural facilities, etc.) were analysed. The aim was to understand how different retrofitting measures — such as upgrading heating systems or improving insulation — could reduce the town's overall energy use.

To speed up decision-making, researchers at Maynooth University developed a Machine Learning (ML) model using a method called Gaussian Process (GP).

This approach can estimate how much energy the entire city will use under different retrofit scenarios in seconds, instead of the many hours required by traditional physical simulations.

Why Mullingar?

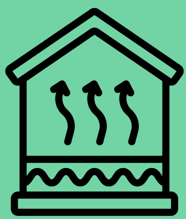
Mullingar represents a typical mid-sized European town with:

- 6076 buildings, including residential, commercial, cultural, health, retail, and administrative facilities.
- A mix of older building stock, much of which predates modern insulation standards.
- Heavy reliance on fossil-fuel heating systems such as gas boilers.

This makes it an ideal testbed for understanding urban-scale retrofitting challenges.

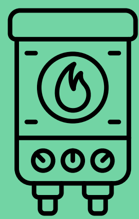
What Was Analysed?

The study examined how three major factors influence energy use in Mullingar:



Heating and Hot Water Systems (HVAC)

Building Envelope



Domestic Hot Water (DHW) Efficiency

Heating and Hot Water Systems (HVAC)
The team compared:
- Traditional gas boilers
- Electric heaters
- Air-source heat pumps

Building Envelope
Including:
- Type and thickness of wall insulation
- Window-to-wall ratios
- Construction materials typical in Ireland

Domestic Hot Water (DHW) Efficiency
Assessing efficiency levels from 70% to 95%.

Methodology in Simple Terms

1. Researchers first created 3D models of every building in Mullingar (over 6,000).

2. They ran detailed simulations to see how much energy the town uses today and how this changes under different retrofitting options.

3. These simulations, however, took 15–30 hours each on a high-performance computer

4. To accelerate future planning, they trained a Gaussian Process ML model using this simulation data.

5. The ML tool can now provide instant predictions of city-wide energy use under multiple retrofit scenarios.

Key Findings

Heat Pumps Deliver the Largest Energy Savings

Insulation Helps, But Less Than HVAC Transformation

Machine Learning Significantly Speeds Up Urban Planning

1 Heat Pumps Deliver the Largest Energy Savings

Switching from gas boilers to heat pumps resulted in a dramatic reduction of energy use:

- 52.4% less energy consumption across the entire city.
- Switching from electric heaters to heat pumps saved 39.2% per square meter.

This makes heating system upgrades the most impactful retrofit measure, far more significant than envelope improvements alone.

2 Insulation Helps, But Less Than HVAC Transformation

Adding more insulation layers does reduce energy use — but the effect is modest:

- Upgrading from 1 to 3 insulation layers saved about 2.2%.
- Adding up to 5 layers saved up to 6.2% per square meter.

Insulation remains important for comfort and long-term efficiency, but its impact is minor compared to the shift to heat pumps.

3 Machine Learning Significantly Speeds Up Urban Planning

The ML model achieved:

- High accuracy (RMSE: 3.24)
- Instant predictions compared to 15–30+ hour simulation times
- Capacity to analyse complex variables at city scale:
- 30%–50% window ratios
- 1–5 insulation layers
- 70%–95% DHW efficiency

This makes rapid, evidence-based planning possible — essential for smart city transitions.

Implications for Urban Planners & Policy Makers

The case study shows:

- Heating system upgrades should be first priority — they deliver the biggest energy reductions quickly and at scale.
- Heat pumps can substantially cut reliance on fossil fuels, improving energy security and lowering emissions.
- Heat pumps can substantially cut reliance on fossil fuels, improving energy security and lowering emissions.
- AI-powered tools can replace months of simulation work, helping cities plan retrofits more efficiently.
- Digital twins powered by ML can model future scenarios, assess policy impacts, and support investment decisions.
- Retrofitting strategies that combine HVAC upgrades + moderate insulation improvements offer a balanced, impactful approach.

Conclusion

The Mullingar case study demonstrates how combining engineering knowledge with Machine Learning can transform the way cities plan their sustainability transitions. By reducing simulation times from hundreds of hours to seconds, the GP model enables fast, reliable decision-making about retrofitting entire cities.

Most importantly, the results show that **heat pumps are the single most effective intervention** for drastically reducing urban energy consumption — an insight that can guide national and local retrofitting strategies.

This approach can be applied to other European towns and cities, supporting the EU's goals for digitalisation, decarbonisation, and smart city development.

References

. H. Fakhimi, A. H. Khani, and J. M. Sardroud, “Smart-city infrastructure components,” in Solving urban infrastructure problems using smart city technologies, Elsevier, 2021, pp. 17–54.

A. Januszewski and D. Żółtowski, “The State of Research on Emerging Information and Communication Technologies for Sustainable Development,” in Adoption of Emerging Information and Communication Technology for Sustainability, CRC Press, 2024, pp. 27–49.

A. Shankar and C. Maple, “Securing the Internet of Things-enabled smart city infrastructure using a hybrid framework,” Comput Commun, vol. 205, pp. 127–135, 2023.

Y. Liu, T. Ji, H. C. Ho, C. Guo, and H.-H. Wei, “A decision-making approach for determining strategic priority of sustainable smart city services from citizens’ perspective: A case study of Hong Kong,” Sustain Cities Soc, vol. 101, p. 105147, 2024.

J. S. Kim and Y. Feng, “Understanding complex viewpoints in smart sustainable cities: The experience of Suzhou, China,” Cities, vol. 147, p. 104832, 2024.

S. Blasi, E. Gobbo, and S. R. Sedita, “Smart cities and citizen engagement: Evidence from Twitter data analysis on Italian municipalities,” Journal of Urban Management, vol. 11, no. 2, pp. 153–165, 2022.

CH. Zhang, H. Feng, K. Hewage, and M. Arashpour, “Artificial neural network for predicting building energy performance: a surrogate energy retrofits decision support framework,” Buildings, vol. 12, no. 6, p. 829, 2022.

S. Wenninger, P. Karnebogen, S. Lehmann, T. Menzinger, and M. Reckstadt, “Evidence for residential building retrofitting practices using explainable AI and socio-demographic data,” Energy reports, vol. 8, pp. 13514–13528, 2022.

S. K. Sharma et al., “Retrofitting existing buildings to improve energy performance,” Sustainability, vol. 14, no. 2, p. 666, 2022.

“Mullingar’s population growing faster than Athlone’s,” Westmeath Examiner, Blackhall Place, Mullingar, Co. Westmeath, Ireland.

E. Ó. Broin et al., “Hitting the hotspots–Targeted deployment of air source heat pump technology to deliver clean air communities and climate progress: A case study of Ireland,” Atmos Environ X, vol. 13, p. 100155, 2022.

BR. D. Muddu, D. M. Gowda, A. J. Robinson, and A. Byrne, “Optimisation of retrofit wall insulation: An Irish case study,” Energy Build, vol. 235, p. 110720, 2021.

M. S. Roudsari and M. Pak, “Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design,” 2013.

Joelle Michaels U.S. Energy Information Adminstration, “Commercial buildings energy consumption survey (CBECS).

A. Marrel and B. Iooss, “Probabilistic surrogate modeling by Gaussian process: A review on recent insights in estimation and validation,” Reliab Eng Syst Saf, p. 110094, 2024.

Case study contact: Behnam Mohseni-Gharyehsafa -
behnam.mohsenigharyehsafa.2023@mumail.ie

Website: www.sherlockproject.eu