Geospatial analysis as a tool for effective energy planning

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ABSTRACT

Reducing carbon emissions in the built environment is crucial to achieving the United Kingdom's target to become Net Zero by 2050. Local Area Energy Planning (LAEP) is a data-driven methodology that helps local authorities and distribution network operators create effective plans to support regional and national decarbonisation goals, towards the deployment of local infrastructure and low-carbon technologies like heat pumps, EV chargers, and photovoltaic systems. Unfortunately, such data sets are not readily available and present an important knowledge gap. To resolve this, the use of geospatial analysis techniques becomes crucial, as multiple factors, including heat demand, come into play to elaborate an effective energy plan.

In this article, an engineering-based approach is applied at the urban scale on property data and building stock data from Energy Performance Certificates to develop a domestic heat demand model for the city of Dundee. The model was used to estimate annual heat demand, peak heating load, and heat intensity of 69,349 domestic properties in Dundee. Then, geospatial analysis was used to develop a heat pump suitability model for air and ground source heat pump units. 43% of the analysed residential properties are suitable for installing ASHP units, while only 12% of them are suitable for GSHP units due to their dependence on extensive back garden areas, suggesting that ASHP is a more feasible technology to install in domestic properties in Dundee than GSHP. These results were ingested into a visualisation platform which was used by Dundee City Council to inform a long-term low carbon heating strategy as part of Project RESOP (Regional Energy Systems Optimisation Planning), which is presented as a use case of such data sets in a single energy planning tool.

Keywords: Local Area Energy Planning (LAEP); Energy Performance Certificates (EPC); Geographic Information Systems (GIS); low-carbon infrastructure; heat pump suitability.

INTRODUCTION

The United Kingdom's built environment accounts for around 40% of its greenhouse gas emissions (Cabinet Office Markets, 2022). In order to reach its objective to become Net Zero by 2050, significant effort must be put into decreasing emissions in buildings by improving their energy efficiency.

While decarbonisation goals have been clearly set at the national level, policies and measures that have to be adopted in order to meet them locally are not obvious. Local Area Energy Planning (LAEP) has been devised as a tool to guide local authorities and distribution network operators (DNOs) towards generating effective plans that can serve regional decarbonisation goals. This methodology, which involves stakeholder engagement at various stages, is directly dependent on the availability of data sources to inform the deployment of infrastructure and low carbon technologies such as heat

pumps, electric vehicle chargers, and photovoltaic systems locally.

Results from urban building energy modelling (UBEM) have been used in the past during the energy planning process for visualisation and optimisation purposes. However, work is yet to be done to integrate a comprehensive solution that addresses individual issues encountered in this process, ranging from data generation and acquisition to visualisation and optimisation. Some of these issues are outlined below.

Outdated data

Successfully undertaking LAEP efforts requires updated data inputs that can reflect the reality of the modelled energy systems at any given time. Unfortunately, access to up-to-date data is not always possible. For instance, a workflow to support the decision making for building retrofit and building systems update at urban scale in Zurich had to use census data from five years earlier as one of its inputs (Orehounig et al., 2018). Up-to-date data are regularly preferred in energy planning, and one priority in building simulation should thus be to establish automated workflows and data pipelines that are capable of handling updates with varying frequencies, from real-time readings in smart meters to periodic updates in Energy Performance Certificate (EPC) registries.

Difficulty to acquire data

One major challenge in UBEM is acquiring input data. To overcome this, the potential of remote sensing and geographic information systems (GIS) for UBEM has been studied. Overall, key input components of UBEM can benefit from these techniques and while the applicability of technologies such as satellite remote sensing and Unmanned Aerial Vehicles (UAVs) remains limited, this is a promising approach to improving data acquisition at a large scale (Anand & Deb, 2023). Moreover, the potential of these methods can be further enhanced by incorporating newer techniques such as machine learning and artificial intelligence (Anand & Deb, 2023).

Other sources refer to the use of GIS tools to plan rural or urban grid infrastructure and to build simulation instances where geometry and orientation are considered (Verwiebe et al., 2021). While this approach raises some issues like data integration, geocoding, and data privacy, there have been attempts to address some of them, including a generalised integrated methodology used to predict energy performance of more than two million buildings in Ireland (Ali et al., 2020).

Lack of visualisation tools in optimisation models

One distinctive feature of GIS is their capacity to reference data to geographic shapes with a distinctive location and orientation relative to a reference coordinate system, which makes them ideal to visualise and map energy consumption (Verwiebe et al., 2021). While it is possible to model urban energy demand and come up with optimisation methods for energy planning without relying on an interactive visualisation tool, such models could benefit from allowing energy planning professionals to interact with their data and understand them visually. Previous models generated for energy planning are intended to be delivered to different stakeholders, and therefore have the potential to be further developed into interactive optimisation tools (Orehounig et al., 2018; Ali et al., 2020).

Lack of discoverability

Much of the GIS data available for energy planning in Great Britain lacks discoverability, owing to the massive amount of it that is available (Roberts, 2022). As a result, one can spend significant time searching through multiple portals and resources to find useful locational and property data (Roberts, 2022). In addition, complementary data, such as governmental data sets and census results, also have to be collected and related to the pure locational data, which represents additional processing time. Energy planning professionals could thus benefit from having integrated tools that allow them to focus on more relevant tasks.

High external and internal data requirements

Engineering-based techniques provide a more detailed representation of the physical properties of energy-consuming systems, compared to machine learning approaches or statistical models such as regression and time series analysis. However, this results in higher external and internal data requirements (Verwiebe et

al., 2021). EPC databases contain detailed building stock data that can be used in such models. For example, previous work has been done to improve the results of a building energy model at urban scale taking into account the real characteristics of the built environment in Turin, Italy using EPC data coupled with a GIS-based approach (Mutani & Todeschi, 2021). Such model allowed to design an urban energy atlas as a decision-making platform for policy makers and citizens, allowing to calculate an energy saving potential of 79,064 MWh per year in residential buildings connected to the district heating network in Turin, corresponding to a reduction in greenhouse gas emissions of 12,097 tonCO_{2eq} per year (Mutani & Todeschi, 2021). The use of EPC as an input for energy models has also been documented in other countries, such as Ireland (Ali et al., 2020), which highlights the relevance of this data source due to its ubiquity and wide-spread availability across countries in Europe. Moreover, the prevalence of stock data contained in such databases makes them ideal to use in engineering-based situations.

Knowledge contribution

In this article, engineering-based techniques and GIS analysis are used in a hybrid modelling approach at the urban scale which uses property data from Ordnance Survey (OS), Energy Performance Certificates (EPC), and other sources to generate domestic heat demand and heat pump potential data sets for the city of Dundee, Scotland. These data sets, intended to be used by local authorities and DNOs in LAEP, were later set up into an online visualisation platform as part of the Regional Energy System Optimisation Planning (RESOP) project, an effort involving a range of stakeholders including local authorities and the private sector alike, one of which objectives was informing the retrofit and rollout of air and ground source heat pumps.

The contribution of this article can be observed in three levels: *i)* the use of a bottom-up, hybrid approach that uses both EPC and GIS data as inputs to model heat demand in domestic properties in the city of Dundee at the urban scale, *ii)* the application of GIS techniques to create a heat pump potential data set that can guide the installation of heat pumps, and *iii)* a case study featuring the use of the data sets in an interactive visualisation platform as part of Project RESOP.

METHODS

Property data were obtained from Ordnance Survey Data Hub and collated into a single buildings database including property area, building geometry, and building height. The data sets used were AddressBase Core – 5km, OS AddressBase Premium – 5km, OS MasterMap Building Heights – 5km, and OS MasterMap Topography – 5km. The data downloads were customised to include only the properties within the Dundee City Council territory. The database was then filtered to include only residential properties and exclude height and property area outliers.

EPC data were retrieved from the Scottish EPC Register (scottishepcregister.org.uk) and cleaned up into a building stock database including construction and insulation type for walls, floor, and roof, as well as glazing type.

Both databases were then used as inputs for the domestic heat demand model. The model estimates annual heat demand (kWh), annual heat intensity (kWh.m^{-2}), and peak heating load (kWp), following a building physics approach which calculates the overall heat loss coefficient at an address level. This methodology is documented in the CIBSE Domestic Heating Design Guide – Version 2020-10 (Domestic Building Services Panel, 2021). For this purpose, heating degree days and outdoor design temperature were retrieved from the BizEE Degree Days database (degreedays.net) and used as a complementary data set.

In addition, domestic housing archetypes are built to fill in missing building stock data, following the methodology described by the Building Supply Chain for Mass Refurbishment of Houses project (BRE Group, 2013; The Energy Zone Consortium, 2013). In total, 25 archetypes were created, broken up into property type (Detached, Semi-detached, Mid-terrace, and Purpose-built flat) and property age (Pre-1919, 1919-1944, 1945-1964, 1965-1980, post-1980). For this, property age data from a commercial building stock data provider were used.

The domestic heat demand data set was then passed as an input, along with roads data from the OS MasterMap Highways Network, to a heat pump potential estimation model, which uses geospatial analysis to assess the suitability of properties for Air Source Heat Pump (ASHP) and Ground Source Heat Pump (GSHP) installation, under the following considerations:

1. Air Source Heat Pump
   a. The ASHP unit has to be attached to the buildings on the garden area, and requires at least a square area of 1 by 1 metre.
   b. The distance from the unit to any neighbouring building has to be at least 5.9 metres (due to noise considerations).
   c. The garden area of the buildings has to be at least 25 square metres to support the installation of the unit.

2. Ground Source Heat Pump
   a. 50 square metres of back garden area should be available per suggested kW of peak heating load.
   b. The back garden area is obtained by subtracting the front garden area of a building from its total garden area. The front garden itself is detected via a line which connects the front part of the building to the nearest road.

Since the domestic heat demand is treated as an input to this model, the outliers of the heat demand columns are also filtered before running the heat pump potential model.

Finally, the resulting domestic heat demand and domestic heat pump potential data sets were uploaded to a data visualisation platform which was then presented to local authorities from Dundee City Council as part of Project RESOP, which will be further described in the upcoming sections.

RESULTS AND DISCUSSION

Heat demand and heat pump potential data were obtained for 69,349 domestic properties in Dundee. In Table 1, a summary of the distribution of the three calculated heat variables – annual heat demand (kWh), annual heat intensity (kWh.m^{-2}), and peak heating load (kWp) – can be found.

Table 1: Summary of calculated heat demand variables

Statistic	Peak Heating Load (kWp)	Annual Heat Demand (kWh)	Annual Heat Intensity (kWh.m^{-2})
Count	69349	69349	69349
Mean	5.20995	11489.6	177.211
Median	4.66	10266.5	152.68
St. dev (pop)	2.72105	6000.82	97.9467
Minimum	0.34	759.54	48.38
Maximum	13.35	29430.9	534

A clear distribution is observed in peak heating load values, with the majority of buildings having between 3 and 4 kWp. It is important to highlight that due to the nature of the models used, this value corresponds to the peak heating load of a given year, rather than an hourly distribution. This parameter is also used in the Heat Pump potential data set to provide an estimate of the heat pump capacity that should be installed. The maximum values are between 12.5 and 13.4 kWp, and correspond to those properties with larger premise areas and building heights.

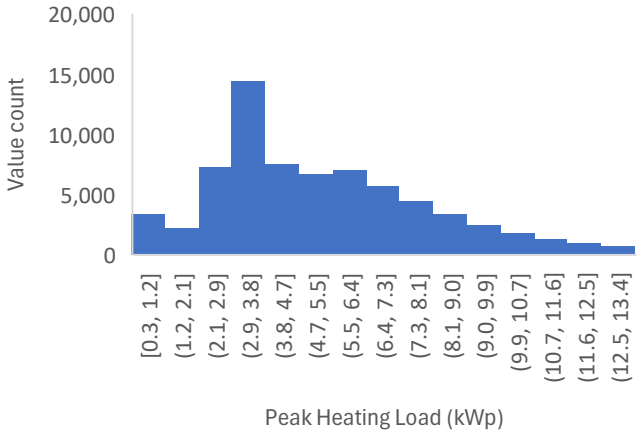


Figure 1: Peak Heating Load (kWp) distribution

The annual heat demand, which is also calculated on a yearly basis, also shows a clear trend with a peak between 6,000 and 8,000 kWh. This represents a monthly average between 500 and 667 kWh. The maximum values, between 27,000 and 30,000 kWh per year, also correspond to the properties with largest height and premise area.

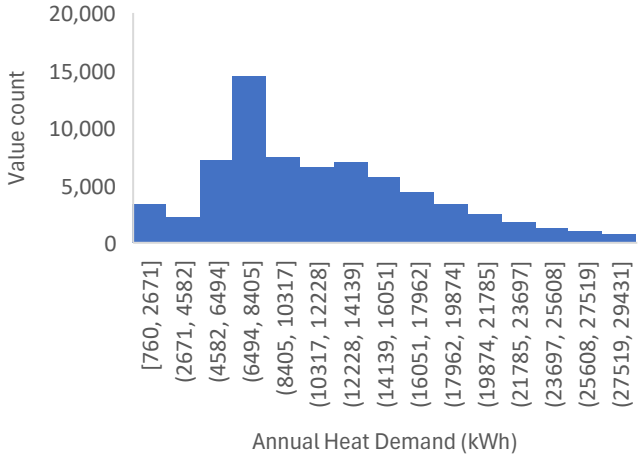


Figure 2: Annual Heat Demand (kWh) distribution

Finally, a skewed distribution can be seen in the annual heat intensity. Using these methods, over 40% of properties have an annual heat intensity between 50 and 100 kWh.m^{-2} per year. Properties below that range are very rare, and the second most common range is between 250 and 300 kWh.m^{-2} per year.

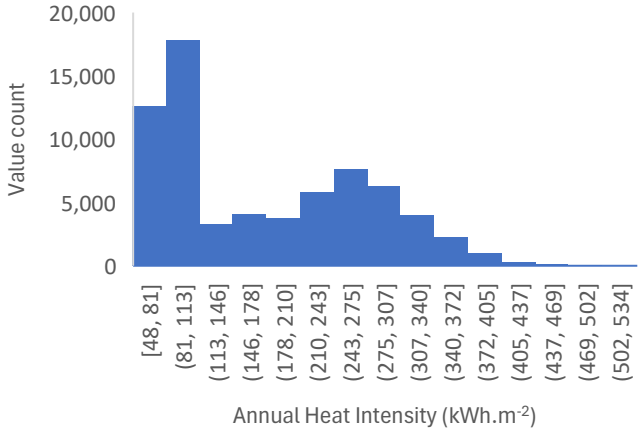


Figure 3: Annual Heat Demand per m^2 (kWh.m^{-2}) distribution

Of the modelled properties, 29,567 (43% of the total) were found suitable for ASHP installation and 8,877 (12% of the total) were found suitable for GSHP installation. The discrepancy between both figures is explained by the dependency of GSHP units on extensive back garden areas, which not all domestic properties have. The results therefore suggest that overall, ASHP is a more feasible technology to install in domestic properties in Dundee than GSHP.

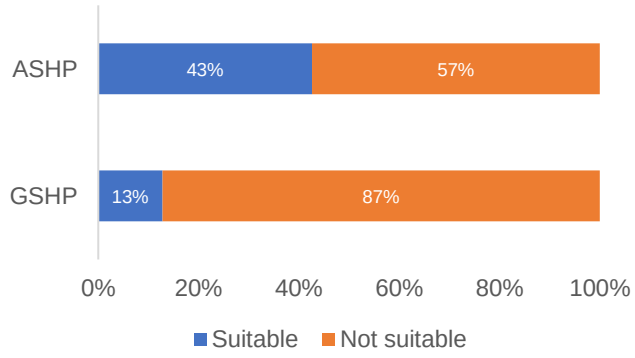
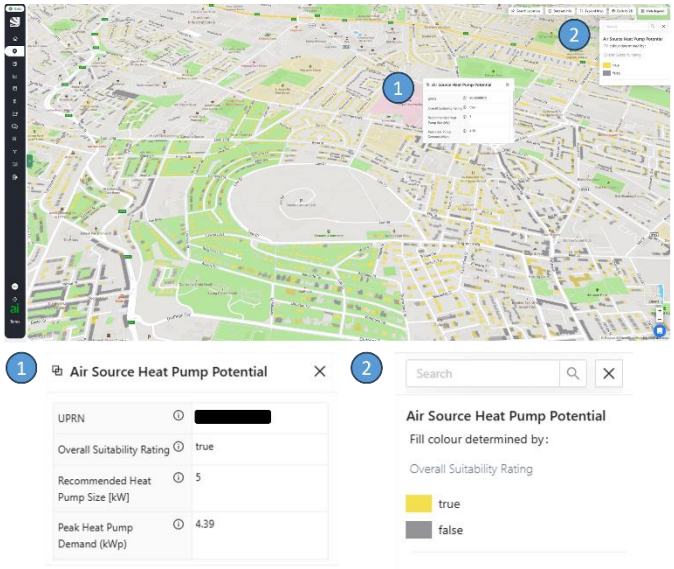


Figure 4: Heat Pump potential summary

CASE STUDY: PROJECT RESOP

The resulting data sets and visualisation platform were used as part of Project RESOP, an initiative involving Dundee City Council as well as other local authorities and Advanced Infrastructure Technology Ltd. This project was later was used as validation to develop and launch the Local Energy Net Zero Accelerator (LENZA) platform.



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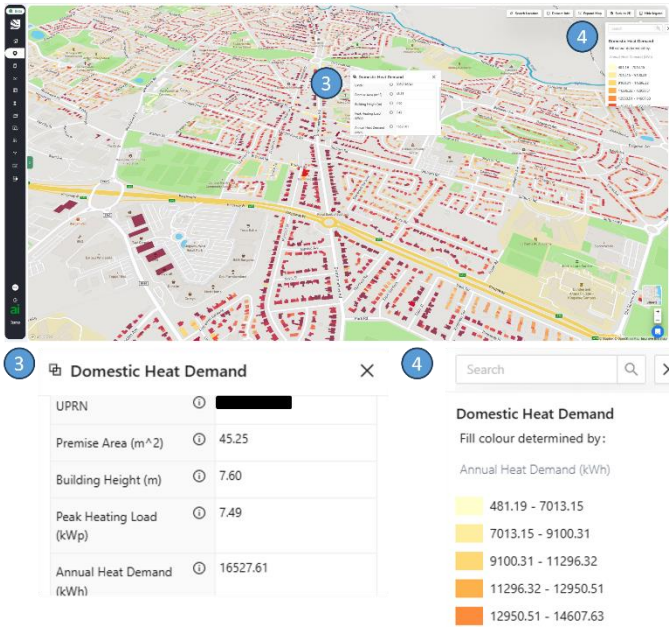

b.

Figure 5: (a) Heat pump potential data set and (b) domestic heat demand data visualised in the LENZA platform (used with authorisation of Advanced Infrastructure Technology Ltd.)

As part of RESOP, Dundee City Council worked with multiple data providers to map suitability of different heating types across the area, to develop a long-term low-carbon heating strategy, among other objectives.

Figure 6: Heat Network Potential Zones from Scottish national assessment overlaid with a desktop assessment of domestic air source heat pump potential produced by Advanced Infrastructure (Reproduced from: https://www.advanced-infrastructure.co.uk/case-study/regional-energy-system-optimisation-and-planning-resop)

CONCLUSIONS

The static modelling approach used in this article provided insight into the heat demand and heat pump potential of residential properties in Dundee. The results show that most properties have a peak heat demand between 3 and 4 kWp, and an annual heat demand between 6,000 and 8,000 kWh. On the other hand, the annual heat intensity has a skewed distribution with over 40% of the values between 50 and 100 kWh.m^{-2} per year. Finally, the geospatial analysis indicates that 43% of the residential properties are suitable for installing ASHP units, while only 12% of them are suitable for GSHP units due to their dependence on extensive back garden areas, suggesting that ASHP is a more feasible technology to install in domestic properties in Dundee than GSHP.

This modelling approach allows to estimate energy demand at scale, which makes it useful for energy planning and projects like RESOP. However, it should be noted that the granularity of the outputs is very broad, thus making these values not ideal for hourly energy analyses. Other approaches could provide a more

detailed description of energy demand at the building level, but in doing so, they could be more limited in the geographic scale.

The use of these data sets in RESOP shows their potential to be used as a tool for energy planning. However, what has made it more useful for stakeholders has been the capacity to visualise data and use it as a supporting tool to come up with energy plans.

FUTURE WORK

The modelling approach hereby adopted could be extended to contemplate other modelling methodologies, such as time series analysis or machine learning algorithms, to fill into knowledge gaps. However, this would also represent additional complexity to gather hourly or half hourly data at scale.

Additionally, the results of the model could be validated against others in the industry, and used in optimisation models for scenario planning to extract the most benefit from the LAEP methodology.

ACKNOWLEDGEMENTS

This article is supported by a Knowledge Transfer Partnership grant from Innovate UK (funder award reference: 10030085) between De Montfort University and Advanced Infrastructure Technology Ltd.

Following this project, the Local Energy Net Zero Accelerator (LENZA) platform was rolled out by Scottish and Southern Electricity Networks (SSEN) and Advanced Infrastructure Technology Ltd. to 58 local authorities in the north of Scotland and central southern England, starting in December 2023. This is an ongoing project aiming to provide local authorities and their delivery partners with access to up to date network capacity (provided by SSEN), building stock data, and modelling tools to support informed decision making.

NOMENCLATURE

ASHP	Air Source Heat Pump
CIBSE	Chartered Institution of Building Services Engineers
DNOs	Distribution Network Operators
EPC	Energy Performance Certificate
GSHP	Ground Source Heat Pump
GIS	Geographic Information Systems
kW	Kilowatt
kWh	Kilowatt-hour
$kWh.m^{-2}$	Kilowatt-hour per metre squared
kWp	Peak kilowatt
LAEP	Local Area Energy Planning
LENZA	Local Energy Net Zero Accelerator
m^2	Metres squared
MWh	Megawatt-hour
OS	Ordnance Survey
RESOP	Regional Energy System Optimisation Planning
$tonCO_{2eq}$	Tonnes of carbon dioxide equivalent
SSEN	Scottish and Southern Electricity Networks
UAVs	Unmanned Aerial Vehicles
UBEM	Urban Building Energy Modelling

REFERENCES

Ali, U., Haris Shamsi, M., Bohacek, M., Purcell, K., Hoare, C., Mangina, E., & O'Donnell, J. (2020). A data-driven approach for multi-scale GIS-based building energy modelling for analysis, planning and support decision making. Applied Energy, 279, 115834. https://doi.org/10.1016/j.apenergy.2020.115834

Anand, A., & Deb, C. (2024). The potential of remote sensing and GIS in urban building energy modelling. *Energy and Built Environment*, 5(6), 957-969. https://doi.org/10.1016/j.enbenv.2023.07.008

BRE Group (2013). Building Supply Chain for Mass Refurbishment of Houses: Impact of Thermal Efficiency (WP2 D1) - Initial Classification of Housing Stock Ttypes, https://doi.org/10.5286/UKERC.EDC.000357

Cabinet Office Markets, Sourcing & Suppliers team & Sourcing Programme team. (2022). *Promoting Net Zero carbon and sustainability in construction*. https://assets.publishing.service.gov.uk/media/631222898fa8f54234c6a508/20220901-Carbon-Net-Zero-Guidance-Note.pdf

Domestic Building Services Panel. (2021). *Domestic heating design guide*. London, England: Chartered Institution of Building Services Engineers.

Mutani, G., & Todeschi, V. (2021). GIS-based urban energy modelling and energy efficiency scenarios using the energy performance certificate database. Energy Efficiency, 14, 47. https://doi.org/10.1007/s12053-021-09962-z

Orehounig, K., Thrampoulidis, E., Mavromatidis, G., & Carmeliet, J. (2018). A GIS based methodology to support multi-criteria decision making for the retrofitting process of residential buildings. *Proceedings of the 7th International Building Physics Conference (IBPC2018): Healthy, Intelligent and Resilient Buildings and Urban Environments*, 1079-1084. https://doi.org/10.14305/ibpc2018

Roberts, D. (2022). Energy related GIS data landscape, Birmingham, England.

The Energy Zone Consortium (2013). Building Supply Chain for Mass Refurbishment of Houses: Impact of Thermal Efficiency (WP2 D2) – Stock archetypes in the UK. Tabulations for the specification of refurbishment solutions. https://doi.org/10.5286/UKERC.EDC.000188

Verwiebe, P.A., Seim, S., Burges, S., Schulz, L., & Müller-Kirchenbauer, J. (2021). Modeling Energy Demand – A Systematic Literature Review. *Energies 2021*, 14, 7859. https://doi.org/10.3390/en14237859