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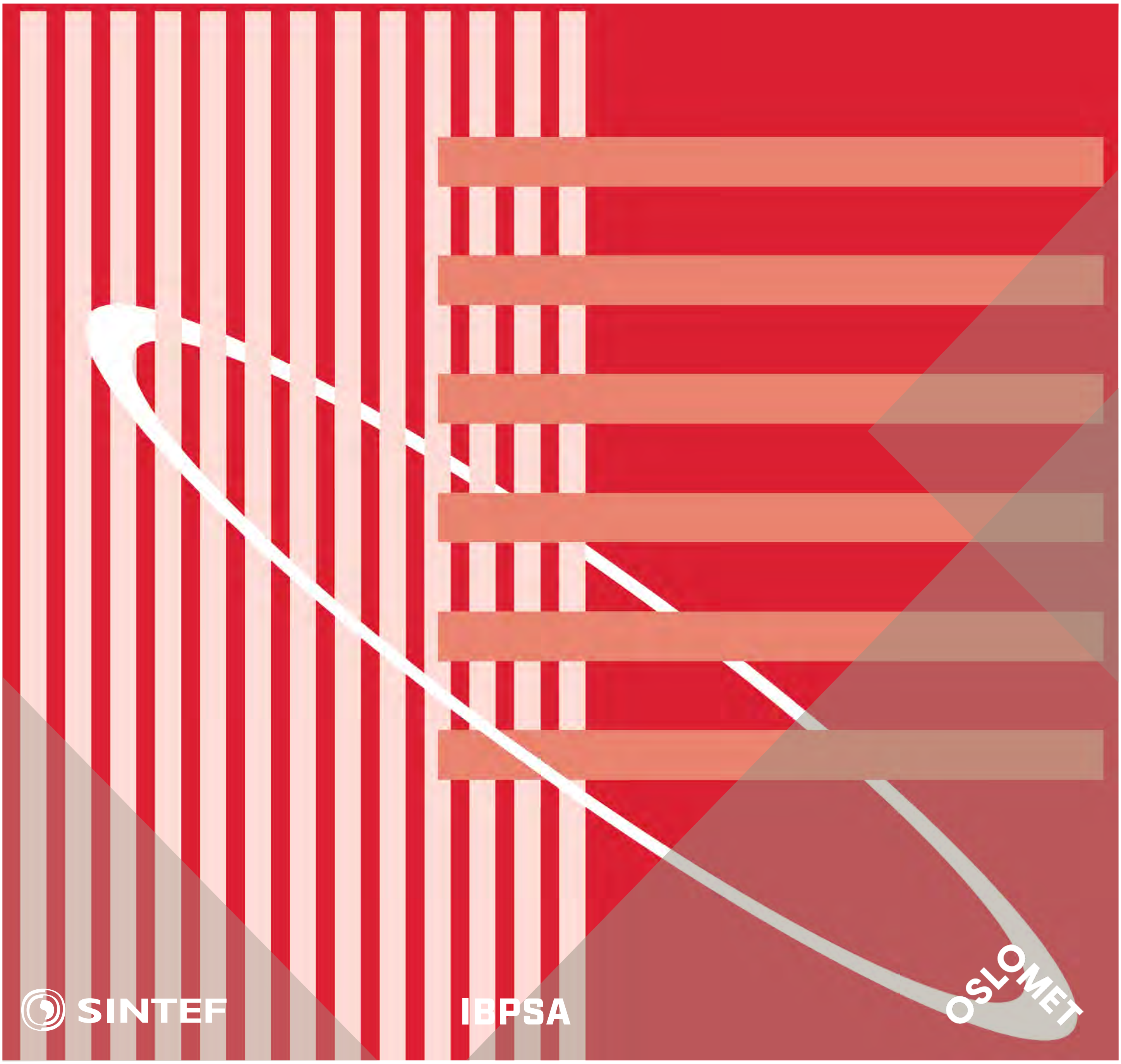

SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

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Keywords:
Building acoustics, Building Information Modelling (BIM), Building physics, CFD and air flow, Commissioning and control, Daylighting and lighting, Developments in simulation, Education in building performance simulation, Energy storage, Heating, Ventilation and Air Conditioning (HVAC), Human behavior in simulation, Indoor Environmental Quality (IEQ), New software developments, Optimization, Simulation at urban scale, Simulation to support regulations, Simulation vs reality, Solar energy systems, Validation, calibration and uncertainty, Weather data & Climate adaptation, Fenestration (windows & shading), Zero Energy Buildings (ZEB), Emissions and Life Cycle Analysis

Cover illustration: IBPSA-logo

ISSN 2387-4295 (online)
ISBN 978-82-536-1679-7 (pdf)

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Address: Børrestuveien 3
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A top-down digital mapping of spatial energy use for municipality-owned buildings: a case study in Borlänge, Sweden

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Abstract

Urban energy mapping plays a crucial role in benchmarking the energy performance of buildings for many stakeholders. This paper studies a set of buildings in the city of Borlänge, Sweden, owned by the municipality. The aim is to present a digital spatial mapping of both electricity use and district heating demand. A toolkit for top-down data processing and analysis is considered based on the energy performance database of municipality-owned buildings. The data is initially cleaned and transformed using the Feature Manipulation Engine tool (FME) and then is geocoded using a python script with an application program interface (API) for OpenStreetMap. The final dataset consists of 221 and 89 geocoded addresses for, respectively, electricity and district heating monthly consumption for the year 2018. The electricity use and heating demand in the building samples is about 24.06 kWh/m^2 and 190.99 kWh/m^2 respectively, where large potential in saving heating energy is observed. The digital mapping reveals a spatial vision of identifiable hotspots for electricity uses in high-occupancy-dense areas and for district heating needs in districts with buildings mostly constructed before 1980. This result will provide a comprehensive understanding of the existing energy distributions to stakeholders and energy advisors. It will also facilitate strategy towards future energy planning in the city such as energy benchmarking policies.

Introduction

Buildings represent large energy end-users worldwide. In the E.U. and U.S, buildings currently consume over 40% of total primary energy usage (Huang et al., 2020). With sights set in the new paradigm shift regarding energy production, efficiency and climate change, Sweden will implement strategies to reach national targets of energy efficiency in the building sector by 2050, According to this target energy use per square metre should decrease by 20% to 2020 and 50% to 2050, in comparison with use in 1995, A national target for energy efficiency in the housing sector is proposed (Ministry of Sustainable Development Sweden, 2006). In 2010, over 50% of the world's population are living in urban areas. By 2050, this number is expected to reach 75% (UN-Habitat, 2009). Urban development and the expansion of cities, through the modification of land uses (from natural to artificial) modify the local energy budget and wind patterns. Such transform has significantly changed the microenvironment and the related energy usage in urban cities (Torabi Moghadam et al., 2019). The mapping of urban building energy plays a crucial role in understanding the multitude of agents that take part in the energy performance of buildings, which will set up the benchmarks in different districts for various stakeholders.

In the context of sustainable cities, spatial visualization is a very effective approach to help decision-makers in the urban planning process to create future energy transition strategies and implement energy efficiency and renewable energy technologies. Geographic Information System (GIS) techniques can be used for visualizing the energy demand or production in buildings, from urban to regional, or even to a national scale. Some of these visualization techniques are: the thematic 2D map (Mhalas et al., 2013); the 'hit maps' (i.e., aggregated data in 3D charts) (Murugesan et al., 2015); the 3D city models with semantic objects (Gröger and Plümer, 2012). There are many studies using GIS techniques to visualize the energy data in building stocks. For instance, Mattinen et al. developed a method for estimating and visualizing the energy use and greenhouse gas emissions from a residential building stock located in Kaukajärvi district, Finland (Mattinen et al., 2014). Using such visualization model, they also analysed the impacts of behavioural and technical changes on the energy performance in the building stock. Finney et al. made a comprehensive mapping of heat sources and sinks in Sheffield City, the UK (Finney et al., 2013). Based on the heat source mapping, they linked these smaller systems to create a combined-heat-and-power based urban-scale network of energy generation and delivery. Huang et al. used GIS technique to obtain the roof area in Kowloon district in Hong Kong. Using the obtained roof are, they evaluated the solar power potentials of the whole district by installing rooftop PV panels. Based on the mapped solar power potentials, they developed an optimal design method to sit the public charging stations (Huang et al., 2019). Similarly, Ramachandra and Shruthi used the GIS technique to map the wind energy resources of Karnataka state, India. Based on the wind power mapping, they analysed their variability considering spatial and seasonal aspects (Ramachandra and Shruthi, 2005).

In Swan and Ugursal's study, the modelling approaches for energy consumption in a number of buildings were classified into bottom-up or top-down approaches (Swan and Ugursal, 2009). The bottom-up approach is more appropriate when there is a need for evaluating the energy consumption based on a high detailed level of data and the ability to model technological systems (Kavgic et al., 2010). Bottom-up models can be divided into two types: deterministic (or engineering) and statistical. The statistical methods search for correlations, utilizing a sample of information in energy bills as a source of data for energy modelling and analysing the link between energy consumption and a range of different variables (e.g. building shape, age, and occupant behaviour) (Nouvel et al., 2015). They can also consider socioeconomic effects in the equations. They calculate reliable consumption based on the available information on the current status of buildings. However, due to their strong dependency on available historical consumption data, these methods are restricted to predict the impact of new technology options and energy saving potential after applying refurbishment measures (Torabi Moghadam et al., 2018). The deterministic methods are detailed models which are based on thermodynamic relationships and heat transfer calculations (Bruse and Fleer, 1998). The main advantage of an engineering-based method is the ability of predicting energy saving potentials for buildings if some renovation measures are to be implemented (Mauree et al., 2017). These modelling approaches require a large amount of information about the building structures and parametric input for estimating the energy usage of a set of reference buildings of the stock based on a numerical model. Additionally, the evaluation of urban planning scenarios is computationally extensive and the availability of construction and geometrical data needed as input for the models is very scarce. The top-down approach treats the entire residential sector as one energy sink. The top-down methods are suitable for a large-scale analysis and not for the identification of the possible improvements at the building at urban and local levels (United Nations, 2015). Compared with the bottom up-approach, the top-down approaches are relatively easy to develop based on the limited information provided by macroeconomic indicators such as price and income, technology development pace, and climate. As summarized by Swan and Ugursal, the top-down approach has advantages including long-term forecasting in the absence of any discontinuity, inclusion of macroeconomic and socioeconomic effects, simple input information required and encompasses trends (Swan and Ugursal, 2009).

Although there are existing studies in mapping energy uses in different cities, a spatial energy analysis in local municipality is necessary as it will be different in various city and culture contexts. Specific consideration in general needs to be paid to the differences between cities when it aims to optimize the integration of urban energy systems operated in buildings, and promote renovation and renewable energy systems. Because cities differ from each other at the local, national and international levels in the perspectives of geography, socio-economy, culture, infrastructure, and information platform. The type of cities and districts will determine the kind of users and needs, and consequently the nature (qualitative and quantitative) of the policy/regulation schemes and the calibration/adjustment of the energy infrastructures. The citizen's behaviours and needs/preference of energy may be different to each other in different cities, which will lead to a great difference in the energy demand. Within the same framework of transforming to sustainable and liveable city, different areas must not only adopt standardized approaches, but also consider the specificities at the local level. A dedicated research into local city and district is therefore of paramount importance to ensure the proper mix between international/national scenarios and local measures.

The urban energy mapping and analysis for Borlänge city have not yet been done. Therefore, this paper aims to cover the research gap by studying a set of buildings owned by the municipality of Borlänge, Sweden. The initial step of the study is to give a spatial mapping of both electricity use and district heating demand. A top-down approach is considered based on the energy consumption data of the municipality-owned buildings. It is expected that this study is able to provide insights that will allow the understanding of the existing local energy distributions. It will also facilitate strategy towards future energy planning in this city.

This paper is structured as the following: Methods, illustrates the data source and the methodology of processing the data; in Results and discussion, both statistical and spatial analysis are presented this case in Borlänge; Conclusion is further depicted after.

Methods

Data sources

Acquiring the necessary data to create an urban model can be a difficult endeavour. New general data protection regulation laws (GDPR) by the European Parliament regulates how the data must be acquired, handled and stored while protecting the privacy of the individuals (European Parliament, 2016). Energy consumption data is sensitive information that fall into the new regulation, greatly complicating the data acquisition. Depending on the data resolution, storing the information can be complicated, may be not kept for large periods of time or stored in obsoletes systems making difficult to be of use.

The primary source of data used for this model is provided by Tunabyggen, a municipality owned company that constructs, manages and rents a set of buildings in the Borlänge municipality. The data is provided in PDF format, containing a total number of 375 pages monthly data for electricity demand, district heating and hot water flow rate for the year 2018. The geographical information is obtained from the official Swedish surveying institution, Lantmäteriet, specifically, the vector data for the property information and LiDAR data for the Borlänge municipality. Other social statistics and specific data such as building year of construction, percentage of occupation, demographics, typologies, are acquired from hitta.se, which is a Swedish search engine that offers telephone directory, addresses and maps. To complete and validate the model, it is necessary to use some extra information that was obtained by visual inspection including the number of floors, area and shape of the roofs. The flowchart, Figure 1, further describes the processes, databases and validation operations.

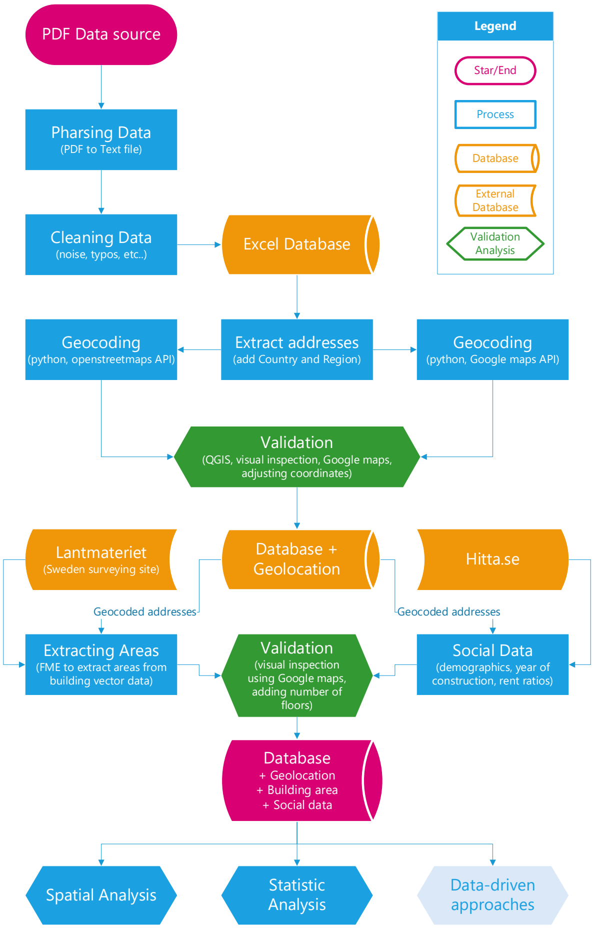

Figure 1 Flowchart for data processing, extraction, geocoding and validation

Data extraction

The first step in the process is to extract the information from the data source provided. The PDF archaic data structure format must be transformed into a common format that can be used by other applications. In order to extract the data a custom python script is written to parse out the information. Then, the data is further inspected for missing data and error correction. From the 375 pages in PDF format, a total of 262 addresses and 463 entry points of monthly data for electricity (kWh), district heating (MWh) and flow rate (m^3) for the year 2018 are extracted.

Geocoding

The extracted addresses from the data source are further expanded to the city and the country. Then, it is run through a python script, using an application program interface (API) for OpenStreetMap, Figure 2, gives the script that uses pandas, geopy libraries. In parallel, another script was used to connect to Google Maps API geocoding services. Two outputs from each geocoding service are obtained with the longitude and latitudes of the addresses. The output format for the coordinate system is the standard LL-WGS84. The location for a total of 222 out of the 262 entry points were found on the first iteration.

```
df=pandas.read_excel ("addresses.xlsx")

from geopy.geocoders import Nominatim

nom=Nominatim(user_agent="my-application")

df["address"]=df["address"]+", "+df["City"]+",
"+df["State"]+", "+df["Country"]

df["Coodinates"]=df["address"].apply(nom.geocode
)

df["Latitude"]=df["Coodinates"].apply(lambda x:
x.latitude if x != None else None)

df["Longitude"]=df["Coodinates"].apply(lambda x:
x.longitude if x != None else None)
```

Figure 2 Python script, for OSM API geocoder

Geocoding validation

The results are plotted and further inspected for validation. During this process, the locations are geocoded and manually centred in the property area, as displayed in Figure 3. The green dots are the geocoded locations and the brown dots are the manually centred locations. The output becomes to 238 out of the 262 total addresses, leaving a total of 24 addresses and 31 entry points that are not able to be geocoded due to unspecific naming until manual visual inspection and analysis of the context is performed. The final result generates a total of 250 geocoded addresses and 12 unclarified ones.

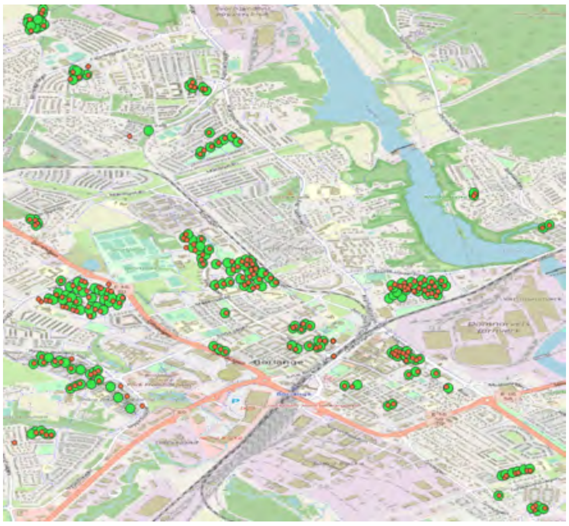

Figure 3 Geocoded data and adjusted coordinates

Area merger code, area validation

Next parameters are extracted from the Swedish survey database Lantmäteriet. The building property vector information is provided in a shapefile (.shp) format, a digital vector storage format for storing geometric location and associated attribute information.

Using the Feature Manipulation Engine (FME) tool, shown in Figure 4, it is possible to extract and calculate the areas for the geocoded addresses points. This information is compared to the visual inspected area, in order to analyse its accuracy. The extra information stored in the shapefile is incorporated to the dataset. This information includes a building description, coordinates in the Swedish reference system SWEREF-99-TM and a unique object identity.

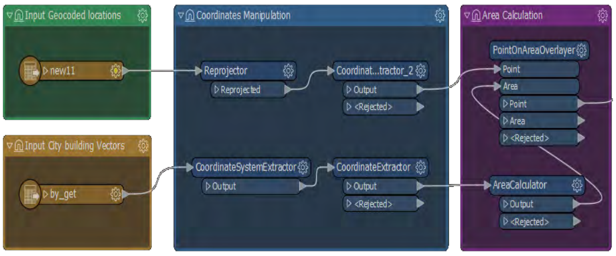

Figure 4 Process of FME area merger workflow

Data processing

All the different sources of information are finally combined together and inspected for errors or inconsistencies. The total building area is calculated using the number of floors and the buildings vector surface areas. Finally, the results for the energy consumption, electricity and district heating in kWh/m^2 for the year 2018 are obtained.

In total, there are 250 addresses that are geocoded, while 28 addresses are excluded from the dataset analysed. This is due missing, erroneous or abnormal information. The final sample dataset consists of 221 buildings for the electricity data and 89 buildings for district heating data.

Results and discussion

Statistic data analysis

In the considered building samples, all of the buildings are residential buildings and the related facility buildings (such as laundries, storage, etc.). The energy use is normalized by dividing the energy use by the heated floor area. The definition of the heated or living floor area has a large impact on the magnitude of the area-specific energy requirement. In Sweden, the heated floor area is defined as the floor area that is heated more than 10^{o}C. As a result, in this study, we assume the heated floor area is averagely 87% of the total external floor area for the analysis (Mata and Kalagasidis, 2009). In addition, electricity demand is further normalized by considering the occupancy ratio of each building. For heating demand there is no need to consider the occupation ratio, as it is common in Sweden for the heating systems to stay on even there is no occupancy in the building.

The annual electricity demand for lighting and appliance in the building samples are illustrated in Figure 5.

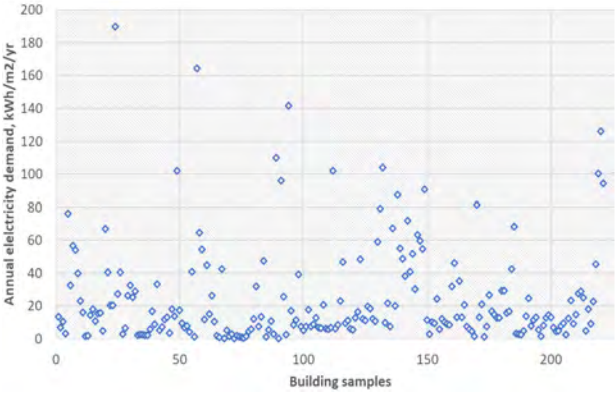

Figure 5 Annual electricity demand for building samples

The mean electricity demand of 222 building samples are 24.06 kWh/m^2, with a total range from minimum 0.02 kWh/m^2 to maximum 189.89 kWh/m^2. Comparing to the average electricity demand of 30-36 kWh/m^2 in Swedish context (Mata et al., 2013), the average electricity demand of the building samples is reasonably low, as most the occupants in the sample's buildings have relatively lower income. The median electricity demand is 12.72 kWh/m^2, which means that 50% of the building samples demand less electricity than this value. Furthermore, over 76% of the building samples achieves lower electricity use than 30 kWh/m^2.

According to the Swedish Housing Agency's building rules (Boverket, 2011), it requires energy performance for buildings depending on their use, end-use heating system and climate zones. The energy performance (heating demand) requirements are given as the specific energy use, comprising the purchased energy for space heating, domestic hot water and electricity for fans and pumps but excluding electricity for household appliances and lighting (Dodoo and Gustavsson, 2014). The annual heating demand for the building samples are displayed in Figure 6.

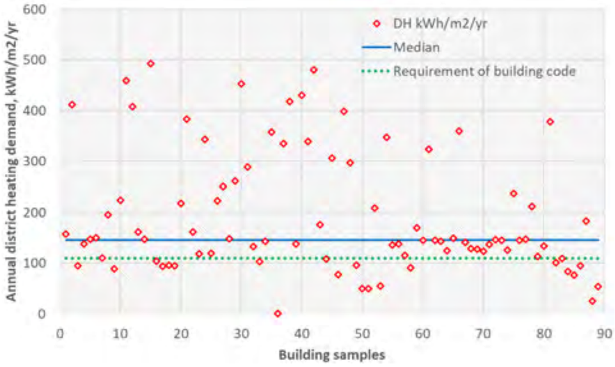

Figure 6 Annual heating demand for building samples

The mean heating demand of 89 building samples are 190.99 kWh/m^2, with a total range from minimum 0.41 kWh/m^2 to maximum 492.52 kWh/m^2. Borlänge city belongs to climate zone II in Sweden, where the new building code requires up to 110 kWh/m^2 energy use for non-electric heated buildings (with district heating) annually. In addition, passive houses criteria even have higher requirements with up to 35% lower value compared to building code (FEBY, 2012). Thus, the average heating demand in the building samples is much higher than either the building code or the passive house standard, which is about 2 times of the requirement by building code, and 3 times of the requirement by passive house standard. The median heating demand is 145.43 kWh/m^2, which means that 50% of the building samples demand less heating than this value. Approximately 25% of the building samples achieves lower heating demand than 110 kWh/m^2. The difference between the different counties is clear. In Gävleborg, it is found that the average heating demand was about 185 kWh/m^2 in 2010. When across the whole Sweden, the average annual energy use for heating in single- or two-dwelling was reported at about 158 kWh/m^2 per year in 2014 (Swedish Energy Agency, 2015). So, the heating use in Borlänge city stays at a high level when compared to the closed regions and the average figure over the country.

However, this high energy demand can be understood since over 60% of the buildings in the sample were constructed before 1980, and therefore it may not be energy efficient dwellings. The annual heating demand average varies considerably depending on the year of construction of the building. For buildings built after 1980, the heating demand is of about 97-98 kWh/m^2 in 2004, while those built before 1980 used heating from 120 to 133 kWh/m^2 per year (Pallardó, 2011). In the sample, the average heating demand for buildings constructed before 1980 is about 187.98 kWh/m^2 per year, where these buildings account for 90,651 m^2 of the heated floor area. So, there is great potential (about 4,532 - 5,439 MWh/year) for these buildings built before 1980 to improve their energy performance through renovations such as, increasing the thermal insulation of the walls/roofs, upgrading windows and heating radiators for example.

Spatial data analysis

Digital mapping method is applied hereby to compile and format the energy data into a virtual image, which is to produce a general map with energy use in Borlänge city based on building samples, which offers appropriate representations of the dedicated areas and districts. Using a Geographic Information System (GIS) tool - QGIS, it is able to visualize the sample energy data on the spatial map of Borlänge. Using the yearly electricity and heating demand in the unit of kWh/m^2 as the weight factor, longitude and latitude of the addresses, two digital maps are generated as shown in Figure 7 and Figure 8, respectively for electricity use and heating demand.

These digital maps provide an interactive and scalable way of visualizing the energy use across the city, which is used to spot abnormalities or faulty energy data points. These maps also illustrate a spatial idea of identifiable hotspots for electricity uses in high-occupancy/dense areas. For district heating demands it shows hotspots with buildings mostly constructed before 1980. For instance, some of the hotspots can be easily identified as several student's accommodation areas in the northwest quadrant. These highly dense buildings have high electricity consumption since the occupants remain indoor for the most learning and living activities, but at the same time these buildings have relatively low heating needs as the buildings are well maintained and insulated. It is observed from these two maps that electricity use is mainly relied on the occupancy density, where higher population per floor area usually results in higher electricity use. On the other hand, district heating demand is dependent on the building itself, where poorly-insulated building leads to higher heating need. As a result, electricity use and heating demand do not always appear in the same district/area since they are influenced by different parameters. This offers clear insights for planning of urban energy infrastructure and distributions, as well as the potential contributions from local renewable energy source (RES) systems. For instance, more electricity distribution or RES power generation is necessary for high-dense residential areas, while higher heating should be distributed to those areas with buildings mostly constructed before 1980.

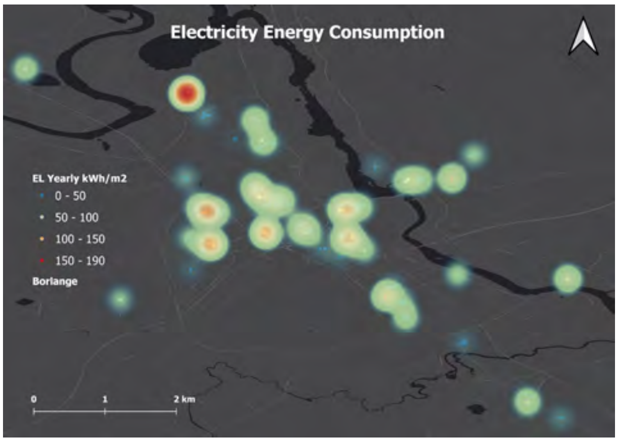

Figure 7 Digital mapping of electricity use in Borlänge city based on building samples

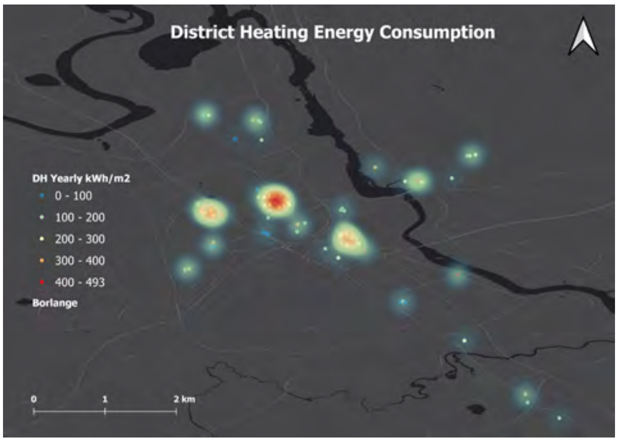

Figure 8 Digital mapping of heating demand in Borlänge city based on building samples

Conclusion

A dedicated spatial analysis of both electricity use and district heating demand in a Swedish local-city context is completed, through a toolkit for top-down digital mapping. The average electricity demand in Borlänge building samples are 24.06 kWh/m^2, which is reasonably lower than the average value in Sweden. The mean value of heating of the building samples is 190.99 kWh/m^2, which is much higher than either the building code or the passive house standard. The heating use in Borlänge city stays at a high level when compared to the closed regions and the average figure over the country. In particular, there are great potentials (about 4,532 - 5,439 MWh/year) for the buildings built before 1980 to improve the energy performance.

The digital maps illustrate a spatial vision of identifiable hotspots for electricity uses in high-occupancy-dense areas and for district heating needs in districts with buildings mostly constructed before 1980. Electricity use and heating demand do not always appear in the same district/area since they are influenced by different parameters. This offers clear insights for planning of urban energy infrastructure and distributions, as well as potential contribution from local RES implementation.

Acknowledgement

The authors would like to appreciate the financial support from Swedish Energy Agency (UBMEM project: 46068). The authors also thank Tina Lidberge for accruing data from Tunabyggen. The master students, such as Péter Tempfli, Mohsin Raza, Anastasiia An and Mrudula Talari, are appreciated for their support.

References

Boverket, 2011. Boverket´s mandatory provisions and general recommendations, BBR, BFS 2011:6 with amendments up to BFS 2018:4 154.

Bruse, M., Fleer, H., 1998. Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. Environmental Modelling & Software 13, 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5

Dodoo, A., Gustavsson, L., 2014. Effect of Energy Efficiency Requirements for Residential Buildings in Sweden on Lifecycle Primary Energy Use. Energy Procedia 61, 1183–1186. https://doi.org/10.1016/j.egypro.2014.11.1049

European Parliament, 2016. Regulation (EU) 2016/ 679 of the European Parliament and of the council - of 27 April 2016 - on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) 88.

FEBY, 2012. Specification for zero energy, passive and low-energy houses.

Finney, K.N., Zhou, J., Chen, Q., Zhang, X., Chan, C., Sharifi, V.N., Swithenbank, J., Nolan, A., White, S., Ogden, S., Bradford, R., 2013. Modelling and mapping sustainable heating for cities. Applied Thermal Engineering, Includes Special Issue: PRO-TEM Special Issue 53, 246–255. https://doi.org/10.1016/j.applthermaleng.2012.04.009

Gröger, G., Plümer, L., 2012. CityGML – Interoperable semantic 3D city models. ISPRS Journal of Photogrammetry and Remote Sensing 71, 12–33. https://doi.org/10.1016/j.isprsjprs.2012.04.004

Huang, P., Lovati, M., Zhang, X., Bales, C., 2020. A coordinated control to improve performance for a building cluster with energy storage, electric vehicles, and energy sharing considered. Applied Energy 268, 114983. https://doi.org/10.1016/j.apenergy.2020.114983

Huang, P., Ma, Z., Xiao, L., Sun, Y., 2019. Geographic Information System-assisted optimal design of renewable powered electric vehicle charging stations in high-density cities. Applied Energy 255, 113855. https://doi.org/10.1016/j.apenergy.2019.113855

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Djurovic-Petrovic, M., 2010. A review of bottom-up building stock models for energy consumption in the residential sector. Building and Environment 45, 1683–1697. https://doi.org/10.1016/j.buildenv.2010.01.021

Mata, É., Kalagasidis, A.S., 2009. Calculation of energy use in the Swedish housing 52.

Mata, É., Sasic Kalagasidis, A., Johnsson, F., 2013. Energy usage and technical potential for energy saving measures in the Swedish residential building stock. Energy Policy, Special section: Long Run Transitions to Sustainable Economic Structures in the European Union and Beyond 55, 404–414. https://doi.org/10.1016/j.enpol.2012.12.023

Mattinen, M.K., Heljo, J., Vihola, J., Kurvinen, A., Lehtoranta, S., Nissinen, A., 2014. Modeling and visualization of residential sector energy consumption and greenhouse gas emissions. Journal of Cleaner Production 81, 70–80. https://doi.org/10.1016/j.jclepro.2014.05.054

Mauree, D., Coccolo, S., Kaempf, J., Scartezzini, J.-L., 2017. Multi-scale modelling to evaluate building energy consumption at the neighbourhood scale. PLoS ONE 12, e0183437. https://doi.org/10.1371/journal.pone.0183437

Mhalas, A., Kassem, M., Crosbie, T., Dawood, N., 2013. A visual energy performance assessment and decision support tool for dwellings. Visualization in Engineering 1. https://doi.org/10.1186/2213-7459-1-7

Ministry of Sustainable Development Sweden, 2006. Swedish national roadmap for implementing the European Environmental Technologies Action Plan (ETAP).

Murugesan, L.K., Hoda, R., Salcic, Z., 2015. Design criteria for visualization of energy consumption: A systematic literature review. Sustainable Cities and Society 18, 1–12. https://doi.org/10.1016/j.scs.2015.04.009

Nouvel, R., Mastrucci, A., Leopold, U., Baume, O., Coors, V., Eicker, U., 2015. Combining GIS-based statistical and engineering urban heat consumption models: Towards a new framework for multi-scale policy support. Energy and Buildings 107, 204–212. https://doi.org/10.1016/j.enbuild.2015.08.021

Pallardó, G.G., 2011. Energy Consumption in Tertiary Buildings in Sweden Case-study: M-building at Lund University – LTH, Lund University.

Ramachandra, T.V., Shruthi, B.V., 2005. Wind energy potential mapping in Karnataka, India, using GIS. Energy Conversion and Management 46, 1561–1578. https://doi.org/10.1016/j.enconman.2004.07.009

Swan, L.G., Ugursal, V.I., 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renewable and Sustainable Energy Reviews 13, 1819–1835. https://doi.org/10.1016/j.rser.2008.09.033

Swedish Energy Agency, 2015. New regional energy statistics for single- or two-dwelling buildings [WWW Document]. URL http://www.energimyndigheten.se/en/news/2011/new-regional-energy-statistics-for-single--or-two-dwelling-buildings/ (accessed 5.10.20).

Torabi Moghadam, S., Coccolo, S., Mutani, G., Lombardi, P., Scartezzini, J.-L., Mauree, D., 2019. A new clustering and visualization method to evaluate urban heat energy planning scenarios. Cities 88, 19–36. https://doi.org/10.1016/j.cities.2018.12.007

Torabi Moghadam, S., Toniolo, J., Mutani, G., Lombardi, P., 2018. A GIS-statistical approach for assessing built environment energy use at urban scale. Sustainable Cities and Society 37, 70–84. https://doi.org/10.1016/j.scs.2017.10.002

UN-Habitat, 2009. Global report on human settlements 2009: Planning sustainable cities.

United Nations, 2015. Global Initiative for Resources Efficient Cities.