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Article

Stakeholder Specific Multi-Scale Spatial Representation of Urban Building-Stocks

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Abstract: Urban building-stocks use a significant amount of resources and energy. At the same time, they have a large potential for energy efficiency measures (EEM). To support decision-making and planning, spatial building-stock models are used to examine the current state and future development of urban building-stocks. While these models normally focus on specific cities, generic and broad stakeholder groups such as planners and policy makers are often targeted. Consequently, the visualization and communication of results are not tailored to these stakeholders. The aim of this paper is to explore the possibilities of mapping and representing energy use of urban building-stocks at different levels of aggregation and spatial distributions, to communicate with specific stakeholders involved in the urban development process. This paper uses a differentiated building-stock description based on building-specific data and measured energy use from energy performance certificates for multi-family buildings (MFB) in the city of Gothenburg. The building-stock description treats every building as unique, allowing results to be provided at any level of aggregation to suit the needs of the specific stakeholders involved. Calculated energy use of the existing stock is within 10% of the measured energy use. The potential for EEM in the existing stock is negated by the increased energy use due to new construction until 2035, using a development scenario based on current renovation rates and planned developments. Visualizations of the current energy use of the stock as well as the impact of renovation and new construction are provided, targeting specific local stakeholders.

Keywords: building-stock; energy efficiency measures; GIS; stakeholder communication; visualization; energy development scenarios

1. Introduction

Buildings account for about 40% of the final energy use and 36% of CO_2 emissions in Europe [1]. At the same time, they provide a possibility for cost-efficient energy efficiency measures (EEM) [2]. The European Energy Performance of Buildings Directive calls for efficiency standards for both new and existing buildings targeting these efficiency opportunities [3,4]. The Swedish government has similarly set policy which strives for substantial reductions in energy use by 2020 and 2050 [5,6]. In order to encourage energy efficiency in buildings, energy performance certificates (EPCs) were introduced in Sweden in 2006 as a result of the EU Energy Efficiency Directive [3]. On a municipality and city level, more ambitious targets on energy savings have voluntarily been adopted. For instance, the city of Gothenburg has defined such targets and aims to reduce energy consumption in residential buildings by 30% by 2020 compared to 1995 levels [7]. For developed countries, it is estimated that most of the buildings that will be in use in 2050 have already been built [8], and the renewal rate of the Swedish residential stock is only 0.6% [9]. This implies a need for EEM in the existing stock, while also considering new construction if the above-mentioned targets are to be met, as well as to allow for evaluation of the impact of new building codes based on the Nearly-zero energy buildings (NZEB) directive [4]. To achieve a sustainable transformation of urban areas, municipal stakeholders (urban planners, energy planners, traffic planners, and environmental planners), developers, property owners, and managers, as well as citizens, need to be engaged. Buildings stocks are one of the important structures to be considered in the transformation process.

To address the challenges of the stakeholders involved in the transformation of the building-stock, building-stock models (BSM) have been used to calculate the energy demands of the existing building-stock [10,11] as well as to evaluate its potential development [12–15]. Bottom-up methods for describing and simulating the energy performance of building-stocks [16,17] have evolved from being used on a country level to being applied at the urban scale by incorporating GIS. Using GIS has several advantages; it facilitates the merging of several databases and further enhances analysis and communication by spatially differentiating and visualizing results. The energy performance modeling has similarly become more sophisticated, to the point where the fields of BSM and building energy simulation are merging [18]. While the spatial resolution has increased to represent individual buildings and energy models have become more advanced, the building-stock descriptions used as an input for these models have seen little development, and are still largely based on using representative buildings which are used to scale results to the desired level of output. Such descriptions lose accuracy with increased spatial resolution, and commonly, results are only presented at aggregate levels for districts or entire cities and not on a building level [18]. The scaling of representative buildings to account for the energy performance of the entire stock is based on the assumption that buildings with a similar year of construction have a similar energy performance. The older the stock that the representative building is aiming to describe, the more problematic this assumption becomes as renovations may have been applied to a varying degree, and the energy performance may have changed significantly from its original state [19,20]. Some models have gone further by incorporating building specific data, most commonly taking advantage of 3D city models based on LIDAR data [21], or by analyzing differences in digital terrain models and digital elevation models [22] as well as using building-specific data from EPCs to better describe the technical characteristics of individual buildings [23]. This development allows for the possibility of visualizing and communicating results on a building level as well as allowing results to be aggregated arbitrarily to suit communication with different kind of stakeholders.

As a representative description of building stocks limits accurate results for higher levels of aggregation, stakeholders operating at a planning or policy level are commonly targeted by BSM. A few exceptions can be found where other potential stakeholders have been identified. It has been suggested that construction companies can use EPC data to assess the size of the renovation market [24,25], which points to the possibility to use the results for educational purposes. As such, the intended stakeholders for BSM varies but can generally be divided into three broad categories; urban planners, energy planners, and governmental bodies needing policy support. However, to the best of the authors' knowledge, there are no studies using BSM to target property owners and managers who are essential to the urban transformation process.

To support these broadly described stakeholders of planners and policy makers, base-line models of the existing stock have been used to assess the current energy performance of cities and districts, to highlight areas where interventions should be prioritized for both energy demand [26] and supply [27]. Similarly, to assess the technical potential of specific technologies, specific measures have been investigated to evaluate the potential to reach environmental targets at an urban level using EEM [28], the potential development of renewables [29], the potential expansion and optimal layout of district heating networks [30], and the impact of urban morphology on energy use [31]. While these models tend to focus on the technical potential, other models have developed more dynamic scenarios to describe the change of the building-stock over time. The scenarios range from assumptions on a fixed rate of technology implementation to agent-based models or other decision models based on economic [32] or socio-economic feasibility [33]. Table 1 shows a review of contemporary studies on a city level, with a focus on the intended stakeholder, the spatial visualization of results, and parameters visualized.

Table 1. Overview of building-stock models (BSM), the city modeled, the stakeholders targeted, the parameters, and visualization.

Reference	City	Stakeholder	Parameters	Level of Visualization	Parameters Visualized
[25]	Zug	Education, urban, and energy planners	Power	City (districts in 2D), buildings for 4 districts (3D).	Peak space heating demand, energy reduction potential, GHG reductions, and Occupancy type
[30]	Zug	Energy and urban planners	Energy and power	Buildings in a district (3D)	Solar potential, infrastructure layout, and optimization (pipes)
[28]	Rotterdam	Policy makers	Energy	City (districts in 2D), buildings in a district (3D)	Gas consumption intensity (2D) and Heating savings potential (3D)
[34]	Corke	Policy makers	Energy and CO_2	Buildings in a district (2D)	Distribution of archetypes and house types
[22]	Esch-sur-Alzette	Urban planners	LCA	City (buildings in 2D)	Global Warming Potential
[35]	Liege	Policy makers	Energy	City (districts in 2D)	Distribution of buildings with shared facade
[36]	Helsinki	Energy planners	Power	City (districts in 2D)	Floor area, peak heating load, and peak heating load
[33]	Turin	Energy planners	Energy and cost	District (buildings in 2D)	District heating network layout
[26]	Milan	Energy planners and local administration	Energy	City (districts in 2D)	Energy consumption for heating, lighting and equipment, Domestic hot water, and cooking
[10]	Benevento	Energy planners	Energy	District (buildings in 2D)	Energy label
[11]	Ferrara	Urban planners	Energy	District (buildings in 2D for historical city center)	Energy label
[37]	Houston	Modelers	Energy	District (density map in 3D)	Power demand
[21]	London	Policy makers	Energy	City (districts in 2D)	Exposed surface area, building volume, and wall–volume ratio
[38]	Manchester	Urban planners and waste managers	Material stock	District (buildings in 3D)	Building typology
[39]	Leicester	Policy makers	Energy	District (buildings in 3D)	Energy
[40]	La Chaux-de-Fonds, Neuchatel and Martigny	Energy managers	Energy	City (buildings in 2D)	Construction period
[29]	Thessaloniki	Energy policy makers and planners	Energy	City (buildings in 3D and blocks in 2D)	Solar potential, DHW from solar (both in 3D), and CO_2 emissions per block

To reach the intended target audience, results are commonly visualized on different scales depending on the purpose, but typically consist of a country [32], regional [27], or city level [36], with city based models often including a more detailed view of a particular district or neighborhood [41]. For country and regional levels of visualization, results are commonly visualized in 2D for statistical zones [21] or zones defined by the authors to be homogenous as to the urban typology, and as such, fit the representative buildings used to describe the stock [34]. On a city level, either zones or individual buildings are used to visualize results in 2D, depending somewhat on the scale of the city in question. Representations of results on a district or neighborhood level commonly use 2.5D (flat roofs) or 3D models of buildings where a higher level of detail is used and more detailed information on roof structure is needed, typically for the investigation of solar energy potential [29,42]. There are a wide range of parameters visualized to support the different stakeholders targeted. While it is most common to present results as energy use or power demand, some studies use geometric information [21] or typologies [34,38] to try and draw more general conclusions by first linking energy performance to such parameters. Typically, the parametric value is visualized by color coding, with a few exceptions, where the areas are extruded and the height indicates the parametric value. While many papers listed in Table 1 mention the ability of these models to provide decision support, it is often not explicitly stated which stakeholder the results are aimed at, but rather broadly refers to supporting decision making in policy, urban planning, and energy planning, despite these models targeting specific cities. Furthermore, it is not stated how the spatiotemporal visualization of results are adapted to meet the requirement of the intended stakeholder.

The aim of this paper is to investigate different spatiotemporal visualizations of urban building-stocks, to communicate the possible developments, and complexities to specific local stakeholders involved. The focus of our study is on the energy performance of the multi-family building stock (MFB). The city of Gothenburg, Sweden, is used as a case study.

2. Materials and Methods

The energy performance of the MFB stock of the city of Gothenburg is visualized with different spatiotemporal resolutions using ArcGIS 10.2. Energy demand was calculated using previously developed methodologies for describing and calculating the energy performance of building-stocks using a bottom-up engineering-based approach [23,43]. The building-stock description treats each building individually, allowing results to be presented at any level of aggregation to suit the need of different stakeholders. To evaluate the potential development of the MFB stock of Gothenburg, a scenario study is applied. The development scenario is based on renovation rates of existing buildings and construction rates of new buildings. In the scenario, the current state of the building stock in 2014 and the development of the existing stock, as well as the ambitions for new constructions until 2035, are calculated, visualized, and discussed from specific local stakeholders' perspectives. This time horizon has been selected to align with the current available planning timeline for the city of Gothenburg.

2.1. Input Data

2.1.1. Energy Performance Certificates

For the description of the building stock, data were retrieved from EPCs which are available for all MFB in the city of Gothenburg. The EPCs were provided by the Swedish National Board of Housing, Building, and Planning and includes all the EPCs performed up until 2015. Parameters of interest for the description of the building stock are ventilation and heating systems, number of apartments, number of stories, attachment to other buildings, heated floor area (HFA), and a building identifier allowing for matching the EPCs to other databases. The EPCs also contain measured total annual energy use of a building (kWh), allowing for visualization and validation of calculated energy performance. For a detailed discussion about the EPC data and their reliability see [44].

2.1.2. National Building Register (BR) and Property Taxation Register (PTR)

For spatially allocating the building-stock description, data from the national building register and property taxation register were retrieved from the Swedish National Land Survey. The BR has data for the year of construction, economic extent of past renovation activities, and geo-referenced mid-point coordinates for each building, as well as the building identifier, also present in the EPC. The property taxation register was used to identify the owner of each building in Gothenburg, enabling aggregation of results on a portfolio level, as well as the possibility to compare the energy performance of different portfolios. The term portfolio refers to the building-stock of a specific owner or investor.

2.1.3. Linking Data—Urban GIS Database

This database contains geo-referenced data of buildings provided by the city planning office of Gothenburg. The data includes, among others, the building footprints and administrative boundaries, such as districts. The datasets from the BR and urban GIS database were spatially linked to footprints of buildings using the mid-point coordinates. The number of stories from the EPC is also spatially linked to the footprints to create a 2.5D GIS model, where surface areas can be extracted for the energy calculation as well as for visualization purposes. In total, building specific information is linked to 5901 MFB, covering 94% of all HFA in the MFB stock.

2.2. Assumed Building Stock Development until Year 2035

For the implementation rate of EEM in existing buildings, the base scenario of the National board of Building, Housing and Planning is used [45]. The base scenario gives a fixed rate of energy reduction of 2 percent per year and is assumed to be implemented first in buildings that currently have the lowest energy performance based on the EPC.

For new buildings, the strategic development plans for Gothenburg [46] are used to estimate the rate and location of new constructions. The plan for the non-central areas details spatially differentiated ambitions for new construction until 2035, with 15,000 apartments constructed until 2022 and another 32,000 apartments until 2035. A step-wise linear development is assumed, as well as a continuation of current average apartment sizes, i.e., 85 m^2 HFA per apartment, as obtained from all EPCs collected for the city of Gothenburg. The energy performance of these buildings is either assumed to be in line with the most recent draft of the Swedish building code [47], which aims at interpreting the EU directive on NZEB for buildings constructed after 2020, or assumed to have similar energy performance to current regulations for buildings constructed before 2020. The energy performance refers to delivered energy for heating, hot-water, and non-domestic electricity use. Table 2 summarizes the key features of the assumed building-stock development, i.e., implementation rates and assumed improvements in energy performance for new and existing buildings.

Table 2. Key features of the assumed building-stock development.

	Existing Buildings	New Buildings
Annual implementation	2% EEM for the least performing buildings first	212,000 m^2/y until 2022, then 194,000 m^2/y
Performance (kWh/m^2)	−25% if 150 > X, −50% if 150 < X	75 kWh/m^2/y until 2020, 55 kWh/m^2/y until 2035

2.3. Stakeholder Mapping for the City of Gothenburg

With the exception of private property owners and managers, the majority of the stakeholders interested in EEM and building-stock development can be related to the municipality. These stakeholders include policy makers in building and environmental committees, energy and urban planners at the city planning office, environment analysts at the environmental administration, and the municipal owned companies such as the largest residential property owner and manager (Framtiden

AB), as well as the local energy company (Göteborg energy AB). In addition, Framtiden AB consists of four subsidiaries, which to a certain extent, own different parts of the stock. While the policy makers at the different committees are key stakeholders, the information is typically related through the city planning office or the environmental administration. As the municipality owned companies follow the owner directives and guidelines set out by the city council, energy and environmental targets set by the city are more relevant to them than private property owners. Figure 1 presents and describes the relation between the key municipal stakeholders.

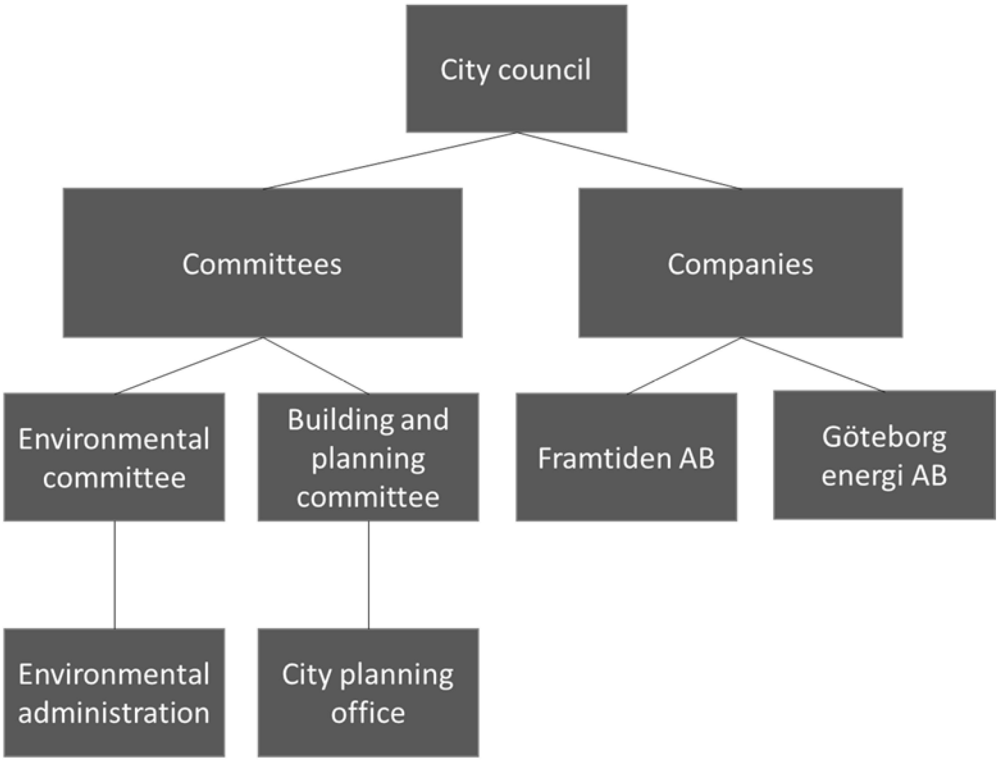


Figure 1. Main municipal stakeholders in the city of Gothenburg.

2.4. Spatiotemporal Energy Mapping

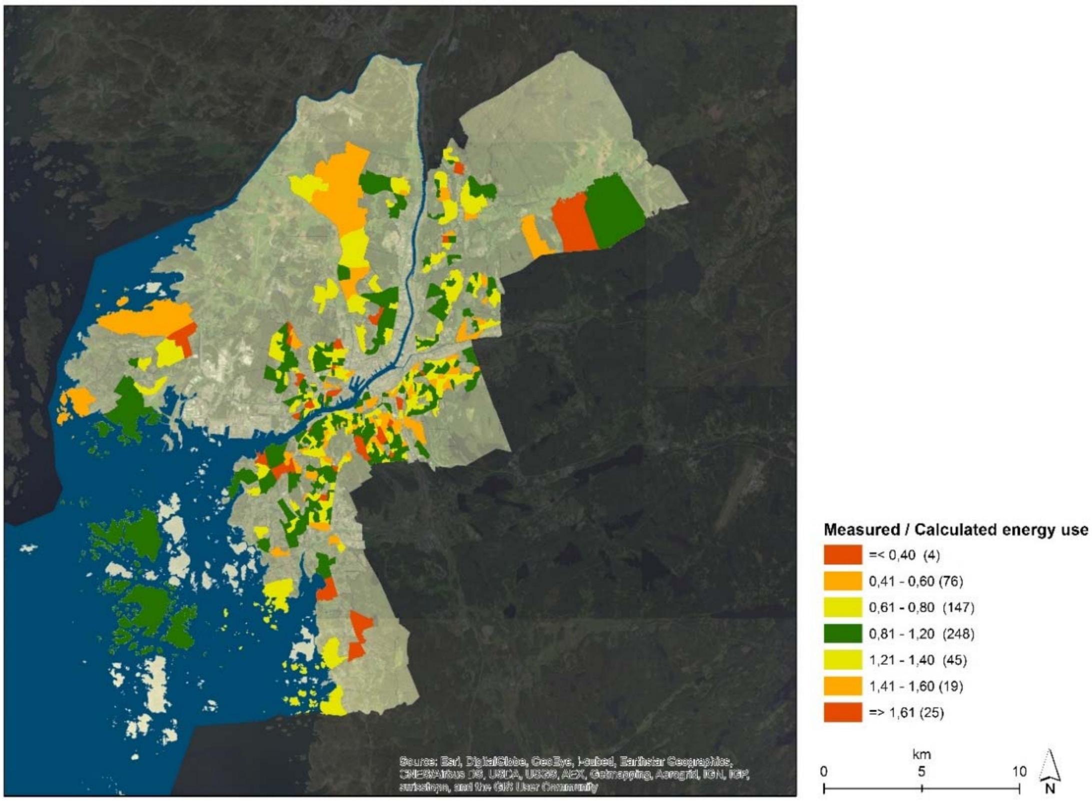
The yearly energy use is spatially mapped with visualizations of different spatial resolutions and units adapted to perceived stakeholder needs. For municipal stakeholders such as the energy company, energy and urban planners, as well as policy makers, the results are presented in administrative districts such as base areas (935 in Gothenburg) or primary areas (96 in Gothenburg). The base areas are regularly updated according to new and planned construction with the aim of keeping them homogenous regarding type of construction, while the primary areas seldom change. Either the delivered total annual energy or the energy use per m^2 HFA area are visualized. For the latter, results are classified according to established energy classifications. For Framtiden AB, the energy use is visualized at different levels of aggregation, from the building level to neighborhood to base area, to show the limitations of only using one spatial scale when presenting energy use information.

3. Results

Results are presented based on the identified stakeholders in the city of Gothenburg, and are structured based on which information we propose that the stakeholders are typically interested in. First, we present a visual validation of the BSM with calculated and measured energy use. Second, we present the current and future state of the stock with a focus on energy performance, which stakeholders are targeted, and how those results are visualized. Third, we show the importance of spatial aggregation when attempting to target areas in need of renovation and to define renovation strategies based on energy performance.

3.1. Energy Performance of the Existing MFB Stock

For the existing stock, calculated energy use for space heating (SH) and domestic hot-water (DHW) is within 10% of the measured consumption values given in the EPC, with calculated energy use being 2170 GWh/y and measured energy use being 1950 GWh/y. The deviation between calculated and measured energy use for SH and DHW is shown visually in Figure 2. While a deviation between calculated and measured energy performance at a stock level of 10% is within acceptable limits, certain areas show larger deviations. This is to be expected, as some areas contain fewer buildings or buildings that are difficult to accurately model using the available data. As such, the remaining visualizations will show measured consumption values based on EPCs.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2. Visual validation of the BSM showing measured energy use in relation to calculated energy use for base areas. Numbers in brackets indicate number of buildings.

In Figure 3, the energy planners and energy companies are the intended stakeholders as the spatial distribution of calculated delivered energy use is given as kWh per year aggregated to statistical areas. For those stakeholders directly involved with the energy grid, total amount of energy delivered is selected rather than the average energy performance of the statistical areas, this could be used to assess the potential for extending the district heating network. The areas with the highest total energy use are generally those with the largest amount of HFA. In some cases, this also highlights areas, which to a large extent, have not been renovated. In Figure 4, policy makers are the intended stakeholders with results instead presented in kWh per m^2, HFA aggregated to statistical areas (base areas). As opposed to Figure 3, this highlights the average energy performance of the statistical areas regardless of how densely built it is. This can be used to suggest what areas to target policy instruments related to EEM.

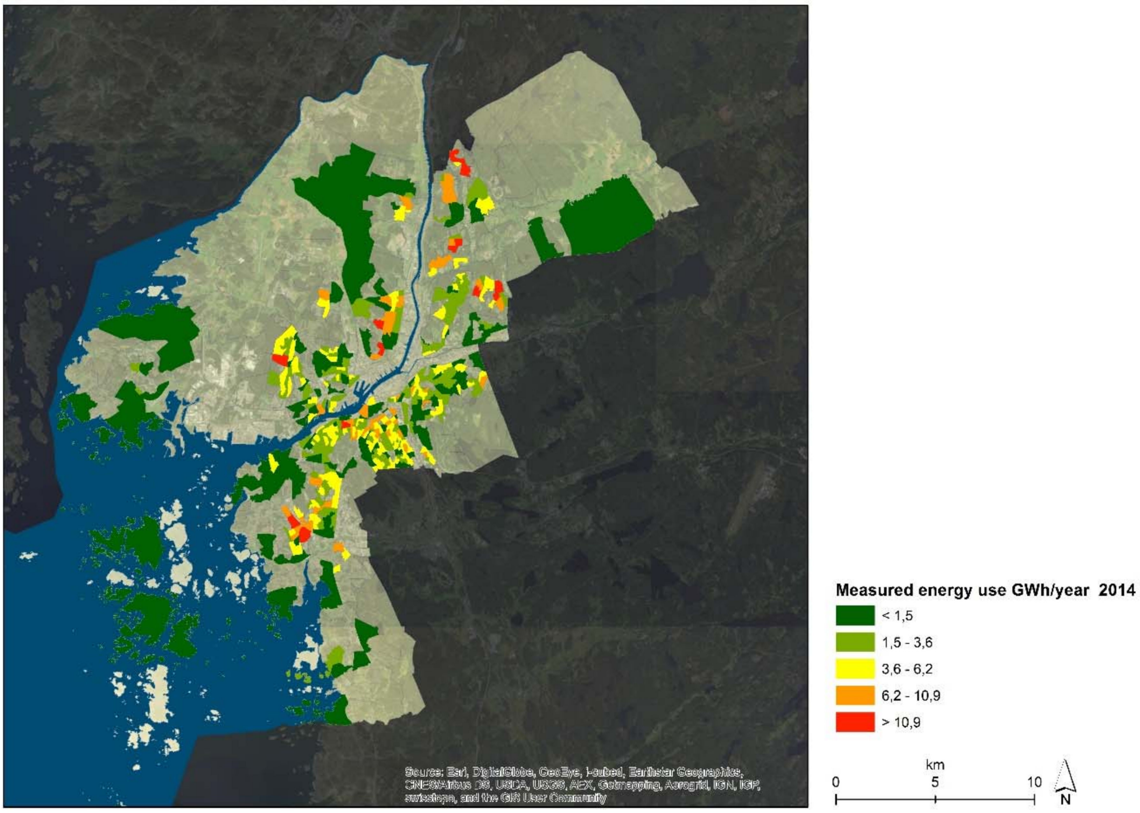


Figure 3. Measured energy use in the building stock aggregated to base areas.

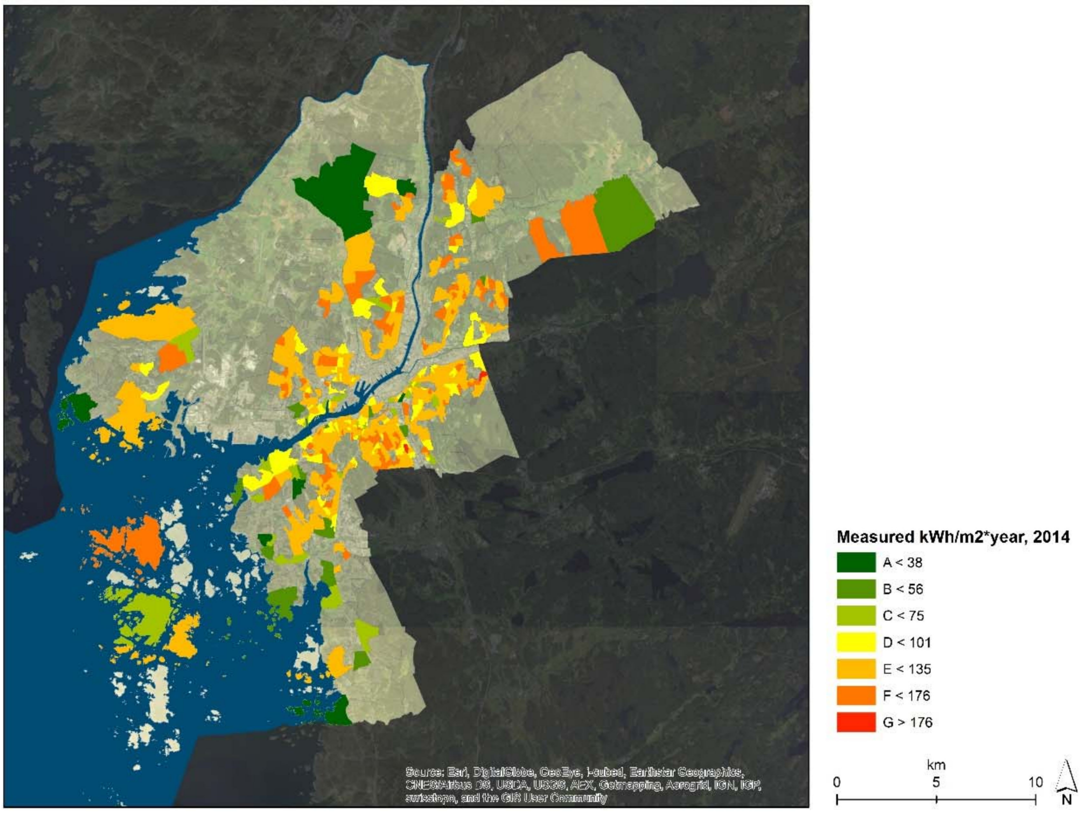
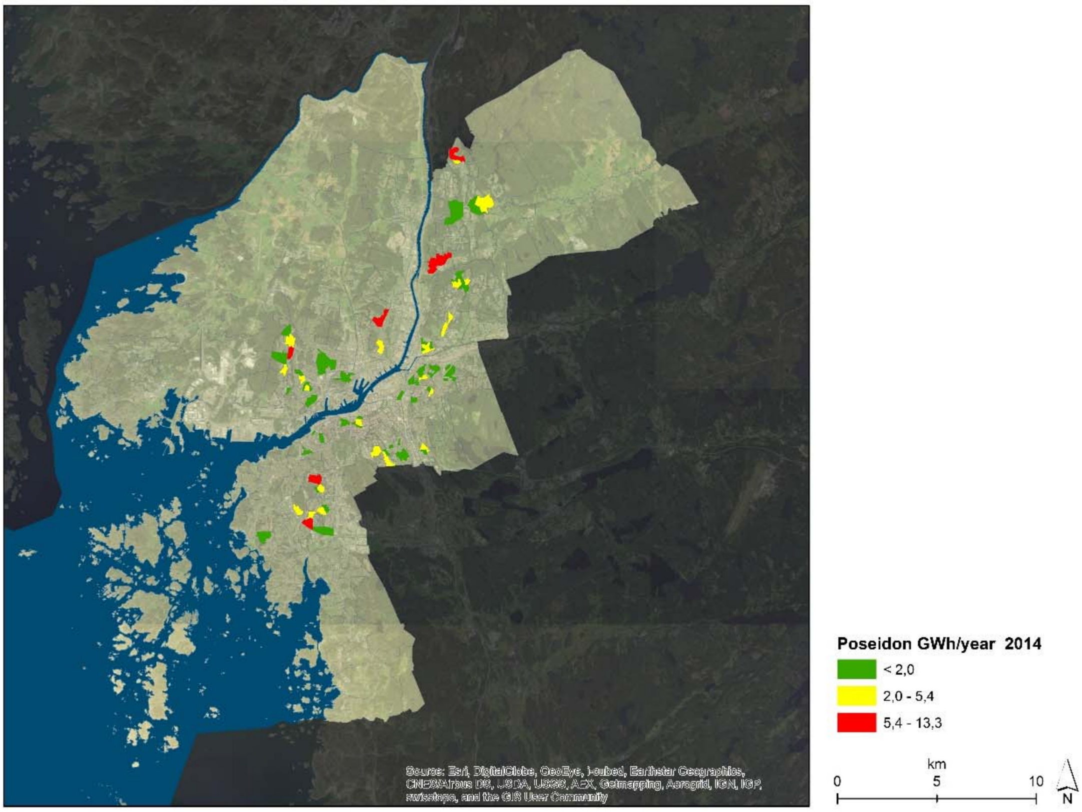


Figure 4. Measured energy use per m^2 HFA in the building stock aggregated to base areas.

Figure 5 shows the spatial distribution of calculated energy performance for one of the municipal housing companies as a density map. The highest densities of energy use, colored red in the figure, are observed in areas outside the city center, likely in part due to these being built during the 1960s and 1970s, which to a larger extent have not been refurbished compared to older parts of the stock, and also partly due to a higher density of their portfolio being situated in these areas. This can be used to highlight areas where large energy reductions can be achieved.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 5. Density map showing measured energy use for buildings owned and managed by Poseidon, a subsidiary of the municipal housing company Framtiden AB.

Figure 6 targets policy makers by showing the information from Figures 3 and 4 simultaneously, where the color relates to the energy performance per m^2 HFA using the classification from the EPC, and the height of the bar represents the total energy demand for the base areas. The comparatively low bars in the city center highlights the issue of aggregating results to predefined statistical areas. As these statistical areas are smaller in the city center compared to the outskirts they contain fewer buildings, and despite being more densely built, the visualization wrongly points to a lower density of energy use in the city center when the opposite is true. This can be used to target areas where many low energy performance buildings can be found.

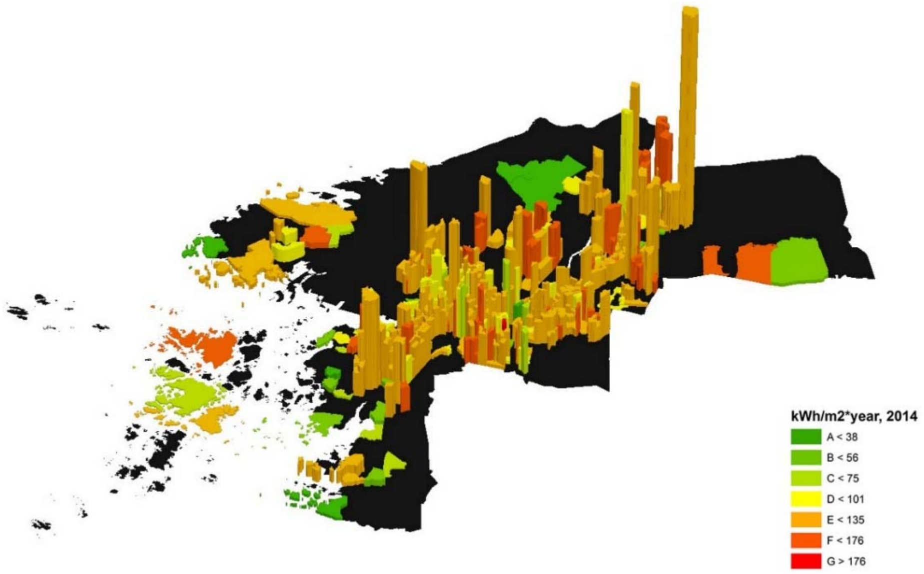


Figure 6. 3D visualization of energy performance and total energy use in aggregated–base areas. The color of the bar represents the average energy performance using the scale from the EPC [kWh/m^2] while the height represents the total energy use of buildings in the different statistical areas [GWh].

Figure 7 details the distribution of ownership for the four subsidiaries of the municipality's housing company. While not directly related to energy, it highlights the spatial distribution of ownership and where two or more of the subsidiaries operate. Non-energy related information of this kind can be used to better coordinate energy related renovation strategies and maintenance plans when used in conjunction with energy use data.

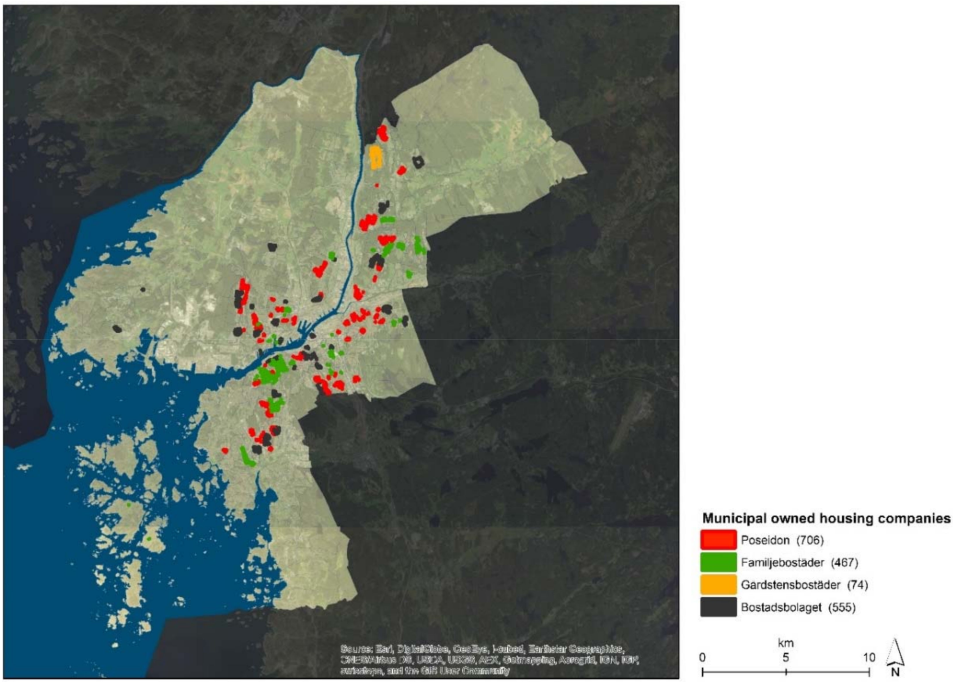


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Figure 7. Spatial distribution of ownership for the four subsidiaries of the municipal housing company Framtiden AB. In brackets is the number of managed buildings per company. Numbers in brackets indicate number of buildings.

3.2. Energy Development Year 2035

The reduction in energy demand until 2035, due to renovation of the existing stock, is shown in Figure 8 and the total decrease in energy demand, including new construction during the same period, is shown is Figure 9. The spatial distribution of energy reductions in the existing stock can be used by energy planners to assess the future demand on the grid. As the assumptions for Figure 9 are based on renovation being prioritized in buildings with a low energy performance, and the development strategy for new construction in the city of Gothenburg is based on the densification of areas where buildings with a low energy performance typically can be found, there is no clear difference in spatial distribution of future energy demand. Furthermore, as the results are aimed at policy makers, showing how targets can be reached by a change in energy performance for the entire stock does not warrant spatially differentiated results. As can be seen, the entire 20% reduction in the existing stock is estimated to be counteracted by new construction, which indicates that to reach targets on reductions of CO_2 emissions set by the municipality, further improvements to reduce emissions on the energy supply side are needed, as the reduction in energy demand will be limited under the assumed development scenario.

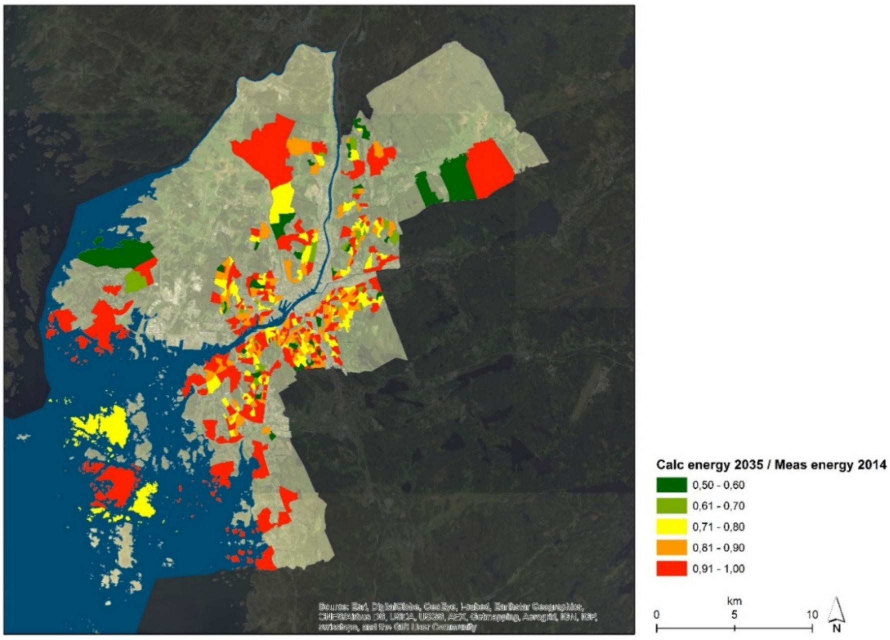

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Figure 8. Reduction of energy demand until 2035 for base areas based on renovations in the existing stock as a fraction of current energy use.

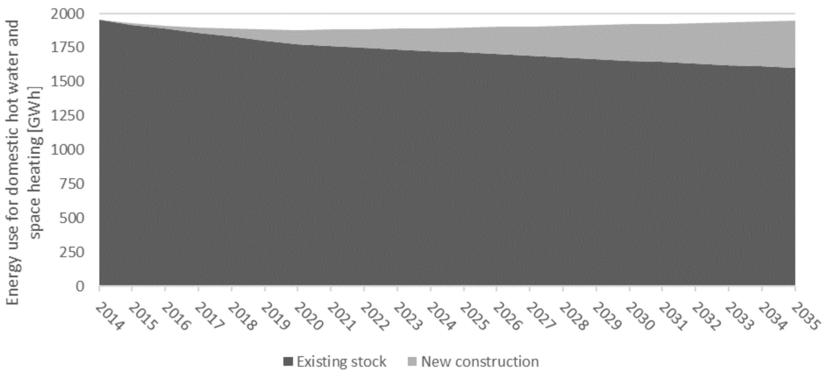

Figure 9. Future development of energy use for domestic hot water and space heating for the existing and future building stock until 2035.

3.3. The Importance of Spatial Resolution

Figure 10 shows the energy performance for the MFB stock of the municipal housing companies at a building level, as well as aggregated to statistical areas (base areas). While results on a higher spatial scale can be used to identify areas where EEM should be prioritized, with increasing spatial resolution the more differentiated and detailed this prioritization can be done. The results show a large distribution in energy performance for buildings having the same owner in the same geographical area. Although density maps provide a first insight as to which areas should be the focus for renovation measures to have the highest impact, it also points to the limitations of presenting aggregated results to stakeholders where building-specific information is needed. To make the necessary priorities for where renovation measures would be most effective within areas, a higher level of detail is required.

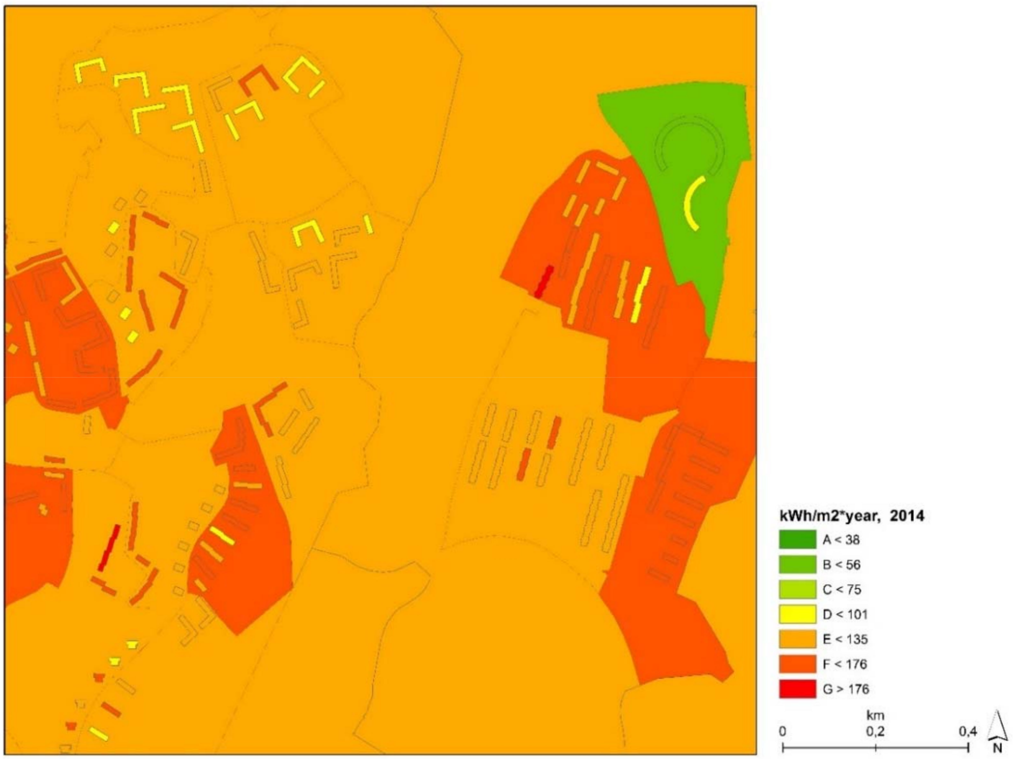

Figure 10. Energy performance for individual buildings and aggregated to statistical areas (base areas).

4. Discussion

In this paper, we have investigated the energy performance of the existing MFB stock in the city of Gothenburg, as well as its future development under given scenarios, with focus on the visualization and communication of results from a stakeholder perspective. Different spatiotemporal resolutions of urban building stocks have been applied, to visualize results and communicate both the current state and possible developments of the MFB stock to specific stakeholders involved in urban transformation.

Information relating to energy use has been visualized using several scales and metrics to target specific stakeholders, showing energy use as total amount per statistical area or per m^2 HFA. In the latter case, the classification from the EPC is used to help put results in context for the stakeholder. While other metrics which incorporate the shape, factor, and size of buildings may provide additional insight and understanding, familiarity with the metric has been prioritized. Furthermore, change in energy use is shown as a percentage, with a color scheme going from red to green. Total energy use is visualized using natural breaks with a color scheme as above. Visualizations are provided at a spatial scale suitable for the intended stakeholder, which is only possible due to all information being building specific. For future scenarios, where building specific developments are not known, visualizations are provided at a higher level of aggregation. For stakeholders, such as planners and policy makers, aggregated results that provide an overview are considered preferable. While changes in future energy demand is of interest, stakeholders such as the environmental department, the energy company, and policy makers are also interested in related CO_2 emission reductions. As most of the energy in the city of Gothenburg is supplied via district heating, stakeholders can easily convert energy use to CO_2 emissions using conversion factors based on their current projections. Further work is needed to increase temporal resolution, in order to provide more relevant information such as load curves and peak power demand to the energy company and energy planners; this would require more detailed information on user behavior or higher resolution energy consumption data. While there has been little discussion in the field of BSM on visualization and communication, a wider use of visualization of the flows of material and energy using 3D GIS has been called for in the adjacent field of urban metabolism [48].

For property owners and managers, a detailed overview of energy use in their stock provides an opportunity to prioritize energy efficiency measures across a portfolio, for larger districts and potentially down to individual buildings. As opposed to other stakeholders, portfolio owners are more concerned about the current state of the stock rather than the potential future development of energy performance. The current scenarios for future development are generic, and in order to be relevant to property owners, scenarios could be tailored to specific stakeholders to better reflect their agency. Using a renovation rate based on reaching environmental targets set by the authorities may not be relevant to a private property owner. A special case exists where municipal housing companies are owned by the city and must follow directives and environmental targets set by the municipality.

While energy performance is of interest to the targeted stakeholders, it is by no means the only important aspect. By using other information in conjunction with energy related data such as ownership distribution, a richer picture can be provided. Other studies have gone further and incorporated socio-economic data, which can highlight areas where rent increases due to renovation may result in affordability issues [49]. For many of the stakeholders targeted, the building stock is only of partial interest. For energy planners, the building stock (housing stock) is only one of several infrastructures in urban environments to be considered. Similarly, the scope of environmental authorities is larger still, and contains areas ranging from transport (private cars, public transport, ships, and flights) to industry and production, consumption and food. While the building stock is recognized as an important sector with explicit goals regarding the use of fossil free energy sources and reducing total energy use, it is only part of the puzzle. However, while information relating to the building stock constitutes partial information to individual stakeholders, it opens the possibility to facilitate communication and joint understanding between the different stakeholders. Visualizations could be used to inform urban planners and policy makers regarding the energy related implications of the city development plans. In extension, the contribution from the future building stock to reach environmental targets can be communicated, thus connecting the city planning office with the environmental department.

While spatial representation is an important tool in promoting joint understanding, it is not always relevant to all stakeholders. For property owners, spatially visualizing energy related information only makes sense for portfolios of a sufficient size. However, spatially visualization of results using this level of detail is not always needed, and the spatial aspect may not always be warranted. GIS may still be used for practical reasons regarding data acquisition, merging, and analysis.

One of the main benefits of a bottom-up modeling approach is the ability to aggregate results to different scales depending on the use case. Care should be taken not to visually represent data at a scale at which the methods used to derive it is not accurate. As such, the practice of visualizing results on a building level when distributing aggregated data or when results are based on archetypes should be avoided.

The list of stakeholders provided in this paper is by no means exhaustive but provides a starting point for further discussion on the development of BSM where adapting visualization and communication of results to target specific stakeholders is integrated in the research. The energy performance modeling and visualizations have been presented to different stakeholders, such as energy planners at the environmental authority, municipal housing companies, managers of resident owned housing, GIS strategists, and energy providers at different occasions for tentative testing of what information is needed and how it can be visualized to support their decision-making processes. Further work is needed to assess and develop the current proposal, which could be informed by geovisualization research [50] and qualitative studies to align the communication of results with the decision making process of specific stakeholders. Furthermore, additional indicators as well as scenarios relevant to the decision-making process of specific stakeholders should be included. Further work is also needed to assess if administrative zones are the most relevant level of aggregation.

5. Conclusions

By applying previously developed BSM methodologies to the MFB stock of the city of Gothenburg, calculated energy use of the existing stock is within 10% of the measured energy use. Furthermore, by using a development scenario based on current renovation rates and planned developments, the potential for EEM in the existing stock is found to be cancelled out by increased energy use due to new construction until 2035. Based on these results, and building-stock information from EPC, a proposal has been presented for visualizing energy related data for urban building stocks at different spatiotemporal resolutions, to communicate the possible developments and complexities to specific stakeholders involved in urban transformation. Visualization and communication of results have been designed to target specific stakeholders, which were identified using the city of Gothenburg as a case study. By mapping specific relevant stakeholders, rather than broadly referring to supporting planning and policy makers, spatial visualization and communication of results have been adapted to stakeholder needs. The current proposal is to be seen as a first step in an attempt to formalize and structure visualization and communication of results when using spatial BSM. While the extensive use of building-specific information is likely to be a limiting factor in transferring the approach to other cities, adapting the visualization and communication of results by targeting specific local stakeholders is universally applicable. Further work is needed to assess and evaluate the current proposal through qualitative studies.

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