A GIS energy model for the building stock of Goteborg

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ABSTRACT

Towards sustainable management of building stocks, descriptions of the environmental performance are needed in a structured form, accessible to several actors and addressing a local context. However it is often difficult to get an overall picture or to identify hotspots of the resource use in buildings within a region in spite of the fact that buildings, and by that, environmental data are spatially referenced. A GIS implemented energy model is presented for the building stock for the city of Goteborg. - What energy data is accessible and how those data can be presented is discussed. The aim of the model is to support the decision making process by benchmarking and communication of the environmental performance of buildings between real-estate managers and municipal administrations. Energy data comprises energy source and amount of energy used for heating, hot water, and for electrical appliances. Data are collected from energy suppliers and real-estate managers.

INTRODUCTION

What is the environmental impact from buildings? To gain a better basis for decision-making towards an environmental adapted real-estate management and to support the communication of environmental data, a model is presented to visualize building related energy data by linking Geographic Information Systems (GIS) and building stock modeling.

The building sector in Sweden uses about 40 percent of all material and all energy used in Sweden (BYKR 2001). The use of energy has a considerable environmental impact (CO_2 emissions) and climate issues are coupled to which energy sources are used – non-renewable or renewable – and how a more efficient energy use is utilized (IVA 2004). Buildings have an environmental impact during their whole life-time including the construction phase, use-phase and demolition-phase with a considerable impact during the use-phase.[1] Energy aspects belong to the prioritized fields regarding environmental adaptation of buildings (BYKR 2003) and are important factors when developing the urban environment i.e. distribution systems. Because of the long life-time of a building, the management and energy use/conversion play an important role for sustainable development of the Swedish society. Thus, this energy use should be clarified.

In Sweden, a law for energy declarations has been suggested on the national level (SOU 2004) and an extension of the Swedish real-estate taxation register with an environmental part (energy part) has been investigated (Lantmateriet 2003). On the EU-level strategies for sustainable development are developed for urban agglomerates (EU 2004) and energy declarations for buildings are worked out (EU 2003). To support theses ongoing work and to fulfill the Swedish environmental goals (miljomal.nu 2005), structured descriptions of the environmental performance of buildings are needed.

Ongoing Swedish research comprises environmental studies of individual buildings (Adalbert 2000, Thormark 2002) structuring of building data (FI 2002) and degradation studies of the built environment with the help of GIS (Ollén & Rydsted 2003, Haagenrud et al 2000). None of them models the building stock from a total resources use perspective nor or urban structures' dynamics. Thuvander (2002) has developed a conceptual model for an 'Environmental Building Stock Information System for Sustainable development', called EBSIS^{SD} which models building stocks from en environmental perspective including a time and spatial perspective. With help of this information system, environmental information on building stocks will be structured, analyze and visualized. With this background, an energy model has been developed to exemplify and to illustrate how energy data can be linked to buildings and administrative districts out of an urban context.

AIM AND GOAL

What energy data is available and how can it be presented to support decision-making, communication and benchmarking of the environmental performance of buildings? The purpose of the study is to support development of visualization strategies for building related environmental data by linking GIS and building stock modeling. The goal is to develop an energy model which is an integrated part of EBSIS^{SD}.

The specific goal is:

- to investigate the information content and the geographic encoding potential for GIS applications.
- to visualize underlying environmental data by mapping the energy use on different levels of detail and from different data sources.

Addressed users are different actors in the building sector, among others real-estate managers and municipalities. A wider purpose is to contribute to how the multi-dimensional, global and political vision about sustainable development can be translates to local situations and specifically related to the built environment supported by GIS.

METHOD

An energy model based on GIS has been established and examined for a chosen part of Goteborg city for the years 2000/2001. Thus, time is handled as a so-called time-slice. In the investigation, data from different sources is explored to describe the energy use in building stocks: real-estate and building data out of the building register received from the National Land Survey Sweden (Lantmateriet), energy data from the energy supplier Goteborg Energi AB and three real-estate managers in Goteborg and finally energy statistics from Statistics Sweden (Statistiska Centralbyrån, short SCB). The energy data comprises energy use for heating and hot-water and type of energy/energy carrier (gas, district heating and electricity). The data describes different scales, from building to parts of the town.

The building stock model EBSIS^{SD}, which the energy model is an integrated part of, contains structural building data such as 'year of construction', 'use of building' and ‘real-estate owner’. The overall modeling approach for EBSIS^{SD} is based upon a systems approach, where the system-in-focus varies (se also Thuvander 2002). Further, a ‘top-down’ approach is applied together with a ‘bottom-up’ approach, i.e. statistical data and is combined with building data. The combination of the two approaches can compensate lack of data and complete each other. The two approaches are also applied to the energy model, in which energy statistics is included by an age-use matrix for buildings with a spatial dimension. The integration of the energy model is illustrated by thematic layers describing population, terrain, road-network, etc.

The analyses and visualizations are carried out with the GIS software ArcView 3.2 and ArcGIS 8.3 from the software provider ESRI Inc. The data from the National Land Survey Sweden has been formatted in a Microsoft Access database prior importing tables to the GIS. Data from real-estate managers has been delivered on paper-print outs in tables and diagram out of the managers’ energy software. The analog data has been scanned to editable tables in Microsoft Excel. Data from the energy supplier has been delivered as Microsoft Excel-files which has been exported to the GIS as dbase-files.

DATA AND DATA SOURCES

The building register

Data from the building register (BR), obtained from Lantmateriet (LM), comprises all existing buildings in Goteborg year 2001, about 68200 records. BR, a part of the real-estate data system, contains compulsory basic information (parcel key and building key, administrative data, coordinates, evaluation information, owner and status), complementary information (location within statistic area, information from building permits, building area), and voluntary information (LMV 2001, se also Stendel 2000a). In many cases a parcel contains only one building; however a parcel may also contain several buildings and a building can have several taxation and evaluation units.[2]

In the BR every building, parcel and taxation unit has a specific key (Table 1). Beside the different attribute data such as ‘year of construction’, ‘year of reconstruction’, and ‘ground floor area’ with varying grade of coverage, every building has a geographic reference – coordinates for the centroid of the buildings. Coordinates for parcels and buildings are available for the national coordinate system (RT90) and Goteborgs local coordinate system. In the study, the national coordinate system has been applied. BR-data are the basic data for the building stock model and has been used to construct an age-use matrix (se chapter ‘Matrix’) with a spatial dimension the energy model is integrated with. Table 2 summarizes the attribute data applied in the study.

Table 1. Parcel key with the belonging building key. The example shows a parcel with three buildings.

Parcel key	Building key
140000053	14800023035
140000053	14800023036
140000053	14800035495

Table 2. Attribute data out of the building register, i.e., the part of the real-estate data system included in the study. The bold marked key gives the spatial linkage.

Building coordinates
Building key
Parcel key
Year of construction
Use of the building
Address

Data from energy supplier

Energy data has been provided by the energy company Goteborg Energi AB (GE), the most important energy supplier in Goteborg. Data from GE describe delivered energy in kWh and comprises the annual energy use of district-heating energy, gas and electricity for the year 2001 for both private and industrial customers in the GE-nets distribution region. GE represents their data in different sections, which in turn consists of sub-sections, which then results in 'metering districts'. In every district there are several metering stations. Totally, the town is divided into 96 sections comprising 590 districts and 260 000 metering stations. Table 3 summarizes the attribute data used in the study.

In the study, data from GE is aggregated on the district level, which corresponds to the geographical areas of the subsections. The data-file from GE includes addresses for the metering stations. The geographical encoding of the energy data, then, is based on the geographic database for the Goteborg roads with addresses. Encoding problems occurred due to un-complete address data from GE (no street numbers). Interesting for our study is that data for delivered energy could be used – meaning real data instead of the more often used calculated data. However, data is not explicitly related to buildings or properties but to metering stations which comprises several buildings or parts of buildings (flats).

Table 3. Applied attribute data from energy supplier. The bold marked key gives the spatial linkage.

Address
Delivered kWh gas
Delivered kWh electricity
Delivered kWh district heating
Code for section
Code for metering district

Data from real-estate managers

Energy data has also been delivered from three real-estate managers in Goteborg, two of them are municipal real-estate managers of domestic building and one is a private one managing both domestic and non-domestic buildings. This energy data comprises heating energy inclusive hot-water and electricity for real-estate appliances, i.e., exclusive electricity used in the flats. Data covers the years 1999-2001 and are measured data in kWh/m^2*year. For heating energy about 680 records has been provide. Besides energy data, we also have got addresses and names of the owned properties. Real-estate managers usually do not use the real-estate keys used in BR (Table 1). Thus, a spatial relation is given by addresses and energy data has been geocoded and linked to the BR, se Table 4.

The limited data supply from the real-estate managers depends on the time-consuming procedure for the managers (data is stored in different systems and has to be adapted to the purpose of the study), some real-estate managers were not positive to deliver data on the requested level of detail and some did not have data at all. Also, it is difficult to obtain data for single family houses and tenant-owned houses in an efficient way because of many different owners are involved. However, as the study is a test of data sources a full coverage of data judged as not being necessary to draw initial conclusions. Furthermore, because data has been delivered on paper print (in contrary to what we expected), additional efforts had to be laid on digitizing data. Real-estate managers data (type and system limits) is discussed in more general in Brunklaus & Thuvander (2002).

Table 4. Applied attribute data from the real-estate managers. The bold marked key gives the spatial linkage.

Address
Real-estate name
Heating energy incl. hot-water kWh/m^2*year

Energy statistics

Additionally, to compensate a lack of data energy statistics has been examined as a data source, in our case for blocks of flats. The energy statistics (SCB 1999) presents, among others, for different kinds of heating systems and energy carriers, divided for different age classes of buildings, from 1940 in ten-years-periods. Because district heating systems are the most common heat-supply system for blocks of flats in Goteborg, the average values for this kind of system has been applied on the building level for the chosen age-classes (se Table 6). In this way ‘top-down’ data (statistic data without linkage to a specific building) is applied as ‘bottom-up’ data, i.e. related to a building. This approach demands a careful interpretation of results but is advantageous if, for example, total flows of resources (such as energy or material) within a geographically limited area are modeled and no other data is accessible. Table 5 summarizes the attribute data included in the study.

Table 5. Applied attribute data from energy statistics. The bold marked key gives the spatial linkage.

Year of construction
Use
Heating energy incl. hot-water kWh/m^2*year

Maps and other statistics

The town planning office of Goteborg has placed GIS-implemented digital basic maps to our proposal, here for the year 2001, in which among other parcels, buildings and roads are illustrated. The properties have parcel keys corresponding to the one in the BR part but no building keys. In the study the maps are used for representations of buildings in mainly 2D and to illustrate linked attribute data such as ‘energy use’ or ‘year of construction'. The data base from the town planning offices also contains 3D data for terrain modeling and 3D data for buildings. Further, population statistics and road-network data with addresses are used for the year 2000 gained from SCB and Goteborg municipality (se thematic layers Figure 6).

MATRIX AND MAP SHEET DIVISION

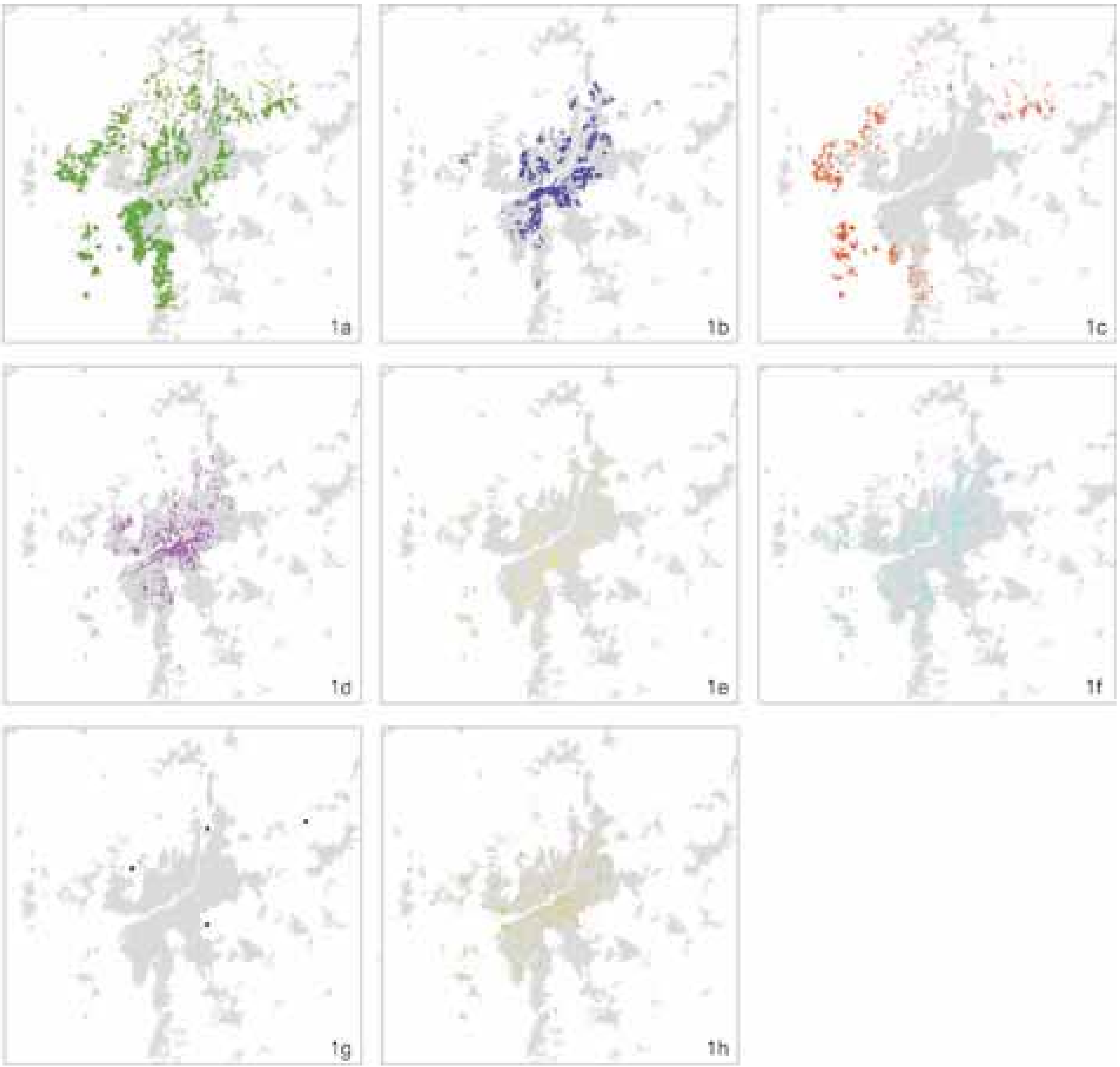
An age-use matrix for buildings has been developed. 'Age' (year of construction) and 'use' are common attributes for building stock descriptions. Buildings with the same use often have similarities (construction, size, spaces, maintenance intervals, installations, etc). In a corresponding way, buildings constructed within a certain time period have similar properties (construction and material). The chosen matrix division (Table 6) is based on earlier building stock studies (se Stendel 2000b) and building statistics from SCB, which is advantageous for time-including studies and integration of energy statistics from SCB. A spatial dimension of the matrix is given by linking the building coordinates from BR. The matrix, then, supports the combination of 'top-down' and 'bottom-up' data. Figure 1 illustrates the use-classes of the matrix for Goteborg year 2000.

Table 6. Age-use matrix for buildings.

Building stock	Use	Year of construction					
		-1940	1941-1960	1961-1975	1976-1990	1991-2000	No value
Domestic buildings	Single family houses						
	Blocks of flats			▨			
	Weekend houses						
Non-domestic buildings	Shops and offices						
	Hospitals and schools						
	Industrial buildings						
	Farms						
	Ohter						

Number of buildings, number of units (m^2)

Figure 1. Spatial distribution of use-classes for all existing buildings in Goteborg year 2000. The grey area marks the built-up area. 1a) Single family houses. 1b) Blocks of flats. 1c) Weekend building. 1d) Shops and offices. 1e) Hospitals and education. 1f) Industrial buildings. 1g) Farms. 1h) Other.

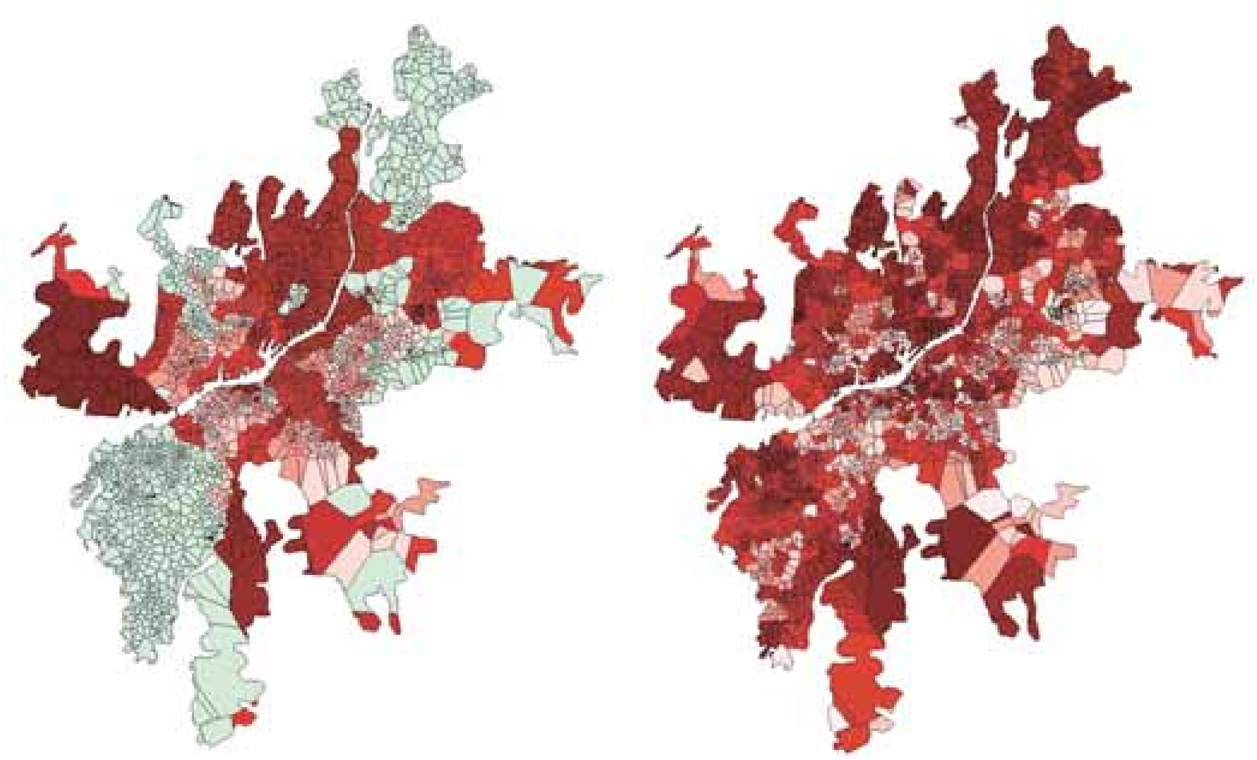


For the analysis of the model, only parts of Göteborg have been investigated in order to make it possible to handle the large amount of data. As a geographic unit a map sheet[1] has been chosen as unit, about a size of 3200m x 2400m. It is an established system and changes over time are limited compared to other administrative divisions. By that, it will be possible to compare different map sheets, for example a map sheet from the city centre with map sheets from the edge of the city.

AN INTEGRATED ENERGY MODEL

Below the energy model is presented for different data sources. The energy use has been modeled for Goteborg as a whole out of data from GE: natural gas, electricity and district heating. The energy use is presented for distribution areas but not linked to buildings.

Figure 2. Model for the energy distribution in Goteborg for different energy sources and for the reference year 2001. The classification on the map illustrates the energy use in the sub-sections. The darker the red, the higher the energy use.



2a) Natural gas, private customers.
In total: 739 494 MWh.

2b) Electricity private customers.
In total: 1 947 218 MWh
(Industri: 2 773 964 MWh).

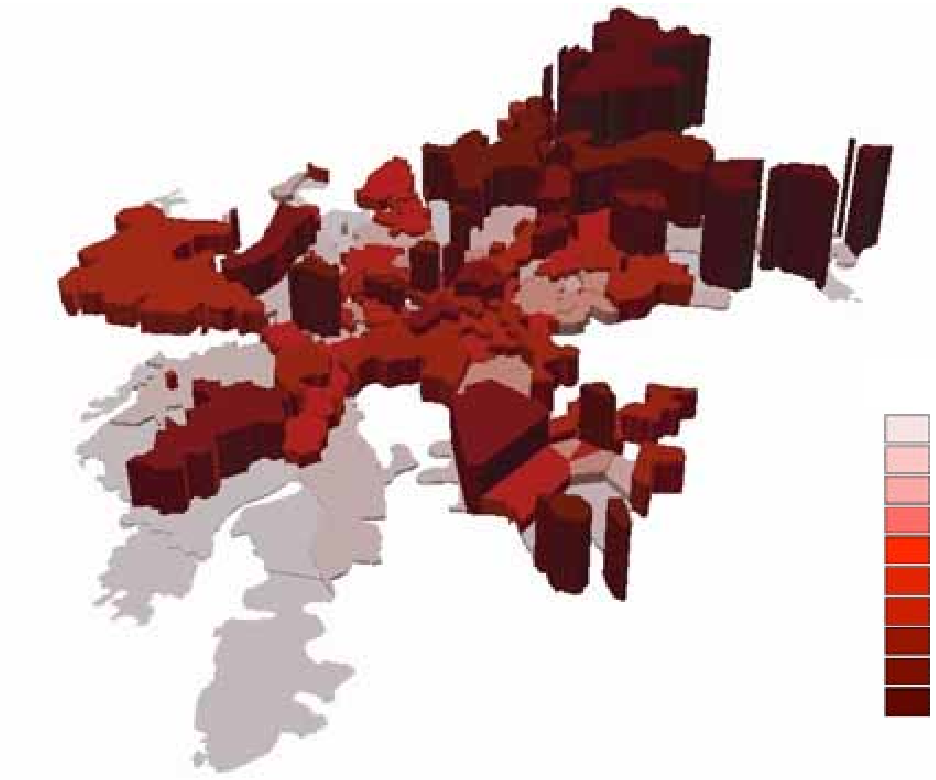
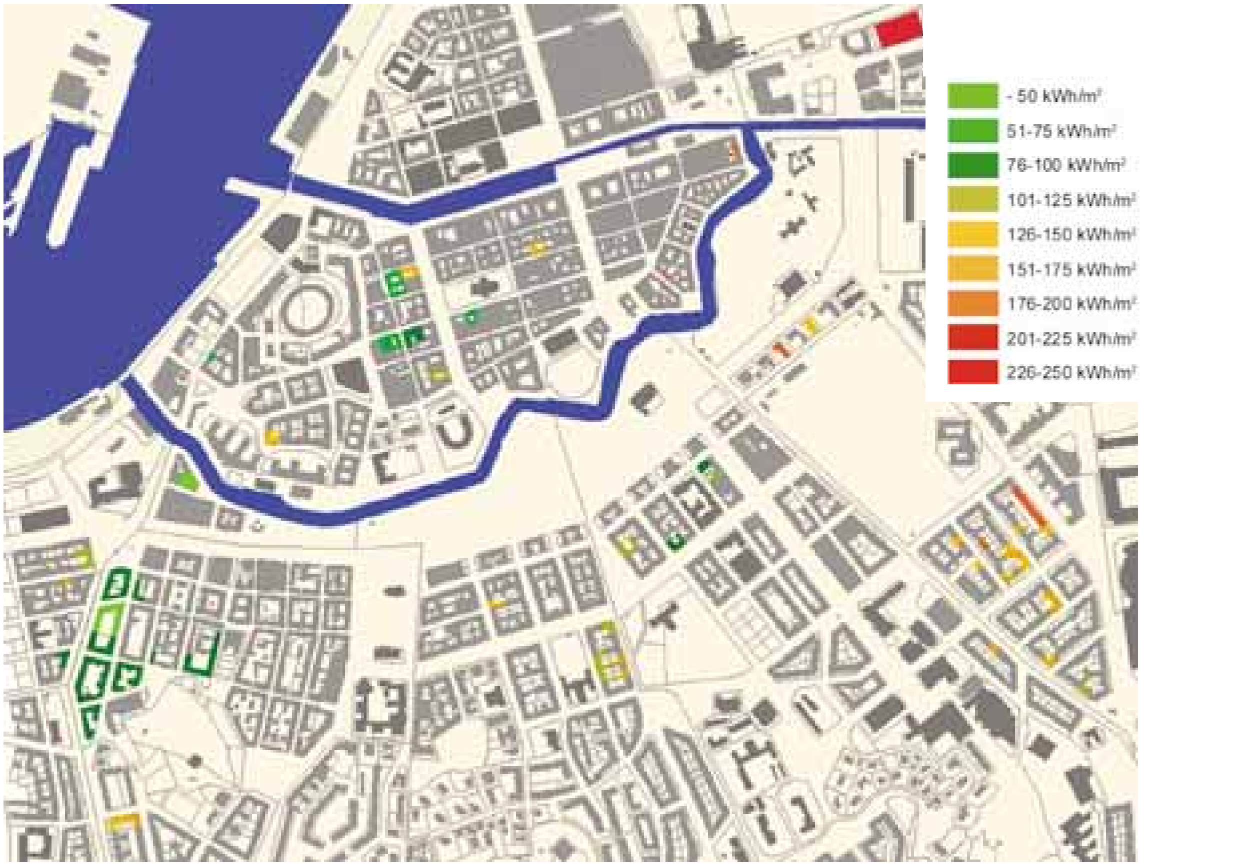


Figure 3. 3D energy model for district heating distribution. Delivered energy from GE year 2001. In total: 3 926 861 MWh.

Real-estate managers’ energy data for heating and hot water has been calculated and visualized on the building level for two map sheets. Figure 4 shows a part of one map sheet.

*Figure 4. Energy model illustrating the energy use in kWh/m^2*year for heating and hot water for buildings owned by three real-estate managers in Goteborg. The reference year is 2000. The grey marked properties are not owned by them.*



The statistical energy data has been modeled for blocks of flats for the same map sheets as for the real-estate managers. The energy use is illustrated on the building level, Figure 5.

*Figure 5. Energy model based on energy statistics for blocks of flats. The average energy use is illustrated based on SCB-data (1999) in kWh/m^2*year in age-classes, i.e. year of construction.*

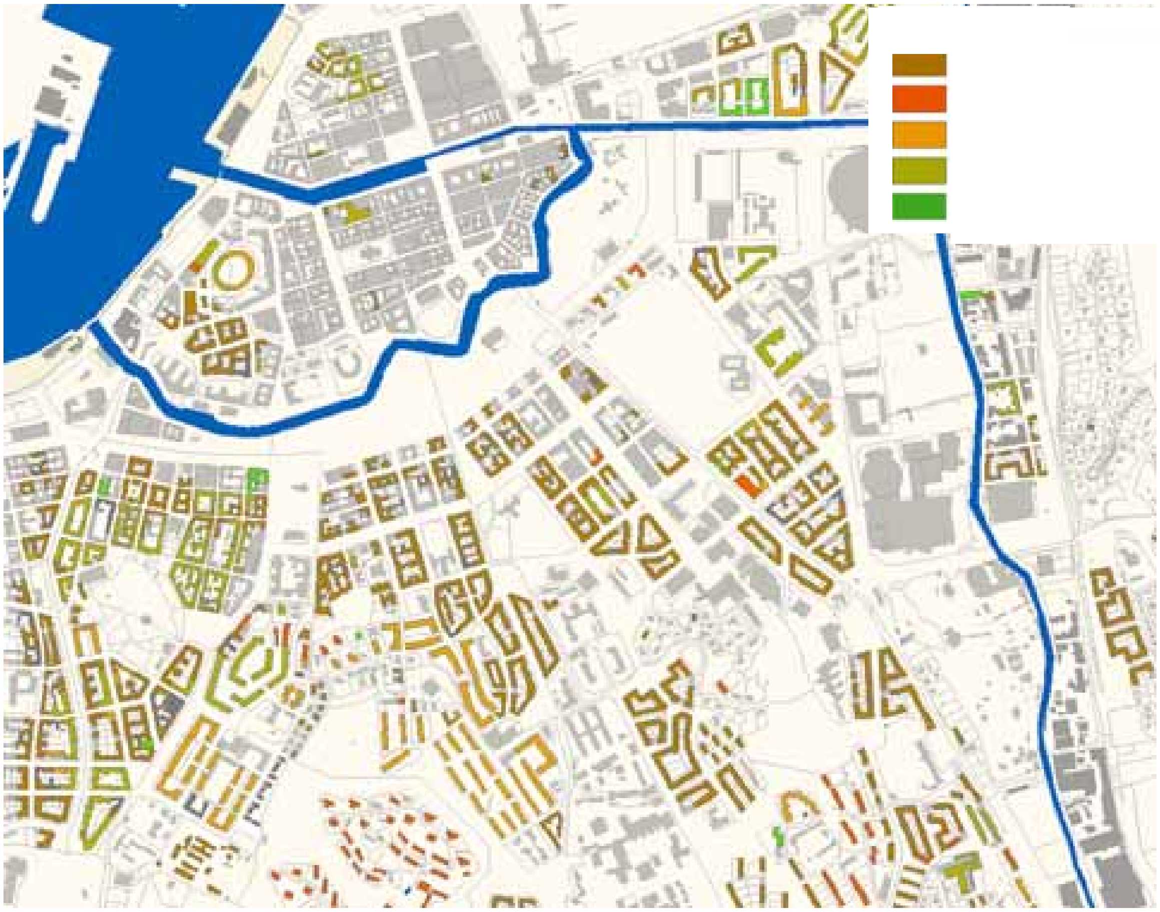


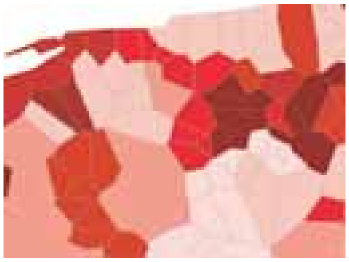
Figure 7. Thematic model for a map sheet.

Information layer 1&2: Population and building coordinates. 23090 persons live in the investigated sheet; there are 612 working places (15 different branches) and 7601 employees.

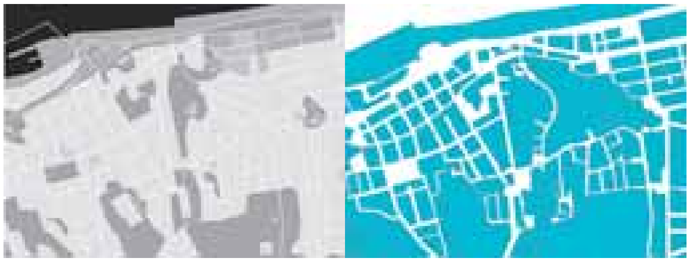
Information layer 3: Buildings and their 3D presentation. The number of buildings is 352, 329 of them blocks flats and 23 industrial buildings (without year of construction). The average year of construction within the map sheet is 1938.

Year of construction	Number of buildings
-1940	234
1941-1960	18
1961-1975	41
1976-1990	24
1991-2000	11

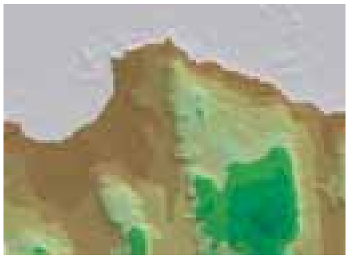
Information layer 4: Energy use within the map sheet for the reference year 2001. Natural gas: 22.133 MWh, district heating: 567.270 kWh, electricity private customers: 99.660.372 kWh, electricity industrial customers: 60.396.764 kWh.



Information layer 5: Roads and parcels.



Information layer 6: DEM.



DISCUSSION

An energy model has been developed which is an integrated part of the building stock model EBSIS^{SD}. Different data sources potential for GIS applications has been investigated and visualized by mapping the energy use on different levels of detail. The chosen data sources have been proven as appropriate but they have some deficits such as inefficient data collection and varying grade of coverage (data from real-estate managers) or to low resolution if buildings are the system-in-focus (data from energy supplier). The data from real-estate managers are interesting, because total values for annual energy use can be obtained for different aggregations, kWh or kWh/m^2, for different type of buildings and for different uses (heating, electrical appliances). Today, unfortunately a lot of manual work is necessary to generate suitable input data from this source. Data from suppliers gives a rather quick overview over the city’s energy use but data can not directly be linked to buildings. However, what is considered as appropriate scale depends on the use of the results: benchmarking or information about a specific building stock. Statistics can compensate lack of data but is only advantageous if total energy flows within an area are modeled. For more integrated results, more data and data manipulation is needed. Worth to emphasize is that mainly real data instead of theoretic calculated data has been used.

What has not been discussed so far is the possibility to geographical multidimensional analysis. To calculate and analyze parcels, real-estates and other spatial variations topologically linked to energy data would imply a considerable potential. In Sweden and other countries all over the world, we have 3-dimensional real estates, implying that the modeled information flows also must work in three dimensions. Today, there is no working topological multi-dimensional GIS-based environment – maybe because software companies are waiting for a stronger market so that research and development is economically advantageous for them (Stoter & Zlatanova 2003). Also, comprehensive calculation operations are needed, demanding fast high capacity computers. When we will see such technology is difficult to know, but it seems on the way, meaning that also research in this field should be intensified to meet up the technical possibilities to analysis, modeling and simulation in multidimensional environments.

The visualizations of spatial and building related environmental data, which normally is difficult to get access to (physically and mentally), function not only as a working tool and a better basis for decision-making but they also gives a further dimension for data interpretation. Visualizations can comprise N-dimensions, the most common ones are 2D and 3D, but also 4D (including a time-perspective) increases, for example, to show changes over time. The visualizations of the study presented here, is mainly based upon 2D and 3D approaches. What type of presentation is the most appropriate one, has to be discussed in connection with the purpose of the visualization and analysis. Management of 3D-properties is one aspect, recognition of the urban environment another one.

More general, visualizations increase the transparency of results and the understanding of relations between local and global phenomena. In the study, the energy model gives an impression about the distribution of the energy use and ‘hotspots’ can be identified. Indirectly it can be seen, which buildings or areas contribute little or much to the green house effect. A red marked building or area in the model illustrates ‘Attention! This building or part of town has a bad environmental performance.’ or a marked building is exceeding certain goal settings. In that way, the energy model and in a longer run EBSIS^{SD} as learning support system, a system supporting planning and decisions towards sustainable management of building stocks.

CONCLUSION

The study shows that energy data from different sources have the information content and the geographically encoding potential to be used and be integrated in one spatial energy model. Besides the common energy data, measured energy data as applied in this study, the model can be extended to include also data and indicators which so far not have been considered, for example, energy related emissions, emissions from processes, energy declarations or buildings which have been got an environmental declaration. For adding more information layers, among others, deep-studies of individual buildings are needed.

GIS-applications with their visualization and analyzing possibilities can be an effective way to make energy data accessible. The study has given the basis for development of visualization strategies for building related environmental data which in the future research must be grow in case studies with concrete users. In summary, the future research on the energy model should focus on completing the database, 3D visualizations, extension of the time perspective, variations between raster data vector data, and finally, development and assessments in cooperation with future users of the system – often at the same time data supplier.

ACKNOWLEDEMENTS

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END NOTES

[1] According to Adalberth (2000) stands the energy use during the use-phase for about 80% of the life-cycle energy use. However, this varies (is less) depending on the buildings real life-time, use of the building and the energy needs for heating.

[2] A new system – BALK (Buildings, Addresses, Flats with map support) has been introduced in October 2002, i.e. after the project data has been delivered.

[3] The map-sheet division for Goteborg exists since the 1930s.

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