GIS-BASED MAPPING TOOL OF URBAN ENERGY DEMAND FOR ROOM HEATING AND HOT WATER

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Abstract:
A GIS-based tool is presented, which generates a grid-based map of the annual energy demand for room heating and hot water in a city. Required inputs are a polygon layer of building outlines and an attached data table with a building type property and the number of floors. Optional inputs are year of construction and measured energy consumption. Output is a raster layer of aggregated annual heat demand on a 200·200 m² grid. It can be used to assess the feasibility of different heating technologies, especially district heating.

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1. Introduction
Energy is becoming expensive and its use by means of conventional technologies, based on fossil fuels, causes emission of greenhouse gases. This leads to the necessity to switch energy conversion to renewable sources with fewer emissions and to reduce the demand for energy as long as renewable energy is not available in abundance.

Demand reduction can be accomplished in two ways: the first way is change of behaviour (e.g. less use of cars, reduced consumption of energy intensive goods). The second way is improving energy efficiency, i.e. increase the amount of useful energy per unit of energy input.

1.1 Urban heat demand
Most energy in European countries is not used for electricity, but for providing heat. Among that, room heating is typically the biggest consumption type. Fig. 1 illustrates this fact with the example of domestic energy use. It shows the shares of energy carriers (natural gas, fuel oil, electricity) in total energy demand. Nearly 70 % of the total demand of about 2500 PJ is satisfied by natural gas and fuel oil. Wood (7 %), district heating (5 %) and coal (1 %) contribute some 13 % together. The remaining 17 % or 450 PJ are accounted to electricity, from which a fraction is also used for heating. Consequently, huge gains in demand reduction can be achieved by reducing energy demand for room heating and domestic hot water.
1.2 Urban heat supply

There are many options to satisfy a given heat demand. Tab. 1 summarizes the most common technologies with indications of key strengths and weaknesses. All except the last entry, district heating, constitute energy conversion units for local heat generation, while district heating describes a different paradigm of heat supply with central heat generation and an attached distribution network. Its main advantage is the higher achievable efficiency of that single conversion unit due to its larger size. Zinko et al. (2008) conclude that cost reduction in heat distribution networks could render district heating economically viable in regions with heat densities down to 10 kWh/(m²·a).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas boiler</td>
<td>+ Low investment</td>
<td>- CO₂ emissions</td>
</tr>
<tr>
<td>Oil burner</td>
<td>+ Low investment</td>
<td>- Needs tank space</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- High CO₂ emissions</td>
</tr>
<tr>
<td>Solid fuel burner</td>
<td>+ Renewable fuel</td>
<td>- Needs storage space</td>
</tr>
<tr>
<td>Heat pump</td>
<td>+ Flexible</td>
<td>- CO₂ emissions (elec.)</td>
</tr>
<tr>
<td>Cogeneration unit</td>
<td>+ High total efficiency</td>
<td>- High investment</td>
</tr>
<tr>
<td>District heating</td>
<td>+ Can be very efficient</td>
<td>- Very high investment</td>
</tr>
</tbody>
</table>

Geothermal energy can be an interesting option in regions with accessible heat sources, but are not easily available everywhere. Solar heat, realised with roof collectors, can contribute a considerable amount of heat for water heating during summer, but is incapable of satisfying base load heat demand during winter. This weakness can be compensated by employing seasonal heat storage, but available technologies (hot water, molten salt) are huge and still too expensive to be competitive.

The decision, which technology to use in a specific case, depends on the local demand structure, especially the density of heat demand. Hence, there is a need for tools to visualise this quantity easily for a huge number of individual buildings.

1.3 Existing heat map methodologies

There are several reported efforts of creating the digital heat map of a city. Blesl (2001) uses 18 building types, e.g. row house, apartment building and industrial estate, assigned to districts. This yields relatively low spatial resolution, but consistent results. Rylatt (2003) use a per-building typology for dwellings applied to Leicester, UK. Properties of individual buildings were derived...
from digital map data, partially by hand, to yield significant results even down to the building level. Monthly domestic energy demands are derived from the detailed model BREDEM-8. Mavrogianni (2009) also uses building shape from map and assigns properties by building type and age to buildings in London. Resulting heat demand is aggregated to districts to overcome errors from generalisation. Strzalka (2010) calculate per-building heat demand by an energy balance according to DIN V 18599 for a residential area in Stuttgart, Germany, with nearly 10,000 inhabitants. Building properties are also assigned by building type (row house, multi-family house) and year of construction. Results show good agreement with measured demand after aggregation by building type, i.e. reduction of user behaviour.

2. Method

The aim of the presented tool is to generate a map that localises the otherwise accumulated heat demand. It is based on a polygon layer of building outlines, together with information about their heights (number of floors), their use (building type) and their age (year of construction). From this data, a grid map of heat demand densities per raster cell in MWh/a is estimated, as described in the following paragraphs.

2.1 Building database

Essential basis for the calculation of total heat demand is the total floor area \( A_{\text{bld}} \). This quantity is supplied by the buildings’ polygon outlines in a GIS shape feature with area \( A_{\text{polygon}} \). A data table attached to the polygon layer contains the number of floors \( n_{\text{floors}} \). The total floor area is then obtained by

\[
A_{\text{bld}} = A_{\text{polygon}} \cdot n_{\text{floors}}.
\]  

(1)

If the building height \( h_{\text{bld}} \) is known, for example from laser scanning, \( n_{\text{floors}} \) can be estimated by

\[
n_{\text{floors}} = 0.32 \cdot h_{\text{bld}}.
\]  

(2)

In order to localise the heat demand of each building in the raster map, the centre point of each building polygon is calculated and stored as an attribute.

2.2 Specific heat demand

Building usage is the main variable that determines the specific heat demand. In this tool, there are nine generic building types, representing the most common (residential, trade, industrial) have two different types for small and big buildings. Residential and office building have different building age types.

<table>
<thead>
<tr>
<th>Building type</th>
<th>Year of construction (and newer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential small</td>
<td>150</td>
</tr>
<tr>
<td>Residential big</td>
<td>125</td>
</tr>
<tr>
<td>Office</td>
<td>130</td>
</tr>
<tr>
<td>Trade small</td>
<td>140</td>
</tr>
<tr>
<td>Trade big</td>
<td>85</td>
</tr>
<tr>
<td>Industry small</td>
<td>50</td>
</tr>
<tr>
<td>Industry big</td>
<td>60</td>
</tr>
<tr>
<td>Other</td>
<td>55</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
</tr>
</tbody>
</table>

Tab. 2: Specific annual heat demand of various building types in kWh/(m²·a) in Germany, partially with different values per year of construction. Data from Schloemann (2002).
2.3 Resulting heat map

Finally, the attributes building type and year of construction select the appropriate value for \( d_{th} \) (kWh/m²/a) from Tab. 2. Together with the total floor area \( A_{bld} \), an estimate for the total annual heat demand in kWh/a is derived per building:

\[
D_{th} = A_{bld} \cdot d_{th} \tag{3}
\]

These values are then summed up per cell of a 200·200 m² raster, according to the location of their centre points. The resulting raster dataset then can be displayed together with building outlines.

3. Result

An exemplary application of the tool is shown in Fig. 2 for part a German city. Shading of the raster cells mark the accumulated estimated heat demand. White polygons show the building outlines. Dark grey areas with high heat demand should be first checked for (a) data inconsistency and (b) opportunities of demand reduction. Where not possible, either because of heritage or in case where high building density causes the high heat demand, the area should be taken into consideration as candidate for a district heating network.

Fig. 2: Building shapes (white polygon outlines) and estimated annual heat demand (grid colours) per 200·200 m² cell in a German city.
4. Conclusion
A tool for calculating a map of urban heat demand for room heating has been presented. It uses a minimum of data (building geometry, usage and age) to estimate the heat demand of a given building stock. It yields a raster map (200·200 m²) of cumulated demands in order to reduce the impact of user behaviour, which renders the estimation meaningless on a per-building scale. The main application of this tool is the identification of areas with high heat demand, which could be targets for renovation measures and/or district heating networks.

References


