Towards « Energy Efficient Cities »

Optimising the energy, energy and resource efficiency of the demand and supply side on settlement and community level

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ABSTRACT: To improve the overall energy efficiency in community systems the mere focus on single component optimisation runs short in effect. To display and analyse a holistic energetic community system is a promising approach and solution for decision makers and urban planners. Based on a GIS data base the city of Wolfhagen attempts to create a tool which will enable them to optimise their overall energy performance as a complex and interactive system. This includes the analysis of the energy demand side represented mainly by the building stock, the electricity sector and the transportation sector. The heat demand for thermal comfort in buildings accounts for approximately on third of the total energy demand profile of the community. To step forward in the analysis, a heat demand cadastre forms a basic data source for further optimisation on the supply infrastructure. The approach and first results are presented in the following.
Keywords: energy, GIS in energy planning, heat demand cadastre

CONTEXT

Despite the fact that energy, climate and sustainability rank high on the political agenda and many municipalities have set ambitious targets on this issue (zero-CO_2 commune), the successes in practice, particularly in the building sec-tor, often fail to fulfil the high expectations. This is caused by numerous obstacles that span the administrative and judicial level, as well as planning and technical sectors.

Nevertheless communities are obliged to take their burden-share in fulfilling the Kyoto-protocol targets of their countries. The building sector in Germany and many other central European countries accounts for more than one third of the total energy demand followed by the transport and industry sectors. The necessity to use energy in the most efficient and economical way should therefore be an essential interest in municipal policy strategies since may have very central influence the energy related fields. Most municipalities have in the past not addressed this issue, but with rising energy prices which affect both local residents and industries, the awareness has significantly risen and numerous projects have been started.

Looking at the present situation of the realisation of energy projects on a community level, it can be stated that, that in the majority of cases single measures are being applied without a general energy implementation strategy (renovation of one single municipal building, photovoltaic plant, biomass plant). The potentials of a holistic analysis and approach are on municipal level mostly either unknown or unrepresentable. The invested economic power does not achieve optimal results regarding the energy and CO_2 –emission reduction. The implemented measures are not communicated sufficiently among the relevant actors and regarding the entire systems the results are neither monitored nor measurable. With this municipalities lack the next to a monitoring tool also the possibilities to quantify and communicate success.

APPROACH AND METHOD

The key concept is to regard the municipality as “energy system“ in a geo-graphically defined system area, as it represents a collective system of energy consumers (sinks) and energy sources in the form of different actors (residents, local government, utilities, industry and trade) with different profiles of energy use. In the context of the energy system “municipality”, the building stock is only next to transportation and consumer sector one of the largest energy demanders and of the highest saving potential. For the time being, the majority of residential buildings appear to be on the demand side due to heating and electricity consumption. Yet buildings of other usage like industry, trade and service buildings as well as future high efficiency residential buildings (plus-energy-buildings) can offer the potential to become energy producers at times.

The evaluation is carried on from final and primary energy approaches (CO_2 emissions) to an exegetic, see

[Annex49 2008], perspective and is displayed on basis of simplified categories (electricity, burnable fuels, heat at different temperatures). Both renewable and fossil energy portions are balanced. On the demand side this results in a geo-referenced energy and exergy inventory of the municipality that exhibit the distribution of sinks in the first step. The work is set upon available research on the different aspects of building related energy demand and eventually harmonises them on a geo-data based platform [ESRI, ArcView].

Fig. 1: Using GIS-based database the location of different sinks and sources within the balance boundaries can easily be identified and referenced [Negash 2008].

IMPROVING OF ENERGY SUPPLIES ON A LOCAL LEVEL

Within the balance area of the community in a first step the energy demand profiles are being evaluated. This is being achieved by grouping the different profiles into a typology of similar structures according to heat, cold and electricity demand, load duration curve profiles and area characteristics. Most low-exergy uses are heat applications that show a large variance in time and load.

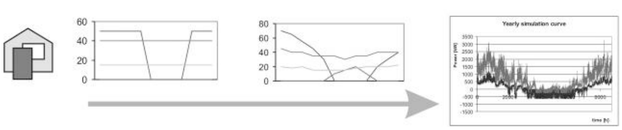

Fig 2: The definition of load duration curves is crucial to the improvement of exergy use, therefore simulation results should be aimed at.

An optimised connection between the demand and the supply side can only be achieved when both fort he demand and the supply side the load duration curves are well known.

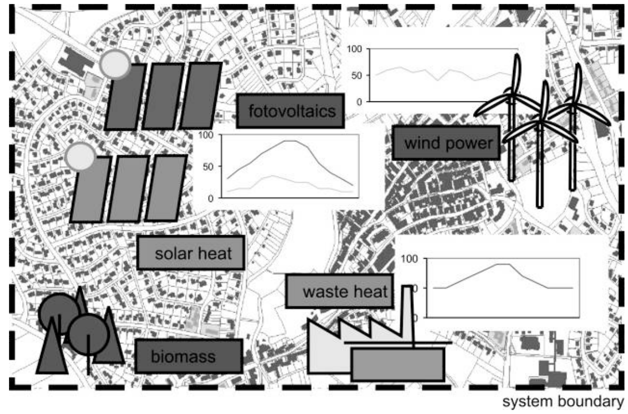

Fig. 3: Options for local energy supply displayed in the GIS data base.

In the next step the exergy potentials within the boundaries are analysed. In the majority of cases these are low-exergy renewable energy sources like geothermal heat, solar energy and industrial waste heat. To some extent high-exergy sources like biomass and wind energy can be included. To use the available lo-cal sources to the maximum extent, structures have to be established to allow a "cascading" use of the available sources. For this the location of both sources and sinks are crucial, since only in close neighbouring an economic connection for heat transfers such as by district/local heat grids can be realised. By using the locally available exergy potentials, the import of high-exergy and mostly fossil energy carriers can be minimised and limited to locations where no grid-connection is feasible.

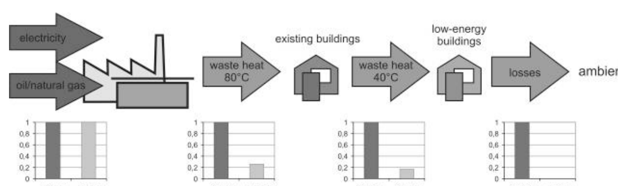

Fig. 4: Principle of "cascading" until full use of exergy content.

Balancing the imported and exported energy carriers on a local level indicates the level of self-sufficiency towards a zero-carbon-community. Even net-plus-energy concepts are possible, especially for rural communities with large biomass potential or good wind locations.

The geographical area of the municipality is limited and often subject of competing interests, that have to be solved in the course of urban planning. The same piece of land can only be used either for a new settlement development, for the production of biomass for energy or for environmental compensation measures. With improved energy saving measures the locally available area and resources can be used increasingly to meet the total demand. In practise, the indicators are geographically displayed in order to decide which available technologies fit best to the local conditions, especially for the work on space demand and potentials of the different renewable energy sources. The overall goal is to include optimised energy use into everyday urban and region planning procedures and to supply the needed information and tools for a sustainable development of municipalities.

COMMUNITY CASE STUDY: DEVELOPMENT OF A HEAT CADASTRE FOR THE CITY OF WOLFHAGEN

The city of Wolfhagen serves as a middle centre in the heart of Germany. It has approximately 14,000 inhabitants who live in the ancient city and the eleven outer city districts and villages. The city encounters the typical problems of a rural community in an economically rather weak area in central Germany. To en-sure the continuous stable development of the past decades for the future, the city council decided on an ambitious energy transformation process with the goal of supplying the full electrical energy demand of the city by means of 100% renewable local sources. To not limit the scope of energy supply to the electricity sector but to come to a holistic strategy, including all relevant energy consumption sectors, the city of Wolfhagen initiated a research and develop-ment project in cooperation with an interdisciplinary team of researchers to analyse the most efficient and promising strategy. With this approach the city of Wolfhagen successfully participated in the "energy efficient community con-test" launched by the German Federal Ministry of Education and Research in 2008 [BMBF 2008]. The scope of the contest is to develop holistic energy efficiency strategies for communities taking into account not only technical feasibility but also implementation strategies on political level and citizen participation. Out of the fifteen selected communities in the second phase of the con-test, three to five will then be financially supported over a period of three to five years in the implementation phase.

For Wolfhagen, next to the development of a renewable electricity supply, which shall be realised by a small community-owned wind park of three wind mills, the main focus is on retrofitting the existing building structure and introducing an electricity-based efficient transportation solution. To monitor the success of the strategies and to come to an integrated planning tool in the earlier described sense, an energy demand inventory for the old city of Wolfhagen has been worked on by the Fraunhofer-Institute for Building Physics in the course of the year 2008 as preparatory work for the research project.

DATA SITUATION IN WOLFHAGEN

A common situation in German towns of comparable size like Wolfhagen, is that there are no community-wide databases on energy demand structures. The local building authorities are in charge of the designation processes of new building development areas. Since the 1990s this is done on a GIS-based standard software which allows the community planners to perform mostly standardised processes in the context of development plans and property administration. Energy issues are so far not included at all in these data bases. For Wolfhagen there could be no information obtained neither on the thermal insulation situation of the existing buildings nor were the actual construction dates implemented into the data base. Although obviously all this information could theoretically be obtained on a one-by-one bases from the (paper-) documents and archives at the local building authorities, this would have meant an out of scale amount of work for a total inventory. Therefore the work focussed on options to simplify and generalize the data acquisition.

The basis of the heat demand cadastre was the "Automatisierte Liegenschaftskarte [ALK 2008]" the digital general land registry map of the city of Wolfhagen. This data base contains information on the plots of land, borderlines, administrative borders, buildings, types of use and traffic areas. The ALK for Wolfhagen does not contain any information on geographical elevation, slopes or building heights. Nevertheless from the ALK the basic information on the total building areas of Wolfhagen could be drawn. In a first approach to a full heat demand cadastre the attention was focussed on the residential buildings, which are the majority of buildings.

PROCEDURE OF ANALYSIS

To exclude all unheated adjoining buildings like garages, sheds and buildings of the community services like transformer buildings there was a size limit set to the buildings taken into account as heated spaces. This limit was set to 25 m^2 of ground area, meaning that all building smaller than the limit in their base floor area were filtered from the data base. The limit was found by analyzing the size distribution in the data base, setting the limit at a point where a large number of typical floor areas, which are the garages, could be found. For a plausibility check these building were displayed on the map (Fig. 5).

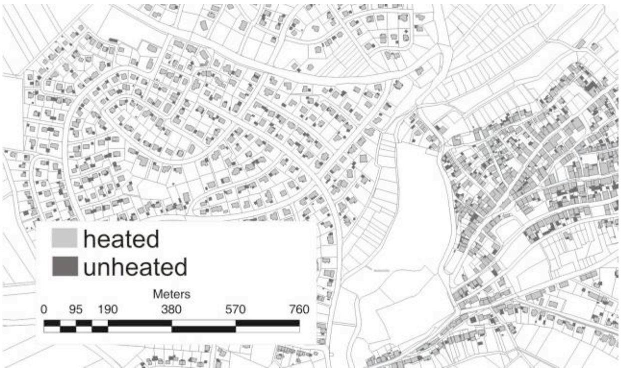

Fig. 5: Map extract of Wolfhagen for area plausibility.

The total number of residential buildings in Wolfhagen after filtering the small auxiliary buildings from the data base, resulted in 1,740 heated residential buildings which quite well matched the estimate of the local building authorities.

The next steps toward an estimate of the total heat demand was the evaluation of the building heights and number of stories to come to a total heated floor space. Also the building age and building type had to be estimated to rate the thermal standard of the buildings. Since there was no digital data on this avail-able, a brief data assessment on site became necessary. Some information regarding the building types, such as detached single family and duplex houses, row houses and multi-family houses could already be drawn from the aerial photographs that were available in a geo-referenced format. Building structures are, neglecting the ancient town centre, very well recognizable (Fig. 6). Based on the photographs there was a first building typology created, which then could efficiently be checked for plausibility during the on-site assessment.

Fig. 6: The aerial photograph already shows the building typology.

The preparatory work for the on-site assessment included the transfer of the map based development plans, dating back to the early 1950s into the GIS-database. These maps covered only the areas under development. From these maps the information on the building periods, and also the buildings already existing in the plans at the time of the developments could be analysed and referenced in the GIS-maps. Within a two-days on-site assessment, which was mostly limited to a street-wise analysis of building stories and the plausibility checks of building areas and types, a preliminary building typology of Wolfhagen was created.

ENERGY DEMAND OF THE EXISTING BUILDING STOCK

To assign the residential buildings a typical heat demand, the area profile of the existing building stock in Wolfhagen was compared to the German building ty-pology published by the Institut für Wohnen und Umwelt in Darmstadt [IWU 2007]. This was done in a first step to make a plausibility check of the calculated areas including the estimated or roughly assessed building heights and number of stories. It showed that, compared to the German average, the few multi-family buildings in Wolfhagen are significantly smaller, here differences up to 54% in the average heated building areas occurred. The areas of the detached single-family buildings and duplex buildings showed a good match with a maximum difference in the average heated floor spaces of 11%. The large differences for the multi-family buildings can be explained by the rural structure of the town, where only very few and rather small multi-family buildings exist. During the site-visit these were explicitly checked to validate the data. The building typology for Wolfhagen (Fig. 7) was then transferred into the GIS-Database (Fig.8). On the map the development of the town over time is well visible.

Fig. 7: Excerpt from the Wolfhagen building typology.

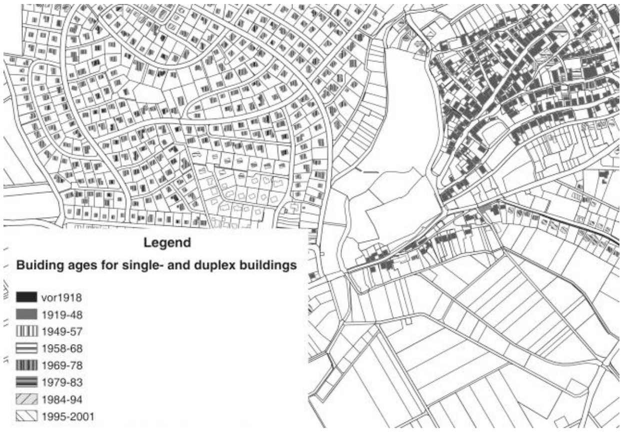

Fig. 8: Map extract showing the distribution of the Wolfhagen building typology.

The heat demand was then assigned according to the building typology on the basis of the study of the Gesellschaft für Rationelle Energieversorgung [GRE 2007].

The evaluation of the data base clearly shows the structure of the town development in Wolfhagen. The town was largely built between 1949 and 1978. Also the old town centre built mostly before 1918 accounts for about one third of the total area.
The heat demand as well reflects the situation in the existing building stock. The old centre accounts for the largest total energy demand. Also the single-family buildings of the economic boom period in Germany should now be the central focus of refurbishment measures.

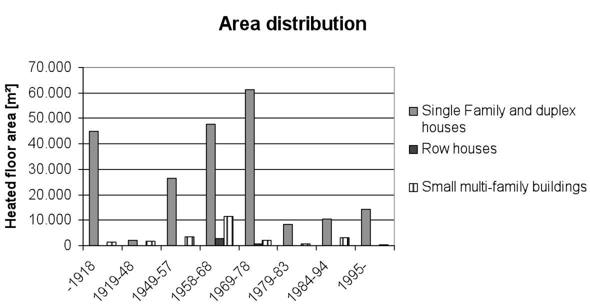

Fig. 9: The distribution of total heated areas shows the dominance of single-family and duplex houses in Wolfhagen.

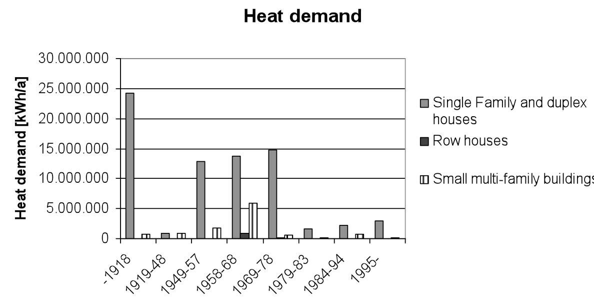

Fig. 10: The distribution of the total heat demand shows the buildings that should have priority in the renovation measures.

CONCLUSION

The estimate of the heat demand of a small scale rural town is feasible with an appropriate effort, even when the available data is incomplete. The current status of the pre-study gives a good foundation for further analysis in the course of the BMBF research project. The GIS platform has proven to be a good and well to use tool to easily process and check large amounts of data. Also it offers many options for targeted visualisation for the communal participation processes (Fig. 11). In the course of the oncoming project the next steps will be to include further available data on the non-residential buildings and to inte-grate the electricity demand of both households and local industry and trade. At that point also the differentiation between the different energy sources from the exergetic perspective will have to take place. First approaches of an exer-getic evaluation of community systems is currently being developed in the scope of the ECBCS Annex51 mainly by the interest of the Dutch participants. To validate the assumptions on the heat demand, a household survey shall bring fruitful information on the actual energy consumption and improvement potentials. The comparison of these results and the estimated heat cadastre will bring useful information on the assessment accuracy and procedures. To fur-ther develop the tool into a useful decision making and monitoring tool, the in-formation needs and interfaces will have to be defined and introduced to the local building authority.

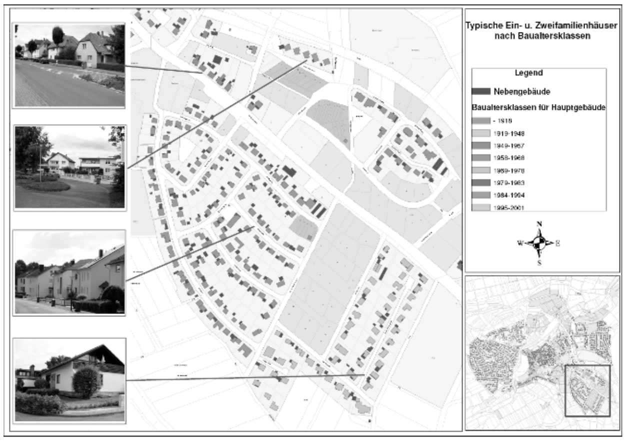

Fig. 11: Example of a map generated from the GIS-database for a communal information event on the research project.

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