ENERGY BALANCE OF URBAN QUARTERS FOR THE DEVELOPMENT OF ENERGY EFFICIENCY AND MANAGEMENT STRATEGIES

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Summary:
As a historic and contemporary operational scale in the development of European cities the urban quarter represents a favourable platform for the planning and implementation of energy efficiency and management strategies. This paper argues that the whole potential of the efficient use of resources can only be obtained with approaches tailored to the characteristics of urban quarters. Therefore, after the underlying rationale has been developed aspects of energy supply and demand specific to urban quarters are discussed. This includes also the identification of possible links to social science addressing questions of lifestyle or consumer choices in connection to the social dimension of urban quarters. Finally first steps towards an energy balance for urban quarters are identified building on the characterisation of energy relevant aspects in the urban context as well as the assessment of the performance of individual buildings.

Key Words:
energy efficiency, integrated urban planning, energy assessment, urban quarter, neighbourhood
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1 INTRODUCTION

Today nearly 90 percent of the German population lives in cities (BMVBS, 2007) the ratio thus even exceeds the European average of 75 percent. At the same time heat accounts for 59 percent of the total German end-energy balance and is therefore the most important form of energy in Germany (Erdmenger, 2007). The need for action imposed by climate change therefore especially requires mitigation strategies targeting urban areas as one of the mayor fields for the implementation of energy efficiency measures and the promotion of renewable energy resources. In this framework communities and cities respond in the form of local climate protection strategies (see Düsseldorf, 2005; Heidelberg, 2006; NRW, 2000) that encompass a wider range of sectors but usually address the building sector as a key component. The focus is often put on individual buildings both public and private neglecting that also the “[u]rban design, including the clustering of buildings and mixing of different building types within a given area greatly affect the opportunities for and cost of district heating and cooling systems” (IPCC, 2007) and thus the efficiency and applicability of a range of energy supply systems. Solutions aiming at buildings in the form described tend to not give a holistic image of the potentials and will not deliver integrated planning strategies. It is thus assumed that in the analysis of energy efficiency strategies the scale largely influences the choice of measures or technical solutions applied. Consequently an enlarged system boundary holds possible benefits in order to increase the energy efficiency and enable a sustainable development of urban areas. The demand for an integrated planning approach therefore also questions the scale of individual buildings as the scale at which urban decision makers should take action.

2 URBAN QUARTERS
2.1 Socio-Spatial Aspects
From a historical European perspective the urban quarter can be regarded as a building block of the expansion of cities and the development of urban areas (Albers, 1983). Well known and clearly defined examples are the blocks of the period of promoterism and the residential developments of the 60’s to give just two examples of historic urban forms. Today the quarter as an operational scale of urban development still remains relevant even though, in recent times an increased activity in the conversion of existing parts of the city can be observed (Breuer, Schmell, 2007). In their study on contemporary concepts of urban quarters the authors define the term „urban quarter“ as an area built up according to a homogeneous urban concept with a size of above 500 residential units. For the competition “ÉcoQuartier” launched by the French Ministère de l'Écologie, de l'Energie, du Développement durable et de l’Aménagement du territoire (MEEDDAT, 2008a) three categories were introduced for urban quarters. These are areas with less than 500 inhabitants, between 500 and 2000 inhabitants and above that number.
Although the given definitions seem quite weak it illustrates the fact that the term “urban quarter” holds different layers of meaning that seem inseparably interlinked. On the one hand those areas recognisable as quarters tend to have a relatively homogeneous morphology as they are often created as historic or recent urban development areas following a coherent scheme with a similar building age. On the other hand any meaningful definition of urban quarters includes a social dimension. The word “quarter” is also commonly used to describe an area inhabited by a certain social or ethnical group. Though, in this dimension the definition seems harder to locate as the area of the social quarter is defined by a social network or system of social relations, it is none the less important. A prominent historic example of such a social definition forms the “Quartier Latin” in Paris. The German research programme “Soziale Stadt” also builds on the strength of the social coherence of urban quarters as it “works on the premise of area-based, socio-spatial action and active resident participation”(BMVBS, 2008). Galster (2001) suggests ten spatially based attributes defining a neighbourhood: structural characteristic of the buildings, infrastructure, demographic characteristic, class status of residents, taxes and availability of public services, environmental characteristics, proximity to mayor destinations, political characteristics, social networks, identification. As noted above the two dimensions seem quite difficult to separate but to cover comparable areas as strong dependencies can be expected from the build form resulting in a common condition of the housing stock and therefore a certain level of rents. Also larger changes in the built structure such as road infrastructure will result in a division of homogenous urban plan but will at the same time also limit social exchange across this border, as Jacobs (1971) described in the “The death and life of great American cities”. Even though the duality of the description poses practical problems in the definition of the system boundary it also points at the suitability of the scale of urban quarters to implement measures to enable a sustainable urban development as it seems to allow for the application of energy efficiency measures to a relatively homogeneous structure and in parallel to involve an already defined social group in urban development processes.

While this paper focuses on the assessment of energy efficiency strategies by the development of an energy balance for an urban quarter the inherent social structure of an urban quarter seems nevertheless important when discussing possible energy management strategies.

2.2 The Politic Discussion

In close connection to the technical and social aspects of urban quarters described above a political discussion of energy efficiency strategies on this specific scale has recently been articulated. In the French context the concept of an “eco-quartier” was developed during the Grenelle de l’Environnement (MEEDDAT, 2008b). Until 2012 it is envisaged to construct at least one eco-quartier in the communities with a considerable development plan in place1 (ADEME, 2008). Similar yet more technical approaches are explored in the German research programme EnEff:Stadt by promoting efficiency measures on a neighbourhood level (Kratz, 2007). In addition social aspects on the level of neighbourhoods are considered in the German programme “Soziale Stadt” that started in 1999.

The need for an enlarged scale of the assessment is also implicitly brought forward by the discussion of energy efficiency standards for individual buildings. Today the notion of “Positive-Energy Buildings” gains more and more support (Maugard, 2008). “Positive-Energy Buildings” are defined through a positive energy balance, in other words such buildings produce more energy than they actually consume. On the first sight this seems merely a continuation of the evolution from low energy to passive houses - another step in a homogeneous development. In fact the terms “Positive Energy Building” and Passive House are often used as synonyms. In contrast to this view it can be argued that the switch from passive to positive energy houses as a defined goal resembles rather a change of paradigm for the energy infrastructure to supply those buildings. Firstly it would no longer be sufficient to understand buildings as the demand side of an energy system. Consequently buildings then will have to be also regarded as part of the supply side at the same time. In current approaches towards “Positive Energy Buildings” mainly electricity accounts for the supply side of a building’s energy balance (Heinze, Voss, 2009). The electricity is generated on site by the means of photovoltaic, combined heat power (CHP) or combined cooling, heat and power (CCHP). This idea of counterbalancing the heat demand is also considered in the new German Energy Savings Directive (EnEV 2009) that allows for the reduction of the calculated end-energy demand for a specific building when electricity is generated in direct spatial connection to the building and the electricity not consumed is fed into the grid (§5, EnEV 2009). The limitation to electric power in the German context seems to be a consequence of the availability of a usable grid and a defined market mechanism in the form of the Renewable Energy Sources Act (EEG) and the CHP Act (KWKG). From a technical point of view, however, also the different flux of heat losses could become a relevant part in a buildings energy balance as they become more and more exploitable as usable (i.e. controlled) flows of energy for example in mechanical ventilation systems. Consequently a political commitment to the introduction of positive energy buildings induces a need for new calculation procedures to describe neighbourhood heating networks or local area grids when looking at the energy balances of such advanced buildings. The balance of a building block or an urban quarter therefore seems a necessary prerequisite to grasp the full technical and economic potential of positive energy buildings.

3 ENERGY IN THE URBAN CONTEXT

Until now the case has been made to enlarge the scale of energy assessment to include whole neighbourhoods. With such an increased scale also aspects specific to the urban context become visible for the first time. Looking at the urban scale of energy efficiency projects Kratz (2007) states that due to the complex interrelations between renovation and energy supply system a method that goes beyond the assessment of single buildings of the same use is needed to analyse the integration of energy efficient renovation measures, efficient supply systems and new

2 In the French context these are referred to as Bâtiments Energie Positive - BEPOS
3 “Tous les bâtiments et équipements public devront être construits dès maintenant (2010) en basse consommation (50 kWh/m2) ou seront à énergie passive ou positive. » (Maugard, 2008)
4 EEG - Erneuerbare-Energien-Gesetz, Gesetz für den Vorrang Erneuerbarer Energien, as of 25. October 2008
5 KWKG - Kraft-Wärme-Kopplungsgesetz, Gesetz für die Erhaltung, die Modernisierung und den Ausbau der Kraft-Wärme-Kopplung, as of 19. March 2002
technologies and to discover existing synergies. In the following three main aspects will be further investigated that seem relevant to the defined scale within the urban context. These are:

- the scale of energy supply systems
- energetic aspects specific to the urban morphology
- the cascading or coupled usability of energy

3.1 Scale of Energy Supply Systems
As noted above the assessment of single buildings and their mere addition will fail to consider certain measures or technologies that are either for technical or for economic reasons not applicable to small consumers. It is only by combining a number of consumers to one bulk buyer that those technologies can provide alternative strategies as Nast (2004) points out. In its original context this statement is referring to neighbourhood heating networks but might as well be applied to other technologies such as the use of waste heat. Neighbourhood heating networks with either a pure heating or a combined heat power (CHP) conversion technology are widely promoted as especially the latter generally deliver a higher overall efficiency than the separate generation of heat and power. In the German context a national target of 25 percent of the total power generation is defined in the current CHP Act. As the operating hours of CHP units are usually oriented to meet the heat demand and not towards a specific power output the systems are dependant on a high density of heat demand. Woods et al (2002) describe the advantages especially in the environmental assessment on large scale CHP systems compared to individual solutions. Even though high electric efficiencies can be reached in the small scale systems a high CHP coefficient makes this segment less suitable for the implementation (ASUE, 2005). This underlines the relevance of scale even with regard to established technologies such as CHP systems. Therefore the assessment should allow varying different scales of systems as will be discussed below.

3.2 Energetic aspects specific to the urban morphology
As explained above the assessment is explicitly directed at urban areas. As the view is enlarged also specific aspects of different locations in the city can be included in the evaluation of projects. These characteristics include a range of factors influencing energy supply systems and the structure of demand in dependence from the urban morphology.

3.2.1 Passive Solar Gains
In current planning practice the most prominent characteristics of the urban form that influences the energy efficiency is the optimisation of solar gains. While the optimisation itself plays a role in the development of new settlements (Wortmann et al., 2008) also in the existing building stock specific characteristics can be linked to building typologies including the density and height of buildings (Everding, 2007). The influence on the total energy demand, however, greatly depends on the building’s performance. The passive solar gains through transparent building parts will only play an important role with an increased performance of the buildings as

6 Own translation after (Kratz 2007)
Figure 1 illustrates. The values refer to a renovation project of a residential building of the late 50’s using passive house components (Koch, 2007).

**Figure 1 : Monthly heat demand of a residential building before and after renovation in relation to solar and internal gains**

Source: Own calculation after DIN 4108-6 referring to the implemented measures

3.2.2 Costs of infrastructure

Another aspect largely influenced by the specific location of a project is the costs of the infrastructure, e.g. heating networks or local electricity grids. On the one hand the density of urban areas is resulting in a relatively high heat demand density and therefore is favourable for the financial viability of heating networks so that there is a negative correlation between density and costs for this type of infrastructure including the operation (Siedentop, 2006). On the other hand construction costs greatly vary with the different surfaces of road infrastructure. An inner-city area can therefore be expected to have significantly higher costs as road surfaces will have to be restored. Jentsch et al. (2008) show that as a result heating networks in rural areas can also be financially viable in those cases where flexible piping systems in simple trenches can be used. Both factors will have to be considered in an economic assessment as it can be expected that the resulting costs should vary from building blocks to whole quarters as the latter scale will certainly include costs for the restoration of road infrastructure. In the cost assessment of the above quoted project it was concluded that “the restoration of the tarmac surface is generally resulting in higher costs than the complete building costs when using flexible pipes under unsurfaced (non-tarmac) surface”  

7 „Besonders deutlich wird in dieser Abbildung [Anm.: Abb. Kosten Netzbau], dass die Oberflächenwiederherstellung einer Asphaltierung in der Regel mehr kostet, als der gesamte Netzbau bei Verlegung flexibler Rohre unter unbefestigter Oberfläche.“ (Jentsch et al., 2008)
3.2.3 User Behaviour
The social dimension of urban quarters has already been discussed above. In relation to this the sociological concept of lifestyles\(^8\) could allow to describe energy demand more precisely (Prose, Wortmann, 1991). Lifestyle approaches consider not only classical social stratification criteria such as income and educational level, but also include the normative dimension of peoples’ life. Based on the concept of lifestyles, types of consumers that are likely to display different patterns of energy consumption could be identified. It remains to be tested, however, how strong such lifestyle patterns will influence the energy demand. As the decision for a certain surrounding reflects individual lifestyles or milieus (Otte, 2008; Hammer, Scheiner, 2002) the analysis should also consider specific behavioural aspects of energy demand. Similar to passive solar gains user behaviour for example in connection with manual ventilation will become more important with rising building standards (Richter et al. 2003). Regarding the implementation such an approach might also be suited to make assumptions on the acceptance of certain technologies or the preparedness to invest in certain measures.

3.3 Cascading usability of energy
In the above quoted progress report on heat\(^9\) Erdmenger (2007) explicitly points towards the down welling or coupled usability of energy stating that substantial substitution effects lay in its consequent application. With rising energy prices the exploitation of waste heat as a source for the supply of other uses becomes more viable as the exploitation costs can be expected to stay constant or even be reduced as standard components can be employed. To understand the full potential all energy intensive process within the given boundary of a quarter will have to be further investigated. Current pilot projects show the feasibility of the use of sources like waste water (Piller et al., 2004). It seems, however, that yet few assessments of all the relevant processes have been conducted. And even though the greatest potential is assumed in the use of waste heat from processes also in the residential sector different temperature levels can be identified resulting from the age of the installation and the distribution system. While new buildings use energy on a rather low temperature level (e.g. 35°C/28°C with floor heating systems) old buildings use temperatures up to 90°C as a flow and 70°C as return temperature in connection with radiators and old boilers (DIN V 4701-10\(^{10}\)). The assessment of the potential synergies will be further described under 4.4.

In any case the coupling of heat sinks and sources involve means of distribution in the form of heating or cooling networks of different size. The number of connected entities will therefore vary depending on the clustering of different sources of waste heat in comparison to the heat sinks within the quarter. To optimise the use of energy the two should have matching characteristics in the amount of usable energy and the demand as well as their temporal availability. Figure 2 illustrates the structure of an integrated network of heat sinks and sources differentiating endogenous and exogenous sources of energy.

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\(^8\) or similarly: social milieus
\(^9\) “Sachstandsbericht Wärme”, (Erdmenger, 2007)
\(^{10}\) DIN V4701-10:2003-08 Energy efficiency of heating and ventilation systems in buildings - Part 10: Heating, domestic hot water, ventilation
As it is only by the possibility of trading energy that the connection of energy supply and energy demand provides a potential for energy management strategies (Heidelberg, 2006) eventually the precise location of the individual processes will have to be considered as further described in the following.

4 METHODOLOGICAL APPROACH

4.1 Objective

In order to provide guidance in the planning process of energy efficient urban redevelopment projects the objective is to develop a methodology that describes the energy balance of urban quarters building on an integrated assessment of energy efficiency measures and efficient supply systems. An energy balance is in this context understood as an assessment of the heating or cooling demand (i.e. the amount of heating or cooling the system has to deliver) and the energy demand that has to be provided to the system. In addition the energy balance shall be described in a level of precision that allows for the investigation of expected synergies in mixed use quarters. Reflecting the spatial definition of the system boundary the method to describe the
energy balance is seen as an integration of approaches on different scales. Therefore elements of a bottom-up approach will be included to classify individual buildings or zones. On the other hand the discussion of the relevance of the urban morphology made it obvious that also elements of a top-down approach will have to be included to describe the characteristics of the urban quarter as well as the specific setting within the larger urban context.

4.2 Description of the system and subsystems
Changing the scale of the assessment raises the question of how to link the two spatial spheres. From a general point of view the benefits of the overall scale of an urban quarter have been discussed above. The in depth analysis of possible efficiency potentials and their localisation within the system will at least to a certain degree require calculations of single buildings or supply systems as sub-systems. It is therefore expected that the number of buildings (i.e. the size of the area) should be limited due to the rising complexity of the calculation. The increase in the number of actors and interest groups involved could eventually prove as another limiting factor. As a result the scale of the system boundary of the energy balance should be large enough to allow for different technical solutions to be included in the assessment but should on the other hand be as small as possible to limit its complexity. In connection with the need to localise heat sinks and sources within the quarter a stepwise calculation of subsystems is suggested to identify efficiency potentials and to allow for the definition of individual characteristics on different levels. Figure 3 illustrates a possible proceeding from small to larger scales calculation different subsystems.

![Figure 3: Scales of Balancing Steps: From Zones to Quarters](Source: Own Illustration of the author)

The smallest entity is defined as an individual zone characterised by a certain use and time pattern. In addition to the resulting demand zones can include supply systems or provide for
energy storage. Different zones are then aggregated to individual buildings as also suggested in normative approaches such as DIN 18599. Together with non-building consumers (e.g. street lightning) or sources these are then grouped to form areas (i.e. building blocks) of which a certain number forms the urban quarter. The expected benefit of the proposed proceeding is to localise the potential synergies on the smallest possible scale to minimise the size of distribution networks and therefore losses. At the same time characteristics applicable to a building, area or a whole quarter can be included at the corresponding scale.

4.3 Temporal resolution
The inclusion of cogeneration will further require a high temporal resolution of the energy balances to allow for a meaningful cost-effectiveness analysis (VDI 4655) which as discussed is also true for the use of waste heat. The modelling of the energy flows therefore has to rely on load profiles in combination with quasi steady state or simplified dynamic calculation procedures on the level of single consumers (i.e. zones or buildings) to arrive at an aggregated energy balance for an urban quarter. It is assumed that at least an hourly resolution should be attained to provide for the needed accuracy.

4.4 Thermodynamic description
Especially the assessment of the potential to reuse waste heat requires other means in the description of the energy balance as commonly used in the planning procedure. While heating systems are laid out to meet a specific demand the availability of waste heat depends on the effective use of heat exchanger in the system. Therefore the temperature level and the mass flow will have to be described, which suggests the use of enthalpy instead of energy as the relevant thermodynamic description.

A proceeding analogue to the pinch analysis as pursued by approaches such as (Girardin, 2008) seems promising to model these specific energetic aspects. In analogy to coupled industrial processes different levels of temperature possibly could be described within urban quarters even though these processes remain on a relatively low temperature level. In this form of analysis temperature and enthalpy of cold and hot processes are combined to form cumulative curves (Linnhoff 1982). The overlap of these curves then corresponds to the maximum quantity of heat that can be recovered within the system. In more recent approaches the methodology was successfully applied to non-industrial uses as hospitals (Kemp, 2007). Still this only shows half the picture as all the processes in the urban context are more or less immobile. The question of localisation already raised above remains another aspect to be included in the description of the energy balance of urban quarter.

4.5 Spatial description
Besides the characteristics of the location of an urban quarter and its relation to the whole urban agglomeration the spatial description of the single entities of the energy balance illustrated in Figure 3 has a strong influence of the usability of different urban energy sources. After the description of a theoretical potential the localisation of processes will be a prerequisite to assess losses and costs of the energy distribution network. The spatial analysis would then lead to the technical potential which needs to be considered when discussing the benefits of possible energy management strategies.
In addition to technical aspects such as the evaluation of the efficiency of energy distribution systems the spatial descriptions could also provide for an interface to open a mere technical discussion to other disciplines. The relevance of lifestyles in the choice of localisation for residential areas is just one example where benefits from an interdisciplinary approach can be expected.

5 CONCLUSION

It has been shown that in the energy assessment in addition to the scale of single buildings and whole urban areas the specific scale of urban quarters can be identified. The definition will in any case rely on aspects of the urban morphology or built form as well as on existing social networks and characteristic lifestyle patterns. Current research programmes were described in brief as an expression of a political focus on the subject.

Specific questions of energy in the urban context were explored to show potentials of an energy balance on the scale of urban quarters. At the same time interdisciplinary questions were raised that would allow to integrate professionals from other disciplines both in research and practice.

First steps towards a method to describe the energy balance of urban quarters were described. The method eventually will allow for an assessment of the efficiency of the use of energy resources in a given context as well as to identify potential synergies between the various heat sinks and sources in the urban context. A link to the planning professionals involved as well as the assessment of infrastructure costs could be made via the inclusion of the spatial dimension in the procedure.

As a final remark it can be said that due to the dual nature of an urban quarter it can provide a platform to promote a sustainable urban development as it opens the possibility to integrate technical and sociological assessments in urban planning processes.

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