Energy demand assessment of European urban structures based on a multi-scale approach

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Introduction

Climate change is meanwhile one of the key phenomena in recent human societies also facing future cities development. Respecting the growing conscience and political foresight, be it by responding to the approaching demands which the cities have to react to or be it by meaning to the overall responsibility of cities to make their contributions to reduce climate effective emissions. Influencing the structures of the urban fabric, changes planning procedures and triggers at the same time various climate protection strategies addressing the global level. There is an essential need of understanding the influences and need of climate change to existing cities structure and strategies in local action. These new demands will lead to new methods of research and planning.

Transnational climate challenges of cities

The effects, results and time scope of changes due to climate change may vary according to the different simulation models but there is no deny: the phenomena are persuasive and transnational and will affect all locations but all above the structure of existing cities (Daschkeit, 2008, Cassin et al., 2008).

The action of cities is playing a key role in climate change prevention activities. At the same time they have to adapt to the consequences of the local climate change. Instruments so far are local climate protection plans, eco-settlements, energy efficient urban projects/quarters and the management of the total energy performance of buildings. Nevertheless, other national and international levels have simultaneous started climate policies. In Europe, not only the States but also the European Union are getting involved in this issue and are giving an institutional and legislative framework to this challenge.

Main responding levels in processing, structuring and acting are:

- Climate protection on the level of community policies
- Local climate change scenarios and levels of influence on existing city structures
- Main response strategies and actions in planning of existing cities
- Planning methods facing climate change, energy efficiency

Energy relevant policies – planning policies

Facing the global perspective of reducing CO2 emissions, it is obviously essential to harmonize the actions on the local level and to focus on the long term perspective of the main actions. Climate change commitments in French european presidency for e.g. has decided to engage primary in the climate protection strategies (Laurent and Le Cacheux, 2008, Jordan, 2005, Maréchal K., 2006). On the national level these responsibilities are mostly projected to the communal level (Cassin et al., 2008). Cities will play a key rule in these strategies (Jacob et al., 2008, Daschkeit, 2008).

The new requirements of the low carbon city are referring to knowledge, contracts and legislation on the supranational level. In the framework of a global need and perspective all the planning issues should finally refer to this international level. European institutions try to harmonize and to govern these requirements to a local translation. The Climate policy of the EU has its roots in the international negotiations about climate change (UFFCCC / Kyoto Protocol). Both the EU and the Member States are signatories of these treaties. The EU has become since then the leader of the fight against climate change at a global scale. But although the EU is strongly committed at the international level, it has faced more difficulties to implement a domestic action. Indeed, its own priorities (set by the Lisbon strategy: competitiveness, employment and economic growth) prevented the EU to make the policy against climate change its priority. Moreover, pressures of lobbies have been particularly strong throughout the building of the mitigation policy – companies unwilling to pay to pollute, and states fearing those companies to leave in case of too severe policy. Steps have been crossed anyway, but less strong than expected (Louchard, 2005).

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Energy efficiency to reduce climate change

In general the total energy consumption amount is highly contributing to greenhouse gas production and climate change. Most of this consumption takes place in the existing cities. The estimated world's energy consumption located in urban areas is about three quarters of the total and the responsibility of producing around 75 - 80 per cent of the global carbon dioxide gas emissions within this system puts therefore its certain pressure on cities and their agendas (Satterthwaite, 2008, UN, 2007) [1]. In this context, cities are primarily taken into the arena of discussion spotted by the light of huge chances and possibilities that lie in their high potential of reducing the world's energy consumption through viable actions and measurements that are hidden within their built environment.
According to this the situation the energy consumption is therefore becoming a highly relevant theme for the development of future urban planning strategies, facing the action plans for CO2 reduction in cities. Their conceded contribution is largely accepted and the advised strategies and measurements will take effect through mitigation actions on the communal level. Moreover it's important to take into consideration the different adaptation strategies. Every mitigation action is reducing the pressure on adaptation (Weizsäcker U., 2009).
The main challenge for urban planning in the new century surely is the answer to how to take hold of the different demands to the structure, which will be the rule of structure, morphology and technology and how urban planning will participate and channel it to achieve the low carbon city.

[1] www.c40cities.org

Building activity and building stock

Although there is still a remarkable amount of new building activities on new developed land site, it is obvious that in high industrialized countries the process of inner transformation regains more and more consciousness for planning and assessment (Ewing et al., 2008).
Investigating the future decisions regarding energy demand requires more knowledge about spatial, space-related and temporal dynamics in inner urban development. The close interrelation between energy and space becomes obvious by looking at the historical development of cities, where 85 % of the worldwide energy is consumed nowadays. Obviously, most of the energy efficiency potential and the relevant changes impacting the future energy demand are likely to take place in the existing urban fabric (Nijkamp and Perrels, 1994). Yet the localization of these incidences, their dynamics and interferences are only scarcely known. At the same time there has always been a reciprocal correlation of energy and the dynamics of urban development. The enormous amount and demand of a widespread sprawling urban development will be a key issue for a climate protecting future urban development and offers the demands to the existing planning disciplines. The challenge of the “Low carbon city” will be beyond new technologies, beyond reducing singular demand and efficiency, but primarily a long term perspective complex planning issue.

Energy on urban scale

The allocation of urban structures is historically related to the availability of energy spatial development of production and transport environments. At the same time urban structures are the result of the interactions of the several urban functional processes. But the availability of energy in urban space has not been a decisive prerequisite for the development of cities since at least the industrial age. Whereas the medieval city was erected as trade place at walking distances – human and animal transport energy- for the predominantly rural population, industrialization based on the use of carbon resources, steam machines and steel led the way towards technical progress and therefore increased its spatial extension. The mechanization of agriculture and higher yields induced a drift from the land and made it possible to feed the increasing population. Suburbia and city merged. In the 20th century petroleum, chemical and electrical industry became drivers of development in the modern world (Gandy, 2004). As long as accessible, the localization of former urban activities became more and more irrelevant. On this basis, the limits of energy production, supply and transport were no longer absolute determinants for the urban structures.

But still energy demand in most urban agglomerations is continuously rising (Rickwood, 2007). The aim of an energy efficient and sustainable urban development is close connected to the challenge of a consistent resource management and becomes more and more important for urban planning decision. Assessment and management of the existing building stock will become a key issue to carry out energy efficient cities and regions. Still there is a considerable lack of knowledge concerning the future amount of materially and economically resources bound in the existing buildings and the dynamics of change in these metabolisms. Existing building stocks generate large amounts of energy and mass flows for construction, during its operation, for maintenance and even for demolition with impacts to environmental systems and human health. Furthermore still there is not much knowledge existing concerning the amount and speed inner urban transformations of existing urban structures, its predictability and the energy amount bound in these processes and the methods to transfer this to existing local and national planning procedures.

Technology and demand-supply interaction on different scales

The main challenges to supply existing cities with energy and the complex demand modulation constitute key issues for an efficient energy use. In Germany as well as in other countries, major national support and development programs are currently addressing the energy demand of the existing building stock, leaving aside the specific reproduction rate of this structure. According to the German national energy efficiency action plan (EEAP) for instance, the main goals are: the reduction of energy use in buildings, the duplication of micro Combined Heat & Power (mCHP) for electricity production, the achievement of efficiency in economy and traffic, new establishment of standards and labels for equipment. Most of these actions take place on urban scale, which eventually requires the localization and the information of dynamics to establish long-term strategies. Meanwhile many data concerning the statistical distribution of economic sectoral energy needs are nowadays available but still there is lack of information concerning the localization and the presence in space as part of a communal strategy. These concepts also have to take into consideration the existing energy infrastructure and related concepts of a consistent supply side structure. Beside the current available technologies the quantified distribution in space represents a key issue of future research.

Energy and urban development

The authors concentrate on four main hypotheses:

Rather than at the level of individual buildings, energy efficiency measures should be considered and implemented on larger scales: settlements, cities and agglomerations represent a relevant structure of action and objects of long-term perspective in planning. The traditional urban form is and will be more and more influenced by the needs of new consistent energy clusters of localized supply. The existing structure also dictates new influences to the local energy needs.
Beside the sectoral energy efficiency, the localization of energy demand in the urban space and the related adequate energy supply clusters will constitute a key issue to describe adapted and optimized systems. An enormous amount of knowledge concerning the energy demand exists, but still its dynamics of change as well as localized information about change potentials and innovation are inconsistently described.
Even though most of the energy efficiency potentials lies in the demand side management, the localization of energy demand, its dynamics and its interaction with the existing structures offer unknown possibilities to establish new supply systems and raises new potentials.

The time and spatial dynamics of the urban space and more precisely the diffusion of innovations of decentralized technologies will become a key issue to understand and assess the distribution of energy efficiency measures within the urban space. Modern supply techniques and methods can be adapted to these needs, by understanding, analyzing and simulating these changes in order to optimize the exploitation of present and future energy efficiency potentials.
Localisation of energy demand and the dynamic of changes in space will play a key rule to understand and react to future urban development. By this the idea of a low carbon city will be probably less realized by the vision of solar city or an overall energy efficiency performance on the building level but predominantly by understanding and anticipating long term urban dynamics and consistent demand-supply structure adapted to the local situation applied on different scales.

Planning focus and cities

With the challenge of a low carbon city all agglomerations will face long term planning perspectives and transformation processes. Most of the changes will focus on the urban building stock – the field and action of traditional planning and building disciplines. The enhancement of the planning process and the question of how to improve measurements for building up CO2 reduction action plans are often focused and explained in taking actions just on the level of the single buildings and its performances. This view seems to neglect the fact that also the urban design, including the clustering of buildings and mixing of different building types within a given area greatly affect the opportunities" (IPCC, 2007) and requests for a more integrated view of more than the single building itself. Solutions aiming at single building scale do not give a holistic image of the saving potentials (integrating supply potentials) and will not deliver integrated planning strategies that profit from the actions at different scales.

This paper introduces to a methodology whose objective offers on the one hand side a better understanding of the ongoing processes of CO2 emission in urban areas, and on the other hand side enables to address more appropriate and effective tackling CO2 reduction through the combination of the available results, methods and opportunities related to energy consumption.
The authors propose a methodology based on up-to-date methods of analysing urban morphology, dynamics and drivers. Urban planners and decision makers will have and enormous need for consistent tools and methodologies to deliver answers to energy efficient sustainable development of cities. In order to identify strategies to reduce energy consumption at the corresponding operational levels, integrative methods at different scales of action may offer a new approach and planning perspectives as this may impact the planning strategies for urban communities.

Energy demand in urban structures

The present development of mid-European cities is characterised by highly diversified reactions in different scales to complex interrelations: growth and shrinking are becoming increasingly unevenly distributed within existing cities (Allen 1997). Beside, the increasing energy demand in urban structures and its interrelation is becoming a key phenomenon for future analysis and planning issues.
This paper is presenting a view on methods towards a methodology and will show the influence of the rising awareness towards energy efficient urban structures planning.
Rather than at the level of individual buildings, energy efficiency measures should be considered and implemented on larger scales: settlements, cities and urban agglomerations represent the objects of actions in a long-term planning perspective. The traditional urban form is and will be more and more influenced by the needs of new consistent energy clusters of localized supply. The existing structure also dictates new influences to the local energy needs. Beside the sectoral energy efficiency, the localization of energy demand in the urban space and the related adequate energy supply clusters will constitute a key issue to describe adapted and optimized systems. An enormous amount of knowledge concerning the energy demand exists, but still its influences on different scales as well as localized information about change potentials, dynamics and innovation are inconsistently described.

Research methods

The goals of "low carbon cities" implies existing knowledge and considers basic research on arising methods of urban planning, the rule of new actors, their changing influences and the evaluation of processes. Furthermore this approach aims to assess current urban planning concepts and methodologies influenced by the arising needs of the development of these so called "energy efficient cities". It analyses the main planning approaches, single methods of implementation, scale of action and the influence of new actors to this described processes. This also leads to the analysis of adjusted technical implementation on different urban scales. Thus it addresses both a transformation process of the mid-European city as well as the new site developments. (Ferrara, 2004, Bradley and Kohler, 2006, Keim and Viejo, 2009).

Main methods are:

- Data analysis on building stock and spatial functions based on different available sources and its localized dynamics

- Studies on interaction of building stock and spatial functions and specific statistical energy demand attributes to support the spatial dynamic approaches have been continued. Cross overlapping to existing optimization models have been investigated.

- Simulation of urban development

- Resulting energy demand on the urban scale

The presented methods are introducing the data of spatial development needed for assessment the quantity of transformation, the described generalized patterns influences and the driving forces of change and development. We consider therefore the analysis of an urban structure reorganization process dealing predominantly with replacement of existing built structures in inner urban cohesions and associated with variable refurbishment scenarios of existing structures (Kohler, 2007, Bradley et al., 2005). They include the study of the localized material economy as well as the composition and distribution of the total amount of the building stock (Baccini and Bader, 1996). For this the study is focusing on the ongoing urban process of the transformation of the existing structure, taking place under different labels of observation and scales and which are coming at least from different disciplines (architecture, planning, infrastructure, economics, sociology) representing different points of view.
The authors will present analysis of this transformation process, the influence to the urban fabric and the resulting relevance for the assessment of future energy demand and point out the relevant scales, methods and actors of implementation.

Energy assessment changes

The focus of research in the urban context for intervention of the CO2 emissions reduction which are targeting the questions of simulating the energy consumption scenarios are using more or less statistical data bases. This is widely spread as due to the fact that on the level of the long term strategic planning and the policy decision making process many studies structured on statistical values and methods are available (IWU, 2003, Diefenbach et al., 2005, Schlomann et al., 2004). This kind of approaches have as target the definition of guidelines on the macro-scale to better address policies and they have therefore, highlighted the possibilities in dropping energy consumptions and emissions, quantifying the effectiveness of different policies on an aggregate level of definition.
Furthermore, on the micro-scale of single buildings, well established guidelines, quite uniform across European states (BMVBS, 2007, Everall, 2005, ACE, 2009), have been defined,

giving methods for the energy assessment of energy consumption and emissions for the building sector, whose results will feed databases and knowledge for more sophisticated statistical modelling in a near future (IWU, 2008) .
Therefore, for both the macro and micro scale, references are available and much knowledge has been produced. But still a lack of methodologies able to quantify possible actions and intervention within the urban tissue are missing, as far as on one hand, statistical models give aggregative results and on the other hand, energy assessment models of buildings do not give answers for the neighbourhood or urban scales, nor are their result fully implemented in the planning departments and still domain of research and academia (IWU, 2008). In these approaches is seen the restriction of the utility of their results to one single levels of the urban system, narrowing results and interventions to one defined scale, constraining hardly their integration in operational urban planning decisions.

Anyhow, tools and methods supporting decision making on urban level, able to get into the specificity of the build urban structures are partially developed but are fruit of quite recent studies (Robinson et al., 2007, Ratti et al., 2005, Fredrik, 2007). The authors argue that nowadays the possibility to integrate such different methods into an integral approach, based on actual data and knowledge availability in order to perform right energy assessment of cities and local policies is strongly needed as also as suitable.
To take into account are recent developments of data creation and management through Geographic Information Systems (GIS), giving the possibility of integrating the actual energy modelling practice as well as the results coming from studies analyzing the properties of different urban scales, in order to give answers for urban fragments or the city as a whole, whereas the main focus is in the localization of interventions and potentials.

Methodology of inter-scalar approach

Based on the tradition of the geo-simulation and urban modelling studies as (Batty, 2005, Benenson and Torrens, 2004, Bettencourt et al., 2007, Wegener and Fürst, 1999) much knowledge has been developed concerning urban scales and their dynamics. Through this kind of approaches, the urban system is understood as a complex system, focused on the matter of scale and time of its subsystems and their mutual feed-backs. But from this urban modelling field, the focus on energy and sustainable matters is still missing (Wegener, 2009), a wide range of potential improvements (EEA, 2006, Wegener, 2009).
The interactions of multiple objects at lower scales can emerge phenomena that are just appreciable at higher scale. Snow-ball or domino effect can have unexpected consequences that can not be derived from the characteristics of the objects by its own, but just as a group.

At the same time, the interactions from the upper scales into the object at lower scales create *imergent* phenomena, where the whole has an effect into the parts. Looking at the case of heat island, these effects of the objects at lower scale have an effect at city scale (increase of temperature in dense populated areas) and this effect has a feedback or inmergent interaction with the buildings that compose this area.
When it comes to the energy efficient city, above all the scale of appearance and action is playing an important role for the scale of effects. Some effects can be shown at different scales. For example the shadowing of buildings have a great impact into the isolation and the heat demand of isolated buildings. This effect can be seen when blocks of buildings are analyzed at the same time. Individual heating models can not show the interrelation effects.
Another example is the localization of urban neighbourhoods in space. The same neighbourhood structure, located in the centre of the city will have a different behaviour to one located on the suburbs. The amount and quality of infrastructure, networks, and dynamics, affect in great manner consumption and demand.

Both *emergent* and *inmergent* phenomena can not be analyzed without taking into account the several scales that are included in the system. That is way to be able to model, simulate and quantify energy consumption and CO2 emissions, a multi-scalar approach is unavoidable.

Interscalar approach

As presented before, the actual approach to energy consumption and CO2 emission on urban areas is strictly constrained to one scale of action at a time. Is the aim of this paper is to change the focus from single scale view to a multi-scale approach.
The consumption of energy is dependent on many factors. By constraining the design process to one of the scales, all the variables that have an effect at other scale are faded out. This relationship between parameters on different scales at the same time is called *inter-scalar*, where the relationship between objects at one specific scale is called *intra-scalar*.

The authors argue that for an efficient energy planning to reduce consumption and CO2 production, it is necessary to take into account the different scales of the planning in an integrative approach. Even when the scale of detail is directly dependent on the purpose and the object to be planned, it is necessary to include in the planning process the interrelations and dependencies with the immediate upper and lower scales.

Table 1 shows an overview of the classical scales of action for urban planning. The higher position on the scale, the more general the questions that arise, and the less definition possible. The lower the scale, the more precision is necessary and local heterogeneities come into foreground.

Structural variable	**Region**	**Individual settlement/City**	**Neighbourhood**	**Building**
Settlement pattern (e.g. size and spacing)	●			
Communication network between settlements	●			
Size of settlements	●	●		
Shape of settlements	●	●		
Density		●	●	
Interspersion of land uses		●	●	
Orientation of buildings/ building groups			●	●

Table 1: Extended and modified table (EIFER 2009),
source of origin: Owens, S. (1986: p5) in Gordon Mitchell [2005: p4]

The influences and emerging interdependencies on different scales causing various problems which cannot be explained just by looking at one scale are shown in Table 2.

SCALE	Parameters	Problems and challenges
Global	Global Warming	CO2 reduction
Region	Socio-economy, culture	Economical growth, stability
City	Heat islands	Planning processes, functionality
Neighborhood	Heat canyons	Sustainable neighborhoods
City block	Shading	
Building	Material, typology	Comfort

Table 2: Scales of action, problems, challenges and relevant parameters

Geographic Information Science (GISc) – tools for urban planning

Since the advent of digital geographical information systems in the 60's like the Canada Geographical Information System (H.S., 2000), the amount of digital geographical information has increased enormously. This fact represents a new and let's say unique situation in history urbanism, where the amount of data that is produced, stored and updated is much more larger than the capacity to analyse it.

The combination of both the amount of digital information, and the computation capabilities are directly interrelated with the development of software and hardware for personal computing. From this landscape, it can be followed that new possibilities for research and knowledge creation about urban environments are available, not just from the theoretical or qualitative point of view, but also from the quantitative sciences.

Even if a large amount of research is still necessary for the development of standard methodologies and tools accessible to the public, there exist some examples where the new approaches are partially visible.

Building energy assessment

For a comprehensive description of the energy demand of the building sector within European cities, the inception of the obligation to define an energy pass for new and existing buildings, will surely become one of the most useful databases for future developments (IWU, 2008). Anyhow their integration into an operational urban plan has not been done yet and not all variables can be explained nor are their boundaries for changes implemented for the single cases.

As mentioned before it can be learned from the national building energy assessment guidelines, the main dimension for the energy assessment of the building sector is the building itself, through its physical dimension and constructional qualities and attributes. Out of this primary information, heat energy demand estimation can be assessed. For the definition of the primary heat energy demand, heating systems and energy carrier have to be known, as also as its technical definitions. For this, the energy pass can become a useful information source, whereas the supply side should be a question to up scaled to the neighbourhood or urban level.

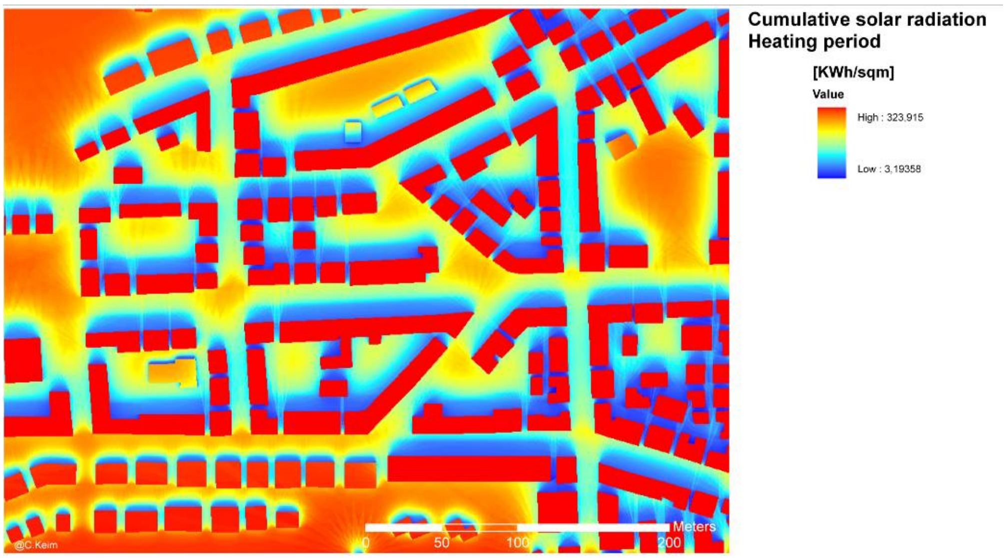

Figure 1 : Cumulative solar radiation for the heating period expressed in kWh/sqm – example of Stuttgart innercity. Data source: OpenstreetMap

Socio-economical parameters and their influence on the energy consumption is mostly concerning the electricity consumptions, which is accounting for about 20 % of the total energy consumption of a dwelling and represents still a field of research (Viejo and Keim, 2009). Anyhow different micro-geographical data are available from different sources, which can be easily addresses to single buildings or neighbourhoods (STALA 2009, http://www.infas-geodaten.de/.)

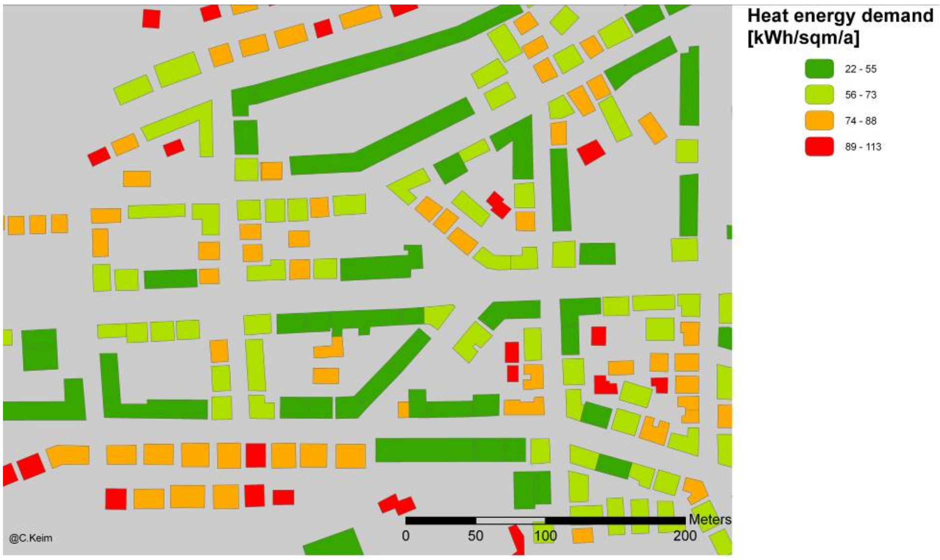

Figure 2 : Heat energy demand of buildings. As heat energy demand, neither hot water nor heating technology is considered in the calculation.

The most useful and comprehensive description of the urban fabric can surely be seen in the cadastre plan of cities. But this 2 dimensional information is still missing of more attributes to be found in other databases. The developments of remote sensing systems and geographic information system have created the base to implement these energy calculation models into comprehensive 3D description of the urban fabric. In the meanwhile the implementation of 3D data from laser scanning is research theme for academic studies, their implementation in real world application is an already ongoing process, serving both planning as also as commercial uses and European and worldwide cities are applying such kind of information systems in the planning institutes (Ulm, 2002, Takase et al., 2003, Kolbe et al., 2005, Evans and Hudson-Smith, 2001), (http://www.citygrid.at). The implementation of such 3D information has already been proved by many studies, changing tool or data format and proved to be feasible to better address energy matters on urban level (Ratti et al., 2006, Ratti et al., 2005, Ratti and Morello, 2005, APUR, 2007, Robinson et al., 2007, Compagnon, 2004).

With such systematic implementations into a GIS the possibility of integrating the inter-scalar approach can be developed, assessing the needed variables and parameters of the different urban scales (Table 1 and Table 2). This kind of approach permits to give the needed consistency for the definition of operational urban planning actions and to identify and localize operational priorities, concerning the different scales (Table 2). With the implementation into cadastre plans of such generated information, priorities can be easily identified and the cross-sectional integration with other sustainability matters be developed for precise urban fragments, accounting for the specificity of the considered site.

Results and outlook

The close interrelation between energy and space becomes obvious by looking at the historical development of cities, where almost 85 % of the worldwide energy is consumed nowadays. Investigating the future decisions regarding energy demand requires more knowledge about spatial, space-related and temporal dynamics in urban development (Batty, 1997). The localisation and the dynamic will be a key fact for predicting urban energy demand. A reciprocal influence between energy and urban dynamics will have an enormous impact to future planning approaches and needs. Obviously, most of the energy efficiency potential and the relevant changes impacting the future energy demand are likely to take place in the existing urban fabric where as the actual building stock is about 85% of the cities of 2035. Yet the localization of these incidences, their dynamics and interferences are only scarcely known. The presented methods of appropriated data analysis and spatial simulation offer basic methods insights to the structure and demands of the future low carbon city.

Furthermore an analysis of the continuously rising energy demand in urban context requires more detailed knowledge for different kinds of drivers of change and investments in the urban fabric. For this matter, information is particularly lacking concerning the spatial distribution of energy demand on local scale and the interaction with the urban development.
Supporting this highly relevant issue on socio-economic investment and decision-making process the question on planning for the century's challenge of CO2 reduction in the focus of urban areas is becoming as well more and more feasible through supporting methodologies which are coming up. They will bring together the profession and working fields of research, planning and technology.
The approach intends to provide urban planners resulting in possible planning tools for mid and long term directions as well as the formulation of CO2 reduction measures.
The focus of research in the urban context for intervention of the CO2 emissions reduction is shifting from a statistical view on the existing building stock with today's possibilities to localized methods. The actual possibilities for assessments of the energy demand is evolving the chance towards a more and more building oriented, focused statements whereas embedded levels of influences are taken into account. This opens a new view and gives a wide range of local specific answers to questions.

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