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ICT-based solutions supporting Energy Systems for Smart Cities

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ABSTRACT

In this chapter we discuss ICT solutions for planning, controlling, maintaining, observing and assessing the urban energy system in order to improve its sustainability and take into account energy efficiency. There is in fact not one urban energy system, but – like the city itself – a system of sub-systems addressing different spatial and temporal scales, spatially ranging from buildings to blocks, districts and the city, temporally ranging from real time data aggregated to hourly, monthly and finally annual totals. ICT support must consider these different scales as well as the supply and the demand side of the energy system. Thus the chapter is divided into several sections. We start with framework conditions and requirements for ICT solutions, and then we discuss models and tools simulating and assessing urban development. Further we describe solutions for urban energy policy decisions support regarding energy supply and energy efficiency improvement. The next section deals with energy supply and demand topics, focussing on Smart Grids, district heating and cooling including general demand side management. The final part describes building automation systems addressing the smallest spatial scale within the urban energy system.

INTRODUCTION

With respect to urban energy planning, ICT systems and solutions address all Information- and Communication Technology-based instruments and features which (i) simulate the urban system as spatial framework and the (urban) energy system behaviour for *ex ante* assessment of applying energy strategies and measures, (ii) monitor energy supply and consumption as well as the state of the energy generation and transmission system, and (iii) manage - which is control and adaption of the energy supply and - if committed –also the demand side, to improve the future energy system performance: to enhance energy use efficiency, to mitigate environmental impacts, to reduce supply and transmission costs and finally to strengthen energy supply security.

Integrated city planning and management are crucial to initiate transformation on urban development, urban governance and infrastructure required to become a Smart City. There exists a wide range of ICT solutions for different purposes, audience and scales – spatial as well as temporal – to support these urban transformation processes. One urban planning approach is supporting a holistic view by integrated modelling – i.e. modelling the city as a system of systems considering all important interdependencies. A different approach is to support sectoral planning applying solutions which are tailored for experts in the sector to give answers on technical questions, as well as assessing the related impact. Both approaches support decision makers in evaluating different options and effects of energy supply technologies and changes in demand. Thus decision support tools play a crucial role for performance assessment, benchmarking and easy-to-understand visualisation of different transformation scenarios and their economic, environmental and social impacts (Tommis and Decorme, 2013).

Going into detail would require a complete book instead of a single chapter. Taking into account the wide range of available and suggested ICT solutions and the given space for this chapter to debate the most relevant topics, we have divided this chapter into several sections to give an overview. Keirstaed (2011) has carried out a classification of models, related to urban systems and energy systems which gives some orientation for structuring the chapter:

- *Urban development models* – including urban growth, land use change and - transportation models. Those models are the key to understand urban energy topics as they typically model structure and activities in a city, finally used to estimate the energy demand for these activities.
- *Policy assessment models* examine the city and try to assess long-range policy goals, e.g. to identify which measures and technologies could meet a given carbon target most cost-effectively.
- *Technology design models* target energy supply and demand side, dealing with optimisation of energy supply technology, supply mix and costs and finally improvement of consumption shapes to better balance supply and demand.
- *Building design (and automation) models* look at the performance of buildings.

Following Keirstaed's classification, this chapter is divided into the following sections:

- Background and requirements for ICT solutions related to energy and Smart Cities,
- General ICT solutions for urban development, as a framework for energy planning
- ICT solutions for energy system planning enabling smart urban development
- ICT for energy supply solutions: Smart Grids, district heating
- ICT for demand side energy management
- ICT for building automation
- Future research directions
- Conclusions and outlook.

BACKGROUND: GENERAL FRAMEWORK CONDITIONS AND REQUIREMENTS ON ICT SOLUTIONS FOR INTEGRATED SMART CITY DEVELOPMENT

The transition of cities in becoming smart requires an appropriate process which has to involve a wide range of stakeholders (citizens, energy service providers, real estate developers, NGOs, etc.) and experts from various administration bodies and finally policy makers. A Smart City transition process shows typically three stages:

- The first one is the elaboration of a Smart City Transformation Agenda with drafting, negotiation and finally commitment of a Smart City Strategy addressing the overall view at city-wide scale, long time horizon and integrating all relevant topics, e.g. space heating and cooling, street lighting, mobility, industry, communication, system control, etc. (Non-energy issues are also part of such a Smart City Strategy, but we focus on energy here.)
- The second stage deals with the (on-going) implementation of measures to achieve the objectives of the transformation agenda through a set of activities.
- The third stage refers to the assessment of the progress achieving the defined energy efficiency, saving target and renewable energy ratio objectives.

Energy performance improvement activities are carried out frequently at building to block levels in neighbourhoods of a city. The selected measures must be tailored for the particular area to find approval of the involved stakeholders, experts and policy makers.

Some activities to improve urban energy performance – e.g. those related to mobility and transportation - require decisions not for a local scale, but for the city-wide scale - considering city wide targets and consequences. Thus such an improvement process requires decisions and related (ICT-based) support for different scales related to the different viewpoints of interest groups,– from the personal view focussing on a single house, to the developers' view, interested in delivering an economically successful and technically feasible project for a district, and finally to the political representatives' view, who have to consider the citizen's personal desires and the wellbeing of the entire city in terms of environment, society and economy. So the ICT solutions must satisfy various clients regarding energy-related and urban-development-related decisions on the implementations of strategies and measures, which will be illustrated in the following paragraphs.

In the European research project IREEN on energy efficient neighbourhoods, interviews with around 30 senior city and region representatives, responsible for urban energy systems, have been conducted across Europe (http://www.ireenproject.eu/). The questions refer to current urban energy-related ICT use, ICT systems and infrastructure and the needs and benefits the interviewees hoped to gain. The requirements on ICT systems to support cities' transitions towards smart energy use are very diverse, as the following exemplary compilation, extracted from Tommis and Decorme (2013), shows.

> Barcelona (Spain) summarizes: "Our objective is to be a self-sufficient, independent city in terms of energy. Being capable of providing as much local and renewable energy as possible, promoting a reduction on energy demand and, at the same time, being able to produce economic growth." (Tommis and Decorme 2013). A set of requirements on ICT solutions have been listed that enable the following items: buildings' energy efficiency, improvement of public building infrastructure to save energy, smart monitoring, easy tools to check energy efficiency in buildings.
>
> Cardiff (Wales) recognizes ICT as a key enabler of efficient services: supporting to take energy efficiency measures to the next level with a holistic view on integration/interoperability of systems beyond energy and water; developing infrastructures control, applying smart meters and intelligent maintenance, along with more relationships with citizens and businesses.
>
> Gent (Belgium) suggests an open data warehouse to collect all energy data: "For such a central platform we need requirements and a key framework for data formation and clarity on legal boundaries. Each stakeholder, including the citizen, can share information and people will only have access to the platform when they also deliver data. (…) We can also use information from our 3D models of the city, such as the shade of buildings for the calculations on effectiveness of solar panels." (Tommis and Decorme 2013).

So we address the set of ICT tools as a backbone to provide services to an urban community at all levels, providing appropriate tools - addressing the city as the physical, social, technical and political framework and the related energy demand and supply management. Smart ICT systems shall secure privacy and shall not be experienced as a surveillance framework, but as a supporting instrument allowing user communication and feedback ensuring appropriate reaction of the system to improve user satisfaction.

ICT SOLUTIONS FOR URBAN DEVELOPMENT AND DESIGN

Before discussing details for ICT solutions for energy planning we start with an introduction on common tools for generic urban development analysis and modelling. Energy planning has a close relationship with urban planning and urban development, as planning strategies (development directions) and urban design (zoning-, height- and density regulations, distribution of urban functions, transportation network) influences energy consumption to a certain extent which requires to carry out both energy and urban planning in parallel to make us of positive dependencies for improvement of both systems the urban and the energy system. Thus urban-planning-related tools serve as a backbone for energy planning.

Integrated and sustainable urban development is an issue which can profit a lot from ICT tools. Applications may address various activities which are typical for urban policy making processes: issue identification, impact analysis, decision support, policy implementation and evaluation. To understand the physical impacts of planning decisions, detailed insights into the urban system structure and their interdependencies are necessary. Various ICT-related planning and analysis tools have been developed, helping to prepare decisions and evaluate impacts through visualization and quantitative analysis of development scenarios (c.f. Boyd and Chan 2002). To allow detailed impact assessment not only the scope of effects but also the distance or vicinity of energy generation and energy use hot spots and the volume of receptors exposed to environmental pressure (vegetation, wildlife, inhabitants etc.) have to be considered, which requires spatially explicit scenarios by integrating various measures to be modelled.

Although urban simulation tools have been often enriched with selected GIS functionality[1], improvement is still welcome. From the academic side, large efforts have been put into development of concepts to facilitate integration of urban planning tools with GIS technologies, and the whole topic is still object of intense research work..

A promising simulation tool for urban development simulation is “UrbanSim”, originally developed by Paul Waddell and continuously improved at the University of Washington and the University of California, Berkeley (c.f. Waddel 2000). UrbanSim is a state-of-the art simulation system for supporting planning and analysis of urban development, incorporating interactions between land use, transportation, economy and environment. UrbanSim adopts a micro-simulation approach: households, businesses or jobs, buildings, and land areas are represented through individual agents, addressing different spatial entities to be selected, ranging from buildings and parcels to grid cells and districts. The model simulates urban development dynamics by interactions of many actors, making decisions within the urban markets for land, housing, non-residential space and transportation.

The user interacts with the tool to create scenarios, specifying alternative population and economic development expectations, land use policy assumptions, and other exogenous inputs. The tool is thus intended for use by planning authorities and researchers interested in exploring effects of planning policy choices including transport modes and accessibility, housing affordability, greenhouse gas

[1] GIS: Geographic Information System – a software system which allows storage, geometrical manipulation, analysis and viewing of geospatial data.

emission targets or open space and habitat protection. Results can be viewed through a results manager (Fig. 1). (http://www.uanalytics.com/urbansim/).

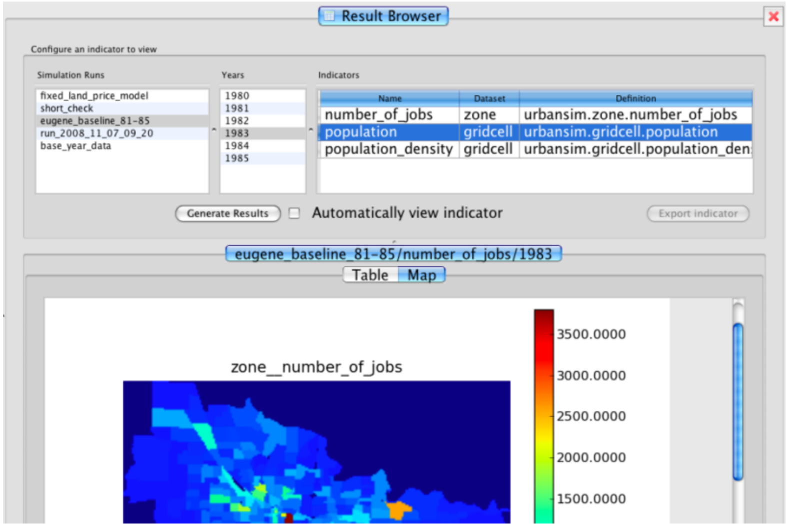

Fig. 1: UrbanSim result browser, Urban Analytics Lab.

(Source: http://www.urbansim.org/downloads/manual/dev-version/opus-userguide.pdf)

The tool has been applied in more than 50 metropolitan areas in all continents. UrbanSim is licensed as open source software based on the Open Platform for Urban Simulation "OPUS", designed for own programming and extension. As the model is rather complex it cannot be easily operated by non-experts, needing assistance by scientists and trained planners. If not used in academic environments but in city administrations, applications are usually supported by consulting firms like Urban Analytics which are specialized on UrbanSim modelling and related input data harvesting (http://www.uanalytics.com/urbansim). Now a re-engineered implementation, prepared by Synthicity, which incorporates 3D visualisation, is available (http://www.synthicity.com/urbancanvas/).

A further comprehensive tool has been developed by the Dutch Technology Research Organisation TNO – "Urban Strategy". This tool does not simulate urban development as an automatic generation process, but allows conducting impact assessment of urban planning decisions, applying a set of models which simulate traffic, energy use, air quality, noise, groundwater and other topics addressing sustainability. The tool must be commercially obtained by TNO. It has not been conceived to be sold as a standalone product but as a support instrument for consulting services of TNO provided to city authorities. (More details on: https://www.tno.nl/downloads/IB_URBAN_STRATEGY_NL.pdf) Like UrbanSim, Urban Strategy needs a lot of input data following a standardized data structure. Tool application requires training and the output requires advice regarding interpretation. Much emphasis has been put into result visualisation capabilities. Model results are presented as 3D presentation, as 2D maps, and as charts and graphs providing an overview through key performance indicators. The tool has been applied since 2007 for different planning projects in various (mostly Dutch) cities or regions, which are clients of TNO (van Lit and Kolthof 2014).

Besides these complex applications requiring intensive guidance and training through the developing institutions, also more easy to use commercial products have been developed recently, to create 3D city models, supporting interactive planning, urban design and presentation. A well-known tool is "ESRI CityEngine" (http://www.esri.com/software/cityengine). A remarkable feature of an earlier CityEngine version (as developed by Procedural before the company has been sold to ESRI) - the automatic creation of virtual cities (Parish & Müller 2001) - has been excluded, so ESRI CityEngine is now an urban design and 3D-visualization tool. Creation of a virtual city is possible by loading existing GIS or CAD data and by interactive allocation of new or modifying existing buildings with convenient 3D-editing functionality – 3D extrusion, texturing, lighting, shading, adding property-attributes (see Fig. 2).

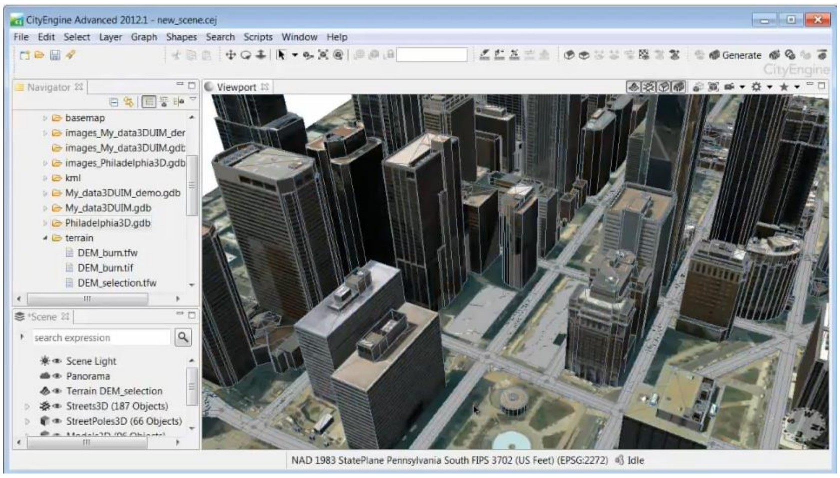

Fig. 2: ESRI CityEngine user interface, screenshot from tutorial video for creating a new scene. (Source: © ESRI Inc. , http://www.esri.com/software/cityengine/features)

ICT SOLUTIONS ON ENERGY POLICY SUPPORT IN TERMS OF SMART URBAN DEVELOPMENT

This group of instruments has its focus on *ex ante* policy evaluation of selected strategies through modelling scenarios by adding virtual implementations of possible energy-related measures like efficiency improvement of the building stock, new technologies for energy demand reduction and distributed (renewable) energy generation, substitution of fossil energy carriers, finally assessing the impact on energy performance, use of renewables and greenhouse gas mitigation.

Growing urbanisation and higher demands on living standards require appropriate urban development strategies and energy policies addressing the entire energy-cycle (e.g. generation, supply, consumption and related spatial and institutional framework conditions). Today, urban energy planning is confronted with a set of questions such as:

- How to choose between different types of energy generation and distribution technologies (e.g. central vs. distributed energy generation, exploitation of renewable energy sources like solar- groundwater-, wind- and geothermal energy)?
- How to deal with construction and extension of supply and utility infrastructures?
- How to increase energy efficiency (e.g. retrofitting technologies for buildings) and how to simulate?
- How to locate energetically inefficient buildings?
- How to evaluate (spatially and temporally) the energetic performance of a city or quarter?
- How to simulate different scenarios according to different energy policies?
- How to evaluate the impact of these measures?

Answering these questions demands a holistic approach for strategic energy-planning from the perspective of the city administration and the energy providers as well. In parallel, participatory, integrated and sustainable urban development is an issue which can profit a lot from ICT-based tools.

Nowadays, precise information about all physical and functional characteristics from a single building to the urban scale is theoretically feasible, but cannot be carried out with the standard computer resources and data availability for an entire city. In addition data privacy is an issue and city-wide energy consumption data at the building level is – in most cities - not available. Hence it is required to adopt a top-down approach where the energy characteristics of buildings at the block or city level are obtained or estimated in different ways. One possibility is to take statistical data describing the building size and building age distribution and further population and household data at census-district level serving as proxy data to estimate energy consumption.

There exists a variety of tools for decision support in urban energy planning. An overview of such tools can be found e.g. in Connolly et al (2010). Here we describe two exemplary ICT solutions for different levels of detail and for different purposes.

The TRANSFORM decision support tool carried out within the TRANSFORM project – carried out by two teams: AIT (the Austrian Institute of Technology) and Accenture B.V. Netherlands – is a complex instrument which allows an integrated view of energy generation, supply and demand as well as simulating measures for energy efficiency improvement addressing an entire city at a district level and addressing a selected district at block or – if data is available - at building level (Loibl et al. 2014). The tool is designed as a flexible modelling framework which allows the allocation of interactively defined areas for measure implementation and can be extended through own calculations by a measure editor. Spatial allocation is enabled through GIS functionality. Measure application regarding energy efficiency changes, energy carrier selection and energy supply technology changes are simulated to evaluate possible impacts at the local scale and its contribution to Smart City targets. Data which is considered consists of:

- City layout with focus on buildings and blocks containing specifications (e.g. building age) to estimate energy demand for heating and cooling and the energy efficiency improvement potential,
- Population: details on population and households to estimate electricity consumption,
- Energy consumption and (distributed) production potential by energy carrier.

The tool give stakeholders a deeper insight on the impact of energy use improvement measures regarding the city's or district's performance on energy efficiency, energy consumption, CO_2

emissions and energy supply. Figure 3 depicts the initial page of the GUI with scenario selection and measure allocation windows.

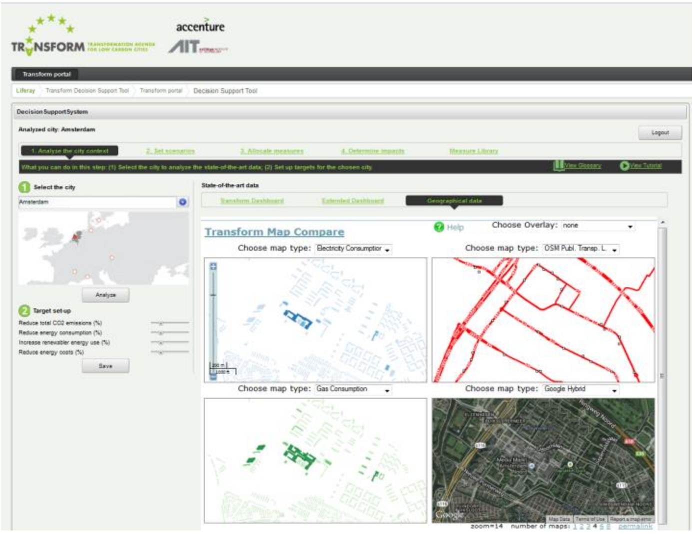

Figure 3: User interface of the TRANSFORM tool – initial page (Source: Loibl et al. 2014).

As the tool shall support the planning process in a city administration, the sequence of steps made during such a decision process is included into the tool's usage flow: Step 1 is the selection of the spatial context: the higher the level of detail of the explored data, the more detailed the analysis can be conducted. Step 2 refers to the selection of a scenario considering current and future framework conditions regarding energy demand and energy supply, as well as future changes (e.g. through urban growth, energy prices). In step 3 measures are defined by a measure editor (adding conditions, variables and factors to model the measure) and allocated through an interactive map. The final step 4 determines impacts through simulation of measure implementation over time to be explored through maps and diagrams. The results are concentrating on definition and allocation of defined measures and on KPI calculation regarding environmental impacts, costs and savings as well as on comparison of scenarios and cities. The results provide annual data and to some extent monthly data. Up to now the mapping is related to 2D views.

With the growing availability of virtual 3D city models in recent years, energy system modelling, analysis and simulation processes 3D analysis and visualisation are now more and more incorporated into energy planning tools. For 3D city modelling, CityGML (Kolbe 2009) is today a common standard for, storage, manipulation, presentation and data exchange of virtual 3D city and landscape models (www.citygml.org). The standard defines a generic model describing geometry, topology, semantics and appearance of 3D objects in urban environments, with five possible levels of geometric and semantic detail (LoD). Included are also generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. The benefits tied to a spatio-semantically coherent urban model (Kolbe 2009) are multiple, as well as the possibility to exploit such a model for further, more advanced applications ranging from urban planning, augmented reality, utility network management (Becker et al. 2013) to energetic simulation tools (Agugiaro et al. 2012).

The term virtual "3D city model" does not refer only to geometry. (e.g. height, volume, position of objects), but also by semantics (e.g. building type, usage, construction date) and topology (e.g. adjacency to other buildings, shared walls).

By means of "enriched" virtual city models, information regarding the building (roof, wall and window surfaces, amount of shared surfaces, year of construction, building size and typology, building use, etc.), as well as other data about inhabitants, local climate, etc. can be used to estimate an energy balance between heat losses and gains. Further analyses can be performed to estimate the potential gains from building retrofitting and the adoption of new technologies or renewable energy sources. City objects can be connected by external links to specific ancillary data (e.g. cadastral data, solar yield estimation of the roofs). The underlying idea regarding the spatio-semantic modelling of a city is that many urban entities are physical objects occupying space in the real world. Elements, like buildings, can be subdivided into smaller entities (e.g. rooms), for detailed modelling.

The use of 3D city models (thus enriched with as many external data sources as possible) has been proposed and investigated e.g. by Carrión et al. (2010) and Strzalka et al. (2011), who have proposed algorithms to estimate heating energy consumption of buildings. The project EnergyCity, located in Frederikshavn (Denmark), was aimed at making a 3D city model to act as an awareness tool that allows politicians and citizens to visualise and understand the change of energy consumption and energy sources in an urban environment over a period of time (Kjems and Wen 2011). The project "Energy Atlas Berlin" (Krüger et al. 2012) resulting in a city-wide energy atlas, focussing originally on heating energy consumption for buildings, but with the primary goal of introducing the concept of an integrated framework for transparent planning processes at all levels of decision-making in cities concerning strategic energy-planning. Successively in the Energy Atlas Berlin the approach has been extended from heating energy demand - to total energy demand estimation where other sources of energy consumption (e.g. warm water and electricity) and finally production (e.g. solar potential of the roofs, geothermal heat potential) have been integrated (Kaden et al. 2013). Similar approaches have been applied in other cities, namely London in the UK and Trento in Italy (Agugiaro 2014) (Figure 4).

Figure 4: Example of heating energy demand estimation for residential buildings in the city of Trento, Italy. (Source: Agugiaro 2014).

"CitySim" developed by École polytechnique fédérale de Lausanne (EPFL), is a sophisticated energy planning tool for districts, focusing on heating energy, serving as a decision support for urban energy planners (Robinson 2009). CitySim comprises a Graphical User Interface to facilitate the buildings' 3D shape for urban districts (allowing to work with several hundred buildings) and to attribute these buildings' thermo-physical properties as well as the visualization of simulation results. It also includes a CitySim Solver for simulating the energy demand and supply of buildings for space conditioning. Energy supplies of these buildings by renewable sources can be determined, including the radiation exchange driven by the urban environment, allowing to work at different temporal resolutions. A range of graphical tools support the analyses of the energy consumption to identify the improvement potential of the buildings' performance.

The tool can be requested for free from EPFL's CitySim-website (http://citysim.epfl.ch/) as a basic version. Field surveys within residential and non-residential buildings, and accounting for a range of commonly used heating, ventilation and air conditioning systems as well as further building energy analysis software have been used for validation of models and algorithms implemented in CitySim. The buildings are stored in CityGML standard allowing 3D viewing as well as shape, orientation and size related analysis. Fig. 5 depicts the short wave radiation exposure of the buildings' walls and roofs.

Further software tools supporting the energy planning process are EnergGIS (Girardin et al 2010) SynCity (Keirstead 2009) or ReMAC (Metrex 2014) working at different spatial levels.

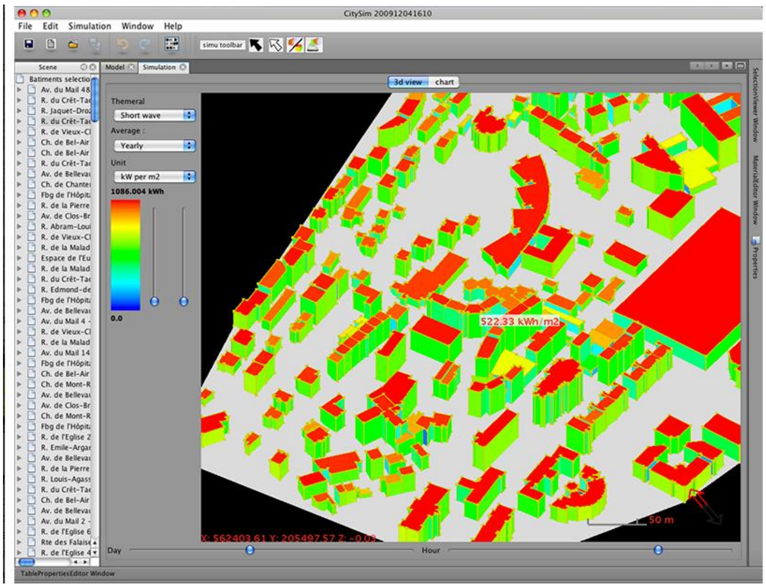

Figure 5: CitySim analysis screenshot: buildings exposed to short wave radiation volume. (Source: http://citysim.epfl.ch/).

The following sections describe ICT solutions with a close link to supply technology which are not necessarily tailored to urban energy systems. Nevertheless they are important elements to enable Smart City progresses from the energy side.

ICT SOLUTIONS FOR ENERGY SUPPLY - SMART GRIDS

Smart Grid is an often used term in context of future planning and operation of electricity networks. Referring to IEA (2011), a Smart Grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users". Smart grids thus co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximising system reliability, resilience and stability." (IEA 2011) Reasons for introducing Smart Grids and related ICT are various: integration of renewable energy and related CO_2-reduction, improving security of supply, rural electrification, peak-load-reduction; renewables integration, reduction of electricity losses.

In terms of managing the different actors and technologies in the electricity network ICT is the key enabler. The CEN-CENELEC-ETSI Smart Grid Coordination Group (2012) provides a technical reference architecture, defining the functional information data flows between the main domains of this energy supply system (see figure 6). The architecture is merging the five interoperability layers (business, function, information, communication and components) with the two dimensions of the Smart Grid Plane, i.e. zones (representing the hierarchical levels of power system management: process, field, station, operation, enterprise and market) and domains (covering the full electrical energy conversion chain: bulk generation, transmission, distribution, DER and customers' premises).

Met opmerkingen [LW1]: ??

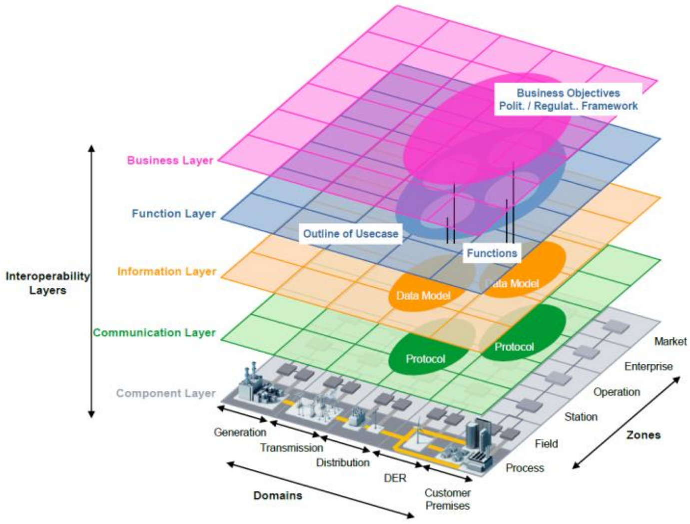

Figure 6: SGAM Framework. (Source: CEN-CENELEC-ETSI Smart Grid Coordination Group 2012).

Information technology enhances the traditional power grid infrastructure by enabling new applications alongside the transport of electrical energy. The ICT infrastructure supports the exchange of information between all involved actors and allows them to access data, services or devices available in the power grid. Access must be ensured, providing secure and reliable protection complying with data protection requirements. Smart grids thus involve various application domains as figure 7 illustrates.

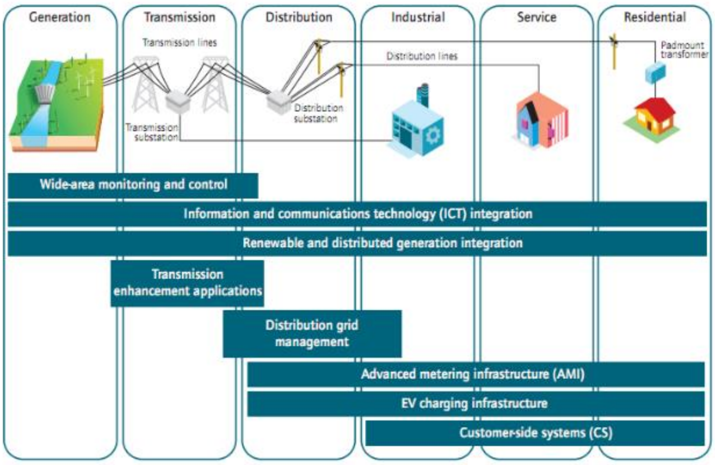

Figure 7: ICT application domains in the Smart Grid. (Source: IEA 2011).

The realization and handling of Smart Grids is strongly system based. As shown in figure 7 above, Smart Grids have a distinct influence on the kind of energy transmission and distribution, network components, generation, consumption and storage as well as power markets and all associated businesses. As network operation is a regulated market in many countries, regulatory aspects must be considered. Without competition in the market as innovation trigger technology improvement efforts are humble. In the end for future operation of electricity networks, three topics are crucial: the technical, the economic (commercial) and the regulatory framework.

For Smart Grids the following measures depend on a system-wide IT infrastructure (Acatech 2012, modified):

- Integration of renewable energy
- Peak load reduction (adaptation of the load profile)
- Transformation into a bi-directional supply structure (consumers are also producers)
- Storage capacities enabling new services and products (e.g. electric mobility)
- Dynamic pricing within the energy market (for all participants)

The following table gives an overview of the Smart Grid features and ICT applications.

Table 1: ICT Applications of Smart Grid features and applications

Electricity sector challenges	ICT applications
Generation	
Renewable energy generation	• Smart meters • Vehicle-to-grid (V2G) and grid-to-vehicle (G2V)
Distributed, small-scale electricity generation	• Virtual power plants • Vehicle-to-grid (V2G) and grid-to-vehicle (G2V) • Smart meters
Transport (Transmission & Distribution)	
Transmission and distribution grid management	• Sensor-based networks • Embedded systems and software • Integrated software systems and application programming interfaces (APIs) • Smart meters • Communications protocols, including machine-to-machine communications (M2M)
Storage	
Storage capacities (physical and logical)	• V2G, G2V and vehicle-to-home (V2H) • Smart meters • End-user interfaces
Retail	
Dynamic and real-time pricing for electricity consumption and distributed generation	• Smart meters • End-user interfaces
Consumption	
Electricity conservation and energy-efficiency	• End-user interfaces • Smart meters • Electricity data intelligence
(Automated) demand management	• End-user interfaces • Smart meters • Communications protocols, including M2M • Smart building technologies • Smart electronic devices • Data centres and cloud computing
Integration of electric vehicles (and renewable energy sources)	• End-user interfaces • Smart meters • V2G, G2V • Communications protocols, including M2M • Integrated software systems and APIs
Facilitate access to electricity in developing countries (Electrification)	

Source: OECD 2012

Since in an urban environment, electricity networks have higher hosting capacity for renewable energy resources, the main focus is on optimizing the electricity supply on neighbourhood, district as well as city level. In general a Smart Grid is not a final product or single solution; it is more a process of improving and maximizing the utilization of existing electricity grid infrastructure and of designing future grids in order to be prepared for future development, securing high supply quality under consideration of the capital expenses (CAPEX) by avoiding or delaying network reinforcement as well as taking into account the operational expenses (OPEX) of the infrastructure.

Effective load management requires real-time information about electricity generation as input to the grid and load on the grid (i.e. electricity demand). Transmission lines transport electricity at high voltages from bulk power plants to substations where electricity feeds into regional and urban distribution systems. Balancing load and voltage across a transmission and distribution grid requires the ability to react to sudden changes, e.g. drops in output or peaks in demand

ICT-based applications are already in use at grid operators to monitor the status of mainly national grid infrastructures (transmission networks). Applications include Intelligent Electronic Devices (IEDs), Phasor Measurement Units (PMUs) and Supervisory Control and Data Acquisition (SCADA) systems. However, requirements for communications and data handling are expanding rapidly: the increase in market actors due to liberalisation amplifies the need for fast and interoperable access to electricity data. (OECD 2012)

Dispersed (renewable) energy production and storage through "private" PV-panels and G2V/ V2G /V2H models (grid 2 vehicle / vehicle to grid / vehicle to home distribution and storage models using e-car batteries as intermediate power storage device in case of load surplus and of power delivery in case of peak demand) even increases the complexity of national grids and in distribution networks and require better and faster information provision. The main ICT components in improving grid monitoring and control systems are (OECD 2012):

- *Sensor-based networks* with sensors (which monitor various characteristics such as voltage, temperature and tension across T&D lines) and embedded software (converting sensor signals and feed them into a communications channel).
- *Integrated software systems, databases and APIs*. Software systems provide automated monitoring and control activities conducted by the sensors. Through application programming interfaces, data about the grid status can be provided to a large number of stakeholders including individuals.
- *Smart meters* at customer premises may support grid management two-fold: They can enable improved individual control over electricity consumption and billing, and can further receive remote control signals to trigger household appliances to be automatically turned on and off.

Integration makes the difference in a Smart Grid, combining business and technical intelligence. In recent years ICT companies have developed tools for supplying advanced communications and analysis services to utilities and to some extent to individuals.

Today real time pricing is usually not a topic at least for private households. Prices for retail customers, however, are today largely static and billing is based on periodic meter readings. Smart meters and other end-user interfaces (e.g. web portals, mobile applications) can provide dynamic pricing information and consumers can then make choices when they buy and when they feed electricity back into the grid. Price signals could impact private electricity consumption and thus lower demand peak. In the domain of wholesale electricity trading, large customers could decide on spot trading making use of dynamic pricing.

A Smart Grid can be strongly supported from smart meters by providing the following functions:

- Sensor for monitoring of low voltage grid infrastructure
- Gateway to customer side applications and data exchange for display and analysis on 3rd party devices. A variety of 3rd party software and hardware allows consumer information about electricity consumption. E.g. Google's PowerMeter, can receive information from households equipped with smart meters of electricity suppliers Yello Strom (Germany), first:utility (United Kingdom) or SDG&E (United States) (OECD 2012).
- Dynamic pricing. Accurate metering function of smart meters and dual-way communications between electricity provider and customer enables dynamic pricing to encourage customers to adapt better to load variation supporting load-shifts to reduce peak demand and enables utilities to purchase high priced electricity at the spot market during peak times.
- Display of consumption-related information: real-time prices, accurate use numbers and implicit environmental costs (GHG emissions)., which allows customers to observe and adapt consumption behaviour.

- Accurate metering and billing. The majority of customers still pay their bills based on utility's estimates, which are adjusted after in regular readings in larger intervals (often only once per year). Smart meters allow frequent billing periods.

An advanced metering infrastructure (AMI) can be an enabler for effective peak demand management, particularly when coupled with dynamic pricing schemes and "smart" electrical appliances. Improved information about the current supply and price can help consumers to shift the timing of certain household appliances - dishwashers and washing machines, even charging the electric vehicle.

ICT SOLUTIONS FOR DISTRICT HEATING AND COOLING

Supply side operational optimizations and network design: Depending on the scope of the analyses and the time scales to be considered (see Figure 8) there are various ICT tools available.

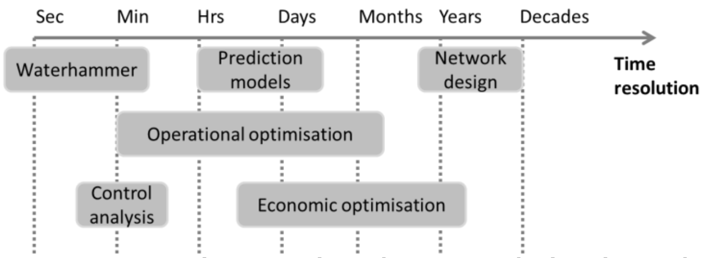

Figure 8: Time considerations in district heating networks depending on the focus of the analyses. (Source: Valdimarsson 1993)

For economic and operational optimization of the scheduling of various heat generation plants in a district heating (DH) network a number of ICT tools are available, e.g. deco (www.iet.tu-berlin.de/deeco), FreeOpt (Gnüchtel 2010), dems (www.siemens.at/dems), BoFiT (www.procom.de), ENFOR-PRESS (www.enfor.dk), THERMIS (www.schneider-electric.com), MARKAL/TIMES (www.econ.kuleuven.be), MODEST (www.optensys.se), ENERGYPLAN (www.energyplan.eu). They perform scheduling optimization considering the operational costs of the plants based on fuel consumption, maintenance, CO_2-certificates, starting/stopping plant costs, forecasted potential revenue from electricity market sales in the case of CHP (combined heat and power) plants and prediction models of heat demand. At this scope, DH network topology is not implemented and simplifications on the distribution heat losses and pumping energy are considered. Additionally, power plant modelling is in general realised by the implementation of characteristic curve and production efficiencies, only in few cases by simplified physical models.

Design of DH networks requires a higher detail level of modelling and at that purpose different network simulation environments are commercially available, e.g. SisHyd (www.bentley.com), Sir3S (www.3sconsult.de), Stanet (www.stafu.de), T*SOL (www.valentin.de), EC.GIS (www.globema.com), being able to implement the network topology, pipe properties, pump characteristics, etc. Thus DH simulation software supports network design and subsequent network modifications (e.g. extension). However, those tools usually perform static calculations and are not able to evaluate dynamic effects, like the water hammer (a pressure wave which occurs when a fluid in motion stops or to changes direction), like fluctuating energy sources (solar thermal energy, wind energy) powering heat pumps, like bi-directional load flow from PV panels or demand side management strategies. Also power plant characteristics can be implemented in a simple way.

Those dynamic modelling capabilities are offered only by few simulation tools like Apros (www.apros.fi) or libraries of the open source modelling system Modelica (www.modelica.org). Dymola (www.dymola.com) allows further modeling bi-directional load flow, part load operation of power plants, implementation of customised control strategies, integration of advanced building models for assessing demand side management, and coupling of models of other engineering fields (e.g. assessing thermo-mechanical stresses) and the consideration of instationary effects and hydraulic phenomena.

Demand side management for improved district heating network performance requires smart heat meters installed at the customer side, enabling to monitor energy consumption dynamics for customers as well as for the network operator, which supports the network operator in assessing the network status, dynamic pricing and cost related billing, more precise load forecasting and identification of problems on the customer side, e.g. high peak loads or high return temperatures.

Low return temperatures are beneficiary for district heating (DH) systems as they reduce pumping cost (reduced mass flow due to increased temperature potential) and energy losses (lower gradient to the environment) as well as increase the usable potential of renewable sources (e.g. groundwater via heat pumps, solar thermal energy or industrial waste heat). Return temperatures can be decreased by technical modifications at the customer side (e.g. removal of installation mistakes) and by adaptation of customer behaviour (e.g. temperature control). Visualizing the return temperature profiles via smart heat meters enables the customers to react and improve the performance of their energy system accordingly (e.g. motivated by appropriate tariff systems (Gullev 2005)).

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The night set-back (reduction of room temperatures during night time) is a usual measure to reduce the energy demand in buildings (e.g. Moon 2011). Fluctuating heat consumption can turn out as a significant problem for DH network operation if heat is generated by fossil fuel. Integrating additional functionalities into smart heat meters could shift heating loads to off peak times and smooth the dynamic variation (e.g. Basciotti 2013). Similar applies also for district cooling.

However, since many European urban district heating networks have been installed several decades ago, the general diffusion of ICT and sensors in the networks is rather low. Often, relevant data is monitored only at the supply side, at some critical network points, at larger customers and in recently installed network sections. As a consequence, the added value for introducing such smart heat meters with additional functionalities as described above has to be elaborated carefully: suitable systems are still relatively expensive and the installation costs are high (including the setup of an appropriate communication infrastructure). Additional barriers are legal issues (e.g. data security and privacy) and a possible impact on the comfort of the customers being subject to demand side measures. Nevertheless, for the most relevant loads in DH networks (e.g. industrial customers, big office buildings, swimming pools, hotels …) the potential for load shifting and the effect of return temperature reduction is large compared to individual single family houses and the implementation of smart heat meters could be very cost effective.

In the district heating systems of the future Smart Cities, ICT will gain significant importance for enabling overall analyses, control and system optimization, especially considering the interfaces to other energy vectors (electricity and gas, e.g. www.orpheus-project.eu) but also to the related energy conversion technologies and various storage options. However, this will require the development and diffusion of open and standardised interfaces between the different networks and communication infrastructures to allow interoperability.

ICT SOLUTIONS FOR DEMAND SIDE MANAGEMENT (DSM)

In general, customers demanding electricity have particular consumption preferences at different times of the day resulting in diurnal consumption patterns with distinct peaks and sinks. To achieve high levels of reliability and robustness in energy supply systems, the infrastructure is designed for peak demand. Overcoming these problems, different solutions have been developed to shape the consumers' energy consumption profiles in a way that power or heat generation capacity can be used more efficiently to avoid deploying additional energy generation and transmission infrastructure or purchasing peak power at high prices to supply short term peak demand. These solutions are generally known as demand side management (DSM), aiming at reducing or shifting energy consumption to smooth consumption peaks and sinks.

The success of DSM depends on the share of the controlled total. One option in DSM is direct load control where, based on an agreement between the utility company and the customers, the utility e.g. controls remotely the operation of certain appliances in a household by switching them on and off to avoid consumption during peak load time. A further option is to supply specific pricing to encourage users to individually manage their loads to reduce their own energy cost. Here we address targeted incentives, technologies and customer education programs directed towards reducing or changing patterns of energy use.

Today most individual load control decisions are made manually, which makes it difficult for the participants to monitor real-time prices and to use advanced pricing methods. In fact, lack of knowledge among consumers on how to respond to time-varying prices is currently a main barrier for fully utilizing the benefits of real-time pricing methods and DSM in general. This problem can be to some extent resolved by equipping customers with home automation systems and implementing automated energy consumption scheduling units providing pricing information to schedule the operation of residential appliances (Samadi et al. 2011).

Thus automated DSM systems can significantly enhance efficiency and reliability of power supply and grid operation. Applications, monitoring energy supply and consumption follow the concept of SCADA systems (supervisory control and data acquisition) which monitor and control real time data – starting with single sites and ending with systems covering large areas (ranging from industrial plants to nations). There exist various ICT solutions to support DSM at the national level, the utility level and /or the customer level.

The "Optix" product line from the company EnergySavy is one example for demand-side management systems that enables utilities and their partners to achieve DSM goals. Not only the energy service company (ESCO) gets insight in consumer behaviour, also the customers learn where to start and proceed with energy efficiency by enabling them to monitor their progress in energy saving. Several tools can be obtained – Optix-Engaging is the starter, providing households with a user-friendly experience, Optix-Evaluate allows real time performance analysis (see fig. 9), Optix-Manage allows results tracking entire consumption for the ESCO.(http://www.energysavvy.com/products/).

ESCOs from several U.S. states and cities have applied the system to enhance the state's or company's DSM: Utah, Puget Sound Energy, New Jersey Natural Gas, Efficiency Vermon, just to name a few.

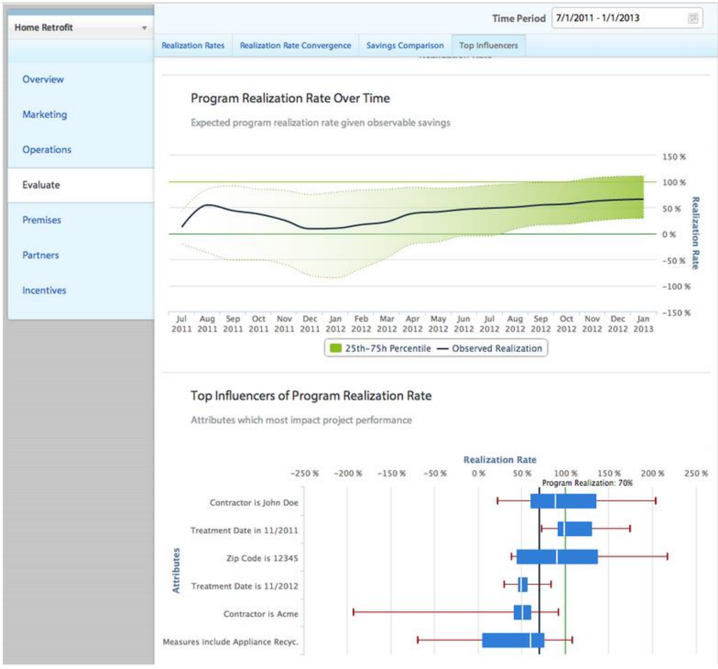

Figure 9: Screenshot from analysis results carried out by Optix-Evaluate
(Source; http://www.energysavvy.com/products/optix-evaluate/).

ICT SOLUTIONS FOR SMART BUILDINGS: BUILDING ENERGY MANAGEMENT AND BUILDING AUTOMATION

As stated earlier, a Building Information Model (BIM) describes all physical and functional characteristics of a single building. A BIM is conceived as a source of shared knowledge to support decision-making about a facility from its early conceptual stages, through design and construction, during its operational life and eventual till demolition. Today a number of approaches exist for BIMs to estimate the total energy demand and to raise the buildings' energy efficiency.

Building automation and control systems (BACS) are well-established infrastructural systems in functional buildings today. Information on the building physics and the building's energy systems can be used in building operation by BACS to ensure higher control quality. Building automation provides the functionality necessary to operate complex buildings and supports different domains like heating, ventilation, air conditioning (HVAC), access control, lighting, sun blinds or fire alarms. The building automation system is the combination of information and communication technology to enable efficient and flexible building control. All relevant systems in the building are connected by a communication network, the most commons being LonWorks, BACnet and KNX (Loy et al. 2001, Maerz et al. 2009). With its sensors, actuators, communication networks and computing resources a BACS is the perfect platform for enabling the building to become a service provider to a Smart City with respect to energy demand control. Building automation saves energy during operation. The

European standard EN 15232 (CEN 2012) defines different energy efficiency classes for building automation and control systems. In heating control, for example, the building automation can have no automatic control (class D), outside temperature compensated control (class C, the reference class), indoor temperature of distribution network water temperature (class B) or additionally have a total interlock between heating and cooling control (class A). A building management system that fulfils the requirements of class A (not only in heating, but also in lighting, HVAC and sun blinds) has an efficiency factor of 0.7. (The efficiency factor, defined by European standard EN 15232, indicates the ratio of the achieved efficiency compared to the reference class C efficiency which has a factor of 1). EN 15232 uses only state of the art technology to increase energy efficiency with IT methods. But the strength of building automation systems is their versatility: the building automation infrastructure can be used for different applications simultaneously and create synergetic effects between them. A development in this direction is demand side management in buildings: buildings, and especially the HVAC systems in the building, can operate in a way that does not affect user comfort, but allows adapting the electric consumption profile over the day. This flexibility can be used for better integration of volatile renewables like photovoltaic systems or wind power. A BACS that can modify its demand based on available renewable energy increases on-site usage of energy, reducing the amount of energy that needs to be transported in the electric grid and thus reducing transport losses.

From the perspective of a Smart City single buildings among several 1,000 to several 10,000 and maybe some 100,000 households consuming energy are not easily addressable though simulation systems. This is, however, necessary, if energy management on city level is envisioned. Currently buildings and their embedded households and flats are island systems that do not provide standardized communication interfaces to the smart infrastructure. Much effort is put into possibilities for influencing building operation with goals from the "outside". The market of building automation is still fragmented and common, standardized solutions still wait to penetrate the market. City-level demand side management (DSM) strongly requires this access, but this demands a change in the way a building automation system is conceived. Currently the top instance is the supervisory control, responsible for overall control of the building and for providing a user interface to the building operator. Traditionally it was not foreseen to have an instance above the supervisory control. With the introduction of Enterprise Resource Planning (ERP) tools this became more common, but is still vendor specific in a fragmented market. A building consists of many components, which are connected into a system – the building. Still, the building is just one component in a bigger system – the city. Once it is understood that systems are only components of bigger systems, the building can become an active participant in a Smart City.

SOLUTIONS AND RECOMMENDATIONS

ICT is one of the main enabling technologies for Smart Cities. However, the selection of target-oriented and cost-effective equipment will be one of the main challenges in the future.

Examples described above may differ in scale or approach, but they all present some common traits that will be summarised in the following. First and foremost: ICT-based tools are tightly connected to the goals to be achieved when speaking of Smart Cities. The focus is indeed both on modelling approaches and data integration.

Regarding the former, today a number of solutions already exist, ranging from the more "classical" top-down approaches, especially at city-level, to the more specific bottom-up ones. Which approaches and tools to adopt depend of course on a number of conditions, but major roles play the amount and quality of available data. An important step is the slow but progressive switch from simple qualitative analyses to precise, quantitatively and spatially defined ones. Information, at any level, must not only be known in detail, but must show a precise spatial reference.

Given the multiplicity of system elements and energy topics to be dealt with, the availability of a common set of data, to be shared among the stakeholders in the planning process is of great importance. A consistent, detailed data repository is required to avoid errors, ease management and enhance cost-effectiveness for scenario development. Thus there is quite some effort necessary for the exploration, collection, error check and integration of heterogeneous data sources, required describing cities. Data integration can drain huge quantities of resources (in time and money!) When a simulation and assessment framework has to be established for a city. If original data are not available proxy data has to be made available, allowing a workaround for modelling and assessment. These are necessary steps which, once carried out, finally result in reducing the overall effort for many future repetitions of simulation, analysis and assessment.

The adoption of 3D city models has recently started, showing the potentials and strengths such tools may offer. 3D city models will be further exploited as they allow the inclusion of many relevant entities and aspects of a city and can act as a model framework for all energy-relevant aspects within a city. If Smart Cities are supposed to deal with complex topics in a holistic way, then 3D city models are (one of) the right approaches to go for.

When supporting urban energy planning in an integrated way, different resolutions regarding space, time as well as spatial dimensions (3D!) must be incorporated. An ideal final state of an integrated urban energy planning tool for monitoring and maintaining urban energy systems may cover the following topics:

- real time monitoring of energy consumption by energy carrier for the entire city, certain districts, selected blocks or even buildings,
- control of the systems including distribution network connections and the appliances of a household connected to the grid in case of emergency or as routine,
- assessment of consumption by energy carrier, by consumer groups and/or by appliance groups and related key performance indicators to evaluate progress on energy efficiency, renewable energy use share, greenhouse gas mitigation performance,
- decision support for energy consumption improvement measures allowing *ex ante* assessment of the impact of adaptation scenarios for the entire city or for selected areas addressing districts, blocks or selected groups of buildings or individual buildings, which finally will turn out as hot spots in need for quality improvement,
- decision support for urban development analysing energy supply alternatives to identify the most sustainable and cost effective solutions.

FUTURE RESEARCH DIRECTIONS

There is still research necessary for software and hardware solutions to make continuous progress in the development of fully integrated systems, requiring to span the range of the different temporal and spatial resolutions. As all single functionalities describing the system entities and the processes are developed, the research resources must be concentrated on the dynamic scalability of such a system.

Enabling bi-directional Building-to-Grid connections (buildings demanding energy from the grid but also delivering energy into the grid) requires to provide an IT-framework which allows electric profile control of buildings according to the needs of a Smart Grid, e.g. supporting to smooth consumption peaks by delivering electricity from local PV panels into the grid.

Here we see the same maturity of methodology development: most of the required information and communication technology is already in place: buildings can communicate and control the building system, do the necessary calculations and store data for later analysis. Nevertheless there are two main developments that need to be done before smart buildings can become fully integrated into a Smart Grid and a Smart City: the first is the integration of advanced ICT methods into building automation, the second is the need for open (and possibly standardized) systems. Advanced ICT methods summarize developments in other domains that can bring benefit to smart buildings.

On-site electricity generation and storage models (distributed power generation through private PV panels, and related G2V/V2G/V2H models - see table 1) makes consumers become *prosumers* capable of changing their role in the market. Technological innovation and business models will go hand-in-hand here (see e.g. Kanchev et al. 2011).Various countries are leading the Smart Grid development, while others still do not have a market as they don't have common regulations for flexible consumer/prosumer behaviour in an energy grid. (Brandstatt et al. 2012).

The usage of ICT and information fusion for smart and grid-friendly buildings can be categorized as follows:

- *Energy efficiency*: sensor networks, remote (consumption) data acquisition and data mining are the tools to discover correlations between expensive and emission-prone consumption peaks and operational data and to benchmark the building against others (e.g. kWh per employee and year). Up to now, consumption figures are yearly aggregates and do not provide much information. ICT is currently changing that and feeds energy information further up the line into enterprise resource planning tools and accounting software.
- *Consumption dynamics*: As the behaviour of buildings is slowly leaving the statistical patterns of the last 100 years (due to on-site photovoltaic systems, response to dynamic prices, etc.), established methods fail to consider their dynamics in grid management. At the same time, intelligent buildings offer some degrees of freedom that were unexploited up to now. Both combined leads to buildings that co-operate with other distributed energy resources in the grid. The ICT interfaces and protocols are far from being standardized and established. See Palensky and Kupzog (2013) for an overview of related Smart Grid topics and their ICT aspects.

Two examples shall be given:

(1) The first example addresses the predictability of the building behaviour as response to framework conditions in the near future in order to properly exploit the flexibility in building operation: How will outside temperature and indoor occupancy influence energy usage? How much will the volatile renewable energy source produce?

    This information is needed to establish predictive control of the energy systems in order to optimize operations. The according algorithms are today used in industrial processes known as model based predictive control.

(2) The second example is the optimization of building operations by analyzing and understanding the recorded operation data. Building automation data records can help identify inefficient operation, but requires methods and algorithms that are today found in data mining applications. Open systems provide interoperability and open software standards which allow

learning from other buildings behaviour with respect to certain building and framework conditions.

While building automation uses a set of communication protocols to standardize interaction between the components, there are today no established standards for accessing building management systems from outside or for defining services that could be used from outside (e. g. the flexible service for Demand Side Management). Current building management systems are proprietary, closed systems that were not designed to interoperate on this level. Before buildings can be integrated into a large scale, city-wide operation and optimization, it is necessary to agree on standardized and open system definitions.

CONCLUSIONS

Given the complexity of a city, including multiple energy (sub)-systems that are linked to different spatial and temporal scales, ICT solutions must be able to include these different scales, but also to cope with the demand and the supply side at the same time.

Any energy-related urban planning action is today confronted with several, sometimes concurrent, challenges and decisions, regarding for example the selection of different types of energy generation and distribution technologies, the construction and extension of supply and utility infrastructures, the overall increase of energy efficiency, as well as the need to simulate different scenarios according to different energy policies, to assess the impact of the measures. ICT tools can therefore help in the holistic approach which is needed to tackle these challenges. First of all, problems can be analysed and given a quantitative answer, with different levels of accuracy depending on the level of detail we are considering.

Nowadays, precise information about all physical and functional characteristics of a single (modern) building can be organised, simulated and stored. Moving from the single-building dimension to the urban one can be achieved by means of different strategies, depending on the amount and accuracy of available data. The adoption of a virtual 3D city models can be seen a major step toward data integration and harmonisation, and, although the resources-intensive step of data integration is still required, the emergence of new tools is making the task easier. Even the move from 2D to 3D is allowing for more possibilities to extract data automatically (e.g. computation of shared walls or volumes).

In the near future, the goal is to formally define and create an integrated and coherent platform aimed at decision support for urban energy performance improvement and related impact assessment. This platform should be based, among the rest, upon semantically enriched 3D virtual city models (which will serve as data hub for all city-relevant simulation tools), being able to deal with the interactions between energy demand, supply, networks and storage, taking into account the scales, from (sub)-building level to blocks, neighbourhoods, districts and finally the entire city. Additionally the integration of different temporal scales (ranging from minute time slices to annual totals) shall be possible to allow balancing of system load by simulating, monitoring and controlling the energy demand and supply state – the latter by integrating dispersed power generation through “private” PV-panels and integrated power delivery/storage/consumption models (G2V/ V2G /V2H) to head off load surplus and shortage through demand fluctuation).

Thus the final goal for maintaining and improving Smart Urban Energy Systems is to strengthen applicability of models and tools with respect to:

- Integration of observation, control, simulation and assessment of centralized and distributed energy supply systems,
- Integration of the energy supply and demand side control at individual and aggregated levels - from individual household demand and building modelling to city wide demand / supply modelling, control, observation and assessment.
- Simulate real-time system behaviour which allows spatial as well as temporal aggregation of supply, storage and demand.

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Keywords:

Building automation: ICT-based control of the energy performance of buildings with respect to security, fire and flood safety, lighting, shading, heating, cooling, humidity control and ventilation.

Demand side management: Control of the individual energy demand and observation of the individual and aggregated energy demand

Decision support tool: ICT-based tool supporting decision making through simulating the implementation of probable measures and assessing the resulting effects.

District heating and cooling: This is a technological concept comprising infrastructure for delivering heating and cooling services to distributed customers. It is mainly based on a wide range of local (fossil but renewable) energy sources that under normal circumstances would be difficult to use or remain unused (e.g. CHP (combined heat and power plants), geothermal, large scale solar thermal or ambient energy (via heat pumps) and industrial waste heat). The energy source may change over time as the energy market and technologies change to favour new generation technologies or other more economic sources.

Energy policy assessment: Assessment of the effectiveness of energy policy decisions with respect to effects on (fossil) energy demand reduction, greenhouse gas emission mitigation, renewable energy usage increase and further (positive or negative) socio-economic and environmental development.

Energy supply management: Monitoring, assessment and control of the energy supply, currently considering the integration of distributed (renewable) energy sources.

Smart grid: The extension of a power grid system from a unidirectional system of electric power generation, transmission, electricity distribution, and demand-driven control to a bidirectional system enabling distributed power generation and supply providing continuous information on the system state by means of digital processing and communication, making data flow and information management a central feature.

Urban development simulation: Modelling of (spatial) urban development processes over time through simulation of individual actors decisions resulting in change of land use, land use density and spatial interaction as well as changes in urban metabolism (energy consumption, emissions, waste, wastewater) through land use related activities, some of them listed in the energy planning tool description below.

Urban energy planning tool: ICT-based tool which allow spatially explicit assessment of energy efficiency improvement potentials, modelling of energy demand and energy supply through activities triggering energy consumption (heating, cooling, lighting, mobility) and energy generation. The spatial explicitness refers to different spatial scales ranging from building to block, neighbourhood and city level and to visualisation of model results in maps and 3D renderings.

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