Thinking Local, Acting Global: Urban-scale Energy Modeling for Global Cities Governance

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Abstract

Cities, undergoing rapid change in all parts of the globe, face a common set of "metabolic" challenges: sustainably provisioning for energy, water, and food supplies under sanitary, healthy, economically productive living conditions. Diverse decision makers, such as government, utilities, project developers and bankers must be able to visualize multiple impacts of plans and proposals. Global urban governance initiatives are currently bringing major cities together to learn from one another in addressing common challenges.

Energy-related emissions, produced primarily by cities, are a huge challenge to the global climate, which in impacts growing urban areas. Urban infrastructures will have to be planned to meet the needs of increasing populations under increasingly demanding circumstances. This paper discusses the role of urban energy and climate modeling to analyze and predict trends that are a consequence of today´s fossil energy economy and to develop strategies for moving towards clean and carbon neutral urban energy systems.

Efforts to mitigate climate change are still largely limited to political target setting at the local, national or transnational scale resulting in fragmented or very slow actual change in the levels of urban energy efficiency and renewable supply. There is a knowledge gap between global climate targets and how to translate these into concrete urban energy strategies that can be monitored, regularly assessed and reported back to decision makers.

The translation of global climate targets to local and regional energy transformation strategies requires large amounts of data, many tools to model complex energy systems, and ways to inform how best to manage them. This paper suggests that the energy and infrastructure problems that cities face world-wide today are comparable and differ mainly by density, climatic boundary conditions and local resource availability. Thus, a global energy research agenda to address common urban problems seems possible.

An integrated platform for urban energy modeling is proposed based on a common data model using the 3D CityGML standard. The platform is assessed for the scope of research and planning questions that it can address, such as building/community technology scenarios for decision-support, policy-making, infrastructure needs over time, zoning rules and impact-analysis, micro-climate predictions and alert systems. The work presents the first applications of the platform on case studies in Europe and New York.

Introduction

This paper reviews the place of geographically based urban energy modeling in the development and conduct of energy policy, spanning from the local to the global scale. Key challenges of urban energy modeling are presented, including data quality and quantity problems and integration issues. Cities are viewed as aggregations of buildings where stakeholders implement energy decisions and also as the major locus for the implementation of sustainable energy policies. The concept of urban-scale models is seen as providing the basis for common understanding, learning and coordination across cities with the potential for creating a global scale energy science and related governance mechanisms.

Cities as Driver and Driven

The sustainable Cities' report (2013) states that cities occupy only 2% of the Earth's land, but account for over 70% of both energy consumption and carbon emissions. Improving urban energy efficiency is thus essential to prevent climate change (Van der Veken et al. 2004) and the exhaustion of energy resources (Pérez-Lombard et al. 2008).

In the last decade global GDP expanded by 50% and continued economic growth is anticipated at the cost of still further increasing fossil fuel use (Reid et al., 2005). This leads to increasing CO2 levels in the atmosphere with 400 ppm already reached, a numerical reminder of how managing the global commons may already be beyond stable system capacities despite urgent warnings

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about a possible overshoot of planetary boundaries (Rockström et al., 2009) and the negative economic impacts associated with depleting essential natural resources (Turner, 2008). The impacts of crossing such boundaries will be felt most deeply in the urban aggregations of population. Assuring sufficient food, water, energy, shelter, human health and safety, while managing a growing population riding the currents of rapid social, economic and environmental change, will be the hallmark of the 21st century.

On-going research suggests that rising temperatures will correlate strongly with growing urban concentrations, located especially in the developing world. Developing-nation local governments will be faced with crisis-level situations with limited capacities. In the face of deteriorating conditions, populations will further move into other urban centers, with ramifying challenges to services and governance. Research and research-based planning is important to anticipate and address these challenges.

Connecting local to global scales in urban energy research: the role of data sets and modeling

While modeling individual buildings is well established for evaluating energy impacts of design and energy code compliance, many urban planning issues require a multi-building platform that can handle non-additive interactive and environmental effects. Large data sets, as shown in Figure 1, have been used to develop detailed 3D cityscape representations with associated semantics.

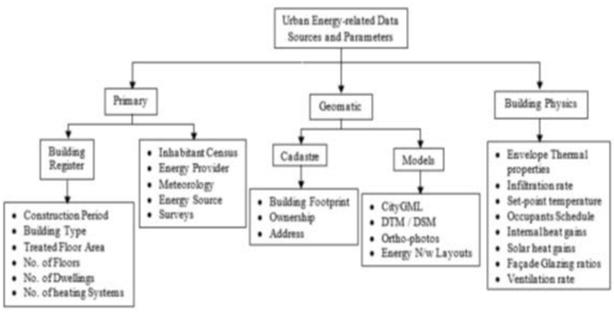


Figure 1: Types of Data Sets for Integration.

Calculation toolkits are integrated so that analytical work can be done within the framework, greatly simplifying workflows and providing visualization of analytic outputs.

Deficiencies. Availability of data sets, their inter-operability, matching-up analysis tools and output presentations are on-going technical challenges. Without common data structures, integration of each new data set is a challenge. Moreover, problems that can be addressed by urban-scale modeling are not yet well articulated and therefore poorly understood by policy-makers. Only with strong problem-formulation ("use case") skills, appropriate at the policy level, will urban scale integrations be continued and utilized.

Weak or non-existent national energy regulations, R&D innovations misaligned with the planning and investment processes, and other mainly contextual barriers have been identified as major barriers to advancing energy efficiency in buildings (Vogel et al., 2015). This "energy gap" describes, the situation where the performance of buildings lags far behind the technical knowledge of how buildings could and should perform. The contextual level is used here to denote the needed framework for lower levels - the building sector and individual projects - to effectively aggregate to achieve efficiency targets at an urban scale.

Fragmentation between the buildings level and the urban scale

Urban system research is fragmented in many ways, especially in the energy sector, where efficiency work at the individual building level has not yet been comprehensively linked to renewable supply transformations, network-based distribution systems, the transport sector, nor have urban microclimates and user behaviors been adequately taken into account to understand the complex system interactions.

Given the low rates of building refurbishment and the dominance of the fossil fuel sector, it is increasingly obvious only coordinated strategies in urban areas that interrelate the different sectors with their stakeholders can lead to the desired result of significant carbon reduction. In addition a global framework for coordinated energy research and policy could remove barriers and make sure that energy efficiency and sustainability become key aspects of urban transformation strategies.

A common feature of energy-related decision-making is the dominance of short-term profits without adequately considering life cycle costs for efficiency measures in the urban building stock and the external costs of today´s predominantly fossil fuel supply. Without a more global approach and framework to tackle the energy question the numerous local initiatives for energy efficiency improvement and renewable integration will not gain the momentum required for climate change mitigation.

Urban Data Sets

Our purpose here is to describe a research transformation based on newly available data, tools for working with it, and how such methods can lead to analysis reaching towards a global scale. In the process, the chief forces shaping energy systems and resource assessment at the dawn of the 21st century will be considered.

As computerized systems have proliferated towards the end of the 20th century, making mass data storage less and less expensive, large data sets have emerged with associated "Big Data" applications based in computer science such as Geographical Information Systems (GIS). An important aspect of work with large data sets is visualization, which has spawned an entire sub-field. GISmapping integrates the visual with data. Building-information modeling (BIM) accomplishes this at the building level. Urban mapping tools join these scales with

3-dimensional visualization and embedded data for large numbers of buildings.

Beyond "tagging" information on maps, data sets underlie model and visualization tools, which feed a wide range of simulation and optimization models, enable model calibration and progress monitoring, and in some cases, use real time data. Data sets vary from traditional, relatively static but extremely valuable property tax records, to highly dynamic transactions from digital meters found, for example, in taxis, subway turnstiles and electrical distribution to buildings. Studies have begun to identify the patterns in such large-scale urban flows, often labeled as "urban metabolism".

Legal requirements in the EU at the national level and in the US at the city level have begun to make building energy use data that can be readily aggregated available and viewed. For example, New York City's energy benchmark database (which is required for properties 50,000 sf and larger) represents roughly 20,000 buildings with publicly available building characteristics, annual data and underlying monthly data.

Building Construction Libraries as a special type of Data Set

A realistic building construction library is essential to address districts with several hundred or thousands of buildings. They link building typologies (defined by building types and age classes) to representative building physics parameters. These libraries can exist at a national level (e.g. EU Project Tabula or the follow up Episcope (Balares et al., 2016), for certain regions (e.g. the states of Bavaria and Schleswig Holstein in Germany), or for specific city quarters with exemplary monitoring projects (e.g. Karlsruhe Rintheim, Nouvel et al., 2013). Generally, the more local and specific these building libraries are, the higher the accuracy of the on-site construction characteristics.

All available data sets regarding the building physics, energy systems and building use are useful, enabling to refine the urban thermal model and improve the result accuracy. Nevertheless, urban modeling can be started with some minimum building attribute data, namely the building usage and building year (or age class), which is necessary to pick up realistic building physics parameters from the building libraries. The refurbishment year or refurbishment state, although not necessary to start the energy analysis, are valuable data that strongly impact the precision of the heating and cooling demand and energy savings results. For the final energy and CO2 emission calculations, information about building heating and cooling systems, combustible type and system efficiency are additionally required.

Linking Cities via Data Sets and Modeling Platform

The concept is that a global energy system could be studied with the new science that capitalizes on emerging observations using big data with models that could, to varying degrees, depict global-scale physics and socio-economics. This new thinking seeks to overcome a traditional mindset steeped in local-scale perceptions, research agendas and management approaches to energy.

The purpose is to understand inherent joint features and variability of urban energy systems, their predictability, and the human dimensions. We expect reciprocal benefits when considering local-to-global scales. Thus, a global viewpoint offers context to local-scale phenomena and in many cases, defines what happens over the smallest of domains (e.g. climate, urban energy and thermal comfort under global scenarios of climate change). In turn, the local scale offers critical ground-truthing opportunities for global concepts and, as we shall discuss, is the prism through which human interactions with their urban energy system ultimately become globally significant.

Methodology

Usable urban geometry models are in place for many cities including the author´s case studies in Europe and the USA, employing Geography Mark-up Language specifications (**GML, cityGML**) for inter-operability of representational objects and data sets as semantic layers. A Service-Oriented Architecture (SOA) enables the "plug-in" of additional elements, motivating the continued incorporation of external modeling frameworks. These models are developed and used in the research program of a network of EU-US universities with a specific objective of supporting cities in their planning and governance process. Simulations are built and run as experiments. In the process of doing these experiments, the researchers articulate and extend the range of problems that can be usefully addressed using the simulation platform.

The Integrated Urban Energy Modeling Platform

Urban systems are complex by nature. Their energy modeling involves buildings, energy supply and distribution systems, the urban microclimate and last, but not least, the user interacting both in operation and planning. Energy and resource flows have to be analyzed within the city, but also across city boundaries. Change over time, via socio-economic and technical strategies, are required for energy transitions to be quantified and visualized in ways that are usable by stakeholders.

Urban data are heterogeneous and often are characterized by data inconsistencies, a lack of quality control, and multi-jurisdictional coordination challenges (business, NGOs, municipal stakeholders etc.). Decision-making is difficult as many stakeholders are involved, data are fragmented and there are no standardized interfaces between different modeling environments. At present a disconnect exists between the priorities of the multiple stakeholders across multiple scales (governmental, geospatial, and temporal). Combining large data sets from very different sectors and domains remains a major challenge.

Features of the Urban Modeling Platform / Virtual 3D city models

Virtual 3D city models are extremely powerful data models for urban energy modeling, since the geometrical and semantic data of an entire city can be efficiently managed. The LiDAR (Light Detection and Ranging) technology, which uses a dissipating laser to acquire distance measurements remotely, make it possible for many cities to derive 3D city models quickly. By 2014, the complete building stock of Germany had been modeled in CityGML – LoD1.

The OGC (Open Geospatial Consortium) Standard CityGML is an open, multifunctional virtual city data model offering the possibilities for numerous and varied urban environmental analyses such as urban wind flow studies, photovoltaic potential or energy demand calculations (Kroeger et al., 2012). Its spatio-semantic model can specify object modeling at five different levels of detail (LoD). Due to this, it is an excellent database for heating and cooling demand analysis of existing building stocks, since the level of building parameter availability can be reflected in the LoD of CityGML.

Urban energy analysis based on the virtual 3D city model has been already carried out in several cities such as Berlin (Carrión et al., 2010 and Kaden, Kolbe 2013), Karlsruhe and Ludwigsburg (Nouvel et al., 2013), as well as some other European cities that are partners in a European project called SUNSHINE (Schrenk et al., 2013). Disparities in the required input data in these projects, such as reliance on the specific (non-standardized) data structures defined locally, is one issue that makes data availability problematic. Many projects are aiming at either standardization of required input data for urban energy management (SUNSHINE project), or setting up a directive for a database format like INSPIRE (Official Journal of the European Union 2007). Moreover, Nouvel et al. (2014) have introduced an urban heating model based upon nationally available databases in Germany and different level of details of input data.

Data Challenges

The input data quality to the models is one of the common challenges of urban energy models. Inadequate input data and limited details on the available data often necessitate the use of default values present challenges to urban building modeling.

In many areas of urban energy research, the lack of quantitative data from real world case studies is a problem. In urban energy resilience research, the link between infrastructure, resources, land use, governance and socio-demographic aspects cannot be properly quantified due to the lack of urban data (Sharif et al., 2016). Correlations between urban energy consumption and socio-demographics and other factors most often rely on aggregated data due to the lack of granular resolution and can only yield very limited analysis possibilities. A study in London based on 4765 so-called lower super output areas (small scale data) showed rather predictable correlations between land area for domestic buildings and gas consumption, while electricity consumption was more correlated with tariff structures than with the size of the buildings (Tian et al., 2016).

On an aggregated scale, the World Urban Database and Access Portal Tools (WUDAPT) is an initiative to collect data on the form and function of cities around the world. The goal is to classify cities according to the Local Climate Zone framework as the starting point for characterizing cities in a consistent manner. The main application focus is urban climate and weather modeling, including simplified energy balance studies to compare cities around the world.

Model integration Challenges

Another challenge in urban modeling is to integrate tools from different domains and scales. Modeling frameworks are generally distinguished by top-down, bottom-up, or hybrid approaches. In urban ecosystem models, bottom up models include spatially explicit models for land use changes in urban areas using agent-based models, while top down models use national or regional aggregated data and focus on energy and material flows in cities (Chen et al., 2014). Top-down models yield energy footprints of cities as the impact of a city into the area of productive land it relies on and might account for all resources and all energy and matter consumed by the city (Rees, 1992). Such models necessarily simplify the physical processes related to energy generation, distribution and use and the interaction with the users. The general consensus is that it is unrealistic to model the complex urban ecosystem by one model alone and that the goal should rather be model integration into a joint framework.

The energy domain is a highly heterogeneous and multi-disciplinary field. Furthermore, within each field we have multiple stakeholders requiring information with varying level of granularity that use diverse devices to access and visualize information. This makes it a challenging task to share, retrieve, update and visualize information in a seamless manner.

With the recent advancement in Information & Communication Technology (ICT), Service Oriented Architecture (SOA) has been gaining momentum. SOA is an enabler that exposes software functionalities as web services and allows exchange among connected components. Semantic Web Services use geospatial ontologies for semantic descriptions of data, services, and geo-processing service chains to support on-demand delivery of geospatial information and knowledge. A primary issue in promoting Semantic Web Services is to provide rich and consensus-based geospatial ontologies on the Web, so that geospatial resources including data and services can be described using widely used terms or vocabularies and merged into a web of data. To achieve efficient geospatial analysis and knowledge discovery, high performance data mining, workflow process modeling and service technologies have to be used. Big Data mining needs to aggregate diverse data sources and run on parallel computing nodes. In addition, traditional knowledge discovery methods are not applicable to dynamic streaming data. Therefore, effective technologies are needed to support data stream mining, web analytics, and knowledge service.

Many simulation and modeling tools are available to answer urban energy system challenges, but they are not yet interlinked and do not use the same data models (Keirstead et al., 2012). The scales from building level to the city quarter, and up to the national and international scales are not addressed and connected in joint simulation tools (Pfenninger et al., 2014).

Optimization is widely used for energy system design and operation (Voll, 2014) and further for urban planning problems, especially the assignments of land use and transportation (Keirstead et al., 2013). Within the specific field of urban energy systems optimization, techniques are mainly applied to network design, utility sizing and operation strategies (Girardin et al., 2010, Fazlollahi, 2014, Menon et al., 2013). However, most approaches lack a detailed representation of the buildings and where they do so, the case studies are limited in size. Thus, further research is required to optimize holistic urban energy systems on a large scale. Further most problems are formulated as linear equation systems, which means simplifications of the problem statement. Closer links to simulation would help to clarify uncertainties associated with the problem simplification.

City Infrastructure Planning - Common Challenges Across Global Cities

To connect macro-scale views on climate change and energy transformation to the local and regional level, energy sciences need to combine global data sets with much more granular information about current energy consumption and emission and develop urban data sets for model development and calibration exercises. Global data sets and models span many thematic domains, including water engineering, climate and carbon models, urbanization trends, renewable potentials. However, they are necessarily extremely aggregated and do not take into account the challenge of matching more and more intermittent energy generation with demand responses.

While emerging macro-scale data sets and models have been instrumental in repositioning the vantage point through which we can monitor and understand energy, the local-scale perspective is crucial to develop actionable solutions for urban energy management.

Macro-system planning and decision support systems applied today do not capture micro-scale dynamics fully. The communication between urban spatial-temporal dynamics and urban policy-making should be enhanced by better understanding the feedback of ecological consequence to human health and welfare. A more rational urban energy management (UEM) requires carefully selected and validated sustainability indicators that reflect not only emissions standards, but also the impact of UEM on ecosystem services in addition to economic stability at various scales. International Coordination

International efforts are necessary to bring together the disperse scientific community involved in urban modeling under the common goal of developing and testing strategies for sustainable urban energy systems. Enhanced communication and better data flow are necessary to establish how global decision-making can be broken down to national and local urban energy system transformation strategies. On the other hand, understanding the impact of local decision- making on the achievement of global targets is crucial, be it on a building scale, a city quarter, an entire city or metropolitan region.

A Future Energy Research Agenda can be envisaged, similar in spirit to the emerging Future Earth initiative, relying on a similar call to the global change community to expand its mission to one that co-produces actionable scientific knowledge with the environmental planning, policy, and management communities.

One immediate and tangible opportunity to pursue this objective involves the post-2015 phase of the Millennium Development Goals (MDGs), now collectively referred to as the Sustainable Development Goals (SDG). The SDG process has initiated complex member-state negotiations with the aim of setting targets and tracking progress toward sustainability, with important extension of the MDGs to include not only the developing world but developed nations as well (Yudhoyono, 2013).

This Future Energy Research Agenda directly supports Goal 7 of the SDGs, which is to ensure access to affordable, reliable, sustainable and modern energy for all. This goal is accompanied by several targets such as universal access to affordable, reliable and modern energy service, increasing substantially the share of renewable energy in the global energy mix, doubling the global rate of improvement in energy efficiency by 2030, and enhancing international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology (United Nations, 2015). These targets can also be addressed through better international coordination of research agendas and improved energy simulation capacity at various scales derived from improved data quality, quantity, web services, and model integration techniques.

Lessons from the MDGs show the critical need for a sound scientific foundation, and technical and institutional capacity from the energy sector, in addition to the systematic monitoring of progress. However, it is not simply a question of providing money and engineering. Among the new SDG commitments is the intent to consider alternatives to the common measures of economic well-being like GDP and to begin identifying and more coherently evaluating the role of the environment in sustaining society. Yet, it is apparent that there is a palpable tension between making investments needed to alleviate short-term threats (i.e. restricted to grid stability) as advocated by the developing world and the long-term environmental sustainability promoted by rich countries.

Examples of urban data and modeling applications

Use-Case Experiments and Results To-Date

Example use-case experiments are presented that demonstrate the value of urban-scale modeling for issues common to cities globally. These and other simulation experiments are at various stages of progress.

Renewable Energy Provisioning

Building geometry and energy use are conjoined in assessing potential Solar Energy Fraction (SEF) and emission reduction goals. Mapping enables incorporation of shading factors between buildings. Load-side technology changes are explored for potential in impacting the SEF. Simulations strongly support the hypothesis that high-density tall urban environments must import renewable energy even after on-site technology advances, informing policy formulation for renewable energy imports to reach low- carbon goals.

Neighborhood-scale Micro-Climate Effects

Urban form is combined with meteorological data (boundary conditions), a high-resolution multi-scale dynamical model, and flow effects analyzed with computational flow dynamic (CFD) tools to predict local (micro-climate) outcomes and building energy demands under various conditions. Results focus on urban heat island /heat stress and air quality conditions that have significant dimensions for urban public health. The predictive value of simulation is shown for municipal government preparedness.

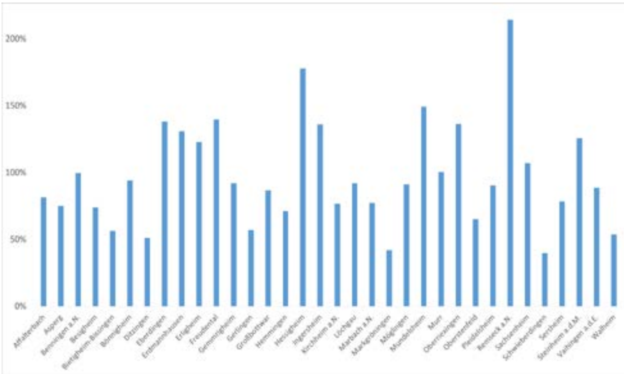
Municipal Buildings and Utility Load Management

A portfolio of municipal buildings with energy use data is mapped against utility local distribution networks to assess potential impact for near-term and long-term load management on highly loaded sub-stations and feeders. The simulation compares alternative retrofit investments with cost-benefits from delayed utility reinforcement. Actual energy use incorporated into the modeling improves simulation reliability. Clustering effects are shown to be significant in local network reliability.

Applying the methodology to case studies

To demonstrate the potential of urban data and its applications, some case studies of PV potential estimations at urban level are outlined, as well as some of the conclusions that can be drawn from them. The authors have developed an integrated simulation framework, where 3D urban geometry based on the CityGML standard is used for modeling heating and cooling demand of each building and renewable energy potentials. The framework allows simulations at an urban and regional scale by combining geometry processing and simulation functions in the software environment INSEL8.2 (SimStadt, 2016, www.insel.eu). The results can be visualized in different ways with performance indices, graphs or maps, as well as exporting them to a file. As an example, the photovoltaic potential has been simulated for a region in Germany and for Midtown Manhattan.

Based on the 3D model of the region, it is possible to know the total built area and the geometry of the buildings that shape it. However, many circumstances may lead to the reduction of the total roof area. In the present study, the technical PV potential is the result of the implementation of PV panels on all available surfaces. This means that the whole available roof area after applying some reduction coefficients will be used. Those reduction coefficients include considerations of construction restrictions, protected buildings, obstructions of surrounding buildings, separation of the PV panels and others. In addition, the reduction of the PV yield due to the efficiency of the PV modules, system efficiency, cabling losses and so on is considered. The radiation processor can compute the incoming irradiance on every building boundary surface, based on their geometry and the direct, diffuse and horizontal irradiances delivered by the weather processor. There are several radiation models implemented within SimStadt,



some of which take into account the effects of the interactions among neighboring buildings. Multiple analytical steps, that would previously have been conducted separately with substantial porting of data between tools, are integrated into a single workflow within the modeling platform.

Case Study: PV potential analysis of several municipalities in the Ludwigsburg County

In this example, all the 3D CityGML models of the municipalities that constitute the County of Ludwigsburg in Germany were simulated within the SimStadt platform. Of the total 39 municipalities of the County, 34 are analyzed. In total, 157724 buildings are considered. Assumptions on efficiencies and reduction coefficients are applied (16% of PV modules efficiency for example), and the PV fraction is calculated by comparing the PV potential with the electricity demand of each municipality, which was obtained from concession bills. The results are illustrated in Figure 2.

Figure 2: PV fraction of all the municipalities in the Ludwigsburg County.

The results show that many municipalities could achieve even more than 100% coverage of the electricity demand if all the available roof area of the region after applying the reduction coefficients is used. The reason for such high values is that the case study is mainly a medium-density rural region, with a lot of available space for PV implementation

Case study: High-density area in Manhattan, New York

As a further example of the capabilities of urban data models, a specific high-density area of Manhattan, New York has been analyzed, with a total of 5882 buildings. This area was chosen due because it is the most densely populated borough of New York City with the highest concentration of high buildings.

The simulation platform delivers many interesting outcomes such as analyzing the PV potential of the region both for roofs and facades, urban shading factors depending on the orientation of the buildings, depending on their height, and many other possibilities. The area under study and its radiation map obtained through SimStadt is visualized in Figure 3. Based on reported meter data from a sample of 50 public buildings, an average value of 156 kWh/m2•year has been used for the electricity consumption. This value is then referenced to the Gross Surface Area of the buildings in order to calculate the percentage of on-site solar contribution feasible ("solar fraction"). Further work in the modeling platform is planned to be able to develop a more precise mapping of building energy use.

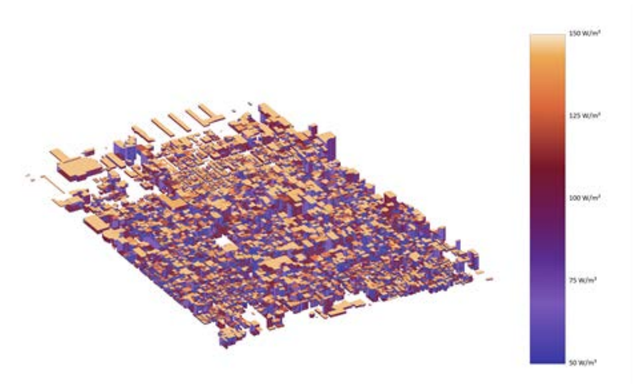
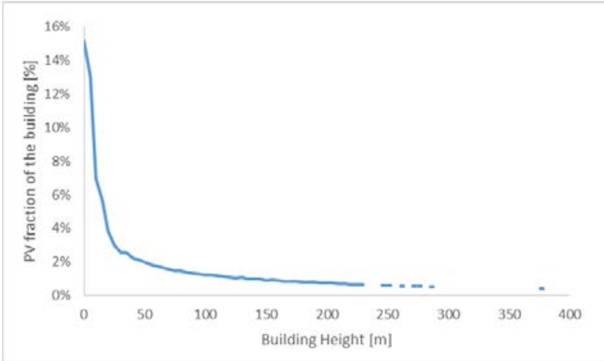


Figure 3: Radiation map of the region under study (average annual irradiance in W/m^2.

The PV potential analysis allows the extraction of relevant data, such as the influence of the building height with regards to the fraction of their electricity demand that can be obtained from the PV modules. The results of the region under study are shown in Figure 4.

Figure 4: Influence of the building height on its PV fraction for New York City.

It can be seen that the PV potential of a high-density region such as Manhattan results in much lower PV fraction values than for the German counterpart. This is due to the relative scarcity of available roof space



compared to rural regions, and the fact that the NYC buildings in a highly commercial area are more intensive electricity consumers with a demand nearly four times higher than in the German mainly residential area. Further modeling with specified constraints will enable an aggregate view of residential properties, largely multi-family apartment buildings, in Manhattan and build-out of the model will enable extension to more residential outer-borough areas of the city, which generally have lower constructions.

The ability to perform this kind of calculation at aggregated scale is of great value to policy makers and planners who must consider sources of supply and provisioning. In the NYC case it becomes apparent – and is subject to further modeling analysis – how much electric supply must come from a combination of efficiency and external purchasing of renewables in order to achieve targeted high solar fractions and low greenhouse gas emissions (New York City, 2015).

Urban shading factors: middle and high-density areas

Another possible outcome derived from the urban simulation platform under study is the assessment of shadings, considered to be of great importance for building energy modeling due to their noticeable influence on energy demand.

The availability of 3D models and different radiation processors within the SimStadt simulation platform allow for surrounding buildings to be considered or for the assumption that each building under study is isolated. In this way, the influence of the obstructions caused by other buildings can be quantified by comparing the computed irradiance on each surface for both models. Having done that, it is possible to assess the shading factors in specific buildings or calculate average values for whole regions.

As an example, the average rooftop monthly shading factors of the two previously mentioned case studies in New York and the County of Ludwigsburg/Germany are presented in Figure 5.

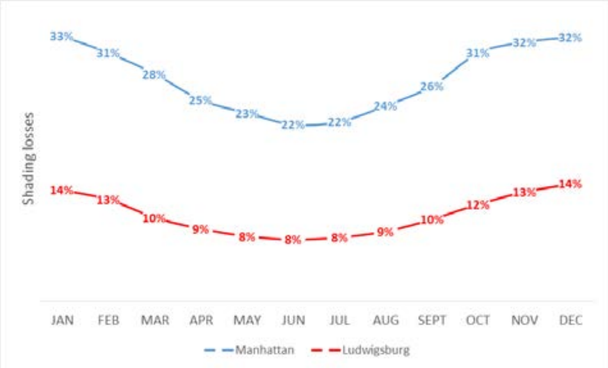


Figure 5: Rooftop monthly shading factors.

As expected, shading losses are lower in the summer months due to higher solar heights. In addition, it is apparent that shading losses in Manhattan are greater, as a result of the higher density of the area as well as building heights.

Conclusion

Key urban energy and environment issues (use-case experiments) are investigated using 3D CityGML-based modeling tools, showing the relevance of urban-scale simulation to energy planning scenarios and policy decisions. Flexibility is demonstrated for integrating new data sets and tools for continuing development. Coupling between the built environment and its surroundings across a large range of spatial scales, from individual buildings to full cities, is added to the simulation platform, providing a significant new dimension for urban planning and urban governance globally.

In this work the need for a global research agenda on urban energy and related modeling frameworks (UEM) has been suggested. The research and planning questions that can be addressed range from building, city quarter and community level efficiency and technology scenarios for decision-support and policy-making, the analysis of infrastructure needs over time, zoning rules and impact-analysis up to micro-climate predictions and alert systems for critical energy systems. Such questions and planning issues are expected to be seen consistently across cities, albeit with starting points, details and outcomes varying based on local context; a shared modeling framework would greatly facilitate learning and sharing between cities.

Urban data sets and a range of representative case studies are essential to demonstrate the potential, to calibrate models and to set best practice examples. An innovative simulation platform based on 3D city models was developed by the authors, which allows detailed analysis of the building heating, cooling and electricity demand within the context and workflow of an urban scale mapping platform.

First examples focusing on renewable integration into urban areas are shown for case studies in the US and Europe and the next steps towards a globally integrated modeling platform are analyzed.

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