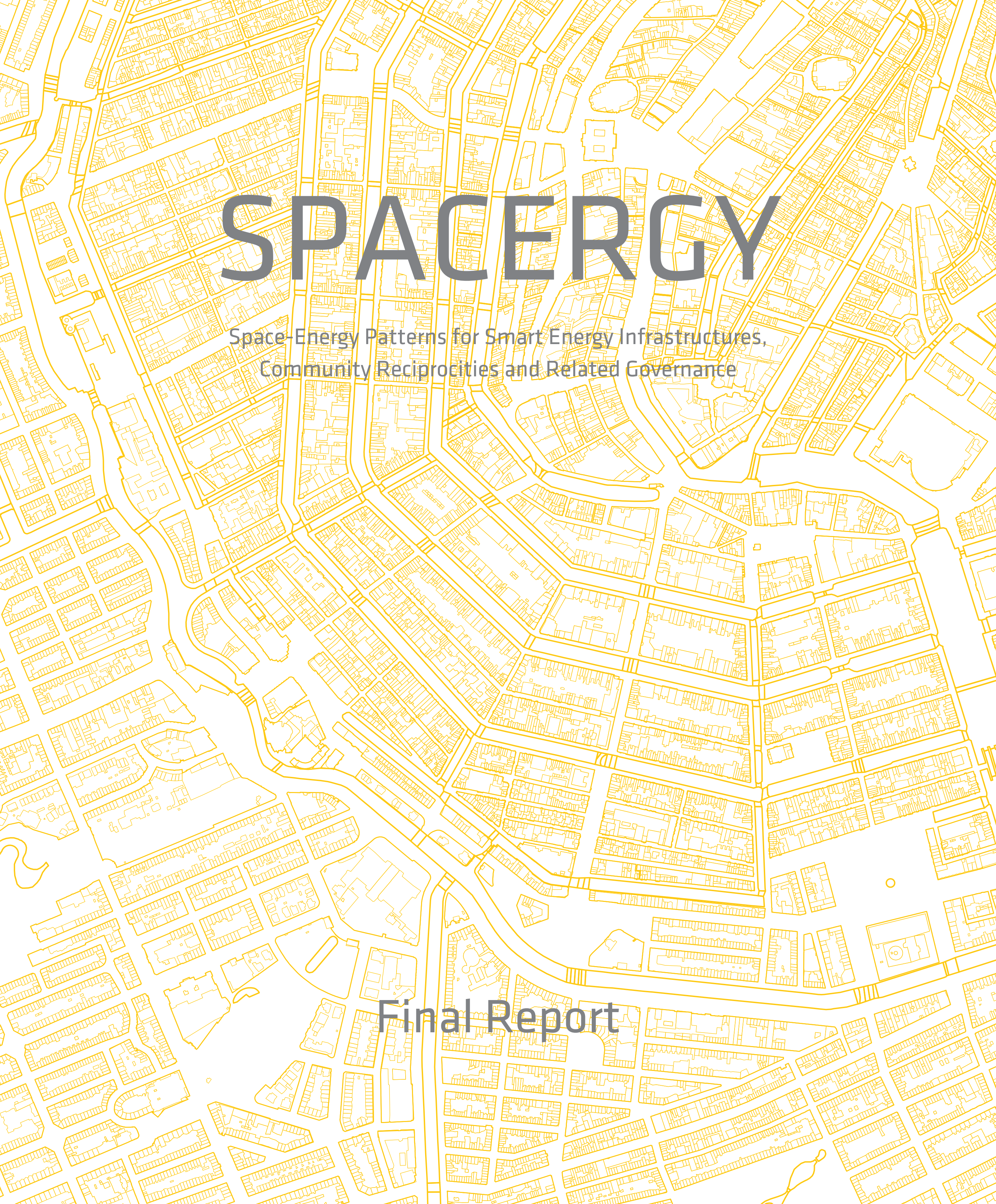

SPACERGY

Space-Energy Patterns for Smart Energy Infrastructures, Community Reciprocities and Related Governance

Final Report

Spacergy

Space-Energy Patterns for smart energy infrastructures, community reciprocities and related governance

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Final Report

The SPACERGY Project

SPACERGY builds upon the need of planning authorities to develop new models to implement energy transition strategies in the urban environment, departing from the exploitation or reciprocity between the space and energy systems. Several policies have been made by each EU nation, but effective and practical tools to guide the urban transformations towards a carbon neutral future present several challenges. The first challenge is to confront long term changes in envisioning how a specific socio-cultural context can respond to the application of solutions for energy efficiency. Secondly, the engagement of communities in bottom-up approaches mainly includes the sphere of urban planning that underestimates the importance of relating spatial transformations with the energy performances generated in the urban environment. The third challenge regards the tools used for the assessment of the energy performance and the necessity of enlarging the scale in which energy demand is analyzed, from the scale of the building to that of the district. In this context, the project explores the role of mobility, spatial morphologies, infrastructural elements and local community participation in regards to the smart use of local resources. The project addresses a knowledge gap in relation to interactions and synergies between spatial programming, energy and mobility systems planning and stakeholder involvement necessary to improve models of development and governance of urban transformations.

Based on detailed spatial morphology and energy use modeling, SPACERGY develops new toolsets and guidelines necessary to advance the implementation of energy efficient urban districts. New toolsets are tested in three urban areas under development in the cities of Zurich, Almere, and Bergen, acting as living laboratories for real-time research and action in collaboration with local stakeholders. The results of this research project support planners and decision makers to facilitate the transition of their communities to more efficient, livable and thus prosperous urban environments.

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5 - Integrated energy infrastructures (Space and energy use for transport)

6 - District Energy Integration Model: Conceptual Framework and Application


Street network
Global,
Local,
Aquifer
Integration
Aquifer step depth
from
Public transit stops
Ressource
flow (in/out)

Introduction

by Prof. Arjan van Timmeren

Although urban dwellers on average use approximately 40% less energy then suburbanites, energy demand in cities is globally growing, the burning of fossil fuels for energy being the leading contributor to GHG emissions worldwide. The rising energy demand is strongly related to changed lifestyles (with a significant role for mobility and the built environment) that involve increasing levels of comfort and use of space. While fossil fuels will be quite difficult to replace for many applications (fertilizer, medicine, plastics, etc.), renewable energy systems offer a viable, carbon-free and often locally available alternative that many countries are beginning to transition towards (Jong, 1996). This globally initiated transition towards renewables is starting to influence the use of space, including the cityscape and natural landscape. The growth and densification of interdependent infrastructures that support people, information, water, materials, energy, and waste and the rigidity of current urban planning and design methodologies make our cities increasingly vulnerable to cascading effects caused by anthropogenic climate change (i.e. increased weather perturbations, resource scarcity, etc.). As such, the concepts of vulnerability, increasing complexity and resource scarcity become essential to defining future trends in sustainable development, governance, urban planning and design. Within this context, in the last decade, these trends have made the topic of energy generation and consumption reappear in the agenda of spatial planning (Schubert 2014), with a stronger focus on reciprocity of 'clean energy production' and an energy system that can become gradually dominated by renewable resources, while being smart and more integrated and interconnected to use(rs). Additionally, Information and Communication Technologies (ICT) have become a ubiquitous part of everyday life. ICTs will have an integral role to play in developing more sustainable and resilient patterns, and in particular, matches of consumption and production. Of all the areas in which ICTs contribute to sustainable development, technologies coming from the user-centric field of sustainable Human Computer interaction (HCI) could potentially be used to buttress sustainable behaviors. Within this, and the coming energy transition, the inclusion of Distributed Energy Generation (DEG) at a local scale and with included HCI based feedback loops will be of rising importance (Pepermans et al. 2005). DEG means that bilateral energy trading becomes possible with the use of local resources, (temporal) storage and exchange facilities and alternative network geometries (Timmeren et al., 2012).

Within the perspective of alternative network geometries and the context of reciprocities of cities and their surrounding area (hinterlands) towards regional sustainable metabolisms, urban environments can not only act as energy consumers, but as spatial structures useful for the production, storage and exchange of energy (prosumers). One of the resulting and urgent challenges is to build adequate energy infrastructure that ensures proportionate penetration of renewable energy, and new 'grid functionality' (including spatial lay-out and functional use for building and mobility related), including all the necessary spatial, economic, logistical and social components (Alanne and Saari, 2005) that support the idea of the Inclusive and Energy Sensitive City (the city as generator). As the focus still is mostly on energy performance, and as the operating energy efficiency of a building shell continues to increase, embodied energy makes a more significant contribution to a building's lifetime energy consumption. According to Newton and Meyer (2011), it is now slowly approaching a 1:1 ratio compared to the average building life. This leads, on the one hand, to a larger importance of the two higher spatial scale levels and on the other hand, to calls for development of an integrated life cycle energy analysis encompassing embodied energy, operating energy efficiency and local energy generation as a basis to achieve zero-carbon housing. SPACERGY focuses on the former ; the interaction of the higher scale levels and the building(use)s. Measures that are taken at city level (as opposed to more general measures like taxation and technological innovation) can contribute significantly to a reduction of energy consumption and CO2 emissions (Kamal-Chaui & Robert, 2009; Glaeser & Kahn, 2010). The design and integration of a new energy system into the city environment must begin to tackle a variety of issues and resolve critical aspects regarding interdependency between the city, its underlying (infra)structures and end-users. Recent research (e.g. Schlueter et al. 2015) has pointed out how different urban forms and programs can have direct implications in the way we consume and produce energy in the built environment. This holds even stronger when one includes mobility (Silvester et al., 2013). The strong ties between patterns of consumption and related infrastructure represents a series of opportunities to study how different urban morphologies either benefit or constrain the performance of energy and mobility infrastructures. As urban form shapes the demand of energy and mobility, modes of transportation (public, private, electric vehicles, trams etc.) and the penetration of DEG in an area (including for instance roof top area for harvesting solar potential, temporary storage in parked EVs, etc.), it is urgent to evaluate the interaction among these variables in early stages of urban (re)development. In this context, new models of governance and urban development considering the integration of urban and energy planning approaches are extremely important to facilitate a transition to a more efficient, inclusive and liveable urban environment.

The transition processes involved in the implementation of infrastructural systems "have a strong spatial (and in particular, urban) dimension in which not just technical, but also social processes are reflected" (Schubert 2014). SPACERGY focuses on the role of optimized mobility, spatial morphologies and infrastructural elements, while adding local community participation in regard to the smart use, storage and exchange of local resources. It addresses a knowledge gap in the interactions and synergies between spatial programming, energy and mobility systems, and models of governance to support the transition towards a more Energy Sensitive City.

Executive Summary

The transition towards a carbon-free society is considered one of the principal challenges of the coming decades for cities and metropolitan regions. This transition marks the shift from the fossil fuel era to an era where the new energy mix is dominated by renewables energy production. Urbanized areas, which account for a substantial portion of the energy demand, are gradually becoming spatial structures for the production, storage and exchange of energy. However, realising Energy Sensitive Cities is not just a technological challenge, but needs to consider the consequences in terms of values and uses for the communities, and to support decision makers in the development of a long-term vision. In this context, the main scope of the research is to explore, within the transition, the reciprocal relationship between urban planning and the development-applications of energy strategies to reduce demand, produce and re-use energy, based on the maximum exploitation of energy potentials of specific urban environments.

In this context the SPACERGY project investigates how to implement and use decision making tools that allow for the integration of the spatial and energy dimensions in urban development projects. Firstly, it explores the use of Living Lab approach in developing a design-oriented scenario method to envision and evaluate possible futures, taking into account the spatial and energy transition components, as well as internal and external drivers of pressure. Secondly, quantitative tools are discussed and tested to assess thefuture energy demand, enlarging the computational scale from the building to the district level. Finally, a District Energy Integration Model (DEIM) is developed by coupling four different modules for the synergic assessment of energy demand for the building and the mobility sector at the scale of a district.

In the first phase of the project, relevant data on the case studies are collected and analyzed, looking at the three focus areas of Floriade (Almere, the Netherlands), Mindemyren (Bergen, Norway) and Hochschulquartier (Zurich, Switzerland) and their spatial contexts. On one hand, land use characteristics and goals set for urban areas aiming towards a sustainable transformation, deal with physical and system proprieties in terms of energy transition strategies. On the other hand, national policies delineate priorities to achieve an energy balance between use and supply, to comply with targets set. Within this context, the practice of integration of spatial and energy-based planning is introduced and analyzed according to its different components. Two integrated frameworks are employed in this phase. The selection of three case studies is based on determinant factors defined by the Living Lab environment (Veeckman et al., 2013). Context research, Co-creation and Evaluation

are defined as pillars of the project activities defined by the Living Lab approach. On the gathered information, a description of the status quo Energy context, Urban transition and District space is given by using a transition practice based approach (Faller, 2014).

The knowledge base developed has been further used for building scenarios for the three case studies. Scenarios are instruments that allow the critical exploration of alternative models or urban transformations, and can also support decision makers in developing new future pathways. However, these are often used in the field of energy planning only to compare the energy performance of different possible solutions, underestimating physical and local spatial components that can guide design processes. In order to bridge this gap and promote a synergetic integration between spatial and energy system planning, a new type of scenario is needed for the construction of common, so-called "desirable futures". In the SPACERGY project, such a method is developed to meet this demand within energy transition processes and support coordination of design, research and planning towards an energy-sensitive approach. The hybrid Design-Oriented Scenario (DOS) method allows to define common visions within a multi-actor Living Lab (LL) approach. The DOS method, tested in the three case studies, combines descriptive, explorative and normative components. It aims to help decision makers in complex multi-actor processes by setting common objectives, sharing and creating a multidisciplinary common ground, and exploring alternative spatial and energy performative visions.

Within the first analytical phase, the main goal was to identify social, political and economic components to determine potential trajectories to develop energy concepts in the different study areas. The exploration of energy-spatial strategies to guide robust design choices and processes of implementation requires the creation of a solid and common knowledge basis. Therefore, workshops with stakeholders and experts have allowed the creation of Internal and External Scenarios. Three Workshops took place in the cities of Almere (the Netherlands), Bergen (Norway) and Zurich (Switzerland) between September and October 2016, involving the SPACERGY academic partners (TU Delft, HIB Bergen, ETH Zurich), together with most relevant local stakeholders (energy experts, administrators, technicians, etc.) for each of these locations. The main aim of these workshops was to discuss external trends and to determine design-oriented scenarios for the development areas.

The second part of the project focuses on collection of knowledge and development of tools for the assessment of building energy demand and mobility energy demand at the district scale. The role of urban form and energy related attributes are also discussed. Although morphological factors are considered fundamental because of their influence on energy demand, potential for consumption, temporal storage, matching of supply and demand, and integration of production, they are frequently overlooked in the design process. This holds in particular for the neighborhood scale. herefore, quantitative parameters to analyze morphological attributes of the building environment are discussed and used to describe the Zurich baseline scenario. Space

Syntax and ENVI-met tools are used to address the spatial dimensions of building geometry and street network.

Moreover, a dynamic energy demand model for the Hochschulquartier was developed in order to analyze the demands of the area. The work was carried out in the City Energy Analyst (CEA), a computational framework for the analysis and optimization of energy systems in neighborhoods and city districts. CEA comprises a collection of physical models for the simulation of energy demands and supply in the area of study as well as statistical databases containing building properties for typical archetypal buildings as well as operating parameters and schedules. The results for two different models are presented and discussed. The first one is the Status Quo, that is, the area at the time of publication of the new Masterplan for the area, 2014. The necessary information about 3D geometry, materials, occupancy and mechanical components was obtained from GIS data, owner information and the archetype database. Data on energy-relevant retrofits for the main building components was scarce and thus estimated. The second model presented corresponds to the SPACERGY Baseline scenario, which is roughly based on the 2014 Masterplan for the area.

The results show that the demand for heating per square meter in the Baseline is significantly reduced due to the construction of highly-insulated buildings, but the demands per square meter for electricity and cooling increase with increased usable floor space. University Hospital and ETH Zürich are the largest consumers for both the Status Quo and Baseline scenario due to their large built areas and highly energy-intensive functions. The University of Zurich's demands are much lower, but increase in the Baseline scenario due to its increased usable floor space in this scenario. Other buildings in the area hosting complementary functions such as residential, gym, and restaurants have a comparatively smaller impact on the energy demand of the area. Due to the increase in energy efficiency in the buildings in the area and the introduction of low emission cooling infrastructure, the overall performance of the area in the Baseline scenario is better than in the Status Quo. Nevertheless, 2000 Watt Society targets are not met, and hence further proposals need to be made to reduce the operating emissions and primary energy demand of the area in order to meet this goal.

A model for testing out the relationship between the spatial structure of the mobility network and energy usage for transport is built up for Bergen and Zürich. First, a Space Syntax map was made for Bergen and Zurich, and this map was used to carry out various Space Syntax analyses. Geographic Information Systems (GIS) are used as a platform to correlate the results of four different spatial parameters with one another. The following four spatial measurements are used:

- Through-movement potentials on a city-wide scale
- Through-movement potentials on the neighborhood scale
- To-movement potentials on a city-wide scale
- To-movement potentials on the neighborhood scale

In addition, we also conducted analyses on the building-street relationship (urban microscale tools). The aim was to reveal the extent to which the energy usage for transport is affected by the degree of permeability and visibility of adjacent buildings from the street.. After finishing the spatial model, the data on energy consumed by car traffic for the mobility network of the present context was correlated with the results from the spatial analyses. MATSim was used to get the data for energy usage for transport. Here, data was gathered on average speed, origin and destination of travel for Zürich and Bergen. GIS was used as a platform to correlate all the data with one another.

As the results from these aggregations for Zurich and Bergen show, the spatial structure of urban space and the nature of building-street interface affect energy usage for transport. High local integration and short urban blocks, combined with buildings with active frontages that allow for interaction with the streets, contribute to a high degree of 'walkability' in streets. Areas with high integration on the main routes running through the locally highly integrated neighbourhoods yield for an efficient public transport system on the integrated main routes network. In Bergen as well in Zürich, some of these streets have tram, busses or light rail lines on them.

The private car in particular is a major contributor to energy usage for transport. If the to-movement potentials on a local scale are well-integrated with the high-scale through-movement network, private car usage is reduced. Walking and cycling seem to become a natural choice for shorter, local trips. In addition, these streets need to be constituted and have a high degree of inter-visibility from adjacent buildings. As indicated by Jacobs (2000) and Gehl (2011), this urban microscale aspect contributes to a natural surveillance mechanism and makes walking attractive as a local transportation mode. When combined with an equally well-integrated, diverse public transport system, local trips can then extend to car-free regional trips, thus reducing energy usage further. As we have seen in the energy usage equation, longer and high-velocity car trips consume exponentially more energy.

Neighbourhoods with high values on all the four spatial measurements on the street network tend to have short urban blocks. In line with Jacobs (2000), short urban blocks enhance walking as a transportation mode. Walking and cycling are two means of transport with the lowest energy consumption. Therefore, the first task is to elaborate on the kind of spatial features that enhance these modes of transport.

So far, the studies of Bergen and Zurich have shown that short urban blocks (or a fine-grained urban mobility network within a short metrical distance), integrated main routes running through neighbourhoods with short urban blocks, constituted and inter-visible streets from adjacent buildings are complex, but necessary conditions for enhancing sustainable means of transport and a high degree of walkability. All these parameters need to be present at the same time for making neighbourhoods attractive for walking. Moreover, neighbourhoods with these spatial features tend to naturally transform into highly urbanised areas with high building density and land use diversity (Ye and van Nes 2014).

Highly integrated main routes connecting various neighbourhoods with one another supports the public transport network. Urban areas with low values on the angular choice with a low metrical radius and buildings turned away from streets generate private car dependency, low density urban sprawl into the countryside and mono-functional areas. This, again contributes to complex travel routes between work, shopping, leisure activities and home.

Finally, an integration between the tools previously described is attempted in two stages of integration by coupling different models. Methods for partial integration separately address mobility and building related energy assessment.

A computational approach has been developed for assessing the building energy demand. It allows quantitative analysis of building energy demand on a district scale, including interdependent factors such as local air temperature, relative humidity and wind speed, diversity in building geometry and materials, as well as user behaviors. The method, which links the microclimate model ENVI-met and the district-scale energy simulation tool City Energy Analyst, has been applied on a Masterplan for a district development in Zurich and Almere, in order to analyze the energy performance of the proposed design and define guidelines for improvement.

Focusing on mobility and transport, which account for 25% of energy usage in cities, a second approach asks, what are the factors of urban form and networks that affect patterns of movement and choice of transport mode in relation to energy usage? Using a quantitative analysis of spatial elements influencing mobility choices with Space Syntax, we demonstrate how spatial configuration and degree of walkability relate to energy usage for mobility. By correlating the spatial analysis data with energy consumption data obtained from measured traffic data, findings show that street segments with both a high level of local and global integration tend to exhibit lower amounts of energy usage for car traffic. This suggests that cities with highly integrated streets advance walkability and choice for sustainable means of transport (i.e. cycling and public transport), which then reduces energy usage.

A complete integration model for assessing energy demand jointly for the building and the mobility sector on a district scale is developed and tested. The District Energy Integration Model (DEIM) was used to estimate energy demand for space cooling in the Baseline Masterplan of the Hochschulquartier in Zurich and for other three scenarios. The results allow for an overall quantitative comparison between scenarios and illustrate the complex interdependent relationships between buildings and street network transformations, and the overall district energy performance. The four modules employed consist of available simulation models, ENVI-met, City Energy Analyst (CEA), Space Syntax and MATSim, which have been coupled in the workflow.

The results of the mobility analyses show that the lowest amount of car traffic and related energy consumption is seen in the Synergy scenario (21.2 TWh). This is, however, higher than the Status Quo (18.6 TWh). The highest energy consumption by cars (23.7 TWh) occurs in the Baseline scenario. Most car and bicycle traffic follows streets with high through-movement potential on the city scale, whereas most pedestrian traffic follows the shortest path to the central railway station in the northwest of the study area. On the local scale (R=500), there are some considerable improvements in through-movement potential between Hochschulquartier and the east bank of the historic city centre. However, the values do not increase in the masterplan area itself, with exception of the Synergy scenario. Here, the newly introduced promenade sees a distinct increase in local through-movement potential.

In all scenarios, the amount of walking is higher than the Status Quo. The differences between the scenarios themselves are marginal. The highest amount of walked distance occurs in the Super Urban scenario. Interestingly, the amount of distance driven by cars is not lower as a consequence.

Regarding building energy demand, heating for space conditioning, domestic hot water and processes is the primary contributor to the demands of all scenarios (31–37 GWh/yr). However due to the large share of functions with high energy demands for processes, lighting and appliances, the demand for electricity is similarly significant (31–35 GWh/yr). As expected, the energy demands are highest for the Health Campus scenario, mainly due to the increased demand for domestic hot water and process heating, cooling and electricity. The demands are lowest for the Synergy and Super Urban scenarios due to the increase in residential buildings in these scenarios, which lead to an overall decrease in process energy and space cooling demands.

The average space heating demand for all scenarios is around 40 kWh/m2/yr, whereas the space cooling demand ranges from around 12 kWh/m2/yr for the Synergy scenario to 18 kWh/m2/yr for the Health Campus scenario. Regarding process cooling, the minimum is also encountered in the Synergy scenario (10 kWh/m2/yr) while the highest demand is also found in the Health Campus scenario (18 kWh/m2/yr). The domestic hot water demand is also highest for the Health Campus scenario (26 kWh/m2/yr), while the other scenarios range from 17-20 kWh/m2/yr.

A key assumption in the definition of the SPACERGY scenarios was that the introduction of residential buildings in the Synergy and Super Urban scenarios would lead to peak shaving and a more balanced load throughout the day. However, while the peaks were indeed lower in these two scenarios with respect to the baseline, the load balancing effect was largest in the Health Campus scenario. This is due to the fact that hospital buildings not only have night time occupancy, but also have demands for domestic hot water and process heating during off-peak times.

When accounting for the effects of urban microclimate on the hottest day of the year, there was a noticeable dip in the peak demand for all scenarios, with a decrease in the peak power required, ranging from 5% for the Synergy scenario to 7% for the Health Campus scenario. However, due to the higher nighttime temperatures on the hottest day of the year, there was an overall increase in the cooling demand of 4% for the Baseline scenario to 6% for the Health Campus scenario. The effect of occupant models on the predicted demands of the area was also analyzed by comparing the standard CEA deterministic occupant model with a new model using the MATSim population as a basis. The results showed that the predicted peak power for space heating was barely changed by the choice of occupant model (< 5%), however the peak power for appliances and lighting as well as for space cooling varied by an average of 15% when changing the occupant model.

The application of the DOS method has showed its capacity to support complex multi-actor processes of spatial-energy transformation by helping in setting common transition objectives, sharing and creating a multidisciplinary common ground, and exploring alternative spatial and energy performative visions in a participatory workshop setting. In the scenario method elaboration phase and its application in the Almere, Bergen and Zurich Living Labs, visions were considered a fundamental contribution for the body of information and knowledge developed, while being consistent in terms of description regarding the relations between the energy impact factors and processes. The modeling framework developed allowed the computation of energy demand based on the principal types of factors that shape building and mobility performance, such as urban form, design, systems and behaviors. Moreover, the multi-domain simulation framework constitutes an attempt to tackle the major limitations of the single computational methods which have been discussed in the previous reports describing the partial coupling methods. Through the application of partial integration models on each of the Living Labs, the transferability of the proposed framework developed for the Zurich case study was demonstrated.

References

Alanne, K. , Saari, A. (2004). Distributed energy generation and sustainable development, Renewable & Sustainable Energy Reviews.

Baudirektion Kanton Zürich. (2014). Masterplan Hochschulgebiet Zürich-Zentrum September 2014. Zürich, Switzerland: Kanton Zürich, Baudirektion.

Faller, F. (2016). A practice approach to study the spatial dimensions of the energy transition. Environmental Innovation and Societal Transitions, 19, 85–95. https://doi.org/10.1016/j.eist.2015.09.004

Gehl, J. (2011). Life between buildings: using public space. Washington DC: Island Press.

Glaeser, E.L., Kahn, M.E. (2010). The Greennes of Cities: Carbon Dioxide Emissions and Urban Development. Journal of Urban Economics 67, nr.3 pp404-418

Jacobs, J. (2000). The death and life of great american cities, London, Pimlico.

Jong, T.M. de (1996) 'The existing Environmental perception inhibits considerations of effective solutions to the ecological crisis', in: The Architectural Anual '95-'96', Delft University of Technology, Faculty of Architecture, 010 Publishers, Delft/Rotterdam.

Kamal-Chaoui, L., Robert, A., (eds.) (2009). Competitive Cities and Climate Change, OECD Regional Development Working Papers N° 2, OECD publishing

Newton, P.W., Meyer, D. (2011). Consuming the urban environment: a study of the factors that influence resource use in Australian city, in P.W. Newton (ed) Urban Consumption, CSIRO Publishing, Melbourne

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D'haeseleer, W. (2005). Distributed generation: definition, benefits and issues, Energy Policy 33.

Schlueter, A., Fonseca, J. A., Willmann, A., Wirz, C., Moebus, S., Hofstetter, S., … Gruenewald, T. (2015). Nachhaltige, softwaregestützte Arealtransformation vom Industriestandort zum Stadtquartier. Zurich.

Schubert, S. (2014). The Need for Local Thermal Energy Planning, Journal of Urban Technology, 21:3, 21-26.

Silvester, S., Kumar Beella, S., Timmeren, A. van, Bauer, P., Quist, J., Dijk, S. van (2013); Exploring design scenarios for large-scale implementation of electric vehicles; the Amsterdam Airport Schiphol case. Elsevier, Journal of Cleaner Production, 48, pp. 211-219.

Timmeren, A. van, Zwetsloot, J., Brezet, H., Silvester, S. (2012) Sustainable Urban Regeneration based on Energy Balance. International Journal Sustainability 2012, 4.

Veeckman, C., Schuurman, D., Leminen, S., & Westerlund, M. (2013). Linking Living Lab Characteristics and Their Outcomes: Towards a Conceptual Framework. Technology Innovation Management Review, 3(December 2013: Living Labs and Crowdsourcing), 6–15.

Ye, Y. and van Nes, A. (2014). Quantitative tools in urban morphology: combining Space Syntax, Spacematrix and Mixed-Use Index in a GIS framework," Urban Morphology, vol. 18, no. 2, pp. 97-118.

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1.

Urban energy planning context in relation to urban Living Lab approach

Authors:
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Contents:

Summary

The energy transition of cities and urban districts depends upon multiple intrinsic and extrinsic variables as well as processes. In order to achieve a successful transition towards a carbon neutral society, integration of spatial and energy-based planning needs to be developed in a coherent process along the different scales and dimensions that the urban transformation involves. However, the coordination of spatial and energy-based planning requires a solid base of knowledge and information on the area of focus, urban and national context. On one hand, land use characteristics, and goals set for urban areas aiming towards a sustainable transformation, deal with physical and system proprieties in terms of energy transition strategies. On the other hand, national policies delineate priorities to achieve an energy balance between use and supply, to comply with targets set. Within this context, a reflection on the practice of integration of spatial and energy-based planning is introduced and analysed according to its different components.

The chapter summarizes the results of activities performed in Work-Package 2. The main goal of the first phase of the SPACERGY project has been to collect relevant data on the case studies, looking at the three focus areas of Floriade (Almere, the Netherlands), Mindemyren (Bergen, Norway) and Hochschulquartier (Zurich, Switzerland) and their spatial contexts. To identify the benefits and the challenges that this working frame can bring to the research and development process, also the definition, methodological setup and benefits of using a Living Lab approach are discussed. The energy policy and planning context are also described for each of the cases, at both the national and local (city) context.

1.1. Introduction

1.1.1. Spatial dimension of Energy Transition

Urbanised areas will remain the dominant consumers of energy in the coming decades. They will be dealing with significant transformation processes regarding new developments, densification and retrofit of existing urban areas. In this transition process, multiple opportunities emerge to advance new integrated design approaches for European cities through creating synergies between available energy resources, infrastructures and the typical spatial characteristics that facilitate the application of strategies to reduce the energy demand, re-use of waste flows and the production based on renewables.

There is a common acceptance that the process of Energy Transition both is dependent on, as well as provokes, spatial changes. Considering this spatial context both as physical space, as well as a place of interaction within the urban environment. In Transition Studies (TS), in general, the spatial dimension is key focus in the debate, while it involves both theoretical and empirical perspectives.

According to Geels [1], the transition of the energy system should be conceptualized as a socio-technical transition, since it includes a high interrelation between networks of actors, institutions, knowledge and material artefacts. Because of the interdependency among the different components of the system, the urban energy transition diverges from a simple technological transition. It includes multidimensional transformations in addition to the technological dimension and involves a 'set of processes that lead to a fundamental shift' [2], along technological, material, organizational, institutional, political, economic and socio-cultural dimensions.

This multidimensional perspective highlights the fact that despite the fact that one of the biggest challenges to realize a transition towards a low carbon society is the re-orientation of the energy sector, also other components play a fundamental role. In the course of such a transition, new products, services, business models, and organizational schemes emerge within fundamental transformations in technological and institutional structures, as well as cultural perceptions regarding services. Moreover, socio-technical transitions encompass complementary technological and non-technological innovations [3]. Not only the structure of the existing energy systems is transformed, but also other related societal domains are affected such as

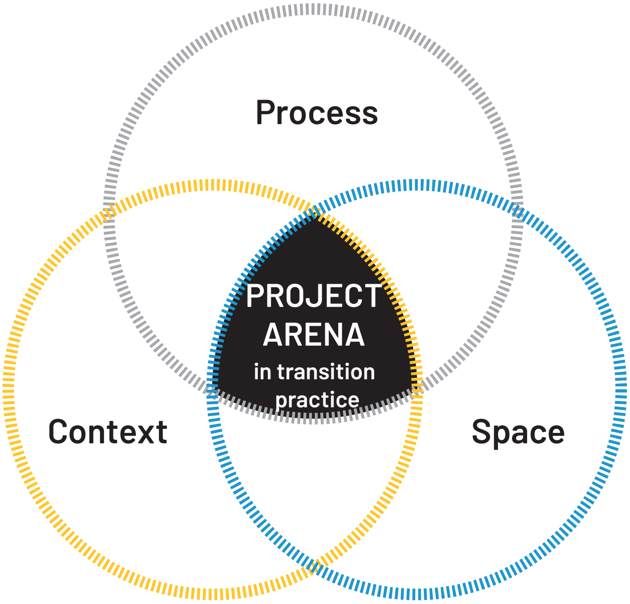

FIG. 1.1 Analytical framework for understanding transition practice in project arena.
Source: Adapted from Faller, 2014

living and working, while planning and policymaking, as well as production in the real environment will be affected as well.

Although TS can be considered advanced as to their description and analyses of transition processes, thus being able to describe interplays of its complex dynamics [4], the spatial dimensions related with those and the characteristics to achieve a sustainable transition often are underestimated. So far, the spatial and institutional context in which socio-technical transitions unfold have not received much attention in literature. Analyses based on the Multi-Level Perspective (MLP) also have failed to analyse the spatial particularities of transitions in a more systematic way [5].

The spatial dimension related with the process of Transition has been under discussion in the last decades from different perspectives. In recent literature, TS highlight the importance of the spatial dimension of Energy Transition, focusing on the understanding of the role of space, place and scales [6, 7]. Notable recent research proposes explicit incorporation of spatial and temporal scales, considering the spatial dimension as a 'relational scale, constituted by network and actors across different territories' [6]. Raven et al. (2012) describe the 'implications of multiple spatial levels on socio-technical transition', illustrating the importance of interaction between spatially distributed actors, institutions and economical structures within heterogeneous spaces for innovation [8]. In what he calls the second generation of MLP, consideration of space introduces new elements and analytical dimensions of the socio-technical system in transition. Although, the theoretical framework remains analytic and bounded to the understanding of the processes in relative spatial scales only, a translation towards analytical studies in absolute spatial scale [9] like for instance cities, regions and nations as 'containers of spatial variables', could help to explain transitions processes.

1.1.2. Empirical Studies in Energy Transition

Empirical energy Transition Studies address the spatial dimensions by stressing the importance of practice-sensitive analysis for a better understanding of a transition. Further studies seem to be needed in this direction in order to expand knowledge on transition practice through case comparisons [10]. Energy Transition, according to Bridge et al. [11] mainly relies on the 'interaction of natural, technical and cultural phenomena in a geographical setting'. Various authors pose the importance of implementing alternative urban visions [12], role of actors' networks [13] and the relevance of the local framework for the energy transition [14]. Musiolik and Markard [15] observe that more studies are needed on the role of actors in the transformation of socio-technical systems, such as related to the energy system. Moreover, local and urban analyses are less common, since the majority of TS studies focus on national settings [16]. In addition, several authors emphasis the need for a spatial perspective for transitions [7, 17] to understand place and actor sensitivity for a practical approach. Moreover, they state that further research is needed in transition literature about the local conditions which influence the specific, local results achieved [7].

Empirical studies have been contributing on the spatial perspective on transitions. Faller [18] illustrates a transition practice-based approach, built on Schatzi's 'theory of practice', in which the 'project arena', interpreted as a practical phenomenon, describes the 'relation range of experiences emerging from, as well as constituting related practices' and constitutes society and its geography (Fig.1.1).

In this framework, Processes, Context and Spaces, are connected by the 'arena' for the project under examination. Institutions, technologies and visions associated with the energy system are the contextual elements of the energy system. Understanding the geography of transition from a Transition practice approach in this sense means to focus on actors related to the development and making of the focus areas and its transition and related space. Spaces of Transition in this understanding have a dual sense as 'Euclidian, absolute spaces of latitude and longitude' [18] and reflect the 'relational proximity of one element of the system to another' [19].

1.1.3. Living Labs and Transition

Processes, Context and Space represent the key-elements of a transition practice and the necessary information in order to develop an efficient transformation of the three SPACERGY case study areas.

The studies referred to before consider this analytical framework applicable on the status quo in order to understand the starting conditions on which urban transition goals are set, and based on that try to achieve a combination with the concept of a Living Lab framework. It would support the move from analyses towards the implementation of energy transition guidelines. Therefore, in the SPACERGY project two parallel, each other informing routes are created based on Transition Studies and Living lab methodology.

Though parallel, the frameworks main focuses are sequentially used in different phases of the project. The living lab approach offers a structure for research actions. The methodology for Living Labs by AMS Institute is followed [20]. A selection of case studies is based on the characteristics of a Living lab environments and methods to develop activities. After the selection of the project delimitation –for each case study– the analytical framework is applied in order to describe the status quo of the specific energy and (spatial) planning context at the different scales. This includes mapping and describing partial characteristics and the processes of change.

1.2. Living Labs and Case Studies

The SPACERGY project makes use of the Living Lab (LL) approach [21,20]. The term is used to refer to a wide variety of local experimental projects of a participatory nature. The aim is to develop, try out and test innovative urban solutions in a real-life context. The definitions and structural elements that can bring a joint collaboration between researchers and key local actors to create a desired outcome is discussed in this section. The Living Lab concept embraces an extensive range of activities and it is regarded as an approach that involves users and actors in a process of co-creation that potentially facilitates the construction of innovative values. Since the 1990s, when it first appeared in the academic discussion, the notion of Living Labs has constantly been redefined and enlarged with new significances. In particular, the process of extension of the concept saw an important development after 2006, with the promotion of European innovation system projects based on Living Labs and the undertaking of the ENoLL initiative [22].

Despite the growing interest for this research area, an unanimously accepted classification of the innovation activities covered by a LL approach does not exist. LL have been conceptualized from a variety of perspectives and thematic approaches, which results in the lack of a common understanding of the notion as well as a universally accepted definition [23]. The LL concept is regarded as an approach for co-creation that involves users and actors to potentially facilitate the construction of innovative solutions. In addition to this conceptualization as an approach to promote innovation, LL is referred to in the academic debate as a methodology, an environment [24], a system and a network [25].

As a methodology (e.g. [26, 27]), the LL concept is defined as a set of open tools, platforms and activities within an innovation network. According to Higgins & Klein [28], the methodological approach of LL is built on the tradition of action research, with the core challenge in breaking 'the tradition of sequential models of innovation, development, implementation and adoption'. They claim that in a systemic vision, the LL becomes an environment where real world settings accommodate pioneering development, where there is the opportunity to study the implications of proposed solutions, while support from institutions can be mobilized, and thus a feedback loop is created to improve the research development and implementation strategy.

Another fundamental definition is elaborated by Westerlund and Leminen [25]. They describe LL's as 'physical and virtual regions or interaction spaces, in which stakeholders form public-private-people partnerships (4Ps) of companies, public

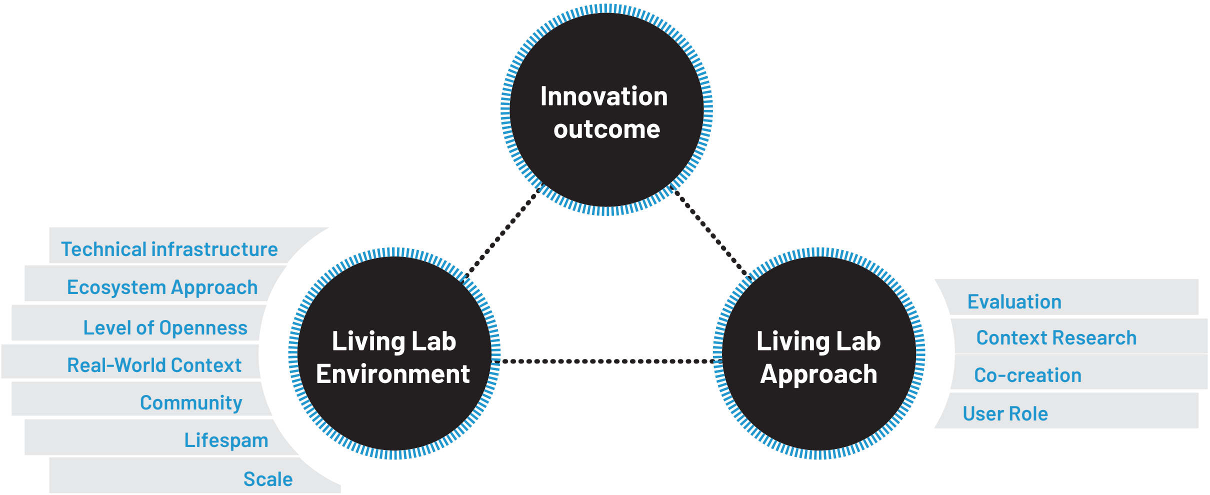

FIG. 1.2 The Living Lab Triangle. Source: Adapted from Veeckman et al., 2013

agencies, universities, users, and others stakeholders, which collaborate to create, prototype, validate, and test products, services, systems, and technologies in a real-life context'. This theoretical vision emphasizes the network function of LL's, considering the network as a space for interaction built upon participation and coordination of stakeholders. Although a common definition of LL is lacking, fundamental characteristics have been pointed out by several authors, thus highlighting it's core. Higgins and Klein [28] have compared different research approaches (Lab research, Action research and Living Labs), and outlined a basic description of the key elements that constitute the specificity of a Living Lab approach.

TABLE 1.1 Comparison of research approaches (Higgins & Klein, 2011)

LAB RESEARCH (USER LABS)	ACTION RESEARCH	LIVING LAB
Controlled environment	Real world setting, yet typically confined to an organisation or department	Real world setting, involving multiple stakeholders from multiple organisations and their interaction
Limited, clearly assigned role of users	Not specific about user role	Active role of users as co-innovators; exposing technology to the creative & destructive energies of the users; facilitating dynamics of collective action
Designed for replicability	Active (social and political) role of researcher in the research setting	Multi-disciplinary research teams actively involved in the research settings, confronted with the technical, social and political dynamics of innovation, at times even driving the agenda
Designed for observation of outcome	The researchers observe and take part in the creation of an outcome	Joint collaboration to create a desired outcome

Veeckman et al. [21] establish a comprehensive framework to analyse the links between 'building blocks of living labs and their effect on the living lab outcomes'. This framework has three pillars: the Living Lab Environment, the Living Lab Approach and the Innovation Outcome. This framework is developed for comparative evaluations to improve understanding of the outcomes of Living Labs. It offers a detailed description of the key characteristics which describe the environment and the approach. Eleven key characteristics are attributed to a generic and project level. The characteristics on the generic level refer to the material and immaterial components of a Living Lab environment, while the key components of the approach refer to the characteristics of the project and the actions possible which facilitate to achieve the goals of a Living Lab.

1.2.1. Living Lab Environments

A first case specific definition of the LL test cases for the SPACERGY project has been determined following the elements of the Living Lab Triangle as described in the previous section:

- **Community:** interest of users and co-creation with researchers and developers.

- **Real-world context:** selection of similar conditions of transformation of the area and similar objectives in a real environment, in which the process of design of the new urban area is started.

- **Scale:** similar scale in space and different time frameworks. Different stages are important in order to support a learning expand process.

- **Lifespan:** refers to the duration of the process in a long-term perspective.

Living Lab ETH University campus, Zurich (Switzerland)

The urban transformation towards the new 'Hochschulquartier' (HQ) represents one of the most important and challenging urban developments within the city of Zürich. The university district in the center of Zurich is developed as an internationally competitive location for knowledge and health. In an already existing dense urban area, the interests and demands in terms of space, energy and transportation of three key stakeholders, ETH Zürich, the University of Zürich and the University Hospital of Zürich have to be considered and coordinated. This transformation requires a multitude of interventions, starting with the retrofit of the large existing building stock including its planned extensions, as well as allocating currently unused areas, resulting in a further increase of the density of the urban fabric.

Living Lab Floriade 2022+ legacy 'Growing Green' residential district, Almere (The Netherlands)

The legacy of the site of Floriade 2022 (the world's largest horticultural expo) in Almere, will be co-developed as a green extension to the city center, once started as a New Town. Current strategies of the city are based on the theme 'Growing Green'. It envisions the extension of Almere city center, opposite the existing center, transforming the inbetween lake ('Weerwater') into a central feature of the city, while at the same time trying to establish an improved connection of disparate neighbourhoods. The project creates an energy-neutral (potentially –positive) extension to the city center (a mixed use residential area and campus), and through its flexibility with emphasis on innovation in green, energy, new mobility, material use / recycling, and building morphology, aims to become a crucial and strategic part of the ambitious city plan and transition based on the 'Almere Principles' (based on the Cradle to Cradle philosophy by McDonough and Braungart [29]), from the original perspective of the 'Garden City' towards a 'Growing Green City', based on four main themes of development: Feeding the City, Healthying the City, Greening the City, and Energizing the City.

Living Lab Mindemyren area, Bergen (Norway)

Bergen Municipality plans to transform the coming years a centrally located industrial area to an urban, attractive intensive business and dwelling areas. The potential is to implement 22.000 working places and approximately 1400 dwellings. At the moment, the number of inhabitants in Bergen municipality is increasing. Due to high pressure, also based on geographic limitations, there is a need to realize higher densities, without losing existing, good living qualities. The tradition in Bergen has so far been to implement new housing areas on green fields outside the city. This urbanization process has contributed to a low density of urban sprawl, generating high private car dependency. Therefore, the old industry area Mindemyren was selected, as it offers high potentials for transformation into a lively urban area, well connected to the city by public transportation. The challenge is to make a spatial solution that offers low energy use for transportation, while achieving high densities and an inclusive approach with a large group of involved stakeholders.

1.2.2. Living Lab Approach

The four components of the Approach in the Living Lab triangle [21] refer to characteristics and activities that have the potential of facilitating the projects in achieving the goal of supporting decision makers in realization of the energy transition in the three urban areas of focus. SPACERGYSPACERGY bases its research activities on the pillars determined in this approach: context research, co-creation, and evaluation. Key stakeholders are involved in all (actual) phases of the project, making use of active and participatory research methods. These activities are included within the stated methodological frameworks and involved meetings, workshops and interview sessions. In the first phase collection of data and information resulted to be fundamental. To achieve this, during this (and subsequent phases) representatives of the municipalities working in energy and planning departments are involved through meetings and interviews. Moreover, regarding the masterplans' development for the selected case studies project teams were asked to provide (geo-referenced) data and explanation of the state of the art. In the second phase of co-creation the information collected was used to identify drivers of change, based on which the key actors of each of the case study areas were requested to develop future 'possible' and 'desirable' scenarios. Two evaluation phases followed, to address the resilience of the envisioned futures and a final evaluation performed at the end of the project on developed guidelines.

Building knowledge base in a Living Lab

In this first stage of the project the main goal is to collect information to describe the specific Living lab environments. A list of data required for the analysis of the three case studies' spaces, processes and contexts, have been built by the academic team, with support of material by the involved municipalities. Data are classified in seven categories that group fundamental requirement related information of the different project phases. The categories have a multi-scalar nature, since they provide information from the national policy level until the building component level.

The six categories are:

- **physical geography** (topographical, geomorphological and hydrographical data);
- **geodemography** (demographic data and socio-economic structure of the population);
- **urban structure** (geometrical and components of the urban structure such as blocks and plots, street network and buildings at the city scale);
- **actors & dynamics** (group information on the development process and phases for the three case study areas);
- **planned transformation** (drawings of the actual/new masterplan(s), objectives for the development and functional program);
- **study area** (data at the finer scale of the buildings, in terms of geometry, energy systems planned, envelope characteristics and occupancy); and
- **policy & regulations** (energy policy at the national level and energy strategies at the city scale).

The data have been collected by involving municipalities departments and the project teams in the three countries/cities. The collected data have framed three Living Lab databases made available to the researchers working into the SPACERGY project. The importance of defining data requirements and building a common database has been beneficial to set a common language, despite the different semantics and glossary used by the different involved disciplines, and moreover to maintain coherent input data and resolution levels along the project.

1.3. Comparing Living Labs in transition

The analytical framework for energy transition previously described, is employed for the description of the Context, Process and Space related status of the Living Lab case studies. The Context section describes national energy goals and related aspects (governance, roadmaps). The Process section stresses the urban drivers of transition. Finally, the description within the Space section addresses the spatial characteristics of the district of each of the case studies.

1.3.1. Energy Context

Netherlands

The Dutch Energy policy is largely determined by European frameworks and based on the commitment of the Paris Agreement on climate change. The main goal of limiting global warming below two degrees Celsius implies that the energy transition in the country has been set as a major target to help achieve the reduction of greenhouse gas emissions. More concrete, the European Council in 2014 have agreed on reducing carbon (equivalent) emissions by 40% (compared to 1990), increase the share of renewables up to 27%. The achievement of this long-term vision is expected to change fundamentally the energy mix supply by reducing fossil fuels, stop mining of natural gas and its use, and increase the share of generation of electricity and heat/cold with clean sources. The transition towards a low-carbon energy supply implies a long process of adaptation of demand processes as well as technological systems, including infrastructures and appliances.

The Energy Agreement that is expecting to result in a rise of share of renewables, is developed for the Dutch context until 2050. The National Energy Report and the National Agenda [30] set the particular goals and steps to be taken for the implementation of such long-term objectives. Four so called functionalities are highlighted as main areas of intervention to reduce greenhouse gas emissions: (1) power and light; (2) high temperature heat; (3) low-temperature heat, and (4) transport. For each of them a transition path is defined, together with an indication of priorities and necessary steps to be taken. All this, with the clear objectives of reducing the carbon footprint of electricity/heat production and conservation for the building sector and of reducing the emission of the mobility sector. The pathways identified focus on technological innovation and on supporting the implementation of a combined centralized and decentralized energy infrastructure for energy production and re-use. At the same time, however, the focus seems to orientate on a shift from a focus on policies of energy demand reduction to new concepts of sustainable production. In doing so, behavioral aspects regarding the necessity of reducing the equivalent kWh per person are to some extent less prioritized (or even ignored).

The Agenda describes the dimensions of governance, spatial integration, innovation and economic investments and benefits. The most innovative dimension consists of the promotion of an integrated spatial policy, able to facilitate from the national to the municipal level the implementation of energy transition measures. The challenge, however, can be found in the resulting increased demand of space to allocate new types of infrastructure for energy production and distribution. A significant consequence, as it advocates the need of innovative spatial transition, design and management, emphasizing above all spatial aspects of the transition within public debate and general energy transition strategies and design elaborations of the built environment of both new and existing areas.

Norway

By signing the Energy Agreement in Paris, Norway has set the ambitious target of reducing the greenhouse gas emissions by 40 % before 2030, similar to the Netherlands. Within the context of its global role as one of the larger natural gas and oil producers, the country has started the transition towards a more sustainable low carbon society relatively in an earlier stage compared to many other countries. Natural context here is of importance to mention. The energy supply and building use is already fundamentally based on carbon free sources such as hydroelectric electricity production. Therefore, a long-term perspective of the energy transition aimed for primarily involves the development of a new Norwegian economic model, since the global energy transition will likely affect that part of the economy based on oil and natural gas industry [31].

The improvement of renewable sources into the energy mix has therefor a double goal: allowing the achieving of the European targets, while finding a new market model for the national economy. The main strategy builds upon promotion of innovation related to energy and climate technology, as well as to increase the flexibility and the efficiency of the conjunct energy infrastructures. Regarding the renewable energy sources the target for 2020 is set at a massive share of 67 % of the total final energy consumption, and 10% for the transport sector (which now still is largely fossil based). The inclusion of different (renewable) energy sources includes use of waste heat and promotion of new plants for district heating, similar to part of the Dutch strategies. A large foreseen potential lies in the production of bioenergy due to the large agricultural sector and its potential for producing and using biofuels. This is considered as a possible economic shift of focus, which also supports the transition in the mobility sector, along the inclusion of more electric based vehicles.

Differently from the Swiss and the Dutch energy transition context, here the main trajectories for energy transition focus on infrastructure development and making the energy mix more heterogeneous and efficient, by a focus on technological and economic innovation. As a result, behavioral and spatial components are of secondary importance.

Switzerland

The trajectories traced by the Federal Energy Strategies and the city's Energy Policy have been acknowledged in various occasions as ambitious and challenging. The reason can be found in the type of supply as well as the geographical nature of the country. At the national level, the energy transition strategy of Switzerland follows different objectives compared to other European countries. After the Fukushima (Japan) disaster in 2011, the population expressed through a referendum the will of phasing-out nuclear power from energy supply sources. The resulting energy strategies, that the Swiss government developed took this challenging priority to change the energy mix. Additionally, the Energy Strategy 2050 aims to contribute in reducing the environmental impact of energy production and consumption by focusing on four pillars: energy efficiency, renewable energies, replacement and new construction of large power stations for electricity production, and foreign energy policy [32].

Although the time frame chosen to achieve a nuclear power phase-out and replacement with other renewable sources can be considered long enough, the Swiss transition presents several challenges. Firstly, the use of renewable technologies finds important obstacles in the geography of the country and requires significant infrastructural investments. Topography and climate make it relative difficult and expensive to place large photovoltaic clusters or wind farms with related infrastructure and power stations. At the same time, the hydropower generation with the existing power plants has reached almost the maximum production capacity.

Furthermore, regarding the improvement of energy efficiency, the 'Building Programme' (launched by the Federal Government to reduce the energy consumption of the building sector) has to include addressing a growing uncertainty of future demand. This is mainly a result of external pressures, such as the global temperature rise, that is expected to intensify the energy consumption for space cooling and consequently electricity demand in particular in dense urban areas. Similarly, also the midterm aims of the Federal Energy Strategy appear very ambitious targeting a reduction of consumption pro capita by 43% within 2035. This corresponds to the 13% reduction on 2000 Watt per capita established as energy policy in many cities, including Zurich [33].

1.3.2. Urban Transition Process

Almere


FIG. 1.3 Location of Almere within the Dutch territory

In the process of urban transformation Almere is dealing with the expectations of increasing its population by offering 60.000 new houses and 100.000 new jobs until 2030. This will make this newtown / city growing by almost 400.000 inhabitants the coming decade. Similarly to other urbanization strategies the growth is considered to be an occasion to improve qualities of liveability (Integrated Agreement Framework Almere - IAK, 2010). This aim can be explained by the challenge to differentiate available attractive spaces in the metropolitan region and Northern Randstad. Social, economic and environmental sustainability are part of the well known 'Almere Principles' for development, first published in 2008 together with William McDonough and Michael Braungart [29]. Emphasis has been put on improving accessibility and ecological qualities within the urban setup of (polycentric) Almere by extending the urbanization to the other side of Weerwater lake [35].

At the same time, the main energy goals set guiding the energy transition is becoming an energy neutral city by stimulating the production of renewable energy with sustainable technologies. Wind farms outside the dikes are being planned in coordination with the regional authorities, while solar production on building roofs and efficient district heating are measures applied at the municipal level. In addition, as in the entire metropolitan area of Amsterdam (and the Netherlands), the phasing out of natural gas from the energy mix provided is a key-priority. Contrary to the National Agenda, urban scale transition here emphasizes the support of good behaviour by means of provision of examples, information and dedicated advises.

However, reduction of the energy demand also here still seems to be less highlighted. The focus on production has been emphasized more compared to the retrofitting of the building stock with the purpose to increase the thermal performance of buildings. New, upcoming challenges, such as an expected increased energy consumption due to climate change and the need of space cooling, so-far hasn't been addressed clearly in urban strategies.

Bergen


FIG. 1.4 Location of Bergen within the Norwegian territory

The 'green transition' in Bergen has the main goal of implementing a fuel-free city by three incremental steps: reducing gas emissions with 30% by 2020, phasing out fossil fuels including oil and natural gas by 2030, and limiting climate footprint to stay below the 1,5 degree warming by 2050 [36]. The main challenge in the transition process of the city is the control of a rising energy demand among with the growing population. The prognoses of the municipalities in fact indicate an increase with 75.000 inhabitants by 2040. The critical sector to achieve a carbon free city is that of transportation, that is today oil dominated and dependent. Besides, the building sector also counts, in particular regarding its heating. The inclusion of electric vehicles, sharing strategies and the improvement of more accessible public transport are identified as the key strategies for a successful transition regarding the transportation sector. In addition, small scale energy production on buildings and extension of existing district heating networks has been identified as the main solutions to achieve a stable energy balance, as to electricity production and supply.

The reaction of the Bergen economy to the global energy transition is largely dependent on the capacity of innovation and investments in new types of services and green industry. This is found to be the most relevant factor to provide a sustainable socio-technical transition.

The spatial dimension is addressed largely through the mobility related energy transition. Design of space to encourage walking and biking are amongst the few space related measures taken into consideration by the Bergen municipalities.

Zurich

FIG. 1.5 Location of Zurich within the Swiss territory

The city of Zurich is facing a demographical growth and an increasing pressure regarding urban density. The high population density, compared to the other major Swiss cities, is expected to increase further due to the shift from an urbanization strategy oriented on expansion towards one which emphasizes a more concentrated distribution in existing (urban) areas. Competition for space is considered to be a problem, and therefore this holds too for energy production based on renewables. Recently, instruments like the Energy Masterplan [34] have been improved, promoting a stronger coordination and integration of energy sector and urban planning related plans.

At the city level, the objectives of the Zurich energy policy aim to secure sustainable supply to reduce no renewable resource use and overall primary energy consumption and related emissions. These are based upon Federal and Cantonal climate protection laws and the 2000-Watt goal [33]. Within this context, a powerful instrument called 'Energy Masterplan' has been developed. This has two fundamental roles. First of all, to strategically connect long term objectives to the annual Action Plans, and secondly to define the quantitative targets to reduce the consumption per capita by two kilowatt hours per hour for five beforehand identified areas of actions and implementation tasks.

However, still the coordination between spatial planning and energy planning remains a crucial issue. Although regarding settlement development the Energy Masterplan states that spatial planning and energy planning are coordinated, in practice there are examples in which the coordination appears to be complex. This holds in particular for the case of the HQ development plans.

1.3.3. District Space

Floriade 2022+ legacy, Almere (The Netherlands).

FIG. 1.6 Floriade Masterplan (MVRDV)

The legacy of the site of Floriade 2022 (the world's largest horticultural expo) will be co-developed for its life after the expo as a green extension to the city centre of Almere, a lasting Cité Idéal with the theme 'Growing Green'. It envisions the extension of Almere city center, as opposed to the existing state. The intention is to transform the in-between lake into a central feature connecting the disparate neighbourhoods of this Dutch new town. The main aim of the new development is to create an energy-neutral (potentially–positive) district with a mixed-use residential area which gives space to innovation in new mobilities, material use and innovative energy systems. The ambition of the municipality is to build a strategic urban part to further implement the transition of 'Almere principles' from the Garden City towards a Growing Green City. This is based on four main themes: Feeding the City, Healthying the City, Greening the City, and Energizing the City.

The Floriade terrain is located on the 'Weerwater' and is crossed by the highway A6. The designed masterplan is structured by a green street grid proposed by Winy Mass, the winner of a design competition. The initial design principles have been integrated to reinforce the green nature of the district. The concept of the 'arboretum' has been used to organize the distribution of vegetation species around the blocks along with the creation of a tree garden to accommodate the world horticultural exhibition in 2022. Regarding the distribution of building volumes, the key actors involved in the second design stage have developed two different masterplans for the expo, called the Floriade Plus which refers to the transformation of the district into a residential area at the end of the event in 2022. The shift in functional uses from an exhibition pavilion to housing development have implications on the building geometry. Therefore, a replacement of the built structure has been considered by the project developer. However, both the vision and the district are characterized by low density developments and there is a predominant role of green and efficient technologies to reduce the energy footprint of users and inhabitants.

Mindemyren area, Bergen (Norway)

FIG. 1.7 Design proposal for the Mindemyren district

There is a strong need for commercial zoning and thousands of new dwellings within the central valley of Bergen which puts focus on identifying potential areas for development. In cooperation with the Municipality of Bergen, surrounding municipalities and the Hordaland County, the Business Region Bergen has put focus on the total coverage of commercial zones in the entire Bergen region. Better utilisation of the commercial spaces in Mindemyren is an important long-term strategy for covering the demand for commercial and residential space. The potential of the project is to implement 22.000 working places and 1400 dwellings. At this moment, the number of inhabitants in the Bergen municipality is increasing. There is a high pressure and need to implement high building densities without losing good living qualities. The stated goal goes in the opposite direction of traditional urbanization models of implementing new housing areas on new grounds outside the city. However, this urbanisation process has contributed to low density of urban sprawl and generated high private car dependency.

Mindemyren is a business area that will see a transformation from industry and warehouses into offices and services. Several new office buildings with service functions in the street plan have been completed in the last few years, and new ones are planned. Land-use plans have been placed to accommodate new infrastructure, including a new, second light rail line that will run across the area. The plan location is demarcated by Fjøsangerveien to the west, residential buildings and Wergeland local center to the east, Fabrikkgaten to the north and Kristianborgvatnet to the south. Today, the Mindemyren district consists of ca. 250.000 m^2 of built area with around 4.000 workplaces and a ground area of around 500.000 m^2. The development potential is an estimated total of 500.000 m^2 floorspace and 20.000 workplaces. The challenge is to achieve an attractive and provident spatial solution that offers low energy usage for transportation, while dealing with a large group of involved stakeholders, and providing conditions for private investments to be implemented within a reasonable period. Mindemyren is a large area, which, when fully developed, could yield results that can make a difference in the field of climate and energy. Workers commute by light rail, bicycle, bus or by foot. While realizing the high ambitions of energy-saving construction methods, the intensification of use and environmentally friendly energy sources are achieved and supported by green structures.

Hochschulquartier Campus, Zurich (Switzerland)

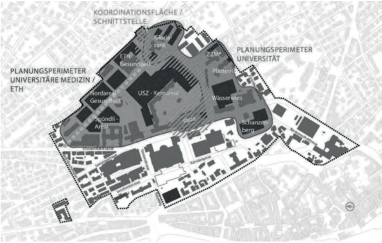

FIG. 1.8 Hochschulquartier Masterplan 2014 [37]

The Hochschulquartier (HQ) represents one of the most important and challenging urban transformations within the city of Zurich. In the dense and central area, the transformation of the university district is meant to create an internationally competitive location for knowledge and health. Here, the interests and demands in terms of space, energy and transportation the considerations and coordination of existing residential functions need to be met by three key stakeholders, ETH Zurich (ETH), the University of Zurich (UZH) and the University Hospital of Zurich (USZ).

The transformation plan increases the usable floor space by 40%,and includes a variety of interventions such as: retrofitting the large existing building stock, building extensions, and the allocation of built volume on currently unused areas to increase the building density. Another key objective, which might be more difficult to achieve, is to realize synergies and create a liveable urban district, exploring options to share the use of common functions and spaces (such as services, restaurants, cafeterias, housing etc.) and to introduce new land use types.

These needs have to be balanced with the use of green spaces which are of great relevance for the area already. Meanwhile, the spatial transformation also has to go hand in hand with new energy solutions and have a set strict goals regarding energy performance. There is already a challenging situation with different functions competing spatial usages. The additional challenge is to meet the Swiss 2000 Watt Society urban goals. Furthermore, at the other (higher) administration levels, the energy policy commits to a challenging switch in the energy mix from nuclear power production to renewable energy generation by 2050. The HQ transformation takes this into account. Although, the potential to employ new energy sources and infrastructures has to be tied to a century-old distribution network as well. In addition, it also needs to comply with the varying demands of the new developments in terms of quantity, quality (temperature) and dynamics.

A master plan was approved in September 2014 (EBP, 2014) and provides a first outline for renovating the structural and operational infrastructures of the site for the next 30 years. For the city of Zurich, the area represents not only one of the most challenging tasks in the near future but it is also supposed to serve as an incubator and demonstrator for a new inclusive planning process that connects relevant actors and leverages synergies. Due to its complexity, the integration of spatial development, energy planning and mobility is crucial for the success of the transformation in the end.

1.4. Discussion and Conclusions

This chapter discusses and applies in an integrated way an application of the Living Lab and Transition Analytical frameworks to the three case study areas of SPACERGY. To start with, the selection of these three case studies have been based on determinant factors of the Living Lab environment scheme. Here, so framed 'context research, co-creation and evaluation' are considered as main pillars of the project activities. In the first phase of the project the context research and knowledge base are defined by employing a review of the existing literature and by collecting and creating a common data-base structure (and infill) for the three Living labs.

Next, a description of the status quo of energy context, urban transition and spatial delimitation is given by using the analytical framework methodologies above mentioned.

With respect to energy transition, in the long-term, the national goals in Norway, the Netherlands and Switzerland consist of different drivers and related challenges. Nevertheless, some common elements can be found in the definition of targets, such as the reduction of carbon emissions. National policies in the Norwegian and Dutch case studies are more orientated towards a shift from policies of energy demand reduction towards concepts of a production based on renewables. In the Swiss case however, a larger attention is put on energy reduction of consumption.

At the city level the process of energy transition is challenged by the expected population growth in different urbanization models in the three cities. In the first two cases (Almere and Bergen) emphasis is being put at the user behavioural perspective and the engagement of citizens and companies, strengthened further by a significant focus on innovation. Only the city of Zurich employs a clear target of energy consumption pro-capita. The spatial aspects of the transitions is analyzed and discussed in all the three cities. However, only Zurich makes a clear attempt to regulate integration of spatial and energy planning through a normative instrument.

Finally, at the district scale the three cases are confronted with the same spatial need of increasing the building density and include energy measures in coherence with the national and city goals, even though the land use programs differ. The spatial dimension of energy transition requires therefore further analysis and will be addressed in the following chapters.

References

[1] F. W. Geels, "From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory," Res. Policy, vol. 33, no. 6–7, pp. 897–920, Sep. 2004.

[2] F.W. Geels, and J. Schot, "The dynamics of transitions: a socio-technical perspective", in: Grin, John, Rotmans, Jan and Schot, Johan (eds.) Transitions to sustainable development: new directions in the study of long-term transformative change. Routledge, pp. 11-104, 2010. ISBN 9780415876759

[3] F.W. Geels, and J. Schot, "Typology of sociotechnical transition pathways", Res. Policy, vol. 36, 399–417, 2007.

[4] F.G. Geels, "Towards sociotechnical scenarios and reflexive anticipation: using patterns and regularities in technology dynamics", in Sørensen, KH and Williams, R (eds.) Shaping technology, guiding policy: concepts, spaces and tools. Edward Elgar, Cheltenham, UK, pp. 359-385, 2002. ISBN 9781840646498

[5] A. Smith, J. Voß, and J. Grin, "Grin Innovation studies and sustainability transitions: the allure of the multi-level perspective", Research Policy, vol. 39 pp. 435-448, 2010.

[6] R. Raven, J. Schot, and F. Berkhout, "Space and scale in socio-technical transitions," Environ. Innov. Soc. Transitions, vol. 4, pp. 63–78, 2012.

[7] L. Coenen and P. Benneworth, "Toward a spatial perspective on sustainability transitions," Res. Policy, vol. 41, no. 6, pp. 968–979, Jul. 2012.

[8] T.G. Bunnell, and N.M. Coe, "Spaces and scales of innovation", Progress in Human Geography, 25 (4), pp. 569-589, 2001.

[9] C.C. Gibson, E. Ostrom, and T.K. Ahn "The concept of scale and the human dimensions of global change: a survey", Ecological Economics, vol. 32, pp. 217-239, 2000.

[10] F. Faller, "A practice approach to study the spatial dimensions of the energy transition," Environ. Innov. Soc. Transitions, vol. 19, pp. 85–95, 2016.

[11] G. Bridge, S. Bouzarovski, M. Bradshaw, and N. Eyre, "Geographies of energy transition: Space, place and the low-carbon economy," Energy Policy, vol. 53, pp. 331–340, Feb. 2013.

[12] H. Rohracher, P. Späth, "The Interplay of urban energy policy and socio-technical transitions: the eco-cities of Graz and Freiburg in retrospect", Urban Stud. 51, 1415–1431, 2014.

[13] M. Seiwald, "The (up) scaling of renewable energy technologies: experiences from the Austrian biomass district heating niche." Moravian Geog. Rep. 2, 44–54, 2014.

[14] H. Martin, and L. Coenen, "Institutional context and cluster emergence: The biogas industry in Southern Sweden", Eur. Plan. Stud., 2014. http://dx.doi.org/10.1080/09654313.2014.960181.

[15] J. Musiolik, and J. Markard, "Creating and shaping innovation systems: formal networks in the innovation system for stationary fuel cells in Germany", Energy Policy vol. 39, 1909–1922, 2011.

[16] J. Markard, R. Raven, and B. Truffer, "Sustainability transitions: an emerging field of research and its prospects", Res. Policy 41, 955–967, 2012.

[17] B. Truffer, "Society, technology, and region: contributions from the social study of technology to economic geography", Environ. Plan. A 40, 966–985, 2008.

[18] F. Faller, "Regional strategies for renewable energies: development processes in greater Manchester", Eur. Plann. Stud. 22, 889–908, 2014.

[19] G. Bridge, S. Bouzarovski, M. Bradshaw, and N. Eyre, "Geographies of energy transition: Space, place and the low-carbon economy", Energy Policy vol. 53, 331–340, 2013.

[20] K. Steen and E. van Bueren, "The Defining Characteristics of Urban Living Labs," Technol. Innov. Manag. Rev., vol. 7, no. 7, pp. 21–33, 2018.

[21] C. Veeckman, D. Schuurman, S. Leminen, and M. Westerlund, "Linking Living Lab Characteristics and Their Outcomes: Towards a Conceptual Framework," Technol. Innov. Manag. Rev., vol. 3, no. December 2013: Living Labs and Crowdsourcing, pp. 6–15, 2013.

[22] B. Dutilleul, F. Birrer, and W. Mensink, "Unpacking European Living Labs: Analysing Innovation's Social Dimensions", in: Müller, Karel; Roth, Steffen; Zak, Milan (eds.): Social Dimension of Innovation, Prag; Linde, 2010.

[23] E. Almirall, and J. Wareham, "Living Labs: arbiters of mid- and ground-level innovation", Technology Analysis & Strategic Management, 23(1), 87–102, 2011.

[24] P. Ballon, J. Pierson, and S. Delaere, "Test and Experimentation Platforms for Broadband Innovation: Examining European Practice", SSRN Electronic Journal. 10.2139/ssrn.1331557, 2005.

[25] M. Westerlund and S. Leminen, "Technology Innovation Management Review Managing the Challenges of Becoming an Open Innovation Company: Experiences from Living Labs," no. October, pp. 19–25, 2011.

[26] S. Leminen and M. Westerlund, "Cities as Labs : Towards Collaborative Innovation in Cities," Orch. Reg. Innov. Ecosyst. Espoo Innov. Gard., no. ii, pp. 167–175, 2015.

[27] B. Bergvall-Kareborn, M. Hoist and A. Stahlbrost, "Concept Design with a Living Lab Approach," 2009 42nd Hawaii International Conference on System Sciences, Big Island, HI, pp. 1-10, 2009.

[28] A. Higgins, and S. Klein, "Introduction to the Living Lab Approach", in: Tan YH., Björn-Andersen N., Klein S., Rukanova B. (eds) Accelerating Global Supply Chains with IT-Innovation. Springer, Berlin, Heidelberg, 2011.

[29] W. McDonough and M. Braungart, "Cradle to Cradle: Remarking the way we make things", Powell's Books, 2010

[30] Ministry of Economic Affairs, "Energy Agenda. Towards a low-carbon energy supply", The Hague, March 2017.

[31] International Energy Agency, "Energy Policies of IEA Countries. Norway ,2017 Review", May 2017.

[32] Swiss Federal Office of Energy SFOE, "Energy Strategy 2050": Chronology 23, 2018. At http://www.bfe.admin.ch/energiestrategie2050/index.html?lang=en&dossier_id=06603

[33] City of Zurich, "ROADMAP 2000-Watt Society", 1st ed. [pdf] Zurich, 2016. Available at: https://www.stadtzuerich.ch/content/dam/stzh/portal/English/portrait_city_of_zuerich/Documents/Report_Roadmap-2000-watt-society-einseitig.pdf

[34] Stadt Zürich, "Masterplan Energie der Stadt Zürich, Energiebeauftragter", Stadt Zürich, Switzerland, 2016.

[35] RRAAM, "Concept Gebiedsontwikkelingsplan Almere Centrum Weerwater", Werkmaatschappij Almere Centrum Weerwater, 2012.

[36] City Council Bergen, "Green strategy – Climate and energy handling plan for Bergen 2016", Bergen 2016.

[37] Baudirektion Kanton Zürich, Masterplan Hochschulgebiet Zürich-Zentrum September 2014, Zürich: Kanton Zürich, Baudirektion, 2014.

2.

Plausible scenario trajectories of urban-energy-mobility transition

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Contents:

Summary

To achieve a reduction in energy demands and to introduce solutions for production, storage and re-use of energy, different scenario methods have been applied in energy and spatial planning over the years. Scenarios are instruments that allow the critical exploration of alternative models or urban transformations but can also support decision-makers in developing new future pathways. However, these are often only used in the field of energy planning to compare the energy performance of different possible solutions, which can underestimate physical and local spatial components that can guide design processes. In order to bridge this gap and promote a synergetic integration between spatial and energy system planning, new types of scenarios are needed for the construction of common, so-called 'desirable futures'.

The SPACERGY project proposes a method to meet this demand within energy transition processes and support coordination between design, research and planning towards an energy-sensitive approach. This report describes and elaborates on the application of the transdisciplinary Design Oriented Scenario (DOS) method for energy transition strategies. The hybrid DOS method, developed in the three Living Labs, combines descriptive, explorative and normative components. It aims to help decision-makers in complex multi-actor processes by setting common objectives, sharing and creating a multidisciplinary common ground, and exploring alternative spatial and energy performative visions.

Within the first analytical phase, the main goal was to identify social, political and economic components to determine potential trajectories to develop energy concepts in the different study areas. The exploration of energy-spatial strategies help guide robust design choices. In addition, the processes of implementation require the creation of a solid and common knowledge base. Therefore, workshops with stakeholders and experts have enabled the creation of 'internal' and 'external' Scenarios. Three Workshops took place in t Almere (the Netherlands), Bergen (Norway) and Zurich (Switzerland) between September and October 2016. The workshops involved the SPACERGY academic partners (TU Delft, HIB Bergen, ETH Zurich), and the most relevant local stakeholders (energy experts, administrators, technicians, etc.) that corresponded with each location. The main aim of these workshops was to discuss external trends and to determine design-oriented scenarios for the development areas.

In this chapter a new hybrid Design Oriented Scenario method is described. The method also defines common visions within a multi-actor Living Lab (LL) approach. In the first part of the general framework different classifications of commonly used scenario types are set. Next, new scenario objectives and the method applied are presented. Finally, the method is tested on the three Living Labs in Almere, Bergen and Zurich.

2.1. Introduction

2.1.1. Background

Scenario tools are often used in urban planning and design, in circumstances where it is important to take a long-term perspective on techno-social developments and related strategies. It is frequently used when there are a limited number and high level of uncertainty of key factors that can influence appropriate strategies [1]. Scenarios build plausible views of different possible futures for relevant actors based on the clustering of certain key social, spatial and environmental influences and drivers of change. The result is a limited number of logically consistent, yet different scenarios that can be considered alongside each other (Ibid).

Two fundamental definitions of scenarios can be distinguished that reflect upon different epistemological views [2,3]. First, Kahn & Wiener [4] defines scenarios as built sequences of hypothetical events. The second is by Rotmans et al. [5] who sees scenarios as descriptions of alternative images of the future, created from models that reflect different perspectives on the past, present and the future. According to these definitions, different types of scenario methods have been described in literature and applied in different contexts [6,7,8,9,10].

In urban planning and design, types of scenarios can be classified according to content and objectives as well as processes and methods. According to Manzini [11], one of the main distinctions between Policy-Oriented Scenarios (POS) and Design-Oriented Scenarios (DOS), is that POS deals with the macro-scale and political decisions, whereas DOS are envisioned as tools in design processes. DOS, as Manzini et al. claims, “should propose a variety of comparable visions to create inspiration for designers” and contain various proposals that forms a concrete plan, or a global vision which pictures the effect of the implementation, and which explains the main possible constraints and general benefits, for example in terms of sustainability, economics, and social wellbeing. Another way to classify types of scenarios relates to the objectives on which they are built upon. According to Borjeson et al. [7], scenarios are classified in three types: Predictive, Explorative and Normative. While predictive scenarios relate with the concepts of probability and likelihood, explorative scenarios aims to explore developments that are considered possible to happen. Very often, these take a starting point in the future and are elaborated with a long-term horizon to allow for more profound changes. In normative scenarios, the focus is transformed from visions into objectives and possibilities to reach a certain target. The main interest in this case is the creation of a desirable future and how this can be realized. Besides this, Rotmans et al. [5] distinguishes normative (prescriptive) scenarios and descriptive scenarios. By using a deductive thinking process, this last scenario category describes how the future might unfold by applying known process dynamics or by similarities with other processes or experienced situations.

In recent years, scenario planning and scenario modelling have become more common [12, 13], in particular, to support the process of creating a vision [14]. The Living Lab Approach implies the necessity of far-reaching integration of disciplines and active participation of different actors. The process of envisioning possibilities for an energy transition should be developed by creating joint discussions in the communities and by including all relevant public stakeholders, citizens and users [10]. Moreover, complex trajectories that build upon innovation requires technical expertise, especially for processes that undergo urban transformations and development towards low carbon urban energy systems.

Scenario methods should thus, function as processual tool, that supports development processes with multiple actors, and multi-disciplinary focuses. The benefits would concern both the actors, who are informed of strategic options regarding (positive) future pathways, and designers and decision-makers who can evaluate the robustness of different strategies. Therefore, a scenario-based method is needed which allows common objectives to be set and enables the exploration of alternative future pathways. The scenario also helps with the construction of a shared, so-called 'desirable visions'.

2.2. Scenario Building in SPACERGY

2.2.1. Goal and Methodology

In the SPACERGY project, the selection of the type of scenario is based on the main objective: the building of a conceptual and methodological toolset to guide the design and urban development (including its technical systems) in the Living labs to achieve a successful energy transition. Although DOS have been identified as a useful approach to guide the process of design and to identify visions in the specific context of urban transformations. These are often developed as a designed research product, without the involvement of all relevant stakeholders. In particular, concerning the field of energy, planning and design, DOS have been associated with the visualization of energy footprints at larger scales, as an explorative instrument, and for informing planning strategies. Therefore, in the context of an energy transition towards a carbon free society, Sager-Klauß [10] states: "to start a process of energy transition in small and medium sized communities, guiding principles based on energy should be integrated in the urban development concept on a broad basis". The process of envisioning a future transformation should be developed by creating joint discussions with communities and by including all relevant actors. Within this context, the main question thus became: What type of scenario model is needed in the Living Lab approach and how should the DOS approach be adapted for use in all LLs?

The scenario building method incorporates several central scopes that are intended to be a tool for co-creation and are recognised to be the following in a Living Lab environment:

- to collect knowledge by multi-disciplinary experts and actors and to understand drivers which influence the urban development (DESCRIPTIVE);

- to explore possible internal energy-spatial integrated development (EXPLORATIVE);

- to understand how to achieve national and urban objectives set for the energy-spatial transformation (NORMATIVE).

Therefore, a new type of DOS is developed and framed as a hybrid DOS. For its methodological definition, a framework merges different phases and characteristics of descriptive, explorative and normative scenario models in the procedural

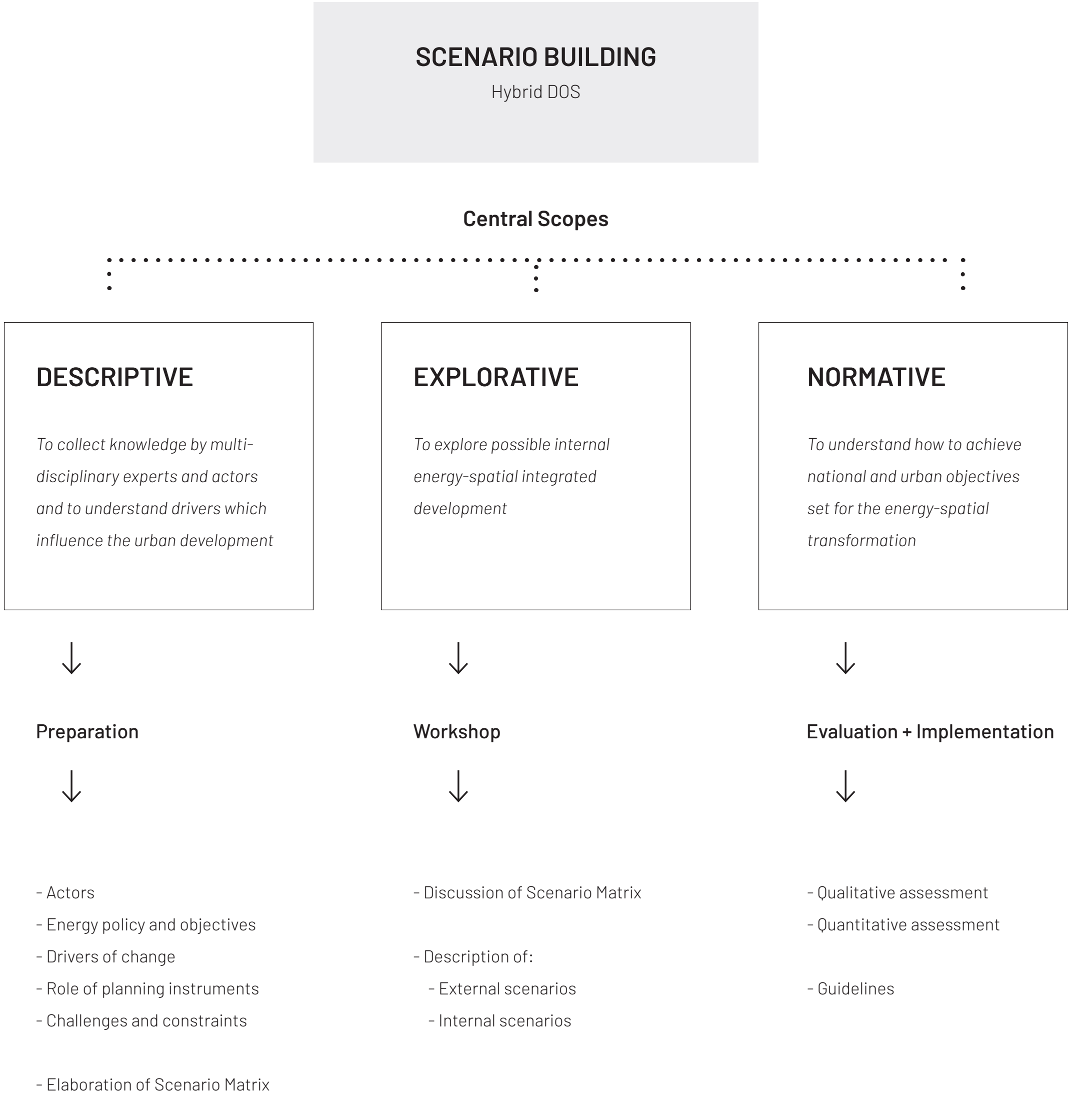


FIG. 2.1 Hybrid DOS methodology

structure. Furthermore, the procedure inserts an employment of techniques and activities which facilitates the interaction between scientific partners/researchers and experts in different fields, municipality administrators and engineers. The scenario method is structured into three main phases which involves the following activities:

- **Preparation:** i) Actors, energy policy, energy objectives and key drivers of change are identified. The role of planning instruments are highlighted as well as the main challenges and constrains for urban transformation. ii) A scenario matrix is developed by taking into account the main factors of uncertainty.

- **Workshop:** i) The scenario matrix is discussed and validated in a workshop setting. ii) The participants divided are divided into four heterogeneous groups to describe and discuss four external and internal visions according to the assigned matrix. External scenarios are driven by factors beyond the control of the key actors. For example, macro-economic and political are used as drivers of change that can influence policies and the implementation of planning strategies. Internal scenarios on the contrary, are framed around local drivers that may guide related spatial and energy designs of the urban areas under study.

- **Evaluation and implementation:** The multidisciplinary research team assesses the outcomes, with qualitative and quantitative techniques. i) An initial evaluation is performed by the stakeholders by comparing the internal and external scenarios (when possible) in order to discuss the robustness of the principles used for the energy transition. ii) A second type of quantitative assessment is performed only for one case study and is carried out and described in work package 8. In that later stage, the resulting design scenarios for the Zurich case will be assessed based on their energy performance with an integrated simulation model.

This chapter focuses on the application and the consequences of the developed DOS in the three Living Labs. The diversity of geographical, cultural and political contexts required minor variations in the deployment of the method described above. Therefore, a section for each case study illustrates the detailed application and the results of the three phases.

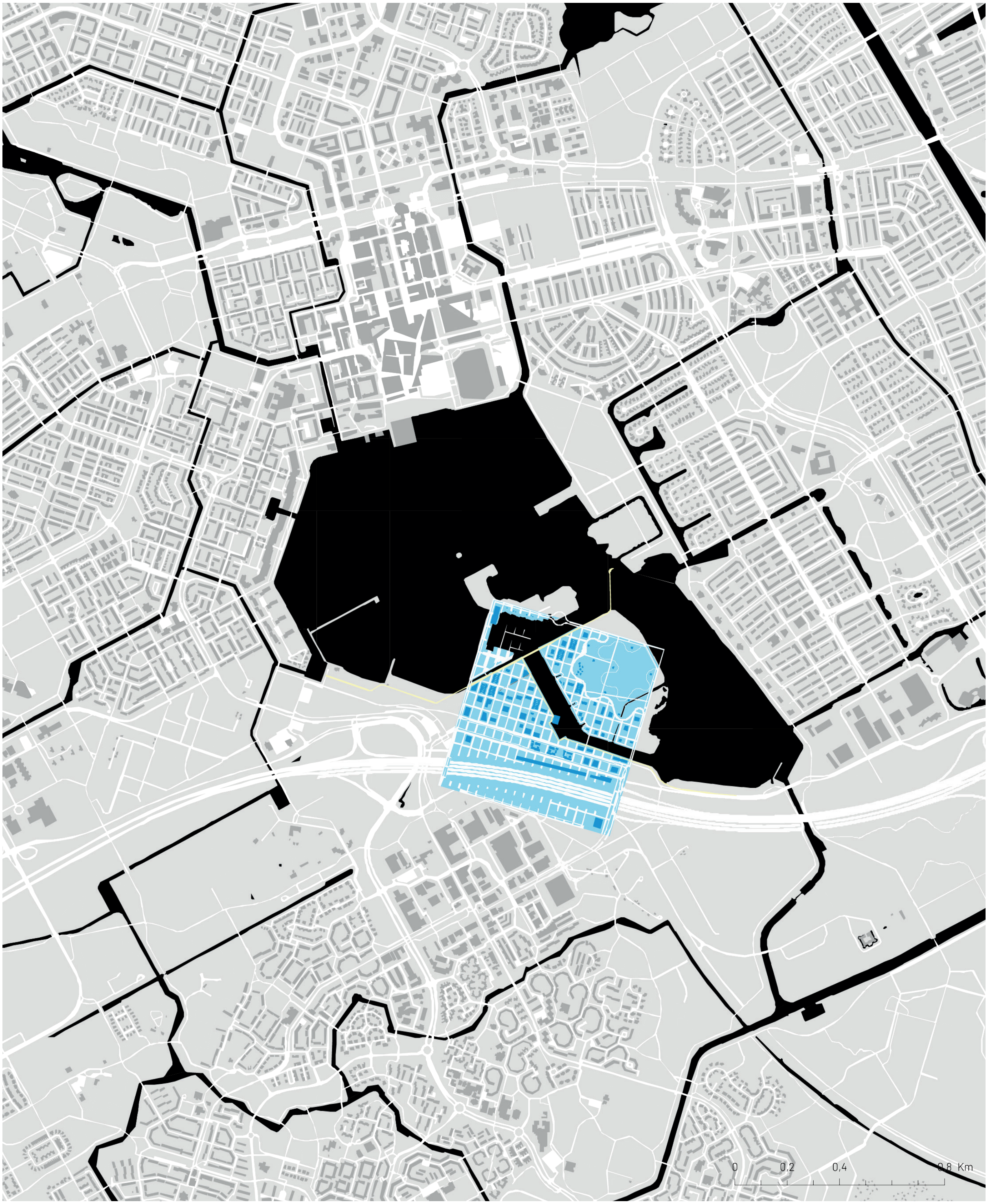


FIG. 2.1 Floriade context in Almere

2.3. Almere

2.3.1. Scenario Matrix and Workshop Settings

In order to build scenarios for the energy transition in the Almere Living Lab, four micro-stories and a scenario matrix are generated in the preparation phase by analysing driving pressures that can change the future of Floriade energy transition and related spatial-energy integrated design.The micro-stories on external scenarios address economic, political and technological driving forces that depend on the extrinsic environment. In addition, the matrix on internal scenarios are guided by principles that can condition the design aspects of the Floriade. The involved stakeholders are requested to describe in the first stage, challenges and implications for Almere, derived from processes at larger scales (global trends). In the second stage, they are instructed to describe possible futures for the four internal scenarios that emerges from the two-axis structure.

2.3.2. External Scenario Micro-Stories

Four key driving forces are selected to define the External Scenarios for the (post-) Floriade urban development. The first two factors are based on the relationship between Amsterdam and its surrounding metropolitan area, as well as on the different urban development pressures and strategies. As Almere started as a satellite 'new-town', based on a strategic connection with the city of Amsterdam, future possible changes are discussed regarding the attractiveness of living in the metropolitan areas. Therefore, the first two micro-stories challenge the effects of a diffused development pressure on the Amsterdam metropolitan area, including Almere, and the other of a more concentrated and intensified use of the space in the city of Amsterdam.

The other two key drivers relate with the energy transition and the implementation of strategies to reduce energy demand and related Co^2 emissions. The two micro-stories derived here are based on the conditions of development and the application of measures to boost sustainability. These take into consideration economic and political processes that can potentially influence a slow and ineffective achievement of the 2020 CO^2 reduction, or at the opposite spectrum, a long-term successful transition by production with renewables technologies.

2.3.3. Scenario Building

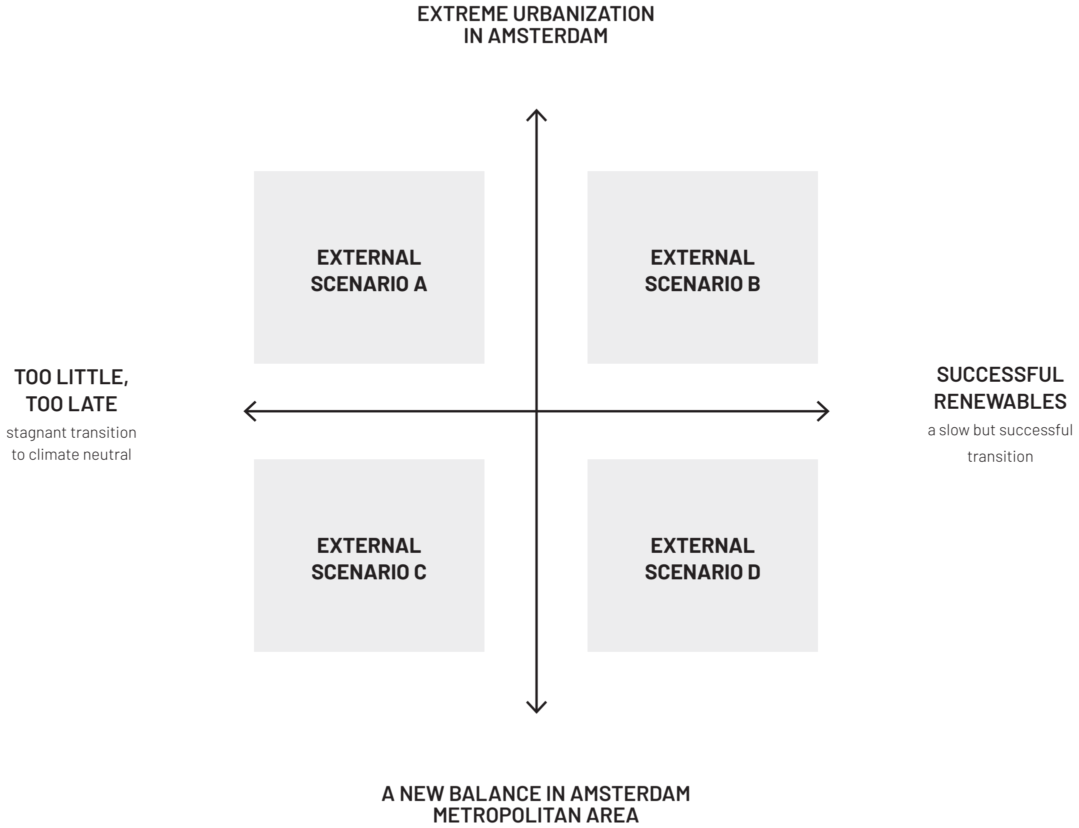


FIG. 2.2 **External Scenario Matrix.** Four key driving forces are selected to define the External Scenarios for the (post-)Floriade 2022 urban development. The first two factors are based on the relationship between Amsterdam and its surrounding metropolitan area, as well as on the different urban development pressures and strategies. As Almere started as a satellite 'new-town', based on a strategic connection with the city of Amsterdam, future possible changes are discussed regarding the attractiveness of living in the metropolitan areas. The other two key drivers relate with the energy transition and the implementation of strategies to reduce energy demand and related Co^{2} emissions.

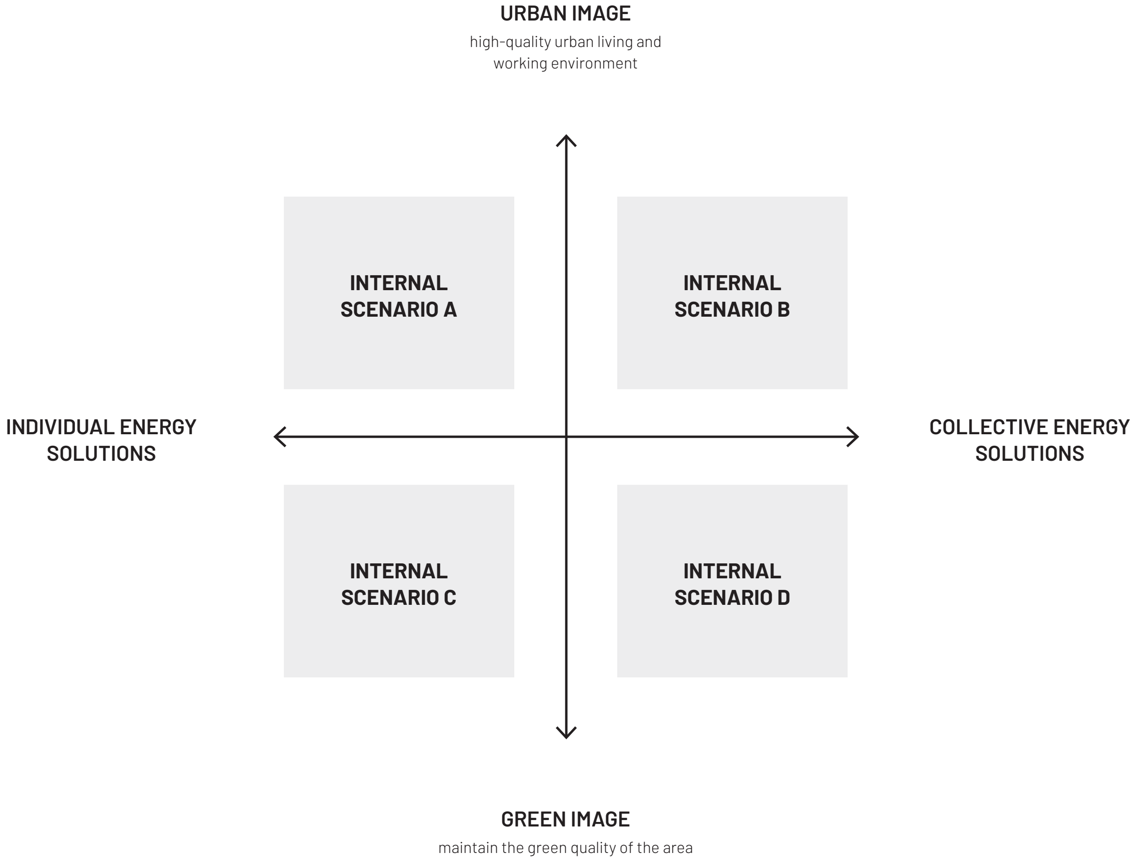
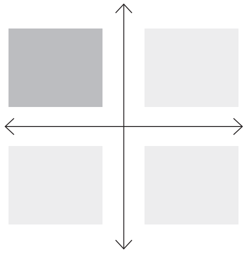
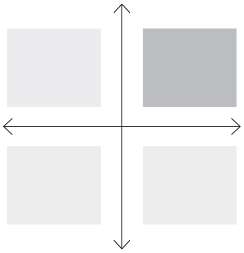


FIG. 2.3 **Internal Scenario Matrix.** The internal scenario matrix develops around the possible qualities promoted by the Floriade district and the process of implementing solutions can change energy demand and supply. The vertical axis reflects on the vision of the future district, counterposing spatial conditions that could reinforce the green image that Floriade aims for, to those that can create a stronger urbanised one. The horizontal axis focuses on the organizational dimension on the application of energy transition measures into the district. Here, it diverts from the individual realization of solutions to a more collective one for the entire neighbourhood.

2.3.4. External Scenarios' Results





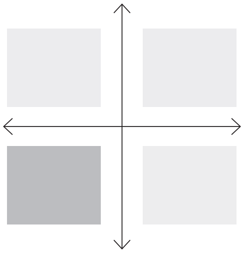
A Extreme urbanization

Amsterdam is fun while Almere is dwindling. Population growth in downtown Amsterdam continues, and 'people want to be part of the city life' and are avid in avoiding long commutes for more than 30 minutes. Population growth is concentrated in Amsterdam itself and (to a lesser degree) its adjoining municipalities, where real estate prices are continually rising. In downtown Amsterdam, there is a strong tendency to use less m^2 per person. Almere has problems meeting the growth targets that were set in the 'Schaalsprong'. There is also insufficient housing demand especially for the more remote dwellings in the Eastern part of Almere. Various transport solutions were suggested to bring Almere closer to Amsterdam, but none were accepted. Almere opted for various national sports- and cultural facilities. However, even though it got a new stadium, the demand for cultural and sports facilities were insufficient to shift major facilities from Amsterdam to Almere.

Ultimately, a consortium of high-tech companies suggested for the Schiphol-Amsterdam-Almere-Lelystad Airport axis to develop the first experimental hyperloop transport link, which solves both Schiphol's growth problems and connects Almere's central area directly to Amsterdam Central Station. However, the cost of this link were tremendous, and national/regional governments are still struggling about its costs and the risks involved.

B A new balance in the Metropolitan Area

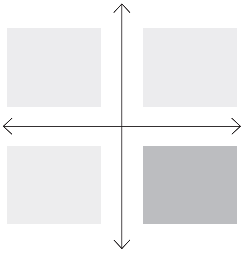
In Amsterdam, the strong urbanization of the 2010s came to an end as the tide turned the ship. The strong increases in real estate prices made dwellings in downtown Amsterdam unaffordable for middle income groups. Moreover, mortgage interest rates returned to higher levels, which brought many Amsterdam residents that had taken large mortgages into financial problems. These groups gradually left the city as they just could not afford it anymore or decided to invest their capital into something else than a city dwelling. Moreover, the decrease of traffic by telework, had already been forecasted in 2000, has finally started taking off. City parking had become far more expensive due to the rich population of downtown Amsterdam having a high rate of car ownership. This had also driven up parking rates, while EV prices remained relatively high due to lithium scarcity. Public transport could not provide additional capacity in time to make up for larger commuter demand. As a result, employers created workplaces outside Amsterdam for telework and began learning to work in an organization without being in the same office. As a result, families with children moved away from Amsterdam, and some even as far as Friesland. However, bonds with family and friends kept most people in the region. Therefore, after a period in which Almere's population began to stabilize, a new wave of growth started for Almere in 2025.



C Too little, too late: the transition stagnates

The decline of energy consumption, caused by the recession of 2008-2012, caused a general belief that Europe could achieve its CO2 reduction targets from the established policies in 2015. However, in 2015-2017, energy consumption rose quickly again. Industry and the transport sectors could not afford to spend time with carefully designed processes of change and to switch to renewable fuels. The economy was booming and there were no experiments.

EVs were introduced successfully, but they were only used for commuting, and by 'two-car-households'. The limited radius of EVs and their inability of pulling a caravan/trailer were amongst major factors for households to be against switching completely to EVs. Single car households did not abandon fossil fuelled cars for similar reasons. The number of EVs stabilized at about 20% of all vehicles. As the population stabilized, the construction sector was dwindling. Fewer new houses were built, and the focus shifted towards the necessity of upgrading the existing stock. The initial successes (2010-2015) had turned people asleep. The transition to a fossil free energy system halted in 2017, was picked up again by growing sales of EVs, but came to a standstill in the 2030s. New and drastic measures were proposed, such as a complete phase out of fossil fuelled cars and the demolition of energy inefficient dwellings, but they did not get sufficient support.

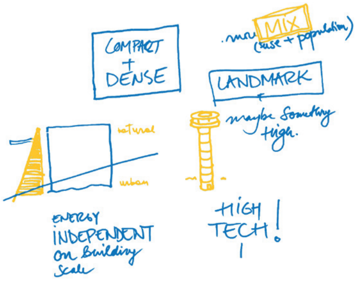


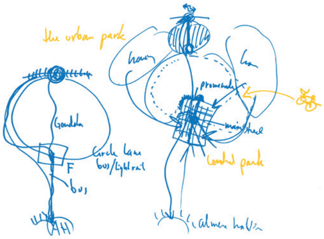
D Renewables, a slow starts but ultimately successful

Dwellings consume less heat since climate change creates less need for heating and because of better insulated dwellings and more passive houses. Heat pumps strongly improved and have become more affordable. These devices are also used to provide cooling in summer. Boiler- and even CHP-systems are converted to heat pumps which reduces primary energy consumption by a factor 5.

Hardly any fossil-fuelled cars are around and EV's almost completely took over. This is also due to the bans of fossil-fuelled cars in inner cities. Battery technology gave EVs a range of 400+ km. Rapid charging allows cars to recharge in 10 minutes. Trucks and heavy-duty vehicles are for a large part fuelled by biofuels, CNG, and biogas. CNG and biogas are used for inland shipping. Aircrafts were increasingly fuelled by biofuels. Transcontinental shipping uses additional wind power, air-lubrication and reduced transportation speeds for non-perishable goods. Industrial electricity consumption is declining due to a growing recycling rate, less resource consumption, and a higher overall efficiency. Electricity consumption is nevertheless increasing due to the introduction of EV's, heat pumps and a continued growth in the number of IT devices. Natural gas is declining and is mainly used as a back-up fuel for electricity production. Electricity storage remains as an important issue. The core of a European super-grid is operational and diminishes the need for storage.

2.3.5. Internal Scenarios' Results





A Urban image + Individual energy solutions

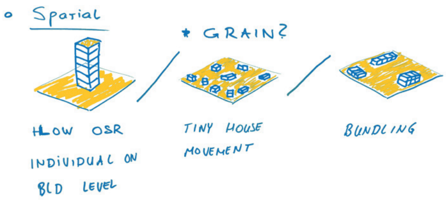
This scenario depicts a spatial condition for the Floriade district which is characterized by a high building density and compactness. The neighbourhood is well connected with the Almere city center and landmark buildings reinforce its identity and allows for a visual recognition of the area.

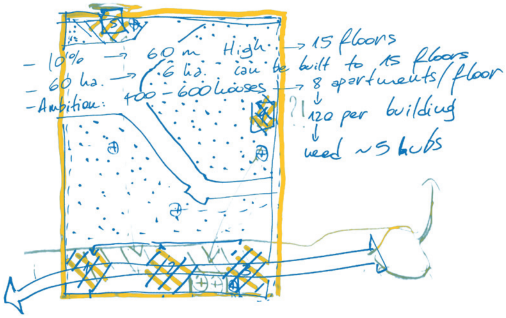
Floriade hosts a rich functional mix of uses and provides a flexible balance of temporary and permanent activities. The flexibility is evident also in the application of energy measures which allows the testing of innovative solutions at the household and building level. Companies are therefore encouraged to install new technologies and employ new techniques that can reduce energy demand and support clean energy supply. Electricity is mostly produced locally at the building level by using rooftops and façades.. The buildings that are connected to a smart micro-grid balances demand and production in the area. Floriade is a bike and a pedestrian friendly area. Electric vehicles and bikes are used for short distance travelling. The municipality of Almere supports all of this with economic incentives for owners and companies to promote energy neutrality.

B Urban image + Collective energy solutions

This scenario describes a vision driven by the concepts of sharing and connectivity. The district is designed and built as an unitarian urban organism conceived as a new core in the urban polycentric structure of Almere. The new centre derives its urban image from its strategic role as a node. In fact, Floriade facilitates the physical connection of Almere centre with the suburban areas on the south side of the 'Weerwater' lake. Therefore, the district becomes a new centre supported by the provision of a new infrastructural link between the north and the south parts of the lake by means of a highly frequent and automated boat transportation. The fast connection with the central station facilitates the daily commute to Amsterdam.

Floriade is a dense and multifunctional settlement that hosts various compositions of households. The ground level of the buildings is occupied by shops and facilities. The area is highly attractive for businesses and families due to the attractive qualities of open spaces and the presence of collective facilities such as libraries and co-working spaces. Furthermore, the neighbourhood is car free and bike and car sharing services are provided. Solutions for energy production with renewable technologies are applied at the building block level and by using public space in the neighbourhood.





C Green image + Individual energy solutions

This scenario is based on the relation between a green vision for the district and its spatial-energy translation. In order to establish a strong green image, mostly low-rise single dwelling typologies are spread on the plots. The areas with vegetation are divided between private gardens and public open spaces. The surface coverage by building footprints are very high despite the low building density. Energy solutions applied to single households concern mainly production of electricity and hot water with solar technologies. Regarding mobility electric cars and bikes represent the main transportations means. However, the main question concerns the economic affordability of individual investments. Therefore, the level of energy efficiency on the district depends on the investment capacity and income of building owners.

D Green image + Collective energy solutions

This scenario is based on the vision of a green and energy efficient urban district. The new buildings are concentrated in five dense clusters that are distributed around the highway and on the water borders of the peninsula in order to maintain the rest of the green surfaces. In this compact development, only 25% of the land is occupied by infrastructure and buildings, leaving the larger share of the district for water, vegetation and food production. The area around the highway is designated as mobility hub which provides parking garages for electric car sharing due to the high accessibility to the location. The main mode of transportation inside the district is the bike, whereas a high frequent boat connects Floriade with the city centre. From an energy perspective, a supply mix is proposed. The built-up area and the main boulevard are supplied electricity from PV panels, while water-based heat pumps provide hot (and cold) water and space heating (cooling) in combination with the use of biomass sources derived from sewage and food waste treatment.

2.3.6. Evaluation

A qualitative evaluation of the internal scenarios is performed by the key actors of the Almere Living Lab. The evaluation is based on the external drivers of change. The participants were asked to describe the impact of external conditions on the scenarios they have envisioned. This phase challenges the robustness and the resilience of the developed design-oriented scenarios for the Floriade area.

An overview of the significant characteristics for the four scenarios is shown in Table 1, and a short description of the debate during workshop activities illustrates the influence of the external four drivers on the internal scenarios.

TABLE 1.2 Scenario's characteristics

A) Urban Image & Individual Energy Solutions

Mobility	High share of electric vehicles. Biking and walking encouraged
Urban Design	High density and high compactness. Multi-functional use
Energy Balance	Application of new technologies to reduce energy demand and increase clean production at the building level. Lab for testing new solutions.

B) Urban Image & Collective Energy Solutions

Mobility	Higher connectivity with the city via public transport. Bike and car sharing services
Urban Design	High density. Multi-functional use with high share of collective facilities.
Energy Balance	Reduction of fossil fuel for transportation. Energy solutions at the block and district level.

C) Green image & Individual energy solutions

Mobility	Private electric cars and bikes
Urban Design	Low building density and high surface coverage. Single families' dwellings.
Energy Balance	Electricity and hot water production on single building level

D) Green Image & Collective Energy Solutions

Mobility	Electric car/bike sharing and public transport connection to the city centre
Urban Design	Dense building clusters placed on district borders. Public green areas for leisure and food production. Mobility hub near the highway.
Energy Balance	Supply energy mix by renewable sources: water, sun and sewage/food waste

An ‘extreme urbanization’ scenario will likely make the Scenario A and B fail since Amsterdam will polarize the growth of the metropolitan area, which will reduce the attractiveness for investments in the Floriade area. In comparison, Scenarios C and D that portray a green identity for the district could raise the interest of certain type of households which are looking for a quieter living environment but are still well connected to Amsterdam by the highway.

In a vision of a new urbanization ‘balance within the Amsterdam Metropolitan Area’, Scenarios A and B confirm that Floriade is a successful development project. The strong urban identity and the high level of accessibility can result to be attractive for living and businesses. Moreover, the role of a new urban centre can encourage people in choosing this district instead of other suburban areas further away. The effect of urbanization pressures on Scenarios C and D can potentially confirm the attractiveness and boost the development of a green settlement. However, in Scenario C the high private investments required for decentralized energy systems can determine a potentially longer and more heterogeneous implementation process. The scenarios in which the collective dimension favours an increased sense of community and benefits can be higher.

From an energy perspective a stagnant energy transition at the National and European level can negatively influence Scenario A, B and C which suggests to integrate low tech techniques beside high tech solutions. Moreover, electric vehicles will likely be adopted in a lower share. In Scenario B, that strategically focuses on reducing consumption of the mobility sector by reinforcing public transportion, and a minor negative impact is expected. In contrast, Scenario D will probably see better possibilities for development since the sharing of investment costs and the mix of sources for energy supply might allow for the creation of an energy self-sufficient neighbourhood which will reduce the energy bill for the inhabitants.

According to key actors and experts, the external vision in which the renewable transition is successful can bring benefit to Scenario A, B, C and D since technological applications require lower investments for local energy production and the external conditions will help the development of the neighbourhood. Moreover, the energy production in external clean energy wind farms, solar fields and the increased efficiency of PV systems will likely reduce surface areas that are dedicated to local supply systems and will reduce the district investments.

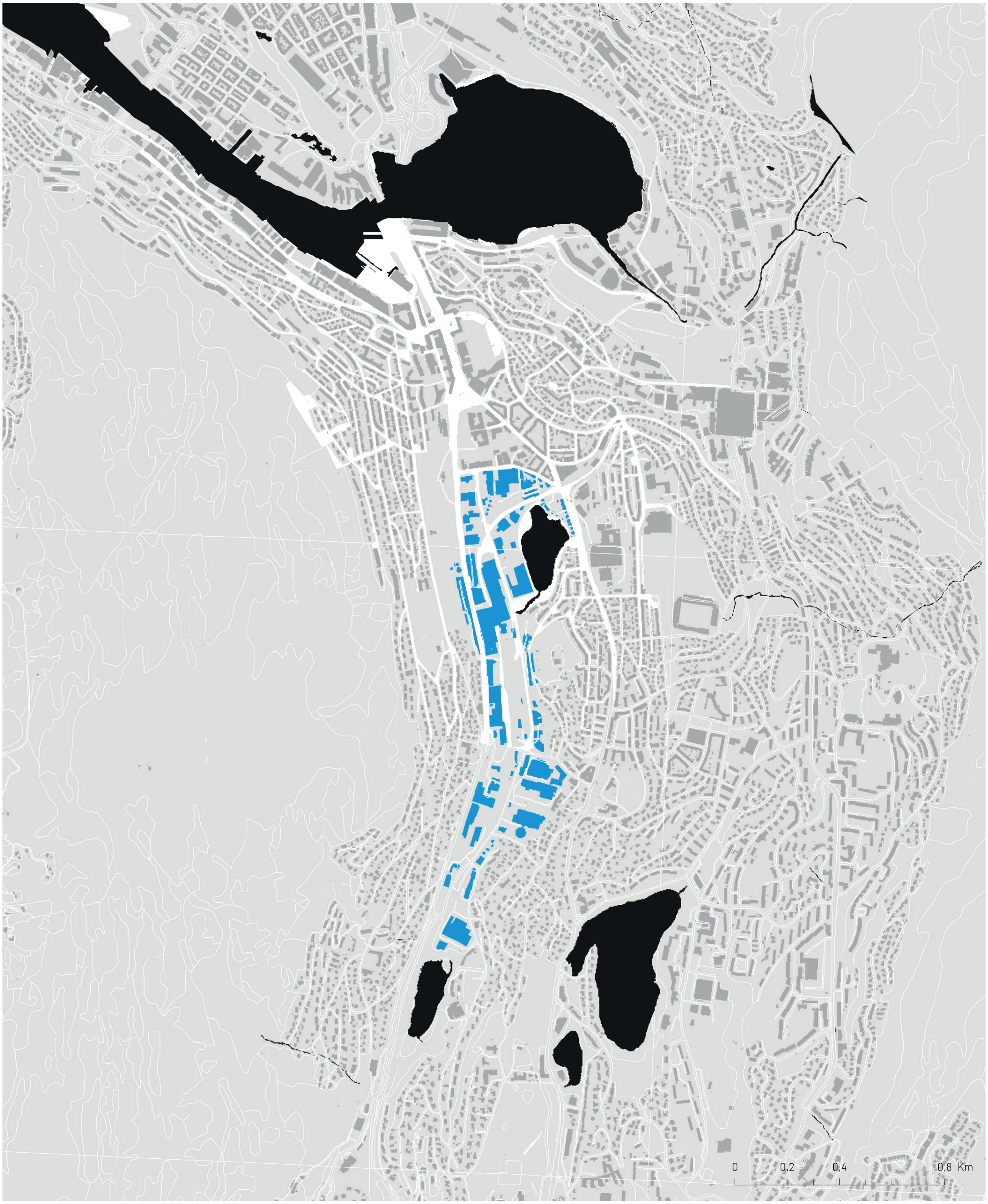


FIG. 2.4 Mindemyren district in Bergen

2.4. Bergen

2.4.1. Scenario Matrix and Workshop Settings

In order to build scenarios for an energy transition in the Bergen's Living Lab, two scenario matrixes are generated by identifying key drivers that can influence the Mindemyren energy transition and its spatial-energy configuration. On the given matrixes, main stakeholders, including municipality representatives and experts in sustainability, mobility and energy sector are called to describe possible future conditions for the four internal and four external scenarios that emerges from the two axes structures.

2.4.2. External Scenario Micro-Stories

Four external scenarios are built around two main drivers of change which are challenged by a high degree of uncertainty. The first key-aspect identified is the effect of Climate Change on Bergen. Climate change in the Norwegian context can lead to the risk of more extreme events of rain and heat and consequentially impact the natural and (to a larger extent) urban environment. Bergen is already characterised by flooding events in the fall season and drought events in summertime. However, the magnitude of the impacts on the ecological, economic and social systems depends upon the level of vulnerability of urban settlements. The vertical axis, based on the uncertainty related to changes in the global atmospheric conditions, requires the exploration of possible consequences, moving from a condition of low to a high climate change impact.

The second key driver of change is considered to be an important energy related factor which is the price of oil. This is relevant as it can globally affect the implementation time of transition strategies, but also because of the large importance of the Oil industry in Bergen economy. The price of oil is dependent on political, market and economic processes which can have a large effect on multiple territorial scales. Therefore, the horizontal axis diverts from low to high oil prices to stimulate the debate around possible future challenges.

2.4.3. Scenario Building

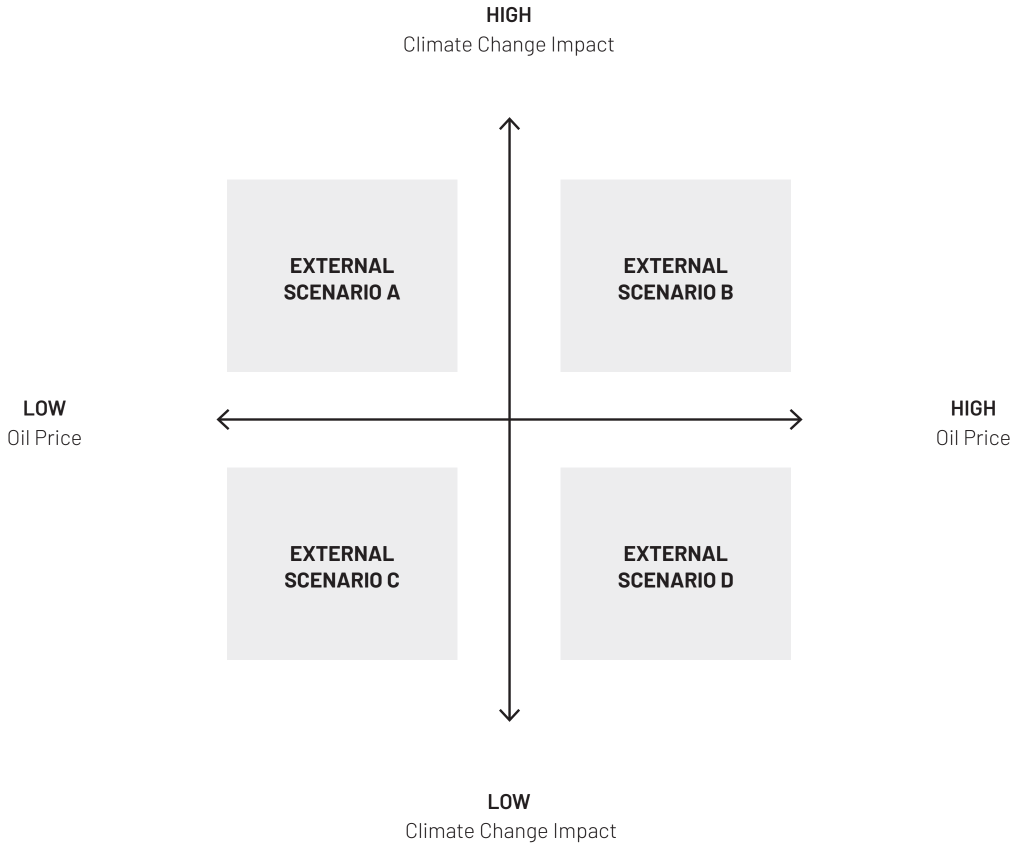


FIG. 2.5 **External Scenario Matrix.** Four external scenarios are built around two main drivers of change which are challenged by a high degree of uncertainty. The first key-aspect identified is the effect of Climate Change on Bergen. Climate change in the Norwegian context can lead to the risk of more extreme events of rain and heat and consequentially impact the natural and (to a larger extent) urban environment. The vertical axis, based on the uncertainty related to changes in the global atmospheric conditions, requires the exploration of possible consequences, moving from a condition of low to a high climate change impact. The second key driver of change is considered to be an important energy related factor which is the price of oil. This is relevant as it can globally affect the implementation time of transition strategies, but also because of the large importance of the Oil industry in Bergen economy.

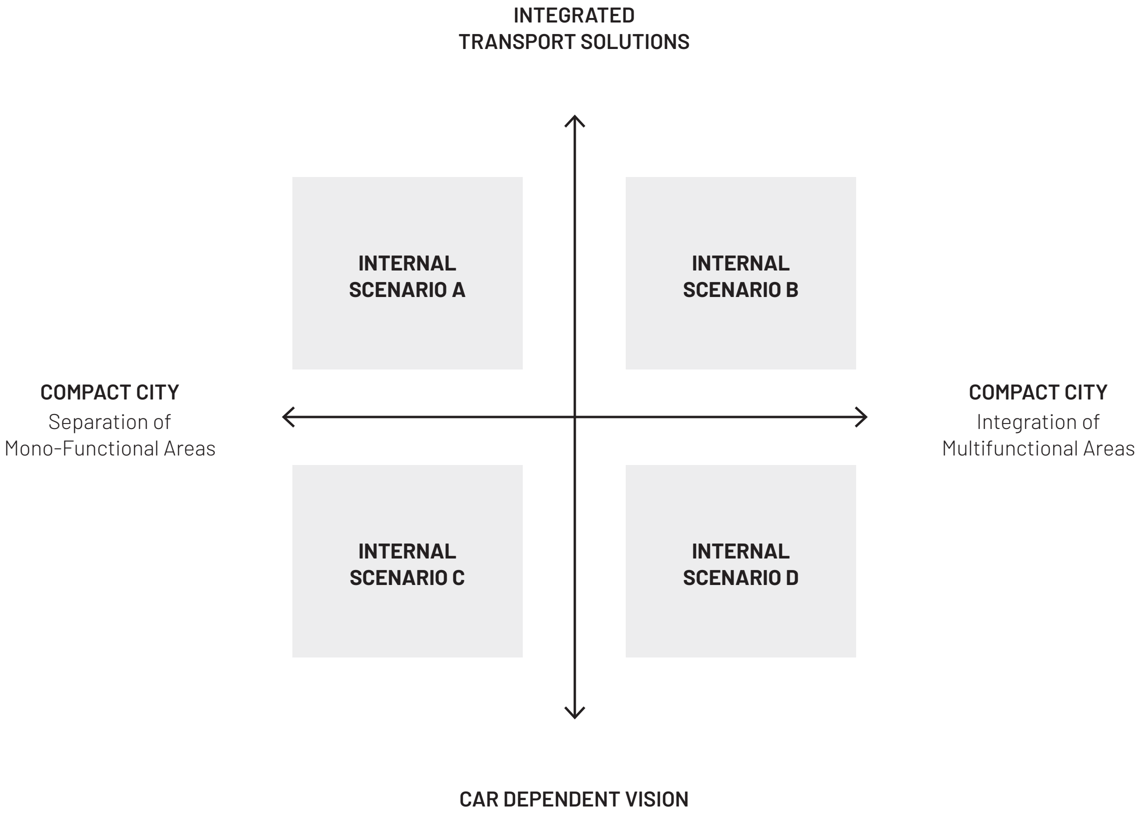
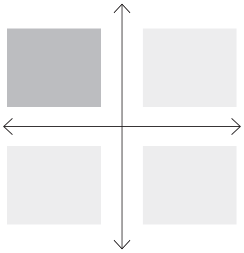
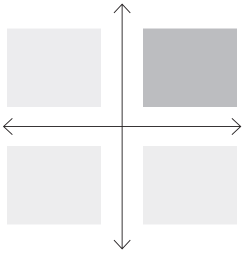


FIG. 2.6 **Internal Scenario Matrix.** The internal scenarios envision four possible future space conditions which are dependent on mobility and morphological principles. Different from previous drivers of change, the key aspects that structures the internal visions are well established concepts used in planning, but are explored within the context of energy transition. In the new development of Mindemyren, these are used to explore the relationship between land use and transportation models. The vertical axis distinguishes on one side, a possible car-centric future and on the other side, solutions that can strategically integrate different transportation models. On the horizontal axis, scenarios are built on the paradigm of a compact city development and are called to explore ways of distributing functional uses in monofunctional clusters and in a highly functional and mixed urban tissue for the new development of Mindemyren.

2.4.4. External Scenarios' Results





A High Climate Change Impact + Low Oil Price

This first scenario envisions a future driven by climate crises and large availability of cheap fossil fuels. Stronger climate impacts affect the vulnerability of the areas within the city, infrastructure and the energy grid. Therefore, more aggressive adaptation measures are required in the city concerning risks such as flooding. Public transportation has a more robust system since it needs to function under different climatic conditions. However, with the increasing costs of maintenance, raises prices and affects the attractiveness of public transportation and developing areas around the stops. Moreover, other parts of the economy can phase instability because of climate change impacting for example the price of the fish and electricity prices. The consequent high price of electricity favours the use of alternative fossil heating sources in houses. As a result, higher levels of pollutants are released.

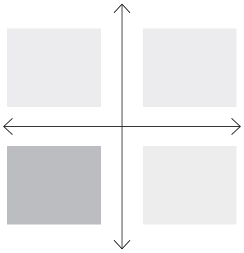
On the flip side, low oil prices decrease the motivation for transitioning to other energy sources or alternative technologies. This condition also lowers the economic motivation for building more robust and resilient energy systems. However, low oil prices have a low impact on people transportation choices, as taxes on fuels remain high. Furthermore, the high level of uncertainty for the future creates instability in the rental market and decreases people’s willingness to invest in development projects.

B High Climate Change Impact + High Oil Price

The difference between this scenario and the previous , is that the costs of fossil fuels are high. However, due to the high impacts of climate change, there are similar conditions. Increased flood risks influence the vulnerability level of the transport system and reinforces the use of cars that are more flexible to make use of safer routes. More frequent breakdowns are registered in the water supply and electricity generation with hydropower stations are a result of extreme dry and hot summers.

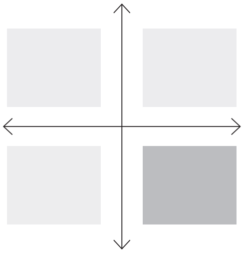
Despite all these negative effects, the longer, warmer summer seasons encourage social life in public spaces and increases the use of bikes.

The high price of oil gives a boost towards the implementation of energy transition technologies and use of electrical vehicles. Furthermore, it is envisioned that the improvement of the energy mix, which will also include solar technologies besides incineration and hydroelectric power production. On the other hand, with the transportation of goods, the high oil price can create economic instability at the national level and at the city level, which can affect the job market and real estate investments.



C Low Climate Change Impact + Low Oil Price

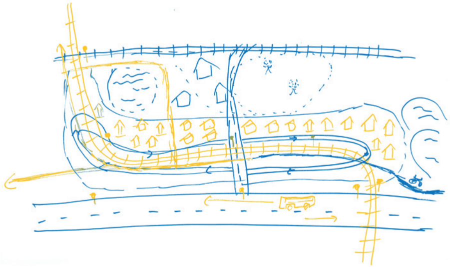
This scenario deals with a possible future in which climate change has a low impact and there are low oil prices. These two aspects define a vision that is considered business as usual in 2016. In fact, fossil fuels are largely used despite the high taxation, and the global oil market affects the local economy of Bergen. The transition to renewable sources for energy supply appears to be stagnant. The initiatives to improve the employment of renewable sources, besides the hydropower production, depends on national and European agreement for CO2 reduction. At the same time, mobility behaviour still favours cars as a main means for transportation. The effect is that TRANSIT models that support concentrated urban development around public transport lines decrease their attractiveness and facilitate the implementation of dispersed and low dense urban expansion. Meanwhile, more frequent peak precipitations and natural disasters occur. Even if impacts have a low magnitude, construction of new buildings and infrastructure need to accommodate to the new conditions.



D Low Climate Change Impact + High Oil Price

In this scenario, the high price of oil encourages the use of electric vehicles and electricity-based transportation. This creates a high need for infrastructures that relies on renewable energy. In the city, mobility sharing systems are introduced and private car ownership is discouraged by restrictions placed on parking lots. Furthermore, high frequent public transport connects to the peripherical areas to the Bergen centre. Local mobility is mainly based on walking and biking. However, a prosperous job market and a richer economy increases pressure on developing new areas for office buildings, and has a negative influence on dwelling prices. Despite the low impact of climate change, flood risk is high. In particular, the most vulnerable areas need robust solutions to ensure connections between different parts of the city

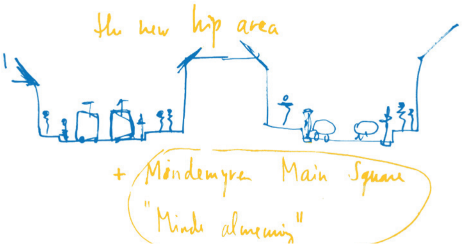
2.4.5. Internal Scenarios Results



A Integrated Transport + Mono-Functional Areas

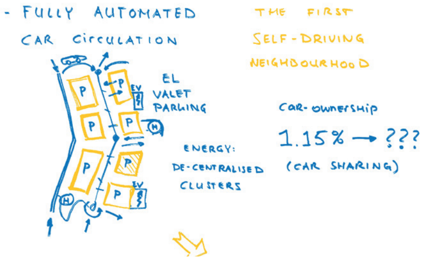
The scenario for the Mindemyren area is structured around the public transport system logic of integration. The 'bahn' is a very good instrument to connect the district to the rest of the city and for internal connections along a main north-south direction. This transport corridor is complemented by a bus service and bike sharing systems that will support inner area mobility. Car sharing gives the opportunity for residents to be connected with the outside world. The space for roads and parking on surface are minimized by moving the majority of car related spaces to the underground level.

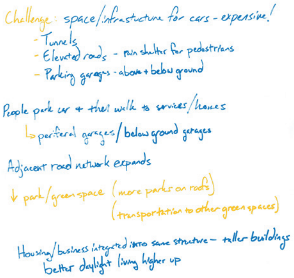
Residential areas grow on the opposite side of the motorway and are closer to the park and lake. These developments are well connected with public transport. For strategic accessibility, office buildings and facilities are concentrated near the highway.



B Integrated Transport + Multifunctional Areas

This scenario matches the national and municipal strategies in densifying existing urban areas and to create a walkable city. In addition, the National Policy also promotes the synergistic development of transport and land use planning. For Mindemyren, the integrated transport solutions focus on the tram as catalyst for a more linear development of local centres near the stops of the line. New business activities and investments in proprieties are attracted to and along the main transport corridor. Car accessibility is not reduced but there is a diminution of parking possibilities inside the area. In fact, a hub (parking garage) allows people coming from other cities to leave their cars and then use public transportation to reach the city centre. With the reduction of surface dedicated to private vehicles, this allows for more compact developments and an increase in general walkability. Thus, the street-profiles are redesigned and reduced in weight to accommodate mainly pedestrians and bikes. A main square is designed and implemented as a principal collective open space of Mindemyren, while the buildings accommodate a high degree of functional mix. The high degree of livability and the quality of spaces attract families, students and the creative community.




Challenge: space/infrastucture for cars - expensive!
- Tunnels
- Elevated roads - rain shelter for pedestrians
- Parking garages - above + below ground

People park car + then walk to services/homes
↳ periferal garages/below ground garages

Adjacent road network expands

↓ park/green space (more parks on roofs)
(transportation to other green spaces)

Housing/business integrated into same structure - taller buildings
better daylight living higher up

C Car Dependent Vision + Mono-Functional Areas

This car dependent scenario envisions a fully automated electric car mobility system and its spatial consequences on the design of the Mindemyren district. The model built upon autonomous vehicles which allows for the mitigation of the negative effects that predominant car use can bring. Specifically, it can help reduce the occupation space of car parking areas and related infrastructure, allowing the transformation of the district to be more of a pedestrian friendly space. Separation of functions leads to structured building clusters with collective parking garages for each group of buildings. Each cluster is also provided with collective facilities and EV charging points. Despite the division in monofunctional areas, the building typologies need to maintain being flexible in order meet future transformations and the ability to allocate new types of functions in case of failure of a certain business. Here, a cluster structure needs to also be a strong collective open space to be able to mediate between the different parts.

D Car Dependent Vision + Multifunctional Areas

This scenario envisions a possible future caused by the failing of both city and national policy, regarding reduction of private fuel-based vehicles use. As a result, the Mindemyren project has to take into account the high demand for car infrastructure. To give high car accessibility to the area and to connect parts of the east and west, underground roads, a parking garage above and below ground are built. Pedestrians move on covered elevated pathways designed as elevated green shelters that repair from the rain during the long fall and spring season.
The majority of the incoming cars are parked in garages placed underground or at the district borders. From there people walk to their destinations. However, the main design challenge is to preserve green spaces. Therefore, predominantly more high-rise buildings are realised. This typology reduces the building footprint and integrates multiple functions. It also benefits electricity demand. The existing green areas are preserved and used by schools and kindergartens for outdoor activities. Moreover, a high frequent public transport service connects Mindemyren to the major green areas in Bergen territory.

2.4.6. Evaluation

After describing the internal scenarios' characteristics, key actors were asked to debate about the robustness of the visions. In a qualitative evaluation, the effects of external drivers on the four scenarios for Mindemyren are discussed. Under the constraint of climate change with high impacts, Scenarios A and B will likely not succeed due to the enormous costs necessary to make the public transport infrastructure robust to climate events. Moreover, extreme weather conditions could discourage people to make use of bike sharing systems. In particular in Scenario B, where a compact and multifunctional district is promoted, there is a difficulty in allocating rain collection measures. The walking space and the lively ground floor of buildings are vulnerable to flooding events and can potentially looe their attractiveness for investments. The difference between Scenarios C and D, is that despite the risk of damage to car infrastructure due to the its low resilience level, it has a higher possibility of adopting climate mitigation measures. In Scenario C, due to the large public space, areas can accommodate measures for water storage and mitigation of heat island effects, while in Scenario D, the elevated walking paths increase the level of safety in case of extreme events.

A future with low climate change impacts will likely make all four scenarios succeed with the condition of reserving a part of the urban surface to implement flood risk management measures and to reinforce the robustness of infrastructure. Scenarios A and B, which have a building cluster configuration and more open space available, can better integrate nature-based solutions.

From an energy perspective the fluctuation of the oil price affects mainly the transport models envisioned in the four internal scenarios for Mindemyren. In fact, Scenario A and B result to be relative resilient a rising of the oil price. It is here that the integration of public transport, private electric mobility, and the encouragement for walking and biking can help reduce the possible negative impact of high oil prices on the urban development of the district. However, due to the effects placed upon the economy and real estate market, there is an increased possibility that a predominant amount of office spaces will be built in the district. On the other hand, Scenarios C and D will only be economical feasible when there is a significant transition from fossil-based cars to electric vehicles.

Under the pressure of a low oil price, Scenarios A and B are likely going to deal with a growing pressure on space, as more areas are needed in order to accommodate more fuel-based vehicles. Moreover, the consequences for the use of land can be highlighted by the fact that the negative impacts on the job market could reduce the demand for office buildings. As a consequence, Mindemyren should be able to attract more real estate investment for families and facilities. A similar, and more extreme, uncertainty in the development is discussed for Scenarios A and B. Despite the benefits of low oil prices for a car-centric vision, the investments in the development of the district are likely to decrease due to the crisis of an important sector of the Bergen economy.

TABLE 1.3 Scenario’s characteristics

A) Integrated Transport & Mono-Functional Areas

Mobility	The 'bahn' connects the district internally and to the city. Complementary bus service. Bike and car sharing systems.
Urban Design	Residential areas are developed close to the park and lake. Office buildings and facilities are concentrated near the highway.
Energy Balance	Reduction of fossil fuel for private vehicle transportation. Increase of electricity demand for public transport and car sharing system.

B) Integrated Transport & Multifunctional Areas

Mobility	Tram as catalyst for a linear development near the stops. Reduction of parking spaces. Parking garage outside city centre.
Urban Design	Densification of existing urban areas to create a walkable city. New main square. Buildings accomodate a high functional mix.
Energy Balance	Reduction of fossil fuel for private vehicle transportation. Increase of electricty demand for public transport system.

C) Car Dependent Vision & Mono-Functional Areas

Mobility	Fully automated electric car mobility system. Reduction of parking spaces and related infrastructure to create a walkable city.
Urban Design	Structured building clusters with collective parking garages, collective facilities and EV charging points, and open spaces.
Energy Balance	Reduction of fossil fuel for private vehicle transportation. Increase of electricity demand for EVs.

D) Car Dependent Vision & Multifunctional Areas

Mobility	Underground roads, above and below ground parking garages. Covered elevated pathways for pedestrians.
Urban Design	High-rise buildings with a high functional mix. Existing green areas are preserved and used by schools and kindergartens.
Energy Balance	Increase of fossil fuel for private vehicle transportation.

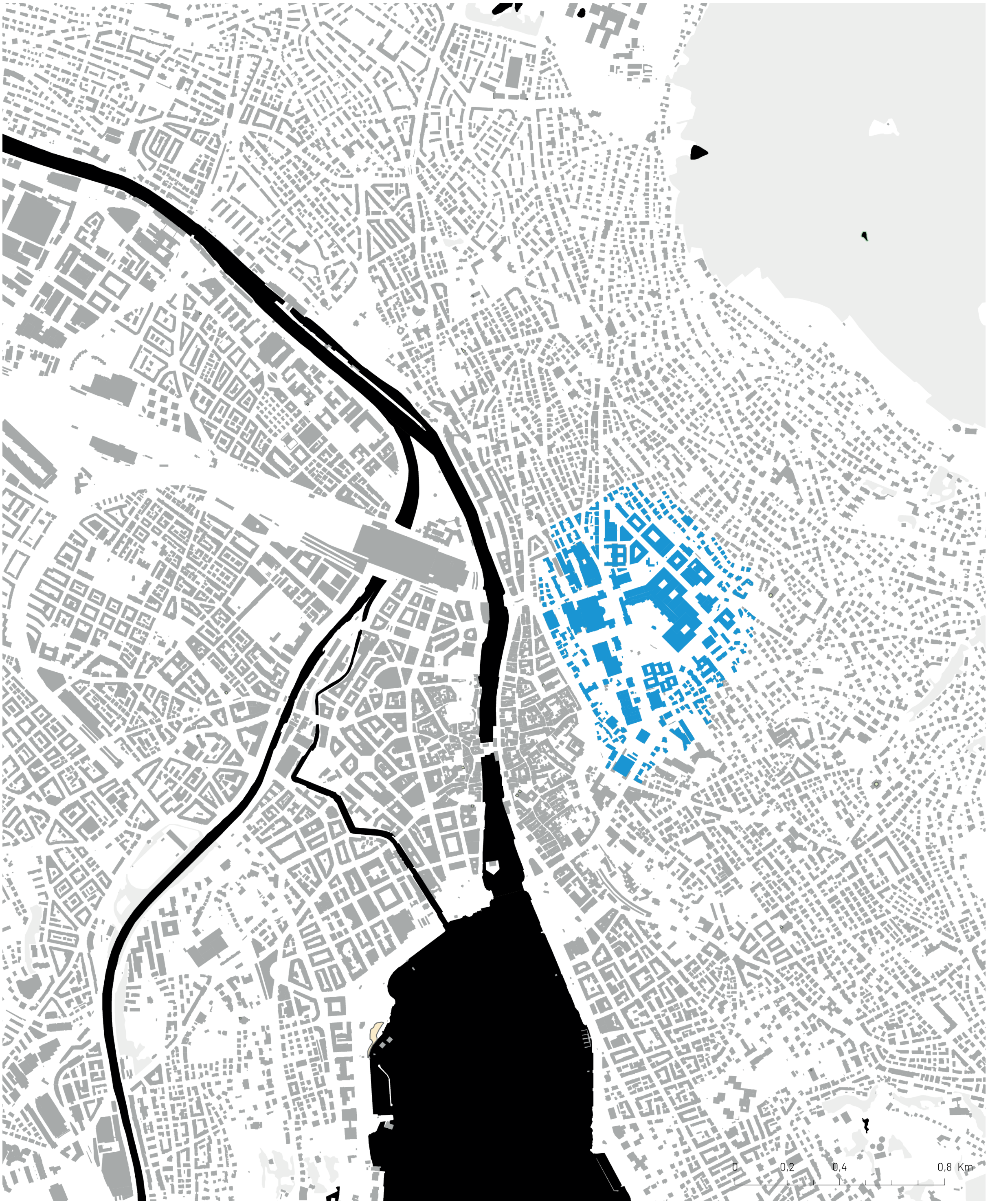


FIG. 2.7 Hochschulquartier Campus in Zurich

2.5. Zurich

2.5.1. Scenario Matrix and Workshop Settings

When taking decisions to address design in urban transformations, it is not only fundamental to understand the drivers of change, but to also explore 'multiple viewpoints that capture the full range of uncertainty and complexity' [12]. Scenarios are often used with these kinds of intentions. In the specific case of the Hochschulquartier (HQ) (according to the vision of a 2000-watt society), SPACERGY will not only use these scenarios as a tool to compare possible future pathways, but to also support an integrated urban design process. After the first applications in the LLs of Bergen (N) and Almere (NL), the hybrid DOS has been improved and applied in the Zurich LL, with a focused on the case study area of the 'Hochschulquartier' (HQ).

In this application of the method, the main observed differences were that only internal scenarios have been developed, and the collection of knowledge (as well as the scenario evaluation) has been more extensive by using a different qualitative approach.

In detail, due to the difficulties in involving a significant number of local actors in workshop activities, and due to the advanced stage of the masterplan, only internal scenarios have been developed during the workshop, and further improved from the academic staff. The evaluation phase regarding this case study was performed through making use of a survey, including the interviewing of key actors that were involved in the Hochschulquartier development in September 2017.

2.5.2. Internal Scenario Matrix

Vertical Axis: Demand Reduction, Share of Renewables, and Integration of EVs

The key aspects that were identified as energy measures consist of groups of solutions that have the potential to change energy demand and supply for the HQ.

In order to provide a successful transition toward a carbon neutral society, reducing energy consumption of the building sector is one of the main goals that needs to be met. The priority of energy efficiency needed for reaching the target of "Nearly Zero

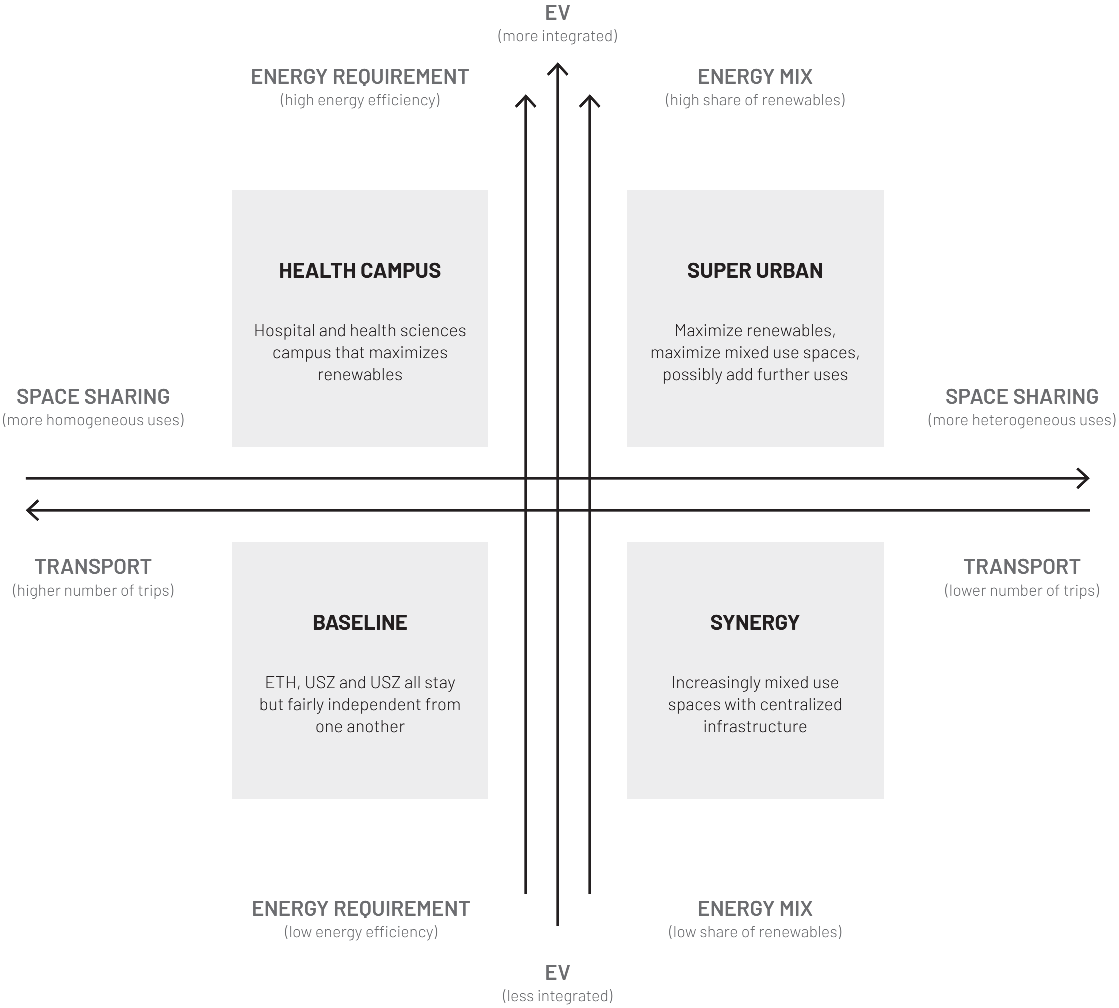


FIG. 2.8 Internal scenario matrix. Based on data regarding energy, space, and transport, a matrix of four different scenarios has been developed around two groups of factors that determine multiple variations in district energy performance. These factors are explored to understand the maximum extent that they can provide change in the energy profile of the Hochschulquartier.

Energy" buildings suggests the employment of technological measures to improve both the insulation of building envelopes, and to use high efficient heating and cooling systems [16]. However, decisions made in the early design stages, such as the one regarding building geometry and density, have been found to have a large and perdurable influence on the thermal losses and gains of buildings. In regards to the previously mentioned solutions, it is worth commenting that research on the urban microclimate has also adjoined to the importance of interpreting local conditions. This is especially true for when the urban form changes and creates a new climatic condition where buildings need to express their future performance. Decreasing energy consumption by changing the microclimate profile through design is one of the possible energy measures that can be explored, especially in the case of redesigning an entire district, and will be comparatively investigated with other energy saving solutions in the new HQ.

The proportion of renewable sources within the total energy supply sources is the second key factor in creating potential scenarios for the HQ. The use of local sources cannot be stressed enough, especially when looking at the energy production potential of a dense urban environment. Various production systems and technologies involving electricity, and the supplying of heating and cooling, can be applied with different degrees of efficiency. However, the total space availability within the urban environment plays a relevant role in the selection of both local energy supply solutions and their total potential production. Finally, the third factor that can change the energy profile of HQ is the integration of Electric vehicles (EVs). On the one hand, these new transport technologies (when compared to the traditional ones) are reducing the negative effects on the environment because of their low CO2 footprint, while on the other sensibly impacting the energy loads.

Horizontal Axis: Space Sharing and Transport

In this group, the well-known aspects selected are based on the logic of compact city planning, the relationships between land use, and demand of transport. During the last 30 years, policies and transition strategies aiming to decrease CO^2 emissions have directed their efforts towards the management of travel demand by trying to reduce the total amount of vehicle-miles travelled. The methods identified were (and still are) based on the correlations between transportation energy consumption and urban density. The aforementioned logic of compact cities planning used to build the HQ scenario matrix are based on two main concepts to reduce mobility energy consumption: (1) That mixed land-use reduces the total mobility demand and trip length. (2) That a denser allocation of activities could promote a positive behavioral change in the modal split by encouraging the use of alternative transport modes (such us public transport, walking, and cycling), and thus lowering energy demand.

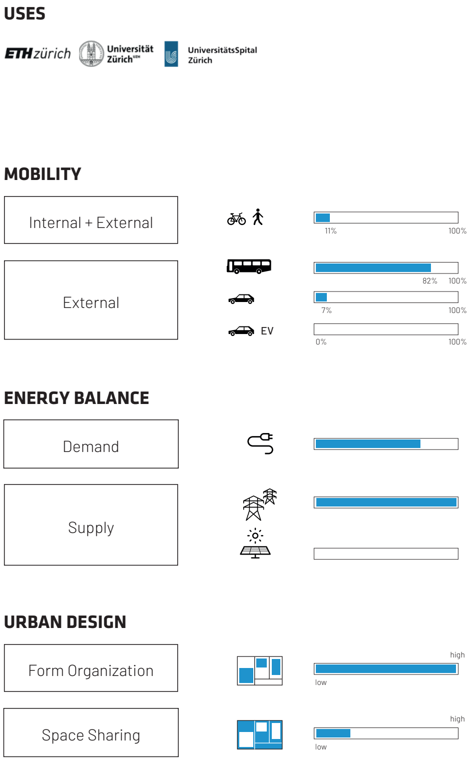
2.5.3. Internal Scenarios' Results

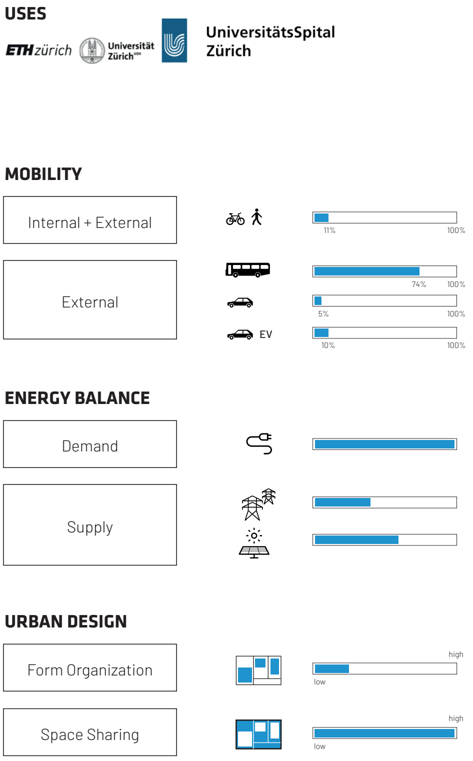
A Scenario 'Baseline' (BL)

This scenario is based on one of the visions of the project for the HQ, as published in September 2014 (EBP, 2014). The scenario describes a future where the three institutions (ETH, USZ, and UZH) separately develop their own spatial plans that exhibit limited integration of uses. The assumption in this scenario is that each of these institutions is extended, thus substantially increasing the total built volume in the area by 40% of the existing gross floor area.

B Scenario 'Health Campus' (HC)

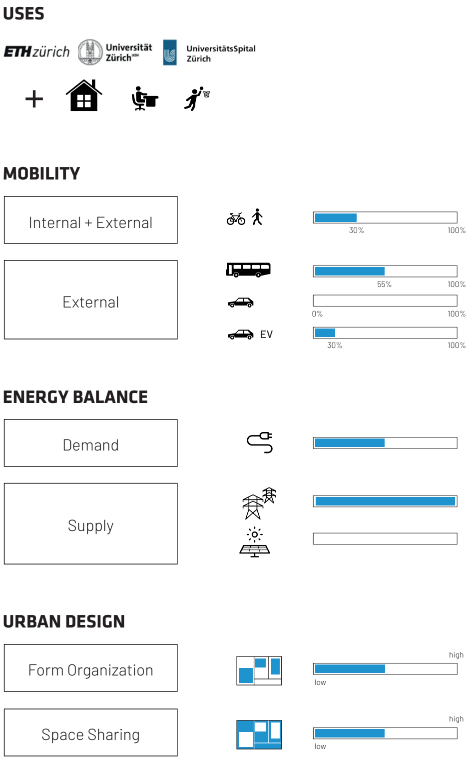
This scenario features a shift towards a higher share of hospital uses, while keeping both the educational and research functions unchanged. It presents an extreme case that increasingly supplies building uses with the highest energy demand with local renewable energy production.





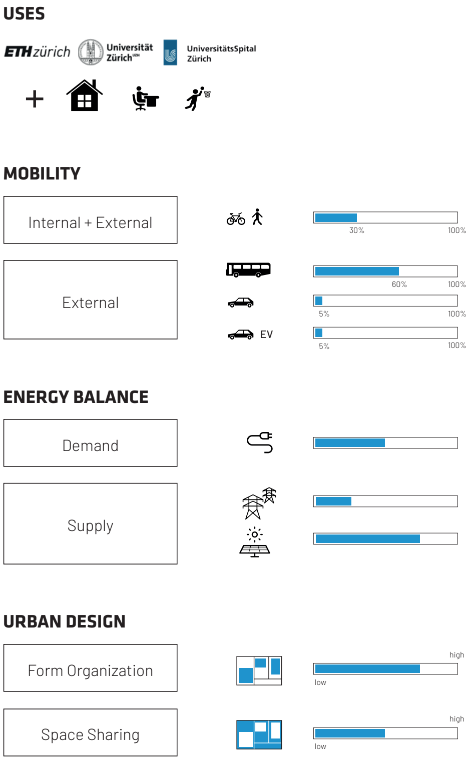
C Scenario 'Synergy' (SY)

This scenario builds on a mix of functions, and focuses on a better functional integration of uses, . Energy supply systems remain unchanged, employing both centralized infrastructures and limited electricity production. The integration of housing, amenities, and facilities within the university cluster results in a 24/7 liveable area that promotes walking and biking for mobility within the campus. This mix of functions has the potential, from an energy point of view, to not only decrease peaks in demand, but also balance the total energy demand of the area. Doing so will increase the overall efficiency, which is defined as the joint energy footprint of mobility and its use of space.



D Scenario 'Super Urban' (SU)

This scenario features a synergetic mix of functional uses and shared spaces that are combined with a high mix of local, decentralized, and distributed energy solutions. The main focus is on multi-functional, highly integrated, and liveable solutions from both energy and spatial perspectives. A combination of university spaces with residential buildings, amenities, and offices is optimized for the balancing of energy demand.



2.5.4. Evaluation

The main scope of the interviews includes an assessment of the Scenarios that collects additional information about both the processes and the background of the actors. As in the matrix previously shown, the point of interest of each scenario is a coordination of decisions taken in different sectors that have an impact on both the total energy performance of the area, and on the design phase itself.

The transformation of the HQ therefore entails the integration of the various needs of different stakeholders, who are primarily ETH, USZ, and UZH. Whenever possible, the participants in the interviews were selected from both the real estate and energy departments of each institution. From the University Hospital, however, only one representative from the energy area was available for an interview. The interviewees are directly involved in the planning of new buildings and energy infrastructure in the area.

The coordination of needs from each of these players takes place at the cantonal level. Thus, a representative from the Office of Planning and Architecture of the Canton of Zurich was also invited for an interview.

Finally, given the foreseeable effects that the transformation of the HQ will have on the inhabitants of the area, it is their role in this process that was also a key interest to the success of the SPACERGY project. As shown on the next page, the HQ is made up by four neighbourhoods, mainly Oberstrass, Fluntern, and Zürich 1 Rechts der Limmat, including a small area located in Hottingen. Each of these neighbourhoods has a "neighbourhood association" (Quartierverein), who were also invited to these interviews. From these associations, however, only Quartierverein Fluntern accepted the invitation, while Quartierverein Oberstrass directed us to documentation available online to submit their official position on the project.

2.5.5. Survey Questions

The questions included in the survey have been grouped according to the dual aim of the interview phase. The goal of the first group of questions is to collect information on the background of the participants, and on the state of the project itself. The questions asked in this section have the following objectives:

- Identify the role that the interviewed person has in the transformation process

- Know if they are familiar with the concept of participatory activities, especially in the context of urban transformations, their corresponding methods, and whether they are considered to be of value for the decision process;

- Identify the main energy factors and indicators taken into account in the planning/decision phase; and

- Understand the structure involved in the coordination of different planning areas on energy issues, and in particular the way decisions on energy and spatial factors are integrated in the whole planning and design process.

Identify the energy measures (defined as decisions relating to energy demand or supply in the area) selected in this first stage of the project, and understand if there is an awareness regarding the influence of microclimate measures on energy demand. In addition, a question on the feasibility of fulfilling the 2000-Watt Society goals has been used to understand the coordination between energy decisions and urban policies.

The second group of questions specifically regards the four Scenarios presented before and the interviewee's assessment of them. The main objectives here are to:

- Understand the interviewee's experience with not just scenario methods, but also the purposes of which they were used for, especially in different decision processes.

- Assess the Baseline Scenario, and understand the current planning stage, including the latest updates regarding HQ.

- Know the interviewed people's opinions regarding the description of the three other Scenarios, and the synergistic connections between mobility, urban form, and energy.

- Assess the direction of the decision-making process, and the difference between the most feasible and most desirable scenario.

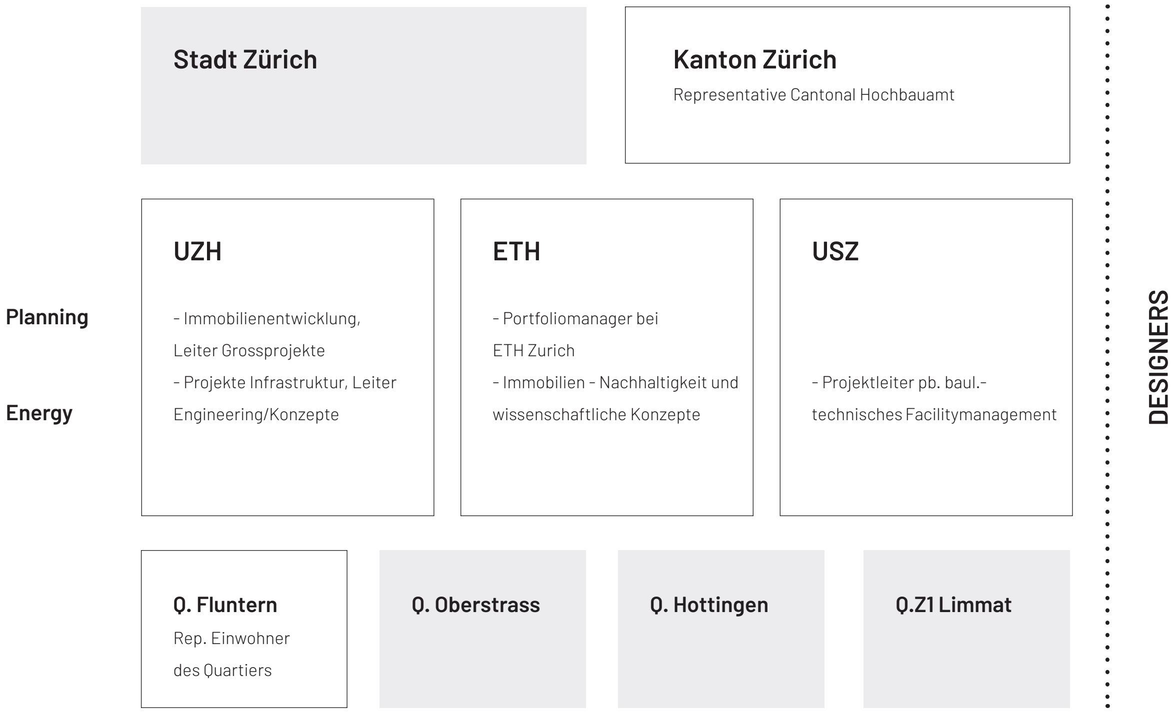


FIG. 2.9 Key representatives involved in the evaluation phase

2.5.6. Survey Results

ROLE: Involvement in the Hochschulquartier (HQ) planning/design process

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Q1: Why are you participating in the transformation process of the Hochschulquartier?

The interviewees are comprised of various representatives that have had different levels of participation within the project. They are made up of energy and spatial planners from each of the three involved institutions (ETH, UZH and USZ), coordinators at the cantonal level, and one of the four neighborhood associations representing the residents of the area.

Institutions: The interviewees from the three participating institutions (who are the main stakeholders in the area) represent the energy and real estate departments that are involved in the transformation process, and they are directly involved in the development of the Masterplan for HQ. Two involved offices from UZH and ETH are responsible for the definition/realization of the users' requirements, including the definition of concepts, feasibility studies, and guidelines regarding the engineering and infrastructural components of the masterplan. The person interviewed from USZ has more of a management role regarding the new buildings and technical facilities on the site.

Coordinator: The representative from the cantonal Office of Planning and Architecture participates in coordination with the "Generation Project Berthold Area," which is a project that is overseeing the development of the HQ. The Berthold project started with the development of the Hospital, but was later expanded into a framework for the supervision and management of the entire area. It is responsible for coordinating the three institutions, the Canton of Zurich, and the City of Zurich.

Residents: Out of the associations representing the neighborhoods that are located in the HQ, only the Fluntern neighborhood association accepted an invitation for an interview. The organization works on a voluntary basis, and it requires a fee in order to participate in the association. According to the interviewees, of the approximately 8000 inhabitants in the community, only about 500 are actual members.

BACKGROUND: Participatory activities

Q2: Have you ever been involved in participatory activities within planning processes?

The majority of individuals who were interviewed affirmed to have previous experience in participatory activities in the form of workshops, lectures and meetings. In the ongoing process, the activities with all the stakeholders including inhabitants have the scope to communicate decisions and receive feedback. However, at the moment inhabitants of the four 'quartiers' are not involved in discourse concerning energy concepts and energy infrastructures, but are only involved in discussions regarding the planning steps.

Although the people who were interviewed seemed to be aware of the value of participatory activities, their experience is reported on few cases. In addition, the methods that have been used are conventional, such as regular meetings to collect the data and communicate the results of analysis from the experts, or to share decisions of the main actors at the coordination level. In the HQ the process "is more of a long discussion about certain topics".

Q3: How do you consider participatory activities in informing the decision making process for urban transformations?

Nearly all the participants in the interviews consider participatory activities to be useful. In order to build awareness of the decisions taken by different parties, it is considered important and necessary that all the actors are involved in the process including the inhabitants. Furthermore, the discussions could enlarge the spectrum of the topics that have to be addressed, and could bring forward new ideas and more sustainable solutions. On the other hand, given the high degree of complexity due to the number of actors involved and to public ownership, many of the interviewees agreed that the process becomes slower and longer, and consequentially more expensive and time-consuming. However, one interviewee did point out that involving the inhabitants creates less opposition, thus can save time in the long term.

The general comments on the relevance of participatory activities are positive. There are two different points of view regarding the consequences in time. In the short term they are considered time consuming, but in the long term these activities could facilitate the decision making process because if the goals and visions are defined by all the actors together, less opposition can be expected during the implementation phase. It appears that there is no clear framework and a structured responsibility regarding the organization of a participative process.

INDICATORS: Impact factors on energy performance

The responses regarding impact factors on energy performance are restricted to the representatives from the three institutions. The resident association has not tackled the topic of energy performance and connected decisions in any discussion and activity, while the "Coordination" representative referred to the report Hochschulgebiet Zürich-Zentrum: Schlussbericht Vertiefungsthema Energieversorgung, published in 2015. The report analyses the supply system and the supply infrastructure, describes possible scenarios of energy demand and investigates a number of strategies for energy supply in the future.

Q4: What are the main factors that you consider relevant to improve the energy performance ?

The answers can be clustered in three main groups considering factors that have been important to improve the energy performance. In order to improve the energy performance, the first group considers principles and concepts as followed:

- A good energy mix and the complementarity between different types of energy sources;
- Decarbonization in order to have primary energy not based on fossil fuels;
- Low exergy and low temperature heating systems and high temperature cooling systems;
- Maximum reuse of waste heat.

A second cluster of answers focuses on a more comprehensive energy policy and strategy in order to steer actions and decisions towards the Energy Strategy 2050.

The third group highlights the importance of targets, either by aiming for recognized standards such as Minergie (for low-energy consumption buildings) or by setting self-tailored standards for energy efficiency, such as by reaching a deal on yearly energy efficiency improvements with the Swiss Office of Waste, Water, Energy and Air (AWEL).

Q5: What are the main factors you take in account when taking decisions that impact the energy performance?

According to the people who were interviewed, the factors that drive the decisions are different. These factors can be grouped as follows:

The first group of factors covers the aspects closely related to the energy demand. Heating, cooling and electricity demand are taken into account. The second cluster of factors refers to the relation between the use of energy and the impacts of it on the environment, where the energy performance can be measured in terms of CO2

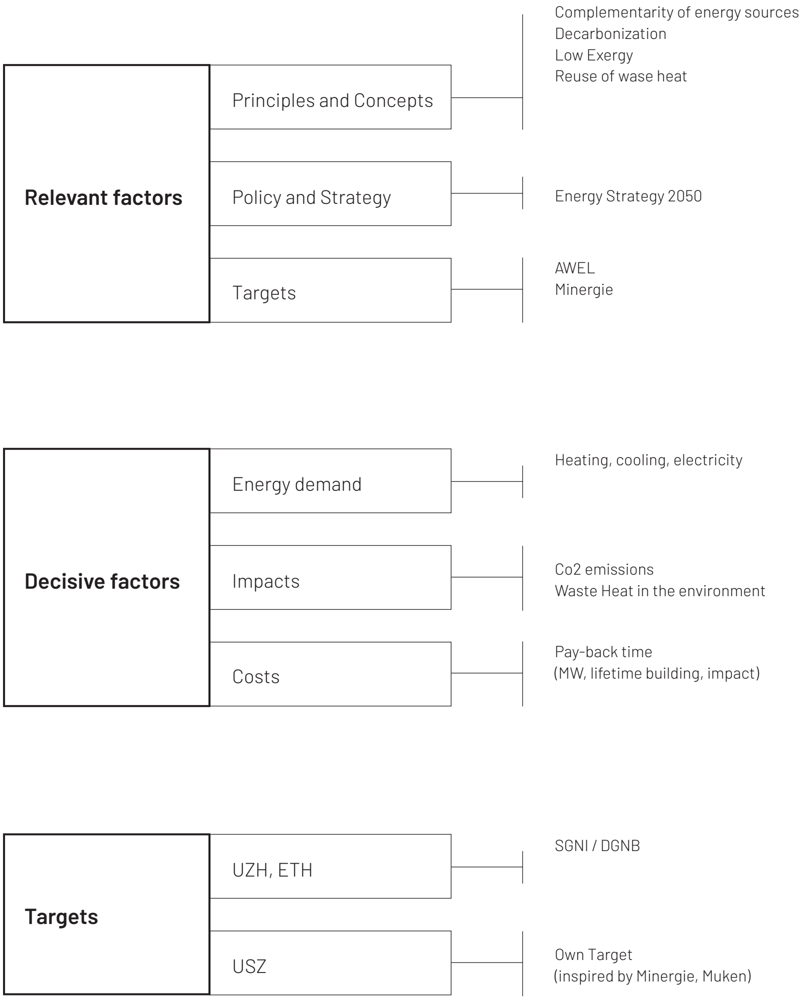

FIG. 2.10 Energy related factors

emissions and the amount of waste heating/cooling released to the environment. The third aspect that is overall mentioned, that plays a crucial role, is the cost of implementation of the chosen energy solution. Here, the main factor is the payback time of the investment for which a maximum number of years is defined based on factors such as the impact of the project on the overall planning, the MW supplied per year by a given technology, and building lifetime.

Q6: Do you have key performance indicators to evaluate the design proposals or a target that you want to achieve?

Many targets have been used until now to set the goals and the standards for the buildings in terms of energy demand and efficiency of production. A common comment regards the lack of appropriate targets for the specific types of functions and uses in the area. Targets for laboratories, hospitals, hybrid types of buildings like the ones for tertiary education, do not find specific standards in the targets catalogues. The targets used are different for the three institutions:

UZH and ETH employ sustainability standards from the German Sustainable Building Council (DGNB) or its Swiss partner, the Swiss Sustainable Building Council (SGNI). The DGNB criteria cover many aspects such as environmental, economic, sociocultural, technological, and functional aspects for sustainable buildings. A number of selected indicators from these criteria will be used to rate the design proposals in the competition phase. USZ developed its own benchmark for its future energy consumption, starting from the current targets based on Swiss norms and energy efficiency standards (Minergie). One important target value regarding the efficiency of energy systems: utilizing at least the 85% of energy purchased.

The indicators that have been used vary in importance according to the phase in which the energy performance is taken into consideration. In a previous stage the relevant energy factors are the expression of abstract concepts that are about spheres of energy principles, concepts, policies and strategic goals. During the second stage, when taking decisions, the factors become measurable indicators for the energy performance and its impacts. Here, the decisions are made based on the amount of energy needed for heating, cooling and electricity, and on the impacts in terms of CO2 production, as well as the costs for the implementation of energy systems and measures.

The third group of indicators comes from the general goal to achieve an energy label at the building scale. The target catalogues that are available seem to be unable to cover the complexity of the intervention in the HQ because of the types of uses allocated in a number of complex buildings. This constrain results in two pathways: the first where a selection of subset of the available indicators is used for design competitions in the form of guide parameters, and the second which see the transformation of the standards to create new target values.

COORDINATION: Spatial-energy integrated decisions

Q7: In the planning/design process of the HQ how are energy and spatial decisions coordinated?

Decisions regarding Energy and Spatial components within the process of the HQ can be subdivided into three different levels. The first level concerns the overall framework managed by the Berthold project team, while the second level of coordination regards the decisions that are made by the three institutions and their internal departments. The third level includes the role of inhabitants of the area and their requests.

1. Overall coordination (Macro level): The hierarchical organization of the overall process has been very clearly explained by one of the participants during the interview: "The process is organized in a hierarchical way between different groups: on top we have the "Projektaufsicht" (project supervision); below there is the "steering committee"; and below that there is the "area and coordination management", which initializes the several project streams (like the Energy and Media Supply Study) and gives a basic financing so the feasibility study can be started; from there a separate group is started with representatives of all stakeholders for specific smaller projects." ETH, USZ, UZH and the engineering company Anex join one of these groups within 'Energy and Media Supply' works on the projects for the lake water district cooling network and the working team.

The Berthold project steering committee (Projektsteuerungsgremium) has the main role for the coordination of all the parties in the area including the Canton and City of Zurich. The main scope of the Berthold team is to create synergies between different levels of decisions and the single projects of the three main stakeholders. In particular, this coordination regarded the definition of the Syntheseplan and the overall Masterplan from a spatial point of view, and in the second stage the feasibility studies for common infrastructures and energy supply.

Despite the coordination role at the Canton level, all of the owners maintain a degree of freedom in decisions. This regards in particular to the Design process and the organization of the design competitions, as well as the construction stage.

2. Inside the institutions (Micro level): Each institution has experts on energy and spatial fields who are coordinated internally. The decisions in energy supply follow the decisions made in the spatial and functional program. After the uses are determined, they are quantified in terms of square meters, and the engineering experts develop a forecast to calculate the energy demand.

3. In relation to inhabitants' requests: The representatives of the inhabitants are part of the discussion process when decisions have to be made. Up until now they have been involved only in the spatial decisions and have not been in the working groups that focus on energy and infrastructure issues. The residents of the area do not have an active participation in the decision process, but there indeed exists a practice of mediation and creation of awareness on the decisions taken as well as an acknowledgement of the inhabitants' demands.

In May 2012 and two years later in September 2014, the neighborhood associations of Oberstrass, Unterstrass, Zürich 1 rechts der Limmat, Hottingen and Fluntern were called to attend to the workshops regarding the HQ transformation.

The result of these meetings has been a document that lists seven requests on role of the public space of the campus, limitations in volume and height of the new buildings, more extended studies on impacts for mobility and a better communication. Therefore, these requests have strongly influenced the spatial decisions acting as constrains within the planning process. However, none of these points focus on energy aspects and their possible benefits to the community.

Q8: In which stage do you think the coordination and the integration have more benefits for the final result?

The responses to this question can generally be classified into two groups.

The first group agreed on the fact that the coordination between different decision-making aspects should take place at a very early stage. In particular, this early stage is described as the conceptual phase, when all the actors define the particular and general visions, main goals and objectives for the transformation, and the basic common principles that can guide the following steps.

The second group, on the other hand, did not consider the phase in which the coordination takes place, to be as important as the complexity of the situation and the location of the project. In this case, the interviewees pointed out that the coordination could not be more efficient than it currently is. These answers give a picture of the diversity of opinions when talking about coordination:

> - *"Normally coordination in an early stage can have more benefits to integrate decisions on spatial needs, functional program and energy strategies, but not in this specific case. Here the problem is not the stage but the starting conditions, and the location."*
>
> - *"This stage is the more appropriate one for coordination."*

The coordination of spatial and energy decisions follows the same pattern at the macro and micro level. Energy concepts, guidelines and studies regarding energy supply and energy performance follow the spatial decisions for type of uses, volumetric configuration and functional distribution. Principles regarding integrated spatial-energy decisions are underestimated and often missing in both levels of

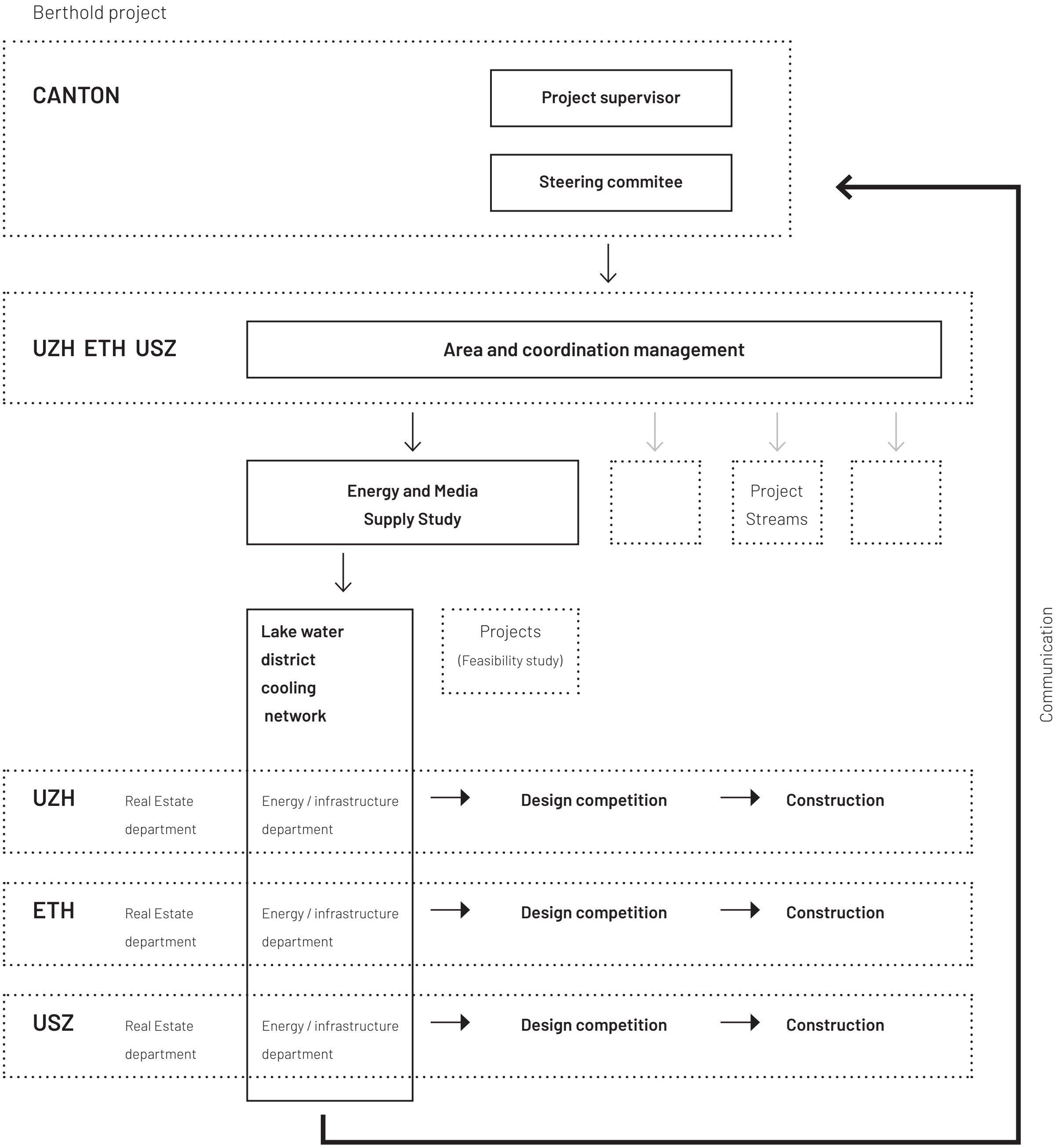

FIG. 2.11 Project organisation

decisions. However, there is awareness that the coordination from an early stage can generate more benefits.

Furthermore, coordination and collaboration between all the actors appear to be a very important issue in the HQ, for the fact that for many years the three institutions have operated in an independent way until the Berthold team assumed the project management role in 2014.

In addition, the framework for the decision process on energy infrastructure have not included discussions with the inhabitants, who also did not express particular interest in the subject, consequently preventing the possible benefits that come from integrated decisions, such as through the use of waste heat from the institutions for the residential area during the night.

The main problem in coordinating decisions between the energy and spatial sector at the macro level in the HQ project is attributed to the complexity in terms of stakeholder types and the starting condition of the location. Firstly, due to the nature of the three institutions and the different types of public administrations: the ETH is a federal institution, while the UZH is a cantonal one, and the USZ is also a cantonal one but is set to become independent. Secondly, considering the location, the complexity relates to the lack of space for the spatial needs of the three institutions. The first consequence is that the spatial constraints become the main drivers and the energy aspects have to follow. The second is that the overall coordination tends to become a political mediation practice that supersedes the importance of a common principle of sustainable development.

STATE OF ART: Energy measures

Q9: What are the energy measures you have selected in the planning stage and on which base is the selection done?

The three institutions are currently supplied heat for space conditioning, domestic hot water and processes primarily from the district heating network, which supplies steam and hot water at two different temperature levels produced at the Hagenholz waste incineration plant. In addition, the ETH and some external (largely residential) buildings were supplied by a local district heating network supplied by the Walche heat pump, but this outdated system will no longer be operated. Mainly vapor-compression chillers provide cooling, while space cooling in summer in the UZH is partially provided by absorption chillers that use steam from the district heating network. The electricity grid provides the electricity. The energy measures selected until now can be divided into two main categories. The first groups common energy measures that are pursued together by the three institutions, while the second category collects the individual selections by each institution.

1. Common Energy Measures: One of the most relevant challenges for all institutions is the supply of cooling to the buildings. Therefore, a team composed by the energy experts of the three institutions and the engineering company Anex is investigating the feasibility of a district cooling system, using water from Lake Zurich.

While the need to exploit synergies between the different types of uses in the area were mentioned, no other specific projects were specified. For example, the future supply from the waste incinerator plant (which makes use of a considerable amount of fossil fuels in peak periods) is treated differently by each institution: from terminating its usage entirely or questioning the actual need for its future use, to accepting it as a part of the future supply but reducing the demand for this service.

2. Individual Energy Measures: While the general energy planning trends of the three institutions are generally in agreement, most decisions are taken individually.

The institutions are now in a phase of collaborative work to find out possible synergies in the supply systems. The main challenge is to supply enough cooling for the new buildings.The individual energy measures selected are very similar in terms of use and reuse: low system temperature for heating and higher temperature for cooling, improvement of the efficiency of the buildings and reuse of waste heat from the cooling clusters (servers room, etc.) wherever possible. On the contrary, regarding the local production by renewables the importance given to electricity production from photovoltaic changes among the entities.

It is worth mentioning that the residents around the HQ are not considered within the common energy measures for the area, and an analysis of the possible benefits to residents from enlarging the district energy infrastructure is not contemplated.

Q10: Are you aware of the role of microclimate on energy requirement? Are you considering microclimatic measures to improve the energy performance?

The interviewees generally agreed that microclimate could have an impact on the indoor and outdoor comfort as well as on the energy demand. However, neither analysis nor further studies to investigate possible measures and energetic benefits are planned. Furthermore, constrains due to the location and the urban structure are described as the main limitation of the disposition’s choice and buildings’ orientation. Orientation of the buildings follows “other priorities and not energy efficiency and solar gains.”

The design briefs in development for the design competition phases do not have specific guidelines concerning microclimate principles. Energy experts see their role in implementation of these measures only if addressed by the designers and urban planners. The explanation is that they miss the competencies to change the design

TABLE 1.4 Comparison of individual energy measures

ETH

USE	REUSE	PRODUCTION
Cooling grid to connect all ETH cooling plants in a loop	Reuse of waste heat from cooling plants	Small electricity production from PV plants
Outdated energy clusters need renovation		Stop using heat from the incineration plant within the next 15 to 20 years.
Lower supply temperature for heating		
Improve efficiency of the buildings with better insulation and windows when possible		

ETH

USE	REUSE	PRODUCTION
Lower the heating demand with better insulated buildings (both for new buildings and retrofits)	Waste heat recovery in the buildings	Use of the maximum spatial capacity for electricity production with PV panels
Lower electricity demand through LED lighting		
Lower input temperature for the heating systems		
Introduce setback temperatures in classrooms		

USZ

USE	REUSE	PRODUCTION
Geothermal storage for waste heat flows	Minimize waste heat flows through heat recovery	Financially-feasible combination of centralized and decentralized energy production
Low heating temperature (max 45 degrees)		Reduce the use of district heating as far as possible
Higher cooling temperature (min 10 degrees)		PV being considered
Reduce electricity demand by demanding more efficient systems from manufacturers		
Reduce process heat demand by moving processes out of the area		

of the area in order to improve the energy performance, reiterating the decision pattern in which energy planning chronologically follows the spatial decisions.

Regarding the role of microclimate, and its impact on energy performance, it seems that there is a general awareness on the topic, but not a real investigation on the area from this perspective. In addition to this issue, these aspects have been neglected in the analytical studies of the energy masterplan. Furthermore, it appears that the microclimate measures are very often identified, but are reduced to the physical presence of green areas as there is an underestimation of the possible benefits for the outdoor and indoor comfort.

Despite these limitations, it is curious to see that the designers are actually expected to be the ones who can give solutions to energy issues, and even propose microclimatic measures. The challenge is if they have the expertise to do so, and if there will still be possibilities for decisions such as these when arriving at the design phase.

SCENARIOS: Working with scenarios

Q11: Have you ever used scenarios in the past?

The second group of questions regards the use of scenario building methods as an instrument in planning and design processes of urban transformation. The larger part of the interviewees claims to have experience in using scenarios.

Q12: With which purpose have you used scenarios?

According to the classification developed by Borjeson et all. (2006), scenarios can be categorized as predictive, explorative, and normative. Following these classifications, the answers are homogeneously distributed into three groups. The first group makes use of predictive scenarios to foresee what is going to happen in the future, more specifically regarding future climatic, urban development, and demographic conditions. For the experts in the energy sector, the use of scenarios has a normative starting point, since the focus is a problem or a need that requires exploration of different energy solutions. Finally, the last group regards use of scenarios with an explorative aim. This type of scenario has been used specifically in planning and design in order to investigate a number of possible solutions through open competitions.

There is a general awareness of the benefits of using scenario methods. In addition, the interviewees report a familiarity with different types of scenario building methods. In the interview sample, there was a tendency to use certain types of scenarios, and was dependent on the interviewee's field of expertise. In the field of engineering and energy, normative scenarios see a larger use, while in the field of spatial planning and design, their main aims involved the investigation into possible future conditions and spatial developments that lead to the use of predictive and explorative scenarios.

SCENARIOS: Assessment

The questions of this section focus on the scenarios that are described in the first part of this chapter. The matrix and the scenario descriptions for the HQ have been developed during the first phase of the SPACERGY project by the academic partners, and the questions that follow have the scope to verify and discuss the results with the stakeholders involved in the transformation of the HQ.

> **Q13a: Do you agree with our summary of the Syntheseplan?**
>
> **Q13b: What are the decisions already made in your office/department which support the Baseline scenario?**

This question aims to verify the accuracy of the Baseline scenario description (which acts as a summary of the Syntheseplan), and if, at this stage, the baseline has seen important updates. The comments given by the people interviewed regarding these changes are summarized in the following points. The general consensus seemed to be that there has already been a shift in focus towards an increased sharing of spaces, and there is momentum for taking advantage of existing energetic synergies between the institutions.

1. Space sharing: There is a general attempt to develop a diverse set of uses that create synergies between working, living, and studying spaces. The current plan states that the ground floor of new buildings should be open to the public, with the general intention of creating a lively area that attracts people for leisure. Furthermore, it is not completely true that each institution separately develops its spatial plan. There is an effort to seek opportunities to share spaces and functions between the institutions that is driven by the need to reduce building volume and height from the original masterplan. However, there is again very little flexibility, which is due to the need to accommodate all the spaces requested by each university for laboratories, rooms, offices, etc.

2. Urban form: The Stadtraumkonzept, which is currently under development, has been reported to include aspects of microclimate. However, the general comment regarding this project is that these issues come to light at a late stage, and when there is no flexibility to integrate these concepts in an effective spatial result.

3. Energy Supply: The lake water district cooling is at the stage of being a feasibility study, and the investigation shows that from an economic perspective, this solution is implementable as long as ETH and USZ both participate in its development. The next stage includes the study of both the system itself, and the network configuration for proper distribution. To provide the necessary heating, different alternatives to the existing network were discussed, including heat recovery from data centers, and even the lake water itself. In regards to the local electricity production by renewable energy sources, and idea has been developed that aims to expand the supply by using solar technologies for electricity generation. However, the share of the electricity demand in the area that can be realistically provided through solar panels was questioned.

4. Energy Demand: While energy reduction through both insulation and heat recovery was common to all institutions, UZH further posited that all new buildings should be self-sufficient.

The comments show that the current situation is, in some regards, moving away from the Baseline scenario, and more towards the Super Urban scenario that regards the possibility to not only include a higher functional mix, but also a decreased reliance on the existing heating infrastructure.

Q14a: What aspect would you like to improve in the construction of this scenario? How can this aspect be improved? (HEALTH CAMPUS)

Q14b: Are there facts or decisions already made in your office/department which support or hinder this vision? (HEALTH CAMPUS)

Q15a: What aspect would you like to improve in the construction of this scenario? How can this aspect be improved? (SYNERGY)

Q15b: Are there facts or decisions already made in your office/department which support or hinder this vision? (SYNERGY)

Q16a: What aspect would you like to improve in the construction of this scenario? How can this aspect be improved? (SUPER URBAN)

Q16b: Are there facts or decisions already made in your office/department which support or hinder this vision? (SUPER URBAN)

Since the interviewees' comments focused on individual aspects, and only a few of them answered by relating all the descriptors and considering the interrelations between them in a possible future vision. Therefore, the results to these questions are summarized by topic, and are based on the descriptors of the scenario definitions.

1. Mobility: Regarding the external mobility, a sensitive point found involves the connection of circulation flows to and from the central station during peak times, and how to address this aspect in a systematic way. The opportunity to be both innovative and proactive is considered to already be lost, since the solutions chosen do not exploit the potential of the area. The interviewees describe the solutions taken as conventional, due to the absence of a vision that expands the simple practice to give a size at the infrastructural system. In addition, electric vehicles are not even considered in the mobility plan.

2. Space sharing: The topic of aggregating different types of functions within the development of the HQ is a central topic that can be defined by three main levels where a mix of uses can be employed. The first is the scale of the building, where the aim is to implement multi-functionality into the buildings by accommodating spaces to eat, to relax, and to work. The second is the overall scale of the area, where all the institutions have multiple possibilities to share some facilities such as laboratories. The interviewees generally state that there is already a high demand for additional functions, yet not enough space available to provide them. For this reason, space sharing between institutions appears to have been done to the maximum extent possible. A third level corresponds to a 24-hour lively area, as described in the Synergy and Super Urban scenarios, which requires additional infrastructure and services for the daily needs of the new inhabitants. Again, the main criticism here is that there is already a limited availability of space for both education and research.

Participants generally refused the possibility to include residential buildings in the development of the HQ because of this pre-existing space scarcity. The general strategy here is to include facilities and amenities for the residents already living in the surrounding neighborhoods. Making the area attractive to these residents, while also improving vertical and horizontal accessibility, are reported as key elements for the livability and safety of the new HQ.

The possibility of removing one institution was refused by all interviewees, as the HQ has an identity role for all of them. The HQ is supposed to become an iconic campus for both the city itself, and for all the institutions represented.

3. Urban form: A large part of the interviewees stated that the design of the buildings is absolutely not driven by energy. Outdoor and indoor comfort would be more likely drivers for the integration of microclimatic measures, as energy is also not the driver for the design of the public space.

In addition, the experts of the three institutions said that they do not have any influence on building form, since it is the result of constraints in the existing area. These constraints are identified as existing orientations and regulations, such as maximum volume, alignments, maximum building heights, etc. Thus, at the current stage, it was stated that it would be impossible to make changes in building form for energy purposes.

4. Energy demand: According to the interviewees, the Synergy scenario corresponds with the best possibility to flatten peaks in energy demand by creating synergy between energy clusters. The main limitations in this scenario is that the institutions have very similar patterns of energy use, and that synergy would only be possible by using waste heat from the hospital, and cooling processes from other buildings.

5. Energy supply: Looking at the energy supply, centralized infrastructures (such as ones found in the Baseline and Synergy scenarios) are considered an instrument for the use of both waste heat and integration of lake water use for district cooling. Comments on the Super Urban scenario were mixed, as even though a majority of interviewees mentioned a push for the implementation of solar technologies to produce electricity, some ended up mentioning the actual relatively low potential within the area. The main constraint for something like this is the limited area for the photovoltaic panels themselves, and that the amount of energy required is too high to be produced locally.

6. Mobility – Space sharing: While the incorporation of new building functions in the area is generally described as utopic (because of the boundary conditions), there are some reflections on the positive values that can be imported to the area, through the integration of living space for students. In particular, the reduced need for students attending lectures to use transportation could help mitigate the currently overloaded transport systems during peak times. Secondly, the increased activity in the area will also make it more safe and lively during the evening/night. These considerations agree with the interrelations between mobility, and the sharing of space described in the Super Urban and Synergy scenarios.

7. Space sharing – Energy demand: From an energy perspective, the concept of using the functional mix in order to help balance the energy demands in the area has been used in the implementation of other projects (namely at ETH Hönggerberg), and is considered an interesting idea. However, from an operational point of view, the main problem in using this type of approach in the HQ is that there is a limited amount of space for heat storage. Thus, this concept is considered impossible to implement at the larger scale. This is because of the actual boundary conditions of the site, but the concept could be possibly implemented at the building or cluster scale.

SCENARIOS: Interviewees vision

Q17: From your point of view, which scenario/s is/are more probable? Why?
Q18: From your point of view, which scenario/s is/are desirable? Why?

The last two questions try to ascertain the scenarios that can be described as most feasible one, and one that can be seen as most desirable. The majority of the interviewees judged Synergy, or a mix between Synergy and Super Urban, to be most probable. Even though there is a general agreement that the Super Urban scenario represents the most desirable vision for the future, this scenario tends to be described as too utopic to realize in the actual situation at hand.

2.6. Results

External and internal scenarios have been developed, discussed, and evaluated by key actors in the three Living Labs, which was achieved by following a hybrid Design Oriented Scenarios method.

In the case of Almere, the scenario that emerged as the more resilient one towards responding to external pressures, has to be Scenario D. This scenario has the potential to be successful for the implementation of an energy efficient district, while also being characterized by a green overall image that uses collective energy solutions. The spatial configuration of the scenario merges dense building clusters with a large area that is dedicated to vegetation and food production. The green identity of the district could raise interest in certain types of households that are looking for a quieter and greener living environment, while at the same time being well connected to Amsterdam by both direct access to the highway, and relatively fast public transportation. Moreover, the sharing of investment costs, combined with the mix of sources for energy supply, might allow the creation of an energy self-sufficient neighbourhood, therefore reducing the energy bill for its eventual inhabitants.

In the Bergen Living Lab, the internal Scenario A is evaluated as the one possibility that can provide a successful energy efficient development to the Mindemyren area. This scenario promotes an integrated transport model with a separated monofunctional and compact design of the district. The separation of use, and the large surface dedicated to open spaces, allows for the allocation of potential climate adaptive strategies to be included into its development more easily. Moreover, the fast connections to the city centre, combined with the high accessibility, support the attractiveness of the district for both families and businesses alike.

For the Zurich Living Lab, a numerical analysis of the energy performance involving the four descriptive/qualitative scenarios will be carried out in a second stage of the SPACERGY research, providing the final assessment need for making a comparison of the scenarios on a quantitative base. However, some preliminary conclusions can be drawn, as factors of influence can be found by extrapolating the partial results presented in this report.

The deductive construction of the four scenarios highlights the connections between the cooperation of land use types, and the availability of space for energy production. Where the integration of functions balances energy demand, it also potentially decreases the competition for space. Furthermore, the introduction of microclimatic measures needs more elaboration in the further construction of a knowledge basis, since there seems to be little awareness among the participants about its benefits, especially from an energy perspective. The Super Urban scenario is identified as a so-called desirable one, since it balances multifunctional uses and the optimization of energy and mobility related aspects. When considering the heightened political sensitivity regarding the HQ area, the request to discuss possible futures in a small setting. combined with the unusual framework in this context, were key elements that led to limited participation of the invited actors in the workshops. It is for this reason that additional efforts were made to include more stakeholders in the evaluation. This was achieved, and the evaluation of the visions were developed during the workshop, by experts, through a methodology of interviews that could complement the hybrid DOS method.

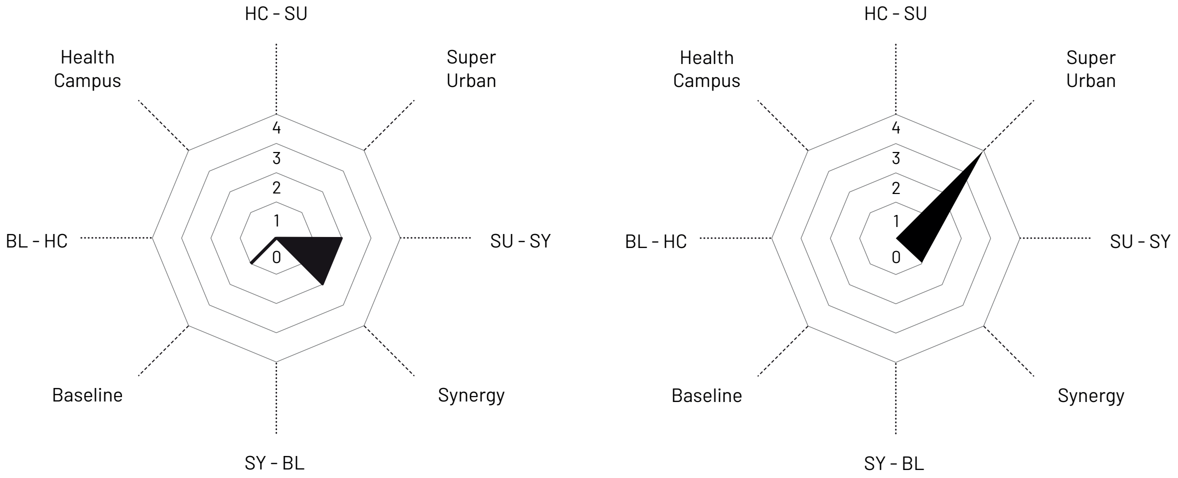

FIG. 2.12 Probable (a) and Desirable (b) internal scenarios for the Zurich case

2.7. Conclusions

The application of the DOS method has shown its capacity to support complex and multi-actor processes regarding spatial-energy transformation by helping in setting common transition objectives, sharing and creating a multidisciplinary common ground, and exploring alternative spatial and energy performative visions within a participatory workshop setting. In both the scenario method elaboration phase, and its application in the Almere, Bergen and Zurich Living Labs, the developed visions were considered a fundamental contribution towards the body of information and knowledge developed, while also being consistent in terms of developing descriptions regarding the relationship between energy impact factors and processes.

Moreover, the evaluation of scenario robustness is based on external drivers, and contributes to creating awareness amongst decision-makers. This is especially true when regarding the interdependency between external, national, and global drivers of change on the one hand, and internal development processes, design principles, and mobility models on the other. The DOS method has shown good results as both a descriptive and exploratory tool. However, further studies need to deal with the normative goal of the method, which was in fact, not completely addressed during these workshop activities.

References

[1] A. van Timmeren, P. van Bauer, S. Silvester, "Smart Use of Storage Potentials of Electric Vehicles for Renewable Energy Generation in the Built Environment; a Design Scenario", Proceedings World Conference Sustainable Building, Helsinki, 2011

[2] P.W.F van Notten, and J. Rotmans, "An updated scenario typology." Futures 35(5): 423-443, 2003.

[3] P. Rikkonen, P. Tapio, "Future prospects of alternative agro-based bioenergy use in Finland—Constructing scenarios with quantitative and qualitative Delphi data", Technological Forecasting and Social Change, vol.76, no 7, pp. 978-990, 2009.

[4] H. Kahn, and A.J. Wiener, "The Year 2000: A Framework for Speculation on the Next Thirty-Three Years", Macmillan, New York, 1967.

[5] J. Rotmans, M. van Asselt, C. Anastasi, S. Greeuw, J. Mellors, S. Peters, D. Rothman, and N. Rijkens, "Visions for a sustainable Europe", Futures, vol. 32, no. 9–10, pp. 809-831, 2000.

[6] R. Amara, "The futures field: searching for definitions and boundaries", The Futurist, 15 (1), 25–29, 1981.

[7] L. Borjeson, M. Hojer, K. H. Dreborg, T. Ekvall, and G. Finnveden, "Scenario types and techniques: Towards a user's guide," Futures, vol. 38, no. 7, pp. 723–739, 2006.

[8] K. H. Dreborg, "Scenarios and Structural Uncertainty: Explorations in the Field of Sustainable Transport", Royal Institute of Technology (KTH), Stockholm, 2004.

[9] G. Carsjens, "Supporting strategic spatial planning: Planning support systems for the spatial planning of metropolitan landscapes", Wageningen, 2009.

[10] C.V. Sager-Klauß, "Energetic Communities: Planning support for sustainable energy transition in small- and medium-sized communities". A+BE | Architecture and the Built Environment, 2016.

[11] E. Manzini, "Scenarios of sustainable ways of living", in Designing designers: Design for a local globalworld, Edizioni Poli.Design, Milan 2003.

[12] P.J.H. Schoemaker, "Forecasting and scenarios planning. The challenges of Uncertainty and Complexity", in Blackwell handbook of judgement and decision making, Blackwell Publishing, 2004.

[13] M. W. Mehaffy, "Urban form and Greenhouse Gas Emissions. Findings, strategies, and Design Decision Support Technologies", A+BE | Architecture and the Built Environment, 2015.

[14] J. D. Lemp, B. Zhou, K. M. Kockelman, and B. M. Parmenter, "Visioning versus Modeling: Analyzing the Land-Use-Transportation Futures of Urban Regions," J. Urban Plan. Dev., vol. 134, no. 3, pp. 97–109, Sep. 2008.

[15] Baudirektion Kanton Zürich, "Masterplan Hochschulgebiet Zürich-Zentrum September 2014". Zürich, Switzerland: Kanton Zürich, Baudirektion, 2014.

[16] A. Dimoudi and S. Zoras, "The Role of Buildings in Energy Systems BT - Energy Performance of Buildings: Energy Efficiency and Built Environment in Temperate Climates," S.-N. Boemi, O. Irulegi, and M. Santamouris, Eds. Cham: Springer International Publishing, 2016, pp. 37–62.

[17] P.W. G. Newman & J. R. Kenworthy, "Gasoline Consumption and Cities",Journal of the American Planning Association, 55:1, 24-37, 1989.

[18] L. Frank, & G. Pivo, "Relationships between land use and travel behavior in the Puget Sound Region", Washington State Transportation Center, Seattle, 1994.

[19] R. Cervero, "Mixed land-uses and commuting: Evidence from the American housing survey", Transportation Research Part A: Policy and Practice, vol. 30, no. 5 PART A, pp. 361–377, 1996.

[20] D.A. Badoe & E. J. Miller, "Transportation–land-use interaction: empirical findings in North America, and their implications for modeling", Transportation Research Part D: Transport and Environment, vol. 5, no. 4, pp. 235-263, 2000.

[21] R. Cervero, "Land-use mixing and suburban mobility", Transportation Quarterly, vol. 42, no. 3, pp. 429-446, 1988.

[22] G. Barrett, M. Jenks, E. Burton, and K. Williams, "The Transport Dimension, The Compact City: A Sustainable Urban Form", E&FN Spon Publishers, London and New York, pp. 171–180, 1996.

3.

Dynamic building energy demand model

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Contents:

Summary

A dynamic energy demand model for the Hochschulquartier was developed in order to analyze the demands of the area for the four Spacergy scenarios. The work was carried out in the City Energy Analyst (CEA), a computational framework for the analysis and optimization of energy systems in neighborhoods and city districts. CEA comprises a collection of physical models for the simulation of energy demands and supply in the area of study as well as statistical databases containing building properties for typical archetypal buildings as well as operating parameters and schedules.

The results for two different models are presented and discussed. The first one is the Status Quo, that is, the area at the time of publication of the new Masterplan for the area, 2014. The necessary information about 3D geometry, materials, occupancy and mechanical components was obtained from GIS data, owner information and the archetype database. Data on energy-relevant retrofits for the main building components was scarce and thus estimated. The second model present corresponds to the Spacergy Baseline scenario, which is roughly based on the 2014 Masterplan for the area.

The results show that the demand for heating in the Baseline is significantly reduced in spite of the increase in floor space due to the construction of highly-insulated buildings, but the demands for electricity and cooling increase with increased usable floor space. The University Hospital and ETH Zürich are the largest consumers for both the Status Quo and Baseline scenario due to their large built areas and highly energy-intensive functions. The University of Zurich's demands are much lower, but increase in the Baseline scenario due to its increased usable floor space in this scenario. Other buildings in the area hosting complementary functions such as residential, gym, and restaurants have a comparatively much smaller impact on the demands in the area.

Due to the increase in energy efficiency in the buildings in the area and the introduction of low emission cooling infrastructure, the overall performance of the area in the Baseline scenario is better than in the Status Quo. Nevertheless, 2000 Watt Society targets are not met, and hence further proposals need to be made to reduce the operating emissions and primary energy demand of the area in order to meet this goal.

3.1. Introduction

3.1.1. Background

Scenario tools are often used in urban planning and design, in circumstances where Cities represent the largest source of resource and energy consumption in the world, with more than 70% of global energy demand and 40 to 50% of greenhouse gas emissions attributed to urban areas [1]. Furthermore, more than half the global population currently lives in cities and is expected to keep growing, with two-thirds of world population expected to be urban by 2050 [2]. As such, the development of sustainable urban areas will be a major challenge on the road to drastically reducing global CO2 emissions.

Within cities, the building sector is a major energy consumer, with heating and electricity consumption accounting for 36% of global CO^2 emissions worldwide [3]. In London, for example, residential and commercial buildings are responsible for 35% and 26% of energy consumption, respectively [4]. In this context, assessing measures on an urban scale becomes increasingly important. From an energy planning standpoint, the urban and neighborhood scales are particularly interesting, as solutions in this size are large enough to have a major impact while also being small enough to allow the development of realistic plans [5]. Furthermore, interconnecting buildings through district- and neighborhood-scale energy systems provides significant advantages and opportunities to optimize buildings' operation through the exploitation of synergies between buildings with different uses and demand profiles. In this context, assessing measures on an urban scale becomes increasingly important.

3.1.2. District-scale building energy demand modeling

Building energy simulation has been a topic of interest for over 50 years now, with a multiplicity of commercially-available tools that have become an integral part of practice in building energy performance. Crawley et al. [6] give a detailed review of existing tools and methods for this purpose. However, when scaling up from the building to the urban level, complex interactions between the components of the urban system arise, such that urban areas cannot be simply analyzed as an aggregation of single buildings by implementing traditional building energy modeling methods [7]. Due to this, the past decade has seen the development of various models and tools specifically designed for the assessment of building energy demand and supply at the district to urban scale [8].

Urban-scale energy models can generally be characterized as either top-down or bottom-up, depending on their scopes, inputs and calculation methods [9]. Top-down models are based on the analysis of an entire area based on macroeconomic variables and increasingly subdividing the stock into smaller subsections. The main advantage of this type of model is their reliance on fairly simple and widely available inputs. This advantage, however, also implies that the results provided are relatively simple: such models do not distinguish between individual end uses and, since they are based on historical data, they cannot be used as predictive tools for future developments. Thus, these models are not capable of comparing the impact of different individual measures on the future developments in an area.

Bottom-up models, on the contrary, are based on the analysis of the area by extrapolating from the analysis of various end uses, individual buildings or groups of buildings. Such models include statistical models and analytical (or engineering) models. Statistical models are based on the analysis of historical data to predict energy demand in the area. Their main advantages are their robustness and simple inputs as well as their capability to account for occupant behavior [10]. However, their simplified nature again makes it difficult to assess concrete measures for an area. Analytical models, on the other hand, are based on physical calculations based on buildings' characteristics and thus provide detailed results and a robust tool to assess various alternatives. However, the large amounts of data required can make them impractical. In order to overcome these methodologies' drawbacks, hybrid methods based on the combination of statistical data with detailed models have gained significant interest [5, 11, 12].

A general review of top-down and bottom-up building energy models and assessments was carried out by Bourdic and Salat [7], who characterized existing tools into the following categories: agent-based, economic, energy environment, and morphological. In particular, they recognize morphological models as the only type of analyses that are able to assess the effects of urban form on an area's energy demand, though the accuracy obtained through the aggregation methodologies used is questioned. Likewise, agent-based models are pointed out as the only ones able to reproduce occupant behavior, but the large amounts of data required and the inaccuracies generated by the aggregation of data from the individual to the urban scale is described as a structural shortcoming of the method. The authors stress that while a variety of methodologies exist based on sound technical and scientific basis, none of them is capable of encompassing the entire issue at hand. Therefore, they conclude, it is necessary to foster transversal approaches that integrate the various perspectives these tools provide.

Reinhart and Cerezo Davila [12] presented a summary of available urban building energy modeling (UBEM) approaches. They primarily focused on bottom-up and hybrid approaches based on the development of statistical building archetypes to characterize an urban building stock. By thus simplifying the variety of buildings in an area, the data collection effort is reduced while maintaining the granularity provided by analytical models. However, they concluded that the key challenge to urban building energy models is precisely the definition of appropriate archetypes to reliably represent the building stock. They furthermore stress the importance of incorporating the impact of occupants' behavior on an area's demand, which only one model in their sample [13] was able to do. The authors point out agent-based modeling as a particularly promising solution for this challenge.

From the energy supply perspective, a full review of existing modeling approaches and tools was carried out by Allegrini et al. [14]. While their review focuses on the simulation of district energy systems, renewable energy sources and urban microclimate, they also provide a comprehensive comparison of existing tools' modeling capabilities and level of detail for both energy systems and buildings as well as their incorporation of spatial and transport considerations.

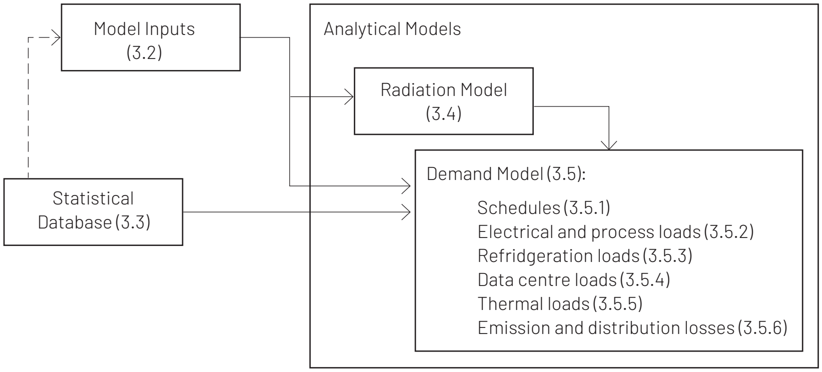

FIG. 3.1 CEA modelling structure and components including section number where each is described

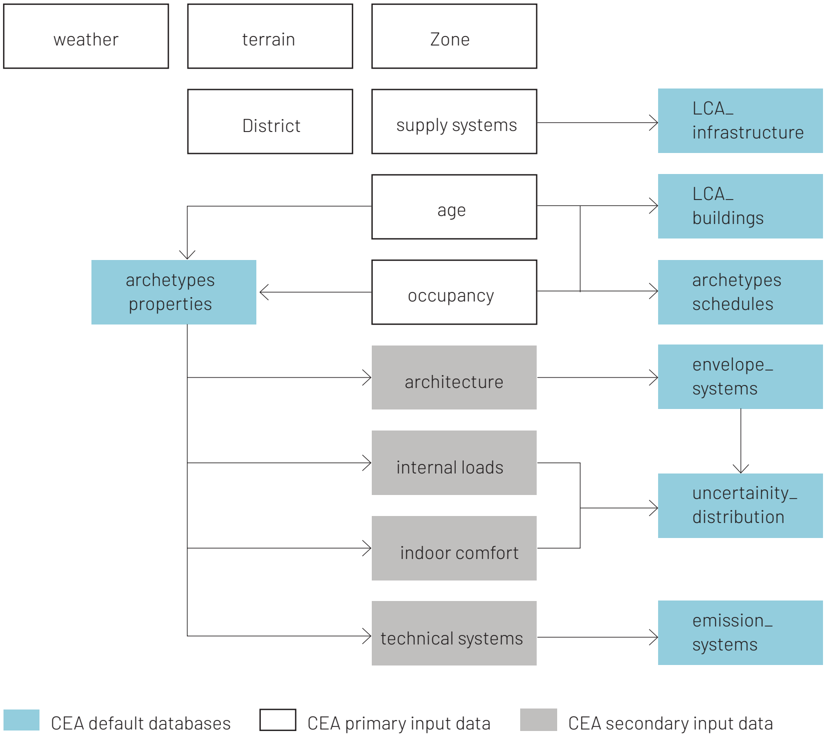

FIG. 3.2 CEA statistical databases, primary input data and secondary input data [17]

3.2. Energy demand modeling on the City Energy Analyst (CEA)

3.2.1. City Energy Analyst (CEA)

As a hybrid model, CEA consists of two main components: a set of physical models for energy demand and supply simulation, and a statistical database that allows the number of inputs to be reduced when detailed information is unavailable. The overall model structure and the components of each sub-model in CEA are shown in Figure 3.1. Each of these components are described in further detail in the next sections.

3.2.2. Model Inputs

In order to run a simulation in CEA, a number of inputs are required from the user. These can be classified as primary and secondary inputs. These inputs and their interdependencies are shown in Figure 3.2. Primary inputs are those which need to be specified by the user, namely:

1. terrain (in tiff format): a digital elevation model of the case study area;
2. weather (in epw format): a weather file for the area being analyzed;
3. zone (in shp format): the geometry of the buildings in the zone of study, that is the ground floor geometry, number of floors above and below ground, and building height below and above ground;
4. district (in shp format): the geometry of the surrounding buildings in the district, specified likewise;
5. age (in dbf format): the age of each building as well as year of renovation of the building envelope and technical systems;
6. occupancy (in dbf format): the percentage of the net floor area of each building that corresponds to each building function (such as RESTAURANT, OFFICE, or SCHOOL).

Secondary inputs to CEA are information about the buildings in the area that should ideally be provided the user but can be completed by the statistical database where precise information about the buildings is unavailable. These are:

1 architecture (in dbf format), which specifies for each building:
  - window-to-wall ratio in each cardinal direction
  - construction materials and shading
  - shares of the gross floor area that is occupied, heated and electrified

2 indoor comfort (in dbf format), which specifies for each building:
  - heating and cooling set point temperatures
  - heating and cooling set back temperatures
  - ventilation rate required in each building
  - minimum and maximum relative humidity in each building

3 internal loads (in dbf format), which specifies for each building:
  - the demand for hot water and tap water per building occupant;
  - the humidity gains per building occupant;
  - the sensible heat gains per building occupant;
  - the electricity demands per m^2 for appliances, lighting, and data centers;
  - the demand per m^2 for process heating and electricity;
  - the demand per m^2 of refrigeration for cool rooms.

4 supply systems (in dbf format): the types of systems used to generate space heating and cooling, domestic hot water, and electricity at the building level.

5 technical systems (in dbf format): the types of systems used to deliver space heating and cooling, domestic hot water and ventilation to the rooms in the building, and the type of controls for their operation.

When assessing large districts, collecting information at this level of detail can be an onerous or impossible task. Thus, these can be extracted from the CEA archetypes database, described as part of the statistical database of CEA in the next section.

3.2.3. CEA Statistical Database

In order to simplify user inputs and to provide information for the physical models in CEA, the software includes a set of statistical databases to complement the bottom-up simulation engine. These are based on the definition of a set of building archetypes that define typical construction and operation parameters for each building function. The software currently includes databases for the two main contexts it has been developed in, namely Switzerland and Singapore. The information included in this database includes construction properties, such as typical thermal properties of the building envelope, window-to-wall ratios, airtightness and technical systems by building function, construction year and renovation year [5]. They also include typical indoor comfort parameters for building operation, internal loads and occupant schedules based on Swiss norms [18].

In order to compare the environmental impact of building and energy infrastructure measures, the software furthermore includes embodied energy and CO^2 emissions for the various different components of each building archetype [19] as well as for different energy systems and energy sources, which are taken from standard values for the Swiss context [20]. In addition to these databases, CEA also includes technology databases with information about system performance, operating parameters and energy costs [16] as well as uncertainty distributions used during sensitivity analysis and calibration [21]. Since these databases do not affect the CEA demand calculations and are only used in other modules, these are not described any further here. Once the case study is well-defined and all input parameters are ready, the simulation proper can be started. First the radiation model needs to be run, since it is a prerequisite to the demand model, and subsequently the demand model, which includes a variety of sub-models, is initiated.

3.2.4. Radiation Model

The CEA includes an engine to calculate the incident solar radiation in buildings [22]. It accounts for both vertical and horizontal surfaces, material typologies, overshading, terrain topography and reflections. The urban solar radiation tool creates 3D representations of the geometry of buildings out of meta information about the the size of windows, height, and number of floors in buildings [22]. Each surface in the 3D representation is subdivided in a grid whose dimensions can be selected by the user, the default grid size for one sensor point being 5m x 5m [23]. It is worth noting that although there is no limitation to the grid size in the radiation grid, the increase in number of measurement points or size of the study area will result in higher computational time. Reflectivity values for the topography layer are taken into account, a default reflectivity value of 0.2 is used in the CEA [23]. The calculation is performed at the centroid of every subdivision for every hour of the year.

The calculation engine is based on the open source software DAYSIM [24], a validated radiation model for daylighting analysis. It considers only short-wave radiation, which means that model surfaces only reflect light, but do not absorb energy. Therefore, DAYSIM cannot accurately represent environmental effects such as Urban Heat Island, unless it is coupled with a thermal outdoor model, which in turn can result in a more accurate demand modelling and outdoor comfort assessment [23]. A sensitivity analysis at the urban scale of DAYSIM was carried out in the context of its implementation in CEA as well [25]. This feature serves as a prerequisite to conducting any further analysis. The main outputs are hourly time series data of global insolation for discrete surfaces in buildings as defined by the user. The results are subsequently used in the demand model to determine the hourly balance of thermal energy in buildings, as described in section 'Thermal Loads'. From the energy supply side, the tool is also used to determine the potential for generation of solar energy in buildings.

3.2.5. Demand Model

The CEA demand model involves the calculation of all energy flows (heating, cooling, electricity) from the building meter (i.e., from the district-scale utility) to the end user. Figure 3.3 shows the full chain of the energy demand model in CEA. In reality, the calculation takes place in the opposite direction: first the heat gains (due to solar radiation Φ_{sol}, due to occupant presence Φ_{occ} and due to lighting and appliances $\Phi_{app/lig}$) as well as transmission losses through the envelope (Φ_T) and through the ventilation (Φ_{ve}) are calculated at the room / end user level, then the demands for hot water (Φ_{ww}), space heating (Φ_{hs}) and cooling (Φ_{cs}) are calculated given the aforementioned boundary conditions. Finally, distribution losses for each of these thermal demands as well as auxiliary electricity needs to operate building systems such as fans and pumps are calculated, which provide the final, building-level demand for heating, cooling and electricity from the utility. In the next sections, each of these modules is described in further detail.

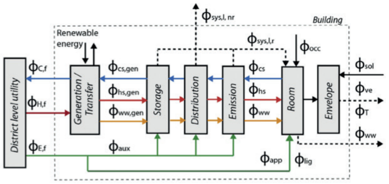

FIG. 3.3 Semplified heating chain showing the subsystems and heat flows of the heating, cooling and electricity supply chains in the buildings as well as solar and internal gains, and ventilation and trasmission losses [5]

Occupant schedules

CEA includes deterministic schedules for 18 building functions (such as single- and multi-family residential, once, school, etc.), which, as previously mentioned, mainly arise from SIA standard 2024 [18]. At the beginning of the simulation for each building, yearly schedules of occupant presence and associated indoor comfort parameters, as well as schedules of electricity and hot water consumption are calculated as a simple average as follows:

$$N_{people}(t) = \sum_i P_{occupancy,i}(t) \text{ x } P_{monthly,i}(t) \text{ x } Occ_i \text{ x } Share_i \,.\, NFA \tag{1}$$

where N_{people} is the number of people in the building at time t, $P_{occupancy,i}$ and $P_{monthly,i}$ are the daily and monthly probabilities of occupant presence for building function i, Occ_i is the occupant density (in people per m^2) of i, $Share_i$ is the percentage of the building's net floor area that corresponds to function i and NFA is the building's net floor area. The electricity demand for lighting is calculated in a similar fashion:

$$E_l(t) = \sum_i P_{al,i}(t) \text{ x } P_{monthly,i}(t) \text{ x } e_{l,i} \text{ x } Share_i \text{ x } NFA \tag{2}$$

where E_l is the demand for lighting, $P_{al,i}$ is the probability of lighting and appliance use at time t and $e_{l,i}$ is the demand for lighting (in W/m^2) for the given building function i. The demand for appliances E_a is calculated the same way. Finally, the deterministic schedules for hot water consumption show the percentage of the daily hot water consumption (in liters per person per day) that occurs at time time t. Thus, the demand for hot water is calculated as follows:

$$V_{dhw}(t) = \sum_i P_{dhw,i}(t) \text{ x } P_{monthly,i}(t) \text{ x } d_{dhw,i} \text{ x } Occ_i \text{ x } Share_i \text{ x } NFA \tag{3}$$

where V_{dhw} and $d_{dhw,i}$ are the demand for hot water at time t (in liters) and the daily demand per person for building function i (in liters per person per day). Likewise, schedules are then generated for occupant-related indoor comfort parameters (such as ventilation, which is defined in terms of liters per person per second). These schedules are then passed on to the thermal loads module of CEA, where they represent either demands to be satisfied for the building in question or internal gains that need to be accounted for in the thermal model.

In addition to this deterministic model, CEA includes the option of using the occupant presence model of Page et al. [26] as an alternative occupant modeling option in the tool. In this model, each occupant's presence is modeled as a two-state Markov process. Transition probabilities between the states "absence" (state 0) and "presence" (state 1) are defined at each hour of the year for each user in the area. For an occupant in a space with function i, the probability of an occupant being in the space in question $P_i(t)$ is taken from the deterministic schedule discussed above as follows:

4 $$P_i(t) = P_{occupancy,i}(t) \text{ x } P_{monthly,i}(t)$$

At each time step, the transition probabilities between these states are calculated as follows:

5 $$T_{11}(t) = \frac{(P(t)-^1)}{P(t)} \text{ x } T_{01}(t) + \frac{P(t+^1)}{P(t)}$$

6 $$T_{01}(t) = \frac{(\mu-^1)}{\mu} \text{ x } P(t) + P(t+1)$$

where $T_{11}(t)$ is the probability of the occupant staying in the room at time $t+1$ given that the occupant was present at time t and $T_{01}(t)$ is the probability of the occupant arriving at time $t+1$ given that they were not present at the previous time step. μ is a so-called "parameter of mobility", assumed by the authors to be constant for simplicity and defined as follows:

7 $$\mu = \frac{T_{01}(t) + T_{10}(t)}{T_{00}(t) + T_{11}(t)}$$

Since $T_{00}(t) + T_{01}(t) = 1$ and $T_{10}(t) + T_{11}(t) = 1$, the only parameter that needs to be estimated is μ, which we randomly draw for each occupant from a normal distribution.

Electrical loads and process heating

Once the schedules for the year have been defined, the energy of each building can be calculated. Since the electrical demands strongly depend on the electricity schedules discussed in the previous section, demands for lighting (E_l), appliances (E_a) and electrical processes (E_{pro}) are simply calculated as in Equation (2). Process heating $Q_{h,pro}$ also depends on the process schedule and is therefore calculated the same way.

Refrigeration loads

The refrigeration loads are again dependent on the corresponding schedule for cool room and are thus calculated as discussed in the previous section. In other to furthermore calculate the quality of the energy that needs to be supplied, the required capacity mass flow rate for refrigeration $m_{re}c_p$ is calculated as follows:

$$m_{re}\ x\ c_p\ (t)=\frac{Q_{c,re}\ (t)}{T_{re}-T_{sup}} \tag{8}$$

where $Q_{c,re}$ is the refrigeration cooling load at the given time step and T_{sup} and T_{re} are the supply and return temperatures, which are respectively set to 1°C and 5°C. Finally, if cooling is supplied by a chiller the electricity demand for refrigeration E_{re} is calculated with a simple heat pump model [27]:

$$E_{re}\ (t) = \frac{Q_{chiller}\ (t)}{COP} = \frac{m_{chiller}\ x\ c_p\ (t)\ x\ (T_{re}-T_{sup})}{\eta_{chiller}\ x\ \frac{T_{evap}\ (t)}{T_{cond}-T_{evap}\ (t)}} \tag{9}$$

where $Q_{chiller}$ is the refrigeration load provided by the chiller, which is equal to the capacity mass flow rate of the chiller multiplied by the change in temperature in the chiller, and the *COP* is the coefficient of performance of the system, which is calculated based on the chiller efficiency $\eta_{chiller}$ and the evaporator temperature T_{evap} (which is equal to the temperature of outdoor air for an air-based system) and condenser temperature T_{cond} (which assumed to be approximately the same as the supply temperature of the chiller, 1°C).

Data center loads

The electricity demand for data centers E_d is again schedule-dependent and is thus calculated the same way as described in section 'Electrical loads and process heating' . However, due to the high electrical loads in them, data centers furthermore require cooling. The amount of cooling required Q_{cre} is assumed to be equal to 90% of the electrical demand, and the capacity mass flow rate is calculated as in Equation (8) for an assumed supply temperature of 7°C and return temperature of 15°C.

Thermal loads

The thermal loads in a building are strongly dependent on the heat gains from solar irradiation as well as the internal gains from occupant activities, electrical demands, etc. Therefore, only after all of the previously-discussed modules can the thermal loads in the building finally be calculated.

The CEA thermal loads model is based on a simplified resistance-capacitance model as described in ISO [28] and SIA standards [29]. The CEA model is an adaptation of the simple hourly method described in SIA 2044 [29]. Each building in the area is represented by a single thermal zone, meaning that the building interior is assumed to be well-mixed with no effects of partitions, occupant distribution within the building or localized temperature differences. The building material properties, solar and internal gains are then represented as resistances and capacitances in an electrical circuit, as shown in Figure 3.4. In this system is composed of four nodes representing the outdoor air (which is at temperature θ_e), the indoor air (which is at temperature θ_a), a surface node (which is at temperature θ_c), and a node in the building's thermal mass (which is at temperature θ_m). These nodes are connected by resistances representing building materials and systems, whose heat transfer coefficients are shown and described in the figure. The solar gains and the internal gains in the building are distributed among the three indoor nodes. The building also has an effective mass area and an internal heat capacity, which represents the thermal inertia in the building thermal mass. The thermal mass of the building is given by the type of construction. In CEA, buildings can be either lightweight, medium weight, or heavyweight, and consequently:

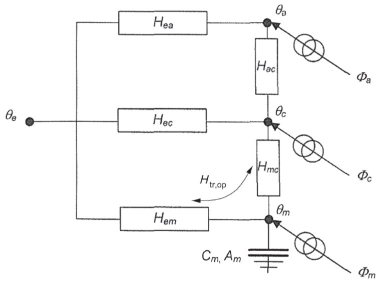

FIG. 3.4 Figure 5 Resistance-capacitance (RC) model used in CEA (adapted from [29]). θ_e, θ_a, θ_c, and θ_m are the temperatures of the exterior air, indoor air, surface node, and building thermal mass, respectively. H_{ea} is the air heat flow coefficient of the ventilation systems, whereas H_{ec} and H_{em} are the transmission heat coefficients lightweight and heavyweight building materials, respectively, and the heat transfer coefficients between the air and surface node, and between the surface node and the thermal mass are H_{ac} and H_{mc}, respectively. The internal and solar gains in the air, surface and thermal mass nodes are Φ_a, Φ_c and Φ_m, respectively. Finally, C_m and A_m are the internal heat capacity and effective mass area of the building.

10 $$C_m = \begin{cases} A_f \text{ x } 110 \text{ kJ/K for lightweight construction} \\ A_f \text{ x } 165 \text{ kJ/K for medium construction} \\ A_f \text{ x } 300 \text{ kJ/K for heavyweight construction} \end{cases}$$

11 $$A_m = \begin{cases} A_f \text{ x } 2.5 \text{ for lightweight construction} \\ A_f \text{ x } 2.5 \text{ for medium construction} \\ A_f \text{ x } 3.2 \text{ for heavyweight construction} \end{cases}$$

where A_f is the conditioned area of the building.

The heat transfer coefficients are calculated according to [29]:

12 $$H_{ec} = A_{win} \text{ x } U_{win}$$

13 $$H_{ac} = A_t \text{ x } 3.45 \text{ W/(m}^2\text{K)}$$

where A_{win} and U_{win} are area and U-value of the windows, and $A_t = 4.5\, A_f$ is the area of all surfaces facing the room.

14 $$H_{ea} = (m_{ve,mech} + m_{ve,w} + m_{ve,inf}) \text{ x } c_{p,air}$$

where $m_{ve,mech}$, $m_{ve,w}$, $m_{ve,inf}$ are the mass flow rates of air from mechanical ventilation, from window openings and from infiltration through the building envelope, and $c_{p,air}$ is the specific heat capacity of air. The total amount of air is calculated based on the number of people in the area and the amount of air to be supplied per person as discussed in section 'Model input'. The amount of air that needs to be supplied by either mechanical or natural ventilation is then calculated as the difference between the required ventilation and the infiltration rate, which in turn can be calculated with a static model based on airtightness or a dynamic model [30]. The static model calculates the volume of air from infiltration as follows:

15 $$q_{V,inf} = 0.5 \times V_{zone}\, n50 \times (1/10)^{(2/3)}$$

where V_{zone} is the volume of the thermal zone (i.e., the volume of the building) and $n50$ is air change rate through the envelope at a pressure of 50 Pa, which in CEA is assigned based on the air tightness of the building as specified by the user (from Very leaky to Very tight). The dynamic model, on the other hand, takes a longer time to model because it is calculated iteratively, but it is based on physical models. The calculation procedure is based on the formulation of all air volume flows into and out of a zone, including infiltration, as a function of the unknown zone reference pressure and calculating air flows through leakages (infiltration), as all other air flows (mechanical and window ventilation) are assumed to be balanced and do therefore not have an impact on the zone pressure [30]. Based on standards [31, 32] standard leakage paths are defined and the leakage through these paths is calculated as a function of the wind speed on site and outdoor temperature (from the weather file), wind pressure coefficient, and total leakage coefficient:

16 $$C_{lea} = V_{zone}\, n50\, (1/50_{Pa})^{(2/3)}$$

The steady state thermal transmission coefficient through opaque surfaces $H_{tr,op}$ is calculated as the sum of the transmission coefficients through opaque building components:

17 $$H_{tr,op} = A_{wall,ag} \times U_{wall} + A_{roof} \times U_{roof} + 0.7\, A_{op,bg} \times U_{basement}$$

The coupling conductance between the thermal mass and surface nodes H_{mc} and between the thermal mass and the exterior environment H_{em} are defined as:

18 $$H_{mc} = H_{ic} \times A_m$$

19 $$H_{em} = \frac{1}{\frac{1}{H_{tr,op}} - \frac{1}{H_{mc}}}$$

where H_{ic} is the heat transfer coefficient of all surfaces facing the room (9.1 W/m^{2}K). The solar and internal gains are distributed among the three indoor nodes as follows:

20 $$\Phi_a = 0.5 \times \Phi_i + f_{HC,cv} \times \Phi_{HC}$$

$$\Phi_c = \frac{(A_t - A_m - (H_{ec}/H_{ic})}{A_t} \; [0.5 \text{ x } \Phi_i + (1 - f_{HC,cv}) \text{ x } \Phi_{HC}] + \frac{A_t - A_m - A_w - (H_{ec}/H_{ic})}{A_t - A_w} \text{ x } \Phi_{HC} \tag{21}$$

$$\Phi_m = \frac{A_m}{A_t} [0.5 \text{ x } \Phi_i + (1 - f_{HC,cv}) \, . \, \Phi_{HC}] \tag{22}$$

where Φ_i are the internal gains from occupants and electrical devices, Φ_{HC} is the heating or cooling supplied into the room and $f_{HC,cv}$ is the convective fraction of the heating / cooling emission system (1 for fully air-based systems, 0.5 for radiant floor heating or chilled ceiling cooling, 0.1 for chilled floor cooling or radiant ceiling heating).

The internal gains due to lighting, appliances and electrical processes are assumed to be equal to 90% of the electrical power delivered, as calculated in section 'Electrical loads and process heating'. The interior gains are calculated from the number of people and the sensible heat gains per person in the room. Thus:

$$\Phi_i(t) = 0.9 \text{ x } \big(E_a(t) + E_l(t) + E_{pro}(t)\big) + N_{people}(t) \text{ x } Q_s \tag{23}$$

where Q_s are the sensible heat gains (in W/p) specified in the user inputs.

The solar gains are calculated from the incident solar radiation on walls, roof and windows ($I_{sol,wall}$, $I_{sol,roof}$ **and** $I_{sol,win}$) taken from the solar radiation model described in section 'Radiation Model'. At each time step, the net sensible heat gain in the building $\Phi_{sol,net}$ is calculated according to ISO 13790 [28] as follows:

$$\Phi_S(t) = \textstyle\sum_k I_{sol,k}(t) \text{ x } a_k \text{ x } RSE \text{ x } U_k - \Big(RSE \text{ x } U_k \Big[4 \text{ x } e_k \text{ x } \sigma \text{ x } \Big(\frac{\theta_{sky}(t) + \theta_c(t-1)}{2}\Big)^3\Big] \text{ x } A_k [\theta_e(t) - \theta_{sky}(t)]\Big) \tag{24}$$

The first term represents the gross solar radiation on the surface, where k is each of the aforementioned building surfaces, a_k is the absorptivity of the building material, RSE is the thermal resistance of external surfaces (equal to 0.04 according to ISO 6946), and U_k is the heat transfer coefficient of the building material. The second term represents the incident solar radiation that is re-irradiated to the sky, where e_k is the emissivity of the building material, σ is the Stefan-Boltzmann constant (5.67×10^{-8} Wm^{-2}K^{-4}), θ_{sky} is the sky temperature (from the weather file), and A_k is the area of the building component.

The temperature of each node is calculated by solving the analogous circuit defined above, which after reorganizing the equations somewhat looks as follows:

$$\theta_a(t) = \frac{H_{ac} \text{ x } \theta_c + H_{ea} \text{ x } \theta_e(t) + \Phi_a(t)}{H_{ac} + H_{ea}} \tag{25}$$

26 $$\theta_c (t) = \frac{H_{mc} \Big(\theta_m (t) + \theta_m (t\text{-}^1)\Big)/^2 + (H_{ec}+H_1)\ x\ \theta_e (t) + \Big(H_1/H_{ea}\Big) \ .\ \Phi_a (t) + \Phi_c (t)}{(H_{mc}+ H_{ec} + H_1)}$$

27 $$\theta_m (t) = \frac{\theta_m (t\text{-}^1)[C_m{}^{-0.5}\ x\ (H_3+H_{em})] + \Phi_{m,tot} (t)}{(C_m + 0.5\ (H_3+H_{em})}$$

28 $$\Phi_{m,tot} (t) = \Phi_m(t) + H_{em}\ x\theta_e + \frac{H_3 [\Phi_c (t) + (H_{ec}+H_1)\ \theta_e + H_1/H_{ea}\ x\ \Phi_a (t)]}{H_2}$$

29 $H_1 = (H_{ea}{}^{-1} + H_{ac}{}^{-1})^{-1}$ 30 $H_2 = H_1 + H_{ec}$ 31 $H_3 = (H_2{}^{-1} + H_{mc}{}^{-1})^{-1}$

Given the above set of equations, the only missing parameter is the actual heating or cooling supplied to the thermal zone, Φ_{HC}. If the day of the year is within the heating or cooling season (as defined in the system controls database in CEA), this is solved following the Crank-Nicholson procedure, that is:

1 Check if heating or cooling is needed:
- Set $\Phi_{HC,nd} = 0$ and calculate the node temperatures. Name the resulting θ_a as $\theta_{a,0}$
- If $\theta_{setpoint,H} \leq \theta_{a,0} \leq \theta_{setpoint,C}$, set $\Phi_{HC} = 0$ and $\theta_a = \theta_{a,0}$; if not, apply step 2.

2 Choose the set point and calculate the heating or cooling need:
- If $\theta_{a,0} \leq \theta_{setpoint,C}$, take $\theta_{a,set} = \theta_{setpoint,C}$, if $\theta_{setpoint,H} \leq \theta_{a,0}$ set $\theta_{a,set} = \theta_{setpoint,H}$
- Set $\Phi_{HC,10} = 10 \cdot A_f$ and calculate the temperatures of the nodes. Name the resulting θ_a as $\theta_{a,10}$.
- Calculate the unrestricted heated or cooling needed to reach the set point $\Phi_{HC,nd,un}$:

  $$\Phi_{HC,nd,un} = \Phi_{HC,nd,10}\ \frac{\theta_{a,set} - \theta_{a,0}}{\theta_{a,10} - \theta_{a,0}}$$

3 Check if the installed heating or cooling power (which is taken from the CEA technology database for each building's heating or cooling technologies) is enough to meet the demand. That is, if $\Phi_{C,max} \leq \Phi_{HC,nd,un} \leq \Phi_{H,max}$, $\Phi_{HC} = \Phi_{HC,nd,un}$ and $\theta_a = \theta_{a,set}$. Otherwise, continue to step 4.

4 Calculate the internal temperature for the underheated or under cooled case
- If $\Phi_{HC,nd,un}$ is positive, set $\Phi_{HC} = \Phi_{H,max}$; if it is negative, set $\Phi_{HC} = \Phi_{C,max}$
- Calculate θ_a for the available heating or cooling power.

If the building has non air-based heating and cooling distribution systems (such as radiators, radiant floor heating or chilled ceiling cooling), the sensible heat loads are equal to Φ_{HC} as calculated above. That is, if Φ_{HC} is greater than 0, then the sensible space heating demand is $Q_{hs,sen} = \Phi_{HC}$, otherwise if Φ_{HC} is less than 0, there is a sensible space cooling demand $Q_{cs,sen} = \Phi_{HC}$. However, in buildings with air-based systems (such as central air conditioning), in addition to these sensible loads the latent loads, i.e., the loads for humidifying or dehumidifying air in buildings, needs to be calculated. For buildings with air-based heating or cooling distribution systems or with mechanical ventilation with humidity control, the sensible load calculation in CEA is followed by the associated latent loads. This is done following ISO Standard 52016-1 [33].

First, the latent and sensible heat loads in the air handling unit for the required ventilation rate in the building are calculated as follows:

32 $$Q_{hs,lat,ahu} = m_{ve,mech} \ x \ c_{p,air} \ x \ (T_{sup,ahu} - T_{ve,mech})$$

33 $$Q_{hs,sen,ahu} = m_{ve,mech} \ (x_{sup,ahu} - x_{ve,mech}) \ . \ h_{we}$$

where mve,mech is the mechanical ventilation mass flow rate as discussed above, hwe is the latent heat of vaporization of water (2466 kJ/kg) and $x_{ve,mech}$ is the moisture content in the ventilation airflows (equal to the moisture content in outdoor air, obtained from the relative humidity from the weather file). $x_{sup,ahu}$ is the supply moisture content, which is the lowest value of the moisture content of outdoor air or the moisture content in saturated air at the supply temperature of the coil in the air handling unit. Thus, this difference in moisture content is equal to the amount of moisture that needs to be added or removed from the air supplied to the building.

If the sensible heat demand according to the R-C model is lower than the sensible heating provided by the air handling unit (i.e., if $\Phi_{HC} < Q_{hs,sen,ahu}$), the building is overheating, and thus the temperatures in the building need to be calculated again with $\Phi_{HC} = Q_{hs,sen,ahu}$. Otherwise, the additional sensible loads required in the building are supplied by air recirculation:

34 $$Q_{hs,sen,aru} (t) = \Phi_{HC} (t) - Q_{hs,sen,ahu} (t)$$

35 $$m_{ve,rec} (t) = \frac{Q_{hs,sen,ahu} (t)}{c_{p,air} \ . \ (T_{sup,aru} - T_{int} (t-1))}$$

where $Q_{hs,se,aru}$ is the sensible heating load from the air recovery unit, $m_{ve,rec}$ is the mass flow rate of air in the air recovery unit, $T_{sup,aru}$ is the supply temperature of the air recovery unit (from the CEA technology database), and $T_{int}(t-1)$ is the temperature in the building at the previous time step.

In addition to humidification or dehumidification in the air handling unit, buildings can have humidity controls, based on which indoor air may need to be treated if the moisture content exceeds the limits given in the user inputs (by default, in CEA the minimum relative humidity in buildings is 30% and the maximum is 70%). If a building were to exceed this control in either direction, an additional latent load for dehumidification would be added in a manner analogous to Equation (33). The associated electricity demand is calculated based on [34]:

36 $$E_{hs,lat,aux}(t) = m_{ve,rec} \times 15\ W/kg/h$$

Hence, the sensible and latent heating loads for buildings with air-based heat distribution are:

37 $$Q_{hs,sen}(t) = Q_{hs,sen,ahu}(t) + Q_{hs,sen,aru}(t)$$

38 $$Q_{hs,lat}(t) = Q_{hs,lat,ahu}(t) + Q_{hs,lat,aru}(t)$$

The sensible and latent cooling loads are calculated in a similar way, although since dehumidification is usually a bigger problem in cooling systems than humidification in heating systems, the calculation is somewhat more involved. In the Swiss context, however, centralized air-based heating and cooling systems are not predominant, hence the description of the dehumidification models in CEA is beyond the scope of this work package.

Emission and distribution losses

Finally, given the sensible and latent loads of the occupied spaces of the building, the losses during distribution of heating and cooling to the room and from the emission systems providing them can be calculated. This is done based on ISO Standard 15316 [35]. The emission system losses are as follows:

39 $$Q_{em,ls}(t) = Q_{hs/cs,sen}(t) \times \frac{(\Delta T_{Qhs/cs} + \Delta T_{cs/hs})}{(T_{int} + \Delta T_{Qhs/cs} + \Delta T_{cs/hs} - \theta_e)}$$

where $\Delta_{TQhs/cs}$ is the correction temperature of emission losses due to control system of heating/cooling system (equal to 1.2°C and -1.2°C, respectively) and $\Delta_{Ths/cs}$ is the correction temperature of emission losses due to type of heating or cooling system, which is obtained from the technologies database in CEA for each system.

The distribution losses are subsequently calculated based on the total loads (sensible, latent and emission losses). The length of the pipe in the building ***L*** is estimated based on the building size and the transmittance of the pipes ***Y*** is estimated based on the building age. The distribution losses for space heating and cooling are then estimated for each system as:

40 $$Q_{i,distrib,ls,j,k}(t) = \left(\frac{T_{sup,i,k}(t) + T_{re,i,k}(t)}{2} - \theta_e\right) \times \frac{Q_{i,k}(t) + Q_{em,ls,i,j,k}(t)}{(Q_{i,k}(t) + Q_{em,ls,i,j,k}(t))_{max}} \times L \times Y$$

where ***i*** is the type of energy service (space heating or cooling), ***j*** is the type of load (sensible or latent) and ***k*** is the type of system (air handling unit or air recirculation unit). The overall system loads (that is, end use energy plus emission and distribution losses) represent the amount heating $Q_{hs,sys}$ or cooling $Q_{cs,sys}$ that needs to be produced by the supply systems.

3.2.6. Auxiliary electricity loads

Having calculated all demands and losses in the building, the amount of electricity required to run the pumps and fans required to operate these systems is calculated. The auxiliary electricity for ventilation is simply:

41 $E_{aux,ve}(t) = P_{fan} \text{ x } (m_{ve,mech}(t) - m_{ve,rec}(t)) \text{ x } \rho_{air}$

where P_{fan} is the fan power, assumed to be 0.55 W/m3/h. The pumping power for heating and cooling distribution systems is

42 $E_{aux,i}(t) = P_{pu,i} \text{ x } (1.25 \text{ x } \sqrt{\frac{200}{P_{pu,i}}} \text{ x } fctr_i \text{ x } b)$

43 $fctr_i = \begin{cases} 1.05 \text{ if } i \text{ is } hs \\ 1.1 \text{ if } i \text{ is } cs \end{cases}$

44 $P_{pu,i} = \begin{cases} 0.2778 \text{ x } \Delta P_{des}\, qV_{des} \text{ if } Q_{i,sys}/Q_{i,sys,max} > 2/3 \\ 0.0102 \text{ x } \Delta P_{des}\, qV_{des} \text{ if } Q_{i,sys}/Q_{i,sys,max} < 2/3 \end{cases}$

45 $qV_{des} = \frac{Qi,sys}{(T_{sup,i} - T_{re,i}) \text{ x } c_{p,w}}$

Similarly to the thermal loads, then, the final electricity loads at the building systems side Esys are equal to the sum of the various end-use electricity demands plus the auxiliary loads:

46 $E_{sys} = E_a + E_l + E_{re} + E_d + E_{aux,ve} + E_{aux,hs} + E_{aux,cs}$

3.2.7. Model outputs

As a result, the CEA demand model produces hourly data for each building on the various energy loads in the building (as seen in Figure 3.3) as well as the operating parameters in the building such as the ventilation rates, mass flow rate of the building systems, operating temperatures, and indoor temperature and humidity and outdoor temperature. These are also aggregated on a yearly scale in order to produce the amount of energy required per building (in MWh) as well as the peak demands (in kW), which are useful for equipment sizing.

3.2.8. Limitations

As a simplified planning tool, the CEA demand model has a number of limitations compared to building-scale energy demand models that are more detailed but require substantially more computational power. The most obvious simplification is the treatment of building geometry, since buildings are modeled as simple extrusions of the ground floor below and above ground. Hence, complex geometries cannot be modeled in the tool. Likewise, a key limitation is the treatment of buildings as a single thermal zone, which makes it impossible to model buildings with different operational parameters in different part of the buildings or even with completely different building systems (e.g., a shopping mall with a residential tower on top). Furthermore, differences in indoor environment cannot be modeled as the air within the building is assumed to be perfectly mixed, thus it is impossible to assess the effects of building occupant densities and activities varying throughout the building. Localized climate effects such as solar irradiation affecting only one side of the building or façade temperatures being different in different cardinal directions can also not be modeled.

In general, occupants are modeled in an extremely simplified way, by which occupant presence is solely defined by the type of functions in the buildings and their associated schedules rather than on actual occupants' behavior in buildings. The fact that occupant, electricity and domestic hot water loads are represented by individual schedules that are not correlated further implies that occupants in the model are completely disassociated from the energy demands they generate. It was due to this that the stochastic modeling alternative was incorporated in the model in order to account for the effects of changes in occupant presence that cannot be controlled.

Likewise, the effect of weather conditions in urban areas cannot be modelled. CEA assumes a single weather file for the entire simulation, typically taken from a weather station in a relatively isolated location. Thus, the effect of urban microclimate such as the heat island effect cannot be analyzed in the model.

Due to these latter limitations, one of the goals of Spacergy has been to analyze means to integrate simulation tools in order to better represent the situation in the area under analysis. Namely, an occupant presence model is in development to couple the occupants in the building energy demand model with the agents in the transportation model, such that the activities that drive both systems are coupled [36]. Likewise, CEA has been coupled with microclimate simulation ENVImet in order to assess the effects of urban microclimate during extreme weather events [23].

3.3. Energy demand model of the Hochschulquartier

3.3.1. Case study description

The Hochschulquartier is a university district in the city center of Zurich, Switzerland. The area is home to the central campuses of ETH Zurich (ETH) and the University of Zurich (UZH) as well as the University Hospital Zurich (USZ) and a variety of secondary uses. The entire district is due for a major redevelopment in the next 30 years with a target of increasing the usable floor space in the area by 40% and turning the area into an internationally competitive location for knowledge and health [37].

From an energy planning standpoint, key challenges include the development of energy infrastructures that can supply highly energy-intensive functions such as hospital and research spaces through renewable resources in a dense historic area. The 2014 masterplan for the area [38] serves as the basis for the Spacergy Baseline scenario, which provides boundary conditions for the case study both in terms of urban form (building locations and dimensions) as well as in terms of construction (buildings require Minergie certification). In this work package, an energy model for the status quo (SQ) was first created and subsequently adapted to conform to the Spacergy Baseline scenario (BL).

3.3.2. Data sources

In order to build the model for the SQ, the primary inputs to CEA needed to be collected, and whenever possible complemented by the secondary inputs to the model. Information on the main function of each building, construction year and energy source for heating was obtained from the Federal Register of Buildings and Dwellings (Eidgenössiches Gebäude- und Wohnungsregister, GWR) [39]. This information was complemented with detailed functional distributions for each building defined based on information from each of the building owners whenever available. Building heights were taken from the city's 3D model [40]. Building materials and building operation parameters were assigned based on the CEA archetypes for each building function and construction year, while construction parameters such as window-to-wall ratios were estimated by visual analysis. A

FIG. 3.5 Visualizations of the CEA model for the Status Quo (top) and Baseline (bottom), orthographic (left) and perspective (right).

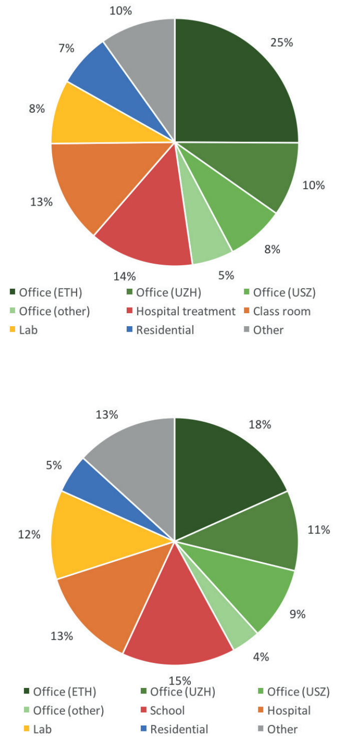

FIG. 3.6 Share of each function in the main usable area of all buildings in the area. The "Office" occupancy type includes all office spaces and workspaces in the universities, hospital, and any surrounding buildings, while "Hospital treatment" applies only to rooms in which treatment is being carried out. Building function "Other" includes exhibition spaces, workshops, retail, cool rooms and server rooms.

preliminary sensitivity analysis of the model of the Hochschulquartier [21] showed the importance of building operating parameters on the results of CEA, particularly for cooling. Thus, for buildings were the supply temperatures of the emissions systems were known (mainly ETH buildings), these were further included in the model. The demands for process heating, electricity and cooling were roughly estimated based on measured data and a previous report on the area [41]. In order to create the BL scenario, new geometries had to be drawn in place of the existing buildings slated to be demolished. This was done based on the 2014 plans for the area [37] and given somewhat more plausible geometries based on the models shown in the same report as well as in visualizations from the Cantonal Building Department [42]. These provide only one possible direction of development of the case study, and indeed later publications from the planners shows completely different building forms for the area [43]. Figure 3.5 show the geometries for the CEA models of both scenarios.

Regarding building functions, the masterplan for the area only defines which of the stakeholders will be located in which building, but it doesn't provide specific functions for them. In order to define building functional mixes comparable to the status quo, archetypal functional mixes were created for hospital buildings, research buildings, and lecture halls. These functional mixes were then assigned to each new building based on the planed function for them. Figure 3.6 shows the total functional mix for each of the two scenarios as defined in CEA. In spite of the increased usable floor space in the district for the stakeholders, the overall functional mix of the area is not greatly affected, as buildings were assumed to have similar functional mixes as current buildings. There is an overall increase in laboratory space due to the number of research facilities being built, and the secondary uses also increase due to the addition of public spaces (such as cafés or exhibition spaces) in each of the new buildings in the area.

Since it was decided during the Spacergy scenario definition [44] it was decided that only new buildings and buildings undergoing construction would be changed from one scenario to the next, the retrofit of historical buildings was not considered in the development of the BL scenario. For new buildings, building envelope properties were assigned according to the CEA archetypes database, which is designed to provide typical U-values for Minergie-certified buildings. The window to wall ratio was assumed to be 40% for all buildings. In terms of systems, since the Spacergy BL scenario assumes that the district cooling infrastructure being considered for the area [41] does indeed get built, all new buildings were assumed to have high-temperature cooling (chilled ceiling) and low-temperature heating (radiant floor) systems. All other systems parameters (e.g., ventilation rates, domestic hot water demand, etc.) were set according to the CEA archetype database.All simulations were carried out using the weather file for "typical" Zurich weather (10-year average) from Meteonorm [45]. In order to provide a more realistic building behavior in the Zurich context, the dynamic infiltration calculation described in section 3.4.5 was used. Likewise, in order to obtain more feasible distributions of occupants in the area, the stochastic model described in section 3.4.1 was used for all simulations.

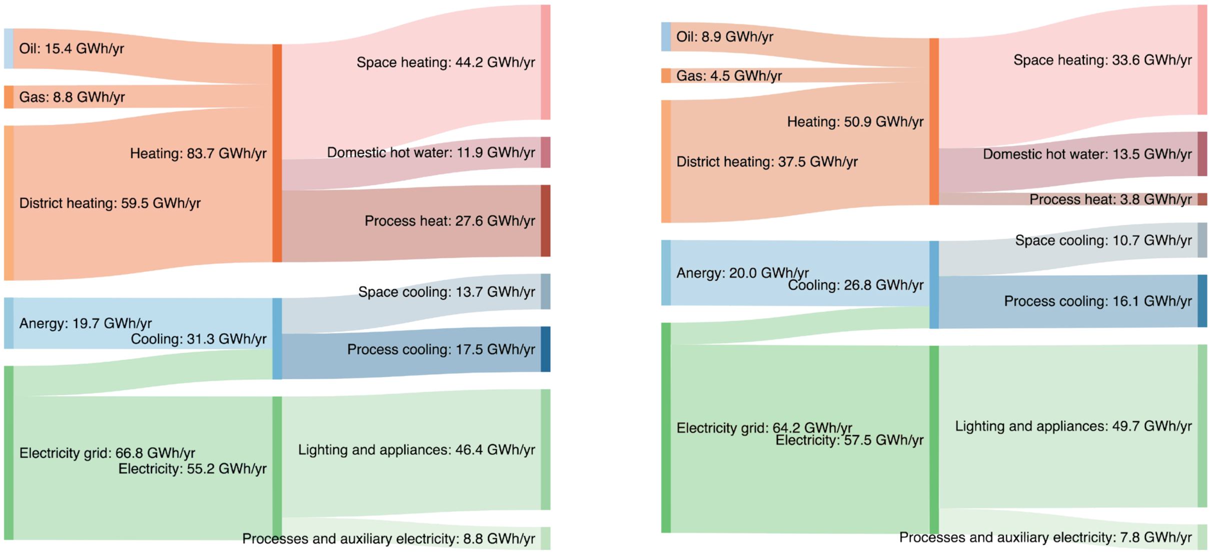

FIG. 3.7 Sankey diagrams representing the energy demands and energy sources for the Status Quo (left) and Baseline scenario (right).

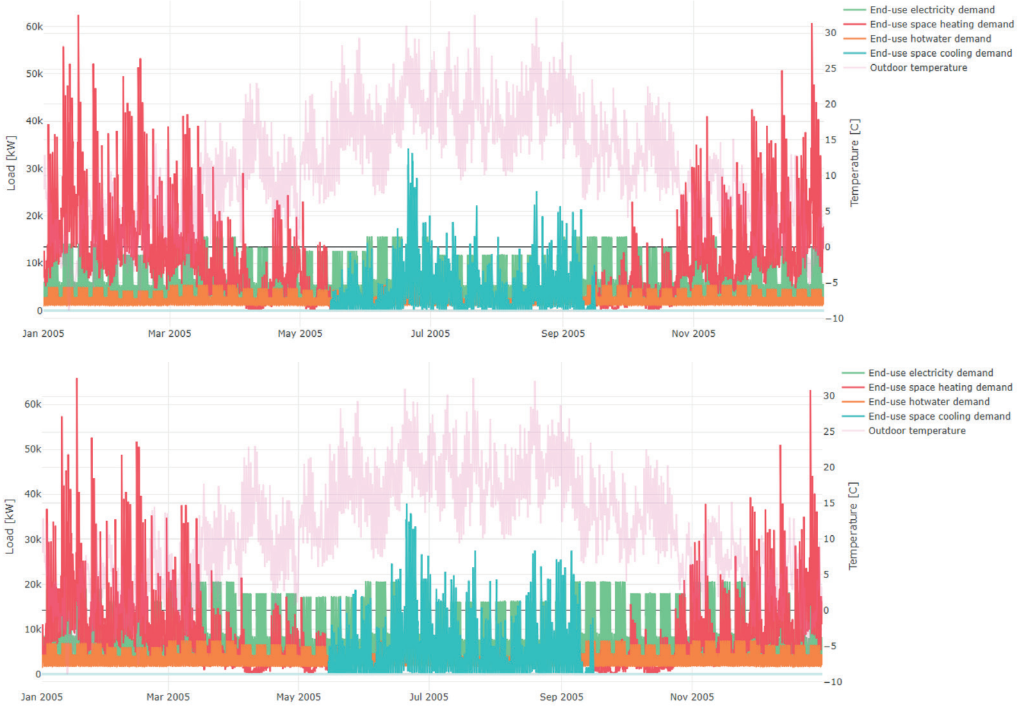

FIG. 3.8 Energy demands in the district and outdoor temperature throughout the year for the Status Quo (top) and Baseline scenario (bottom).

3.4. Results

3.4.1. Energy demands in the Hochschulquartier

Due to the large amount of highly technical functions in the Hochschulquartier, the energy needs of the area are varied. In addition to space conditioning, domestic hot water, and electricity for lighting and appliances, there are significant loads for processes. The demands in the area for both cases as well as the heating systems supplying them are summarized in Figure 3.7. Since systems have as of yet not been modeled for the case study, supply system efficiencies are not accounted for in this graph.

The overall heating demand in the SQ is 97.1 GWh/yr, of which the majority is for space heating (69%), almost entirely provided by radiators. The demand for domestic hot water is also substantial due to the presence of the hospital, while process heat accounts for less than 10% of the total heating demand. In the BL scenario, the space heating demand is reduced by 25% in spite of the increase in usable floor space in the area. This is largely due to the construction of highly efficient buildings with very low demands, while the demands for process heat and domestic hot water remain almost the same. The share of buildings with low temperature radiant floor heating also increases considerably, although most buildings continue to be heated by radiators.

In both cases, the majority of this heating is provided by the district heating infrastructure in the area, which includes a pressurized steam utility (at 12 bar, which corresponds to 192°C), a hot water utility (at 90 – 120°C) and ETH's own district heating network (operated at 72°C) [37]. The utilities are supplied by waste heat from a waste incineration plant, whereas the ETH network was supplied both by the city-scale utility and a heat pump. Although this heat pump was set to be decommissioned by the end of 2017, it was included as part of the Status Quo analysis, and since district-scale thermal networks are still part of ETH's energy masterplan, the availability of this network is also assumed in the future.

The end-use electricity demand in the area increases by about 15% from the SQ (51.8 GWh/yr) to the BL (60.5 GWh/yr). This is due to the increase in floor area and consequently the increase of the demand of electricity for lighting and appliances. At around 15 GWh/yr for both scenarios, the amount of electricity for processes is also considerable. All electricity was assumed to be taken from the electricity grid in

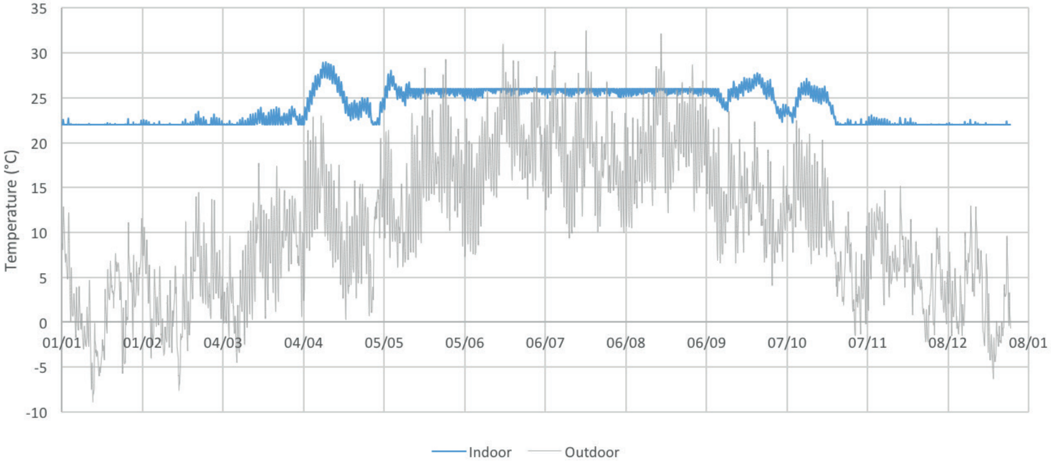

FIG. 3.9 Indoor temperature in a hospital building for the Baseline scenario and outdoor temperature throughout the year.

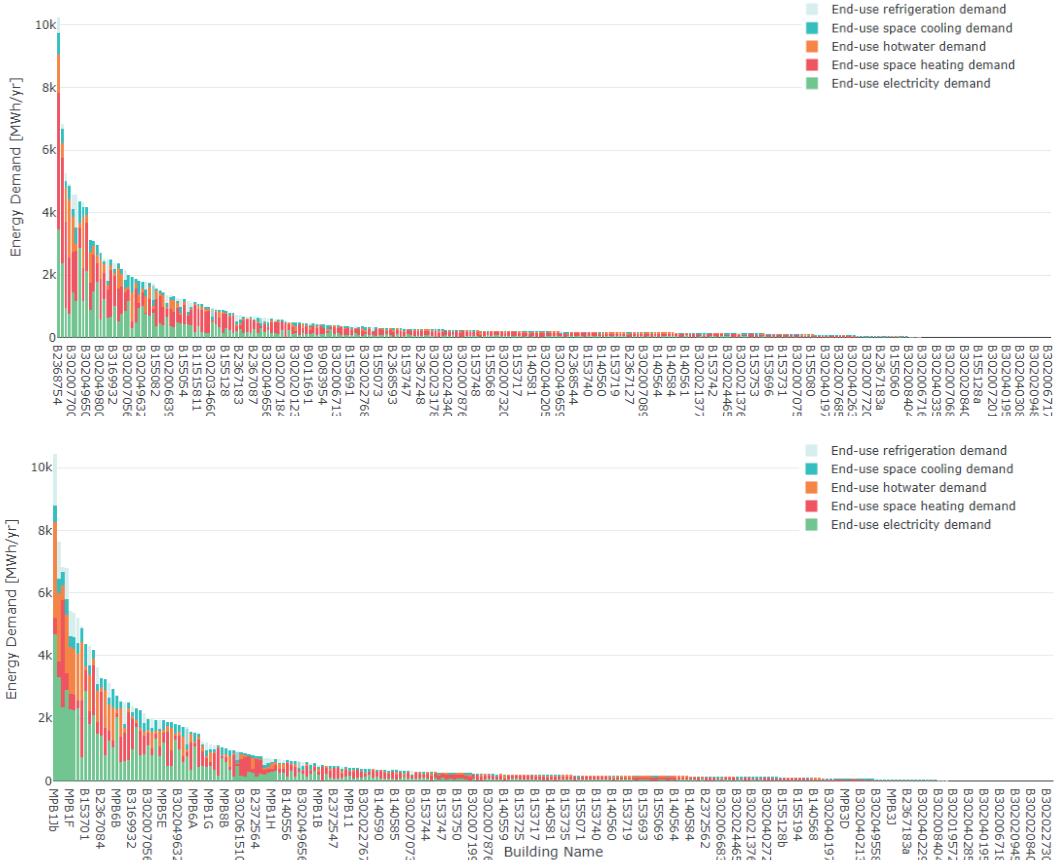

FIG. 3.10 Energy demands (MWh/yr) for space heating and cooling, domestic hot water and electricity for each building in the Status Quo (top) and Baseline scenario (bottom).

both scenarios, as the amount of photovoltaic (PV) panels in the area is negligible and were not considered part of the BL scenario either.

Finally, the demand for cooling in both scenarios is again quite similar in spite of the added floor area, with 32.5 GWh/yr for the SQ and 34.1 GWh/yr for the BL. The majority of this demand, however, is for processes, as both the hospital and the universities' server rooms require a substantial amount of cooling. In the SQ, all buildings were assumed to be supplied by decentralized air conditioning units, while in the BL all cooling was assumed to be supplied by the proposed lake water cooling infrastructure. Likewise, in the BL scenario new buildings were assumed to be built with chilled ceiling cooling systems, hence in the BL around 47% of the cooling is supplied at high temperatures.

Seasonal variations

The seasonal variations in the energy demands in the area are shown in Figure 3.8. The heating season lasts from mid-September to mid-December, with peaks in December and January. The demands for processes are generally constant throughout the year. The demands for appliances, lighting and domestic hot water depend on occupant presence, and are generally higher of the BL case as for the SQ.

An interesting feature is seen in the intermediate seasons (April and September), as there is a demand for heating immediately before the end of the heating season and for cooling immediately after. This likely points out to historical buildings having a tendency to be under heated even in spring, whereas modern, highly insulated buildings might tend to overheat in the moderate seasons due to high internal and solar gains. This overheating can be seen in Figure 3.9, which shows the indoor temperatures in one of the new hospital buildings in the BL scenario compared to the outdoor temperature. Indoor temperatures in April and September reach the set point temperature for the cooling systems, but given that the cooling systems are off at that time the building gets overheated. This may point to the need to optimize the building envelope for the specific function of the building in order to avoid overheating rather than implement the same extremely low U-values for all new buildings regardless of function.

Energy use intensity

Figure 3.10 shows the energy demands for each building in the area for both the SQ and the BL. The graph shows that a relatively small number of buildings is responsible for the majority of the demands in the area. This can be partially explained by the existence of a number of large historical buildings with large demands in the area. Nevertheless, in the BL scenario there are also a number of large modern buildings with very large demands simply due to the large floor spaces they comprise. The energy use intensity for the buildings in the area (shown in Figure 3.11) shows that

FIG. 3.11 Energy use intensity (kWh/m2-yr) for space heating and cooling, domestic hot water and electricity for each building in the Status Quo (top) and Baseline scenario (bottom).

the majority of the buildings have yearly final energy demands between 100 – 200 kWh/m2. While the energy use intensities for lighting and appliances are relatively constant for all buildings, the demands for space heating depend much more strongly on the buildings themselves.

Heating demand

Figure 3.13 shows the spatial distribution of heating demands in the district for both the Status Quo and the Baseline scenarios. The space heating demands are highest for historical buildings such as the ETH main building, whereas hot water demands are highest for both the hospital and the sports centers and process heating demands are highest in hospital buildings. In the Baseline scenario, the construction of new, highly-efficient hospital buildings leads to the reduction of heating demands in the hospital, but the demands for hot water and processes remain comparable to the Status Quo as these depend mainly on the hospital function and not the age of construction.

The histogram in Figure 3.12 the distribution of space heating demands in the area by number of buildings with different energy use intensities for heating. Due to the large number of historical buildings in the area, the space heating demands of most buildings in the Status Quo are quite large, with most buildings falling in the range of 100 to 150 kWh/m2-yr for heating. In the BL scenario, on the other hand, the number of buildings in this range remains considerable, however the number of buildings below 50 kWh/m2-yr is almost doubled. The replacement of a number of buildings with high consumption with new, highly insulated buildings explains the large decrease in space heating demand observed in Figure 3.7.

Cooling demand

The space cooling demands in the area are generally much lower than heating for both scenarios, and are mainly centered in large buildings with many occupants (such as the ETH main building and ML building), sports centers and hospital buildings. Process cooling, on the other hand, is mainly centered in hospital buildings and the ETH server rooms in the LEE building. Unlike heating, the distribution of cooling demands in the area in both scenarios does not show substantial differences between scenarios other than both being more prevalent in large, modern hospital buildings.

The histogram in Figure 3.14 shows that the vast majority of buildings in both scenarios have relatively low cooling demands at less than 10 kWh/m^2-yr. However, an increase in buildings with higher cooling demands can also be seen. This is quite typical of highly insulated buildings with high internal gains such as offices and hospitals as discussed in section 'Seasonal Variations'.

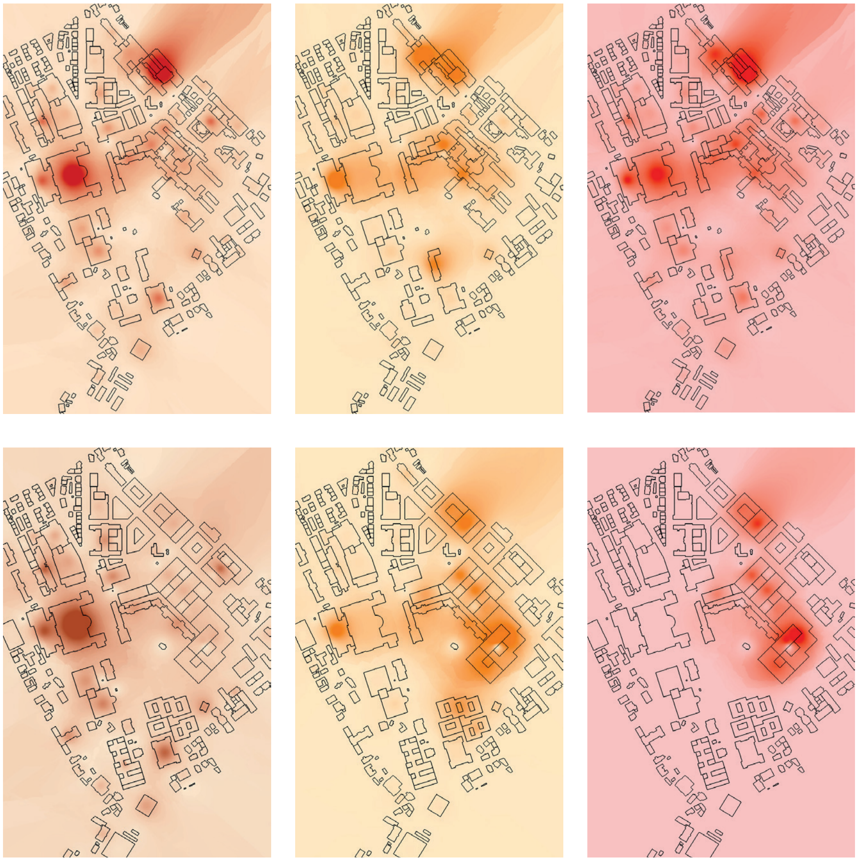

FIG. 3.13 Spatial distribution of the demands for space heating (left), hot water (center) and process heat (right) in the area for the Status quo (top) and Baseline scenario (bottom).

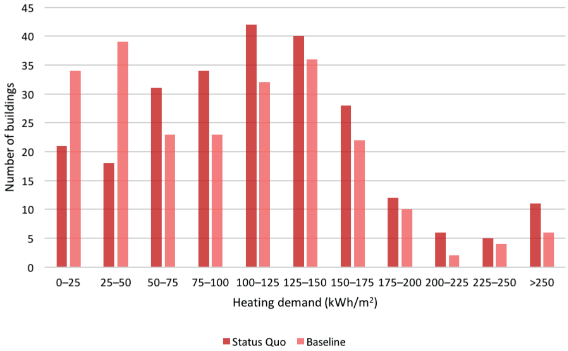

FIG. 3.12 Frequency of space heating demands in the area for the Status Quo and Baseline scenario.

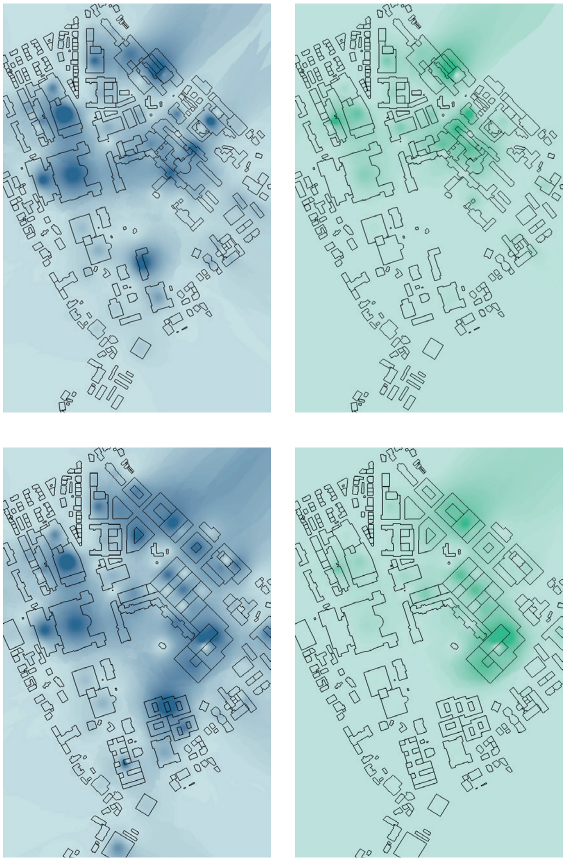

FIG. 3.15 Spatial distribution of the demands for space cooling (left) and process cooling (right) in the area for the Status Quo (top) and Baseline scenario (bottom).

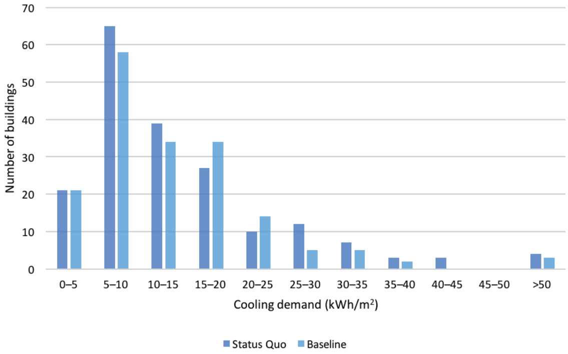

FIG. 3.14 Frequency of space heating demands in the area for the Status Quo and Baseline scenario.

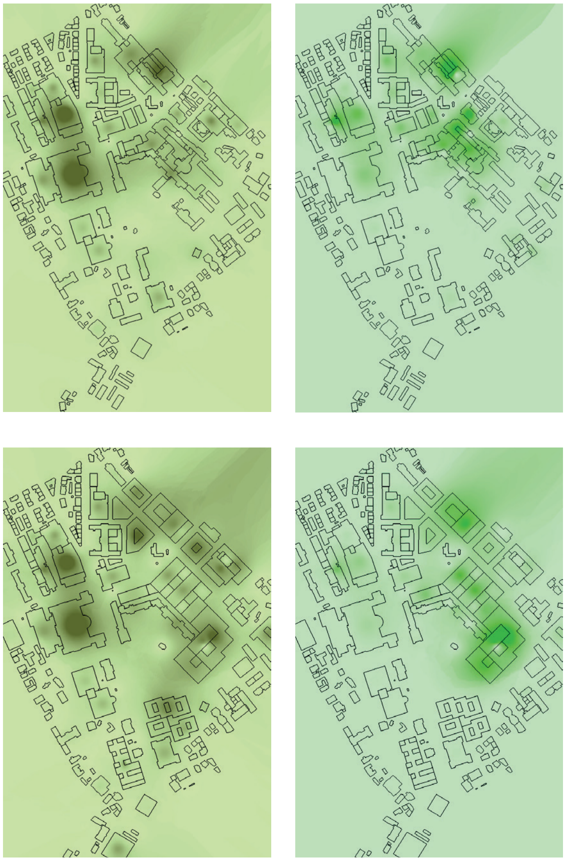

FIG. 3.17 Spatial distribution of the demands for electricity for lighting and appliances (left) and processes (right) in the area for the Status Quo (top) and Baseline scenario (bottom).

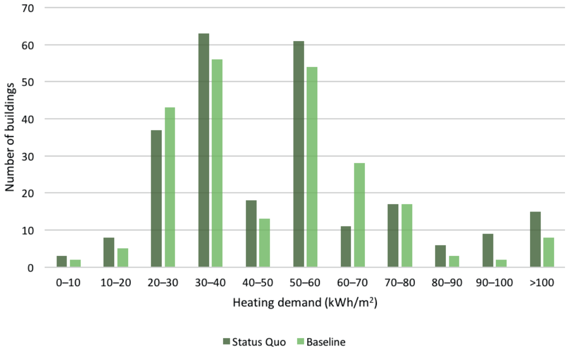

FIG. 3.16 Frequency of electricity demands in the area for the Status Quo and Baseline scenario

Electricity demand

Similarly to cooling, the spatial distribution of electricity demands in the area corresponds more to the building functions and sizes than the age of the building. Hence, the demands for lighting and appliances are highly concentrated in large buildings such as the ETH main building, ML building and hospital buildings, for both scenarios. Process electricity is again highest for hospital buildings, large ETH research facilities, and server rooms such as those in the ETH LEE building.

The electricity demands in the area are mostly within the 30 – 60 kWh/m2-yr range, as seen in Figure 3.16. The demands in both scenarios are fairly similar, although the number of buildings with extremely high demands and below 60 kWh/m2-yr decrease and many new buildings fall exactly within the range between 60 and 70 kWh/m2-yr. This is likely due to the new hospital buildings all being assigned the current hospital's average electricity demands per square meter, hence eliminating extremes in the hospital building stock.

Distribution of energy demands by institution

In this section, the demands for each institution are compared for the SQ and BL scenario. In the current masterplan for the area, however, some buildings are assigned mixed research and hospital functions, as seen in Figure 3.18. For the purposes of this comparison, these are assigned as hospital buildings for simplicity. The energy demands by institution for the Status Quo and Baseline scenario are shown in Figures Figure 3.19. The USZ is a major consumer of all three demand types. Likewise, due to the existence of large research facilities and server rooms in ETH buildings, this university has very large demands for cooling and electricity. The UZH has a much lower share of the overall demand, mainly for heating, whereas all other buildings in the area have demands comparable to those from UZH.

In the BL scenario, the demands for heating for USZ and ETH are reduced, but those for UZH are actually increased due to the large increase in usable floor area for the university. These new buildings are highly glazed and were assumed to host research activities, hence the cooling and electricity demands increase considerably. Although the secondary uses in the area were largely assumed to stay the same in the BL scenario, a large library is to be built, which causes the electricity demand in the area to increase. In addition to that, an existing gym that does not belong to any of the institutions is to be demolished and a new one built in a UZH building, hence the heating demand for the "other" users decreases.

1 USZ

Out of the 285 buildings in the SQ model, 52 correspond to the USZ. These do not represent individual buildings, as due to the way building geometries are generated in CEA some buildings might be modeled as more than one building in order to account for differences in height, construction materials, etc. The BL model includes 41 buildings occupied by the USZ or have mixed hospital/research functions as discussed above.The demands for both cases are shown in Figure 3.20. The largest demand in the SQ is by far space heating, with more than 90 kWh/m^2-yr. With the demolition of most hospital buildings and replacement with highly insulated new buildings, the demand for heating is reduced drastically to less than 30 kWh/m2-yr. While the demands per square meter for domestic hot water and processes were set to match the present-day average for the hospital, due to the inclusion of mixed-use hospital and research buildings in this group, the overall demand per square meter for the hospital is decreased.

2 ETH

There are 47 ETH buildings in the SQ and 39 in the BL, although as discussed above this number excludes mixed-use hospital and research buildings. Since most buildings in the ETH stock remain unchanged from the status quo, the energy use intensity remains relatively constant. The demand for heating is reduced from 62 to 55 kWh/m2-yr, while demands for domestic hot water and space cooling remain approximately constant. Due to the research activities in ETH, there is also a significant demand for electricity for lighting and appliances as well as process electricity and cooling, which includes large server rooms in the LEE building. Nevertheless, the overall demand for process cooling reduced in the BL scenario, mainly due to specific buildings with high process cooling demands being replaced by general research buildings with no defined process cooling demand.

3 UZH

UZH buildings are generally smaller than the other two institutions' and generally do not have large demands for research activities such as process electricity and cooling. Hence, while the number of buildings is higher for UZH (53 in the SQ and 60 in the BL), their demands are lower in absolute terms. Per square meter, the demand for space heating in the SQ is similar to USZ's at 90 kWh/m2-yr, but are almost halved due to the construction of large, energy-efficient buildings in the BL. One of these buildings includes a gym that replaces an existing one in the area, hence the demands for domestic hot water and cooling increase. Finally, the overall demand for process cooling in the BL are not much higher than for the SQ (1.1 GWh/yr compared to 1.2 GWh/yr in the SQ), but since the overall built area increases considerably, the energy use intensity for process cooling decreases significantly. A similar feature can be seen with regards to process electricity.

4 Other

Similarly to UZH, although the number of buildings in the area that do not belong to any of these institutions is high (133 in the SQ and 118 in the BL), due to their much smaller size and generally less energy-intensive functions such as residential, their demands are overall small. The energy use intensity of these buildings is similar

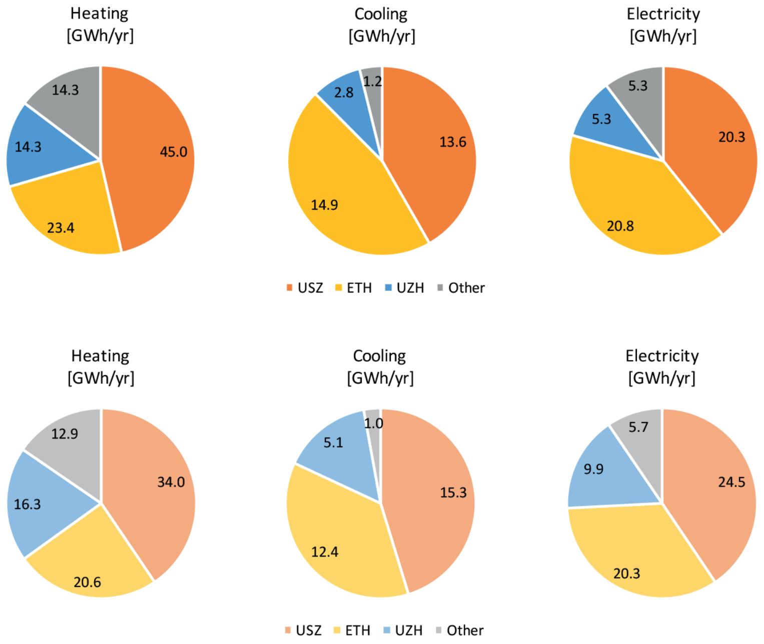

FIG. 3.19 Yearly heating, cooling and electricity demands by institution for the Status quo (top) and Baseline scenario (bottom).

FIG. 3.18 Distribution of functions in the area according to the current Masterplan for the area [38]. Buildings corresponding to ETH are shown in yellow, USZ in red and UZH in blue. Buildings shown in yellow and red denote a mixed function including ETH and USZ uses.

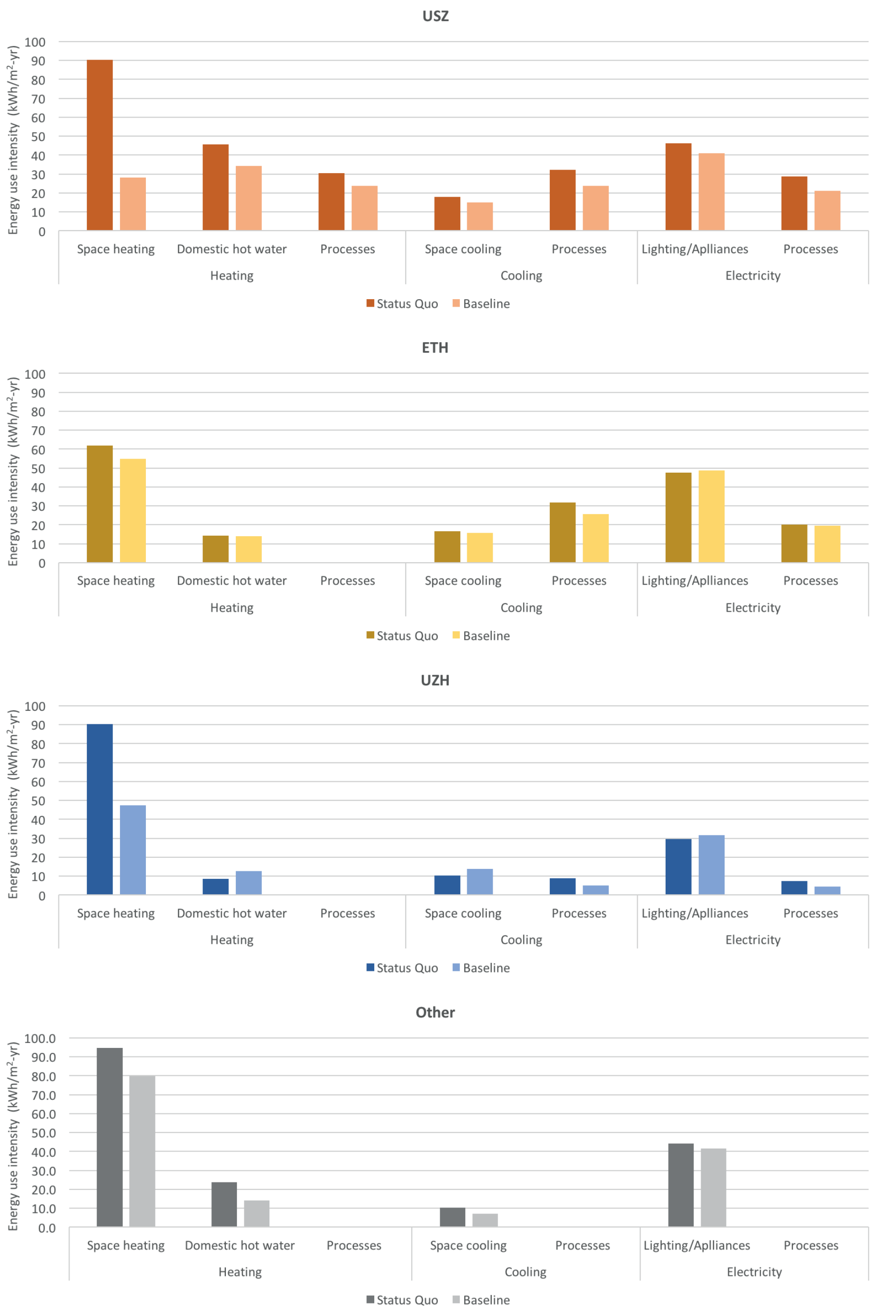

FIG. 3.20 Energy use intensity by energy type for Institutions (USZ, ETH, UZH, Others) in the Status Quo and Baseline scenarios.

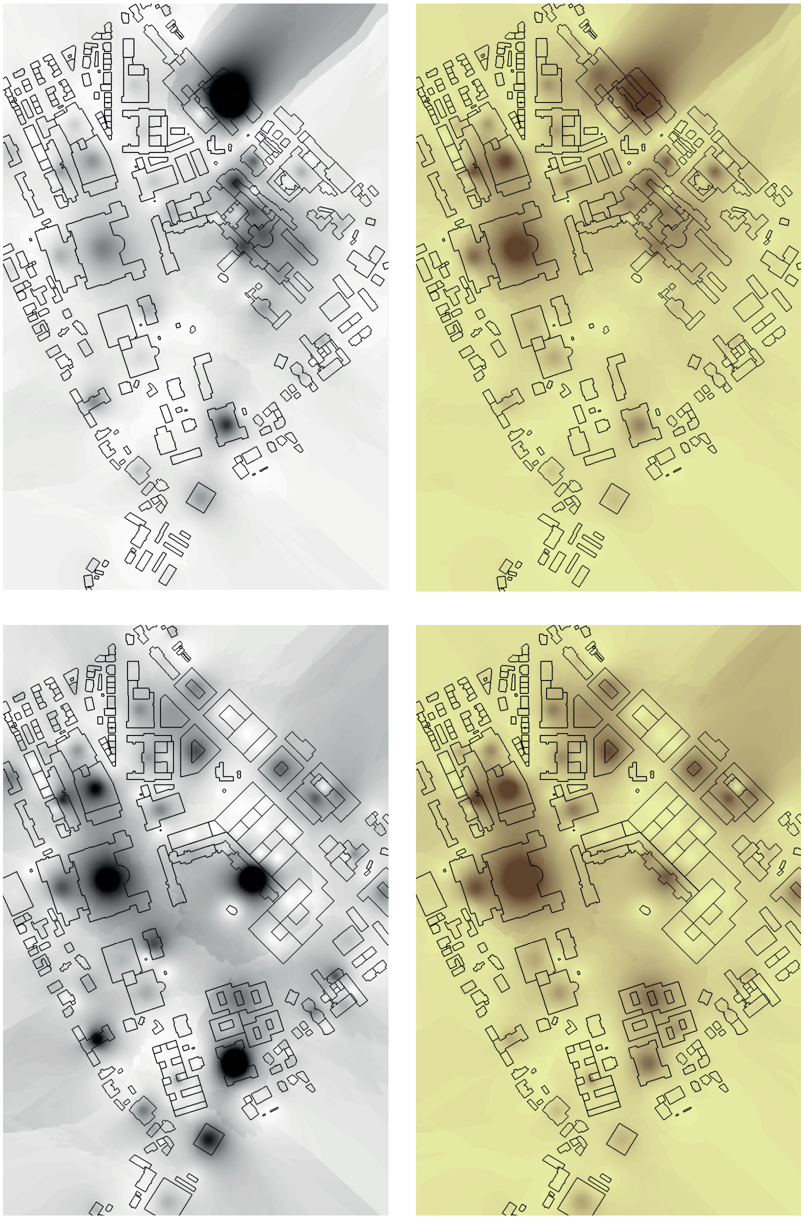

FIG. 3.21 Spatial distribution of yearly operational CO2 emissions (left) and primary energy demand (right) for the Status quo (top) and Baseline scenarios (bottom).

to USZ and UZH (95 kWh/m2-yr) in the SQ. In the BL, since two new buildings are incorporated in the complementary uses (a library and a museum), the energy use intensity of all the buildings in the area that do not belong to one of the universities is lowered to about 80 kWh/m2-yr. As discussed above, due to the demolition of the existing gym, the domestic hot water in this building category decreases, as does the space cooling demand. Since these buildings have no research, hospital or industrial functions, there are no demands for process energy in this category.

Associated emissions and primary energy demand

The distribution of emissions in the area shows a clear shift in the areas of highest emissions from Status Quo to Baseline scenario (Figure 3.21). This is due to a hospital building with extremely high thermal energy demands with an oil boiler (according to GWR) being replaced with much more efficient buildings with cleaner heating systems. Thus, in the BL scenario CO^2 emissions are concentrated in historical and hospital buildings as found in the electricity demand distributions. The primary energy demands in the area follow a similar pattern, although due to the low primary energy factors for district waste incineration found in the KBOB database [20] buildings connected to the ETH network generally perform worse than buildings connected to the city-scale heating network.

The overall sustainability of the area is assessed by comparing to the 2000 Watt Society benchmarks, which the city of Zurich aims to reach by 2050. The CEA databases include target values and present-day estimates for the primary energy demand and emissions for building construction, building operation and mobility based on existing reference values [46] and estimates based on the published calculation method [47].

As a highly technical area with very unique demands, it is not surprising that the area does not meet 2000 Watt Society targets in the SQ, although it does indeed perform better than the Swiss average based on the CEA databases. While the BL performs much better in terms of operation (almost reaching 2000 Watt Society targets for operation), the embodied energy of the large building stocks being developed in the area leads to a much more modest decrease in total greenhouse gas emissions and primary energy demand for the BL, although the overall performance of the area is indeed closer to the target in the BL than in the SQ. This is consistent with the findings of the energy study of the area of 2014 [41]. Thus, further measures need to be pursued in order to lower the primary energy demand and greenhouse gas emissions for the area in order to reach the city's environmental targets.

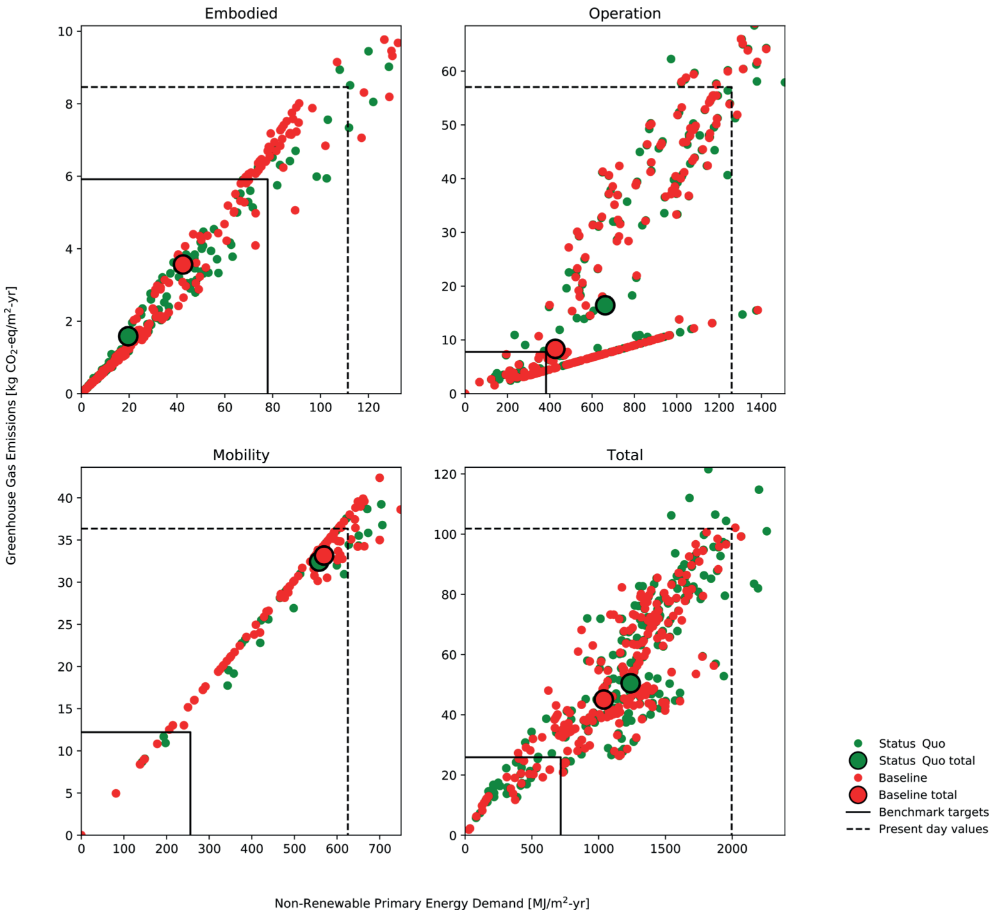

FIG. 3.22 Environmental performance of the area in the Status Quo and Baseline compared to 2000 Watt Society targets. Bigger dots represent the average for each scenario, while smaller dots represent individual buildings.

3.4. Conclusions

Due to its functional mix coupled with a building stock largely made up of historical and protected buildings, the Hochschulquartier presents a high-intensity, highly varied mix of demands that need to be satisfied. Due to the presence of numerous older buildings and the significant demands for hot water demand and process heat in the hospital, heating is the largest demand in the area in the SQ. Electricity and cooling demands, however, are also significant due to the existence of server rooms and research and hospital facilities. Through the introduction of new, highly-insulated new buildings in the area, the demand for heating is reduced by about 20% in the BL scenario in spite of the additional built area, while electricity and cooling demands increase along with the increase in usable floor space. Comfort might need to be considered in these new buildings, however, as they were also found to overheat in temperate seasons due to the high internal gains from the activities in the buildings as well as solar gains through the large glazed surfaces.

USZ and ETH proved to be the largest consumers due to their larger built areas (about twice as large in the SQ) and the type of activities in their buildings, although due to the considerable increase in usable floor space in the UZH in the BL scenario its demands become more significant, particularly as far as cooling and electricity. Secondary uses in the area have the smallest floor area and demands and remain largely unchanged in the BL scenario.

From an environmental perspective, the BL performs significantly better than the SQ due to the higher energy efficiency in the buildings and the introduction of low emission district cooling infrastructure. The embodied emissions of the new buildings are considerable but end up paying off due to the reduced operational energy demand. When compared to the 2000 Watt Society benchmark, however, the area still does not meet the targets for the building functions included in the area. This is not entirely surprising given the highly energy-intensive nature of the area’s activities, however solutions need to be found for the area to further decrease the yearly emissions and primary energy demand in order to ensure compliance to the city’s targets for 2050.

References

[1] Seto, K.C. et al., "Climate change 2014: Mitigation of climate change. contribution of working group iii to the fifth assessment report of the intergovernmental panel on climate change," in World Urbanization Prospects: The 2014 Revision, (ST/ESA/SER.A/366), Cambridge, Cambridge University Press, 2014, p. 923–1000.

[2] United Nations, Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2014 Revision, (ST/ESA/SER.A/366), New York: United Nations, 2015.

[3] S. Singh and C. Kennedy, "Estimating future energy use and CO2 emissions of the world's cities," Environmental Pollution, vol. 203, p. 271–278, 2015.

[4] K. Steemers, "Energy and the city: density, buildings and transport," Energy and Buildings, vol. 35, p. 3–14, 2003.

[5] J. Fonseca and A. Schlueter, "Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts," Applied Energy, vol. 142, p. 247–265, 2015.

[6] D. Crawley, J. Hand, M. Kummert and B. Griffith, "Contrasting the capabilities of building energy performance simulation programs," Building and Environment, vol. 43, no. 4, p. 661–673, 2008.

[7] L. Bourdic and S. Salat, "Building energy models and assessment systems at the district and city scales: a review," Building Research & Information, vol. 40, no. 4, p. 518–526, 2012.

[8] J. Keirstead, M. Jennings and A. Sivakumar, "A review of urban energy system models: Approaches, challenges and opportunities," Renewable and Sustainable Energy Reviews, vol. 16, p. 3847–3866, 2012.

[9] L. Swan and V. Ugursal, "Modeling of end-use energy consumption in the residential sector: A review," Renewable and Sustainable Energy Reviews, vol. 13, p. 1819–1835, 2009.

[10] F. Chingcuanco and E. Miller, "A microsimulation model of urban energy use: Modelling residential space heating demand in ILUTE," Computers, Environment and Urban Systems, vol. 36, p. 186–194, 2012.

[11] R. Best, F. Flager and M. Lepech, "Modeling and optimization of building mix and energy supply technology for urban districts," Applied Energy, vol. 159, p. 161–177, 2015.

[12] C. Reinhart and C. Cerezo Davila, "Urban building energy modeling – a review of a nascent field," Building and Environment, vol. 97, p. 196–202, 2016.

[13] D. Robinson, F. Haldi, J. Kämpf, P. Leroux, D. Perez, A. Rasheed and U. Wilke, "CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning," in Proceedings of Building Simulation 2009: Eleventh International IBPSA Conference, Glasgow, Scotland, 2009.

[14] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer and R. Evins, "A review of modelling approaches and tools for the simulation of district-scale energy systems," Renewable and Sustainable Energy Reviews, vol. 52, p. 1391–1404, 2015.

[15] The CEA team, City Energy Analyst v2.9.0, doi: 10.5281/zenodo.1487867, 2018.

[16] J. Fonseca, T.-A. Nguyen, A. Schlueter and F. Marechal, "City Energy Analyst (CEA): Integrated framework for analysis andoptimization of building energy systems in neighborhoods andcity districts," Energy and Buildings, vol. 113, p. 202–226, 2016.

[17] J. Fonseca and M. Mosteiro-Romero, "FAQ: What are the default databases of CEA," 27 March 2017. [Online]. Available: https://docs.google.com/presentation/d/1xMG-Vhmqh0jwdLih6Wgw-FzJrzhIPGdocQKdzZvYnvil/edit#slide=id.gc6f73a04f_0_0. [Accessed 1 March 2019].

[18] SIA, Merkblatt 2024, Standard-Nutzungsbedingungen für Energie- und Gebäudetechnik, Zurich: Schweizerischer Ingenieur- und Architektenverein, 2015.

[19] E. Thoma, J. Fonseca and A. Schlueter, "Estimation of base-values for grey energy, primary energy, global warming potential (GWP 100A) and Umweltbelastungspunkte (UBP 2006) for Swiss constructions from before 1920 until today," in Proceedings Contemporary Urban Issues, Istanbul, Turkey, 2014.

[20] KBOB, eco-bau, IPB, "Ökobilanzdaten im Baubereich 2009/1," Koordinationskonferenz der Bau und Liegenschaftsorgane derOeffentlichen Bauherren (KBOB), Bern, Switzerland, 2014.

[21] M. Mosteiro-Romero, J. Fonseca and A. Schlueter, "Seasonal effects of input parameters in urban-scale building energy simulation," Energy Procedia, vol. 122, p. 433–438, September 2017.

[22] A. Elesawy and J. Fonseca, "FAQ: How does the Urban Solar Potential feature work?," 5 December 2017. [Online]. Available: https://docs.google.com/presentation/d/1tPRfh0N-b31jf2DuNhf-zLOaadhI9iTImCansuO_IdVs/edit#slide=id.gc6f73a04f_0_46. [Accessed 2 March 2019].

[23] D. Maiullari, M. Mosteiro-Romero and M. Pijpers-van Esch, "Urban Microclimate and Energy Performance: An Integrated Simulation Method," in PLEA 2018, Hong Kong, 2018.

[24] C. Reinhart, "DAYSIM: Advanced Daylight Simulation Software," 2019. [Online]. Available: https://daysim.ning.com/. [Accessed 2 March 2019].

[25] P. B. Neitzel, "A New CEA Radiation Model: Identification of Key Input Parameters in Space and Time and their Implications on Output Uncertainty," Zürich, 2016.

[26] J. Page, D. Robinson, N. Morel and J.-L. Scartezzini, "A generalised stochastic model for the simulation of occupant presence," Energy and Buildings , vol. 40, no. 2, p. 83–98, 2008.

[27] C. Montagud, J. Corberan and A. Montero , "In situ optimization methodology for the water circulation pump frequency of ground source heat pump systems," Energy and Buildings, 2014.

[28] ISO 13790, Energy performance of buildings – Calculation of energy use for space heating and cooling, Geneva: International Organization for Standardization (ISO), 2008.

[29] SIA Merkblatt 2044, Klimatisierte Gebäude - Standard-Berechnungsverfahren fur den Leistungs- und Energiebedarf, Zürich: Schweizerischer Ingenieur- und Architektenverein (SIA), 2011.

[30] G. Happle, J. Fonseca and A. Schlueter, "Effects of air infiltration modeling approaches in urban building energy demand forecasts," Energy Procedia, vol. 122, p. 283–288, 2017.

[31] DIN EN 16798-7, Energieeffizienz von Gebäuden – Berechnungsmethoden zur Bestimmung der Luftvolumenströme in Gebäuden inklusive Infiltration, DIN, Deutsches Institut für Normung e. V., 2015.

[32] ISO 9972:2015-12, Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method (ISO 9972:2015), DIN Deutsches Institut für Normung e. V., 2015.

[33] ISO 52016-1, Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedures, Geneva: International Organization for Standardization (ISO), 2017.

[34] S. Bertagnolio, "Evidence-based model calibration for efficient building energy services," Liège, 2012.

[35] ISO 15316, Heating systems in buildings – method for calculation of system energy requirements and system efficiencies, Geneva: European Committee for Standardization, 2007.

[36] M. Mosteiro-Romero, I. Hischier, H. Becker, J. Fonseca and A. Schlueter, "Effect of occupancy modeling on district-scale energy demand simulations," In writing.

[37] Baudirektion Kanton Zürich, Städtebauliche Vertiefungsstudien Universität Zürich und Universitäre Medizin (USZ/UZH/ETH) - Synthesebericht, Zürich: Kanton Zürich, Baudirektion, 2014.

[38] Baudirektion Kanton Zürich, Masterplan Hochschulgebiet Zürich-Zentrum September 2014, Zürich: Kanton Zürich, Baudirektion, 2014.

[39] Bundesamt für Statistik (BFS), Eidgenössisches Gebäude- und Wohnungsregister, Neuchâtel, 2010.

[40] Stadt Zürich, Tiefbau- und Entsorgungsdepartament, "3D-Stadtmodell," 2015. [Online]. Available: https://www.stadt-zuerich.ch/ted/de/index/geoz/geodaten_u_plaene/3d_stadtmodell.html.

[41] Baudirektion Kanton Zürich, Hochschulgebiet Zürich-Zentrum Schlussbericht Vertiefungsthema Energieversorgung, Zürich, 2015.

[42] Kanton Zürich, "Hochschulgebiet Zürich Zentrum - Weiterentwicklung des Wissens- und Gesundheitsstandorts," 7 9 2014. [Online]. Available: https://www.youtube.com/watch?v=TUBP-WKf9gVs. [Accessed 3 3 2019].

[43] Baudirektion Kanton Zürich, Hochschulgebiet Zürich Zentrum Stadtraumkonzept HGZZ – Schlussbericht, Zürich: Kanton Zürich, Baudirektion, Amt für Raumentwicklung, 2017.

[44] D. Maiullari, A. van Timmeren, M. Mosteiro-Romero, A. Schlueter, H. Becker, K. Axhausen, A. van Nes and R. de Koning, "Space-Energy Development Scenarios for the Zurich Hochschulquartier," 2017.

[45] Meteotest, "Meteonorm 7.0," 2013. [Online]. Available: https://meteonorm.com/.

[46] Bundesamt für Energie BFE, Arealentwicklung für die 2000-Watt-Gesellschaft: Leitfaden und Fallbeispiele, Bern, 2012.

[47] Bundesamt für Energie BFE, Arealentwicklung für die 2000-Watt- Gesellschaft: Beurteilungsmethode in Anlehnung an den SIA-Effizienzpfad Energie, Bern, 2012.

4.

Coupling method for building energy demand assessment

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Contents:

Summary

Rapid urbanization and densification processes are globally changing microclimatic environments in which buildings express their energy performance. Although previous studies have demonstrated the relevant impact of urban microclimate on space cooling and heating demand, modelling tools employed to support the design process largely overlook microclimatic conditions in assessing building energy performance, making use of general weather data.

This chapter presents a study on a computational approach which allows quantitative analysis of building energy demand on a district scale, including interdependent factors such as local air temperature, relative humidity and wind speed, diversity in building geometry and materials as well as user behaviors. The method, which links the microclimate model ENVI-met and the district-scale energy simulation tool City Energy Analyst, has been applied on Masterplans for a district development in Zurich (Switzerland),and Almere (The Netherlands) in order to analyze the energy performance of the proposed design and define guidelines for improvement.

4.1. Introduction

In proceeding through 'the Grand Transition', global energy consumption is predicted to increase between the 22% and 46% by 2060 [1]. A large part of this increase is due to a global demographic growth concentrated in urbanized areas. Not only cities in developing countries, but also European cities have seen a faster overall rise in number of inhabitants in the last decade [2]. Combined with an urbanization shift from an expansive development model to a compact and concentrated one, this has resulted in redevelopment projects in inner city areas. 'Urban re-densification' processes need to comply to several climate and energy targets that aim to reduce greenhouse gas emissions and increase the energy efficiency by 2020, and have the objective of designing a more livable and healthy urban environment.

One of the main challenges during the urban design process is predicting the effect of the urban form on the urban microclimate, which doubly influences outdoor thermal comfort and the energy performance of buildings. Previous empirical and fundamental studies have shown that it is of growing importance to take the local climatic conditions into account when analyzing building energy performance and its consequent environmental impact [3, 4, 5]. Several microclimate phenomena influence the thermal exchange processes that take place between building surfaces and the local environment. First, the Urban Heat Island effect caused by urban geometry, thermal properties of materials (high heat storage capacity and high emissivity) and limited evapotranspiration increases the demand for air conditioning and space cooling in warmer seasons, while during colder seasons it can reduce the need for space heating. A second type of effect regards wind patterns occurring within the canopy layer. In general, wind speeds are lower in the urban environment, however, characteristics of the street network, orientation, building geometry and topographic location can cause significant local differences in speed as well as direction, affecting the potential for natural ventilation and cooling. For example, the acceleration of air flows along the street canyons increases thermal loss from building facades with a negative impact on building energy performance during cold seasons. A third type of microclimate phenomenon regards the influence of shortwave and longwave radiation that according to the compactness of the surrounding urban environment and exposed envelope differently affect thermal gains and building electricity demand for lighting.

Computational models commonly used to support the understanding of building energy performance in buildings, however, largely overlook urban microclimate phenomena. Meteorological boundary conditions adopted in building energy simulation programs are usually based on data from rural weather stations, ignoring the effect of the urban surrounding and its effect on local climate [6, 7]. Recent advancements in computational approaches have allowed attempts in bridging this gap by coupling methods that link urban climatic variables to the thermal performance of buildings. The main advantage of these computational approaches over measurement approaches, is that they can generate explicit information for distinct microclimatic parameters [8] and allow the comparison of urban areas also in a design stage and under numerous time and climatic frames [9, 10, 11, 12].

Coupling methods based on thermal balance in urban canyon models [13], thermoradiative/flow models in urban areas [5, 7, 14, 15, 16] and BES programs are becoming of growing importance to estimate the impact of urban microclimate on energy consumption However, in the present literature, investigations on effects of simulated urban microclimate on building energy demand mainly focus on single buildings and typological explorations [13, 24, 25, 26, 27]. The main reason can be found in computational limitations, since the analysis of district scale in some cases surpasses the capability of energy simulation tools developed for single buildings modelling. Allegrini et al. (2015) have offered comprehensive reviews of existing modelling approaches and tools which address the district scale of energy systems, and state that "it is no longer sufficient to simulate building energy use assuming isolation from the microclimate and the energy system in which they operate" [23]. Therefore, further research is required towards a new generation of simulations tools and methods able to connect different spatial and temporal levels to analyze the reciprocal influence between buildings, their environment and performance.

Moreover, the importance of the climatic environment in relation to energy efficient solutions is assumed to become even larger in view of global warming. In fact, several studies have already estimated the impact of increased temperatures on Swiss energy demand [17, 18, 19], stating that while the number of heating days is expected to decline, the number of cooling days will grow significantly, with a consequent increase in energy demand for space cooling and carbon emissions. According to the comparative study of Santamouris et al. [20], the rise of ambient temperatures leads to an increase of annual electricity consumption for the building sector between 0.5% and 8.5% per each augmented degree. In particular in the Swiss central plateau where Zurich is located, annual cooling energy consumption for office buildings in the scenarios analyzed by Frank [18] is calculated to exponentially increase between 223-1050%, while annual heating energy consumption is expected to fall by 36-58%.

4.2. Methodology

In order to simulate the microclimate effects in the area and the energy demands of its buildings, ENVI-met 4.0 and City Energy Analyst (CEA), respectively, are used in this study. These software tools have been described in detail in previous work packages and hence are only discussed here insofar as relevant to their integration. ENVI-met is widely used to estimate and assess outdoor thermal comfort [28, 29, 30] and in fewer cases is also used to estimate the impact of the urban microclimate on building energy use [6, 31] as is done in this study.

ENVI-met is a three-dimensional prognostic microclimate model designed to simulate the interaction between surfaces, plants and air in an urban environment [32]. It has a typical resolution of 0.5 to 10 meters in space and a typical time frame of 24 to 48 hours with a time step of 1 to 5 seconds. It consists of four models: an atmospheric model, a soil model, a vegetation model and a building model.

The City Energy Analyst (CEA) is a computational framework for the analysis and optimization of energy systems in neighborhoods and city districts. It consists of a collection of tools for the analysis of urban energy systems [33] and contains comprehensive multi-physics mathematical models, using the latest ISO and SIA standards and the state-of-the-art in research. The tool is programmed in Python and can either work as a standalone or using a GIS-based interface. Unlike ENVI-met, the CEA does not have a specific limitation in area or grid for the analysis. It uses GIS-based maps in (.tiff) format to simulate the topography of the analyzed area.

For assessing the solar irradiation, the CEA uses DAYSIM, which is a validated radiation model for daylighting analysis. It considers only short-wave radiation, which means that model surfaces only reflect light, but do not absorb energy. Therefore, DAYSIM cannot accurately represent environmental effects such as Urban Heat Island, unless it can be coupled with a thermal outdoor model, which in turn can result in a more accurate demand modelling and outdoor comfort assessment. The urban heat island effect measures the temperature difference between urban and rural areas, which results in a reduction in heating and increase cooling demand in urban-dense contexts [34]. In order to accurately represent these effects a thermal outdoor model is needed.

4.2.1. CEA – ENVI-Met coupling method

The aim of the coupling method is to model the energy demand of a number of buildings on a district scale level, by taking in account the various factors that are co-responsible for the energy performance: microclimate environment, locus and topographic context, building geometry and materials, energy systems as well as user behavior. Common input for the two software packages are the spatial characteristics of buildings and the macro atmospheric data from a weather station.

Moreover, for the coupling approach types of employed spatial units have been taken in account. In the first place the two models differ in their spatial components. In ENVI-met, building entities are composed of a number of 3D cells or alternatively of meshes for the building facades and ground surfaces. Differently in CEA, buildings are single entities with 3D characteristics which emerge from a process of extrusion from a polygon area. Complex 3D geometries however are not supported and articulated building shapes imposes to split the overall geometrical entity according to the diverse heights. In order to establish a connection between the microclimate data and the CEA model linking steps that aggregate the data for the CEA spatial units are introduced, using a GIS tool.

Differently from previous studies [6, 35] where the linking units are defined as vertical and horizontal planes (exterior walls, roof and ground floor), here the unit is the building 3D shape, which allows to consider the building entity as an absolute mediator between inside and outside conditions.

4.3. Zurich case study

The 2014 masterplan for the Hochschulquartier (SPACERGY Baseline scenario) was the result of an intricate and long process in which the overall design has emerged through the integration of partial masterplans corresponding with the land-ownership division [21]. Although possible building geometries and energy system solutions that meet building energy targets have been investigated, it appears very difficult to achieve the '2000 Watt Society' targets pursued by the city [22]. A design approach that integrates methods to assess the energy demand for space cooling and heating as influenced by the local microclimate and consequently allows for an appropriate selection of energy systems and (technological) solutions to reduce energy consumption could help achieve these goals.

4.3.1. Input, procedure and output data

The method to convert ENVI-met output into CEA input consists of three main phases. In the first phase, the spatial model for the selected case study is built in ENVI-met 4.0 and simulations are performed using the simple forcing method using weather data for the selected days. Secondly, output data for air temperature, wind speed and relative humidity are exported and aggregated in a 3D buffer around single buildings in a GIS platform. In the third phase, the aggregated data are imported in the CEA software and used as boundary climatic conditions for the calculation of the energy demand for each building in the simulation domain. The method has been employed in the selected case study for the hottest and coldest day in a typical year for a total of two cases. In Case 1 a simple spatial model that includes only building geometry is used, with homogeneous building materials, while in Case 2 trees and vegetated surfaces are added to the model. In order to observe the impact of using microclimate data, a Case 3 is also simulated with CEA using climate data input from the closest rural weather station.

TABLE 1.5 Description of simulation cases

CASE NUMBER	CASE 1	CASE 2	CASE 3
Case description	Coupling ENVI-met and CEA (without vegetation)	Coupling ENVI-met and CEA (with vegetation)	CEA simulation using weather station data
Simulation period	Hottest day: 18 August Coldest day: 12 January		

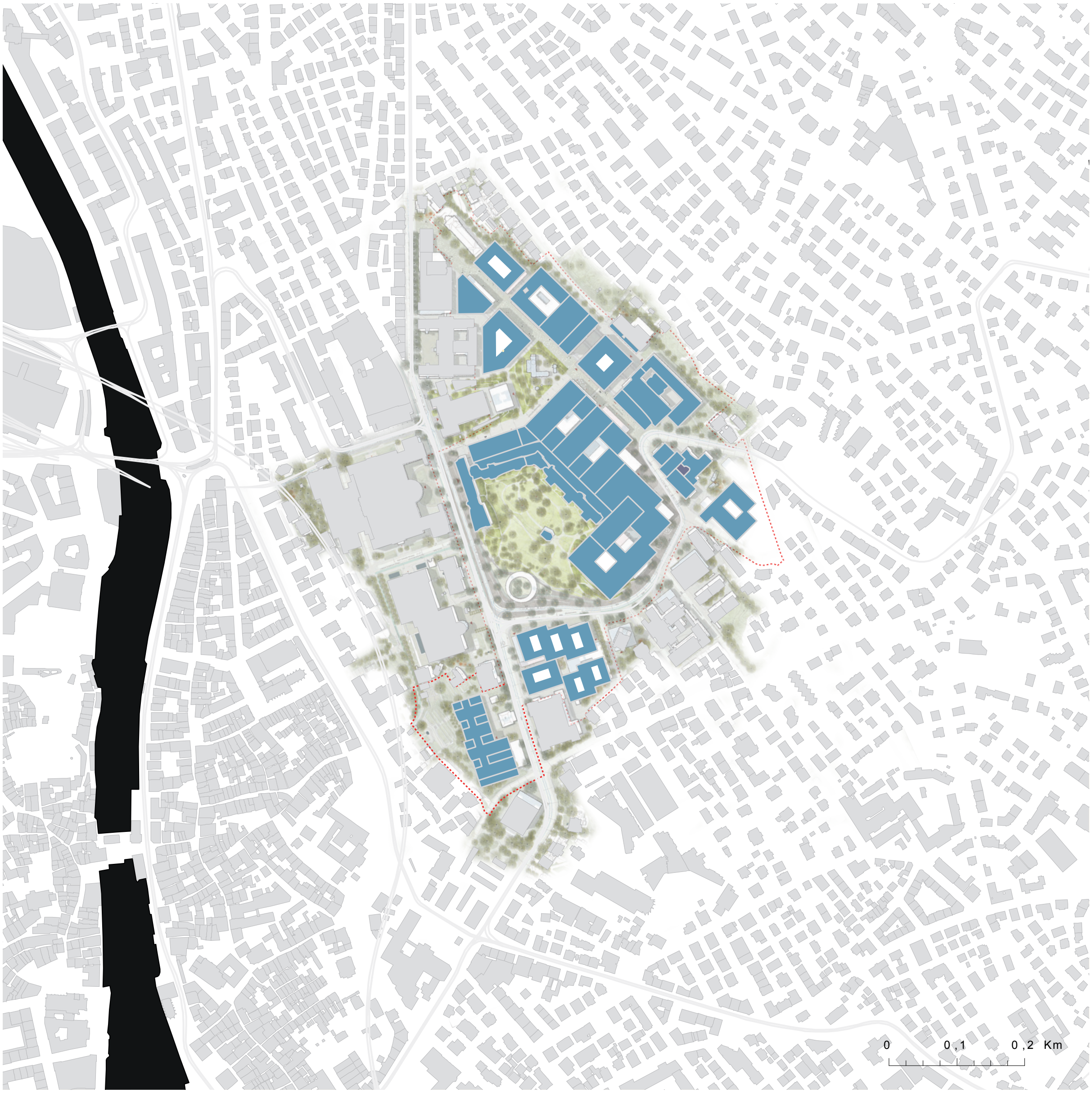


FIG. 4.1 View of the HQ Baseline scenario, elaborated from the 2014 Masterplan for the area [21].

ENVI-met model construction and parameters

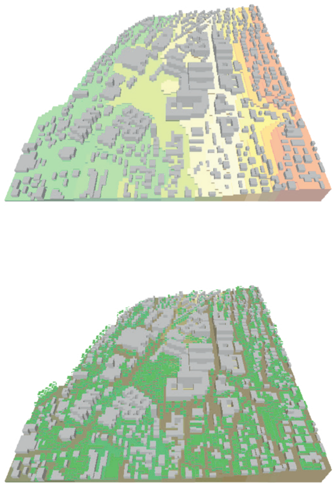


FIG. 4.2 ENVI-met models for the Hochschulquartier Baseline Scenario in Case 1 (top) and case 2 (bottom)

In order to obtain reliable simulation results for the area of interest – in this case the Hochschulquartier- it is necessary to model a larger area, firstly because numerical models do not work reliably at their models borders and the cells very close to them, and secondly, because the urban surroundings influence the microclimate in the area of interest.

In this case study, a first boundary has been drawn around the area of interest including adjacent street canyons and adjoining building facades. From this border an offset area of 100 m is taken as influence area. Based on the dimensions of the total area and the maximum number of cells available in ENVI-met, the cell dimensions can be defined. For the Hochschulquartier, a grid unit of 10x10x7m has been selected in order to cover the area of study plus the area of influence. Based on the grid dimensions a three dimensional spatial model is built in the ENVI-met simulation tool, assigning properties of building height, topography, vegetation and soil and surface materials to each cell in the grid. Weather data information derived by Meteonorm [36] for the hottest day and the coldest day of a typical year constitutes the second group of input parameters. Data of dry bulb temperature, relative humidity, wind speed and wind direction are used as forcing climate variables. Based on the spatial models and weather inputs, Case 1 and 2 have been simulated for the hottest and coldest days.

TABLE 1.6 ENVI-met settings

Domain:	1100 m x 1200 m x 210 m
Grid size	110 x 120 x 30 (dx = dy = 10m, dz = 7m)
Simulation time	36 hours (selection data to analyze for 24 hours)
Plants in Case 2	Grass 0.5 m; Trees 10, 15, 20 m
Ground	Asphalt concreate, Loamy soil

Data aggregation for CEA input

ENVI-met output data for air temperature, relative humidity, and wind speed and direction have been aggregated in order to be used in CEA software as depicted in Figure 4. The procedure for aggregation makes use of the concept of 3D buffering around a building shape. As data from ENVI-met can only be exported in a two dimensional resolution, i.e. for each horizontal layer of grid cells, output for all horizontal planes covering a building has to be extracted and consequently aggregated, in order to obtain a 3D buffer of data around that building. The aggregation is performed using a GIS platform, where cell values for each horizontal layer are spatially joined on a new grid, equal to the ENVI-met grid. Next, hourly values of all cells around the building envelope are selected, summed and averaged. The results of this phase are mean hourly data of air temperature, wind speed and relative humidity for building ID.

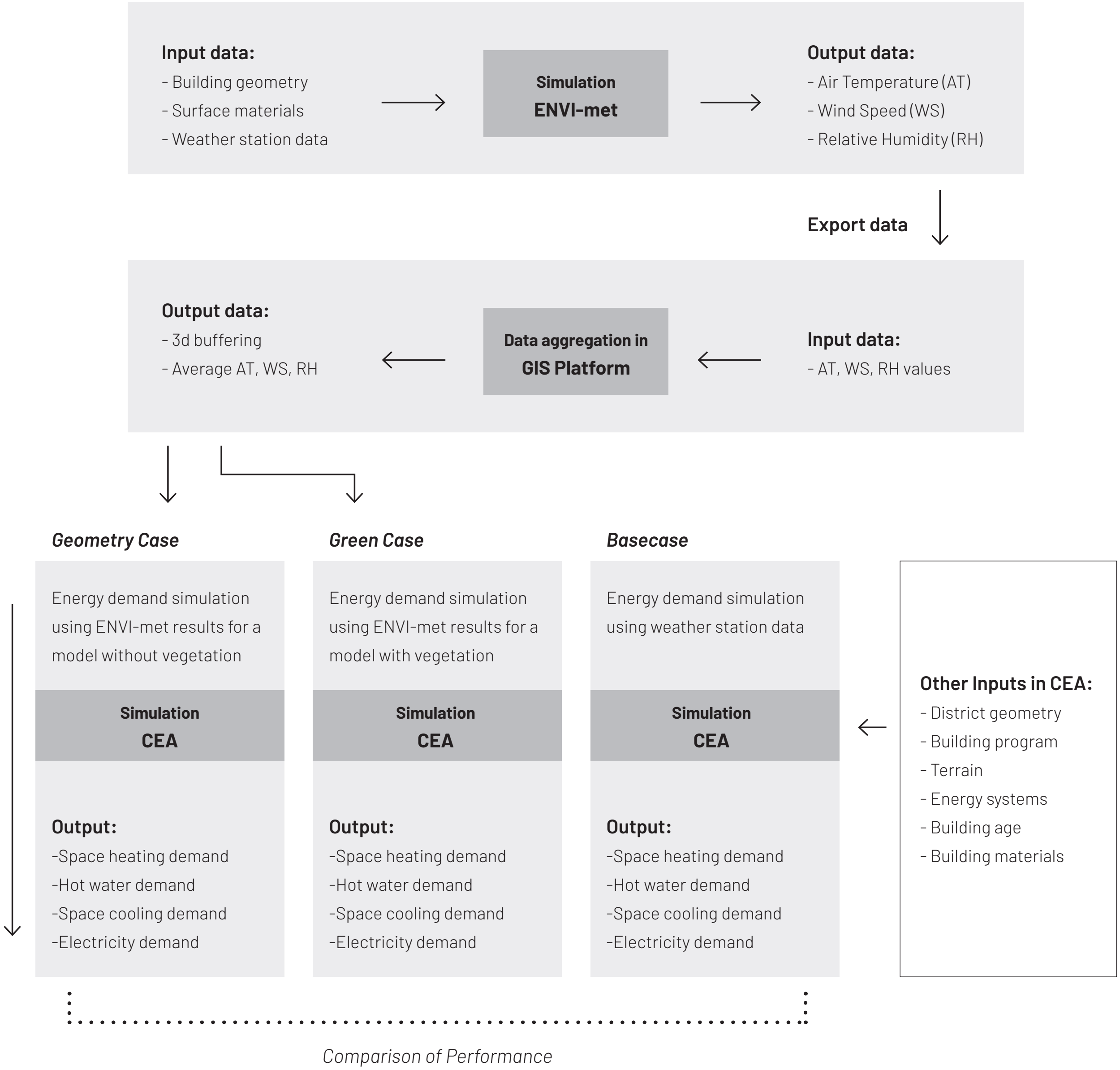


FIG. 4.3 Methodological scheme

CEA model construction

In order to integrate with ENVI-met, the simulated hourly data for the selected parameters was used to substitute the input general weather data from the closest weather station (SMA) for a typical year from the Meteonorm database. The outdoor temperature is used in calculating the thermal loads in the building, which in CEA is done through a resistance-capacitance model based on the methodology described in ISO 13790 [37]. The detailed calculation methods are discussed in Fonseca & Schlueter [38]. The relative humidity, on the other hand, is mainly used in the latent load calculations, which are based on ISO standard 52016-1 [39]. Finally, the wind speed and direction are used for the CEA dynamic infiltration calculation [40].

The CEA demand model produces hourly results on the demands for heating, cooling and electricity for the various services to be provided in each building, as well as information on the number of people in the building at each time step, the losses through different building components, potential sources for heat recovery, etc.

4.3.2. Limitations

The resolution level of the coupled simulation is determined by the dimensions of the modelled area and by the limitations of the individual modelling packages used. Where CEA has the capacity to carry out analysis on a city scale, ENVI-met has a maximum model size. Its model supports a three-dimensional grid with a total number of cells equal to 1875000 (250x, 250y, 30z), therefore to increase the urban area to be modelled implies an enlargement of the cell dimensions with a consequent loss of spatial resolution. The acceptable level of resolution has to be evaluated case by case. In the case examined, taking in account the dimensions of the urban area under consideration, as well as the size and geometrical characteristics of the buildings, cell dimensions were defined at 10mx10mx7m.

In ENVI-met, this level of resolution implies that buildings are represented as volumes without detailed façades characteristics. However, in order to estimate thermal gains and losses, building materials transmittance values and ratio of glazing area are included in CEA model. Furthermore, it has to be noted that in Case 2 the vegetation is considered only in the microclimatic modelling. Green surfaces and trees are not taken in account by DAYSIM and CEA for irradiance calculations.

Concerning linking spatial units, a geometrical approach has been adopted in order to analyze different building typologies. Due to the geometrical complexity of the buildings in the Hochschulquartier (HQ), it was decided to conceptually analyze those by dividing the 3D shape in parts. The splitting of complex building forms in simple geometrical elements according to building height, allows for a higher precision in analyzing microclimate and energy characteristics, since this process prevents the recurring to averaging of the building heights. On the other hand, this procedure presumably leads to a theoretical estimation of performance because in reality indoor thermal behavior results from indoor air flows exchange between the different parts of the complex building organisms.

4.3.3. Comparison of microclimatic and metereological data

The method described in section 4.2 has been applied on the HQ case study to demonstrate the benefits of the presented integrated model. In order to analyze the effect of microclimatic phenomena under different seasonal conditions both the coldest and hottest days in a typical year have been simulated as representative of extreme winter and summer conditions.

ENVI-met results

The mapping of the ENVI-met atmospheric results for three hours is shown in Figure 4.4 and 4.5. For the hottest day, the comparison between Cases 1 and 2 indicates that green surfaces contribute to lower temperatures in the HQ during night and day time. While the cooling effect is more visible in the east part of the district, at night a heat trap effect is visible in the Campus boulevard and in the south side of the hospital. In the coldest day, Case 2 (the model enriched with trees and green surfaces) shows slightly higher temperatures compared with Case 1 (without vegetation) in diurnal hours, in particular in the street canyons. The results suggest that the reduction of wind speed due to the presence of trees as roughness elements could mitigate the extreme cold in this winter day.

Coldest day of the year (district)

This section analyses the site-specific climate results in Case 1 (without green) and Case 2 (with green) for the Hochschulquartier, through comparison with the same measured variables derived by the selected rural weather station. For the coldest day, Figure 4.6-4.8 show the comparisons for air temperature, wind speed and relative humidity data, respectively, observed in the district.

Regarding air temperature, the results show that the urban environment has much smaller diurnal temperature curve compared to the rural environment. Temperature differences between the urban and rural environment are relatively small in the period between sunrise and sunset. During most of the day, the air temperatures in the urban environment are higher, showing a modest heat island effect of max to 2.5°C, which manifests mainly during the night. Figure 4.6 shows that the average air temperatures in the case with green are slightly higher, presumably because trees limit outgoing long-wave radiation and decrease wind speed. Furthermore, there is hardly any evapotranspiration at these low temperatures. The average wind speeds are lower in the urban case with green, as the trees assert more friction, and significantly lower than the wind speed in the free field (Figure 4.7). The relative humidity curve is rather flattened (Figure 4.8), with higher humidity levels occurring in the night and early morning, like at the rural site, as a result of the dropping temperatures. As mentioned before, below 0°C there is no evapotranspiration and therefore no active cooling effect from the vegetation. Remarkably, relative humidity is slightly lower in the case with green, probably because of the slightly higher air temperatures (and consequently higher moisture capacity).

Hottest day of the year (district)

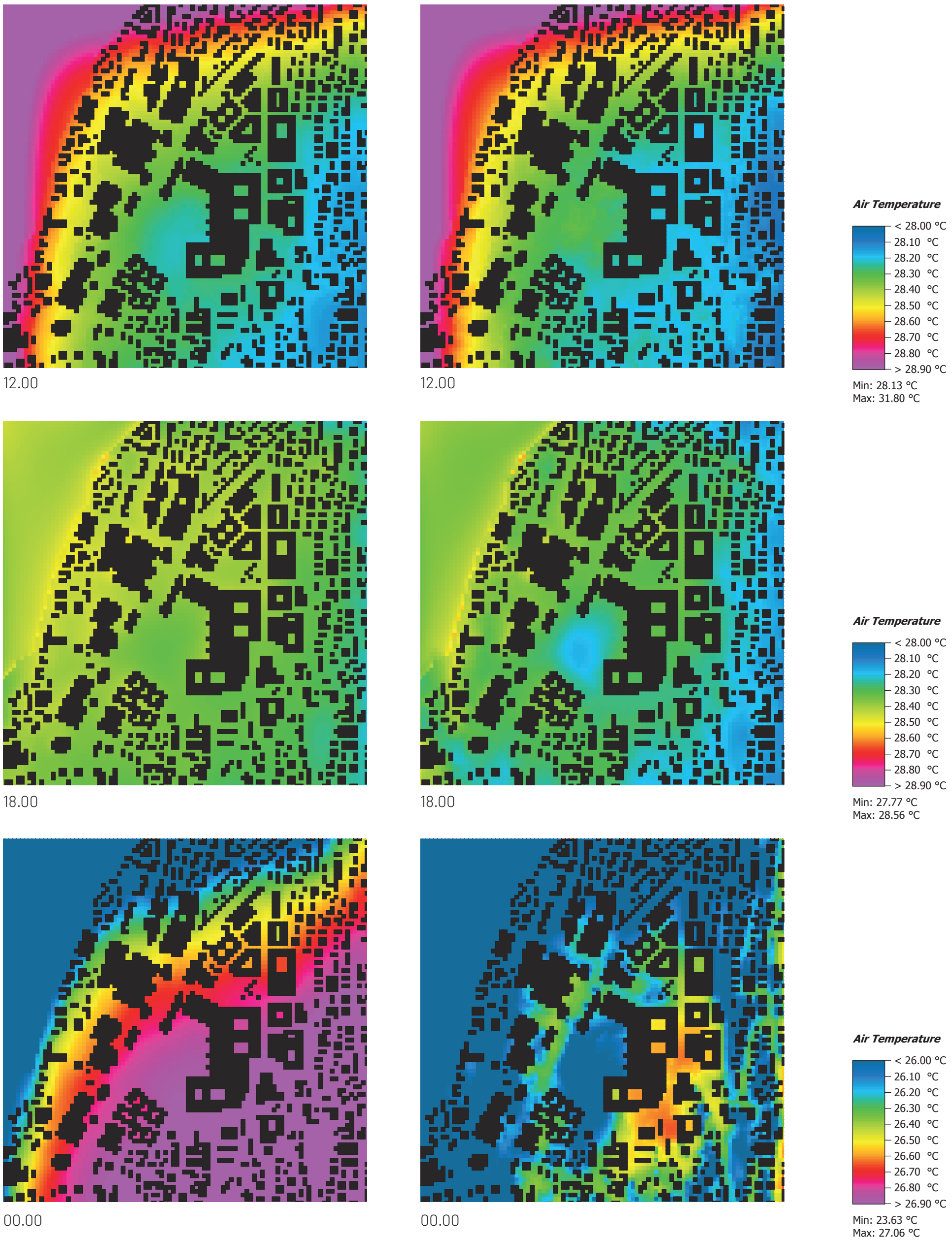
A significant variation between day and night time can be observed regarding average air temperature around the building units (Figure 4.9). In Case 1 and 2 air temperatures during solar time are significantly lower than the rural ones, with a maximum difference of 3°C around 11:00. In contrast, in the hours before sunrise and after sunset, the curves are inverted, registering lower rural air temperatures.

Heat accumulated by urban surfaces and released during night hours contribute to the higher urban air temperatures between 25-26.5°C. In night hours, the air temperatures in Case 2 are observed to be lower than in Case 1 around 0.5°C) suggesting a minor cooling effect of vegetation. In the second comparison it was found that the already low meteorological wind speed, which in the selected day reaches no higher than 0.5 m/s, significantly decreases in both Case 1 and 2 (Figure 4.10).

Finally, data of relative humidity are analyzed for the selected summer day (Figure 4.11). In comparison with the hourly data from the rural weather station, average relative humidity in Case 1 and 2 is found to be significantly higher during the daytime. The maximum variation can be observed in the middle of the day when the simulated humidity reaches up to 57%. In both cases the peak of relative humidity is reached during the sunrise hour, registering a higher value of 3.5% for Case 1.

Day and night variations

In order to observe variations in air temperatures, relative humidity and wind velocity during a 24 hours period, average values for daytime and night time around each building are plotted. As observed in previous studies on the Urban Heat Island effect, air temperatures in cities are higher than rural ones, especially during night hours, caused by a difference in energy budget between urban areas and rural areas. Surface characteristics of urban structures and land cover materials, building density and openness to the sky of the street canyon directly influence processes of (solar) heat absorption and emission.



Case 1 (Baseline without vegetation)

Case 2 (Baseline with vegetation)

12.00

12.00

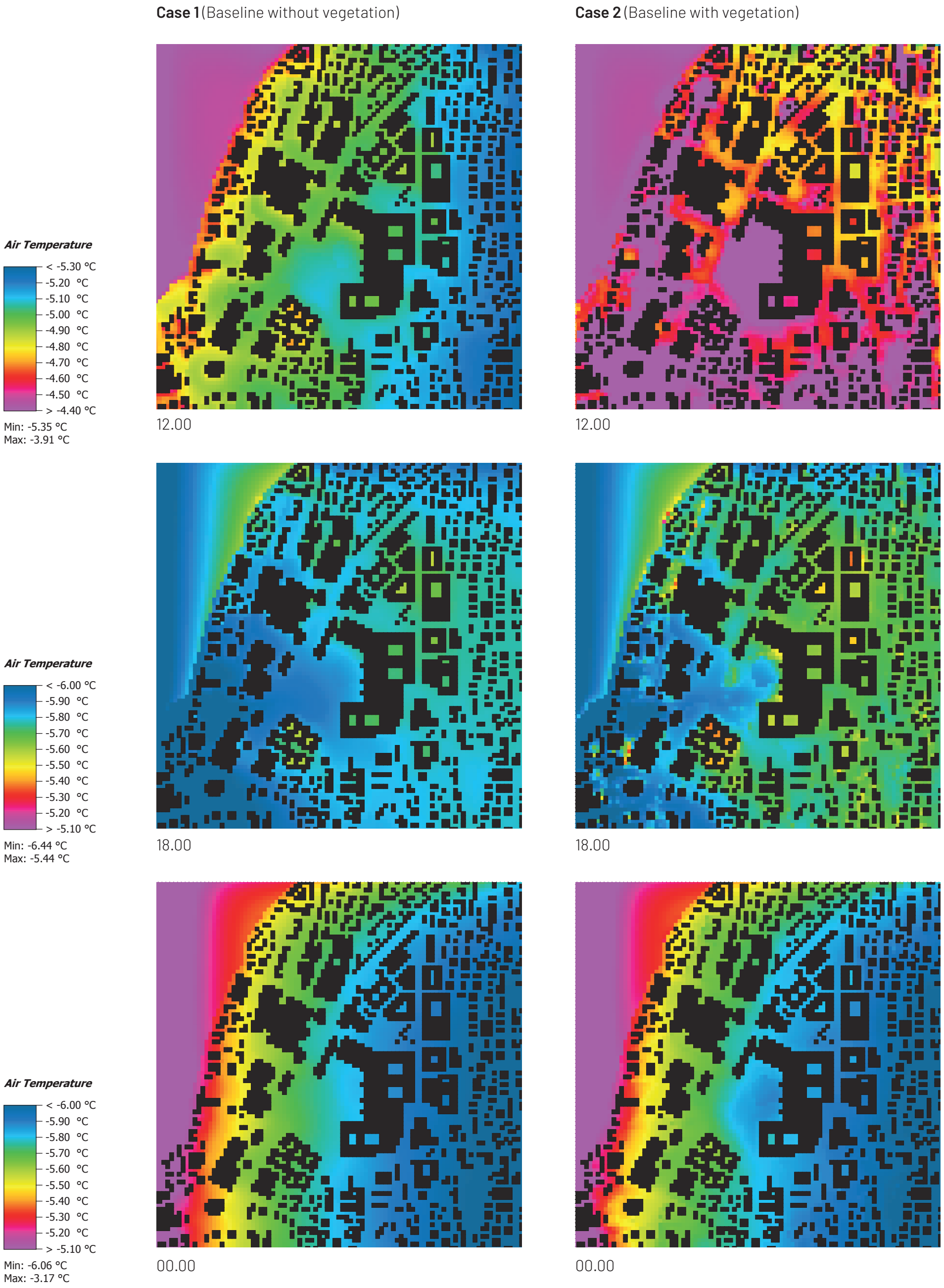
18.00

18.00

00.00

00.00

FIG. 4.4 Results for the Hottest day in a typical year


Case 1 (Baseline without vegetation)

Case 2 (Baseline with vegetation)

FIG. 4.5 Results for the Coldest day in a typical year

Coldest day

FIG. 4.6 Comparison of air temperature from the meteorological weather station (Case 3) and average air temperature around the buildings in Case 1 and 2 (resulting from ENVI-met) for the coldest day in a typical year.

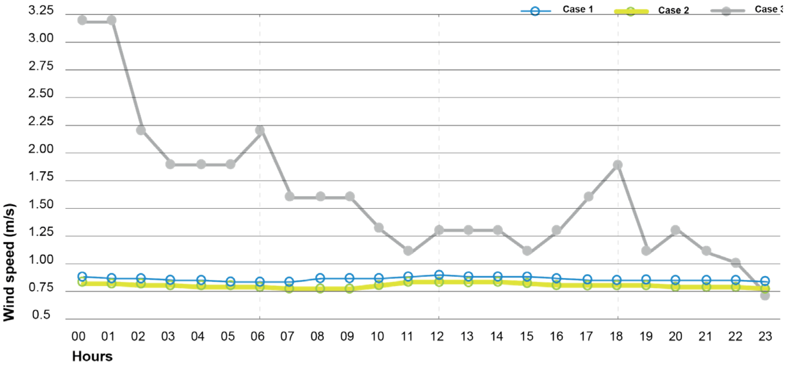


FIG. 4.7 Comparison of wind speed from the meteorological weather station (Case 3) and average wind speed around the buildings in Case 1 and 2 (resulting from ENVI-met) for the coldest day in a typical year.

FIG. 4.8 Comparison of the meteorological relative humidity from weather station (Case 3) and average relative humidity around the buildings in Case 1 and 2 (resulting from ENVI-met) for the coldest day in a typical year.

Hottest day

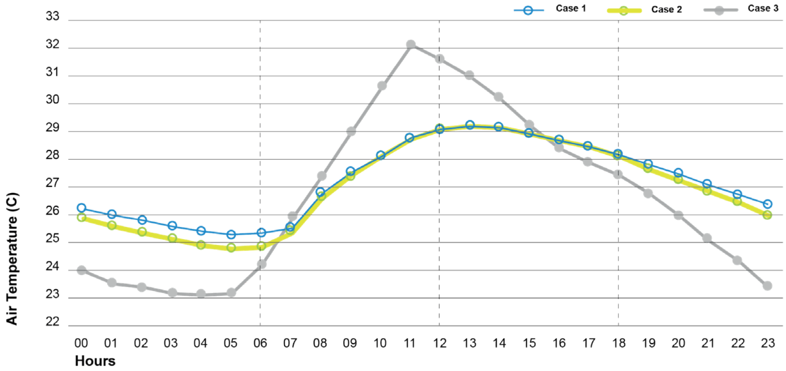


FIG. 4.9 Comparison of the meteorological air temperature from weather station (Case 3) and average air temperature around the buildings in Case 1 and 2 (resulting from ENVI-met) for the hottest day in a typical year.

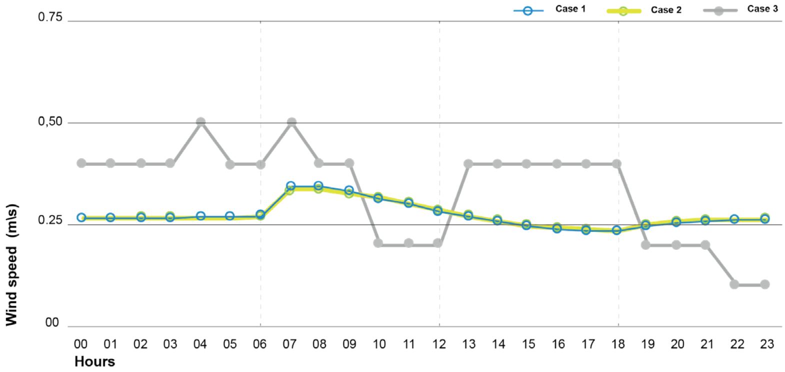


FIG. 4.10 Comparison of the meteorological wind speed from weather station (Case 3) and average wind speed around the buildings in Case 1 and 2 (resulting from ENVI-met) for the hottest day in a typical year.

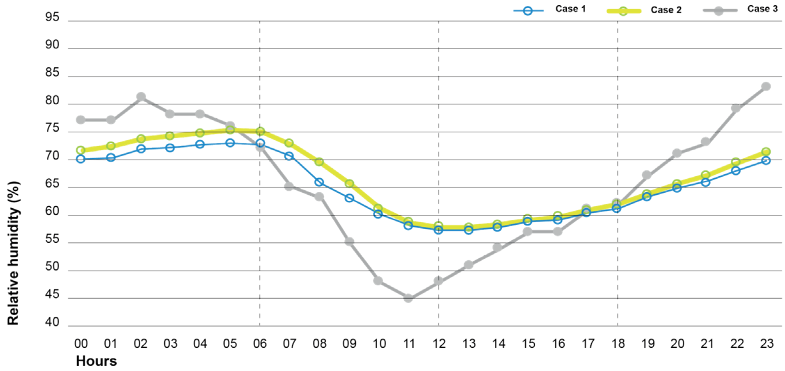


FIG. 4.11 Comparison of the meteorological relative humidity from weather station (Case 3) and average relative humidity around the buildings in Case 1 and 2 (resulting from ENVI-met) for the hottest day in a typical year.

Hottest day

Coldest day

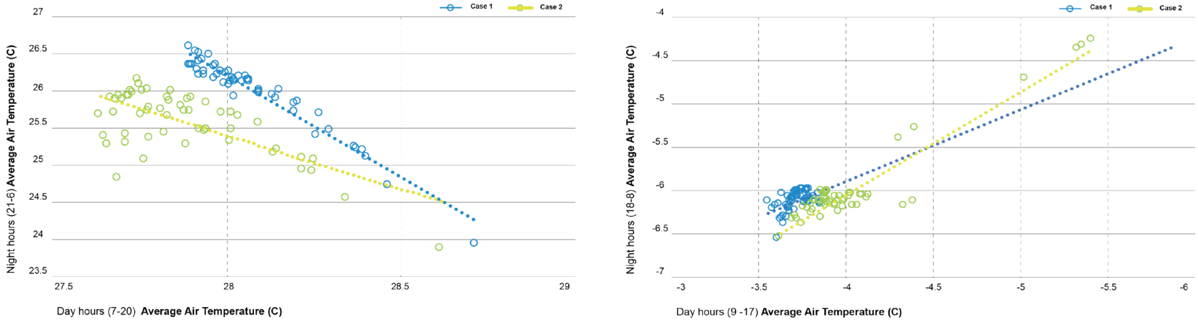


FIG. 4.12 Simulated outdoor temperatures around buildings

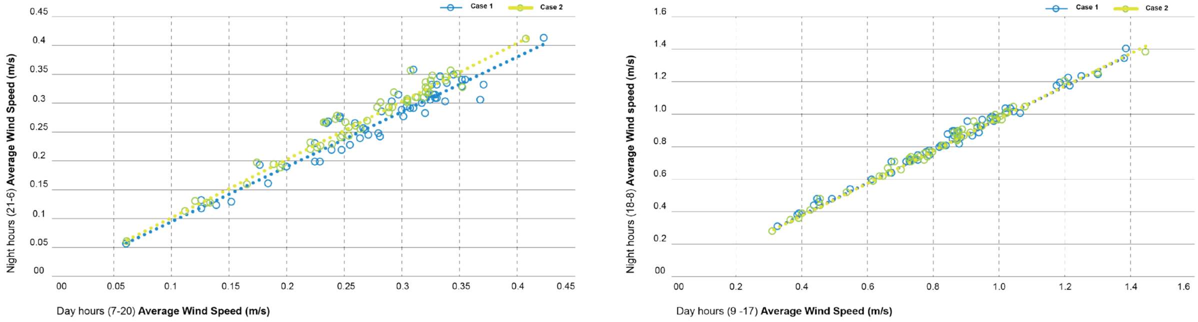


FIG. 4.13 Simulated wind speed around buildings

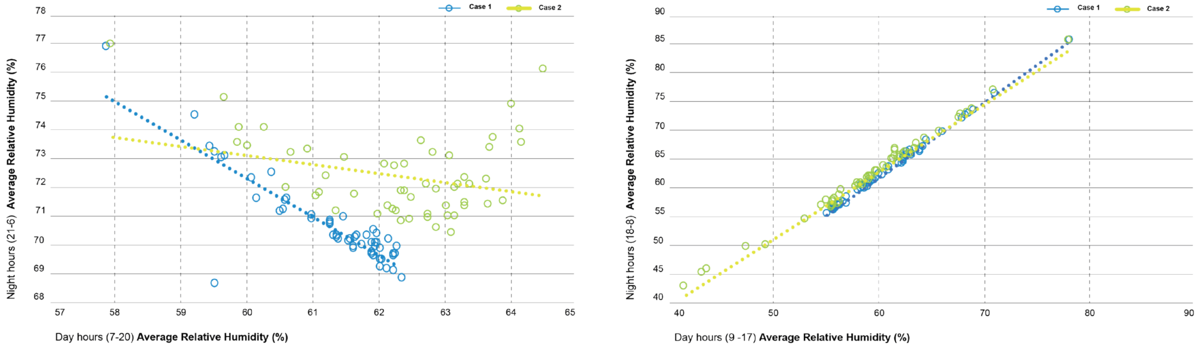


FIG. 4.14 Simulated relative humidity around buildings

In the case of the HQ baseline the relation between day and night values have been observed for Case 1, where building geometry and materials are taken into consideration, and Case 2, with the addition of vegetation components such as grass and trees.

The linear relationships observed in Figure 4.12 shows a diurnal reversal in relative temperatures around building facades: the lower the average diurnal temperatures, the higher the temperatures at night. This means that cooler environments around buildings during sun hours, for example due to the effect of building compactness and shadow, have limited capability in releasing the stored heat during night time. Larger variations are observed in the hottest day compared to the coldest day with average temperatures ranges of 2.5°C at night hours and around 1°C during sun hours. Within the coldest day the variations of average night and day temperatures range equally of around 0.5°C .

In the selected summer day, a negative linear correlation is also found between relative humidity during night and day hours (Figure 4.13); a higher relative humidity between 7am and 8pm relates with lower humidity during nighttime. In contrast, this relation is found positive during the winter day.

Regarding wind speed around buildings, Figure 4.14 highlights the presence of a similar pattern for the two days under study since a strong positive relationship is observed between average wind velocity during night and day hours.

Moreover, the comparison between values in Case 1 and Case 2 shows that the presence of vegetation has a significant cooling effect on the entire area by lowering average temperatures, and contributes to an increase in moisture during day and night hours, due to evapotranspiration. Differently, wind velocity sees a decrease in diurnal hours and tends to slightly increase during night when trees and green surfaces are simulated. These results highlight the importance of vegetation in decreasing air temperatures during summer time and building energy demand for cooling but indicate also the possible negative influence of trees in lowering the already low wind speed in the urban environment.

4.3.4. Comparison of energy performance with and without metereological data

Coldest day of the year (district)

Since all new buildings were assumed to be built to the Swiss energy efficiency standard Minergie, the space heating demand of the buildings in the area was on average extremely low at 14 kWh/m^2-yr for the baseline case without microclimate.

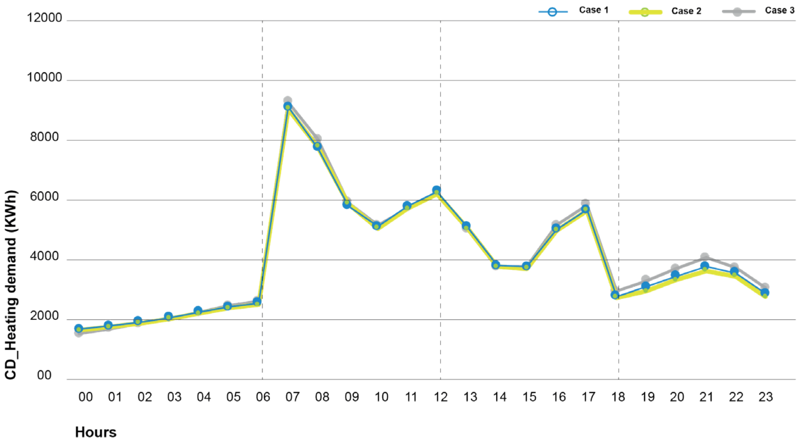


FIG. 4.15 Comparison of hourly heating load for the three cases on the coldest day in a typical year.

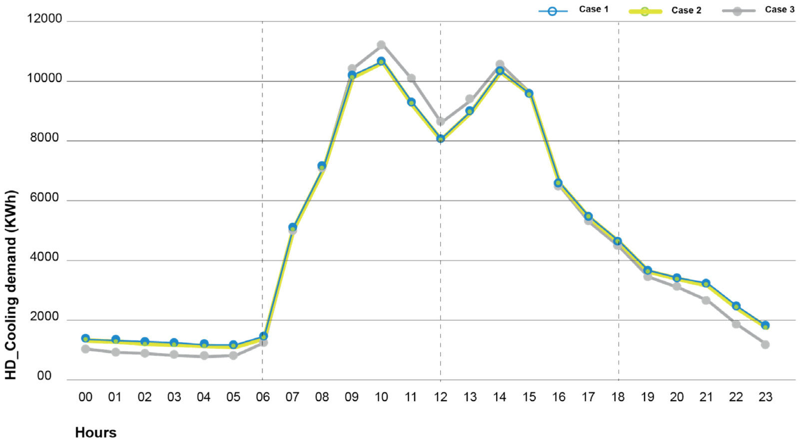


FIG. 4.16 Comparison of hourly cooling load for the three cases on the hottest day in a typical year.

As expectable, older buildings had a higher demand, reaching as much as 167 kWh/m^2-yr.

On the coldest day of the year, the space heating demand in the area for the baseline case without microclimatic effects ranged from 42 Wh/m^2 for a new, very efficient building to 1331 Wh/m^2 for a historical building in the new University Hospital, with an overall average of 147 Wh/m^2 for all the buildings in the area. When microclimate effects were taken into consideration, the space heating demand was decreased on average by 2% when the effect of greening was excluded, and 3% when the effects of greening were included. Similarly, the peak heating power for the entire district is decreased by 1.8% when the effects if microclimate are included, and by 2.4% when the effects of vegetation in the area were further included.

The effect is greatest for the three towers in the new University Hospital main building, which however also coincide with the buildings with the lowest space heating demand. The greatest overall decrease in the energy demand was seen in the new tower in the Gloriarank area, to the east of the case study. This building is in any case a very high performance building (16 kWh/m^2-yr), but on the coldest day of the year the space heating demand decreased from 204 Wh/m^2 for the baseline case to 183 Wh/m^2 for the case accounting for the effects of microclimate and greening. Likewise, the peak heating power for this building on the coldest day of the year decreases from 22 W/m^2 to 20.3 W/m^2 from the baseline to the case including the effects of microclimate and vegetation.

Hottest day of the year (district)

Due to the high level of insulation and the large internal gains in the buildings in the area, the space cooling demand in the HQ case is similarly significant, with 11 kWh/m^2-yr on average. The University Hospital's main building complex has the highest cooling demands at 14 to 22 kWh/m^2-yr, whereas older buildings either had a lower demand or no cooling system at all. On the hottest day of the year, the space cooling demand in the baseline case without microclimatic effects the average space cooling demand in the area was 185 Wh/m^2 (ranging from 11 to 366 Wh/m^2). When microclimatic effects were considered, the overall demand in the area increased by 2% when the effect of greening was excluded, and 1.4% when greening was included. The effect of microclimate on the peak cooling demand was more noticeable, with a 5% decrease in peak cooling power on the coldest day of the year.

The effect was once again more noticeable in the buildings with the lowest cooling demand (<100 Wh/m^2). Furthermore, older buildings showed a greater response to microclimate effects, while newer, highly insulated buildings had a much less significant effect. For the cases including microclimate effects, the daily peak in the cooling demand is lowered for several buildings, however the higher night time temperatures cause several buildings to require cooling earlier than when microclimate effects are not accounted for. The new building of the University

Hospital showed the greatest cooling power demand due to its high internal and solar gains and passive construction. Overall, the cooling power of the University Hospital's main building decreased from 17.9 W/m^2 to 16.9 W/m^2 when microclimate effects were taken into consideration.

4.3.5. Sensitivity analysis

This section investigates variations in building cooling and heating demand between the three cases for the 52 buildings in the area.

A sensitivity study is conducted by performing four multiple regression analyses with a Backward procedure. The aim is to understand the individual impact of selected parameters used in the coupled modelling on energy demand. In other words, to identify the factors that influence the variation in calculated energy demand when using microclimate boundary conditions in CEA. Thus, the energy performance variations between Case 1 (ENVI-met without vegetation & CEA) and Case 2 (ENVI-met with vegetation & CEA) and Case 3 (only CEA), constitute the following dependent variables:

- Heating variation (Wh/square m) between Case 3 and Case 1 results (HeC3-WMnoV)
- Heating variation (Wh/square m) between Case 3 and Case 2 results (HeC3-WMwV)
- Cooling variation (Wh/square m) between Case 3 and Case 1 results (CoC3-WMnoV)
- Cooling variation (Wh/square m) between Case 3 and Case 2 results (CoC3-WMwV)

The impact was analyzed for a selection of independent variables, divided in two categories. Direct parameters are those that describe system and geometry characteristics of the buildings (occupied hours, ventilation rate, set temperature indoor, U value of facades, envelope surface area, and surface to volume ratio), while the indirect parameters describe the morphological attributes of the urban context (Floor Space Index (FSI) and total green surface). These last parameters have been calculated for different buffer areas around each building with radii of 25, 50 and 100m.

As show in Table 3, the four regression models explain the variance in heating and cooling simulations results between 33% and the 71%. The selected variables better explain the variation for cooling demand (67% and 71%) than for heating demand (less than the 45%). This indicates a different impact of the selected building and context variables on energy loads during hot versus cold weather.

TABLE 1.7 Regression analysis between

			Unstd. Coeff.		Std Coeff.		
MODEL	R Square	VARIABLES	B	Std. Error	BETA	t	SIG.
Heating_HeC3_WM-noV	0.410	(Constant)	-.762	1.595		-.478	.635
		occupied_hours	-.181	.042	-.522	-4.350	.000
		U_avg	-1.376	.520	-.316	-2.648	.011
		FSI_50	-.584	.258	-.473	-2.266	.029
		FSI_100	.739	.384	.402	1.923	.061
HeC3_WMwV	0.330	(Constant)	-7.481	3.413		-2.192	.034
		occupied_hours	-.453	.114	-.515	-3.978	.000
		FSI_50	1.066	.398	.340	2.681	.010
		Green_area_100	.000	.000	.255	1.962	.056
Cooling_CoC3_WM-noV	0.715	(Constant)	-10.95	7.034		-1.557	.127
		occupied_hours	1.544	.183	.714	8.449	.000
		U_avg	11.784	2.315	.434	5.090	.000
		Surface_exposed	.000	.000	.160	1.721	.093
		FSI_50	3.893	1.249	.505	3.118	.003
		FSI_100	-6.716	1.798	-.586	-3.735	.001
CoC3_WMwV	0.673	(Constant)	-15.39	7.967		-1.933	.060
		occupied_hours	1.638	.207	.715	7.912	.000
		U_avg	10.527	2.622	.366	4.014	.000
		Surface_exposed	.001	.000	.228	2.297	.027
		FSI_50	3.547	1.414	.435	2.508	.016
		FSI_100	-6.513	2.037	-.537	-3.198	.003

Two variables are found to be statistically significant ($p<0.05$) in all four models: ‘occupied hours’ and ‘Floor Space Index’ in a radius of 50 m. The former is a behavioral component at the level of the individual building which influences cooling and heating loads, the latter expresses the building density of the urban fabric around the building. As found in previous studies, the density of the urban context affects thermal gains as it is responsible for the creation of shadow patterns and changes of wind flows around the buildings. The difference in results between the single and coupled models thus demonstrates the sensitivity to these thermal processes that depend on form attributes of the close context in both hot and cold seasons. Different results can be observed regarding the impact of the U-value variable, which is statistically significant in three regression models (HeC3-WMnoV, CoC3-WMnoV, CoC3-WMwV). A negative linear relation has been found between U-value and heating demand difference between Case 3 and Case 1, while a positive relation emerges for cooling demand in both regression models for the hottest day. In all cases variations are larger for buildings with higher thermal transmittance, but when microclimate boundaries are used in CEA, heating demand tends to decrease, while cooling demand is observed to increase.

Moreover, when the coupling method is used for the assessment of cooling demand in the cases that include vegetation, two other variables are found to be significant: Floor Space Index at 100 meters radius and the area of building surface. Parameters describing the amount of vegetation in the building surroundings do not seem to impact cooling demand variations. However, the missing significance of greenery related variables can be associated with the partial inclusion of green areas and trees in the spatial models, as these components are used to calculate air temperatures, wind velocity and relative humidity in ENVI-met but not included in CEA and in its radiation module, in other words, shading of the building envelope and windows by trees is not taken in account in CEA. As a consequence, the thermal effects of greenery are only partially taken into consideration in the energy modelling.

4.3.6. Discussion of results for the Zurich case study

First, from a microclimate perspective, an atmospheric urban heat island effect is observed in the area. Compared to the measured data from the weather station, local temperatures are higher during the night and wind speed is mitigated for the two days analyzed. The consideration of these local climatic patterns in energy demand calculation leads to a general increased building cooling demand on the hottest day, representing the cooling season, and a lower building heating load during the coldest day, representing the heating season. The difference in impact for the buildings taken into consideration likely depends on the level of envelope insulation and air tightness, position and geometrical characteristics of different buildings.

Due to the general low wind speed and its little variation in the area, heat transfer by wind convection on building envelopes has likely an almost insignificant impact on energy load variation during the hottest day. Therefore, we argue that on this day, air temperature and relative humidity variations are the main responsible microclimate factors for the deviations in building energy demand. Previous studies also found that air temperature change is the main factor that affects energy load variation [41, 42]. Green areas and vegetation around buildings clearly affect the space cooling demand as a consequence of the cooling effect by evapotranspiration on air temperature in the night hours. However, it is an important factor also in winter days since it contributes to lower space heating demand. The reason could be found in the capacity of vegetation to lower wind speed (in the coldest day) and resulting heat losses thought the building envelopes. A sensitivity study is conducted to understand the individual impact of parameters used in the coupled modelling on variation of energy loads. Different variables are found to be statistically significant predictors. Occupied hours, u-values, and Floor Space Index have an impact on the variation in both heating and cooling demand when microclimate boundary conditions are used in CEA. In particular, the density of the building surrounding calculated with radii of 50 and 100m appear to be an important factor that mediates between form and microclimatic processes.

4.4. Almere case study

4.4.1. Case study description

The same method applied in the Zurich case study was used to simulate the energy demand of the planned energy-neutral residential area in Almere, Netherlands, on an extremely hot day. The project for the Floriade district was developed with the initial purpose of hosting the International Horticultural Expo in 2022. However, the new city neighbourhood has been designed to accommodate 660 new residential units after the event and become an example for sustainable and liveable urban areas. Surrounded by a lake and conceptually structured on an orthogonal grid, the site design is shaped by the 'arboretum', a green structure composed by 3000 plant species.

ENVI-met model

First, geometrical data and attributes for buildings, land cover materials, vegetation and energy supply systems have been collected. This information is used to build two scenarios that will be modelled with the goal of analysing the impact of the designed settlement and vegetation on the future local climate. Only the new street network and buildings are modelled in the first scenario, while green areas and trees are included in the second scenario.

In a second phase, models are created by a discretization process of geometries and materials and microclimate simulations are performed by using weather data from a weather station nearby. Urban microclimate simulations are carried out using ENVI-met (version 4), a three-dimensional prognostic microclimate model designed to simulate the interaction between surfaces, plants and air in an urban environment. It is widely used to estimate and assess outdoor thermal comfort and the impact of the urban microclimate on building energy use.

An area of influence of 100 meters from the borders of the district was included bringing the size of the case study to one square kilometrekilometer. A grid with cell resolution of 4x4x6m was used to build the spatial models including geometrical and topographic characteristics. For all scenarios' materials were applied according to the masterplan: light color concrete as street material, sandy loam for soil, and six classes of vegetation were identified based on the average height of the plant type.

FIG. 4.17 View of the Almere Masterplan

Simple plants were used from the ENVI-met database for the six classes: grass, hedge (2m and 4m), and trees (10, 15 and 20m).

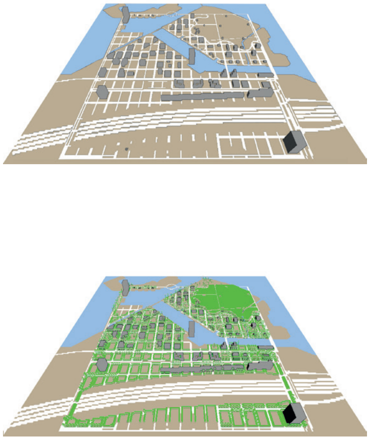


FIG. 4.18 ENVI-met models for Almere Floriade Baseline Scenario in Case 1 (top) and Case 2 (bottom)

Input data for the full forcing of weather conditions, the 19th of July 2006 was selected as an extremely hot day with clear sky. For this day data from Royal Netherlands Meteorological Institute weather station of Lelystad were extracted for the simulations. In these two simulations, differently from the Zurich cases, a full forcing method is used in ENVI-met. This means the diurnal cycle is simulated with hourly inputs of wind direction and speed derived from the weather station.

In a third step, the results obtained for the parameters of air temperature, wind speed and relative humidity are selected in a 3D buffer around the buildings and aggregated to be used as boundary climate conditions in the energy simulation tool. The values extracted were aggregated for each building in a second stage on a GIS platform.

CEA model development

District energy simulations are carried out using the City Energy Analyst (CEA). This tool uses a combination of simplified physical models and building archetypes to simulate the demand and energy production potential of urban districts. Microclimate effects are assessed in CEA by modifying the original weather file with the results extracted in the previous step for the day being assessed. Thus, space cooling consumption patterns in the two scenarios can be compared against a baseline simulation using the weather data from the rural station. Given the large amount of data required for urban-scale energy demand simulations, CEA uses a set of building archetypes and predefined databases to simplify the inputs required from the user. As the first CEA case study located in the Netherlands, however, such databases needed to either be created or adapted from the Swiss context.

Data sources and boundary conditions:
The buildings are all to be built in 2020 and must, according to the Dutch regulations, fulfil the required technical reference values described in the Building Decree [43] and the National Plan Nearly Zero-Energy Buildings (BENG) [44]. The databases fitting the Dutch standard were only implemented for state of the art building system technologies and building materials. According to the described scope of the project, any database and archetype not used for the demand simulations of Almere was not expanded but simply copied from the Swiss database. Both countries being in a similar climatic zone and having a similarly developed building stock, can be a reasonable justification for this approximation. Databases sensitive to the demand results are adjusted. The EPBD (Energy Performance of Buildings Directive) issued in 2010 by the European Union with the aim to improve energy performance of buildings, is on its way to being implemented by the member states [45]. The Netherlands, having begun with the implementation of the topic in 2008 and updated it several times since, has reached an agreement defining that after 2020, all newly

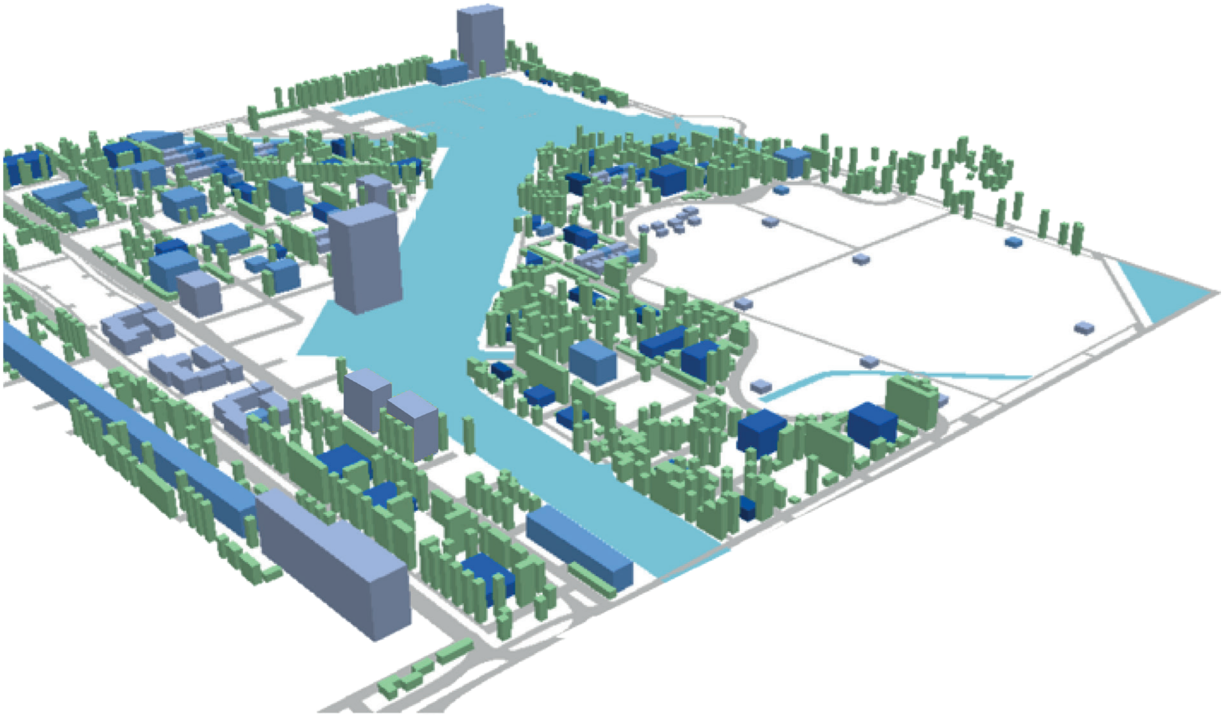


FIG. 4.19 View of the case study Floriade 2022+ as created for CEA. Buildings are shown in blue, while the green blocks represent greenery and were only used for shading analyses.

built residences have to reach the Nearly Zero-Energy Building (NZEB) [46]. The National Plan Nearly Zero Energy Buildings defines required thermal performance and energy consumption values for newly built dwellings, offices, public buildings and others. In this report many values are based on the reference house 'Apartment block' [47]. While assembling the database in CEA, the BENG and Dutch Building Decree are taken as often as possible as a substitution for the SIA standard of Switzerland [48] used in CEA. Whenever the Dutch requirement values were not sufficient for the CEA input the Swiss standards or European reference values were chosen.

TABLE 1.8 Building envelope properties

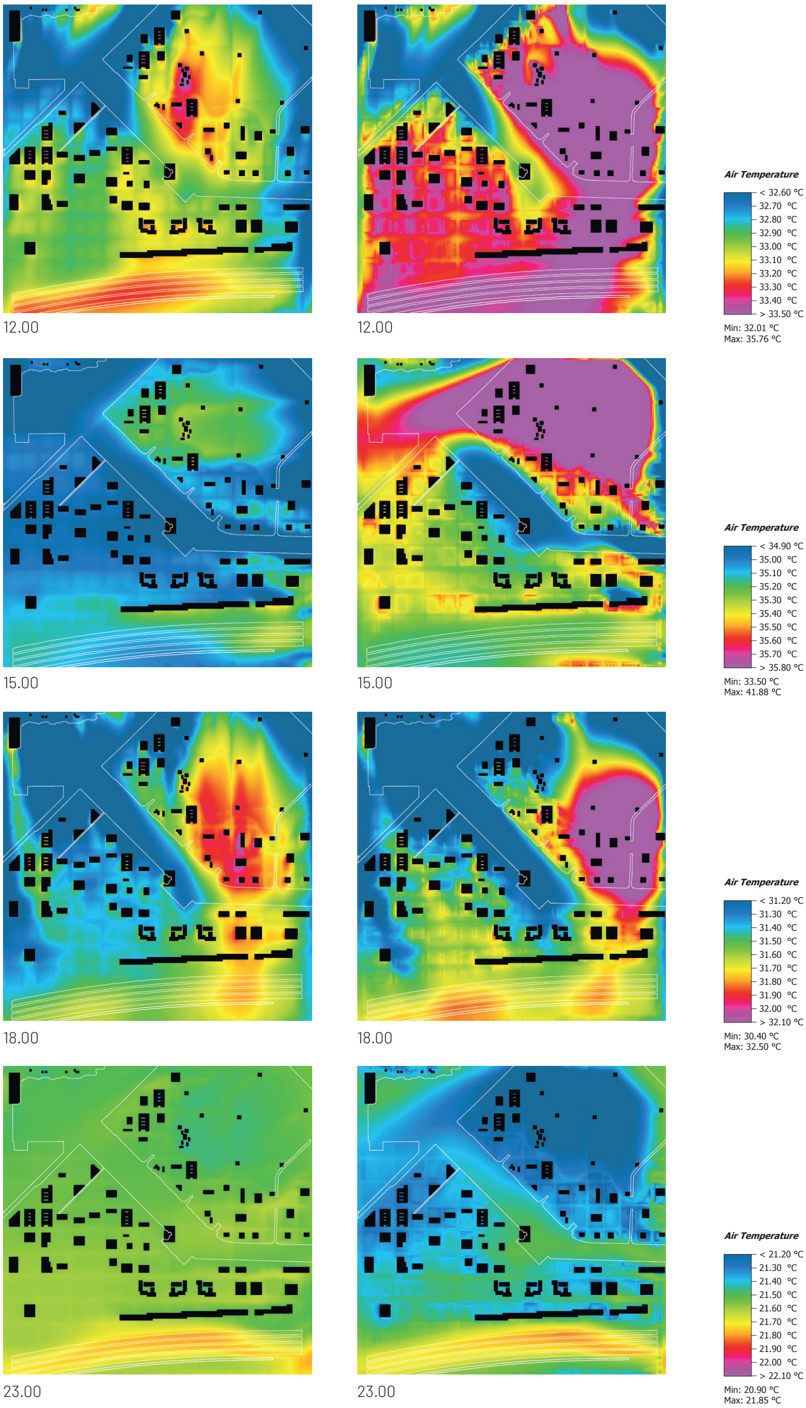
DESCRIPTION	U-VALUE (W/m^2-K)	ABSORPTIVITY	EMISSIVITY	REFLECTIVITY	G-VALUE
Walls and Roofs – Light	0.2	0.4	0.9	0.6	–
Walls and Roofs – Dark	0.2	0.85	0.9	0.15	–
Window	1.5	–	0.84	–	0.595

New materials for the envelope (wall, window and roof) were defined as shown in Table 1.8. The values were chosen in line with the BENG regulations and the Building Decree where minimal thermal resistance values for each component are defined. In order to analyze the effect of materials on urban microclimate and energy demand, a "dark" (high absorptivity) and a "light" (low absorptivity) version of each opaque material was defined. Regarding building energy systems, an energy grid is planned to supply the heating and cooling loads throughout the year [49]. It is thus assumed here that the full cooling and heating loads are supplied by floor heating and cooling. Finally, the occupancy schedule of buildings in the Dutch context was analyzed. Guerra-Santin and Silvester [50] for example suggest occupancies for residential houses, which however do not include appliance schedules nor DHW patterns.

The article was still used to implement an approximated occupancy schedule based on what it suggested. All in all the occupancy schedules were held similar to the Swiss reference case. Furthermore, the article makes it clear that there is a big discrepancy between actual and predicted energy consumption in building and links that to the inexact simulation input data for the building envelope and the use of standard occupancy data. While European standards suggest room temperature set-points similar to Swiss standards, a nationwide survey carried out by the Dutch Ministry of the Interior and Kingdom Relations [51] that compiles information about the characteristics of 4800 residential buildings and over 69000 household questionnaires regarding occupant behavior and household characteristics showed that actual Dutch households typically operate at much lower temperature. Hence, a set-point temperature of 19°C as suggested by this survey was used. Finally, the weather file for a typical year in nearby Lelystad was used for the simulations [51].

Case 1 (Baseline without vegetation)

Case 2 (Baseline with vegetation)



12.00

12.00

15.00

15.00

18.00

18.00

23.00

23.00

FIG. 4.20 Air Temperature comparison

4.4.2. Results and analysis

The results from the ENVI-met simulations are shown in Figures 4.20-4.22. Comparing the scenarios with and without vegetation, it can be seen that air temperatures are higher in the scenario with vegetation during day hours, but lower for the north and central part of the area in the early morning (6 am) and late evening (11 pm). In contrast, relative humidity is stably higher in the scenario with vegetation, due to the evapotranspiration process of vegetation.

Wind speed is largely decreased in the scenario with vegetation, although heterogeneously distributed throughout the area. The main mitigation of flow velocity takes place in the north-east of the Floriade area, where the density of trees is higher, but a clear decrease in wind speed is also visible around the blocks with the arboretum.

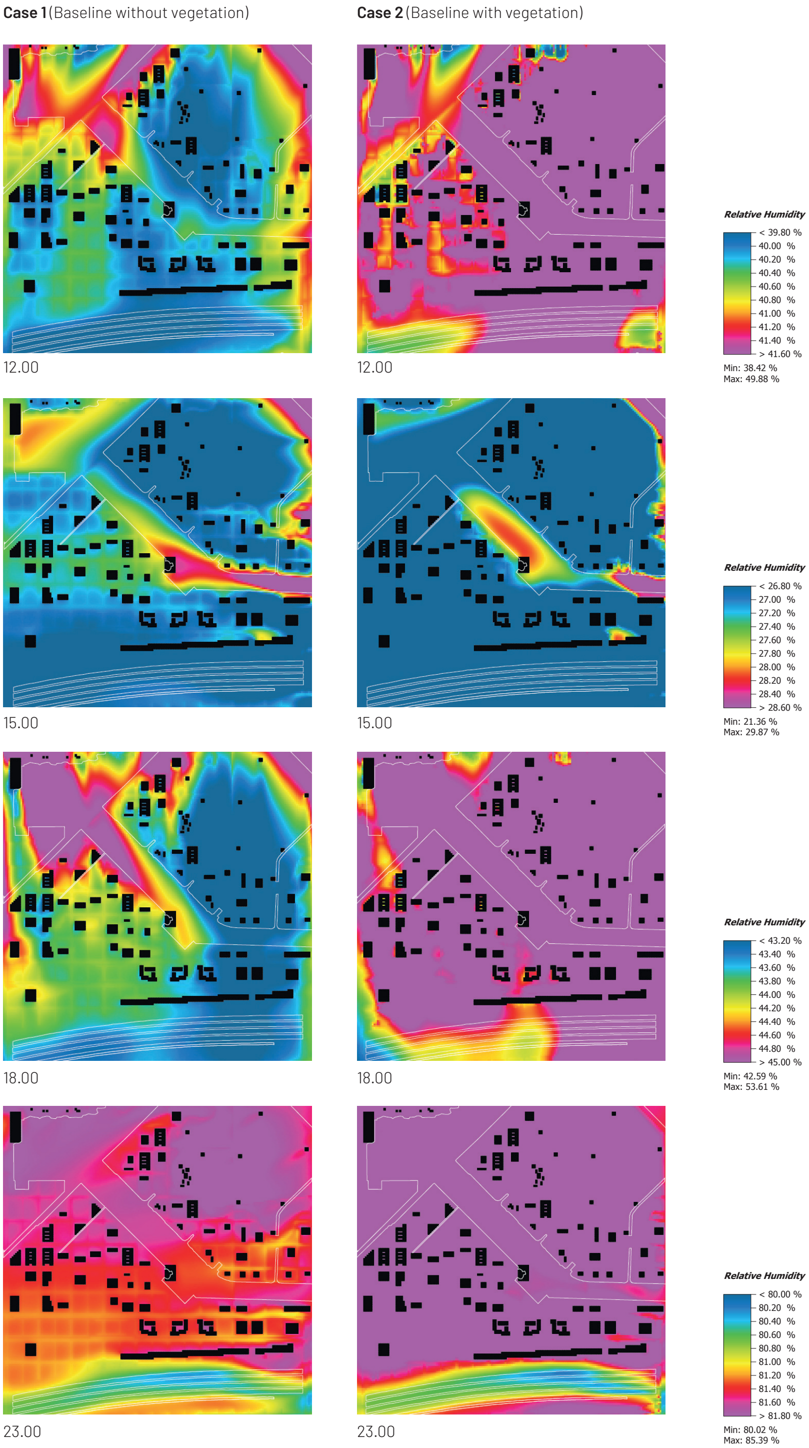
Comparison of microclimatic and meteorological data

The simulation results of the two scenarios described before are compared here with the measured data from the weather station in Lelystad. The hourly patterns for the variables of air temperature, wind speed and relative humidity are analyzed at the scale of the district.

In the extreme hot day under analysis, a significant variation in average air temperature around the 260 buildings is observed. While the meteorological station reaches a maximum temperature of 34°C, local temperatures at the Floriade rise to 35°C in scenario 1 (without vegetation) and to 37°C in scenario 2 (with vegetation). As shown in Figure 4.23, air temperatures in the early hours of the day (until 10 am) and in the late afternoon (after 8 pm) are similar for the two Floriade scenarios and the rural weather data. Conversely, during day time, local Floriade air temperatures are significantly higher than rural ones with a maximum difference of 3.4°C and 1.6°C for the scenarios with and without vegetation, respectively.

The simulation results strongly indicate that the presence of vegetation in the district contributes to increasing air temperatures during the central hours of the day. These results are in contrast with previous findings regarding the cooling effect of greenery in urban areas.

However, a second comparison in Figure 4.24 shows a significant decrease in wind speed, which drops from a maximum of 4 m/s in the rural measurement to 1.7 m/s in the scenario without vegetation and further decreases when vegetation is taken into consideration. Finally, data of local relative humidity are found to be higher along the entire day except for the hours between 3 and 5 pm (Figure 4.25).


Case 1 (Baseline without vegetation)

Case 2 (Baseline with vegetation)

12.00

12.00

15.00

15.00

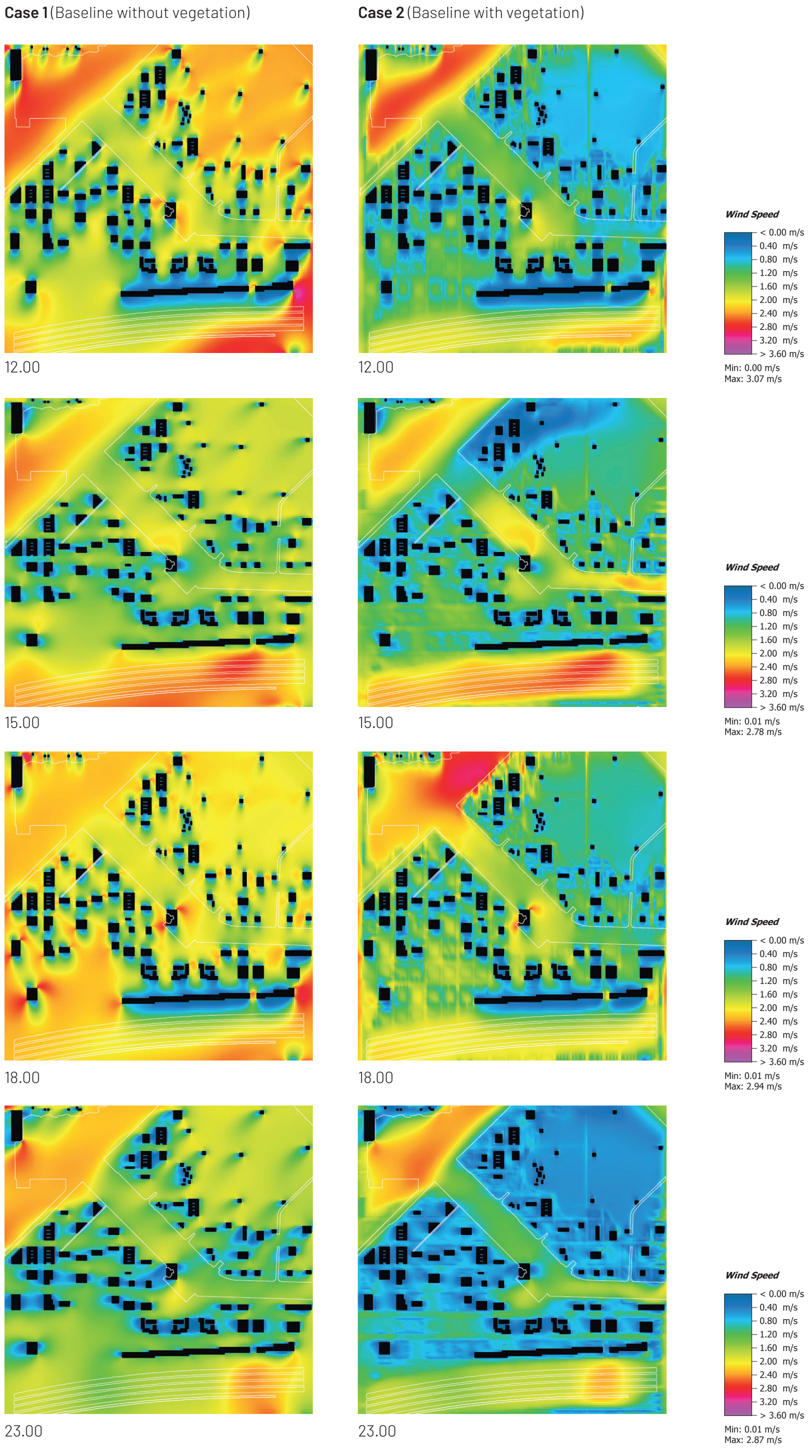
18.00

18.00

23.00

23.00

FIG. 4.21 Relative humidity comparison



Case 1 (Baseline without vegetation)

Case 2 (Baseline with vegetation)

FIG. 4.22 Wind speed comparison

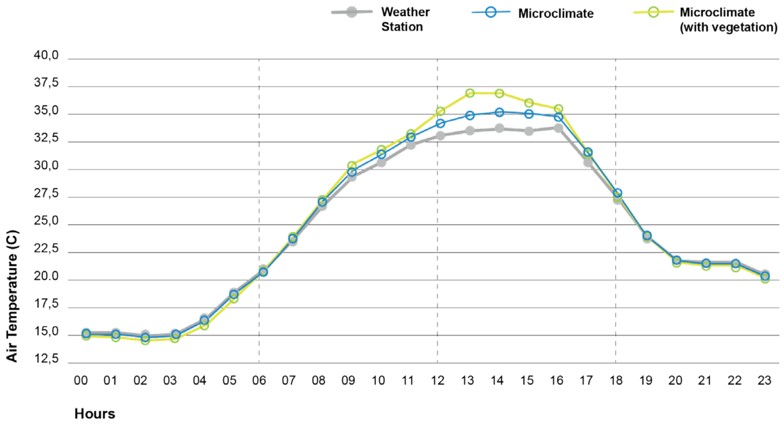


FIG. 4.23 Average air temperature for all buildings in the area for both microclimate scenarios compared to the measured air temperature from the weather station in Lelystad.

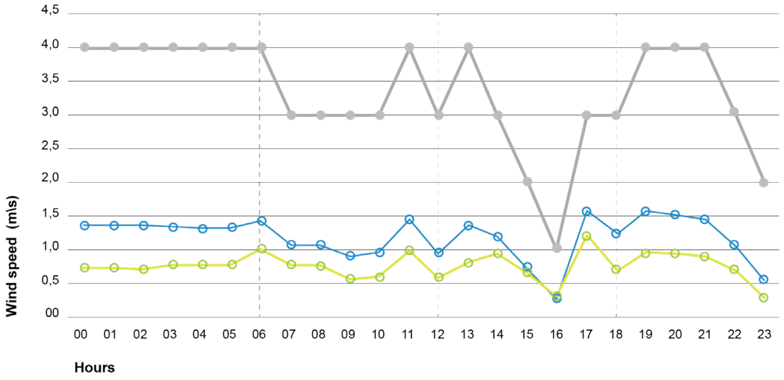


FIG. 4.24 Average wind speed for all buildings in the area for both microclimate scenarios compared to the measured air temperature from the weather station in Lelystad.

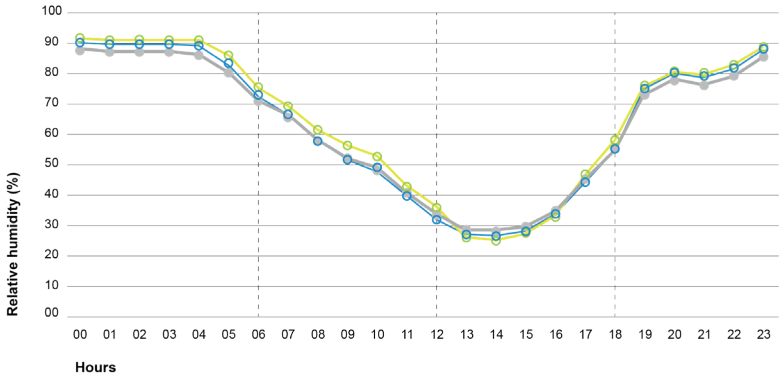


FIG. 4.25 Average relative humidity for all buildings in the area for both microclimate scenarios compared to the measured air temperature from the weather station in Lelystad.

Relation between microclimate parameters

The Urban Heat Island phenomenon that emerges from the simulation results is characterized by higher temperatures in the urban district compared to the rural area during the daytime. This type of pattern has been observed for both Floriade scenarios and average temperatures result to be even higher when the green structure is modelled. This finding appears to be in contrast with previous studies that support urban vegetation as an important strategy to mitigate the UHI effect [56, 57].

However, in literature the cooling effect of green areas and trees is observed mainly in tropical and arid urban environments [58, 59, 60] with relatively low wind speeds or when methods that do not consider wind velocity in the modelling are employed [61]. In the specific case of Floriade, the combination of a low building density, high ambient wind speed and the presence of a (cooling) lake upwind gives rise to the hypothesis of a relation between the decrease in wind velocity caused by the vegetation and the type of Urban Heat Island observed.

To test this hypothesis, a Spearman's correlation is used to analyze the monotonic relationship between the climate variables of wind speed and air temperatures as well as wind speed and relative humidity for all the hourly values calculated in the buffer areas around the Floriade buildings. The correlation studies employed shows that in Scenario 1 (without vegetation) the relation between wind speed and air temperature is significant ($p<0.05$) for all the hours taken in consideration except for the hours between 11am and 3pm. When significant, the relationship has a preponderant negative direction meaning that a decrease in wind velocity corresponds to an increase in air temperatures. Conversely, a positive relationship is found between wind speed and relative humidity, illustrating that the higher the wind speed the higher the level of moisture in the air. Despite the moderate entity of the correlation coefficients, this last relation can be explained by the entrainment of moist air resulting from evapotranspiration by the lake that surrounds the district and the vegetation by the wind.

Regarding the results of scenario 2, a significant relationship is found between air temperature and wind speed also for the hours between 11am and 3pm. However, the direction of the correlation changes between day and night hours. Before sunrise and after sunset the positive relation suggests that a decrease in wind velocity corresponds to lower air temperatures. This could be explained by turbulent heat flux between surfaces and atmosphere; lower wind speeds are less successful in replacing warm air - heated by materials that release their stored heat at night – by cool air. In contrast, during sun hours low wind speeds correspond to higher temperatures, suggesting that the presence of vegetation and therewith an increase in roughness length contributes to lowering the cooling effect of wind, increasing air temperatures in the district.

TABLE 1.9 Spearman correlation between microclimate values

CORRELATIONS		WIND SPEED - AIR TEMPERATURE		WIND SPEED - RELATIVE HUMIDITY	
HOURS	SPEARMAN'S RHO	NO VEGETATION	WITH VEGETATION	NO VEGETATION	WITH VEGETATION
0	Correlation Coefficient	-.067	.488**	.135*	-.400**
	Sig. (2- tailed)	.283	.000	.030	.000
	N	260	260	260	260
1	Correlation Coefficient	-.174**	.661**	.242**	-.629**
	Sig. (2- tailed)	.005	.000	.000	.000
	N	260	260	260	260
2	Correlation Coefficient	-.199**	.740**	.268**	-.672**
	Sig. (2- tailed)	.001	.000	.000	.000
	N	260	260	260	260
3	Correlation Coefficient	-.194**	.740**	.263**	-.674**
	Sig. (2- tailed)	.002	.000	.000	.000
	N	260	260	260	260
4	Correlation Coefficient	-.164**	.713**	.232**	-.636**
	Sig. (2- tailed)	.008	.000	.000	.000
	N	260	260	260	260
5	Correlation Coefficient	-.183**	.732**	.252**	-.656**
	Sig. (2- tailed)	.003	.000	.000	.000
	N	260	260	260	260
6	Correlation Coefficient	-.296**	.752**	.365**	-.649**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
7	Correlation Coefficient	-.385**	.499**	.454**	-.535**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
8	Correlation Coefficient	-.522**	-.232**	.591**	-.449**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
9	Correlation Coefficient	-.539**	-.250**	.607**	-.450**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
10	Correlation Coefficient	-.284**	-.436**	.353**	-.212**
	Sig. (2- tailed)	.000	.000	.000	.001
	N	260	260	260	260
11	Correlation Coefficient	-.080	-.499**	.148*	-.226**
	Sig. (2- tailed)	.200	.000	.017	.000
	N	260	260	260	260
12	Correlation Coefficient	-.034	-.289**	.101	-.129*
	Sig. (2- tailed)	.583	.000	.103	.038
	N	260	260	260	260
13	Correlation Coefficient	.014	-.641**	.054	-.489**
	Sig. (2- tailed)	.821	.000	.383	.000
	N	260	260	260	260
14	Correlation Coefficient	.047	-.431**	.021	.608**
	Sig. (2- tailed)	.450	.000	.732	.000
	N	260	260	260	260
15	Correlation Coefficient	-.042	-.506**	.111	.570**
	Sig. (2- tailed)	.499	.000	.074	.000
	N	260	260	260	260

CORRELATIONS		WIND SPEED - AIR TEMPERATURE		WIND SPEED - RELATIVE HUMIDITY	
HOURS	SPEARMAN'S RHO	NO VEGETATION	WITH VEGETATION	NO VEGETATION	WITH VEGETATION
16	Correlation Coefficient	.268**	.056	-.200**	.035
	Sig. (2- tailed)	.000	.371	.001	.569
	N	260	260	260	260
17	Correlation Coefficient	.591**	.501**	-.522**	-.384**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
18	Correlation Coefficient	-.155*	-.199**	.223**	-.252**
	Sig. (2- tailed)	.013	.001	.000	.000
	N	260	260	260	260
19	Correlation Coefficient	-.126*	.160**	.194**	-.370**
	Sig. (2- tailed)	.043	.010	.002	.000
	N	260	260	260	260
20	Correlation Coefficient	-.214**	.005	.282**	-.197**
	Sig. (2- tailed)	.001	.935	.000	.001
	N	260	260	260	260
21	Correlation Coefficient	-.293**	-.065	.362**	-.122*
	Sig. (2- tailed)	.000	.295	.000	.049
	N	260	260	260	260
22	Correlation Coefficient	-.307**	.581**	.375**	-.486**
	Sig. (2- tailed)	.000	.000	.000	.000
	N	260	260	260	260
23	Correlation Coefficient	-.134*	.525**	.203**	-.442**
	Sig. (2- tailed)	.030	.000	.001	.000
	N	260	260	260	260
24	Correlation Coefficient	-.126*	.084	.194**	-.012
	Sig. (2- tailed)	.043	.175	.002	.842
	N	260	260	260	260

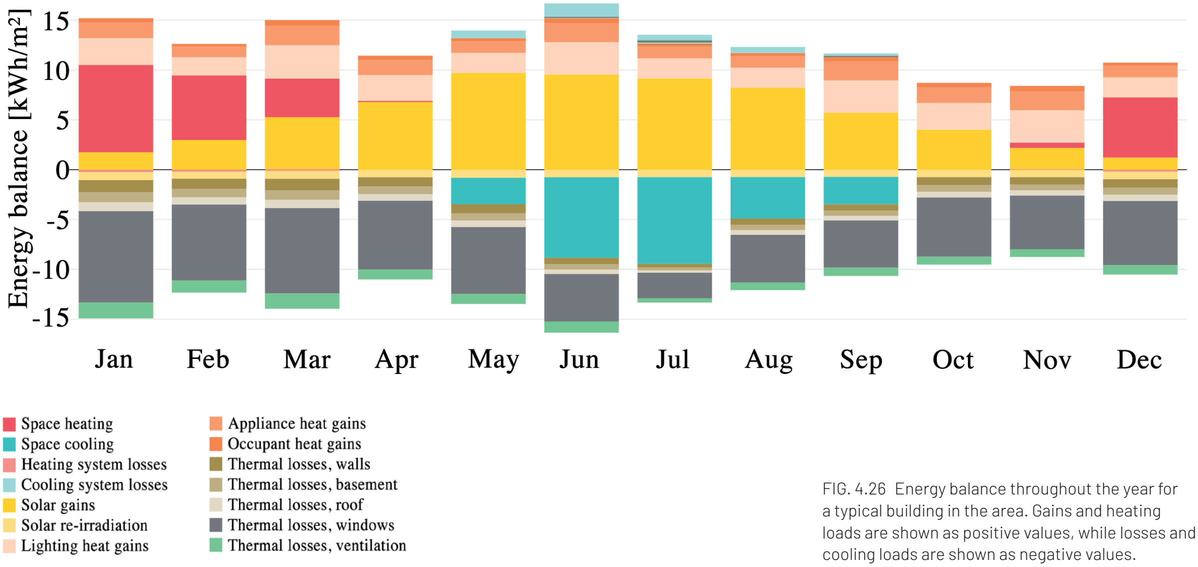


FIG. 4.26 Energy balance throughout the year for a typical building in the area. Gains and heating loads are shown as positive values, while losses and cooling loads are shown as negative values.

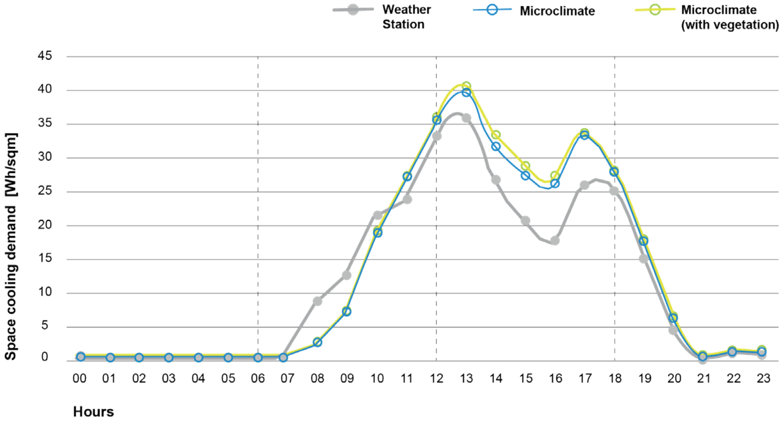


FIG. 4.27 Hourly space cooling demand per square meter for the district for all three cases.

Analysis of district energy performance

Due to the highly efficient thermal properties assumed for all buildings in the area, the average yearly heating demand (24 kWh/m^2-yr) is much lower than the Dutch average of 90 kWh/m^2-yr [12] and meets the reference value of 25 kWh/m^2-yr for nZEB in the Netherlands [13]. The highly insulated and airtight construction leads to a large yearly cooling demand of 23 kWh/m^2-yr for the baseline scenario. Given that there is a source for free cooling in the lake water in the area, space conditioning in the summer could likely be provided highly efficiently. Hence, decreasing heating demand at the expense of increasing cooling the summer time is likely to lead to a net environmental benefit.

The energy balance throughout the year for a typical building in the area is shown in Figure 4.26. Due to the low U-values assumed for opaque building elements, transmission losses through these materials are very low throughout the year. The high window-to-wall ratio leads to significant solar gains all year but also leads to the largest transmission losses through the envelope. Heating and cooling systems are therefore only operated during summer and winter, with minimum to no demands for space conditioning in fall and spring.

Effect of microclimate on district energy performance

The hourly demand for cooling in the district for the baseline case and the microclimate scenario with no green is shown in Figure 4.27. The results show that during night-time there is no cooling demand in any of the scenarios even on this extreme day. For the baseline case, buildings start cooling earlier, but the peak is considerably lower during the day. For all buildings in the area, the inclusion of microclimate data causes the cooling loads at midday to be higher due to the higher outdoor temperature. The high variation in wind speed likely does not cause much of an effect in terms of energy demand in the buildings, as wind speed only affects infiltration in the CEA model, whereas all buildings were assumed to be highly airtight. Over the entire day, the inclusion of microclimate results in the simulations causes an increase in the district's cooling demand of 9.3%. The microclimate results for the case with vegetation showed an extreme temperature increase in the district, approaching a peak of 45°C in the Northeast of the area. Given that the buildings in this part of the area are few and small, the effect on the energy demand of the district is rather small compared to the case with microclimate and no greenery. The increase in cooling demand is 9.8% with respect to the baseline case with no microclimate effects, mostly due to the higher temperatures between 12:00 and 16:00. Thus, while these results represent an extreme situation, the effects are nonetheless small on a district scale. Given this observation coupled with the fact that the hourly demand patterns follow those observed in the case without greenery, only this latter case is considered in the following sections.

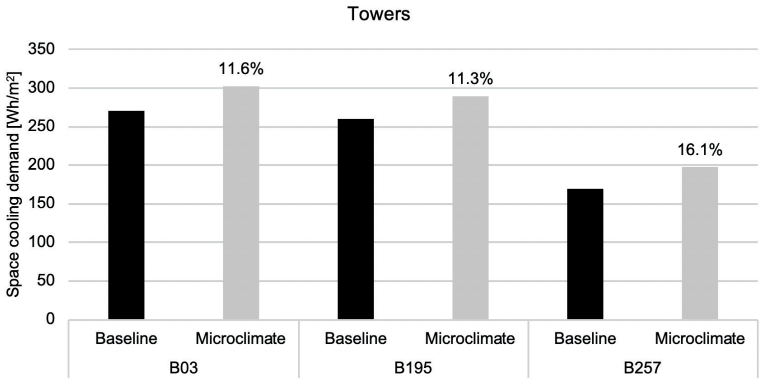


FIG. 4.28 Comparison of the space cooling demand per square meter for the three towers on the day being analyzed for the baseline and the scenarios with microclimate and with microclimate and vegetation.

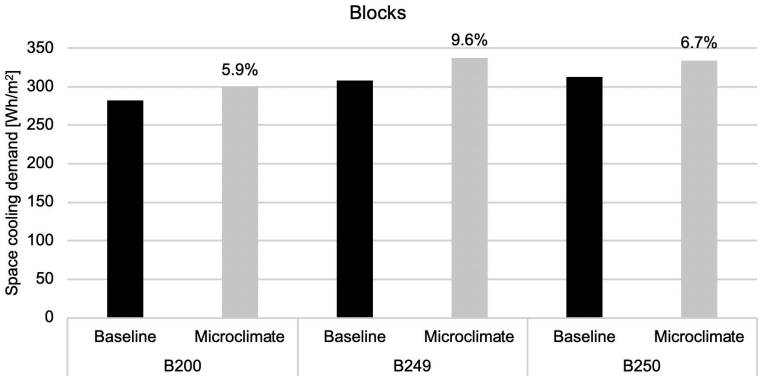


FIG. 4.29 Comparison of the space cooling demand per square meter for the three blocks on the day being analyzed for the baseline and the scenarios with microclimate and with microclimate and vegetation.

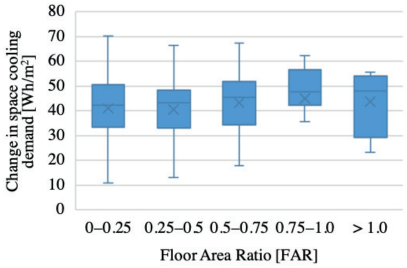


FIG. 4.30 Box plot showing the change in space cooling demand due to microclimate effects for all buildings by their floor area ratio. Each box represents the 1st to 3rd quartile of the distribution for a given FAR, whereas the middle line of the box represents the median and the x represents the mean. The whiskers show the minimum and maximum values, with outliers shown as individual points.

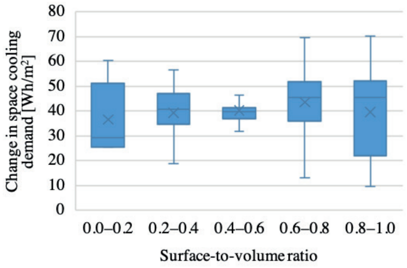


FIG. 4.31 Box plot showing the change in space cooling demand due to microclimate effects for all buildings by their surface to volume ratio. Each box represents the 1st to 3rd quartile of the distribution for a given SVR, whereas the middle line of the box represents the median and the x represents the mean. The whiskers show the minimum and maximum values, with outliers shown as individual points.

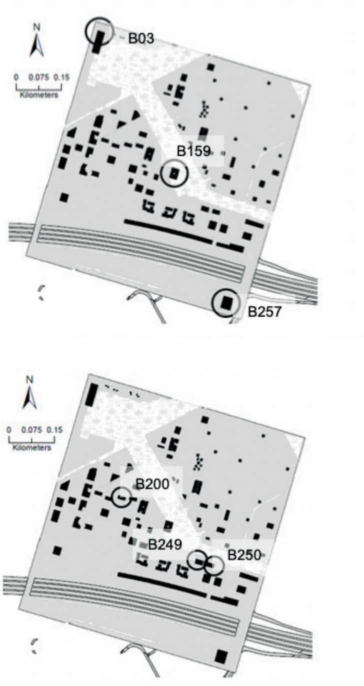


FIG. 4.32 Figure 29. Distribution of typologies analyzed: 59-floor towers (top) and 7-floor blocks (bottom).

Effect of microclimate on energy performance by building typology

The effect of microclimate on energy demand was further analyzed for specific typologies found throughout the case study in different contexts.

There are three 59-floor towers in the area, shown in Figure 4.32: B195 (situated in the center of the district with its foundations placed in the lake water), B257 (in the south-east of the district on the southside of the terrain rise and the highway), and B03 (located in the north-west at the furthest corner of the district, close to the sea bay).

When considering microclimate effects on the towers in general, the cooling demand increases due to the observed heat island effect. B257 is most influenced by microclimate, with a 16% increase in demand. B195 and B03, being located directly on a water body, have a smaller relative cooling demand increase than B257 for the microclimate scenario, but a higher cooling demand per square meter in both the baseline and microclimate scenarios.

Another common typology found in the area are compact 7-floor blocks with similar gross floor area, also shown in Figure 4.32. B249 and B250 are located very close to each other and are of identical size and building properties, however B250 is surrounded by densely-planted trees on either long façade. Both buildings lie at the shore of the lake water at the south east side of the district, on the north side of the highway. B200 is of similar size to the other two but lies further inland and is surrounded by other building blocks. The vegetation around B200 is in less proximity than for B250, however the trees are more densely planted.

Out of the three blocks, B249 and B250 have a higher cooling demand due to their greater exposure to solar irradiation, leading to higher solar gains. B200, being shaded by surrounding buildings on all directions, has the lowest cooling demand (-10%). When comparing the baseline to the microclimate scenario, B249, facing windward, has the largest cooling demand increase than B250 facing leeward. The cooling demand increase is smallest for B200, which already had the lowest demand in the baseline scenario.

Relative effect of building façade properties and microclimate on energy demand

As described in the methodology section, dark building materials were selected for all buildings in order to analyze a "worst case scenario" for the effects in the area. In order to assess the effect of the color of opaque building materials, façade materials with an absorptivity of 0.15 were assigned to all buildings and the demand was compared to the case with dark materials. By assigning façade materials with low absorptivity change, the average total demand of the districts' buildings was reduced by only 1.5%. Compared to the effects from the local microclimate, however, these improvements are relatively minor, hence stressing the importance of microclimate in the energy performance of districts.

Effects of urban density and building compactness on microclimate and cooling

The floor area ratio (FAR), defined as the ratio between buildings' ground floor area and the area of the parcels in which they are located, provides a measure of the density of an urban area. The relation between buildings' change in space cooling demand due to microclimate effects and the FAR of a 50-meter buffer area around each building are shown in Figure 4.33. The correlation between microclimate effects and FAR appears to be minor, with buildings in less dense areas showing an average increase in cooling demand of 41 Wh/m^2 and buildings in denser areas showing an FAR of 44 Wh/m^2.

Furthermore, the relation between building compactness and the effect of microclimate on energy demand is studied in Figure 4.33, which shows the change in cooling demand by surface-to-volume ratio (that is, the ratio between the area of the building envelope and its interior volume). The variation in cooling demand when accounting for microclimate effects was on average quite similar for all groups, although the median is higher with increasing surface-to-volume ratio. This is likely due to the relatively small role of envelope properties on the cooling loads of the buildings (Figure 4.26) caused by the high thermal resistance of the materials assumed for all buildings in the area.

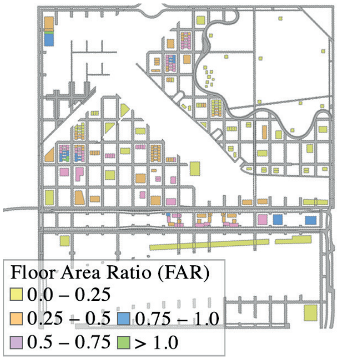


FIG. 4.34 Distribution of buildings by floor area ratio (top) and by surface to volume ratio (bottom)

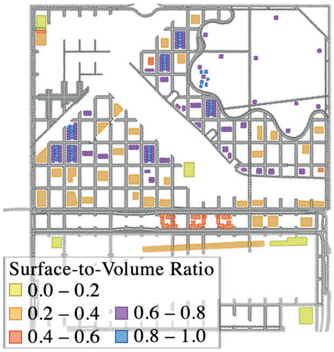


FIG. 4.33 Distribution of buildings by floor area ratio (top) and by surface to volume ratio (bottom)

4.4.3. Discussion of results for the Almere case study

The integration of microclimate simulation tool ENVI-met and district-scale energy demand model CEA showed that the planned district could fall short significantly of its net zero energy targets. The microclimate that arises in the area proved to be much warmer and humid than predicted by the rural weather station in Lelystad, an effect exacerbated by greenery affecting wind patterns in the area.

From an energy perspective, the highly insulated buildings proved to have a much better performance in terms of heating than the average Dutch residential building, but at the expense of a substantially higher cooling demand, exacerbated by the large window-to-wall ratios. When considering the effects of microclimate, this demand was further increased by the higher air temperatures and relative humidity in the area. Building compactness and urban density, on the other hand, proved to have relatively minor effects on the change in demand due to microclimate. The results thus stress the importance of assessing the urban microclimate as part of the building energy planning process in urban areas.

4.5. Conclusions

The study outlines a method for quantitative analysis of district-scale energy consumption taking in account the microclimatic effects created by the design of open and built space. The coupling approach that links ENVI-met and CEA simulation tools is employed in two case studies were urban development processes are expected to change microclimatic conditions and consequentially the energy performance of buildings. The results show that the method helps to quantify the impact of microclimate on building energy consumption for a number of buildings with different materials and location characteristics. The method can support the challenge on improving building energy efficiency by optimizing form configuration, materials and consequent microclimate conditions to design sustainable urban districts. Further consideration should be given to the possible employment of this method during the design process and not only as an assessment instrument. Moreover, it can help to identify the variation of energy demand between buildings, based on geometrical and material characteristics of building surroundings. However, computational costs are still very high, in particular for the time necessary to run ENVI-met simulations and for the data aggregation step.

The coupling method between ENVI-met and CEA has been employed for the baseline Hochschulquartier and Floriade areas. A spatial model with only buildings and surface materials and a second one including vegetation have been built for each case. For the first district the hottest and coldest day of a typical year have been simulated. For Almere a hot summer day with clear sky was selected and climate data extract from Lelystad weather station were used as forcing boundary conditions.

The obtained microclimate results show an evident atmospheric Urban Heat Island phenomenon in both districts. However, the characteristic higher temperatures in the urban areas compared to the rural area, have different patterns along the 24 hours studied. While in the Hochschulquartier local temperatures are higher during the night for the two days analyzed, in Almere local temperatures are higher during the daytime.

The consideration of these local climatic patterns in energy demand calculation in the Zurich case leads to a general increased building cooling demand on the hottest day between 1,4% and 2%, and a lower building heating load between 2% and 3% during the coldest day. The effect of microclimate on the peak cooling demand was more noticeable, with a 5% decrease in peak cooling power on the hottest day of the year.

Similarly, in the Floriade case study the inclusion of microclimate data causes the cooling loads at midday to be higher due to the higher outdoor temperature and humidity. Over the entire day, the inclusion of microclimate results in the simulations causes an increase in the cooling demand of about 9,3% when only building and surface materials are taken into account, whereas further incorporating the effects of vegetation causes an increase of 9,8%.

The vegetation around buildings clearly affects the space cooling demand. However, contrasting results have been found. While in the Hochschulquartier green areas contribute to mitigate the Urban Heat Island effect, in Floriade district low local wind speed correspond to higher temperatures, suggesting that the presence of vegetation and therewith an increase in roughness length contributes to lowering the cooling effect of wind, increasing air temperatures in the district. Future studies need to better investigate the impact of vegetation on wind velocity and urban temperatures in temperate and continental climates, and the consequent influence on building energy consumption.

References

[1] World Energy Council, World Energy Scenarios 2016. The Grand Transition., 2016.

[2] Urban Europe, Statistics on cities, towns and suburbs., Eurostat, 2016.

[3] M. Santamouris, "On the energy impact of urban heat island and global warming on buildings," Energy and Buildings, pp. 100-113, 2014.

[4] S. Magli, C. Lodi, L. Lombroso, A. Muscio and S. Teggi, "Analysis of the urban heat island effects on building energy consumption," International Journal of Energy and Environmental Engineering, vol. 6, no. 1, pp. 91-99, 2015.

[5] C. Skelhorn, G. Levermore and S. Lindley, "Impacts on Cooling Energy Consumption Due to the UHI and Vegetation Changes in Manchester, UK," Energy and Buildings, vol. 122, 2016.

[6] X. Yang, L. Zhao, M. Bruse and Q. Meng, "An integrated simulation method for building energy performance assessment in urban environments," Energy and Buildings, vol. 54, pp. 243-251, 2012.

[7] K. Gobakis and D. Kolokotsa, "Coupling building energy simulation software with microclimatic simulation for the evaluation of the impact of urban outdoor conditions on the energy consumption and indoor environmental quality," Energy and Buildings, vol. 157, pp. 101-115, 2017.

[8] Y. Toparlar, B. Blocken, B. Maiheu and G. van Heijst, "A review on the CFD analysis of urban microclimate," Renewable and Sustainable Energy Reviews, vol. 80, pp. 1613-1640, 2017.

[9] B. Blocken, "50 years of Computational Wind Engineering: Past, present and future," Journal of Wind Engineering and Industrial Aerodynamics, vol. 129, p. 69–102, 2014.

[10] B. Blocken, "Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations," Building and Environment, vol. 91, pp. 219-245, 2015.

[11] P. Mirzaei, "Recent challenges in modeling of urban heat island," Sustainable Cities and Society, vol. 19, pp. 200-206, 2015.

[12] P. Mirzaei and F. Haghighat, "Approaches to study urban heat island – Abilities and limitations," Building and Environment, vol. 45, pp. 2192-2201, 2010.

[13] F. de la Flor and S. Domínguez, "Modelling microclimate in urban environments and assessing its influence on the performance of surrounding buildings," Energy and Buildings, vol. 36, pp. 403-413, 2004.

[14] A. Gros, E. Bozonnet and C. Inard, "Cool materials impact at district scale - Coupling building energy and microclimate models," Sustainable Cities and Society, vol. 13, p. 254–266, 2014.

[15] A. Gros, E. Bozonnet, C. Inard and M. Musy, "Simulation tools to assess microclimate and building energy – A case study on the design of a new district," Energy and Buildings, vol. 114, pp. 112-122, 2016.

[16] Y. Toparlar, B. Blocken, B. Maiheu and G. van Heijstd, "Impact of urban microclimate on summertime building cooling demand: A parametric analysis for Antwerp, Belgium," Applied Energy, vol. 228, pp. 852-872, 2018.

[17] OcCC and Proclim, "Climate Change and Switzerland 2050: Expected Impacts on Environment, Society and Economy," Organe consultatif sur les changements climatiques, 2007.

[18] T. Frank, "Climate change impacts on building heating and cooling energy demand in Switzerland," Energy and Buildings, vol. 37, no. 11, pp. 1175-1185, 2005.

[19] C. Gonseth, P. Thalmann and M. Vielle, "Impacts of Global Warming on Energy Use for Heating and Cooling with Full Rebound Effects in Switzerland," Swiss Journal of Economics and Statistics, vol. 153, no. 4, p. 341–369, 2017.

[20] M. Santamouris, C. Cartalis, A. Synnefa and D. Kolokotsa, "On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review," Energy and Buildings, vol. 98, pp. 119-124, 2015.

[21] Baudirektion Kanton Zürich, Masterplan Hochschulgebiet Zürich-Zentrum September 2014, Zürich: Kanton Zürich, Baudirektion, 2014.

[22] Baudirektion Kanton Zürich, Hochschulgebiet Zürich-Zentrum Schlussbericht Vertiefungsthema Energieversorgung, Zürich, 2015.

[23] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer and R. Evins, "A review of modelling approaches and tools for the simulation of district-scale energy systems," Renewable and Sustainable Energy Reviews, vol. 52, p. 1391–1404, 2015.

[24] M. Kolokotroni, M. Davies, B. Croxford, S. Bhuiyan and A. Mavrogianni, "A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island: Case-study of London," Solar Energy, vol. 84, p. 2246–2255, 2010.

[25] J. He, A. Hoyano and T. Asawa, "A numerical simulation tool for predicting the impact of outdoor thermal environment on building energy performance," Applied Energy , vol. 6, p. 1596–1605, 2009.

[26] H. Radhi and S. Sharples, "Quantifying the domestic electricity consumption for air-conditioning due to urban heat islands in hot arid regions," Applied Energy, vol. 112, p. 371–380, 2013.

[27] J. Liu, M. Heidarinejad, M. Guo and J. Srebric, "Numerical evaluation of the local weather data impacts on cooling energy use of buildings in an urban area," Procedia Engineering , no. 121, p. 381– 388, 2015.

[28] F. Ali-Toudert and H. Mayer, "Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate," Building and Environment, vol. 41, no. 2, p. 94–108, 2006.

[29] F. Ali-Toudert and H. Mayer, "Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons," Solar Energy, vol. 81, pp. 742-754, 2007.

[30] M. Taleghani, L. Kleerekoper, M. Tenpierik and A. van den Dobbelsteen, "Outdoor thermal comfort within five different urban forms in the Netherlands," Building and Environment, vol. 83, pp. 65-78, 2015.

[31] E. Carnielo and M. Zinzi, "Optical and thermal characterisation of cool asphalts to mitigate urban temperatures and building cooling demand," Building and Environment, vol. 60, pp. 56-65, 2013.

[32] Bruse and Fleer, "ENVI-met," [Online]. Available: http://www.envi-met.com/.

[33] The CEA team, City Energy Analyst v2.9.0, doi: 10.5281/zenodo.1487867, 2018.

[34] J. Allegrini, V. Dorer and J. Carmeliet, "Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings," Energy and Buildings, vol. 55, pp. 823-832, 2012.

[35] V. Dorer, J. Allegrini, K. Orehounig, P. Moonen, G. Upadhyay, J. Kämpf and J. Carmeliet, "Modelling the urban microclimate and its impact on the energy demand of buildings and building clusters," in Proceedings of Building Simulation 2013, Chambery, France, 2013.

[36] Metotest, "Meteonorm Version 7.1, Global Meteorological Database for Engineers, Planners and Education," Meteotest, Bern, Switzerland, 2014.

[37] ISO 13790, Energy performance of buildings – Calculation of energy use for space heating and cooling, Geneva: International Organization for Standardization (ISO), 2008.

[38] J. Fonseca and A. Schlueter, "Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts," Applied Energy, vol. 142, p. 247–265, 2015.

[39] ISO 52016-1, Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedures, Geneva: International Organization for Standardization (ISO), 2017.

[40] G. Happle, J. Fonseca and A. Schlueter, "Effects of air infiltration modeling approaches in urban building energy demand forecasts," Energy Procedia, vol. 122, p. 283–288, 2017.

[41] D. Sailor and J. Muñoz, "Sensitivity of electricity and natural gas consumption to climate in the U.S.A. - Methodology and results for eight states," Energy, vol. 22, pp. 987-998, 1997.

[42] W. Fung, K. Lam, W. Hung, S. Pang and Y. Lee, "Impact of urban temperature on energy consumption of Hong Kong," Energy, vol. 31, pp. 2287-2301, 2006.

[43] Nex2us, "Online Bouwbesluit," 2012.

[44] BENG, "Nationaal Plan voor het bevorderen van Bijna-Energie Neutrale Gebouwen (BENG) in Nederland," 2012.

[45] European Union, "Directive 2010/31/EU on the energy performance of buildings (recast)," 2010.

[46] Rijksdienst voor Ondernemend Nederland, "Current Legal Requirements and Status of National NZEB Definition for Residential Buildings in the Netherlands NL," 2015.

[47] Rijksdienst voor Ondernemend Nederland, "Apartment complex".

[48] SIA 2044, "Raumnutzungsdaten fur die Energie- und Gebäudetechnik," Schweizerischer Ingenieur- und Architektenverein, Zurich, Switzerland, 2015.

[49] I. Pothof, "Floriade 2022 en het Weerwater: Inspiratiedocument warmte/koude voorziening," Gemeente Almere, Almere, Netherlands, 2017.

[50] O. Guerra-Santin and S. Silvester, "Development of Dutch occupancy and heating profiles for building simulation," Building Research and Information, vol. 45, no. 4, p. 396–413, 2017.

[51] Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, "WoonOnderzoek Nederland," 2012.

[52] Climate.OneBuilding.Org, "Repository of free climate data for building performance simulation From the Creators of the EPW," 2014–2019.

[53] L. Gynther, B. Lapillonne and K. Pollier, "Energy Efficiency Trends and Policies in the Household and Tertiary Sectors," ODYSSEE-MURE Project, 2015.

[54] DGMR Bouw B.V., "Referentie gebouwen BENG (Bijna EnergieNeutrale Gebouwen) – In opdracht van het ministerie van Binnenlandse Zaken en Koninkrijksrelaties," Rijksdienst voor Ondernemend Nederland, The Hague, Netherlands, 2017.

[55] Tweede Kamer der Staten-Generaal, "Nationaal Plan voor het bevorderen van Bijna-Energie Neutrale Gebouwen (BENG) in Nederland," The Hague, Netherlands, 2012.

[56] Shishegar, N. 2014, "The impact of green areas on mitigating urban heat island effect: A review", International Journal of Environmental Sustainability, vol. 9, no. 1, pp. 119-130.

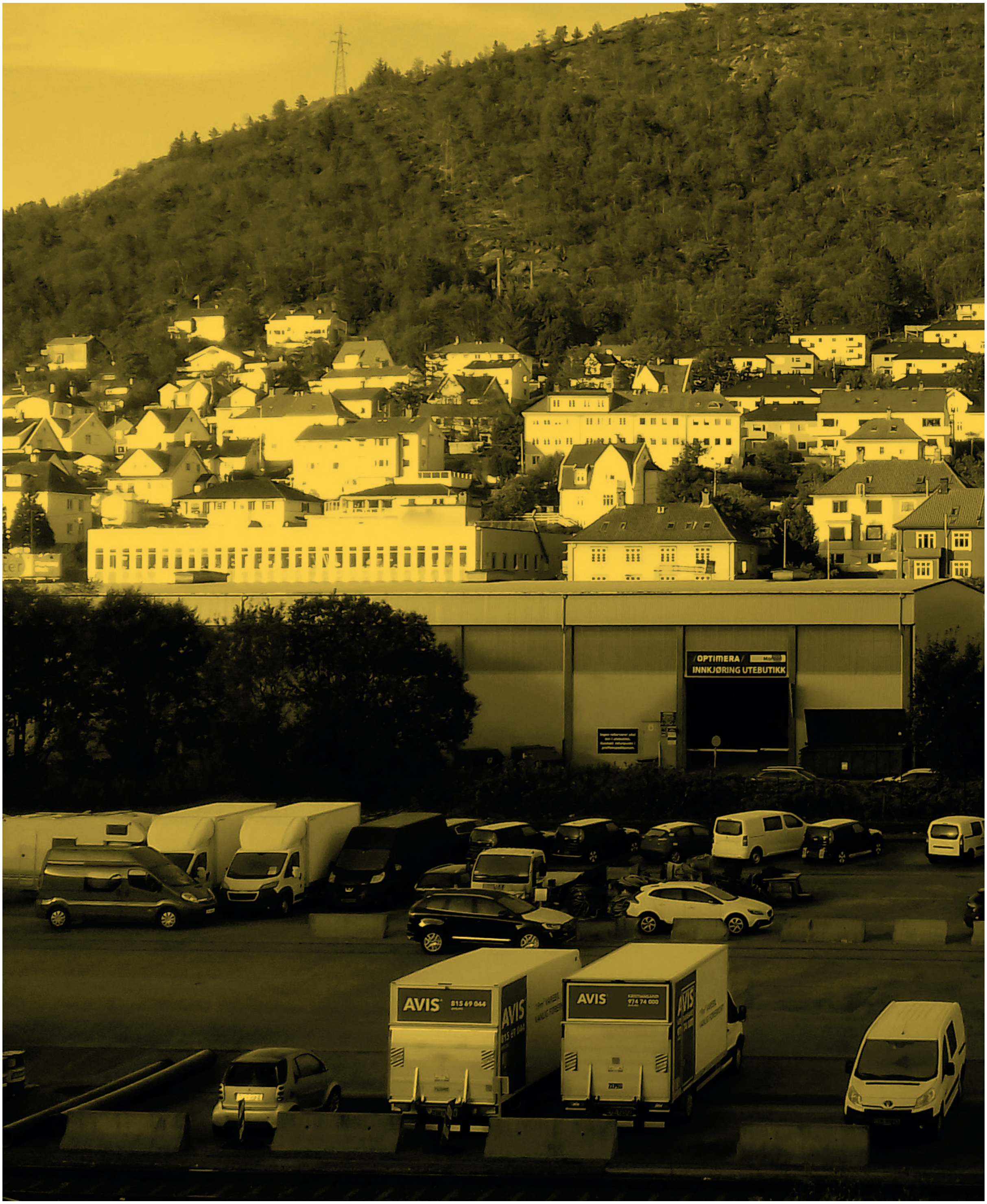
[57] Oliveira, S., Andrade, H. & Vaz, T. 2011, "The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon", Building and Environment, vol. 46, no. 11, pp. 2186-2194.

[58] Wong, N.H. & Yu, C. 2005, "Study of green areas and urban heat island in a tropical city", Habitat International, vol. 29, no. 3, pp. 547-558.

[59] Chen, L., Wang, Y. & Yuan, C. 2012, "A study on the cooling effects of greening in a high-density city: An experience from Hong Kong", Building and Environment, vol. 47, no. 1, pp. 256-271.

[60] Chow, W.T.L. & Roth, M. 2006, "Temporal dynamics of the urban heat island of Singapore", International Journal of Climatology, vol. 26, no. 15, pp. 2243-2260.

[61] Chun, B. & Guldmann, J.-. 2018, "Impact of greening on the urban heat island: Seasonal variations and mitigation strategies", Computers, Environment and Urban Systems, vol. 71, pp. 165-176.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5.

Integrated energy infrastructures: Space and energy use for transport

Authors:
Remco de Koning, Akkelies van Nes

Contents:

Summary

Energy usage in cities is intertwined with their spatial configuration – the denser and more compact the city is, the more concentrated the use of energy. To achieve sustainable communities, cities (and its inhabitants) must reconsider the spatial structure of its mobility network. To facilitate a transition to energy efficient environments, how urban spatial configurations affect energy usage in cities must be understood. Focusing on mobility and transport, which account for 25% of energy usage in cities, this approach asks: "what are the factors of urban form and networks that affect patterns of movement and choice of transport mode in relation to energy usage?" Using a quantitative analysis of spatial elements influencing mobility choices with Space Syntax, we demonstrate how spatial configuration and degree of walkability relate to energy usage for mobility. By correlating the spatial analysis data with energy consumption data obtained from measured traffic data, findings show that street segments with both a high level of local and global integration tend to exhibit lower amounts of energy usage for car traffic. This suggests that cities with highly accessible streets advance walkability and the choice for sustainable means of transport (i.e. cycling and public transport) which then reduces energy usage.

5.1. Introduction

5.1.1. Urban morphology and energy demand

Since the millennium, over half of the world's population lives in cities. This worldwide trend leads to the emergence of very dense mega-cities and metropolises with increased pressure on land and the mobility network. Likewise, smaller cities and urbanised areas are experiencing the increased pressure of population growth. This pressure results in that cities need to reinvent themselves to cope with increased demand for space and facilities. Particularly, major challenges arise when it comes to transport and mobility. As urban areas increase in size and complexity, being able to move around efficiently is at stake, while the challenges to provide an efficient infrastructure to facilitate this become ever greater.

In addition to the challenges of increasing size and complexity and competition for space, the global threats of climate changes offer new problems. We need to reduce our ecological footprints drastically by cutting back on resources and making responsible choices regarding the goods and services we use. When we consider transport as a consumer of resources, we can see an increased awareness among consumers to make responsible choices: some people increasingly favour taking the train over flying, joining a car sharing service instead of owning a car, buying local products, cycling to work instead of driving, and so on. These choices however, depend largely on the possibilities available.

At present, there is a knowledge gap on the relationship between urban form and energy use for transport. This knowledge is needed for planning infrastructures that can facilitate and encourage sustainable mobility means such as walking, cycling and public transport. So far, calculating traffic flows and energy use for transport has been the domain of road engineers and statisticians, whereas analysing urban space and form has been the domain of architects and urban researchers [1]. Each discipline uses its own methods. In this research, we used Geographical Information Systems (GIS) as a common platform to compare and correlate data from the methods from each discipline. As the results show, there is a correlation between urban space and energy use for transport. This knowledge is needed for being able to predict to some extent how the spatial configuration of the built environment can influence energy use for transport. It all depends on various degrees of inter-accessibility on various scale levels, from the building-street relation up to the relation between main routes and various neighbourhoods. Good access to the job market and health and social facilities are two examples of basic human rights that relate to several of the other Sustainable Development Goals (SDGs). For example, SDG 1: no poverty, SDG 3: good health and well-being, SDG 5: gender equality, SDG 8: decent work and economic growth, SDG 9: industry, innovation and infrastructure, and SDG10: reduced inequalities, are directly related to accessibility in cities [2]. The idea is that people should have the right to move freely from one place to another. In built environments, especially when using public transport or owning a private car is unaffordable or difficult, it must be possible to get around by one's own means. This may be especially relevant in urbanised areas in developing countries, but socio-economic equity issues are also experienced in the industrialised countries.

Whereas the goals mentioned above address matters of social and economic sustainability, this research puts focus on sustainable urban form in terms of its transport energy performance. In that regard, choice of route and choice of mode are the factors we are most interested in. Route-choice and mode-choice seem to be determined primarily by the street structure. However, it is suspected that urban microscale aspects, such as the way building entrances constitutes street and the building-street inter-visibility affect route-choice on local levels, particularly for pedestrians. Mode-choice is affected mainly by the offer of public transport options, travel distances, travel times, and, to unknown extent, the quality of the urban environment. Whilst advanced transportation models enable accurate predictions on travel behaviour, the influence of the quality of the urban environment is, although discussed from a normative point of view, largely unknown from a descriptive standpoint. However, it has been shown that a dense, fine-grained network of streets leads to higher building densities and a higher functional mix [3]. This, in turn, promotes the choice of walking and cycling as the main choice of transport mode. Being the most sustainable way of getting around, the types of urban settlement patterns that promote walking and cycling as the primary mode of transport therefore contribute significantly to energy reduction when it comes to energy performance for transport.

The recent Sustainable Development Goals are pushing for improvements in social and environmental indicators. Although set up as stand-alone goals, each SDG has an explicit and implicit relationship with each other. Take for example SDG 11 – Make cities and human settlements inclusive, safe, resilient and sustainable, where the focus is on building cities and communities that are equitable but also sustainable and SDG 7 – Ensure access to affordable, reliable, sustainable and modern energy for all, where the focus is on energy resource resilience and robustness [2]. All major cities have at one point in the last decade been subjected to fluctuations in energy resources, or even problems with access to energy resources. In addition, energy access and use can also have (geo)political ramifications. Any sustainable community must consider the structure and allocation of energy resources if it is to strive towards a sustainable future. Therefore, our aim is to find out what kinds of spatial features of the built environment encourage sustainable transport means.

5.2. Methodological Framework

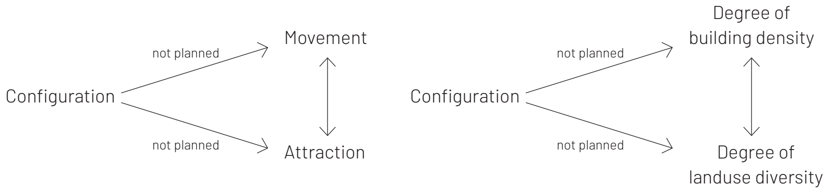
That a fine-grained deformed street network contributes to lower energy consumption for transport was pointed out by Johan Rådberg when he described the density paradox, a term referring to the two seemingly discordant concepts for the ideal sustainable city: the compact city on the one hand, and the green city on the other. The concept of the compact city implies the sharing of infrastructure, space and facilities, thereby reducing the total footprint per capita, and the concept of the green city has connotations of attractiveness and well-being through its 'green' spaces for cultivation, water infiltration and recreation. While both concepts contain elements associated with sustainability, the normative nature of these concepts leaves us lacking the descriptive precision needed to gain knowledge as to what constitutes sustainable urban form, something which Rådberg already advocated [4].

Methods for describing and measuring urban space are in a beginning stage. In the 1950's, scientific methods for analysing the physical components were developed by the urban morphologists [5]. Methods for analysing the spaces between the physical objects have been developed since the 1970's by Bill Hillier and his colleagues. The method is called Space Syntax and consists of four distinctive features. Firstly, precision of the definition of the spatial elements. Space Syntax focuses on the extrinsic properties of space, which are purely spatial relationships. Intrinsic properties such as texture, shape and form are not at issue. Secondly, Space Syntax is a set of techniques to calculate spatial inter-relationships based on three types of distances: topological distance (the number of direction changes), geometrical distance (the amount of angular deviation) and metrical distance (the physical distance). Thirdly, Space Syntax consists of a set of techniques to correlate the results of the spatial data with diverging place-bounded socio-economic data such as movement flow, building density, property prices, distribution of crime, and human behaviour in urban space. Throughout the years, software development and computer capabilities have made it possible to apply these Space Syntax techniques on cities worldwide, resulting in a substantial database of study cases. This has made it possible to develop spatial theories, which leads to the fourth feature: Space Syntax consists of some theories on space and spatial relationships, and on space and flow of movement and economic attractiveness [6, 7].

At present, four theories exist that are based on Space Syntax research: the theory of natural movement [8], the theory of the natural movement economic process [9, 10], the theory of spatial combinatorics [10] and the theory of the natural urban transformation process [3]. First, the theory of the natural movement states that the flow of human movement in built environments depends on the degree of spatial integration of the street network. The higher spatial integration on various scale levels, the higher flow of human movement [11]. Second, the theory of the natural movement economic process states that the spatial configuration of the street network influences the flow of human movement and the location of shops. The number of shops and the number of human movement influence each other, but not the spatial configuration of the street network (see Figure 5.1) [1, 11]. Third, the theory of spatial combinatorics describes four principles on how an object placed in a space contributes to integrate urban spaces or to segregate them from each other [10]. Lastly, the theory of the natural urban transformation process states that the spatial configuration of the street network steers building density and the degree of land use diversity in urban areas (see Figure 5.1) [3]. As research has shown, the spatial configuration of the street network is the underlying driving force for the densification processes of the built mass, the degree of land use diversity, the degree of movement flows through the street and road networks, and the distribution of economic activities [9].

Based on these theories, application of the Space Syntax method can help us make predictions on movement and route-choice. The method's strong post-dict capability when it comes to predicting potential movement patterns and the distribution of economic activities has been widely corroborated [1, 8, 11, 12]. The topological and geometrical structure of the street network and the position of streets within the system allow calculations to be made of through-movement potentials and to-movement potentials of every street segment in relation to all others. However, fine-tuning these theories with regard to mode-choice and energy use for transport is hardly discussed at present [13].

Potential to-movement gives an indication of how likely a street is to be a destination of a route. To estimate to-movement potentials, we perform angular segment integration analyses on two scale levels: 500 meter, representing the local or walking scale, and 5000 meter, representing the citywide scale. Results reveal "how close each segment is to all others in terms of the sum of angular changes that are made on each route" [6].



The theory of natural movement economic process

The theory of natural urban transformation process

FIG. 5.1 The theory of the natural movement economic process (left) and the theory of the natural urban transformation process (right).

Through-movement potentials indicate how likely a street is used as part of a route. Values are obtained through angular choice analysis, which is a result of "counting the number of times each street segment falls on the shortest path between all pairs of segments within a selected distance (termed 'radius'). The 'shortest path' refers to the path of least angular deviation (namely, the straightest route) through the system" [6].

In a research project on urban space and crime, spatial analysis methods were developed on the building-street relationship [14]. This method is named 'the urban microscale tools'. The results from the urban microscale tools were correlated with the Space Syntax analyses and the dispersal of various crime data and human behaviour in streets [15-17]. The results show that the building-street interface matters for the perception of safety and the degree of presence of people in streets. In turn, safety and the presence of people are suspected to influence an individual's decision to walk through a certain street or perform stationary activities there, or conversely, to avoid that street in favour of another one. The microscale tools can tell us something in quantifiable terms about the conditions that promote and impede the presence of people and the perception of safety. To this end, the macroscale analyses from the Space Syntax methods and the microscale analyses from van Nes and López are applied to analyse and describe the spatial features of the built environment.

MatSim is an agent-based program for making large-scale transportation simulations. Agents, representing residents, are assigned a home address and a job or study location. This data is generated using basic population data. Daily activity schedules are appointed or generated using travel surveys. After that, the agents will choose a travel itinerary based on the transportation options available. The agents' route-choice and mode-choice between their origins and destinations is then made based on travel time and costs. The simulation accuracy depends on the amount of detail of the parameters programmed into the model. Only necessary public activities (namely travelling from A to B) are simulated into the MatSim model. Optional and social activities cannot be simulated into the MatSim model [18].

In this inquiry, we work with a hypothetic relationship between urban space, energy usage and microscale. In particular, we focus on the spatial relationship between urban space and energy use for transport (Figure 5.2)

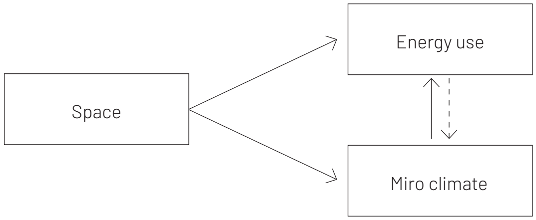


FIG. 5.2 Schematic hypothetic relationship between space, microscale and energy usage

Individual mobility choice follows the rule of the path of least resistance. Travel behaviour choice can be indicated from the spatial configuration from the Space Syntax analyses [6]. The higher spatial integration of the network, the higher flow of movement. The challenge is to identify what type of spatial integration aggregates high private car dependency or high degree of walkability.

5.2.3. Methodology

Aiming to examine a correlation between the configurational street structure, building density, functional mix, walkability and energy usage, a form of mixed-method approach [19] needed to be applied. Although the study does not contain qualitative research elements per se, some of the data can be said to have a qualitative origin. The method of the urban microscale tools is designed to register quantitatively those intrinsic qualities that promote walkability and social interaction in public space, namely the extent of the presence of doors and windows facing the street and the topological distance between private and public spaces. The spatial configuration of the street structure describes extrinsic properties of space. That is, no meaning is given to the urban form; it purely reveals how function, i.e. movement, follows from the spatial structure of the street network [9]. It is all about built form and function and not on built form and meaning.

Space Syntax

Space Syntax methodology is at the basis for analysis of the spatial structure of the street network. This street network is represented in the segment map, based on a hand-drawn axial map following the principle that the fewest and longest set of axial lines of visibility and accessibility cover all convex spaces in a spatial system [8]. Throughout the years, the calculations with the Space Syntax method have been refined. At present, the two main analysis methods used are segment integration and angular choice [7].

The basis of the Space Syntax method is the axial map. The first step is to calculate the topological depth from one axes to all others, in other words, the total number of direction changes from one axis to all others. The integration (I) of an axial line (i) is a function of its depth related to all other axes. The calculation behind it is [20]:

$$I_i = \frac{2(n\left(log_2\left(\frac{n+2}{3}\right)-1\right)+1)/\,(n-1)(n-2)}{2\left(\left(\frac{\Sigma_{j=1}^{n} d_{ij}}{n-1}\right)-1\right)\Big/(n-2)} \tag{1}$$

Where n is the number of segments, d_{ij} is the shortest distance (least number of direction changes) between two segments i and j. The greater the number of steps (d_{ij}) between streets axes, the lower the integration values gets.

Potential through-movement and to-movement:
The Angular Choice value of a street axis provides an indication of how likely one is to pass through that axis when moving around in a built environment. Choice measures the degree of betweenness and measures the through-movement potentials. The formula of choice C of an axis (i) is as follows [20]:

2 $$C_i = \sum_j \sum_k g_{jk}(i)/g_{jk}(j < k)$$

Where g_{jk} (i) is the number of shortest paths between segment j and k containing i, and g_{jk} is the number of all shortest paths between j and k [20].

In the Segment Integration analyses, the axial lines are broken up where they cross each other [21]. The Segment Integration of a street shows how easy it is to get to that segment from all other segments. It calculates the to-movement potentials. Segment integration can be compared across systems. It measures how close each segment is to all others in terms of the sum of angular changes that are made on each route [6]. Here too, a radius of R=500m is taken for the local scale, and R=5000m for the city scale.

The Angular segment choice is calculated by counting the number of times each street segment falls on the shortest path between all pairs of segments within a selected distance (termed 'radius'). The 'shortest path' refers to the path of least angular deviation (namely, the straightest route) through the system [6]. The angular integration of a segment x is:

3 $$AI_x = \frac{1}{n} \sum_{i=1}^{n} d_\theta(x, i)$$

Where n is the number of segments, and d_θ the angle between any two segments on the shortest path on a segment x [20]. When adding the length 'l' of segments, we get the following formula [20]:

4 $$AI^l_x = \frac{\sum_{i=1}^{n} d_\theta(x, i)\, l\,(i)}{\sum_{i=1}^{n} l\,(i)}$$

Aggregating the data:
Finally, the values of the angular choice analyses have been aggregated in a single map. Showing the high and low radius simultaneously helps to find out which areas are integrated well into the local street network, and also have good accessibility on

city scale. We suspect that areas with good integration on both scale levels lead to higher walkability and a reduction in energy usage.

Similarly, areas or streets that are more segregated on either the local or the city scale level can be quickly spotted. If local integration is higher than city scale integration, this is highlighted in green. If the opposite is the case, this is shown in red. The matrix of Table 1 shows how the values were aggregated with each other with low (L), medium (M) and high (H) values on all calculations. We applied the natural break – or Jenks – method in this project to classify the resulting spatial values as low (L), medium (M) or high (H). We applied a 35-meter buffer around the segments, creating aggregated areas for each integration level. This value is based on various research concluding that a dense street network with a fine mesh size of between 60-80 meter performs better than larger blocks, both when it comes to increased circulation and the exploitation possibilities of the urban block [22, 23].

		Angular Choice with Low radius (R=500m)		
		Low	Medium	High
Angular Choice with High radius (R = 5000 m)	Low	LL	LM	LH
	Medium	ML	MM	MH
	High	HL	HM	HH

Energy usage for mobility

Whereas transport is the common name for all movement of people and goods, mobility is the ability for people to move freely or be easily moved from a given origin to a given destination [24]. A trip's purpose can vary from necessity, such as commuting to work or school, doing shopping, visiting the dentist et cetera, to optional trips such as fun shopping, going out to a bar or cinema, taking a walk or a ride, visiting friends and so on. Within mobility, the distinction can be made between private and public transport. Private transport consists mainly of walking, cycling and car driving. The first two transport means are energy-neutral and healthy alternatives in comparison to the resource-consuming, private car. Private car usage is known to be unhealthy, both to those who drive them and to those with whom they share the roads and streets.

The city of Zürich has an exemplary, dense public transport network consisting of a wide range of modes that operate in tune with each other: trams, (trolley)buses, local, regional and (inter) national trains, even a few boat services over the lake and funicular trains leading up the hills.

The city of Bergen has a dense public transport network in its central parts, but coverage decreases sharply only a couple of km from the city centre. Then, one is dependent on owning a private car. The most used public transport mode is the bus and the newly established light rail running through the valley.

This contribution does not include the energy usage of the public transport system, but focuses on the energy usage for private transport. Since pedestrians and cyclists move around using energy they 'produce themselves', the energy usage by cars is the one mode that is useable for comparing energy consumption with to-movement and through-movement potentials. Agent-based MatSIM simulations can however demonstrate a change in the agents' choice of mode of transportation, for example, if a change occurs in the public transport network or a change in the road network.

To calculate the energy usage per street segment, the relevant parameters should give information about the amounts of vehicles that use a specific street segment, and how much energy each vehicle consumes. For the analysis of Zürich, data generated through an agent-based simulation program (MatSIM) are used as input. For Bergen, publicly available, measured traffic data was used. This input data contains the required information mentioned above:

- Maximum traffic speed (Figure 5.3 left);
- Amount of (private) vehicles (Figure 5.3 right).

Red, blue and purple colours in Figure 5.3 show the highest values for maximum traffic speed and the amounts of private vehicles. As can be seen for both Zurich and Bergen, the largest vehicle flow takes place on the roads that also have the highest maximum speed. Notably, these are the motorways, which connect the centres with the peripheral areas.

With the amount of traffic and the distance and time travelled known, the last parameter needed is the amount of energy it costs to move a vehicle from one point to another. Leaving out of the equation the amount of energy that the industry needs to produce the car and the fuel itself, MacKay [25] explains how the total amount of energy that a driving car's engine produces is dissolved into four parts:

1. **Changing speed (and direction):** After a vehicle with mass m speeds up to a velocity v, the built-up kinetic energy is converted by the brakes into heat at stopping points such as traffic lights and pedestrian crossings. Kinetic energy is calculated by the formula:

5 $$E_k = \tfrac{1}{2}mv^2$$

The problem with the parameter for distance is that the way the segments are split up in the model, this formula would assume that each car comes to a full stop at the end of each street segment. The model, thus far, lacks the data on stopping points. However, it is also not possible to calculate in an accurate way the aggregated losses from, amongst others, subtler braking, taking turns, and sloped terrain. To eliminate this inaccuracy, the kinetic energy for braking is left out of the equation. The final estimation of energy usage will therefore be modest, at best, compared to the actual numbers.

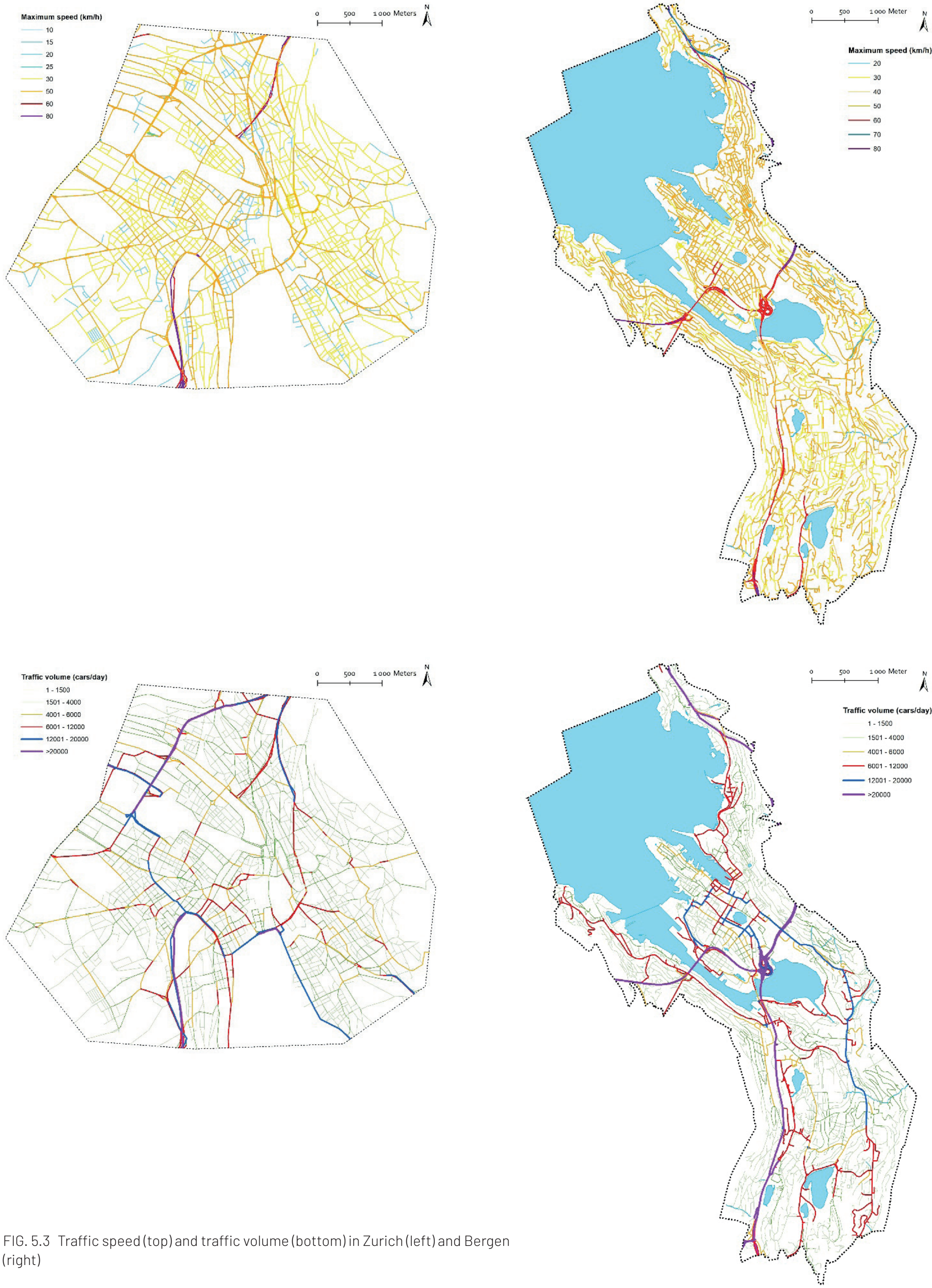


FIG. 5.3 Traffic speed (top) and traffic volume (bottom) in Zurich (left) and Bergen (right)

2. Air resistance: The swirl of air around the car causes a drag, the coefficient of which, c, is depending on the cross-sectional area, size and shape of the vehicle. Following MacKay, we here assume an average car drag value of 0,33. The effective area A_{air} of the air swirl is calculated by multiplying the cross-sectional area A_{car} of the vehicle by this drag-coefficient:

6 $A_{air} = c \,.\, A_{car}$

For air resistance, the kinetic energy of the swirl of the air is calculated. The mass is found by multiplying density by volume. The volume of the tube of air is obtained by multiplying the effective area A by the length of the tube, obtained by vt. The mass of the tube of air is then:

7 $Mass = density \,.\, volume = \rho Avt$

where ρ is the density of air, which is 1,3 kg/m3. The kinetic energy of the air swirl is then:

8 $E_{air} = \frac{1}{2}\, m_{air}v2 = \frac{1}{2}\rho Avtv^2$

9 $\dfrac{\frac{1}{2}\rho Avtv^2}{t} = \frac{1}{2}\rho Av3$

3. Rolling resistance: This is a constant coefficient that depends on the vehicle's mass, and is typically 0,01 for cars. A 1000 kg car with a 0,01 rolling resistance coefficient then requires 0,01 • 1000 = 100N. With: power = force • velocity, rolling resistance is directly related to the speed in m/s by a factor 100:

10 $E_{roll} = 100v$

4. Heat: The poor energy-converting capabilities of conventional fossil-fuel engine cars makes that around three quarters of energy is lost to heat. Whilst modern cars are fortunately getting more and more efficient, A factor 4 is usually assigned to car engine heat loss. So, when we count with 75% heat loss, an average mass of the car of 1000 kg, and a cross-sectional area of 2,4 m2, the formula for the total amount of energy consumed by one driving car:

11 $E_{car} = E_{air} + E_{roll} + E_{heat} = (\frac{1}{2}\rho Av^3 + 100v)\, 4 = 4\, (\frac{1}{2} \times 1{,}3 \times 0{,}8 \,.\, v^3 + 100v)$
$= 4\, (0{,}52v^3 + 100v) = 2{,}08v^3 + 400v$

Now we can generate results per street segment. The total amount of energy E used by a given number of vehicles that drive through a certain street per day at a certain speed is:

12 $E = [amount\ of\ cars\ per\ day] \times (2{,}08\ [traffic\ speed]^3 + 400\ [traffic\ speed])$

Urban microscale tools

The various spatial microscale tools offer detailed spatial descriptions of the relationship between buildings and streets, whereas the Space Syntax analyses on macro level show the degree of street inter-connectivity on various scale levels. The focus on the microscale tools is on how building entrances and windows on ground floor level are connected to streets and how buildings and streets are inter-visible to each other in urban space [14]. A street constitutedness analysis shows whether buildings along a street have entrances directly facing the street or not. Every building that has an entrance connected directly to the street is defined to constitute the street, and every building with no entrances directly connected to the street is defined to make the street un-constituted. A street is considered to be constituted if it has at least one building that has one entrance connected to the street.

A street intervisibility analysis is aimed at describing to what extent buildings are intervisible to one another in relation to the street. A highly intervisible street has buildings with a sufficient percentage of doors and windows on the ground floor level on both sides facing the street to allow people to see into the building from the street, and to allow people inside the buildings to see out on the street. On the one hand, this creates positive conditions for a natural surveillance mechanism that is known to prevent crime. On the other hand, it creates the opportunity for locals, neighbours and passing strangers to interact and engage in chance social activities, which has been observed to attract more activities [26]. The natural conditions for interaction and surveillance are drastically reduced if a street only has buildings with doors and windows on ground floor level on only one side of the street – or less than that. We call such a street poorly intervisible. The intervisibility analysis gives a quantitative indication of the (potential) degree of the natural surveillance mechanism between buildings as well as towards the street, as described by Jane Jacobs [22].

TABLE 1.10 List of variables used in the model

VARIABLE	DESCRIPTION	METRIC	SOURCES
Angular Choice (R=500)	Through-movement potential with 500m metric radius	Numeric	[27]
Angular Choice (R=5000)	Through-movement potential with 5000m metric radius	Numeric	[27]
Aggregated Angular Choice	Combination of high and low radius ([C500] x [C5000])	Numeric	[28]
Angular Integration (R=500)	To-movement potential with 500m metric radius	Numeric	[27]
Angular Integration (R=5000)	To-movement potential with 5000m metric radius	Numeric	[27]
Energy consumed with-out stops	Total car energy usage per street segment per day	kWh/day	[25]
Intervisibility	Visibility between streets and the ground floors of buildings	%	[14]
Constitutedness	Entrances oriented towards the street	0 or 1	[14]

5.3. Results

5.3.1. Results from the macroscale analyses

Combining the various spatial data with the data on energy for car transport gave us the following results. First of all, the spatial structure matters on how transport energy usage is distributed in various streets in a built environment.

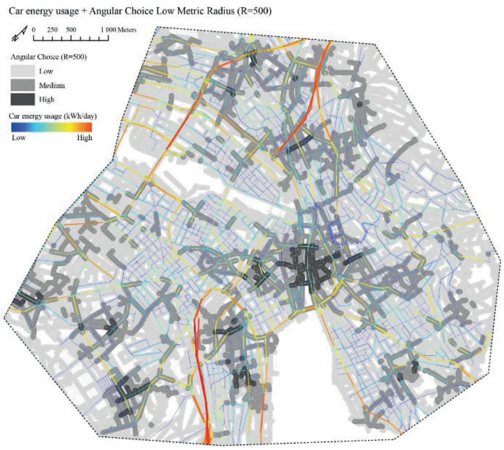
Figure 5.4 shows the energy usage from cars overlapped on angular choice analyses with a low metrical radius for Zürich (left) and Bergen (right). As can be seen in the figure, where the Space Syntax values are high on a local level (the black and dark grey colours), energy usage for transport is low. In historical urban centres and old local centres, streets often have high values in the angular analyses with a low metrical radius. These areas tend to have finely-meshed, short urban blocks and exhibit high rates of pedestrian flows.

Figure 5.5 shows the energy usage from cars overlapped on angular choice analyses with a high metrical radius for Zürich (left) and Bergen (right). The figures show that the main routes through and between urban areas have the highest integration values, and also the highest energy use for transport. When comparing figure 5.5 with figure 5.4, the energy use for transport tends to be lower where the main routes are running through neighbourhoods with high local angular choice values.

Possible relations are found between spatial integration and energy usage for transport on the choice analyses. The first results suggest that there is a possible correlation between the total energy usage by cars and the high-radius angular choice analysis. In other words, central roads and regional roads that link city parts together are responsible for higher traffic energy consumption.

Figure 5.6 shows the correlation between energy usage for transport and angular choice with a low metrical radius (R=500) for Zürich and Bergen. The higher values on the choice values with a low metrical radius, the lower energy usage for transport. In other words, streets that are easily accessible within a walking distance contribute to a reduction in traffic energy consumption. Seemingly, the degree of walkability is high in these areas because of the high degree of local inter-accessibility that these short urban blocks produce.

Conversely, the street segments with a relatively high energy consumption generally also have higher values in the angular choice analysis with radius R=5000. In fact,



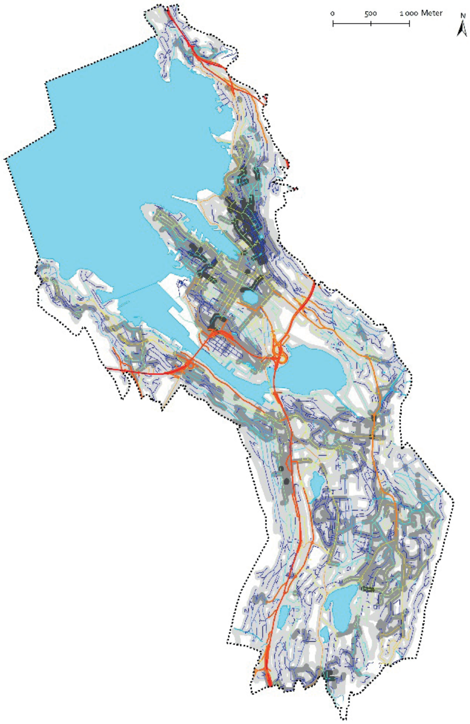
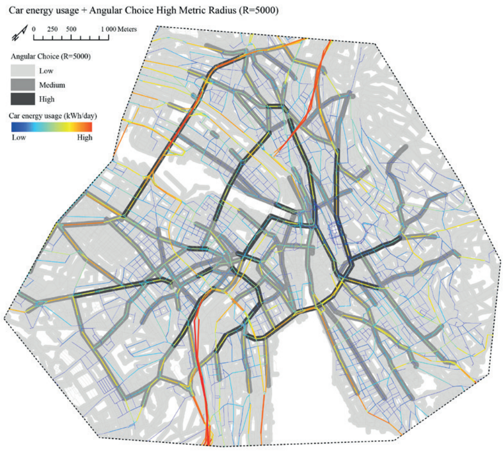


FIG. 5.4 Energy usage from cars overlapped on angular choice analyses with a low metrical radius for Zürich (left) and Bergen (right).



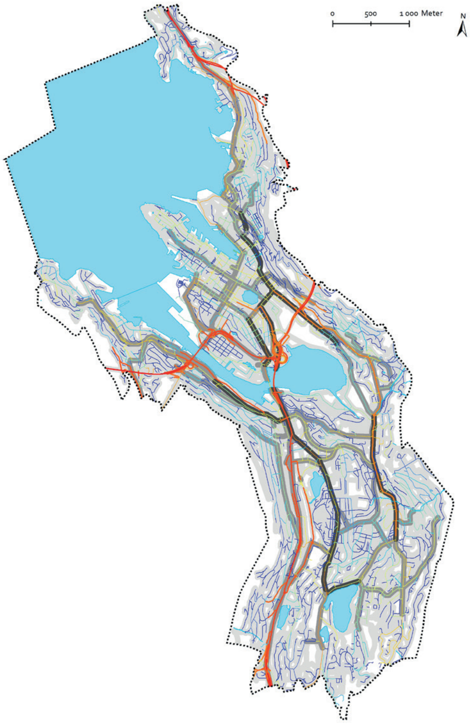
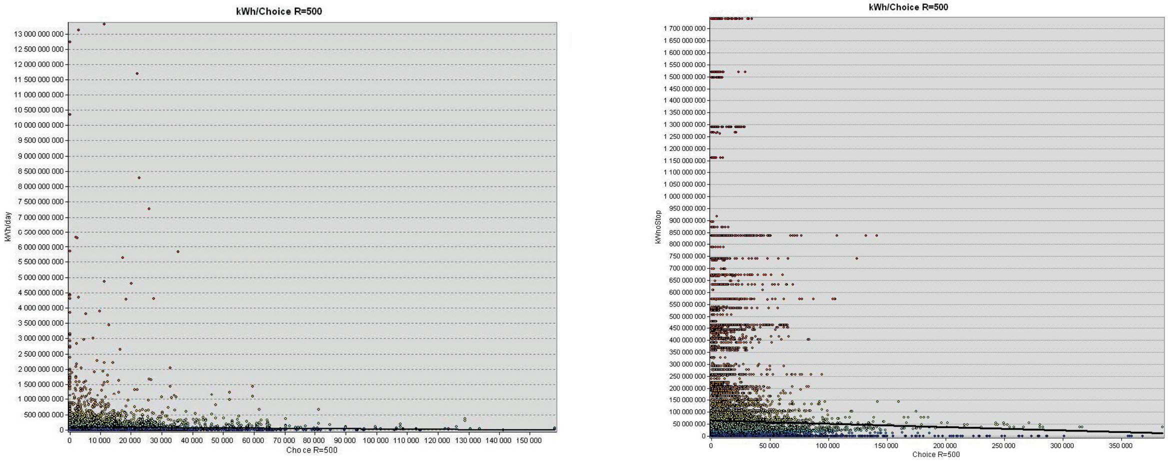


FIG. 5.5 Energy usage from cars overlapped on angular choice analyses with a high metrical radius for Zürich (left) and Bergen (right).

FIG. 5.6 Scatterplot of energy usage over angular choice with low radius



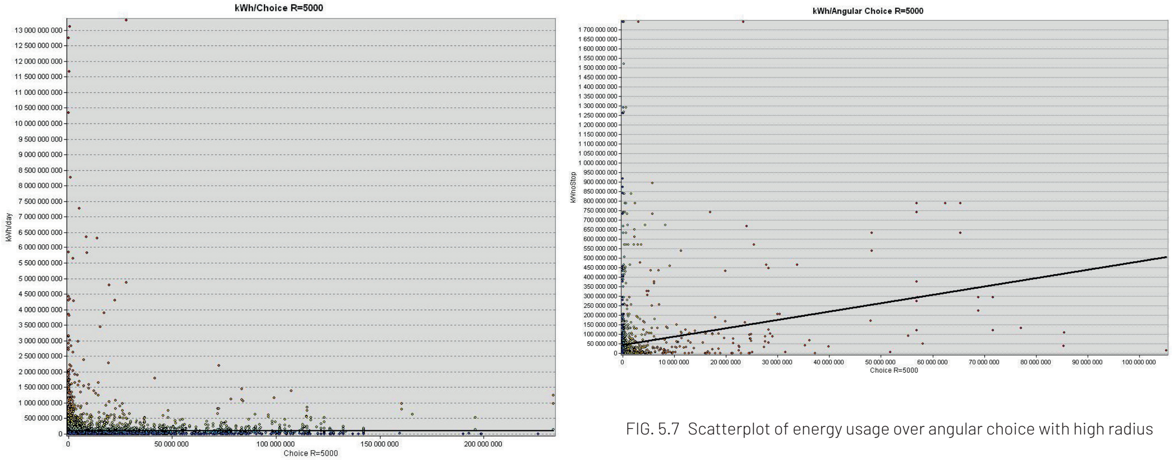
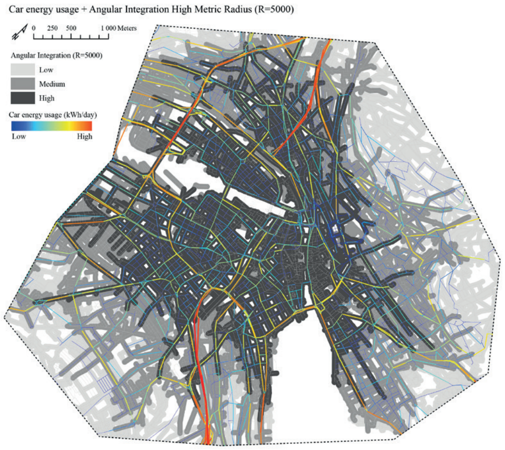
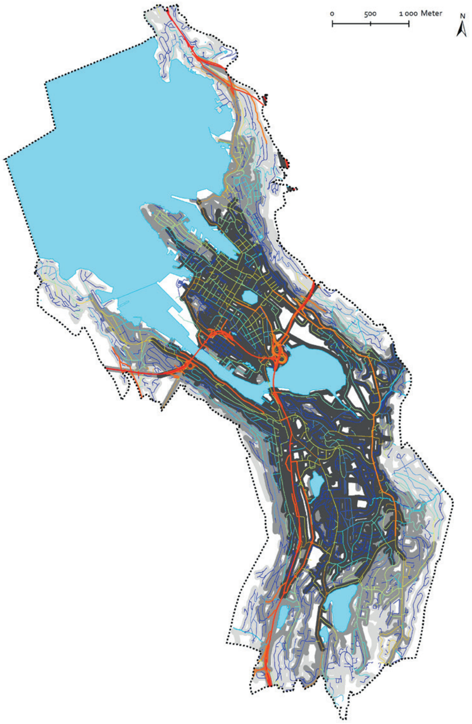
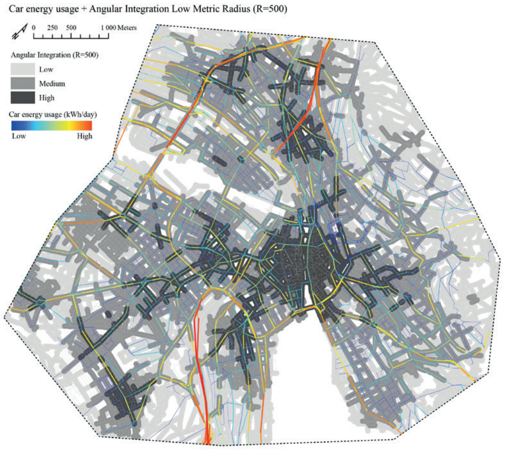


FIG. 5.7 Scatterplot of energy usage over angular choice with high radius







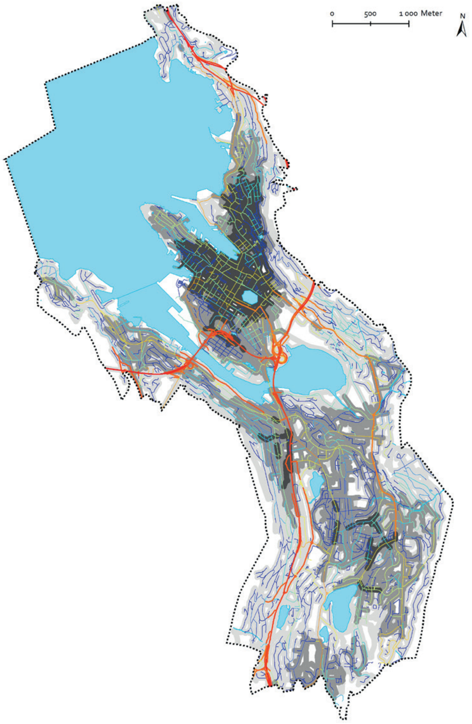


FIG. 5.8 Energy usage from cars overlapped on angular segment analyses with high metrical radius (above) and low metrical radius (below) for Zürich (left) and Bergen (right).

those streets segments that have a high local through-movement and a high energy consumption by car traffic, generally also have high or medium values on the high radius. It is clearly visible how the 'aorta's' of high energy usage 'feed' and connect the areas of high local through-movement. This does not explain, however, why the remaining values are considerably lower. Figure 5.7 shows a scatterplot with the correlation of energy use for transport and angular choice with a high radius (R=5000). It shows a trend where the higher the spatial integration values, the higher the energy use for transport.

The correlation graphs of Figure 5.6 and 5.7 show a trend of increasing energy usage with higher global choice values, and decreasing energy usage with local choice values. If the degree of land use diversity and building density depend on the spatial configuration of the street and road network, then we might assume that where function mixture and building density are at their highest, less energy is used for transport. In Zürich centre, walkability and public transport usage is high. As soon as the integration values drop, the energy usage for transport increases. This is in particular the case in areas where the spatial integration values are high on a city scale, but low on a local scale.

Figure 5.8 shows segment integration analyses of Zurich and Bergen with both a high and a low metrical radius. As can be seen for both cities, the energy use for transport is high on the main routes leading to the centres. The energy use for transport is low inside the city centres, both on the segment integration analysis with a low and a high metrical radius. As indicated, segment integration shows the to-movement potentials, which means that more people travel to these highly integrated centres. The angular choice analysis with a high metrical radius highlights the main routes leading towards the town centres. The energy use for transport is highest at the highways tangenting the city centres.

To gain more insight in the inter-relationship between local and global accessibility and the effects on the presence of energy-consuming forms of mobility, the two scale levels were combined into a single map following the aggregating rules as described in Table 1. What results is a representation of aggregated choice values on both the local and the global scale as seen in Figure 5.9. High values have a dark shade, and colour red if global integration is higher than local integration and green if local integration is higher than global integration. The difference in structure of the red and green areas is clear: streets with high local through-movement potential are clustered together in sub-centres, whereas streets with high through-movement potential on city scale are more linear, elongated and seem to connect the green clusters. By correlating the Bergen maps in Figure 5.9 with one another, we see that areas with high or medium local values score lowest in energy usage. High global values seem to push up energy usage systematically.

The bar in Figure 5.10 representing high global and low local values (HL) scores higher than medium global and medium local (MM) integration, although marginally.

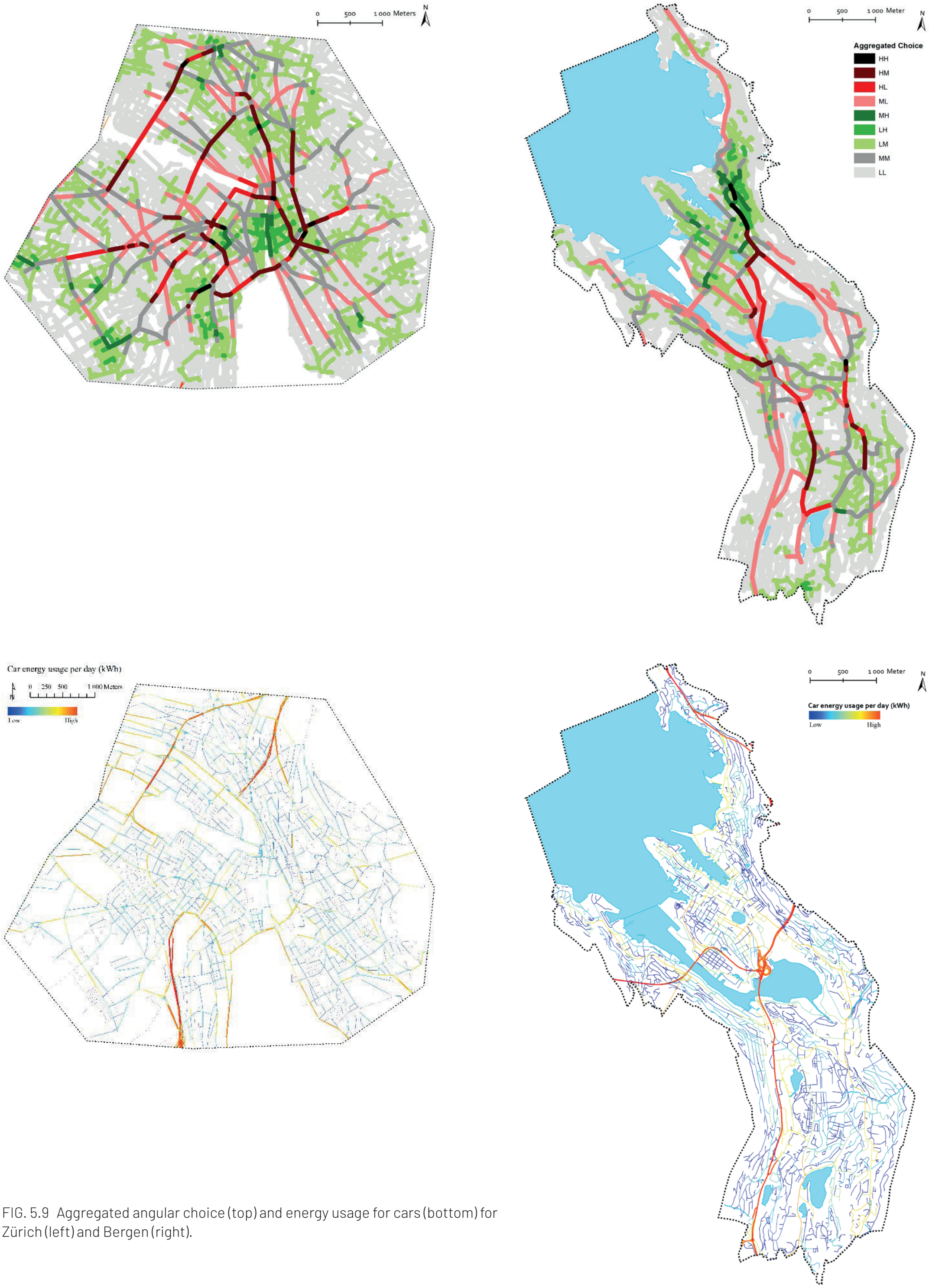


FIG. 5.9 Aggregated angular choice (top) and energy usage for cars (bottom) for Zürich (left) and Bergen (right).

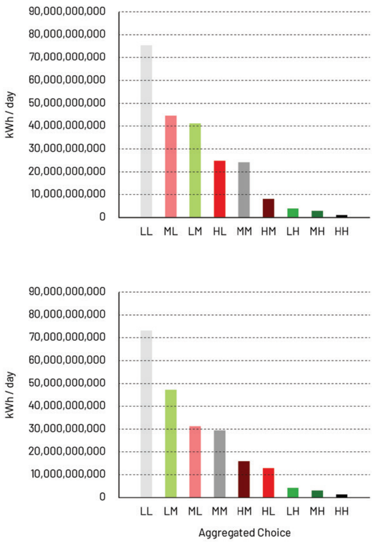


FIG. 5.10 Energy usage for each category of aggregated angular choice for Bergen (top) and Zürich (bottom)

Furthermore, all categories with medium or high local values (apart from LM) stand to the right, scoring low in energy usage. It seems, then, that the presence of high local values has a bigger effect on energy reduction than the presence of high global values.

Figure 5.9 for Zurich shows the aggregated angular choice analyses with both metrical high and low radius (left) and the energy use for transport. Here in Zurich too, we see that areas with high or medium local values score lowest in energy usage.

In the bar diagram of Figure 5.10, which represents energy usage for each aggregated choice category for Zürich, the values in the middle rank slightly different from Bergen. Here, (LM) has higher energy usage than (ML). Likewise, (HM) has higher values than (HL). Again, the differences are marginal, and the higher global integration values are probably responsible for this difference in comparison to the results for Bergen. The similarities, however, are evident: all areas with high local integration, (LH), (MH) and (HH), are ranked lowest in energy usage on the right of the graph. Low local integration values end up equally consistently to the left, scoring high in energy usage.

Categories:
The resulting categories can be interpreted as follows:

- High global, high local choice values (HH): Major road; Connects city districts, often supporting high volumes of traffic. When possible also used intensely by local pedestrians and cyclists.

- High global, medium local choice values (HM): Central road, connecting city districts and the wider region; supports high volumes of regional traffic, and moderate local traffic.

- High global, low local choice values (HL): Regional road, often a motorway or boulevard; supports high speed, large volumes of traffic; little to no local traffic.

- Medium global, high local choice values (MH): District road, connecting neighbourhoods; moderate to high traffic volume, intensely used by pedestrians and cyclists.

- Medium global, medium local choice values (MM): District or local street that supports moderate traffic, often a mix of motorised traffic, pedestrians and cyclists.

- Medium global, low local choice values (ML): District or local road, predominantly for local motorised traffic travelling within and in between neighbourhoods.

- Low global, High local values (LH): Central street within or in between neighbourhoods; high intensity of local traffic, often unmotorised;

- Low global, medium local values (LM): Neighbourhood street; mixed, moderate traffic intensity, mostly local residents.

- Low global, low local values (LL): local road or street serving only the immediate surrounding properties.

This interpretation allows for an understanding of what these categories of aggregated choice may represent in reality. However, since the analysis of spatial configuration merely describes the extrinsic properties of space, no meaning such as a typology or road standard can be appended to it. As an example from Bergen, some of the most highly integrated segments are in fact narrow alleys inhibiting any car traffic, not wide, asphalted avenues. Conversely, some of the most spatially segregated segments are in fact relatively heavily trafficked roads, and could be better typified as district roads. Knowledge about the incongruence between potential to or through movement and actual observed and/or facilitated movement can be useful towards planning policies.

5.3.2. Results from the micro scale analyses

Enhancing walkability implies to have eyes on the streets from adjacent buildings. We tested out to what extent the degree of street constitutedness, street intervisibility from adjacent buildings and topological depth between public and private space influence energy use for transport. Detailed registrations were made of the entire Bergen study area, and a one square kilometre area in and around the centrally located Hochschulquartier. Figure 5.11a shows a combination of aggregated through-movement potential and the constitutedness of buildings in and around the Hochschulquartier in Zürich. The old town centre to the west and most street segments that have high and medium choice values show a higher number of constituted buildings. This phenomenon seems to be particularly strong on Rämistrasse, Zürichbergstrasse, Sonneggstrasse and Hottingerstrasse.

Furthermore, the correlation seems to be strongest with the high scale through-movement potential and the local to-movement potential. The immediate streets around those streets have significantly lower energy usage values. This may indicate that the local street network, through its high local integration, profits from this and favours walking, cycling and public transport. By comparison, Gladbachstrasse to the east has low aggregated through-movement potentials and a low number of constituted buildings. There are no major attractors along this part and the building density and number of public functions surrounding the street is low compared to some of the aforementioned streets. The energy usage from car traffic in this street is, however, comparably relatively high. Public transport is covered by one bus line here.

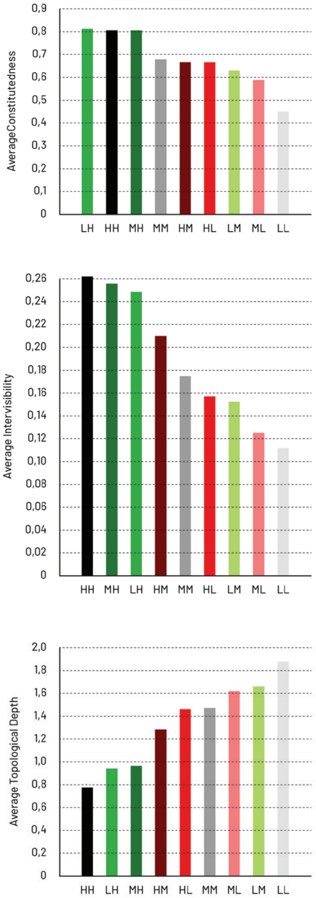


FIG. 5.11 Average constitutedness (a), intervisibility (b) and topological depth (c) for each category of aggregated choice for Bergen

The intervisibility analysis in Figure 5.11b reveals a similar pattern as the constitutedness analysis. Streets that are well-integrated in the local and city-wide street pattern have more buildings facing them than more segregated streets. A clear example of this difference is that between Zürichbergstrasse and Gladbachstrasse: the latter is more segregated and has low inter-visibility, whereas the former is well-integrated, has above average inter-visibility, but low energy usage compared to Gladbachstrasse.

The registration of topological depth of Figure 5.11c shows the opposite result, in that the average distance between public and private is shorter on highly integrated local streets than on less integrated streets. The exception lies with the large, new public buildings part of the masterplan for transformation. Though they have not been built, the relative large distance between public and 'private' in these large buildings can affect the potential for interaction between buildings and the street.

For the microscale analyses of Bergen, two areas are compared to each other by zooming in on a one square kilometre area (Figure 5.11d-i). On the left, the centre area around the old harbour is shown as well as parts of neighbouring Nordnes to the west and Sandviken to the north. On the right, we zoom in on the area of Mindemyren, an industrial zone approximately three kilometres south of Bergen centre, surrounded by residential zones Løvstakksiden to the west and Wergeland to the east. These areas have a suburban character. The industrial area is about to go through a process of transformation. A new, second light rail line is planned to go through the area, and new infrastructure and building activities are aimed at setting the premises for a lively urban centre. It is the first large area outside the city core that is intended to get an urban character by increasing building intensity and allocating a variety of residential, commercial and public functions.

When comparing the images, we can see that the locally well-integrated centre of Bergen has only very few unconstituted buildings, whereas many buildings in and around Mindemyren do not face the street, especially in the areas, marked in light grey, which are locally and globally relatively segregated. A similar pattern is seen when analysing street-building intervisibility in Figure 5.11e,h. High levels of intervisibility are reached in the centre, reflecting a high level of public functions, notably shops. Intervisibility in Mindemyren is very low in comparison, also along the main streets with high global choice values. The suburban and industrial character of these areas, combined with a lack of public functions, is likely responsible for this. This is also reflected by the topological depth analysis of Figure 5.11f,i. The distance between public and private space is one step or less on average in the city centre. In and around Mindemyren, values average on two or higher, especially along the segregated streets. Some of the industrial and commercial buildings, having a public function, do exhibit relatively low topological depth.

The bar graphs in Figure 5.12 reflect the findings from Figure 5.11d-i. They demonstrate that in the Bergen study area, constitutedness and inter-visibility fall as aggregated choice values go down, especially on local level. Contrary to the energy

Micro scale analysis

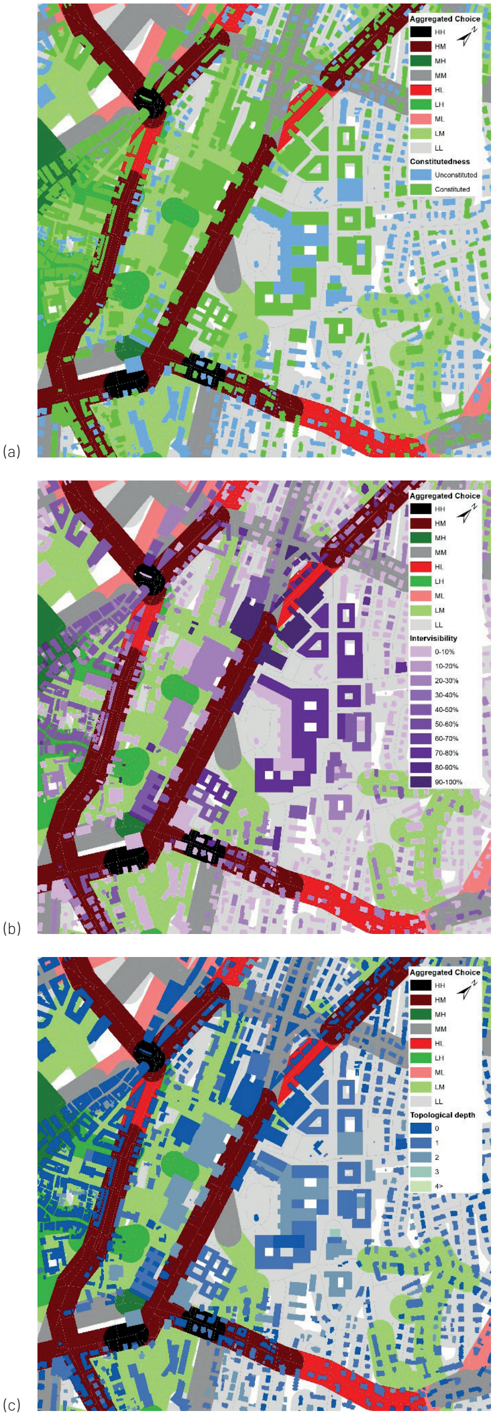
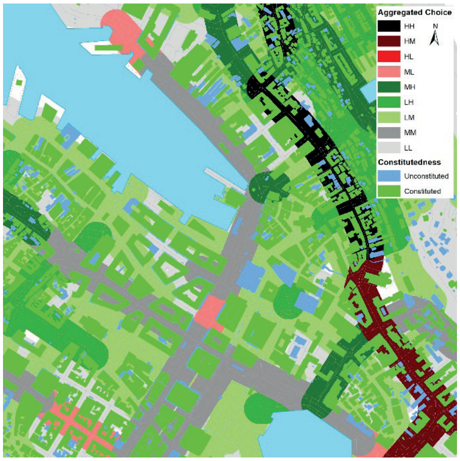

Zürich Hochschulquartier

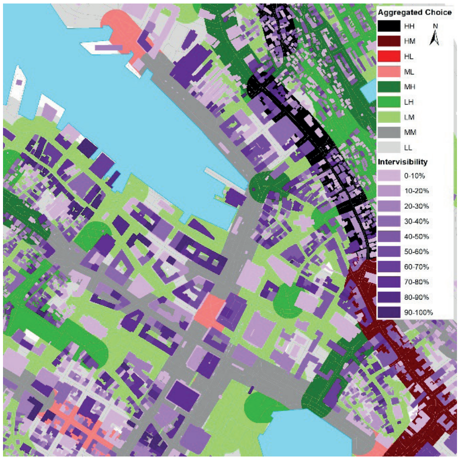
FIG. 5.12 Constitutedness of buildings (a), the degree of intervisibility (b) and the topological depth between private and public space (the number of semi-public spaces between buildings and streets) (c).

1 km2 zoom-in on Zürich Hochschulquartier, Bergen centre and Mindemyren

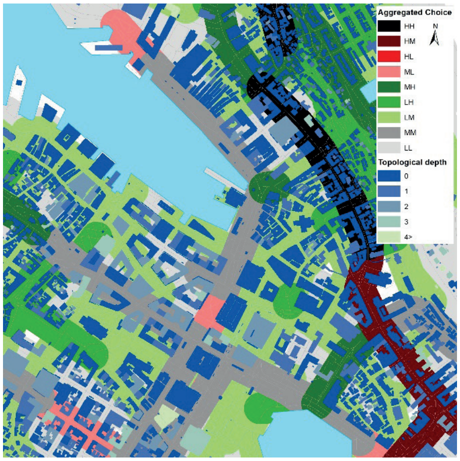
Bergen centre



(d)

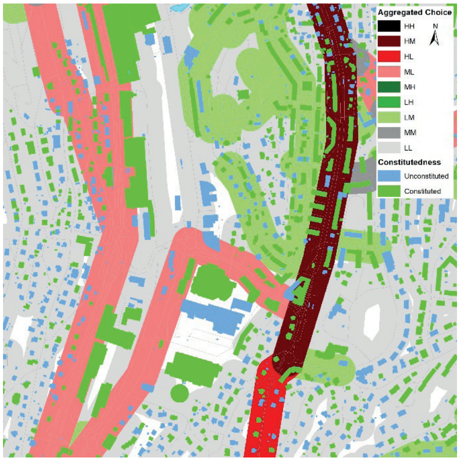


(e)

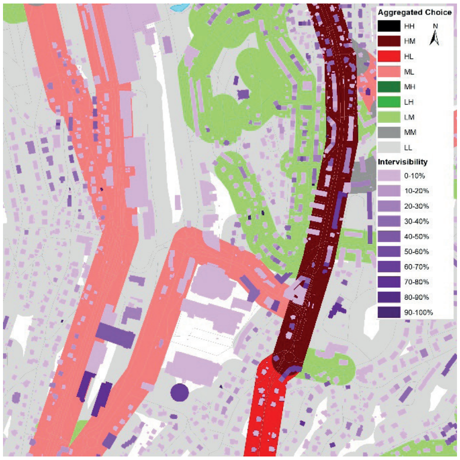


(f)

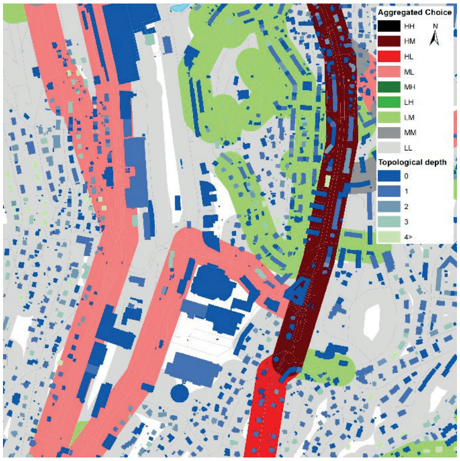
Mindemyren



(g)



(h)



(i)

usage comparisons of Figure 5.10, here, the three aggregated categories with high local values (LH), (MH) and (HH) show up to the left, representing the highest average constitutedness and inter-visibility, meaning the interaction between building and street is on average highest in these areas. Conversely, topological depth increases (Figure 16) as local integration values drop. This seems to point at a possible co-relation between the spatial structure of the street network and the degree of building-street interaction in support of higher walkability: where the street structure encourages more people to walk, buildings interact more with the public domain. Where buildings interact more with the street, more people walk.

Data limitations

The data limitation in this inquiry is that there are no energy registrations for walking. Walking as a transportation mode is more complex than vehicle transport and the requirements for walking are much stricter than those for driving. A challenge for testing our hypothesis in future research is to add registrations for pedestrian flow into the model. Likewise, energy use for public transport such as trams and busses has to be taken into account. However, the calculations of energy usage per user ought to be calculated in a different way than private cars and transport of public goods.

Through the application of the model in two different cities, this inquiry shows some evidence of a relationship between street network configuration and energy use for person transport. One reason is that the Space Syntax method operates with precise concepts of urban space, independently applicable on cultural, economic, social or aesthetical contexts. Moreover, Space Syntax calculates spatial relationships independent from socio-economic data. The MatSim model aggregates traffic data on the mobility network based on the place-bounded data regarding the location of urban functions. Therefore, overlapping and correlating these two models can contribute to knowledge on the relation between urban spatial configuration and energy use for transport.

5.4. Discussions and Conclusions

Seemingly, the spatial structure of urban space and the degree of building-street interface affect energy usage for transport. High angular choice with low metrical radii, combined with buildings with active frontages allowing for interaction with the streets, contribute to a high degree of 'walkability' in streets. Areas with high integration on the angular choice with both high and low metrical radii yield for an efficient public transport system on the integrated main routes, i.e. those streets with high values on the angular choice analysis with a high metrical radius. In Bergen as well in Zürich, some of these streets have tram, busses or light rail lines on themThe private car in particular is a major contributor to energy use for transport. If the to-movement potentials on a local scale are well-integrated with the high-scale through-movement network, private car usage is reduced. Walking and cycling seem to become a natural choice for shorter, local trips. In addition, these streets should be constituted by the buildings and have a high degree of intervisibility from adjacent buildings. As indicated by Jacobs [22] and Gehl [26], this urban microscale aspect contributes to a natural surveillance mechanism and makes walking attractive as a local transportation mode. When combined with an equally well-integrated, diverse public transport system, local trips can then extend to car-free regional trips, too, reducing energy usage further. As we have seen in the energy usage equation, longer and therefore more high-velocity car trips consume exponentially more energy. Neighbourhoods with short urban blocks have high values on the angular choice and angular segment integration values on the street network. In line with Jacobs, short urban blocks enhance walking as a transportation mode. Walking and cycling is acknowledged as the mobility means with the lowest energy consumption for transport. Therefore, the first task is to explain what kind of spatial features enhance these kinds of transport. What makes walkability attractive as a mobility means?

So far, these two case studies have shown that a combination of short urban blocks (or: a fine grained urban mobility network within a short metrical distance) intersected by integrated main routes and constituted and intervisible streets from adjacent buildings are complex necessary conditions for enhancing sustainable transport means in terms of facilitating public transport, walking and cycling. All these parameters need to be present at the same time. Moreover, neighbourhoods that possess these spatial features tend to transform themselves naturally to highly urban areas with high building density and high degree of land use diversity [3]. Urban areas with low values on the angular choice with a low metrical radius and buildings turned away from streets generate private car dependency, low-density urban sprawl into the countryside and mono-functional areas. This again contributes to complex travel routes between work, shopping, leisure activities and home. To counteract this, an effective public transport network should connect various neighbourhoods with one another, supported by highly integrated main routes.

More research is needed, however, on the share of other modes of transport, notably public transport, walking and cycling. Further studies will include energy-calculations for public transport, simulated and/or observed data on travel behaviour of pedestrians and cyclists, and subsequent correlations with the results from this report. The aim is to test if and how a change in the street network, combined with a change in microscale conditions, would alter the share of private vehicle usage versus the more sustainable alternatives. The usefulness of this model is a first step towards an energy classification for different street and road types. However, this model needs testing on other cities before making it operational for evaluating existing, transformative and new urban plans. At least, this model is a first step towards an increased understanding of the spatial conditions that enhance sustainable mobility in cities. For the transport energy calculations, measured data as well as simulated data on vehicular traffic was used to address the mobility (or: person transport) component of transport. Other transport, however, notably transport of goods, has not been part of the research. This is considered by the authors to be a vital missing link in the wider discussion about sustainable transport that has much larger implications for how our societies and economies are organised.

The forces of the free market society have produced a world where profit-maximising, mass-production, outsourcing and mono-culture are prioritised over – to name a few – energy efficiency, local economy, ecological diversity and social equity. Even though impressive distribution networks have opened the door to goods from all around the world and at the same time have managed to achieve competitive prices, local producers and consumers have now become almost completely dependent on the continuity of the supply of these goods. One major negative outcome is the countless CEOs and employees that are on payroll along the unnecessarily long supply chain of distributors, packaging firms, shipping companies, customs, importers-exporters, business representatives and so on – not to mention the energy required to power their offices, cars and houses. Another major disadvantage is the dependence of the local economies on these global supply chains, for example farmers who have no choice but to buy sterilised seeds each year, or hospitals, who's patients' well-being depends on the delivery of medicine from a monopoly-carrying pharmaceutical company thousands of miles away. There are also examples of geo-political conflicts further complicating goods transport, or energy supply itself becoming a political means of power. In the light of our research field however, the largest unaddressed issue is the enormous amount of energy spent to move our perishable, disposable and luxury goods around the globe. With a shift towards thinking in terms of local production and consumption in mind, further research will have to give us new insights how to achieve the Sustainable Development Goals when it comes to the problem of goods transport.

References

[1] A. van Nes, "Road building and urban change," PhD Thesis, Agricultural University of Norway, 2002

[2] United Nations, "Transforming our world: the 2030 agenda for sustainable development," 2015. [Online]. Available: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

[3] Y. Ye and A. van Nes, "Quantitative tools in urban morphology: combining Space Syntax, Spacematrix and Mixed-Use Index in a GIS framework," Urban Morphology, vol. 18, no. 2, pp. 97-118, 2014.

[4] J. Rådberg, "Towards a theory of sustainability and urban quality; A new method for typological urban classification," in 14th Conference of the International Association for People-environment Studies, Stockholm, M. Gray, Ed., 1996, pp. 384-392.

[5] A. V. Moudon, "Urban morphology as an emerging interdisciplinary field," Urban Morphology, vol. 1, no. 1, pp. 3-10, 1997.

[6] B. Hillier and S. Iida, "Network and Psychological Effects in Urban Movement," in Spatial Information Theory: International Conference, Cosit 2005, Ellicottsville, N.Y., USA, A. G. Cohn and D. M. Mark, Eds., 2005, in Lecture notes in Computing Science, pp. 475-490.

[7] B. Hillier, A. Turner, T. Yang, and H.-T. Park, "Metric and Topo-Geometric Properties of Urban Street Networks: some convergiences, divergences and new results," in 6th International Space Syntax Symposium, Istanbul, 16/10/07 2007, pp. 001.01-001.21.

[8] B. Hillier, A. Penn, J. Hanson, T. Grajewski, and J. Xu, "Natural Movement: or, configuration and attraction in urban pedestrian movement," Environment and Planning B: Planning and Design, vol. 20, pp. 29-66, 1993.

[9] A. van Nes, "What is the explanatory power of Space Syntax theory?," in 11th International Space Syntax Symposium, Lisbon, Portugal, T. Heitor, M. Serra, J. P. Silva, M. Bacharel, and L. Cannas da Silva, Eds., 3-4 July 2017 2017: Instituto Superior Técnico, Departamento de Engenharia Civil, Arquitetura e Georrecursos, Portugal, pp. 2693-2714.

[10] B. Hillier, Space is the Machine. Cambridge: Cambridge University Press, 1996.

[11] A. Penn, B. Hillier, D. Banister, and J. Xu, "Configurational modelling of urban movement networks," Environment and Planning B: Planning and Design, vol. 25, pp. 59-84, 16/05/06 1998.

[12] A. van Nes, M. Berghauser Pont, and B. Mashhoodi, "Combination of space syntax with spacematrix and the mixed use index. The Rotterdam south test case," presented at the Eight International Space Syntax Symposium, Santiago de Chile, 2012. [Online]. Available: http://www.sss8.cl/media/upload/paginas/seccion/8003_1.pdf.

[13] M. Silva, V. Oliveira, and V. Leal, "Urban form and energy demand: a review of energy-relevant urban attributes," Journal of Planning Literature, vol. 32, no. 4, pp. 346-365, 2017, doi: 10.1177/0885412217706900.

[14] A. van Nes and M. López, "Macro and micro scale spatial variables and the distribution of residential burglaries and theft from cars: an investigation of space and crime in the Dutch cities of Alkmaar and Gouda.," Journal of Space Syntax, vol. 2, 2010.

[15] A. van Nes and L. Aghabeik, "Ethnic groups and spatial behaviour in Rotterdam's neighbourhoods," in Proceedings of the 10th International Space Syntax Symposium, 2015, London: Space Syntax Laboratory, The Bartlett School of Architecture, UCL.

[16] A. van Nes and L. de Rooij, The perceived safety and spatial behaviour in three different neighbourhoods in Rotterdam (Proceedings Space Syntax. 10th International Symposium). London: Space Syntax Laboratory, The Bartlett School of Architecture, UCL, 2015.

[17] A. van Nes and M. López, "Spatial-socio classification of deprived neighbourhoods in the Netherlands," presented at the Proceedings Space Syntax. 9th International Symposium, Seoul, 2013.

[18] A. Horni, K. Nagel, and K. Axhausen, The Multi-Agent Transport Simulation MATSim. London: Ubiquity Press, 2016.

[19] J. W. Creswell, Research design: qualitative, quantitative and mixed methods approaches. London: SAGE Publications, 2009.

[20] M. Rashid, The geometry of urban layouts. Springer, 2017.

[21] L. D'Acci, "On urban Morphology and Mathematics," in Mathematics of Urban Morphology, D'Acci (ed) Ed. Cham, Switzerland: Birkhäuser (Springer Nature), 2018.

[22] J. Jacobs, The death and life of great american cities. London: Pimlico, 2000.

[23] A. Siksna, "The effects of block size and form in North American and Australian city centres," Urban Morphology, vol. 1, pp. 19-33, 1997.

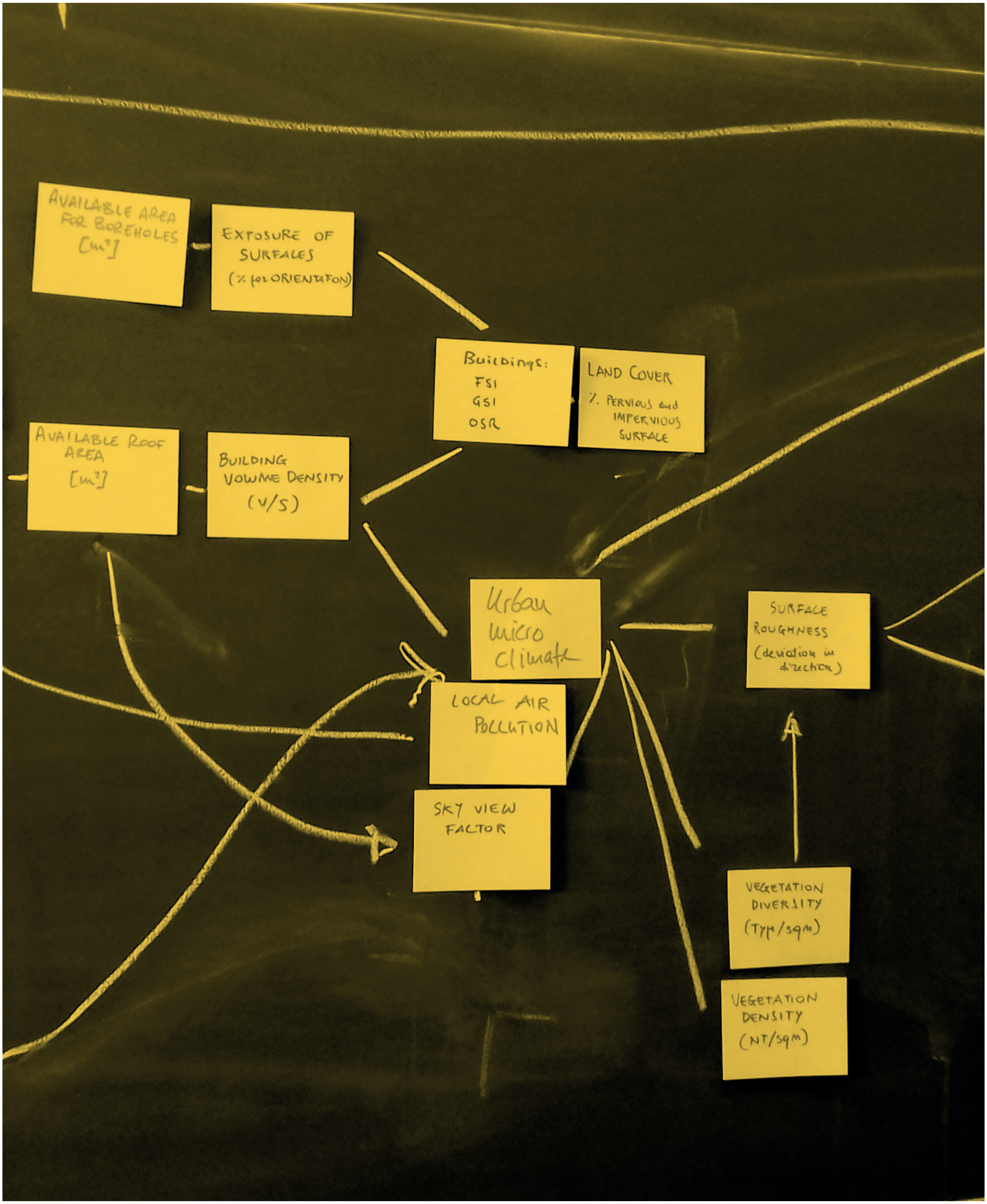
[24] Cambridge Dictionary. [Online]. Available: https://dictionary.cambridge.org/dictionary/english/mobility

[25] D. MacKay, Sustainable Energy - without the hot air, Cambridge: UIT, 2009. [Online]. Available: https://www.withouthotair.com/.

[26] J. Gehl, Life between buildings: using public space. Washington DC: Island Press, 2011.

[27] A. van Nes and E. Stolk, "Degrees of sustainable location of railway stations: Integrating Space syntax and Node place value model on railway stations in the province Noord-Holland's strategic plan for 2010-2040," presented at the Eight International Space Syntax Symposium, 2012.

[28] R. E. de Koning, A. van Nes, H.-J. Roald, and Y. Ye, "Strategies For Integrated Densification With Urban Qualities. Combining Space Syntax With Building Density, Land Use, Public Transport And Property Rights In Bergen City.," in 11th International Space Syntax Symposium, Lisbon, Portugal, T. Heitor, M. Serra, J. P. Silva, M. Bacharel, and L. Cannas da Silva, Eds., 3-4 July 2017 2017: Instituto Superior Técnico, Departamento de Engenharia Civil, Arquitetura e Georrecursos, Portugal, pp. 863-879. [Online]. Available: http://www.11ssslisbon.pt/docs/proceedings/papers/56.pdf. [Online]. Available: http://www.11ssslisbon.pt/docs/proceedings/papers/56.pdf


AVAILABLE AREA FOR BOREHOLES [m²]
EXPOSURE OF SURFACES (% for ORIENTATION)
Buildings: FSI GSI OSR
LAND COVER % PERVIOUS and IMPERVIOUS SURFACE
AVAILABLE ROOF AREA [m²]
BUILDING VOLUME DENSITY (V/S)
Urban micro climate
SURFACE ROUGHNESS (deviation in direction)
LOCAL AIR POLLUTION
SKY VIEW FACTOR
VEGETATION DIVERSITY (Type/sqm)
VEGETATION DENSITY (NT/sqm)

6.

District Energy Integration Model: Conceptual Framework & Application

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Authors:

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Contents:

Summary

District energy demand is recognized to be dependent on a set of several factors for the mobility and the building sector. In literature, complex mutual interaction between urban form, design characteristics, used system, and behaviors have been found to shape the energy performance through different processes. Based on previous energy-related factors, a framework named District Energy Integration Model (DEIM) has been developed to analyze the energy performance of urban neighborhoods and districts. It serves to assess overall energy demand in urban areas by linking several modules. The four modules consist of available simulation models, ENVI-met, City Energy Analyst (CEA), Space Syntax and MATSim, which have been coupled in a workflow. The aim of this study is to develop and test DEIM integration model for assessing energy demand jointly for the building and the mobility sector on a district scale. The DEIM was used in order to estimate energy demand during a summer day in four scenarios built for the Hochschulquartier in Zurich. The results allow for an overall quantitative comparison between scenarios and serve to understand more in detail the complex interdependent relationships between buildings and street network transformations, and the district energy performance.

6.1. Introduction

6.1.1. Building and Mobility energy demand: Available computational tools and integration

Within cities, the transportation and building sectors are two of the main energy consumers, with urban transportation and building heating and electricity accounting for 12% and 36% of global CO2 emissions, respectively[1]. In London, for example, domestic buildings, commercial buildings and personal mobility account for 35%, 26% and 20% of total energy consumption [2]. Thus, numerous models have been developed for the planning of building and transportation systems. Such tools have been in use in planning practice for a long time now with different aims and approaches depending on the expected application and scale.

However, these models have tended to view both systems as fairly independent entities. That is, building and energy models have been assumed to depend only on their physical properties and their occupants, whereas transportation models have analyzed the interaction between space and people's movement through the city. In reality, these systems are part of a larger urban fabric and interact in a variety of ways. Buildings and transportation systems share the users who use them; they share space, as the distribution of buildings in an urban space directly affects transport demands and the efficiency of the transport system; and they are also connected as users of the urban energy infrastructure. Indeed, the overall sustainability of an urban development can be strongly influenced by the transportation behavior of its users, which is in turn strongly affected by the activities and building types developed in the area [3].

In order to analyze these systems, therefore, integrated models are needed which permit the analysis of these interactions and synergetic potentials between the various components of the overall urban system. Integrated transportation and urban energy models have, however, been relatively scarce so far, and methods that include physical building energy models have been particularly lacking.

To the authors' knowledge, there has been only one review to date in which building, energy system and transportation models have all been analyzed as part of an entire urban system [4]. Their classification of the works studied (into technology design models, building design models, urban climate models, system design models, policy assessment models, and transportation and land use models) shows this disconnect. The authors once again stressed a general lack of model integration (especially in relation to land use and transportation models and energy systems), as models were generally developed for specific purposes and audiences. However, they saw several opportunities for improvement in sensitivity analysis, data collection, and in particular in integrating models via activity-based modeling.

A review of energy supply modeling approaches and tools by Allegrini et al. [5] showed only two works in the literature on urban energy systems that included transport considerations, namely SynCity [6] and UMI [7]. The building modeling aspects of these models, on the other hand, are classified as "simplified" and "linked to other program," showing the lack of analytical models capable of assessing both of these systems at the same time.

A number of works in the literature showed an interest in predicting the overall energy flows and emissions in urban areas from both of these sources. A number of works in the literature have looked at the relative demands and emissions for buildings and transportation by either aggregating the results of different models [8, 9] or combining building energy simulations with statistical data [10, 11]. Such studies have been carried out with the City Energy Analyst (CEA) [3] as well. Such an analysis assumes no interaction between the building and transportation systems, being concerned only with predicting values for each and adding them as part of a total demand estimate.

A promising research direction has been the use of activity-based modeling to connect building occupants' behavior to their demands for energy and transportation. Previous work in the land use and transportation field demonstrated the possibility of using such agent-based models as the basis for the modeling of people's activities at the district scale, thus connecting buildings and transportation through their common users. Most of these works define occupants' activities as part of land-use and transportation modeling, and these are then coupled to specific energy demands by means of regression models [6, 12, 13, 14] or by connecting to separate building energy demand models [15].

As a further step in this direction, Robinson et al. [16] proposed coupling agent-based transportation model MATSim to a physical energy demand model by means of occupant exchange, whereby occupants' personal characteristics as defined in the MATSim model would be passed to CitySim to define their preferences and decisions as they relate to energy demand comfort settings in the buildings. However, the authors' found no follow-up reports on the status of the project and therefore assume that the coupling of both tools was not carried out any further. Indeed, later works in the literature [16] appear to indicate CitySim moved back to deterministic schedules for occupant activity modeling.

Moreover, previous empirical and fundamental studies illustrate that it is necessary to take local climatic conditions into account when analyzing building energy performance and its consequent environmental impact [17, 18]. Advancements in computational approaches bridge this gap by coupling methods that link urban climatic variables to the thermal performance of buildings. The main advantage of computational approaches over measurement approaches, is that the former generates explicit information for distinct microclimatic parameters [19]. They also allow for the comparison of urban areas in the design stage and under various time and climatic frames. A series of studies have further developed and tested coupling procedures between BEM and CFD, with the intention to model improvement [20, 21, 22, 23, 24]. They either serve to assess the influence of geometry and materials on urban temperatures and energy consumption [25, 26], or they aim to compare the performance of design measures and decrease heating and cooling energy loads [18]. However, the majority of these microclimate-energy coupling methods find a spatial application only on the canyon and on the single building level. Even when a district or a generic configuration are introduced (e.g. [27]), these create spatial boundary conditions for the studied building.

This project has carried out the proposed integration of building and transportation energy demand models through the exchange of their common users. Occupants' activities as defined in MATSim, and microclimate conditions simulated in ENVI-met are inputs to the CEA occupancy model, which then define the demands for appliances and domestic hot water as well as the temperature and ventilation set points in the buildings in the Hochschulquartier.

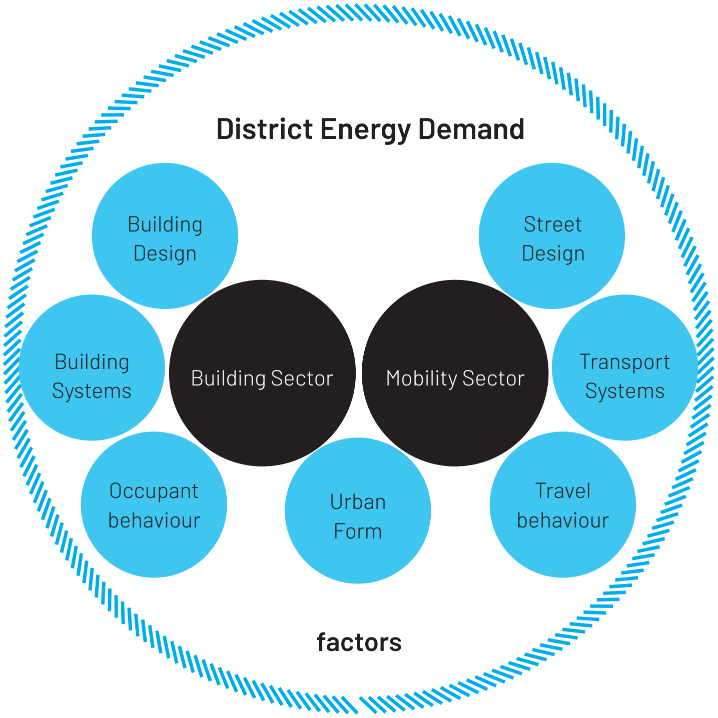


FIG. 6.1 Energy-related factors for urban districts.

6.2. District Energy Integration Model (DEIM): Conceptual Framework

By identifying the relevant factors that contribute to defining the performance level of a district and then including these in a modelling workflow, the definition of an integrated model for energy demand assessment is developed.

6.2.1. Energy factors shaping building and mobility performance

As shown in Figure 6.1, district energy demand is dependent on a set of several factors for the mobility and the building sector. In literature, complex mutual interactions between urban form, design characteristics, used systems, and behaviors have been found to shape energy performance through different processes.

From a mobility perspective, the first of the four aspects identified is the urban spatial structure, which is described as a combination of different types of land use, urban form characteristics and network structures [28]. It is found to be significant in determining transportation flows and connected environmental problems. The larger part of European planning strategies in the past 30 years have focused on urban form aspects. This is particularly the case when using the 'compact city' concept, to reduce mobility energy demand and reduce environmental problems such as air and noise pollution at the city and neighbourhood scale.

The second factor identified is the design of the street network and related characteristics, such as form and material attributes, which, in terms of transport modes, contribute to the energy performance of the urban environment in different ways. In the specific case of cycling and pedestrian routes, design can influence the level of attractiveness because it offers beneficial conditions. For example, a high quality of outdoor comfort or a network free from conflict with motorized vehicles. The third aspect concerns the mobility systems themselves as means of transport, in consideration of their level of environmental friendliness and consumption of energy. This level depends on the overall efficiency of the system as well as its management, but also as it concerns the specific characteristics of vehicles. For example giving priority to public transport as an alternative to a private car, is a consolidated strategy that reduces energy consumption and encourages more environmentally friendly behavior. However, technologies for personal transportation vary significantly in terms of environmental impact [29] and increasing the number of electric vehicles and enhancing the availability of sharing models can also contribute a reduction in energy consumption. Finally, travel behavior, with the previous categories, depends on the location of daily activities. For example the geographical position of living and working places, and their relative proximity to transport systems. However, activities vary according to the demographics of inhabitants income, age, gender, personal preferences).

Similar factors shape building energy performance. Urban form, building design and systems, and occupant behaviors are interconnected factors upon which building energy demand depends [30]. Urban form directly and indirectly relates the effects of environmental context to building performance. Geometrical characteristics of the urban fabric directly determine the level of solar radiation reaching the building surface in long and short-wave form. These influence surface temperature and the availability of daylight. Secondly, the structured assembly of streets and buildings form attributes, contributing to the creation of urban wind, air temperature, and humidity profiles that modify the energy consumption of buildings according to the local climate context in which they perform [31]. In addition, building geometrical characteristics, along with other attributes of orientation, materials and façade solutions are design parameters that can account for a significant variation in energy demand, that as Baker and Steemers [32] demonstrate, can account for 2.5x variation. Interconnected to building design solutions, the design and service of energy systems influences demand for energy. In fact, the level of efficacy and efficiency of the systems used for lighting, heating and cooling indoor spaces strongly influences overall building performance. This last aspect is partially related to the behavior of the end users, which do not only depend on socio-demographic variables [33] like types of use, number of occupants, age and income. They also depend on the presence of consumption monitoring and technological systems which can help inform users with real-time usage information [34].

6.2.2. Methodology for multiple coupling process

Based on previous energy-related factors, a framework named District Energy Integration Model (DEIM) facilitates the analysis of the energy performance of urban neighborhoods and districts. It serves to assess overall energy demand in urban areas by linking several modules. The four modules consist of simulation models; ENVI-met; City Energy Analyst (CEA); Space Syntax; and finally MATSim. These have all been coupled in a workflow.

The coupling of simulation modules allows the computation of energy demand based on the principal types of factors which shape building and mobility performance such as urban form, design, systems and behaviors. Table 1.11 provides an overview of relevant parameters for the factor type identified in existing literature, as well as the simulation module calibrated to process those. This determines if the factor constitutes a valid input (or not) for the four modelling tools. The analysis also suggests a complementary relationship between the tools, since Space Syntax and ENVI-met are both tools that mainly use morphological and design input while MATSim and CEA are process parameters of behaviors and system characteristics.

The multi-domain simulation framework is consolidated to tackle major limitations of single computational methods which have been discussed in the previous reports describing the partial coupling methods.

The integration framework is based on recognition of the factors, their nature, and scales responsible for building and mobility energy consumption. A coupling workflow is developed that is based on this analysis and on the comparison of the software data requirements. Figure 2 offers a schematic description of the procedures for the multiple linking between the simulation tools ENVI-met, City Energy Analyst (CEA), Space Syntax and MATSim. In the first stage, a common database is created in order to use coherent data regarding the district under study. Space and time resolutions are later adjusted according to the tool's requirements. Secondly, microclimate simulations are performed by using ENVI-met and results for three selected parameters create new boundary climatic condition for energy modelling in CEA. The MATSim population's activities in the Hochschulquartier form the basis of the occupant schedules for the energy demand simulations of the four scenarios in CEA. The changes in street pattern for the scenarios, represented in the MATSim simulations and by the Space Syntax axial map, are coordinated with each other to achieve a comparable spatial configuration.

TABLE 1.11 Energy factors and related modules.

ENERGY PERFORMANCE					
MOBILITY			BUILDING		
Factors	Module		Factors	Module	
Urban Structure (land use, street network structure)	Input	Space Syntax	Urban Form (urban geometry, land cover, vegetation)	Input	ENVI-met CEA
Street Design (surface materials, profile)	Input	MATSim	Building Design (building geometry, orientation, façade materials and design)	Input	ENVI-met CEA
Transport Systems (type of mobility systems, characteristics of vehicles)	Input	Space Syntax	Building Systems (type and efficiency of energy systems)	Input	CEA
Travel Behavior (geographical position, type of activity chain)	Input	MATSim	Occupant Behavior (type of building use, number and type of occupants)	Input	CEA

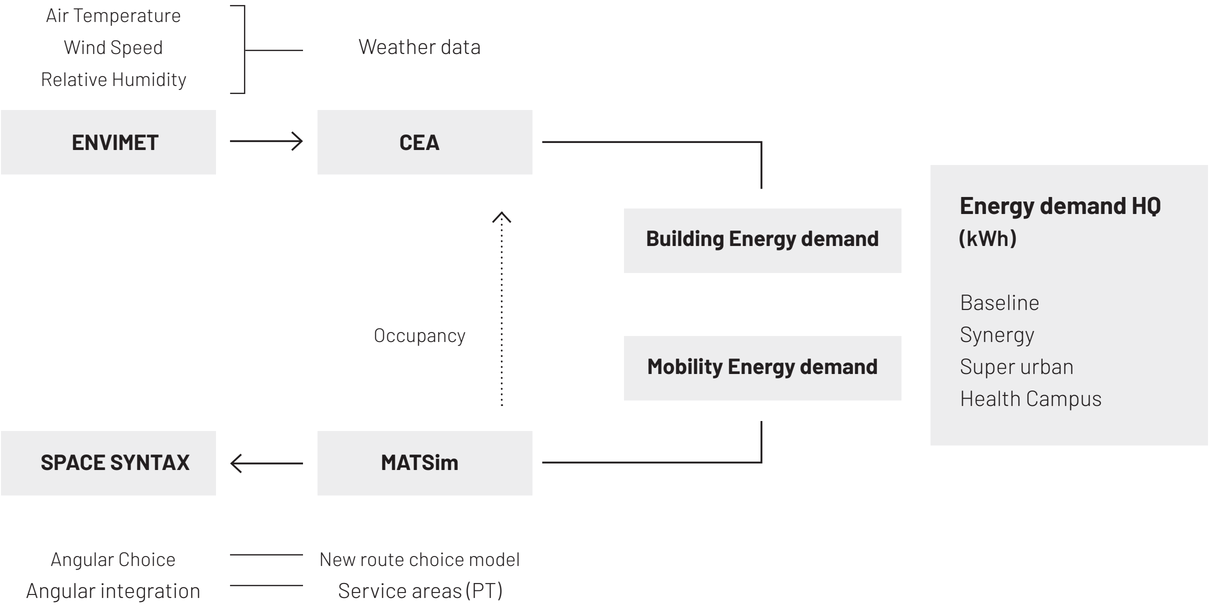


FIG. 6.2 DEIM coupling workflow.

6.2.3. Description of simulation modules

ENVI-met, City Energy Analyst (CEA), Space Syntax and MATSim are used in the DEIM multiple coupling workflow.

ENVI-met

Urban microclimate simulations utilize ENVI-met, a three-dimensional prognostic microclimate model designed to simulate the interaction between surfaces, plants and air in an urban environment. It is widely used to estimate and assess outdoor thermal comfort and the impact of the urban microclimate on building energy use.

City Energy Analyst (CEA)

Building energy modeling is carried out using the City Energy Analyst (CEA), a hybrid model for building energy demand and supply at the district scale [35]. In order to reduce the number of inputs required, the tool provides representative archetypes for different building types in the area and typical operation parameters. Building energy demand is calculated through a custom simulation engine based on a simplified, single thermal zone resistance capacitance model.

Space Syntax

The spatial structure of the street network forms the basis for Space Syntax analysis. The data of street networks per case is sourced from OpenStreetMap between 2016 – 2017 and hand-drawn using the GIS program ArcMap. This creates an axial map for both cases following the principle that the fewest and longest set of axial lines of visibility and accessibility cover all convex spaces in a spatial system – the basis of Space Syntax analysis input [36]. It provides the empirical data for calculating segment integration (to-movement) and angular choice (through-movement).

MATSim

The Multi-Agent Transport Simulation, or MATSim, is a transport model that is capable of generating demand patterns and assigning the demand to a transportation network. Aggregate transportation demand can generally be modelled in three ways: a) using the classical four-step framework, b) econometric models for demand that are combined with assignment models, and c) agent-based (mesoscopic) models such as MATSim [41, 42]. Data requirements for agent-based models are very high because they rely on detailed socio-demographic information for the synthetic population generation and data on activity locations need to be available. In the Hochschulquartier case study, occupancy schedules were based on the functional building programme for each of the scenarios. The simulations also demonstrate changes in the agents' choice of mode of transportation if, for example, a change occurs in the public transport network or the road network.

6.2.4. Coupling methods

ENVI-met – CEA coupling

The aim of the coupling method is to model the energy demand of a number of buildings on a district scale level, by taking in account the various factors that are co-responsible for the energy performance: microclimate environment, locus and topographic context, building geometry and materials, energy systems as well as user behavior. Common input for the two software packages are the spatial characteristics of buildings and the macro atmospheric data from a weather station.

The method to convert ENVI-met output into CEA input consists of three main phases. In the first phase, the spatial model for the selected case study is built in ENVI-met 4.0 and simulations are performed using the simple forcing method using weather data for the selected days. Secondly, output data for air temperature, wind speed and relative humidity are exported and aggregated in a 3D buffer around single buildings in a GIS platform. In the third phase, the aggregated data are imported in the CEA software and used as boundary climatic conditions for the calculation of the energy demand for each building in the simulation domain. The method has been employed in the Hochschulquartier case study for the coldest day in a typical year for a total of two cases. In Case 1 a simple spatial model that includes only building geometry is used, with homogeneous building materials, while in Case 2 trees and vegetated surfaces are added to the model. In order to observe the impact of using microclimate data, a Case 3 is also simulated with CEA using climate data input from the closest rural weather station. The procedure for each phase is described in detail in the following sections.

Space Syntax – MATSim coupling

To couple the data from the static Space Syntax model with the dynamic MATSim simulations, a spatial join rule is applied. This way, the polygon-based, buffered Space Syntax values are lined up with the polylines containing the MATSim values based on spatial location. The buffered data shows whether the potential to-movement and through-movement is low, medium or high. The transport model provides the loads on each street segment for cars, pedestrians and cyclists. The data is acquired by an iterative optimization process that simulates a twenty-four hour cycle, or a typical working day.

Space Syntax can predict movement based on spatial configuration. It can tell if a street is likely to be used or not. What it does not inherently do is project traffic flows or take into account attractors. It merely predicts potential movement. MATSim does predict traffic flows and take into account attractors. In theory, the simulation is able to reflect the 'real' situation, and predict the effect of changes in the road and public transport network, the destinations and the agents' schedules with great precision. However, the accuracy of the simulation is limited to the number of parameters that are entered into the model. Choice of route, transport mode and itinerary, therefore, can only be approximated.

Potential through-movement and to-movement:
With the input of the axial map, DepthMap is used to calculate the topological depth from one axis to all others - the total number of direction changes from one axis to all others. The integration (I) of an axial line (i), is a function of its depth related to all other axes calculated as [37].

$$I_i = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right) - 1\right) + 1\right) / (n-1)(n-2)}{2\left(\left(\frac{\sum_{j=1}^{n} d_{ij}}{n-1}\right) - 1\right) \Big/ (n-2)} \tag{1}$$

Where n is the number of segments, d_{ij} is the shortest distance (least number of direction changes) between two segments i and j. The greater the number of steps (d_{ij}) between streets axes, the lower the integration values gets.

Choice, or how likely one is to pass through that axis when moving around in a built environment, measures the degree of betweenness and measures the through-movement potentials. The formula of choice (C) of an axis (i) is as follows [37]:

$$C_i = \sum_{j}\sum_{k} g_{jk}(i)/g_{jk}(j < k) \tag{2}$$

Where $g_{jk}(i)$ is the number of shortest paths between segment j and k containing i, and g_{jk} is the number of all shortest paths between j and k.

Segment integration of a street shows how easy it is to get to a segment from all other segments. In the segment analyses, the axial lines are broken up where they cross each other [25]. It calculates the to-movement potentials. Segment integration can be compared across systems. It measures how close each segment is to all others in terms of the sum of angular changes that are made on each route [25] (pp. 475-490). Angular segment choice is calculated by counting the number of times each street segment falls on the shortest path between all pairs of segments within a selected distance (termed 'radius'). The 'shortest path' refers to the path of least angular deviation (namely, the straightest route) through the system [38].The angular integration (AI) of a segment x is:

3 $$AI_x = \frac{1}{n}\sum_{i=1}^{n} d_\theta(x, i)$$

Where n is the number of segments, and d_θ the angle between any two segments on the shortest path on a segment x and when adding the length 'l' of segments [37]:

4 $$AI^{l}_{x} = \frac{\sum_{i=1}^{n} d_\theta(x, i)\, l\,(i)}{\sum_{i=1}^{n} l\,(i)}$$

Aggregated angular choice:
Values generated by angular choice analyses are aggregated per case with a 35-meter buffer around both sides of each segment, creating aggregated areas for each integration level. This value is based on various research concluding that a dense street network with a fine mesh size of between 60-80 meter performs better than larger blocks, both when it comes to increased circulation and the exploitation possibilities of the urban block [39, 40]. Showing angular choice for high and low radius simultaneously helps to find out which areas are well integrated into the local street network, and enjoy good accessibility on city scale. We are applying the natural break – or Jenks – method to classify the resulting spatial values from angular choice as low (L), medium (M) or high (H). This allows for a combination of nine categories:

		Angular Choice with Low radius (R=500m)		
		Low	Medium	High
Angular Choice with High radius	Low	LL	LM	LH
	Medium	ML	MM	MH
(R = 5000 m)	High	HL	HM	HH

CEA – MATSim coupling

The coupling between MATSim and CEA occurs by means of the exchange of transportation users and building occupants in the area. As described in previous deliverables, CEA ships with two occupant models: a deterministic weekday and weekend schedules for occupant presence, electricity demand and hot water demand, as well as monthly variations, are defined based on Swiss norms [10]; and a stochastic method based on the model proposed by Page et al. [43] to model occupant presence and periods of long absence in buildings.

In order to be able to import MATSim occupant data, a third method for occupant modeling had to be defined as a starting point of each occupant's schedule. The "typical" day schedules for each agent in the population was obtained from MATSim, assigned a specific energy demand and expanded to a yearly schedule.

The population of occupants defined for the MATSim model provided the number of occupants, their activities and their duration in university and hospital buildings in the area. The schedules for students were based on enrollment schedules, whereas the number of workers in the area was based on the employee registers for university and hospital buildings. For employees, the start and end time of a workday were defined by randomly sampling from normal distributions centered at 8 am (start time) and 5 pm (end time). The resulting distributions of occupants at each time of day for education and office buildings in the area are shown in Figures 6.3.

The occupant distributions derived from the MATSim schedules were then used as an input similar to the weekday building-scale schedules from the national standards, but depend on the individual users of the building and thus vary from one building to the next. Given that this approach only covers employees and university students, the schedules for other users in the area, such as hospital patients, was defined based on the deterministic method.

At the start of each simulation, a daily schedule is assigned at random to each employee and student from the corresponding buildings' pool of schedules as defined by the MATSim population characteristics. Subsequently, at the beginning of each week, another random draw defines whether the occupant starts a period of long absence based on the monthly probability of occupant presence from the national standards. Periods of short absence such as public holidays and single day absences were not considered. For simplicity, periods of long absence were set to last for one week and vacation weeks were assigned so that on average each person would take a total of five weeks of holidays per year, corresponding to the Swiss national average [44].

Each occupant type was also assigned a demand for appliances by assuming the demands for each function could be assigned to individual occupants as follows:

$$d_{a,occ,i} = \frac{d_a}{Occ_i}$$

where $d_{a,occ,i}$ is the demand for appliances for a single occupant in building function I in watts per person, $d_{a,I}$ is the specific demand for appliances for function i in W/m^2 and Occ_i is the occupant density for building function i in persons per m2.

The demands for electricity for appliances in a given building were then derived from these occupant schedules as follows:

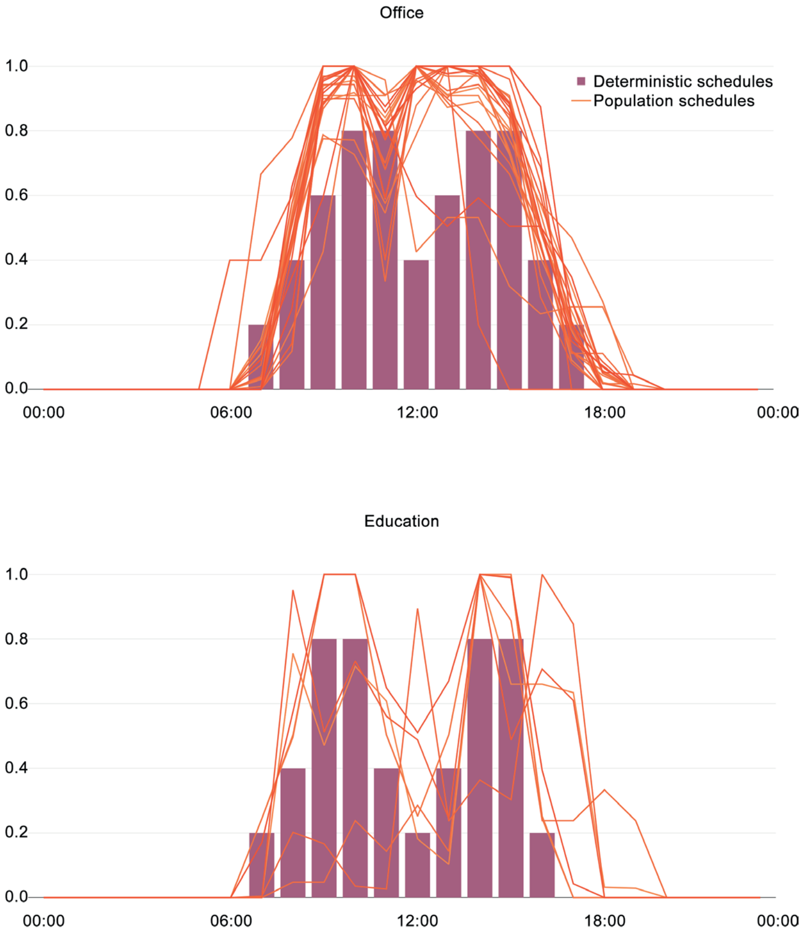


FIG. 6.3 DEIM coupling workflow.

$$D_a\,(t) = \begin{cases} \sum_i N_{occ,i}\,(t) \text{ x } d_{a,occ,i} & \text{if } ''\, N_{occ,i}\,(t) > 0 \\ \sum_i A_i \text{ x } d_{a,off\text{-}peak,i} & \text{otherwise} \end{cases}$$

where D_a is the demand for appliances, $N_{occ,i}$ is the number of occupants of type i from the population's schedules, A_i is the net floor area of function i in the building, and $d_{a,off\text{-}peak,i}$ is the specific demand for appliances (in W/m2) for the given building function I during unoccupied hours, taken from the national standards.

The demands for domestic hot water according to the CEA deterministic schedule produce the liters of water required per person at a given hour. Thus, the volume of domestic hot water required by a given building can simply be calculated by multiplying this schedule with the number of people obtained from the MATSim schedules:

$$V_{dhw}\,(t) = \sum_i P_{dhw,i}\,(t) \text{ x } v_{dhw,i} \text{ x } N_{occ,i}$$

where V_{dhw} and $v_{dhw,i}$ are the demand for hot water at time t (in liters) and the daily demand per person for building function i (in liters per person per day) and $P_{dhw,i}\,(t)$ is the probability of hot water use at time t.

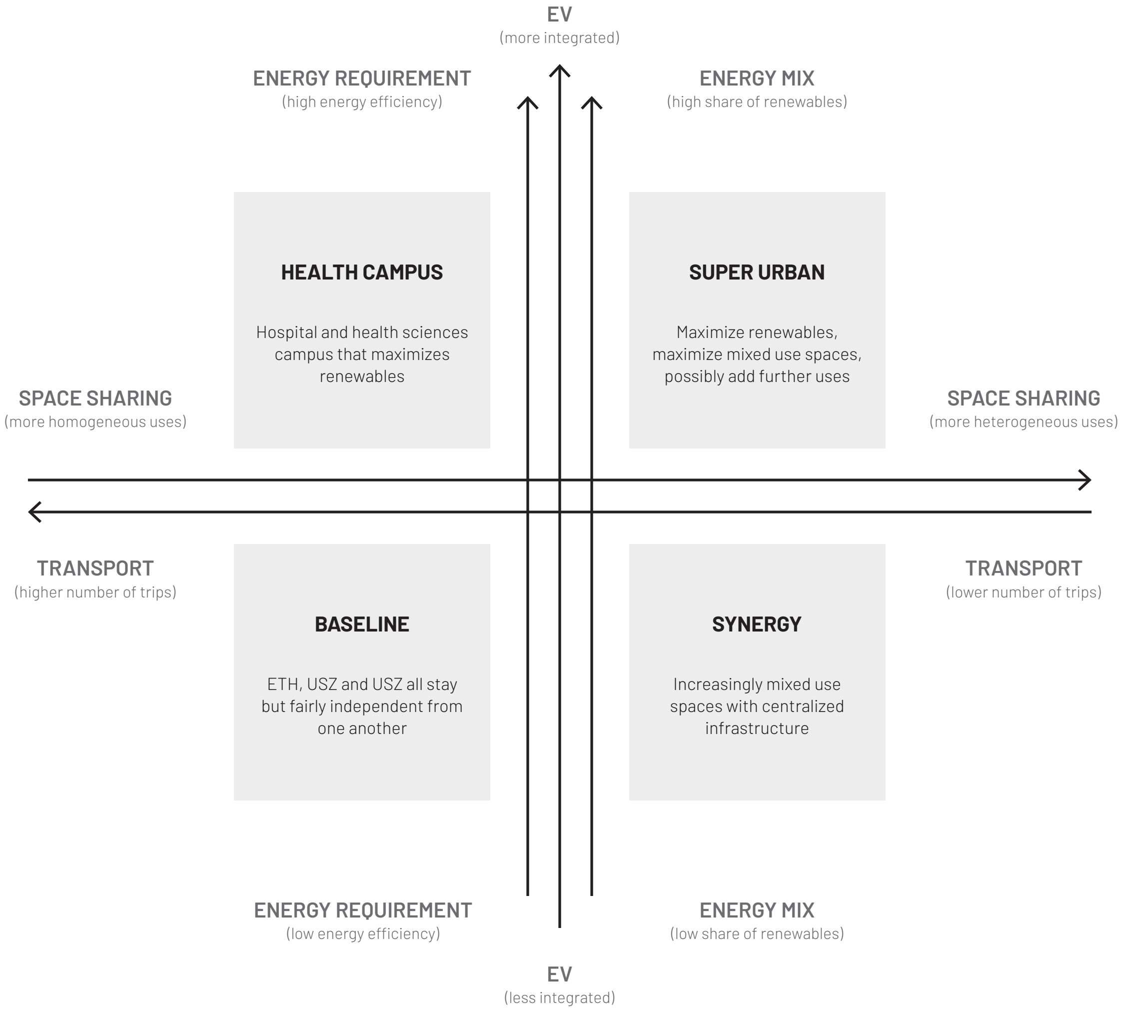


FIG. 6.4 Internal scenario matrix. Based on data regarding energy, space, and transport, a matrix of four different scenarios has been developed around two groups of factors that determine multiple variations in district energy performance. These factors are explored to understand the maximum extent that they can provide change in the energy profile of the Hochschulquartier.

6.3. District Energy Integration Model (DEIM): Application for the assessment of HQ scenarios

6.3.1. Hochschulquartier Scenario Matrix

A scenarios building method for hybrid Design Oriented Scenarios (hDOS) has been developed in the Spacergy project and applied in the Zurich case in order to coordinate design, research and planning to implement an energy-sensitive approach to the Energy Transition of the Hochschulquartier (HQ). This method, differing from the original definition of DOS as an exclusive tool for assisting the design process, has descriptive, exploratory and normative scope in the Living Lab approach. The triple aim structures the process for the construction of the future scenarios (described in WP2) in the three phases: knowledge collection and analysis, exploration of future solutions, and evaluation for the implementation phase. In the first two steps of the scenario method applied in the Zurich case, the key factors that play a role in defining the energy profile of the HQ were identified and a scenarios matrix were developed in a co-creation process which involved research experts in different fields, and relevant local stakeholders. The third phase here described aims to assess the energy performance of the resulting design scenarios by using the District Energy Integration Model (DEIM), simulation model.

The 2x2 Scenario matrix, is built on five critical aspects which have the potential to change the energy performance of the new HQ. Key factors identified are the following:

- Type of measures to reduce energy demand
- Level of sharing of renewables in the energy mix
- Level of integration of electric vehicles (EV)
- Level of mixed land use
- Type and patterns of transport

As illustrated in Figure 6.4, these key factors constitute the organizing principle of the Scenario Matrix and are grouped around the two axes, resulting in four scenarios. On the one axis are organizing principles are identified in the composition of energy measures that can be applied to buildings and to the urban fabric, and the degree of integration of electric mobility. The second group connects land use factors and the demand for transport around the compact city concept.

On the vertical axis, the scenarios range from a condition in which energy generation, heat recovery and demand reduction are strongly integrated, to a less integrated portfolio based on centralized systems and infrastructures. Different energy 'measures' are incorporated, including: changes in configuration and composition of the urban fabric, which impact the buildings' energy demand and renewable supply potential; employment of different technologies for production and reduction of energy consumption; and finally, integration of electric vehicles in the area for energy storage and as an alternative mode of transportation.

The horizontal axis relates to different spatial frameworks in terms of mixed functions and the levels of homogeneity/heterogeneity in the use of built and open space. The level of multi-functionality is directly affecting transport demand. The reason for this is the availability of space for work and leisure facilities as well as for residential purposes, and for the flexible, around the clock use of the campus space reduces the number of trips outside of the area.

In detail, the following characteristics have been assigned to the four scenarios resulting from the matrix.

1. Scenario 'Baseline' (BL)

This scenario is based on one of the visions of the project for the HQ as published in September 2014. The scenario describes a future where the three institutions ETH, USZ and UZH separately develop their spatial plans, maintaining the uses specified in the Masterplan. The assumption is that each of the institutions realizes an extension, thus substantially increasing the total built volume in the area by 40% of the existing gross floor area.

Mobility	Overall accessibility by 'slow' modes as in the original Masterplan; accessibility by motorized modes largely unchanged and missing integration of EV.
Urban Design	Space sharing: Each institute individually develops their spatial plans. Urban form: Largely based on the Syntheseplan, with little regard to the optimization of building geometry for enhancing the buildings energy performance and absence of microclimate control measures.
Energy Balance	Energy demand: Energy performance improved through construction materials and insulation of new buildings. Energy supply: Connected to centralized district heating and electricity grids along with district cooling from lake water.

2. Scenario ‘Health Campus’ (HC)

This scenario features a shift towards higher shares of hospital functions by using the actual mix of medical service, education and research. It presents an extreme case, where building uses with the highest energy demand are supplied increasingly through local renewable production.

Mobility	Electric vehicles (EVs) are integrated in the local energy system; public transport remains the main mode of access to the area without any change of the street network compared to the Baseline.
Urban Design	Space sharing: Functional mix of existing hospital buildings are applied to all the others. Urban form: Building shapes are designed to improve the microclimatic conditions.
Energy Balance	Energy demand: Energy performance improved through construction materials and insulation of building with high standards. Energy supply: Connected to centralized district heating, cooling and electricity grids, along with district cooling from lake water. Building roofs serve for solar energy generation including storage to match demand and supply in order to increase the share of renewable sources in the energy mix.

3. Scenario ‘Synergy’ (SY)

This scenario builds on a mix of functions and focuses on a better integration of uses compared to the Baseline. Energy supply systems remain unchanged, employing centralized infrastructures and limited production within the area. The integration within the university cluster of space for housing, amenities and facilities results in an area promoting walking and biking for mobility within the campus. This mix of functions has the potential, from an energy point of view, to decrease peaks and balance the total energy demand of the area, and to increase the overall efficiency (joint energy footprint of mobility and use of space).

Mobility	Focus is on existing public transport systems and improving walkability and bikeability in the area by making the area more accessible.
Urban Design	Space sharing: Integration of existing uses in terms of distribution, and increase in the share of residential buildings. Urban form: Integrate the different functions in order to create a more livable built environment; spatial design measures do not include microclimate control techniques or building geometry optimization.
Energy Balance	Energy demand: Energy performance improved by insulation of building with high standards. Energy supply: Connected to centralized district heating and electricity grids along with district cooling from lake water.

4. Scenario 'Super Urban' (SU)

This scenario features a synergetic mix of functional use and shared spaces, combined with a high mix of local, decentralized and distributed energy solutions. The main focus is on multi-functional, highly integrated and livable solutions from an energy and spatial perspective. A combination of university spaces and residential buildings, amenities, and offices is optimized to balance energy demand.

Mobility	Pedestrian and bike-friendly area; external accessibility is increased by a better connection to the city center through improved public transportation services and dynamic shared mobility services; electric vehicles (EVs) are integrated in the local energy system.
Urban Design	Space sharing: Integration of existing uses in terms of distribution, as well as the reuse of space in its off-hours to host other functions; resulting in a higher efficiency in building functional program. Urban form: Increased importance as a result of multi-functionality and high interaction, with emphasis on the design of building-street interface to support the walkability in the area; building geometry is optimized for reducing energy consumption.
Energy Balance	Energy demand: Focus on peak reduction through the choice of uses that are complementary throughout the day. Energy supply: Connected to centralized district heating and electricity grids along with district cooling from lake water. Building roofs serve for so-lar energy generation including storage to match demand and supply in order to increase the share of renewable sources in the energy mix.

6.3.2. Spatial translation of the scenario matrix: Design process

The testing of the DEIM model for the scenarios' assessment has been structured in three phases (Figure 6.5): The first phase consists of the translation from the scenarios' descriptions to four spatial configurations. The second phase consists of building four spatial models with related database the DEIM methodology simulates the energy performance of the scenarios. The first stage of spatial translation is critical since the matrix can potentially create an infinite number of future spatial conditions. In the design process in fact, the energy related factors can lead to different choices on the distribution of built volume in the area, the transformation of the street network, and the selection of building typologies. Therefore, a number of principles and targets have been identified and transformed in spatial characteristics illustrated in Figure 6.6.

For the design of the Synergy, Super Urban and Health Campus scenarios, the Baseline Masterplan performs as a base on which form and attributes of buildings, as well as the street network have been reshaped. The main road structure and the total building floor area for each block remains the same across the four scenarios. Moreover, the process has been re-iterative. After every design step, quantitative parameters control the coherence between scenario principles and results. Five parameters serve this purpose. Three of them are indicators that define the performance of building density such as intensity (Floor Space Index), compactness (Ground Space Index) and spaciousness (Open Space Ratio). Angular Choice and Angular Integration describe the topological performance of the street network, while the parameter of Use measures the functional program allocated in each building.

In the second phase, the resulting scenarios' spatial configurations comprised of building and street geometries with relative attributes have been converted in spatial models in GIS. These constitute a common database that will serve as a data source for simulation tools in the assessment phase. Finally, in the third stage, the Scenario Models test the DEIM in order to estimate energy demand on a summer day. The multiple coupling process, illustrated in the section 6.2.2, allows the estimation of energy future consumption for mobility and buildings in the four scenarios.

Designed scenarios

The result of the spatial translation phase are four conceptual masterplans for the four corresponding scenarios. The following illustrations demonstrate plan configuration and the distribution of the buildings' volumetry, as well as form and use characteristics. The HQ Baseline Masterplan is derived from the vision published in September 2014 and structured in seven urban blocks of different sizes. The highlighted buildings in the blocks have a larger grain compared to the surrounding urban fabric and cannot be identified in specific building typologies for the complexity of their geometries. However, the building masses appear to be shaped around simple and multiple courtyards, probably with the idea of providing natural light into these large buildings. High insulation attributes are applied to the new building envelopes with retrofitting hypotheses for existing buildings. The campus' functional mix is composed of 30% office space, 23.8% hospital use and 12% of parking, laboratories and classrooms. Less share of the total floor area is dedicated to restaurants, sport facilities and library.

In the Synergy Masterplan, the main deviations from the Baseline are the increased overall integration of the district network and the presence of a more heterogeneous factional mix. Therefore, in the design process, new pedestrian paths have been drawn to increase the number of connections in the district and to increase the porosity of the central part of the blocks. The large buildings experience a division of the volumetries to accommodate residential uses with a 15% share of the total floor area. Values of coverage (building footprint to block area ratio), intensity (floor area to block area ratio) and consequently open space area do not deviate from the Baseline.

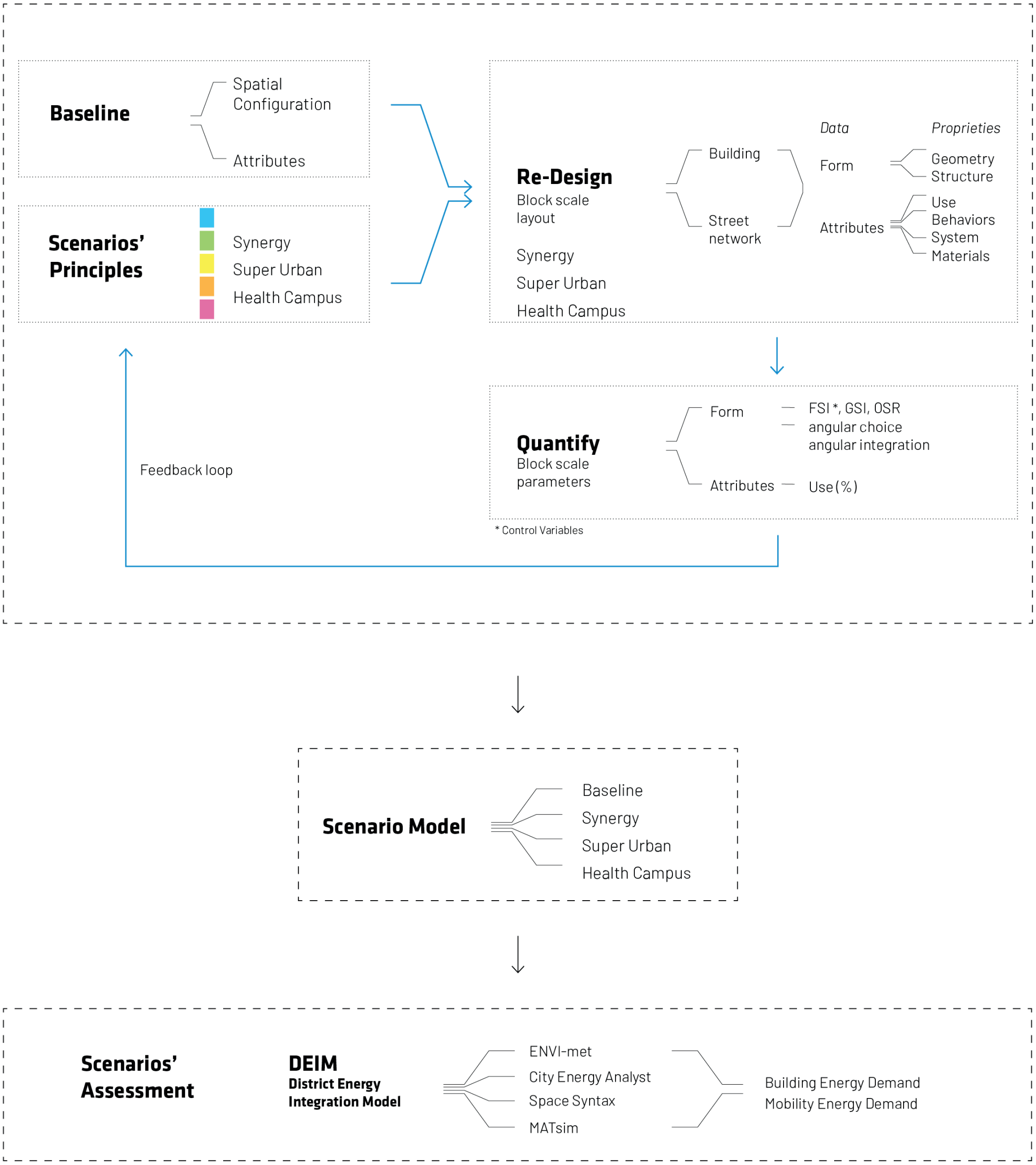


FIG. 6.5 Process for the DEIM testing.

Spatial Change

Health Campus

Renewable energy production (Local)

Integration of solar energy production on rooftops

Electric vehicles 50%

Car / Bike- (High integrated nodes)

Minergie Targets + microclimatic measures

Compact Building Geometry:
(- B. thermal loss / + shadow density)

Hospital functional mix

Unchanged street network integration

Super Urban

Renewable energy production (Local)

Integration of solar energy production on rooftops

Electric vehicles 50%

Car / Bike- (High integrated nodes)

Minergie Targets + microclimatic measures

Compact Building Geometry:
(+ wind speed / + shadow density)

Housing 15% Extension of use for PF

Heterogeneous Buildings' Size

Increase street network integration

Addition of street connections
(More permeablity / accessibility for 'slow' mode)

Baseline

Unchanged street network integration

University Campus functional mix

Minergie Targets

Electric vehicles 0%

Lake water for cooling

Synergy

Increase street network integration

Addition of street connections
(More permeablity / accessibility for 'slow' mode)

Housing 15% Extension of use for PF

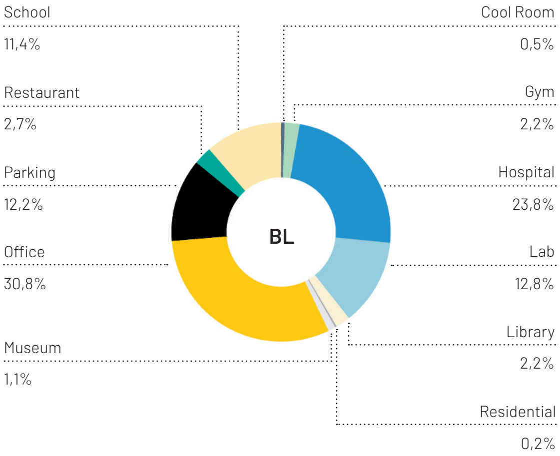
Heterogeneous Buildings' Size

Minergie Targets

Electric vehicles 0%

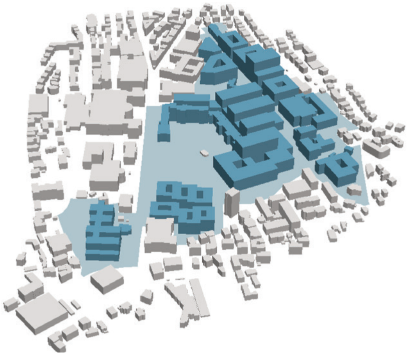
Lake water for cooling

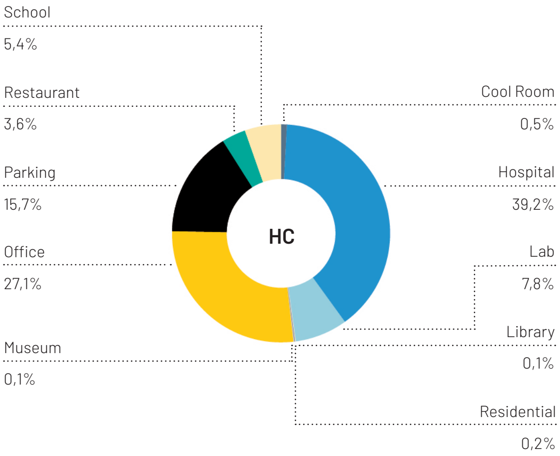
FIG. 6.6 Scenario principles and spatial translation.



Baseline

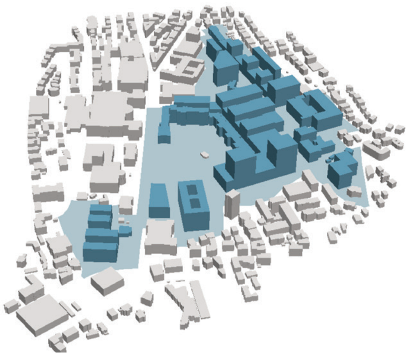
Tot. Building Footprint:	**90 528 m²**	FSI:	**3,35**
Tot. Floor Area:	**634 615 m²**	GSI:	**0,47**
Net Surface Area:	**189 251 m²**	OSR:	**0,15**

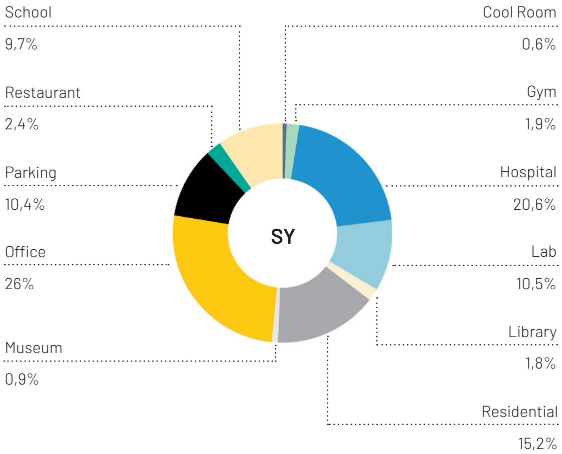




Health Campus

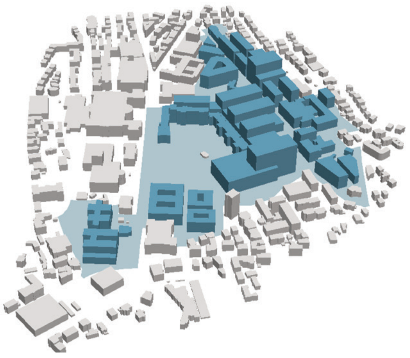
Tot. Building Footprint:	**79 863 m²**	FSI:	**3,35**
Tot. Floor Area:	**634 558 m²**	GSI:	**0,42**
Net Surface Area:	**189 251 m²**	OSR:	**0,17**

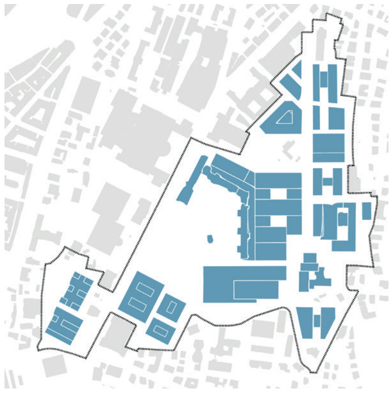


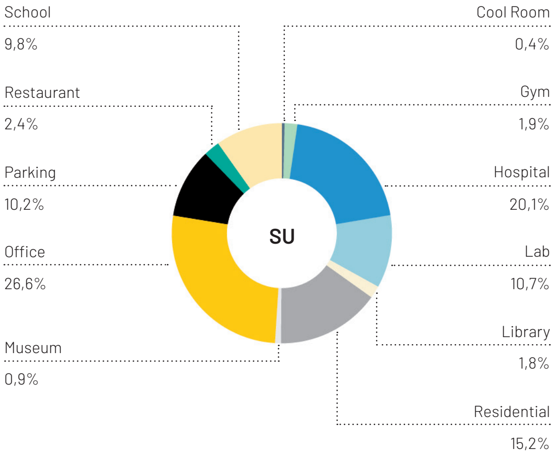


Synergy

Tot. Building Footprint:	**89 794 m²**	FSI:	**3,35**
Tot. Floor Area:	**634 544 m²**	GSI:	**0,47**
Net Surface Area:	**189 251 m²**	OSR:	**0,15**

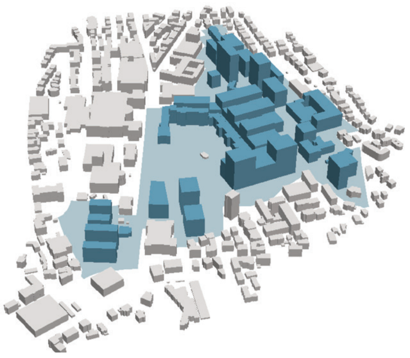






Super Urban

Tot. Building Footprint:	**70 048 m²**	FSI:	**3,35**
Tot. Floor Area:	**634 581 m²**	GSI:	**0,37**
Net Surface Area:	**189 251 m²**	OSR:	**0,18**



Baseline Scenario

Health Campus Scenario

Synergy Scenario

Super Urban Scenario

FIG. 6.7 Main function assigned to each building in each scenario in CEA. University buildings are simply labeled as "Education" here but include a number of uses including classrooms, research labs, offices, etc.

In both Health Campus and Super Urban scenarios, the main principles that influence the space of the district are the introduction of energy measures for production of renewable technologies on roofs and measurements for reduction by testing principles to improve the microclimatic context. The spatial consequence of this last principle is tested with two different approaches. Although district compactness is less than the Baseline, in the Health Campus building, volumes are more compact and clustered together with a lower footprint and increased height. This measurement aims to reduce the amount of direct solar radiation on building facades and reduce losses through the envelope. Also, in the Super Urban, the overall compactness is lower when measured at the district scale (GSI 0.35); however, here the building volumes have an even lower footprint and define more numerous and larger street canyons to facilitate the infiltration of wind flows. This spatial condition also supports the translation of the other principles of increasing pedestrian accessibility by enlarging the street network and the increasing functional mix by dedicating the 15% of the floor area to housing. The scenarios do not include the addition of green surfaces between the measures for space cooling reduction due to the focus on building and district geometry.

6.3.3. Methodology for the DEIM Application

Simulation settings

CEA Settings:
The building energy demand for all four Spacergy scenarios was modeled on CEA. The main function of each building in the area for each scenario is shown in Figure 6.8. The window-to-wall ratio of all new buildings was assumed to be 40%, whereas envelope properties, internal loads (such as domestic hot water demand, lighting and appliance demand, etc.) and indoor comfort parameters (such as ventilation rates, temperature set points, etc.) were assigned according to the CEA archetype database. The functional mix of each new building was assigned based on the average for equivalent buildings in the area today. Thus, for example, hospital buildings were all assigned the functional mix of the present-day hospital, ETH research facilities were assigned the average present-day ETH research facility functional mix, etc. In order to create more realistic occupant distributions, the planned activities for the agent population from MATSim was a basis for the occupant model as discussed in section 'CEA-MATSim coupling'. The simulations were carried out on an hourly bases for a full year using the weather file for a typical year in Zurich from Meteonorm [45]. In order to analyze the effect of the urban heat island effect during extreme weather events, the energy demands of the area were again modeled for the hottest day of a typical year using microclimate results from ENVI-met as an input to the energy demand model.

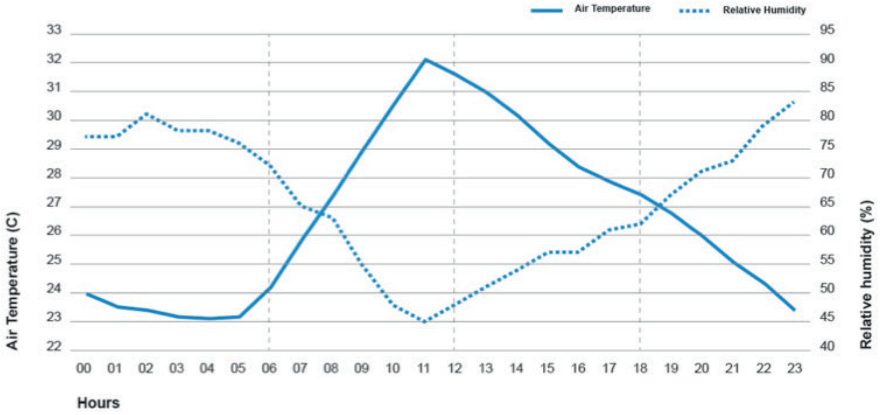


FIG. 6.8 Values of air temperature and relative humidity for the typical hot day used as forcing conditions in ENVI-met

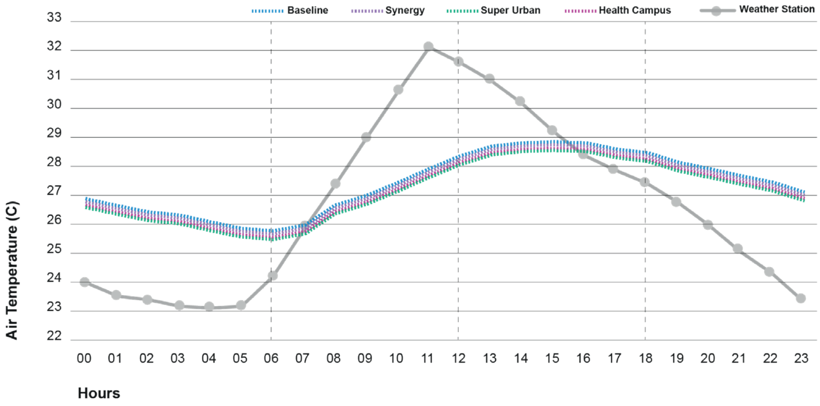


FIG. 6.9 Mean Air Temperature comparison

ENVI-met settings:
The models representing the four scenarios are created by a discretization process of geometries and materials. Consequently, microclimate simulations are performed by using weather data for a typical hot day. Urban microclimate simulations are carried out using ENVI-met (version 4.4). In order to obtain reliable simulation results for the Hochschulquartier, a larger area of interest is included for the simulations. A grid unit of 10x10x7m is defined in order to cover the area of study as well as the area of influence. Based on the grid dimensions, a three dimensional spatial model is built in the ENVI-met simulation tool, assigning properties of building height, topography, soil and surface materials to each cell in the grid. Data of dry bulb temperature, and relative humidity are used as forcing climate variables, while initial wind speed is set at 0.3 m/s. Figure 6.9 illustrates the climate boundary conditions.

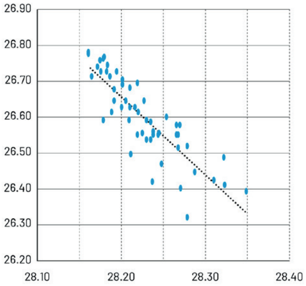
6.3.4. Simulation results

Microclimate simulation results

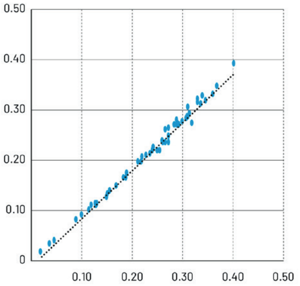
Microclimate simulation results for the four scenarios highlight very little variation regarding average hourly air temperatures and relative humidity in the district. A heat island phenomenon with magnitude of 3°C during evening hours demonstrates that temperatures are higher in the four designs when set against weather station data, while diurnal temperatures are lower in the HQ. This differs when observing average wind velocity around the buildings, despite the overall low speed, the design of the Health Campus and Super Urban scenarios demonstrate to slightly increase the ventilation rate compared to Baseline and Synergy. This is an expected result caused by the geometrical characteristics, such as the larger amount of open space around buildings, which support the vertical mixing of air and enhances wind speed.

However, the variation registered for the mean district values is minimal, and likely of the averaging process. In fact, in the analysis of the linear correlations between day and night-time microclimatic characteristics of buildings, diurnal temperatures are lower than 28.3°C around new buildings in the Super Urban and Health Campus. Moreover, in these two scenarios there is higher frequency for buildings that have a surrounding wind profile between 0.3 and 0.4 m/s. Mapping microclimatic results for an exemplificative hour illustrate the spatial distribution of variations. The minimal magnitude of differences in temperatures (max 0.2°C) and flow velocity (max 0.3 m/s) between the four scenarios can also be justified by the limited responsiveness of ENVI-met in processing geometry variations. As observed in the previous study by Sharmin [46], despite the relative quality of predictions of air temperatures, ENVI-met modelling appears to be unable to evaluate the precise impact of variations in urban geometries.

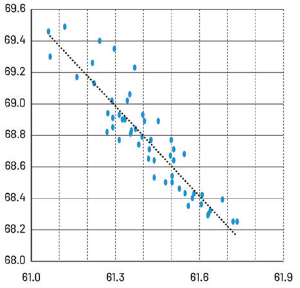
Baseline



Air Temperature



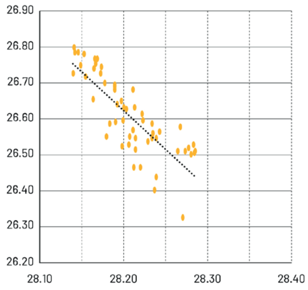
Wind Speed

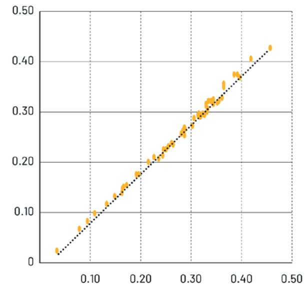


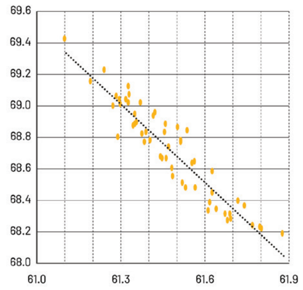
Relative Humidity

FIG. 6.10 Microclimate simulation results for SPACERGY scenarios

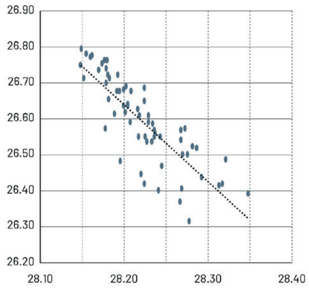
Health Campus

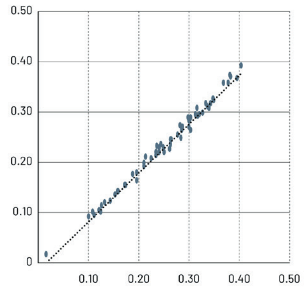


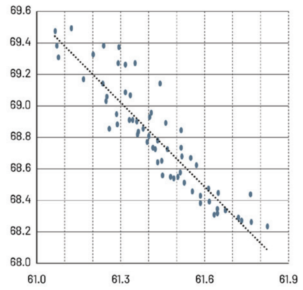




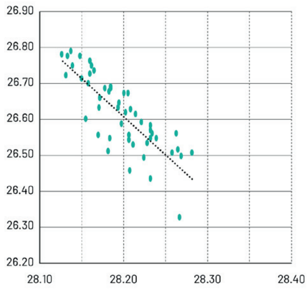
Synergy

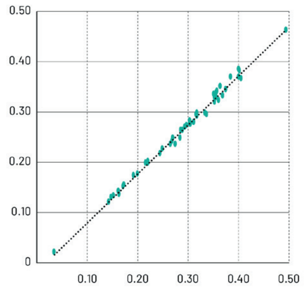


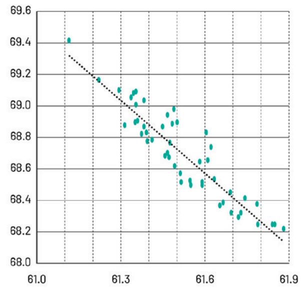




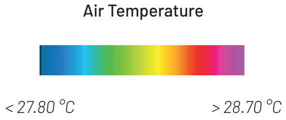
Super Urban

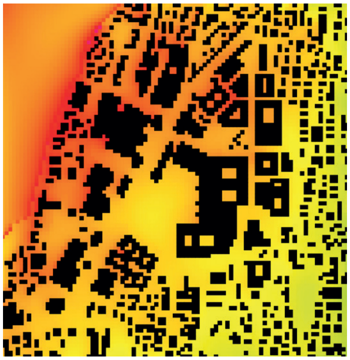




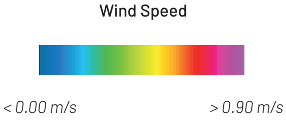


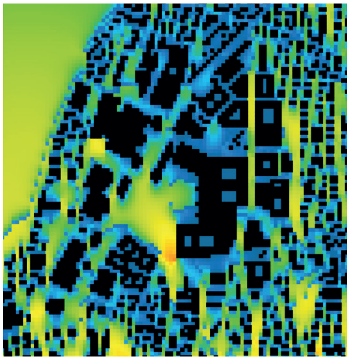
Baseline





Air Temperature

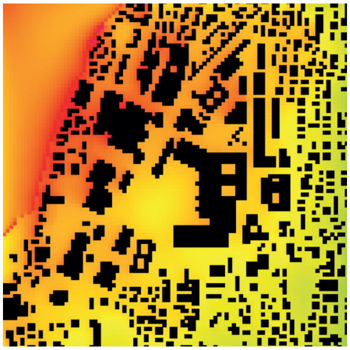


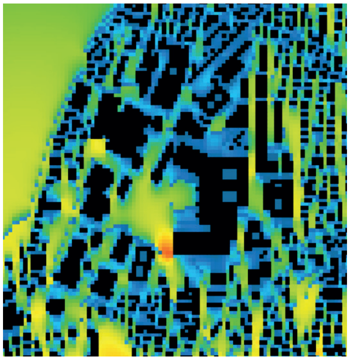


Wind Speed

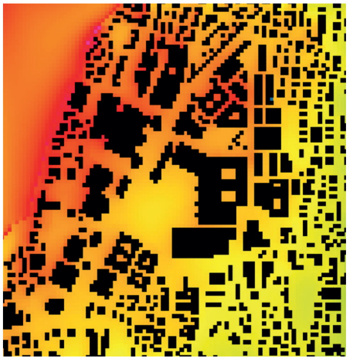
FIG. 6.11 Microclimate simulation results for SPACERGY scenarios

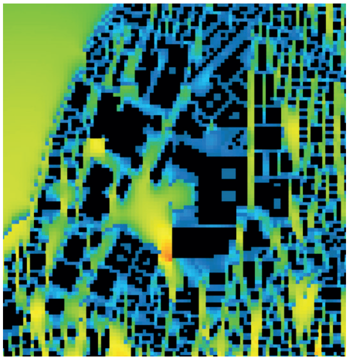
Health Campus



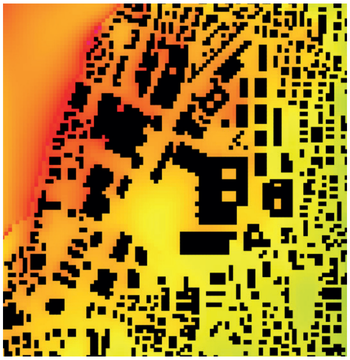


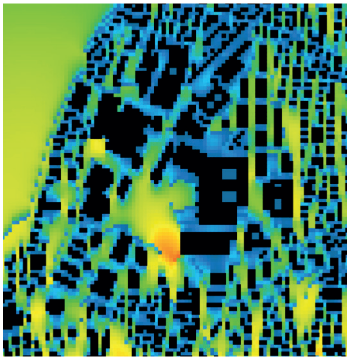
Synergy





Super Urban





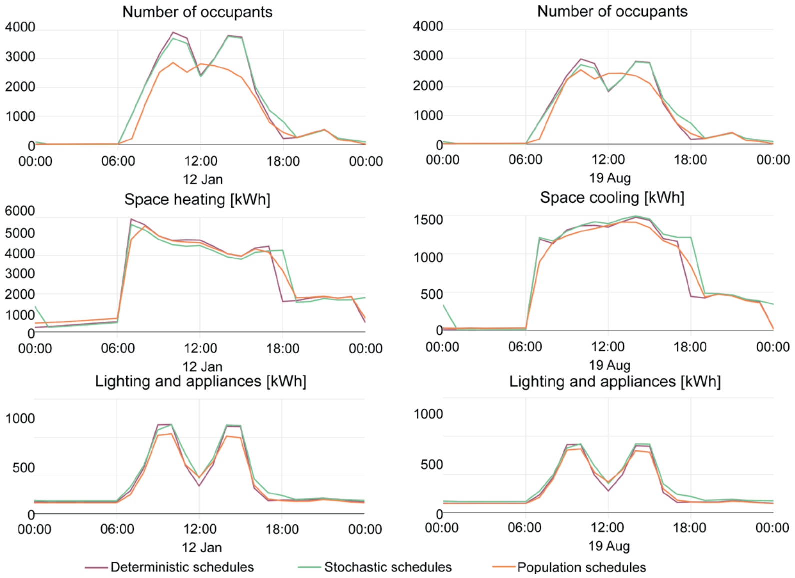


FIG. 6.12 Cumulative hourly demands for space heating, electricity for lighting and appliances, and number of occupants in all office buildings in the status quo on the coldest (left) and hottest (right) week of the year.

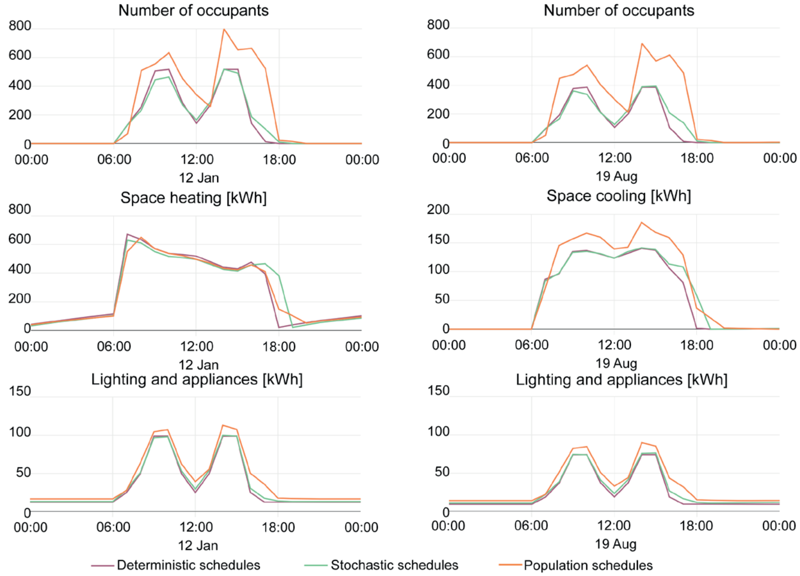


FIG. 6.13 Cumulative hourly demands for space heating, electricity for lighting and appliances, and number of occupants in all classroom buildings in the status quo on the coldest (left) and hottest (right) week of the year.

Building energy demand

Effect of occupant modeling on the demands in the Hochschulquartier:
An analysis of the impacts of occupant models on the energy demand simulations carried out for the Hochschulquartier status quo [47] showed that the variation in the area's energy demands when switching from the deterministic schedules to the stochastic model were relatively minor compared to the effects seen when using the MATSim population as the basis for occupant modeling. Figures 6.13 and 6.14 show the number of occupants and the demands for space conditioning and lighting and appliances in the offices and classrooms in the area for the deterministic and stochastic CEA schedules and for the MATSim population schedules. The effect of changing the population model from the deterministic baseline at different scales is shown in Figure 6.15 through the normalized mean absolute deviation (NMAD) defined for a given demand per square meter q as follows:

$$NMAD_q = \frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{t=1}^{n}\left|q_{i,k}(t) - q_{i,d}(t)\right|}{\sum_{t=1}^{n} q_{i,d}(t)}$$

where $q_{i,k}(t)$ and $q_{i,d}(t)$ are the demand per square meter at time t for building i for occupancy model k and for the deterministic model, respectively, n is the number of time steps, and N is the number of buildings in the sample being considered.

As expectable, the variation is largest on an hourly basis, and is greater for electricity demands given that the demand for appliances was directly connected to occupant presence. However, on a yearly basis, the effect of occupants led to a deviation of less than 10% for all energy demands compared.

Due to the importance of demand peaks for supply system sizing, the larger deviation in the results on an hourly basis implies that occupants may have a significant effect on the demand peaks in buildings in the area. The deviation in the peak power demand for different energy services for each model with respect to the deterministic baseline is shown in Figure 6.16. The results show that the variation in all demands for the stochastic model and in the peak heating demand for the population model are all within 5% of the deterministic baseline, meaning that the choice of occupancy model likely has no effect on system sizing. Peak cooling and lighting and appliance demand in the population model varies by an average of 15% from the deterministic baseline, with a maximum deviation of around 40%, meaning that the choice of occupant model would have a considerable effect on the systems planned for a given building.

Given that the MATSim population is based on actual enrollment and employee data as opposed to the rough estimates in the national standards, the results when coupling with MATSim provide a more realistic basis for the simulations. Hence, the occupancy model based on MATSim populations is used for the comparison of all Spacergy scenarios in the next sections.

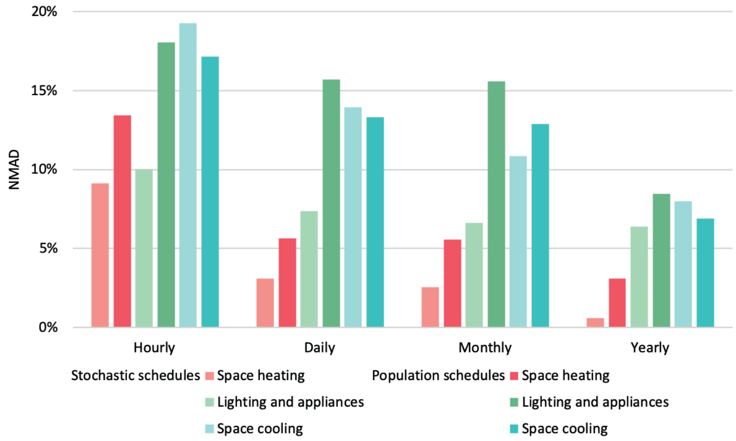


FIG. 6.14 Normalized mean average deviation (NMAD) at different time scales of analysis of the heating, cooling and electricity demands in the buildings in the area for the Stochastic schedules and Population schedules with respect to the Deterministic schedules.

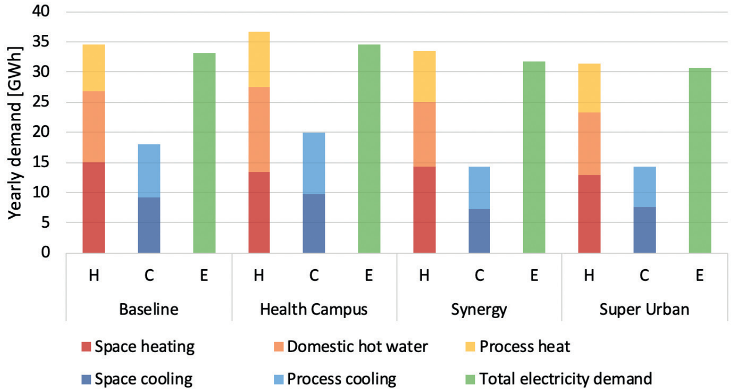


FIG. 6.15 Yearly demands for heating, cooling and electricity for each scenario.

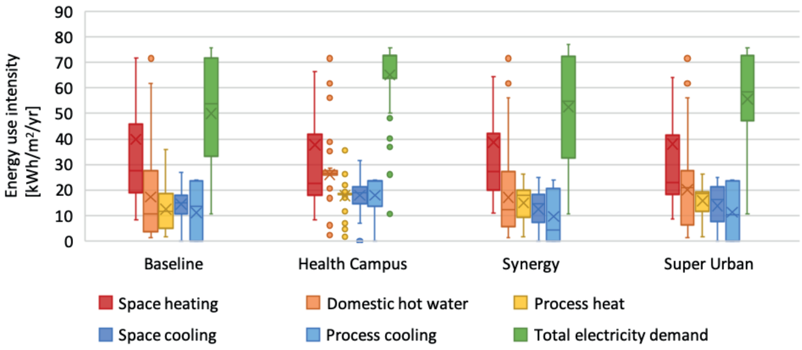


FIG. 6.16 Box and whisker plots showing the demands per square meter for heating, cooling and electricity for all buildings in each scenario. For each demand and scenario, the edges of the box represent the first and third quartile of the distribution, the horizonal line represents the median and the cross represents the mean. The whiskers represent the lower and upper fence in the data set, whereas circles represent outliers in the distribution.

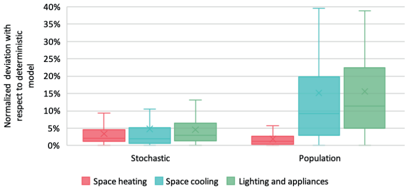


FIG. 6.17 Normalized deviation in the peak power for different energy demands for the stochastic and population models with respect to the deterministic baseline.

Yearly energy demands for the four Spacergy scenarios:
The yearly demands for the district for each scenario are shown in Figure 6.16. Due to the large share of functions with high demands for processes, lighting and appliances, the demand for electricity in all scenarios is comparable to the total demand for heating including domestic hot water and processes. Due to the highly insulated building envelopes assumed and the relatively large window-to-wall ratios in all new buildings, the demand for space cooling is also significant in all scenarios.

As expected, the energy demands are highest for the Health Campus scenario, mainly due to the increased demand domestic hot water and process heating, cooling and electricity. The demands are lowest for the Synergy and Super Urban scenarios due to the increase in residential buildings in these scenarios, which lead to an overall decrease in process energy and space cooling demands.

The relatively monofunctional functional distribution of the Health Campus scenario decreases the distribution of the demands per square meter for all buildings in the area (Figure 6.17) as all new buildings are assigned hospital functions and hence the same demands for domestic hot water and processes. The average space heating demand for all scenarios is around 40 kWh/m^2/yr, whereas the space cooling demand ranges from around 12 kWh/m^2/yr for the Synergy scenario to 18 kWh/m2/yr for the Health Campus scenario. Regarding process cooling, the minimum is also encountered in the Synergy scenario (10 kWh/m^2/yr) while the highest demand is also found in the Health Campus scenario (18 kWh/m^2/yr). The domestic hot water demand is also highest for the Health Campus scenario (26 kWh/m^2/yr), while the other scenarios range from 17-20 kWh/m^2/yr.

Hourly demands and peak shaving:
A key assumption in the definition of the Spacergy scenarios was that the introduction of residential buildings in the Synergy and Super Urban scenarios would lead to peak shaving and a more balanced load throughout the day.

Looking at the hourly demand on a week in winter (Figure 6.18) the peaks are indeed significantly decreased for these two scenarios with respect to the baseline, while the demand on weekends is higher due to the presence of building residents during the weekends. However, this effect is largest in the Health Campus scenario, since hospital buildings not only have night time occupancy, but also have demands for domestic hot water and process heating during off-peak times. Even during peak times the hospital has the lowest heating demand due to internal gains from processes and occupants. Hence, the heating demand curve is flattest for the Health Campus scenario.

The presence of occupants during off-peak hours and weekends also explains the larger cooling demand in the Health Campus scenario, as observed in Figure 6.19. While the peak demands for the Baseline and Health Campus scenarios on weekdays

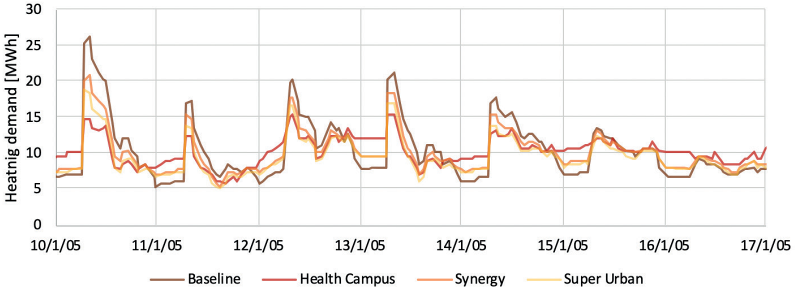


FIG. 6.18 Total demand for heating (space heating, domestic hot water and process heating) for all buildings in each scenario during a week in winter.

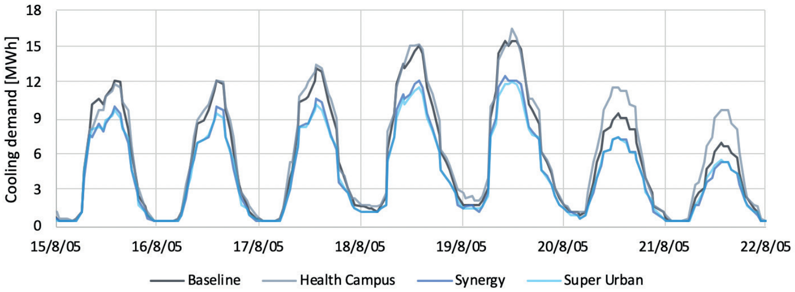


FIG. 6.19 Total demand for cooling (space and process cooling) for the district for all buildings in each scenario during a week in summer.

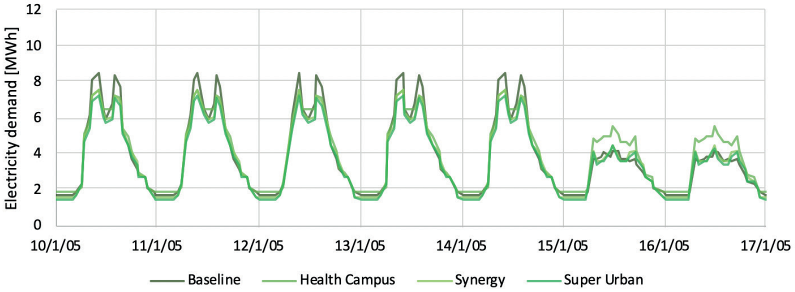


FIG. 6.20 Demand for electricity for lighting, appliances and processes for all buildings in each scenario during a week in winter.

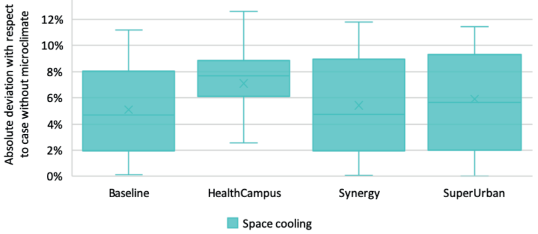


FIG. 6.21 Normalized deviation in the peak space cooling demand for each scenario when considering microclimate effects.

are very similar, on weekends the demand in the Baseline scenario is about 25% lower due to the lower share of hospital buildings in the area. Since residential buildings in Switzerland are typically not equipped with cooling systems, the inclusion of residential buildings in the Synergy and Super Urban scenarios leads to an overall lower cooling demand in the area, with weekday peaks about 25% lower than for the other two scenarios.

The electricity demands in the area show a consistent pattern across all scenarios (Figure 6.20). Similarly to the other energy demands, the Baseline scenario proves to have the highest demands on weekdays, but the Health Campus scenario shows the highest demands on weekends, thus leading to the observed higher yearly electricity demand in this scenario. The three other scenarios have very similar demands on weekends, whereas the Super Urban scenario has the lowest electricity demand on weekdays.

Overall, the scenarios with residential buildings have the lowest demand and exhibit some peak shaving trends, however the flattest demand curves are clearly observed in the Health Campus scenario.

Effects of urban microclimate on space cooling on the hottest day of the year: Figure 6.21 shows the space cooling demand on the hottest day of the year for each of the four scenarios. The patterns throughout the day are fairly similar for all scenarios, although the peaks are 20-23% lower for Synergy and Super Urban due to the increase of uncooled residential buildings. When accounting for the effects of urban microclimate, there is a noticeable dip in the peak demand for all scenarios, with a decrease in the peak power required ranging from 3% for the Synergy scenario to 6.5% for the Health Campus scenario. However, due to the higher nighttime temperatures the cooling demand during these off peak hours is 50-75% higher when accounting for microclimate in the area. Thus, there is an overall increase in the cooling demand on the hottest day of the year of 4% for the Baseline scenario to 6% for the Health Campus scenario.

Overall, the Health Campus scenario appears to be most affected by the UHI effect, with the largest variation in total and peak demand for space cooling on the hottest day of the year. This can be seen spatially in Figure 6.22. The figures show that the central hospital buildings have the highest increase in cooling demand when accounting for microclimate effects. This is due to the fact that these are the only buildings in the case study with off-peak occupancy and space cooling demands, hence the increased temperature during the night causes the total space cooling over the day to be higher than in the case without microclimate effects. Most research buildings in the area have a change in total demand of between -2.5% to 2.5% due to the fact that there is no cooling during the night time, and hence the increased temperature at this time does not have a significant effect.

Baseline

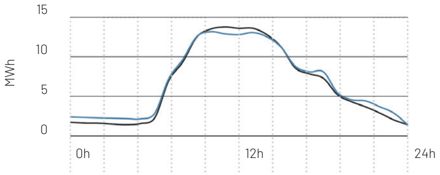


FIG. 6.22 Total space cooling demand in the district on the hottest day of the typical year for all four scenarios.

— Weather station

— Microclimate

FIG. 6.23 Change in total cooling demand on the hottest day of the year due to microclimate effects for each scenario.

%

🟦 -10,6% / -10%

🟦 -10% / -5%

🟦 -5% / 0%

🟨 0% / 5%

🟨 5% / 10 %

🟫 10% / 10,6 %

⬜ District

FIG. 6.24 Change in peak cooling demand on the hottest day of the year due to microclimate effects for each scenario.

%

🟦 -10,6% / -10%

🟦 -10% / -5%

🟦 -5% / 0%

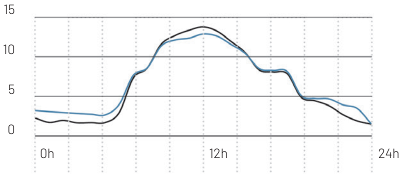
🟨 0% / 5%

🟨 5% / 10 %

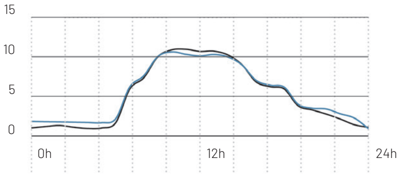
🟫 10% / 10,6 %

⬜ District

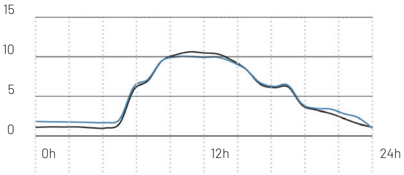
Health Campus



Synergy



Super Urban



Regarding peak cooling demand (Figure 6.25), practically all buildings show a decrease in the peak space cooling demand due to the reduced outside air temperature in the area for the case with microclimate. There are a few significant outliers with increases in peak cooling demand of more than 5%. These are older buildings which were assumed to keep their original air-based cooling systems, while all new buildings were assumed to be equipped with chilled ceiling cooling systems. Thus, while the outdoor temperature during peak cooling times is lower, the latent loads due to the increased outside air humidity causes the overall cooling demand to be higher for the case with microclimate effects.

The average variation in peak power demand due to microclimate effects (Figure 6.22) is 5–7% for all scenarios, with Health Campus showing the greatest susceptibility to microclimate effects. When compared to the effect of occupant modeling (Figure 6.16), microclimate effects appear to have a smaller impact on peak power demand and hence system sizing, but a larger impact on the overall cooling demand of the area.

Mobility energy demand

The main findings are summarized below.

Space Syntax:

- Hochschulquartier is traversed by a few street segments with high through-movement potential on the city scale (R=5000). These high values on city scale do not change significantly in the four scenarios.

- Most car and bicycle traffic seems to follow these streets with high through-movement potential on the city scale, whereas most pedestrian traffic seems to follow the shortest path to the central railway station in the northwest of the study area.

- On the local scale (R=500), there are some considerable improvements in through-movement potential between Hochschulquartier and the east bank of the historic city center. However, the values do not increase in the masterplan area itself, with exception of the Synergy scenario. Here, the newly introduced promenade sees a distinct increase in through-movement potential.

MATSim:

- The volumes of cars, bicycles and pedestrians are simulated only for agents with a destination inside the Hochschulquartier. Therefore, any through-traffic or other traffic with a local destination in the area is not represented in the data.

- In all scenarios, the amount of walking is higher than the Status Quo. The differences between the scenarios are marginal.

- The highest amount of walked distance occurs in the Super Urban scenario. Interestingly, the amount of distance driven by cars is not lower as a consequence. In fact, the Super Urban scenario shows the highest number of cars, and the second highest number of driven kilometers within the area.

- The highest energy consumption by cars (23.7 TWh) occurs in the Baseline scenario.

- The lowest amount of car traffic is seen in the Synergy scenario, and so is the amount of energy used for car traffic (21.2 TWh). This is, however, higher than the Status Quo (18.6 TWh).

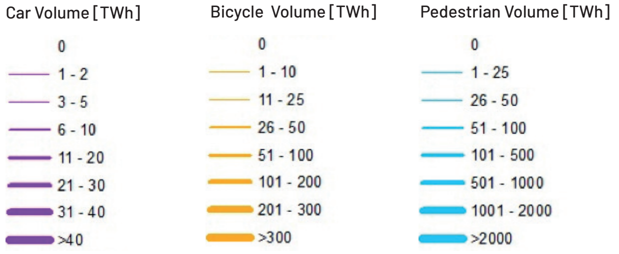
- Compared to the Status Quo and Baseline scenario, the walking network within Hochschulquartier becomes denser in the Synergy, Super Urban

Baseline

Space Syntax

Space Syntax + Car Volume

Space Syntax + Pedestrian Volume



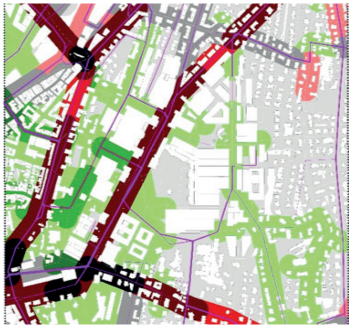
Aggregated Choice

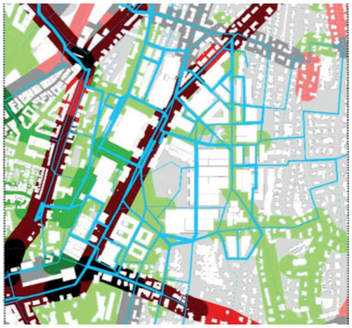
		Angular Choice with Low radius (R=500m)		
		Low	Medium	High
Angular Choice with High radius (R = 5000 m)	Low	LL	LM	LH
	Medium	ML	MM	MH
	High	HL	HM	HH

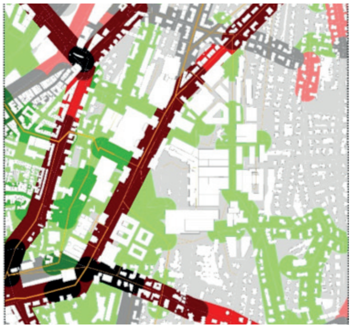
FIG. 6.25 Mobility Energy demand- Space Syntax Analysis

Health Campus

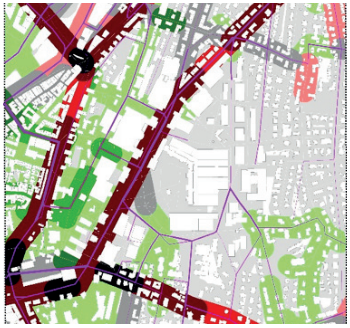
Synergy

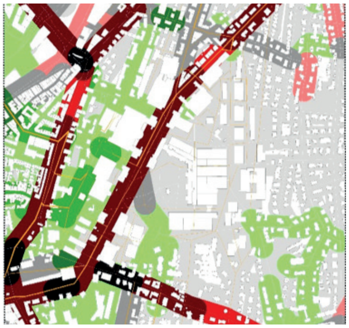


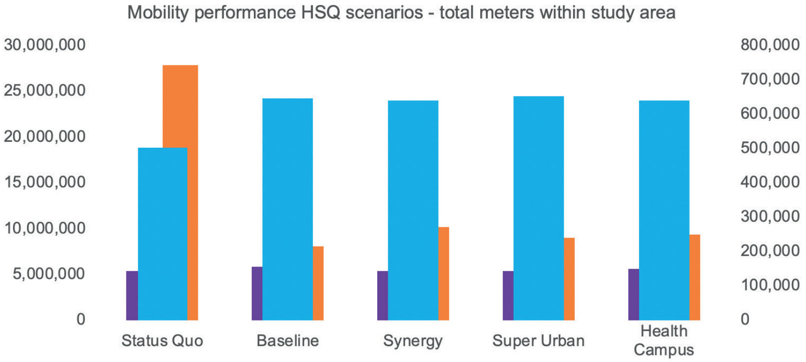




Super Urban






Mobility performance HSQ scenarios - total meters within study area

	Status Quo	Baseline	Synergy	Super Urban	Health Campus
🟪 Car	141,388	156,197	140,904	143,041	147,257
🟧 Bike	743,276	215,414	270,276	237,694	249,158
🟦 Walk	18,745,735	24,238,229	23,964,293	24,477,888	23,929,067

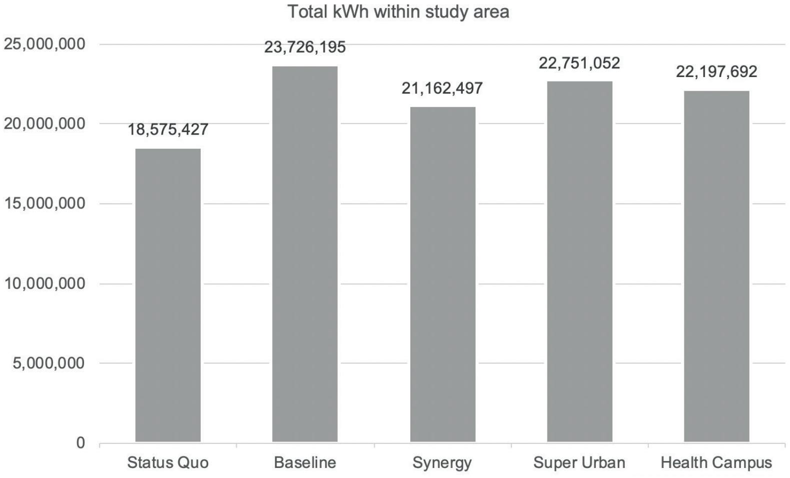

Total kWh within study area

FIG. 6.26 Comparison of the four SPACERGY Scenarios

6.4. Discussion and Conclusions

The obtained microclimate results show an evident atmospheric Urban Heat Island phenomenon in both districts. However, the characteristic higher temperatures in the urban areas compared to the rural area, have different patterns along the 24 hours studied. While in the Hochschulquartier local temperatures are higher during the night for the two days analyzed, in Almere local temperatures are higher during the daytime.

The consideration of microclimatic patterns in energy demand calculation in the Zurich case leads to a general increased building cooling demand on the hottest day between 1.4% and 2%, and a lower building heating load between 2% and 3% during the coldest day. The effect of microclimate on the peak cooling demand was more noticeable, with a 5% decrease in peak cooling power on the hottest day of the year. A sensitivity study identifies the variables of Occupied hours, U-values, and Floor Space Index, as significant predictors of variation in both heating and cooling demand when microclimate boundary conditions are used in CEA.

Each scenario developed for the Zurich case study involved an underlying guiding assumption regarding the effects of various urban measures on the performance of the area. The parameters changed amongst scenarios included: changes in the functional mix from a more monofunctional, purely health-oriented scenario to a more mixed-use district; the incorporation of microclimatic measures to mitigate the demands in the area; and the integration of the street network to improve walkability and bikeability of the area and reduce the number of trips and hence the energy demand for transportation.

The move from the Baseline to the monofunctional Health Campus led to increases in heating (+6%), cooling (+11%) and electricity demand (5%), mainly due to increases in the demands for processes and domestic hot water, which led to 17–20% increases in their respective demands. The increase in residential functions in the Synergy and Super Urban scenarios, on the other hand, led to an overall decrease in the demands for heating (-3% to -10%), cooling (-20%) and electricity (-4% to -7%). The large decrease in cooling demand is mainly due to the fact that residential buildings are typically not cooled in Switzerland. One key assumption in the definition of the scenarios, however, was that the mixed-use scenarios would lead to load balancing and peak shaving, however the most stable load was actually observed in the Health Campus scenario. This is due to the fact that hospitals are the only buildings in the area that have 24-hour active occupancy, and hence a large baseload and relatively constant demand throughout the day.

Regarding microclimate measures, while there was a clear microclimate effect in all scenarios, the effect was very similar in each case. Hence, the effect of microclimate on cooling demand on the hottest day of the year was fairly similar for all scenarios. Due to the decreased air temperature in the area mid-day, the maximum power demand for all scenarios was actually higher when accounting for microclimate effects (-3% to -7%). However, given the higher night time temperatures due to heat storage in the building and street materials, the overall demand on the hottest day of the year actually increases (+4% to +6%). The peak reduction is indeed higher for the scenarios with microclimatic measures, but so is the increase in total cooling demand. The variations between scenarios are, however, mostly negligible.

The installation of district cooling infrastructure proved to have a positive environmental impact for all scenarios, with a decrease in yearly CO^2 emissions of 40–44% with respect to a standard vapor compression chiller system, but at a much larger operational cost (+66–+93%). Increasing the cooling demand by more than 50% was not enough to make the system feasible nor decisively dismiss it from an environmental perspective. This would appear to indicate that the effects of urban microclimate and building occupant behavior (both of which were quantified to contribute to a deviation in total demand of less than 10%) would not be significant enough to affect the decision on whether to build a large district cooling infrastructure.

Finally, for the two scenarios with PV installation, CO^2 emission savings of about 5% could be achieved through PV installation with an increase in electricity costs of only 0.2%. Even cost-optimal alternatives that even made profits of around 2% showed a decrease in yearly CO^2 emissions of 3.5%. The decreases in CO^2 emissions are modest due to the relatively low carbon intensity of the Swiss grid, however primary energy demand was decreased by 15–25%. Given that the CO^2 performance could be improved without increasing the electricity costs in the area, PV appears to be a very promising technology for the area. The introduction of batteries appeared to have minimal impact due to the high self-consumption rates in the area, but the presence of electric vehicle charging stations in the new main building of the university hospital proved to be potentially beneficial from an economic perspective. In spite of the CO^2 savings created by the installation of photovoltaic panels, the Health Campus scenario incurred the highest CO^2 emissions due to its overall higher energy demands. In terms of primary energy, however, the scenarios with no photovoltaic installations performed worst. Due to the combination of lowest demand and least carbon-intensive technologies, the Super Urban scenario had the lowest emissions, primary energy demand and costs of all scenarios.

The four scenarios for development of the Hochschulquartier in Zürich provide with a denser, more integrated local network for walking and cycling within the district. The Space Syntax analyses reveal that this leads to improved walking connections to the city center and the central railway station. Subsequently, the results from the MATSim simulations confirm that there indeed is an increase in pedestrian traffic on these routes and throughout the area, as well as a more even dispersal of walking trips over the surrounding streets. Despite variations in the improved street network for each scenario, no one scenario stands out in particular. This leads to the conclusion that even a minor change in the street network can have significant implications on the capability of the street network to facilitate sustainable transport means. In line with Space Syntax theories, the analyses have shown that by adding missing connections and by making the network denser, local accessibility can be improved in favor of walking.

In general, bicycle traffic is dispersed more evenly throughout and around the Hochschulquartier, suggesting that the local network is utilized better. However, the simulated bicycle traffic is significantly lower for all scenarios than it is in the simulated present-day situation. This may indicate that there is an inaccuracy in the agent-based model. The Baseline scenario has the least cycling, whereas the Synergy scenario has the highest amount of cycling.

The variations in car usage between the present-day situation and the four scenarios are minimal. A visual analysis leads to the finding that the local network for cars within the Hochschulquartier does not change significantly. This is partly due to the fact that many of the new street segments are modelled as car-free, but it is possibly also related to changes in the available parking facilities, something which Space Syntax does not pick up on.

References

[1] S. Singh and C. Kennedy, "Estimating future energy use and CO2 emissions of the world's cities," Environmental Pollution, vol. 203, pp. 271–278, 2015.

[2] K. Steemers, "Energy and the city: density, buildings and transport," Energy and Buildings, vol. 35, pp. 3–14, 2003.

[3] J. Fonseca, A. Willmann, M. Stauffacher, and A. Schlueter, "Assessing the environmental impact of future urban developments at neighborhood scale," in Proceedings of International Conference CISBAT 2015 Future Buildings and Districts Sustainability from Nano to Urban Scale, pp. 457–462, 2015.

[4] J. Keirstead, M. Jennings, and A. Sivakumar, "A review of urban energy system models: Approaches, challenges and opportunities," Renewable and Sustainable Energy Reviews, vol. 16, pp. 3847–3866, 2012.

[5] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer, and R. Evins, "A review of modelling approaches and tools for the simulation of district-scale energy systems," Renewable and Sustainable Energy Reviews, vol. 52, pp. 1391–1404, 2015

[6] J. Keirstead, N. Samsatli, and N. Shah, "SynCity: an integrated tool kit for urban energy systems modelling," in Energy efficient cities: Assessment tools and benchmarking practices, ch. 2, pp. 21–42, Washington D.C., USA: The World Bank, 2010.

[7] C. Reinhart, T. Dogan, J. A. Jakubiec, T. Rakha, and A. Sang, "UMI – an urban simulation tool for building energy use, daylighting and walkability," in Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, pp. 476–483, 2013.

[8] D. Saner, N. Heeren, B. Jäggi, R. Waraich, and S. Hellweg, "Housing and mobility demands of individual households and their life cycle assessment," Environmental Science and Technology, vol. 47, pp. 5988–5997, 2013.

[9] A. Mailhac, G. Herfray, N. Schiopu, N. Kotelnikova-Weiler, A. Poulhes, S. Mainguy, J. Grimaud, J. Serre, G. Sibiude, A. Lebert, B. Peuportier, and C. Valean, "LCA applicability at district scale demonstrated throughout a case study: Shortcomings and perspectives for future improvements," in Expanding Boundaries: Systems Thinking in the Built Environment, pp. 266–272, 2016.

[10] R. Kellett, A. Christen, N. Coops, M. van der Laan, B. Crawford, T. R. Tooke, and I. Olchovski, "A systems approach to carbon cycling and emissions modeling at an urban neighborhood scale," Landscape and Urban Planning, vol. 110, pp. 48–58, 2013.

[11] A. Christen, N. Coops, B. Crawford, R. Kellett, K. Liss, I. Olchovski, T. Tooke, M. van der Laan, and J. Voogt, "Validation of modeled carbon dioxide emissions from an urban neighborhood with direct eddy-covariance measurements," Atmospheric Environment, vol. 45, pp. 6057–6069, 2011.

[12] S. Tirumalachetty, K. Kockelman, and B. Nichols, "Forecasting greenhouse gas emissions from urban regions: microsimulation of land use and transport patters in Austin, Texas," Journal of Transport Geography, vol. 33, pp. 220–229, 2013.

[13] B. Nichols and K. Kockelman, "Life-cycle energy implications of different residential settings: Recognizing buildings, travel, and public infrastructure," Energy Policy, vol. 68, pp. 232–242, 2014.

[14] A. M. de Almeida, M. Ben-Akiva, F. C. Pereira, A. Gauche, C. A. Guevara, S. Niza, and C. Zegras, "The virtual city with real decisions: ITEAM," in Proceedings of 7VCT, Lisbon, Portugal, 11 - 13 October 2011, pp. 173–180, 2011.

[15] F. Chingcuanco and E. Miller, "A microsimulation model of urban energy use: Modelling residential space heating demand in ILUTE," Computers, Environment and Urban Systems, vol. 36, pp. 186–194, 2012

[16] D. Robinson, F. Haldi, J. Kämpf, P. Leroux, D. Perez, A. Rasheed, and U. Wilke, "CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning," in Proceedings of Building Simulation 2009: Eleventh International IBPSA Conference, pp. 1083–1090, 2009.

[17] S. Magli, C. Lodi, L. Lombroso, A. Muscio, and S. Teggi, "Analysis of the urban heat island effects on building energy consumption," Int. J. Energy Environ. Eng., vol. 6, no. 1, pp. 91–99, 2015.

[18] C. P. Skelhorn, G. Levermore, and S. J. Lindley, "Impacts on cooling energy consumption due to the UHI and vegetation changes in Manchester, UK," Energy Build., vol. 122, pp. 150–159, 2016.

[19] Y. Toparlar, B. Blocken, B. Maiheu, and G. J. F. van Heijst, "Impact of urban microclimate on summertime building cooling demand: A parametric analysis for Antwerp, Belgium," Appl. Energy, vol. 228, no. April, pp. 852–872, 2018.

[20] F. S. De La Flor and S. A. Domínguez, "Modelling microclimate in urban environments and assessing its influence on the performance of surrounding buildings," Energy Build., vol. 36, no. 5, pp. 403–413, 2004.

[21] E. Bozonnet, R. Belarbi, and F. Allard, "Thermal Behaviour of buildings: modelling the impact of urban heat island," J. Harbin Inst. Technol., vol. 14, no. Sup., pp. 19–22, 2007.

[22] M. Kolokotroni, M. Davies, B. Croxford, S. Bhuiyan, and A. Mavrogianni, "A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island: Case-study of London," Sol. Energy, vol. 84, no. 12, pp. 2246–2255, 2010.

[23] A. Gros, E. Bozonnet, C. Inard, and M. Musy, "A New Performance Indicator to Assess Building and District Cooling Strategies," Procedia Eng., vol. 169, pp. 117–124, 2016.

[24] J. He, A. Hoyano, and T. Asawa, "A numerical simulation tool for predicting the impact of outdoor thermal environment on building energy performance," Appl. Energy, vol. 86, no. 9, pp. 1596–1605, 2009.

[25] N. H. Wong et al., "Evaluation of the impact of the surrounding urban morphology on building energy consumption," Sol. Energy, vol. 85, no. 1, pp. 57–71, 2011.

[26] A. Gros, E. Bozonnet, and C. Inard, "Cool materials impact at district scale - Coupling building energy and microclimate models," Sustain. Cities Soc., vol. 13, pp. 254–266, 2014.

[27] J. Bouyer, C. Inard, and M. Musy, "Microclimatic coupling as a solution to improve building energy simulation in an urban context," Energy Build., vol. 43, no. 7, pp. 1549–1559, 2011.

[28] W. P. Anderson, P. S. Kanaroglou, and E. J. Miller, "Urban Form, Energy and the Environment: A Review of Issues, Evidence and Policy," Urban Study, vol. 33, no. 1, pp. 7-35, 1996.

[29] H. Brunner, M. Hirz, W. Hirschberg, and K. Fallast, "Evaluation of various means of transport for urban areas," Energy sustain. Soc., vol. 8, no. 1, 2018.

[30] C. Ratti, N. Baker, and K. Steemers, "Energy consumption and urban texture," Energy Build., vol. 35, no. 7, pp. 762-776, 2005.

[31] M. Santamouris, "On the energy impact of urban heat island and global warming on buildings," Energy Build, vol. vol. 82, p. 100–113, 2014.

[32] N. Baker, and K. Steemers, Energy and Environment in Architecture, London: E&FN Spon, 2000.

[33] G. Huebner, D. Shipworth, I. Hamilton, Z. Chalabi, and T. Oreszczyn, "Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes", Applied Energy, vol. 177, pp. 692-702, 2016.

[34] O.García, J. Prieto, R.S. Alonso, and J.M. Corchado, "A Framework to Improve Energy Efficient Behaviour at Home through Activity and Context Monitoring", Sensors (Basel), vol. 17(8):1749, 2017.

[35] The CEA team, City Energy Analyst v2.9.0 (2018). doi:10.5281/zenodo.1487867.

[36] B. Hillier, A. Penn, J. Hanson, T.Grajewski, and J. Xu, "Natural Movement: or, configuration and attraction in urban pedestrian movement", Environment and Planning B: Planning and Design, vol. 20, pp. 29-66, 1993.

[37] M. Rashid, "The geometry of urban layouts", Springer: 2017.

[38] L. D'Acci, "On urban Morphology and Mathematics. In Mathematics of Urban Morphology", D'Acci (ed.), Ed. Birkhäuser (Springer Nature): Cham, Switzerland, 2018.

[39] J. Jacobs, "The death and life of great American cities", Pimlico: London, 2000.

[40] A. Siksna, "The effects of block size and form in North American and Australian city centres", Urban Morphology 1997, 1, 19-33.

[41] J. de Dios Ortúzar, and L. G. Willumsen, "Modelling Transport", Wiley, 2011.

[42] A. Horni, K. Nagel, and K. Axhausen, "Multi-Agent Transport Simulation MATSim", London: Ubiquity Press, 2016

[43] J. Page, D. Robinson, N. Morel, J.-L. Scartezzini, A generalised stochastic model for the simulation of occupant presence, Energy and Buildings 40 (2) (2008) 83–98. doi:10.1016/j.enbuild.2007.01.018.

[44] Bundesamt für Statistik (BFS), Arbeitsvolumenstatistik (AVOL), Neuchâtel, Switzerland, 2018.

[45] Metotest, "Meteonorm Version 7.1, Global Meteorological Database for Engineers, Planners and Education," Meteotest, Bern, Switzerland, 2014.

[46] Sharmin, T., Steemers, K. & Matzarakis, A., "Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment," Sustainable Cities and Society, 34(February), pp.293–308, 2017

[47] M. Mosteiro-Romero, I. Hischier, J.A. Fonseca, H. Becker, A. Schlueter, "Effects of occupant modeling on district-scale energy demand simulations," in writing, 2019.