Investigating the Energy Performance of Buildings with a 3D City Model and Thermal Simulation: Results from the Urban Transition Lab

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The European Conference on Sustainability, Energy & the Environment 2017
Official Conference Proceedings

Abstract

Reduction in consumption of non-renewable energy resources at the local level (e.g. district or neighbourhood) is one of the effective manners to support sustainable development. To achieve this goal, engagement of citizens and other actors in the early stage of research is important. In this regard, the "Urban Transition Lab 131" (R131), which acts as a platform to identify problems and to set goals for sustainable development, was established to engage both the citizens of Karlsruhe through participatory processes and the researchers from the Karlsruhe Institute of Technology (KIT). Within the framework of R131, the energy performance of buildings and thermal simulations were carried out in Oststadt, a district of the city of Karlsruhe. At first, 3D city models were used to perform a morphology and exploratory cluster analyses. Secondly, the heating energy demand of the residential buildings were simulated at different spatial and temporal resolutions. Thirdly, as a proof of concept, three scenarios for the reduction of non-renewable energy consumption in a multi-family building were analysed. The data was collected from multiple sources, e.g. field surveys, interviews with landlords and local utility companies as well as expert and literature reviews. Finally, the results were communicated with the citizens through a formal workshop. This integrated research and the results from this project can help the citizens and local policy makers to identify different options for sustainable energy concepts. Furthermore, the findings can also contribute to the sustainable energy policy agenda in the short and long term, across different districts, cities and regions.

Keywords: 3D city model, Clustering, Building heating demand, Energy concept, Sustainability.

1. Introduction

The way we organize our life in the cities is a crucial determinant of the success of sustainable development. Against this background, the Karlsruhe Institute of Technology (KIT) establishes "Urban Transition Lab 131" (R131), which acted as a research platform to identify problems and to set goals for sustainable development. It integrated science, innovation, and urban development into a transdisciplinary process, where the scientists of KIT work together with committed citizens and local stakeholders. This participatory process addressed the district level, which was especially suited to test sustainable development projects. Therefore, the main concern of the R131 was to merge research, practice and education.

The societal objective of the R131 was to draft a sustainable development plan of the district Oststadt in Karlsruhe. In this regard, a science venue named Future Space for Sustainability and Science, was established in the district (Oststadt) of Karlsruhe for personal interaction, exchange of ideas, and sharing of knowledge through events, regular meetings of various groups, seminars and exhibitions related to the current projects. The research on Energy Concept was carried out in the R131, along with three transdisciplinary research activities, e.g. Mobility, Social Issues and the Urban Space, Sustainable Consumption. They were accomplished through participatory project planning and were designed as transdisciplinary "real experiments" or "sustainability experiments" (Parodi et al., 2016). Figure 1 gives a structural overview of the R131.

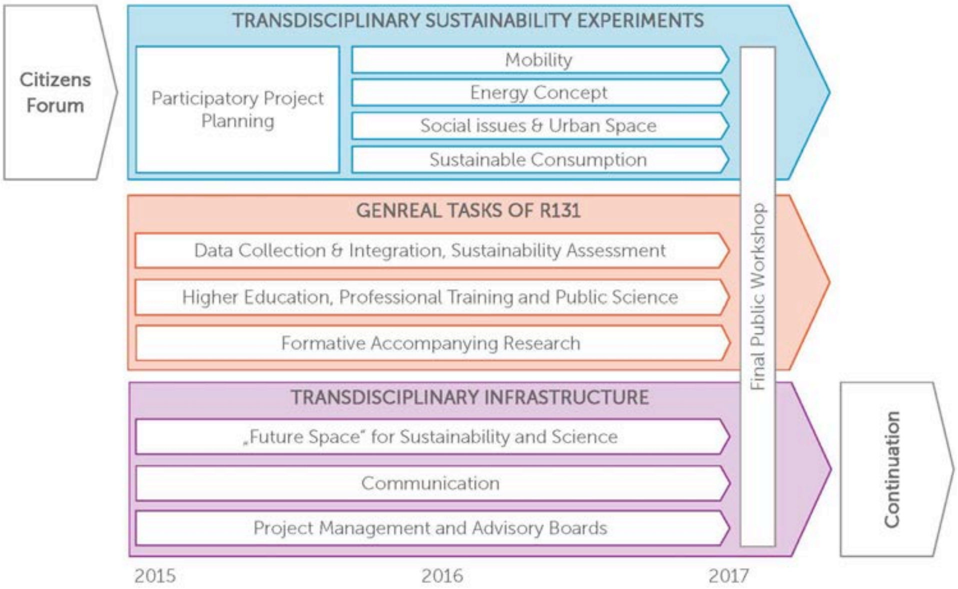

Figure 1: Transdisciplinary sustainable activities within the "Urban Transition Lab 131" (R131).
Source: (ITAS, 2015).

One of the effective manners to support sustainable development is the reduction in consumption of non-renewable energy resources at the local level (e.g. district or neighbourhood). This paper discusses the research activities and results performed in the Energy Concept project. Various aspects, such as energy efficiency, reduction of greenhouse gas emissions, optimisation of energy supply, etc. play significant role in the sustainable energy concepts. Such concepts can be achieved through integrated analyses of existing conditions, e.g. the energy performance of the buildings, spatial and temporal patterns of energy demand as well as energy saving potentials scenarios in the future. The technical solutions can be assessed by statistical analyses and dynamic simulation. Afterwards, the results can be shared with the residents and local stakeholders for better understanding of the short and long-term consequences of energy planning (concepts) and their further implications. The local policy makers and utility companies can decide different options for energy planning and develop alternative scenarios at a district level – by engaging the citizens in the process.

2. Description of the study area and required data

2.1 Study area

The research was carried out in the district Oststadt of the city of Karlsruhe. Karlsruhe consists of 27 districts in an area of around 173 km², with a population of around 308,000 (StatistischesBundesamt, 2016). The total area of Oststadt is around 5.19 km² with a population of 23,000 (StadtKarlsruhe, 2017b). It is characterised by a mixed land use having different residential, commercial and small industries. The district boasts of numerous cultural monuments and technology parks (Figure 2).

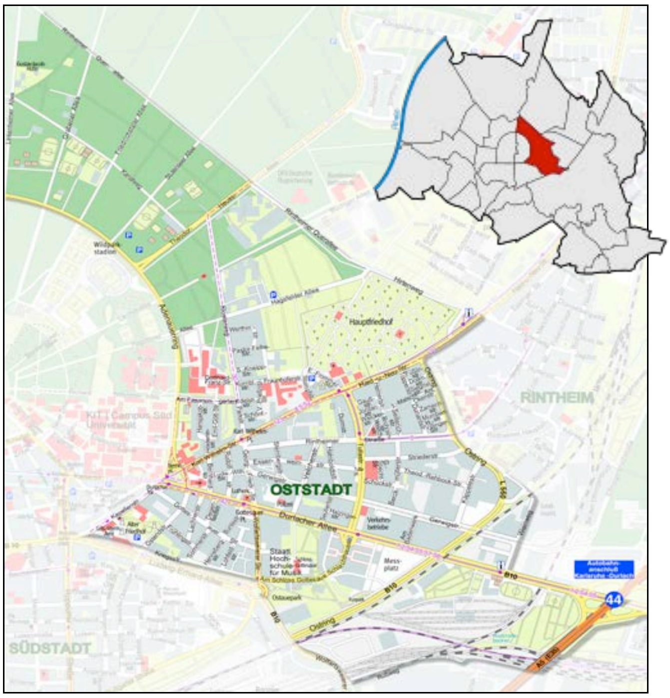

Figure 2: Description of the study area (left: land use map of district Oststadt, top right: boundary of city Karlsruhe and its 27 districts, Oststadt is marked in red). Source: (StadtKarlsruhe, 2017b).

The statistical analyses reveal that about 80% of all apartments in Oststadt are situated in multi-family houses (MFH) and the buildings with 7 – 12 apartments have the largest share (43%) (Figure 3). Around 80% of all residential buildings were built before 1970. In terms of energy consumption, heating (57%) and domestic hot water

(25%) are most dominant. These diverse land use and existence of old buildings make the district attractive to study energy concepts.

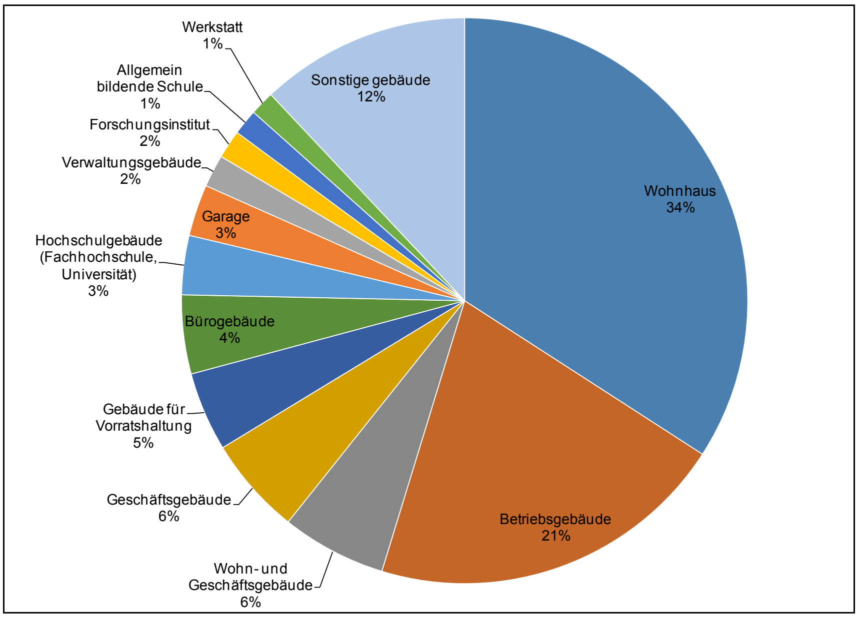

Figure 3: Share of different building types in the district Oststadt. Source: Data Collection Group of the Urban Transition Lab.

2.2 Description of data

Several spatial (2D and 3D) and non-spatial datasets were required for this study. They were collected from multiple sources, e.g. field surveys, interviews with property owners and local utility companies as well as expert and literature reviews (Table 1).

Table 1: Description of data required in this study.

Category	Content/description	Source
Spatial data	3D city model: LoD2 data in CityGML format	(StadtKarlsruhe, 2017a)
	OSM data: building locations, footprints, tags	(OpenStreetMap, 2017)
Building attribute	German census survey: total # buildings, frequency per age class and building type	(ZENSUS2011, 2014)
	Market research data: building type, building age, # flats, # commercial units, etc.	(INFAS, 2011)
	Student survey: building geometry (footprint, height, roof, basement & attic types), size & material of construction elements	Urban Transition Lab
Building typology	EU project TABULA (Typology Approach for Building Stock Energy Assessment)	(IWU, 2015)
Weather data	Solar radiation and temperature profiles	(EuropeanCommission, 2016), (NASA, 2016)

3. Research approach

The energy performance of buildings and thermal simulations were carried out in a holistic manner by incorporating transdisciplinary research of several institutes of the KIT. The building typology in Oststadt was identified with primary and secondary data collected by the R131. They were required to calculate the building energy demand and to perform 3D building morphology and explorative cluster analysis for identifying homogenous groups of buildings. The energy demand of the residential buildings were simulated and mapped at the different spatial and temporal resolutions. Afterwards, as a proof of concept, three scenarios for the reduction of non-renewable energy consumption in a multi-family building were performed. Finally, the outcome of the research were communicated with the citizens through a formal workshop.

The methodological approach of this research can be divided into four main parts (Figure 4): (1) 3D morphology and cluster analyses (2) Mapping of energy demand (3) Simulation of energy concepts and (4) Citizens' participation. The approaches and their interrelationships are explained in the following chapters.

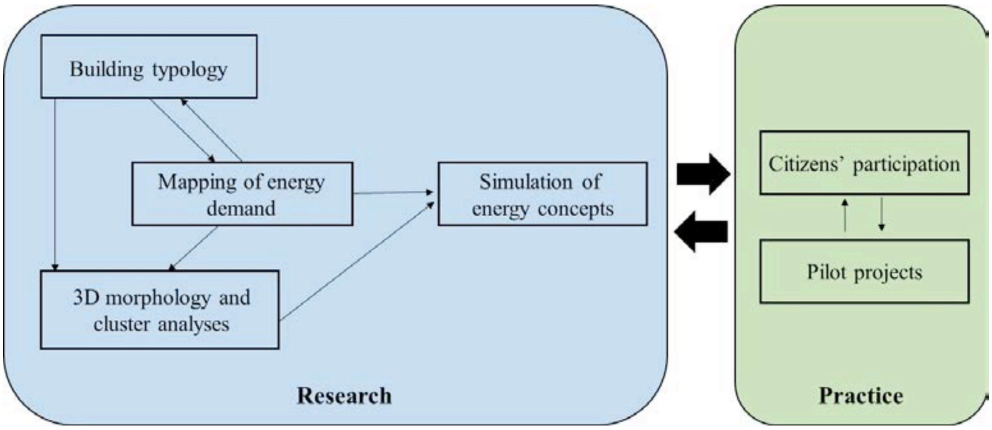

Figure 4: Methodological overview of the energy concept topic. Source: Own depiction.

4. Analysis of 3D building morphology and clustering

The 3D building morphology and cluster analyses were preceded by the exploratory evaluation of different spatial and non-spatial data with different methods and tools. An overview of different geometric and statistical analyses involved in this part of research is given in Figure 5.

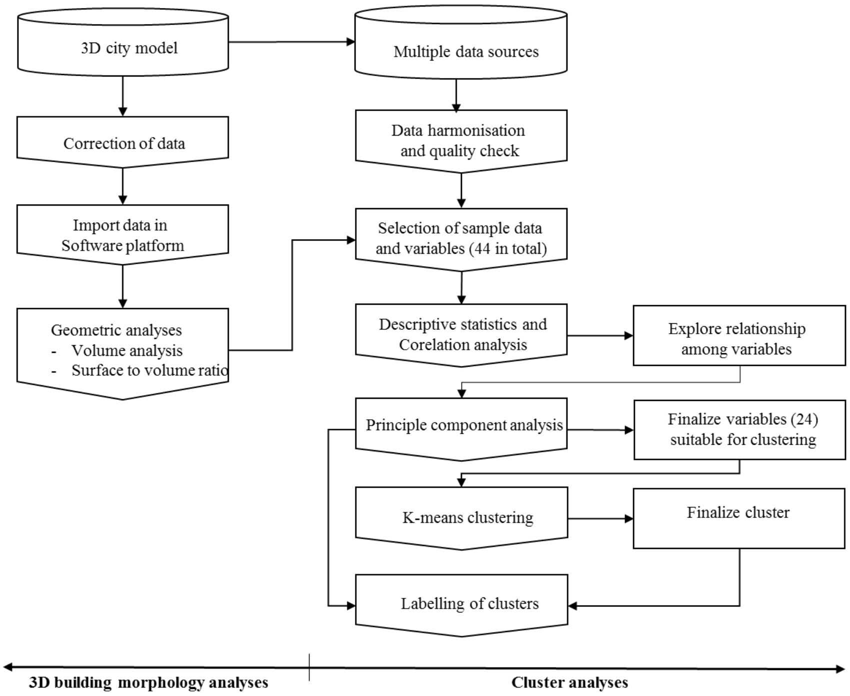

Figure 5: Methodological overview of geometric and statistical analysis. Source: Own depiction.

4.1 3D building morphology analyses

3D city model

Virtual 3D city models are used in various areas of urban and spatial planning such as, sustainability, energy and environment (Biljecki, Stoter, Ledoux, Zlatanova, & Çöltekin, 2015). The energy performance of buildings can be derived from semantic 3D city models (which contains building geometries) and other building attributes (e.g. type, age). CityGML is a widely used standard for displaying 3D city models at different levels of detail (LoDs) (Figure 6).

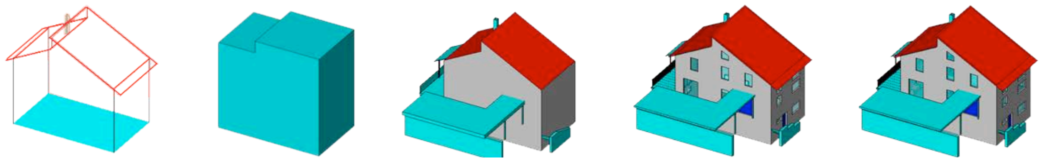

Figure 6: CityGML level of Details (LoDs). From left to right, LoD0 to LoD4. Source*:* (OGC, 2012).

The 3D city model in the CityGML LoD2 (with roof structure) format of the Oststadt was rectified to analyse building (heated) volume and the ratio of the outer wall surface and the building volume (A/V ratio). The data was imported in the open source software PostgreSQL, which is dedicated to the analysis of 3D data and calculation of energy simulation (Murshed, Picard, & Koch, 2017).

Morphology analyses

The (heated) volume of buildings, which is a sum of a storey volume and a roof volume (if heated), was calculated from the CityGML data using a python script developed at EIFER. The python script is based on PostGIS functions and the Python library PyHull[1]. The results were validated with the volume of buildings calculated by the tool Voluminator developed at the TU München[2]. The building volume can be used to estimate the useable area of buildings (Figure 7).

Next, the surface area of the building envelope was calculated using another python scripts developed at EIFER to study the compactness of the buildings. The ratio of building envelope area and heated volume (A/V ratio) gives a general indication of the efficiency of the buildings. High A/V ratio indicates more heat losses or gains, in comparison to a building with a low A/V ratio (assuming everything else is constant), which indicates more energy efficient buildings (Figure 8). Around 30% of the buildings are characterised by the A/V ratio between 0.4 and 0.6 (higher energy efficiency) and 24% indicate the ratio between 0.7 and 0.9.

Furthermore, the volume and A/V ratio give indications on the energy consumption of the buildings and therefore, were used as important variables in the cluster analyses.

Figure 7: Calculation of building volume based on 3D city models. Source: Own depiction.

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[1] http://pythonhosted.org/pyhull/

[2] https://github.com/SteuerHorst/Voluminator

Figure 8: Calculation of building surface area to volume ratio. Source: Own depiction.

4.2 Cluster analysis

Data from multiple sources

Multiple data sets were combined to analyse the building stock of the study area (Figure 9 and Table 1). The building footprints, gathered from the Open Street Map, contain 2,352 buildings. Out of them, only 1,346 buildings contained data from the market research (INFAS, 2011), 1,143 buildings contained data originating from the student survey and 861 buildings contained results of the heating energy demand performed in Chapter 5. Therefore, in order to ensure maximum number of variables to be considered in statistical data investigation, only 861 buildings were used in cluster analyses (Figure 9).

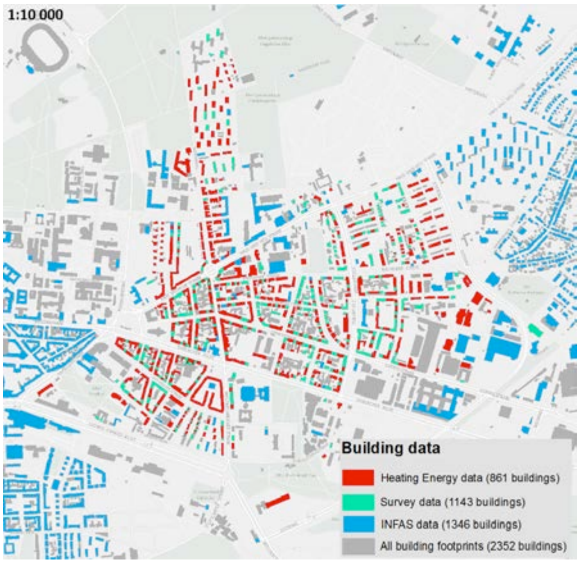

**Figure 9: Overview of the data coverage of the different data sets used in the cluster analysis.
Source: Own depiction.**

Methodology

Multiple statistical methods were applied to analyse this data set (Figure 5). In a first step, descriptive statistics and correlation analysis were used to obtain an overview of the data and to explore the relationship among the 44 variables of these data sets. Correlation analysis indicates a high positive correlation between the number of living units within a building and the volume of the building - a high cullis height or if a flat roof is present (> 0.65) and at the same time shows high negative correlations with the presence of a basement (> -0.4) or the presence of a heated attic (> -0.5). In the Oststadt, most buildings with a high number of living units built in the 1970s are tall and equipped with a flat roof while the traditional style house built in the 19th century are very common in this district and usually occupy a smaller number of housing units and are usually equipped with a pitched roof type.

Furthermore, the correlations of volumetric building variables such as building volume and roof type volume revealed high correlation values (>0.9) and buildings parameters such as building height showed high correlation values with for example building surface area (> 0.9). This indicated that there might redundant variables in the data set. In order to check for redundancy in the data set and to reduce the dimensionality of the data set, **Principle Component Analysis (PCA)** was used to only select relevant variables that will be suitable for clustering. After PCA analysis, the data set was reduced from originally 44 variables to 24 variables.

In order to analyse the data set in an unbiased manner without any presumption of possible outcomes, an unsupervised clustering approach, e.g. K-Means clustering was chosen as it delivered better clustering results than hierarchical clustering that was also tested on this data set. To avoid random cluster generation in the k-Means clustering process, multiple clustering iterations were implemented (Everitt, Landau, & Leese, 2001). In order to select an appropriate number of clusters, statistical cluster validation using the Sum-of-Squares index, the Davies-Bouldin index and the Silhouette index was implemented and 9 clusters have been identified as the optimal clustering solution (Hothorn & Everitt, 2014), (Rousseeuw, 1987), (Davies & Bouldin, 1979). PCA was then used again, not this time to reduce the dimensionality of the data set but to label the clusters by using the highest and lowest loadings of the first three principal components. Figure 10 shows the 9-cluster solutions and cluster labels identified by k-Means and PCA of the study area.

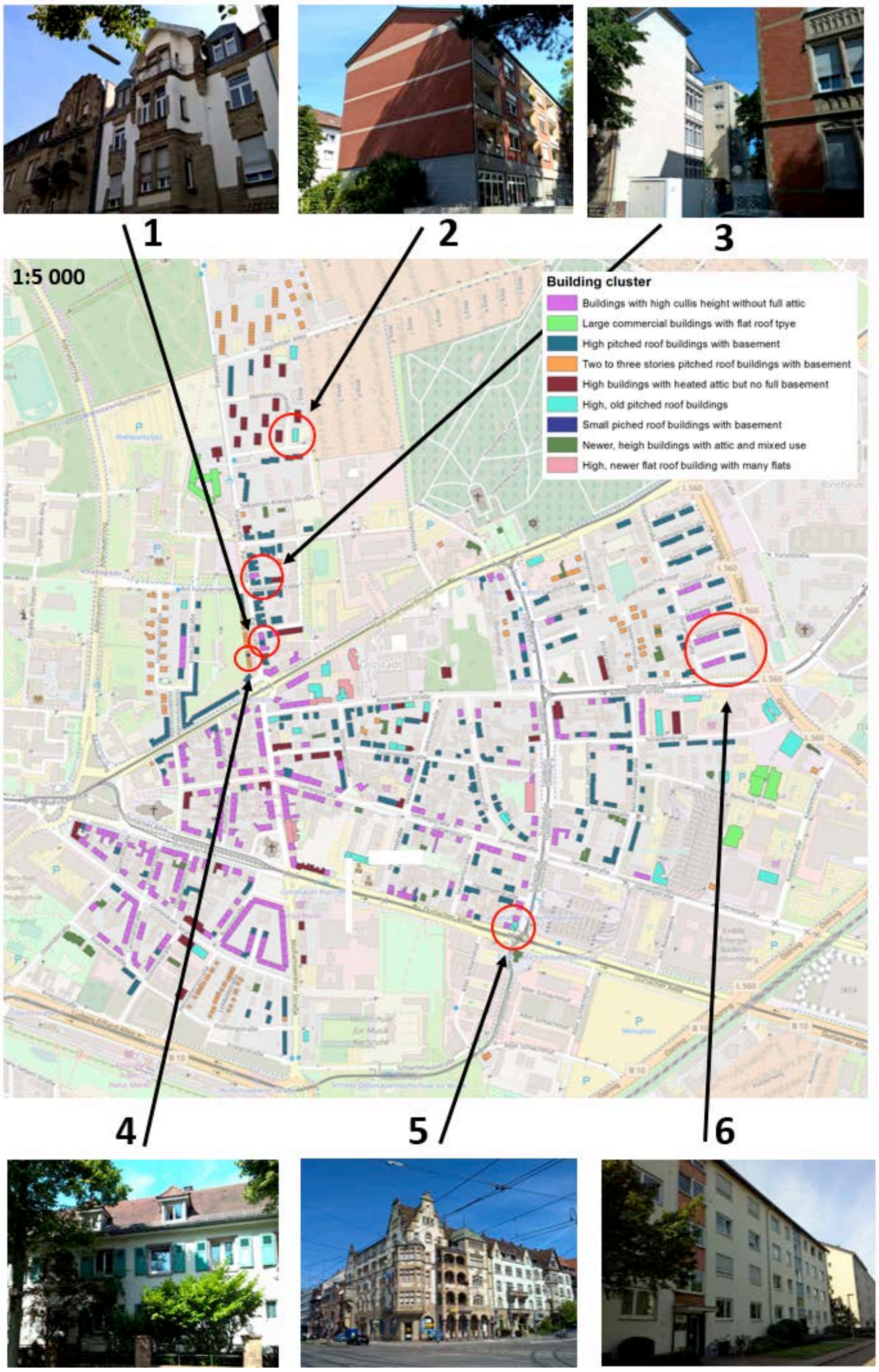

Figure 10: Clustering results of the district Oststadt and the validation of the results.
Source: Own depiction.

Discussion of results

From the Figure 10, it can be observed that the pink clusters shows the largest share that includes buildings with high cullis height without a full attic present, followed by the second largest cluster (dark blue-green) that shows buildings with a high pitched roof and a basement present. Furthermore, some outliers within the homogenous grouping of the large clusters (e.g. Figure 10, 1-6) are present. These outliers required further analysis, therefore, they were visually inspected during a field visit in the district. For example, Figure 10 (1) represents a single building with a full attic surrounded by buildings with a different roof type structure. Figure 10 (2) shows a building that has a commercial unit on the ground floor - surround by buildings with residential units. Figure 10 (3) shows an outlier building with a flat roof in a neighborhood with pitched roof buildings. Figure 10 (5) shows a building with a different and higher attic structure than the surrounding buildings, and the cluster differentiation in Figure 10 (6) is due to the different number of floors of the building. Overall, k-Mean clustering returned meaningful clusters that could be validated by visual inspection of the clusters during a field trip in the city quarter.

The cluster analyses give an indication of buildings of homogenous nature where possible energy concepts can be realized. They also provide an indication of efficiency classification for helping the policy makers for strategic orientation. Furthermore, results may be included in the representation of, e.g. heating cost mapping for the tenants (“Heizspiegel").

5. Mapping of heat energy demand

Methodology

The methodology was based on the creation of a custom tailored building typology, which was then used to calculate the daily heat demand for each building type. These heat demand profiles were then applied to each building in the district and scaled according to the size of each building. Figure 11 provides an overview of the employed methodology and data.

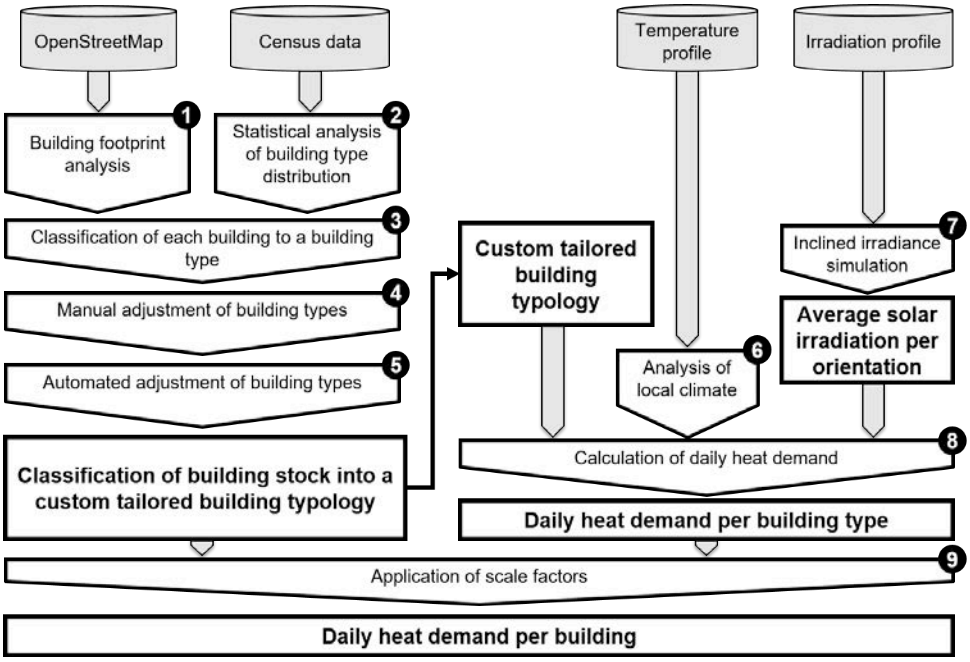

Figure 11: Flow chart of the approach for determining and mapping the heat demand for residential buildings). Source: Own depiction.

The method involves the following steps:

1. Building footprint analysis

Building footprints were obtained from the OpenStreetMap database (OpenStreetMap, 2017). For each of the 3,891 buildings in the Oststadt, the size and centre location of the footprint area was calculated.

2. Statistical analysis of building type distribution

Statistical building data from the German census survey (ZENSUS2011, 2014) was retrieved and mapped to the area of interest. This data contains information on the distribution of the 1,198 residential buildings over 10 age and 10 building size classes for each cell within a 1 km-raster in the Oststadt (Figure 12). These numbers were then combined and aggregated to correspond to the TABULA building typology classes (see 12 age and 4 building size classes in (IWU, 2015)).

Figure 12: Analysis of the Census grid data. The color of each grid cell represents the total number of residential buildings, from blue (10%-quantile) to red (90%-quantile).
Source: Own depiction with data from OpenStreetMap and the German census survey.

3. Classification of each building to a building type

Using the exact centre locations, each building was geographically mapped to one of the census data grid cells. It was then classified as belonging to one of the TABULA building types that were present in this grid cell, using for each building the type that had the closest floorplate size. This was done for all buildings that had been provided by OSM. Since the census data contains only residential buildings while the OSM data contains all building types, some buildings were left unclassified. These buildings usually had sizes that were uncommon for residential buildings (e.g. garden sheds, garages, factories, office buildings, etc.) and were subsequently classified as non-residential. As the project focuses on the residential building stock, non-residential buildings were not further analysed.

4. Manual adjustment of building types

The TABULA building types are meant to represent the national building stock. The local building stock, however, can deviate from the national one in a number of aspects. For this reason, a student seminar was conducted within this project to carry out site and building surveys in the district Oststadt. Based on the observations from the students, 86 parameters in the national building typology were adjusted in order to better reflect the local building stock. Additionally, building types that were present in the national building typology but not in the district had been removed.

5. Automated adjustment of building types

In addition to the manual adjustment of the building typology, an automated adjustment was conducted in order to correctly represent the typical building sizes in the district. Since the buildings were grouped to the building types based on their sizes in the first place, these adjustments were usually not very large. As a result of the first five steps, each building is classified into a new custom-tailored building typology that can then be used to calculate actual heat demands.

6. Analysis of local climate

Through an analysis of publicly available temperature profile data (NASA, 2016), the heating degree-days and average temperatures for each day in a year were calculated.

7. Inclined irradiance simulation

Global horizontal irradiation data (EuropeanCommission, 2016) was retrieved for the location of interest and through a calculation of the sun's position over the course of the year, the irradiation received by inclined surfaces (e.g. the window areas of the building) can be calculated, using the methods described in (Mainzer, Killinger, McKenna, & Fichtner, 2017).

8. Calculation of daily heat demand

With the customized building typology and the temperature and irradiation data, the heat demand can be calculated for each building type. This was done by applying the seasonal method according to EN ISO 13790, on the basis of a one-zone model (DIN, 2008). It considered the heat losses from transmission through the building envelope and from ventilation as well as the internal and solar heat gains. This calculation was conducted for each day in a year and can thus provided detailed results (Figure 14).

9. Application of scale factors

The heat demand per building type was then combined with the classified building stock to determine the heat demand for each single building. This was done simply by scaling the heat demand for the respective building type up/down for each building, depending on the actual building size compared to the building types' average building size.

Results and discussion

With the described method, the specific yearly heat demand for all building types from the customized typology was obtained and compared to the standard building typology. This way, the impact of the specifics of the local building stock as well as of the local climate were analysed (Figure 13). For example, it can be seen that terraced house buildings from the age class 1860-1918 in the district have a substantially lower heat demand than the national average of buildings from the same age and size class, partly due to the warmer-than-average climate and partly due to the observation that retrofit measures are quite common for this building type in the Oststadt.

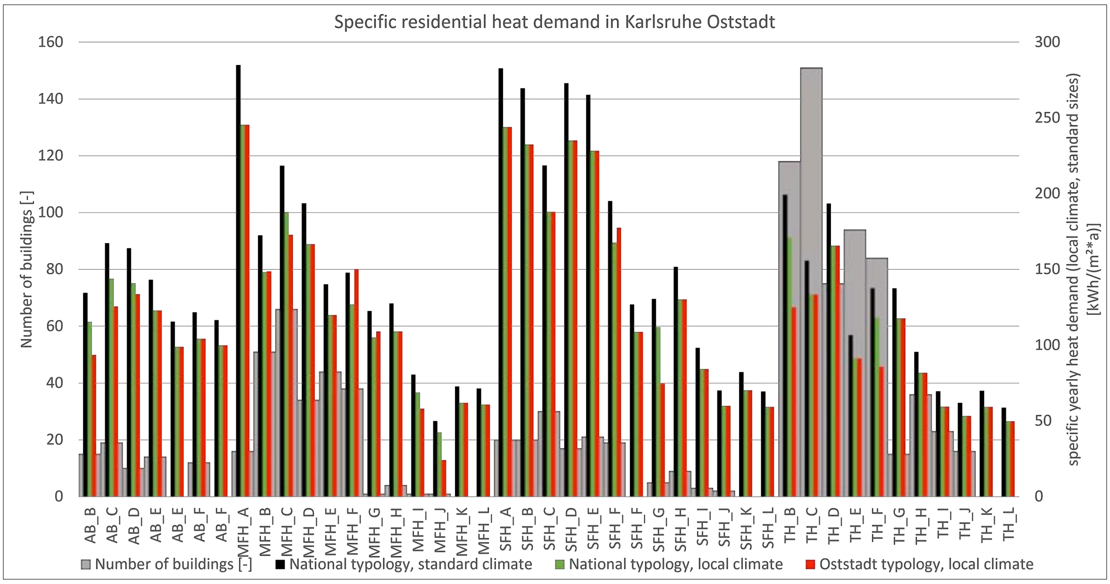

Figure 13: Results for the specific yearly heat demand of buildings from the national and customized typology. Source: Own depiction.

The heat demand profiles with a high (daily) temporal resolution was also calculated by aggregating the (scaled) heat demands for all buildings in the district for each day over the course of a year (Figure 14). These profiles allow for the identification of periods with maximum heat demand and the contribution of the different building types. This could help, e.g. with dimensioning heat networks, calculating the feasibility and profitability of seasonal storage options and other considerations. Therefore, it can help developing an optimized energy supply concept in the Oststadt.

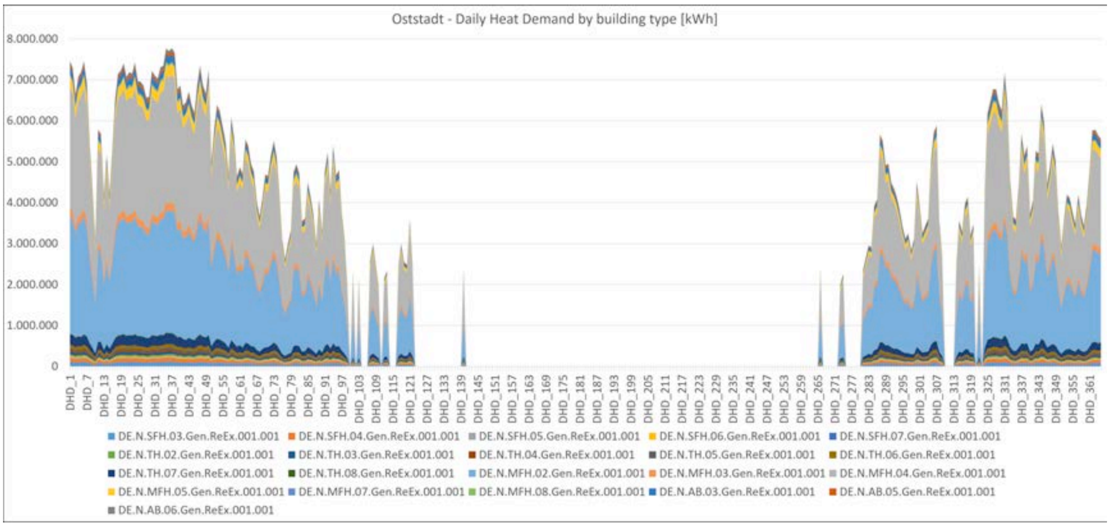

Figure 14: Residential heat demand profiles over the course of a year. Colours represent different building types. Source: Own depiction.

Additionally, the high geographical resolution of the results allowed the creation of detailed heat demand maps (Figure 15). Since each (residential) building in the district is assigned its own heat demand profile, the spatial information could be used to derive optimization potentials, e.g. through connecting areas of high energy demand with areas which could provide waste heat, e.g. from industrial processes. The results can also serve to develop efficient energy supply concept.

Figure 15: Resulting heat demand map. Each building is colored according to its calculated specific yearly heat demand, which depends on type and size. Gray buildings was classified as non-residential. Source: Own depiction with image data from Bing Maps.

6. Simulation of energy concepts

Approach

Most of the residential buildings in Oststadt are multifamily houses. Therefore, the simulation of energy concepts was performed in one of the clustered multifamily buildings (built before 1950), that was identified in 3D morphology and cluster analysis. This building consists of 15 apartments (having three apartments in each of the 5 floor) with a total living area of around 1,218 m² and window to wall ratio 20%. The simulation of energy concept was performed in TRNSYS software, considering assumptions on building insulation options (thickness), cost, and efficiency of heating systems.

For example, the U-value of the building constructions (wall, roof, floor, window) with and without adding insulation (IWU, 2015) and corresponding 16 cases were simulated to identify the optimum case (Table 2 and Table 3 in Appendix). The assumptions for calculating the energy consumption of the multifamily house used in the simulation and associated energy cost and CO_2-emissions factor for electricity and gas are shown in Table 4 and Table 5, respectively. The type of heating system affects significantly on the CO_2-emissions and the overall annual cost. Therefore, three types of heating systems (electrical resistance heater, gas boiler and air to water heat pump - having efficiency of 3, 1, and 0.9, respectively) were considered in this study.

Energy concepts

Three energy concept scenarios were investigated for the reduction of non-renewable energy consumption.

1. Optimize insulation standard: by adding insulation to the construction of the building
2. Effect of changing the heating system: by increasing the efficiency of the system with cost reduction
3. Effect of adding PV panels to the building: by increasing the share of renewable energy resources

1. Optimize insulation standard

Economic and environment effects of the building insulation with different heating systems (gas boiler, heat pump, or electrical resistance heater) were simulated and analyzed. The economic effect was calculated after (BKI, 2015). Figure 16 represents the reduction in CO_2-emissions and cost savings in a case of using gas boiler or air to water heat pump or electrical resistance heater (ERH) with different thickness of insulation. Case 11 (12 cm of insulation to the wall and roof, 8 cm to the floor and change the windows) leads to reduction of the CO_2-emissions by 30 % with a heat pump, 48 % with ERH and 34 % with a gas boiler. The cost was reduced by 13.8 % with a heat pump, 39 % with ERH and 15 % with a gas boiler compared to the reference case.

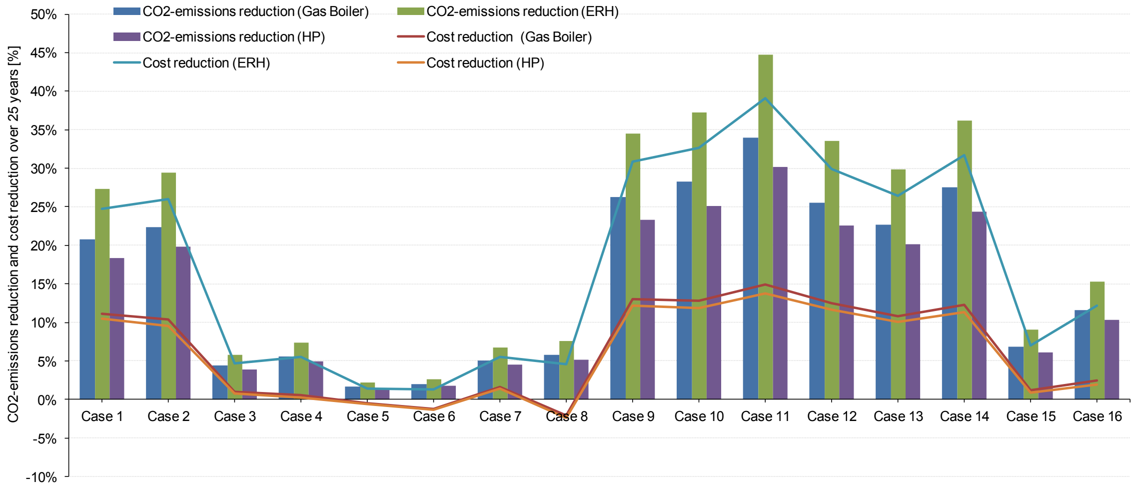

Figure 16: CO_2-emissions saving and cost saving of different cases compared to the reference case, using Gas boiler or air to water Heat pump or ERH as a main heat source. Source: Own depiction.

2. Effect of changing the heating system

It was assumed that the main heating system is ERH and that the installation cost of the ERH is zero Euro as it was an existing system. The economic and environment effects of changing heating system, e.g. using air to water heat pump or gas boiler instead of ERH were calculated. Figure 17 shows the installation and operation costs of different heating systems. The calculations were based on the annuity method in VDI 2067 and the assumptions on the economic factors, such as an inflation rate, an interest rate as well as a cost of the different components of the heating systems. The findings show that the installation cost of air to water heat pump was higher than gas boiler, and the operation cost of the gas boiler and air to water heat pump were significantly lower than electrical resistance heater. The operation cost includes the heating demand and household electrical demand.

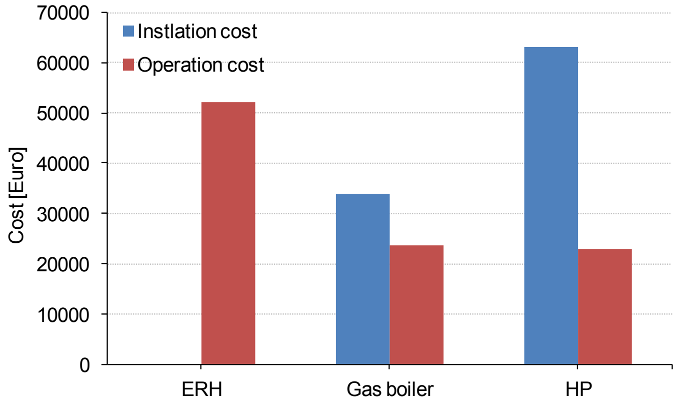

Figure 17: Installation cost and operation cost of different heating systems. Source: Own depiction.

Finally, the total annual cost over 20 years and CO_2-emissions of different heating systems was calculated (Figure 18). The economic heating system is gas boiler, which can reduce the overall cost by 54.6 % per year compared to the ERH. However, the lowest CO_2-emissions can be achieved by using the air to water heat pump, which reduces the CO_2- emissions by 51% compared to the ERH.

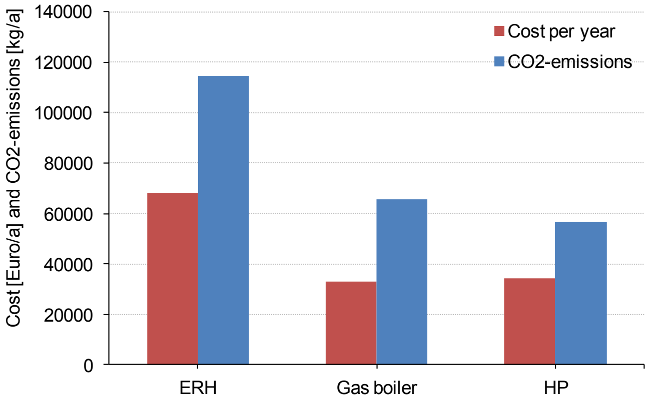

Figure 18: CO_2-emissions and overall cost per year for different heating systems. Source: Own depiction.

3. Effect of adding PV panels to the building

The PV panels can be installed on building roofs with an average area of around 148 m². It was assumed that 21 kWp PV panels, with an inclination angel 40° could generate about 20,683 kWh energy per year. Figure 19 depicts the monthly electrical energy generated by PV panels and household electricity demand for 15 apartments. This electrical energy from photovoltaic could cover 46% of the household electrical assuming 45,000 kWh with an average annual consumption of 3,000 kWh per apartment. In this case, there is no energy surplus from the PV system, even in summer. The share of the electrical energy from PV would increase to 69% of the annual electricity demand per household, assuming an annual electricity demand of 2,000 kWh per apartment.

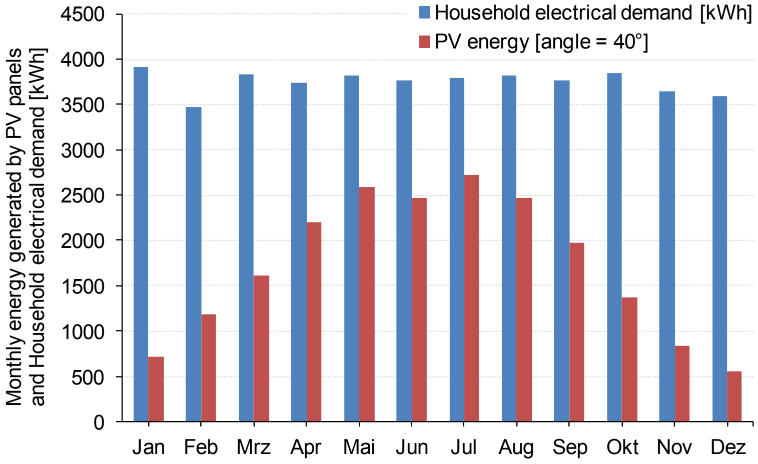

Figure 19: Monthly energy generated by PV panels and household electricity demand.
Source: Own depiction.

The cost calculation shows that PV panels (with a life time of 20 years) may reduce the annual cost to 5,750 € for a building, which represent 19% of the reduction compared to the same building without PV panels (in case of using air to water heat pump as a main heat source). The annual CO_2-emission reduction amounts to 12,761 kg which represents 22.5 % of the reduction compared to the same building without PV panels in case of using air to water heat pump as a main heat source. Figure 20 illustrates the cost and CO_2-emissions in case of the building insulation (see case 11 in Table 3) and 21 kWp of PV modules.

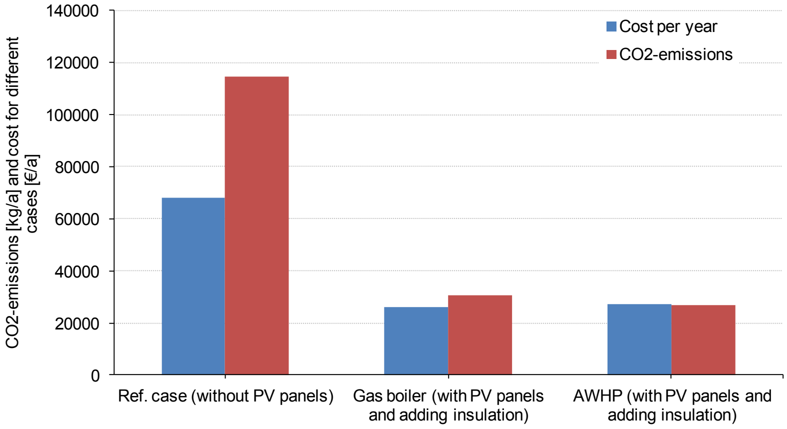

Figure 20: Cost per year and CO_2-emissions for different cases compared to the Ref. case (using ERH without adding insulation and PV panels). Source: Own depiction.

Due to the reduction of the heating demand by using building insulation, and reducing the electrical energy needs, CO_2-emissions and annual cost might be reduced by 77 % and 60 %, respectively, compared to the reference case (electrical resistance heater without building insulation and PV panels).

7. Citizens' participation

One of the objectives of the R131 was to increase the engagement of citizens and other relevant actors in the projects. Several participatory approaches, depending on the objective and overall scope, were tested in the different sub-projects of the R131 (Meyer-Soylu, Parodi, Trenks, & Seebacher, 2016). The citizens and local stakeholders in Oststadt had the opportunity to participate in the above described energy concept study. In this regard, a formal workshop was organized.

During the workshop, several posters depicting the main methods and results concerning the 3D morphology and cluster analyses, mapping of heat energy demand and the scenarios for energy concept were presented. Generally, the citizens were interested in the results as they could identify the overall potential of implementation of an energy concept in their buildings. However, they were more enthusiastic in concrete implication of energy concepts.

Several issues were revealed during the workshop:

- Multi-family houses often contain multiple owners who need more support regarding decisions on energy topics. The property owners and tenants need to be brought together to agree on how the cost regarding renovation, changing

heating systems, etc. be shared. The question of **financing energy concept** to the individual group interested in renovation seemed most important.
- More investigation on **economic feasibility of the energy concept** need to be studied by the experts and scientists. The ideas can then be shared with the citizens concerned.
- In preparing energy concept, the **local authorities**[3] who give advice on energy issues, (e.g., electricity check, heating check) need to be consulted.
- There is an inherent need of improvement of **institutional support**. In this regard, stronger regulatory measures might help in implementing the concepts.
- **Education and awareness development** on energy saving potentials early in the childhood (kindergarten) need to be introduced.
- Some of the residential buildings in the district also contain **old shops** (with single glazing), which need to be integrated into the concept.

8. Conclusion

This research focuses on a holistic approach for studying the energy performance of the buildings by exploratory data analyses and thermal simulations. The cluster analyses, mapping of spatial and temporal patterns of energy demand as well as simulation of different energy scenarios may help the citizens and local policy makers to identify different options for reducing non-renewable energy consumption. Such findings may also contribute to the sustainable energy policy agenda in the short and long term, in other districts, cities and regions.

Due to lack of complete sets of variables in the spatial and non-spatial data, many residential and commercial buildings could not be considered in the cluster analysis. Future research should focus on the collection of a complete set of variables of all the buildings. The cluster analysis algorithm should be further improved to optimize the clusters, e.g. by classifying the outliers exist in some clusters.

The proposed method for energy demand calculation employs building typologies, so that a small number of building types can be modelled explicitly, each representing a larger number of buildings in the district. A potential drawback of using building typologies is that the real buildings might actually differ in some aspects from the standardized and nationally invariant building types. In this study, this is (at least partially) mitigated by adjusting the employed typologies through the application of observations from the local building stock. In future research, the calculation of electricity and cooling demand could be performed in order to incorporate them into the energy concept scenarios.

This study considered three energy concepts. Future research could focus on the investigation of other energy supply concepts, e.g. use of industrial waste heat or geothermal energy, planning of district heating network, possibility of achieving zero energy non-residential buildings (e.g. education buildings), reduce energy demand in the factories, etc. Moreover, the techno-economic assumptions related to the concepts can be improved. Such energy concepts can also be simulated in some other potential clusters.

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[3] E.g. Karlsruhe Energie- und Klimaschutzagentur gGmbH (KEK).

This research included a number of proven technologies that can reduce the use of non-renewable energy and thus greenhouse gas emissions for heating purposes. The exchange with citizens pointed towards issues of financing mechanisms and communication strategies. This leads to conclude that available technologies and applied solutions still are not put into practice to the full extent. Since the project does not include a structured analysis of these aspects, the organizational framework of energy concepts or efficiency measures is clearly identified as an important field for future research.

Acknowledgement

We are grateful to the Ministry of Science, Research and the Arts of Baden-Württemberg (MWK) for funding the “Reallabor R131: KIT findet Stadt” project and ITAS for coordinating the project and supporting us in the organisation of project meetings and workshops. We are grateful to the local citizens who participated in the workshop. We express our gratitude to the city of Karlsruhe for providing the 3D city models and to the data collection group of this project for sharing the building survey data.

References

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A. (2015). Applications of 3D city models: State of the art review. *ISPRS International Journal of Geo-Information, 4*(4), 2842-2889.

BKI. (2015). *BKI Baukosten*. Retrieved from Baukosteninformationszentrum Deutscher Architektenkammern GmbH, Stuttgart:

Davies, D., & Bouldin, D. (1979). A cluster separation measure. *IEEE transactions on patter analysis and machine intelligence, 2*, 224-227.

DIN-Energieeffizienz von Gebäuden – Berechnung des Energiebedarfs für Heizung und Kühlung, ICS 91.140.10(13790) C.F.R. (2008).

EuropeanCommission. (2016). Copernicus Atmosphere Monitoring Service (CAMS) radiation service; Available from: http://www.soda-pro.com/web-services/radiation/cams-radiation-service.

Everitt, B. S., Landau, S., & Leese, M. (2001). Clustering analysis. *Arnold, London*.

Hothorn, T., & Everitt, B. S. (2014). *A handbook of statistical analyses using R*: CRC press.

INFAS. (2011). Soziologische Daten. Marktforschung und Sozialforschung. http://www.infas-geodaten.de.

ITAS. (2015). Reallabor 131 - KIT findet Stadt: Struktur des Reallabors Retrieved from https://www.itas.kit.edu/projekte_paro15_qzrealab.php

IWU. (2015). *Deutsche Wohngebäudetypologie Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden - zweite erweiterte Auflage* (978-3-941140-47-9). Retrieved from Darmstadt: http://www.building-typology.eu/downloads/public/docs/brochure/DE_TABULA_TypologyBrochure_IWU.pdf

Mainzer, K., Killinger, S., McKenna, R., & Fichtner, W. (2017). Assessment of rooftop photovoltaic potentials at the urban level using publicly available geodata and image recognition techniques. *Solar Energy*, 155: 561–573.

Meyer-Soylu, S., Parodi, O., Trenks, H., & Seebacher, A. (2016). Das Reallabor als Partizipationskontinuum. Erfahrungen aus dem Quartier Zukunft und Reallabor 131 in Karlsruhe. *Technikfolgenabschätzung, Theorie und Praxis, 25*(3), 31-40.

Murshed, S. M., Picard, S., & Koch, A. (2017). CITYBEM: An Open Source Implementation and Validation of Monthly heating and cooling energy needs for 3D Buildings in Cities. *The ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Annals), Accepted*(In press), 10.

NASA. (2016). Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2); Available from: https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/.

OGC. (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*. Retrieved from Open Geospatial Consortium:

OpenStreetMap. (2017). OpenStreetMap-Contributors, June 01, 2017. Retrieved from http://www.openstreetmap.org/.

Parodi, O., Albiez, M., Beecroft, R., Meyer-Soylu, S., Quint, A., Seebacher, A., . . . Waitz, C. (2016). Das Konzept „Reallabor" schärfen: Ein Zwischenruf des Reallabor 131: KIT findet Stadt. *GAIA - Ecological Perspectives for Science and Society, 25*(4), 284-285.

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics, 20*, 53-65.

StadtKarlsruhe. (2017a). Das 3D-Stadtmodell Karlsruhe. Retrieved from https://www.karlsruhe.de/b3/bauen/geodaten/3dgis.de

StadtKarlsruhe. (2017b). Die Oststadt. Retrieved from https://www.karlsruhe.de/b4/stadtteile/osten/oststadt.de

StatistischesBundesamt. (2016). *Alle politisch selbständigen Gemeinden in Deutschland*. Retrieved from https://www.destatis.de/DE/ZahlenFakten/LaenderRegionen/Regionales/Gemeindeverzeichnis/Administrativ/Archiv/GVAuszugQ/AuszugGV4QAktuell.html

ZENSUS2011. (2014). Zensusdatenbank 2011, Statistische Ämter des Bundes und der Länder.

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Appendix

Table 2: U-value of the building constructions with and without adding insulation (IWU, 2015).

Construction of the building	U-value W/(m^{2}K)
Wall	
Before 1950	1.7
Add 12 cm of insulation	0.25
Add 24 cm of insulation	0.13
Roof	
Before 1950	1.4
Add 12 cm of insulation	0.41
Add 30 cm of insulation	0.14
Floor	
Before 1950	0.77
Add 8 cm of insulation	0.28
Add 12 cm of insulation	0.21
Window	
Before 1950	2.8
Windows with double glazing	1.3
Windows with triple glazing	0.8

Table 3: Simulated cases (U-value of the constructions after adding insulation).

Case study	U-value of Wall [W/(m²K]	U-value of Roof [W/(m²K]	U-value of Floor [W/(m²K]	U-value of Window [W/(m²K]	Heating demand [kWh/m²]
Ref. case	1.7	1.4	0.77	2.8	85
Case 1	0.25	1.4	0.77	2.8	43
Case 2	0.13	1.4	0.77	2.8	40
Case 3	1.7	0.41	0.77	2.8	76
Case 4	1.7	0.14	0.77	2.8	74
Case 5	1.7	1.4	0.28	2.8	81.5
Case 6	1.7	1.4	0.21	2.8	80.9
Case 7	1.7	1.4	0.77	1.3	74.6
Case 8	1.7	1.4	0.77	0.8	73.2
Case 9	0.25	0.41	0.77	2.8	32.1
Case 10	0.25	0.41	0.28	2.8	28
Case 11	0.25	0.41	0.28	1.3	16.5
Case 12	0.25	1.4	0.77	1.3	33.6
Case 13	0.25	1.4	0.28	2.8	39.3
Case 14	0.25	1.4	0.28	1.3	29.5
Case 15	1.7	1.4	0.28	1.3	71.1
Case 16	1.7	0.41	0.28	1.3	61.5

Table 4: the main assumptions for calculating the energy demand of multifamily house.

Household electrical demand [kWh/a per apartment]	3000
DHW demand [kWh/a per apartment]	2500
Heat Gain [W/m²]	3
Ventilation [1/h]	0.5
The building has only three external wall	N,S and E
Infiltration [1/h]	
Before 1950	0.3
Add insulation to (wall or roof or floor) or change the window	0.2
Add insulation to (wall, roof, floor and change the window	0.1

Table 5 Energy cost and CO_2-emissions factor.

Energy cost	Value [€]
Electricity	0.22[4], 0.28
Gas	0.07
CO_2-emissions Factor	
Electricity [kg/kWh]	0.617
Gas [kg/kWh]	0.241

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[4] Special tariff for heat pump.