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Net Zero Energy Strategies and Planning Support Tools for Campuses and ResidentialNeighborhoods in Germany

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ABSTRACT

Reducing CO_2 emissions by improving energy efficiency and integrating renewables while offering a high quality of living and working in neighborhoods and campuses, is the declared aim of the three German case studies described in this paper. The focus is to assess and analyze the different phases of an energetic retrofitting: planning, construction and operation. Planning tools using 3D geometry of buildings are applied to model efficiency scenarios and the potential contribution of local renewable generation. By means of a holistic approach including all relevant stakeholders, this paper describes the current experiences on very low carbon neighborhoods in Germany.

INTRODUCTION

The need for reduction of energy consumption is undisputed when it comes to protecting the environment and the climate. Cities play a key role in energy efficiency implementation to reach the Paris Agreement climatic goals as nearly 50% of the global population lives in cities. This figure will rise to more than 62% by 2020. Cities claim 2% of land-use but they are responsible for more than 70% of the global CO_2 emissions and consume more than two-thirds of the global energy.

Cities and counties have a tool set in their hands to lay down important framework conditions for the implementation of energy supply and efficiency measures. Framing instruments are land-use plans, environmental and climate protection plans, energy master planning which may lead to operational decision-making processes such as the specification of energy supply structures and specific energy efficiency standards beyond the national minimum requirements. To be successful, energy planning and urban planning must go hand in hand. In addition, cities often have shareholdings in municipal and regional companies such as utilities and housing associations which can be instrumented to contribute actively into the energy master plan and its implementation. for example, the expansion of district heating or the use of renewable energy sources. And cities can act, of course, as role models and imitable examples when the construction or refurbishment of own buildings is based on the strategic energy master plan.

The goal of Germany's building stock is to be nearly climate-neutral by 2050. The rate of refurbishment is currently still under one per cent. In order to reach the 2050 goal, a tremendous effort is needed to come to the necessary refurbishment rate of 3 % per year. Thus, the German government has been funding research on technologies and innovation for years. Since the implementation of the 6th National Energy Research Program several years ago, a specific focus is put on neighborhoods, districts and campuses in order to come to a broader view and more possibilities of change in comparison to single buildings. One focus of the research program is the development of innovative planning and implementation tools for the energy master planning of urban districts. In this context the German research program NEQMODPLUS (Near Zero Energy Quartier Modeling) with the international collaboration project IEA EBC Annex 73 "Towards Near Zero Energy Resilient Neighborhoods" among eight partner countries have been initiated in late 2018. One of the focuses of this project is to research concept tools and modeling tools which allow to evaluate and configurate complex combinations and bundles of energy efficiency and energy supply technologies in the energy master planning of existing and newly built communities. In addition, existing best practice will be

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analyzed regarding performance indicators and success factors.

The societal framework gains more and more importance in the energy master planning process. Exact knowledge of the different stakeholders and actors in a refurbishment or construction process is of high relevance – starting from the municipality defining compelling conditions and ambitious goals, passing on to the investors and finally including the buildings' users. The holistic consideration of urban settlement areas is mandatory for best practice cases, comprising the building stock, legislative aspects, financial resources, planning and implementing staff, technologies, innovation, funding, the people living in the buildings as well as building operators.

Comprehensive flagship projects are funded by the German Ministry for Economics and Energy at the district level in the program "Energy-Efficient City" (EnEff-Stadt). The focus here is on communities as the smallest scale increment and on taking a systemic approach, considering technological, socio-spatial and economic processes as well as energy and material flows. The goal is to realize energy-optimized, sustainable districts that combine energy efficiency with the use of renewable energies through innovative ideas. This is not solely concerned with technical challenges but also with achieving suitable legal framework conditions and economic concepts, as well as the effective networking of all actors. This paper summarizes results of the evaluation of three German best practice cases analyzed against the background of the program "Energy-Efficient City" (EnEff-Stadt) to show the range of possible action: A residential community in Karlsruhe, a school campus in Detmold and a university campus in Stuttgart.

Case 1: Project "Future Proof Neighborhood Development" in Karlsruhe-Rintheim

The project "Future proof neighborhood development" was carried out in Karlsruhe-Rintheim from 2008 to 2013 by the social housing company Volkswohnung GmbH. Rintheim is a district of Karlsruhe, where the Volkswohnung GmbH owns some 30 multi-family houses. The residential buildings date from the years 1954 to 1970.

As the third largest municipal real estate company in Baden-Württemberg, the Volkswohnung GmbH has been offering affordable and high-quality living space to the citizens of Karlsruhe for nearly 100 years now. It owns and manages over 13,200 rental apartments for young, old and/or disabled people, singles, couples and families. The company is committed to energy efficiency. Therefore, new construction activities and modernization measures are closely linked with energy efficiency and energy-saving potential – as shown in the present research project. After completion of an energetic renovation, the existing properties exceeded the building standard for newly built houses according to the Energy Saving Ordinance by 25% to 30% in some cases. Extensive modernization and new energy concepts have also halved the

Figure 1 *Exemplary refurbished multi-family block of flats from three analyzed buildings in Karlsruhe-Rintheim (Source: VOLKSWOHNUNG GmbH).*

primary energy requirement in the properties. Thus, the Volkswohnung GmbH meets a large part of the CO_2 reduction targets of the agenda of the City of Karlsruhe.

In the project presented here, the Volkswohnung GmbH retrofitted 14 buildings within a neighborhood in Karlsruhe-Rintheim at a cost of approximately 70 million euros. At the same time, the neighborhood area was connected to the local district heating system which is powered by low temperature waste heat from the local refinery. A residential environment improvement concept was drawn up and implemented by actively involving the tenants.

For research purposes, different heating systems and different insulation levels have been implemented in three building blocks with 30 flats each. The energetic levels were fixed to a standard retrofitting of the Volkswohnung GmbH (building 1), a three-liter-house level (building 2) and a passive-house standard (building 3). The different thermal insulation variants were combined with the different system variants in such a way that ultimately seven different variants were created.

The results show a decrease in primary energy demand from 174 kWhPE/m^2 (55 MBTU/ft^2) to 28 kWhPE/m^2 (8,9 MBTU/ft^2) (Figure 2). This analysis of the Rintheim neighborhood project shows that a combination of building measures and a (new or existing) highly efficient local energy system is the most cost-effective way to achieve energy and CO_2 targets. With an integrated overall concept for the neighborhood, it is possible to combine an energy-efficient energy system with cost-efficient measures on the building side to achieve even demanding energy targets at reasonable costs. This requires optimal planning, implementation and optimized operation.

However, some buildings showed a higher consumption as before. The energy demand values calculated in advance deviate significantly from the measured energy consumption. This phenomenon is described in the literature as energy

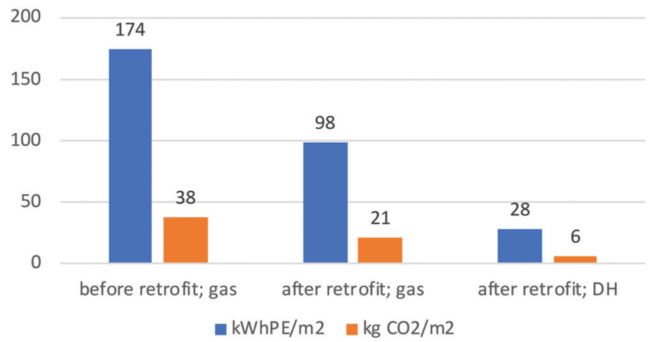

Figure 2 *Specific primary energy consumption and CO_2-emissions of 3 analyzed buildings in Karlsruhe-Rintheim.*

performance gap. The influence of the occupants in buildings with complex, sophisticated system technology often leads to increased energy consumption. Thus, another project has been funded (2012 to 2015) called "The impact of the rebound effect on the refurbishment of the existing building stock". An intensive monitoring has been installed in the three above mentioned buildings with different variants.

In this case, measured data with respect to temperature and humidity are shown for building 3 with three entrances and the different flats (Figure 3). The data stem from one winter month (February 2013). The average temperature (Celsius) of the flat is shown top left, average humidity is shown top right. The values down left show the percentage of the duration of an open window (based on the total hours of the month) and the values down right show the CO_2 concentration as criteria of air quality. The value in the middle of the cells show heating energy consumption in kWh/m^2. Orange tones stand for a high and blue tones for a low consumption.

There are some explanations for the results in building R3, for example the location of a flat (inside or outside oriented) or the orientation towards north and south. Not least the behavior of the tenants, their acceptance or handling of newly implemented technologies (e.g. air heating) make a difference. Further analyses suggest that the user-specific heating behavior of neighboring housing units and the associated heat displacement within a building can have a large influence on the heating energy consumption of a single flat. Thus, the project team intervened with some measures: interviews with tenants, information events at the beginning of the heating period and accompanying surveys. In the course of these measures, the tenants were taught the correct use of the heating and ventilation system as well as the basic principles of an appropriate ventilation behavior.

Case 2: School Campus—Detmold

The school campus in Detmold consists of three buildings from the late 1950s, retrofitted between 2010 and 2015 accommodating around 3,600 students. The buildings of the

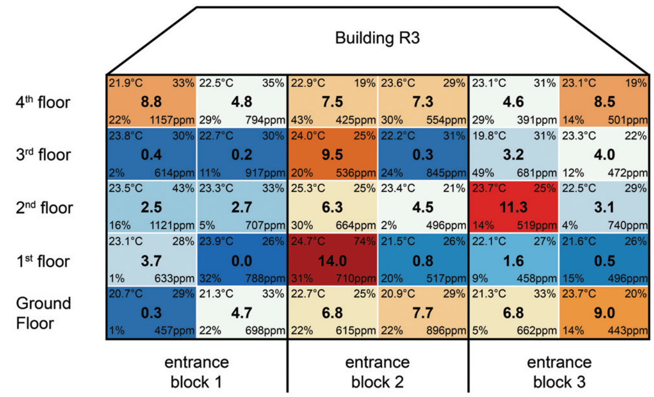

Figure 3 *Chromatic representation of 30 flats in building R3: the colored boxes represent one flat each with their monthly averages measured in February 2013; orange tones stand for a high and blue tones for a low specific heating energy consumption (Source: illustration based on Calì et al., 2016, p.81)*

two vocational colleges (Berufskolleg), the "Felix-Fechenbach-Berufskolleg" with two buildings and the "Dietrich-Bonhoeffer-Berufskolleg" with one building were thoroughly renovated. The aim was to achieve a significant improvement in energy efficiency and to improve the quality of the school stay in terms of high comfort for students and teachers. With an energy related surface of 9,373 m^2 (104,730 ft^2) and a high energy demand of 272.3 kWh/m^2 (86 MBTU/ft^2) per year, the goal of a plus energy campus was challenging. However, the measured consumption after retrofit was 42.2 kWh/m^2 (13 MBTU/ft^2) in 2016, reaching even a lower value than calculated. An intensive monitoring of energy consumption, indoor environmental quality (IEQ) and user satisfaction is still ongoing.

The heating energy consumption of 42.2 kWh/m^{2}a (13 MBTU/ft^2) of the Felix-Fechenbach college and the Dietrich-Bonhoeffer college in Detmold, which is supplied by district heating, fits very well to the numbers calculated in advance (Figure 5). Domestic hot water consumption however is clearly above the calculated value at 23.5 kWh/m^{2}a (6.3 MBTU/ft^2). The upgrading of the previously uninsulated domestic hot water network and the shutdown of irrelevant areas are still being implemented. The high consumption is due to the fact that two oversized circulation pumps have to send the domestic hot water through old pipes over almost the entire campus. Therefore, they need high flow rates due to the large thermal losses in order to minimize the drop in temperature of the domestic hot water in order to ensure the necessary hygiene. For lighting and ventilation, no separate measurements are available.

The original energy target of the Felix-Fechenbach- und Dietrich-Bonhoeffer-Berufskolleg in Detmold was a plus energy standard considering the primary energy demand for

Figure 4 *View on the School Campus Detmold (Source: pape oder semke ARCHITEKTURBÜRO).*

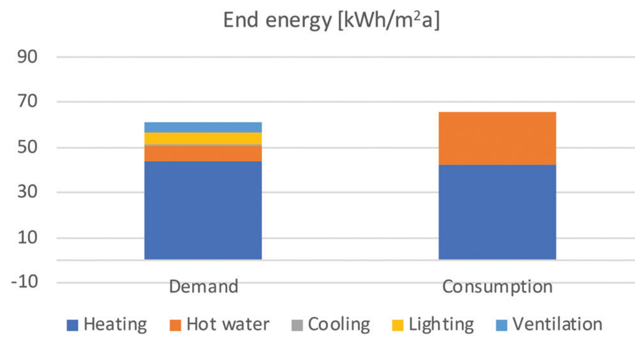

Figure 5 *Comparison of the final energy demand (calculated) and final energy consumption (measured) of the two school buildings of the campus (Source: Reiß et al., 2017, p. 79).*

heating, domestic hot water, lighting and ventilation. Due to the very favorable primary energy factor of the adjacent district heating network of 0.0 and the large PV system on the buildings, the plus energy standard can even be met for the total energy consumption of the buildings (including user electricity).

Pre-post-surveys, interviews and group discussions were conducted in order to gather feedback from the occupants regarding indoor environmental quality (IEQ), overall well-being (Figure 6) as well as their acceptance of new technologies that support energy efficiency. The analyses show that comfort and several environmental conditions in the retrofitted buildings could be improved. However, the experienced comfort varied in detail, e.g. temperatures or indoor air quality were rated poorer than expected, partially due to an uncomfortable usability of control options. Due to these results, readjustments are still in progress.

From an energetic perspective, the project in Detmold can already be considered as successful when looking at the first year of monitoring. The plus energy target could be achieved. Problems only arose with the control of the existing radiators, which led to a significant overheating of the rooms in summer and in the transition period (see occupants ratings shown in figure 6). A further problem is the extremely high energy consumption for domestic hot water preparation. Both problems are still being addressed by a monitoring team from the university accompanying the project (University of Applied Sciences Ostwestfalen-Lippe). Thus, better results can be expected in the second year of measurement.

Case 3: University Campus—Stuttgart

The HFT Stuttgart, University of Applied Sciences, which was established in 1832 is the focus of this case study. Currently approx. 4,000 students are taught by 130 professors focusing especially on areas concerning building physics, civil engineering, architecture and design as well as computer sciences, mathematics, geoinformatics and business management.

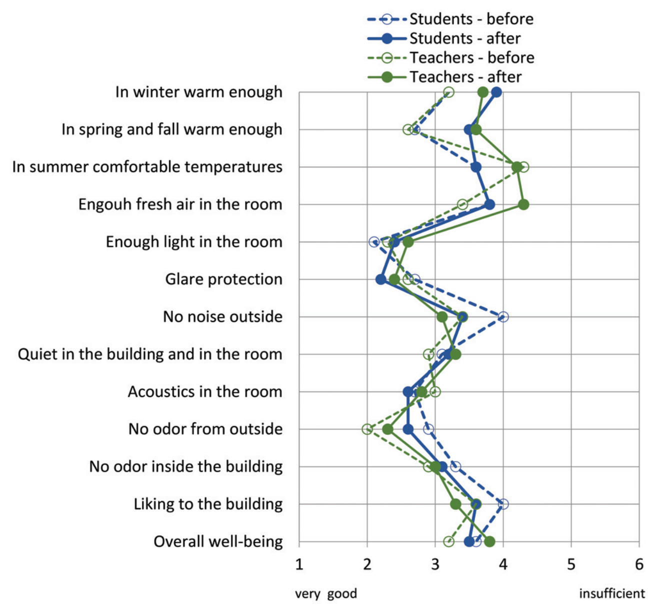

Figure 6 *Evaluation of different parameters by students and teachers before and after the refurbishment (from 1 = very good to 6 = insufficient).*

The university campus, located in downtown Stuttgart, mainly consists of four old buildings (built between the years 1870-1905, some changes and additions over the years but only minor energetic improvements), with a total heated area of 28,850 m^2 or 310,538 ft^2 (Figure 7).

The federal state of Baden-Württemberg is owner and operator of the HFT Campus. Therefore, no direct incentives have been implemented to encourage users to save energy. The overall heating consumption in 2016 was 3,500 MWh/a (11,942 MBTU/a) and the electric consumption 1,900 MWh/a (6,483 MBTU/a). The overall costs for energy for the year

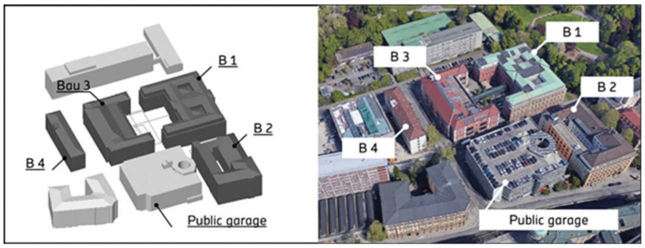

Figure 7 *University of Applied Sciences Campus Stuttgart.*

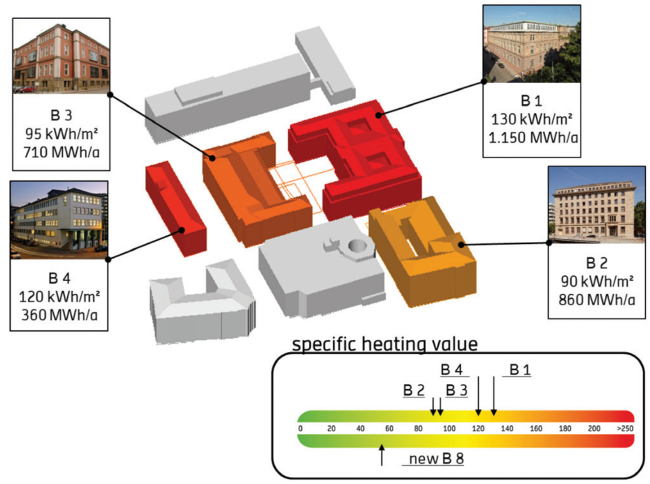

Figure 8 *Status quo heating demand of campus buildings.*

2016 are 646,000€. As can be seen in Figure 8, the specific heating demand is very high especially for B1 and B4.

This shows the need for refurbishment. Therefore, different insulation measures for each building and each of their building parts (walls, windows, roofs, ground floor) are investigated. In this assessment, different insulation materials and methods (e.g. partly insulation, inside versus outside insulation, etc.) are compared. Since all buildings are historically protected to different degrees, there is a particular focus on a refurbishment that conserves the special façades and other building features.

To assess the impact of the different measures on the resulting heating demand, simulations have to be carried out. The simulation platform SimStadt, developed at the University of Applied Sciences Stuttgart, calculates the monthly heating demand according to the German standard DIN 18599 (see (Eicker, Nouvel, Schulte, Schumacher, & Coors, 2012) and (Nouvel, Zirak, Coors, & Eicker, 2017)). SimStadt uses 3D CityGML models to account for the actual geometry of each building. Additionally, building properties, such as U-values of different building components as well as user-specific information such as heating set points, internal loads or occupancy schedules are included. For this case study, the specific material properties for each building of the campus are taken into account.

Simulations with the actual weather data for different years of a station in the Stuttgart city center results in low differences of -3% to 12% heating energy demand for each building from the measured consumption. These remaining differences can be attributed to user behavior.

From all of the above-mentioned different measures, two refurbishment variants have been selected for all buildings, a standard refurbishment (only insulation of roofs and ground floor) and a pilot refurbishment (insulation of walls, roofs, ground floors and replacement of windows). Comparing the two scenarios, the standard variant is financially superior over the pilot variant (9).

Local and renewable electricity generation can be done with photovoltaic systems of the roofs of the campus buildings. Additionally, the neighboring public garage can be used to increase the available PV area. Different PV systems (integration of PV modules in the roof, placement of the modules on the roofs as well as solar tiles. Moreover, integration of PV in the building façades is investigated.

Based on the exact roof areas, PV yield simulations are conducted using INSEL 8.2. Weather data from the local weather station on campus were used for the 15-minute calculation. With the installation of the maximum PV on roofs (using all roofs on campus and the garage, plus façades, except north/east oriented façades), more than 25% of the total electricity demand of the campus can be supplied directly. Almost 100% of the PV produced electricity is consumed on campus (see Figure 10). Since the demand is usually higher than what the PV produces, almost all of the PV can be consumed directly, and no battery storage is needed. Excess electricity from the PV can be fed to the grid. This results in an amortization time of below 15 years.

In order to contribute to the reduction of the primary energy demand and achieve the goal of becoming climate neutral, there needs to be an alternative to the current heating source, which is district heating powered by a gas power plant and waste incineration. Therefore, local heat generation is investigated in form of heat pumps, cogeneration units, solar thermal and PVT modules, the use of waste heat from neighboring buildings or waste water. Different system combinations were tested and analyzed for their potential to supply the demand of the campus. From this, two system combinations were chosen and assessed in more detail (Figure 11).

In both scenarios, electricity produced by the PV on the roofs of the campus buildings and car park is used. In case of the monovalent heat pump with PV, the heating load can be completely covered by the heat pump (Figure 11, top left). The power load that needs to be satisfied by grid electricity (bold line) can be reduced through the PV production (dotted line). The electricity demand of the heat pump needs to be added to that and results in an electricity demand from the grid which is only slightly higher than before. There is even some excess PV electricity that is fed to the grid. In the second case

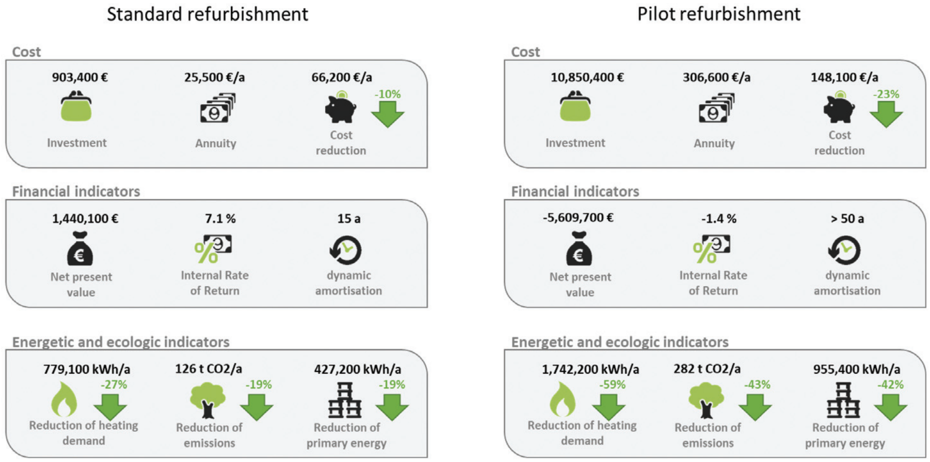

Figure 9 *Standard and pilot refurbishment of campus buildings.*

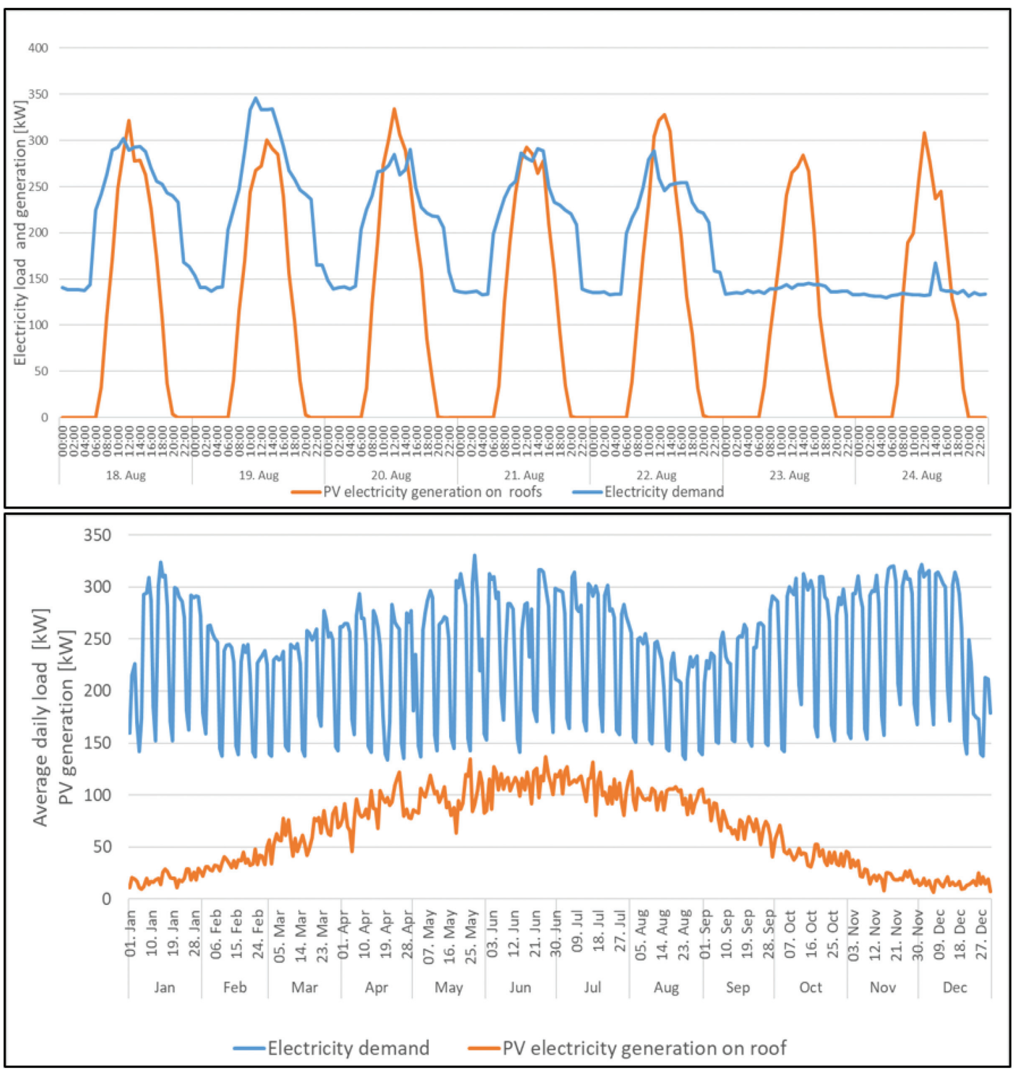

Figure 10 *Daily electricity consumption (measured, blue) and PV electricity production (simulated, orange) on campus for the whole year (above) and one week (below).*

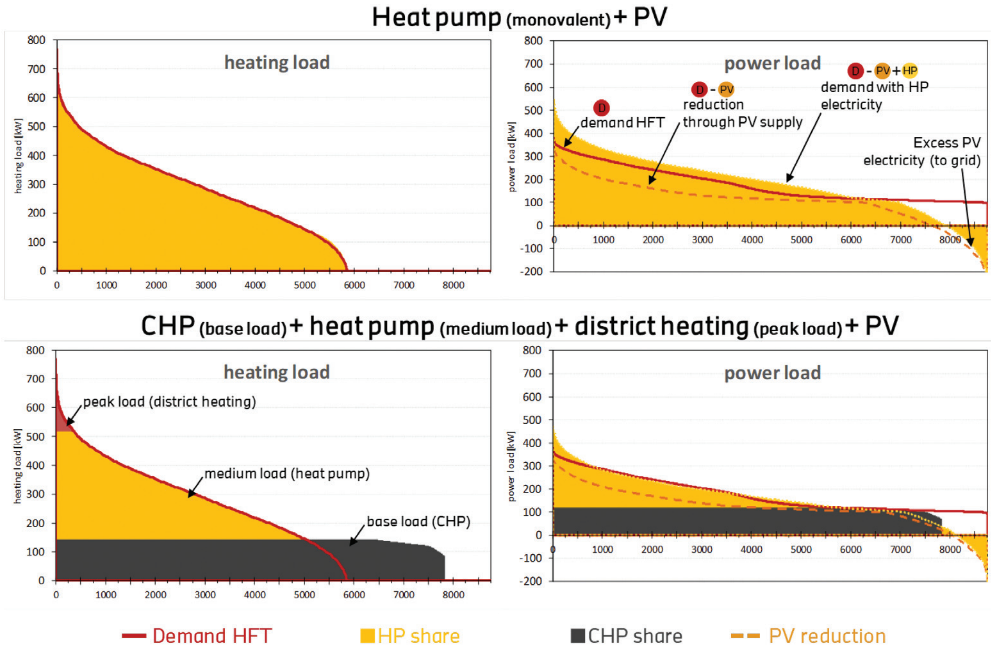

Figure 11 *System combination for heat supply at the campus.*

(Figure 11). The heating load is satisfied by a CHP, which covers the base load and feeds a local heating network, a heat pump for the medium load and the peak load can be provided by the district heating network, to which the system is still connected for resiliency. The power load is covered by the CHP and PV. Here, a very good fit of demand and production can be achieved. Even though the second variant (CHP + HP) has slightly higher investment costs, the reduction of CO_2 emissions and primary energy demand is higher than with just the HP system. Amortization times and internal rates of return are similar (8 years and 12% for the first variant, 9 years and 10.5% for the second variant).

Additionally, minimal-invasive measures concerning lighting, heating thermostats and heating pumps were included in the assessment. Especially the switch from inefficient fluorescent tubes to LED tubes has a large energy and CO_2reduction potential with low investment costs at the same time. If all tubes were changed, 20% electricity could be saved. The investment can be amortized in less than 3 years.

CONCLUSION

The three projects from the program "Energy-Efficient City" point out that a good energy performance is a combination of building refurbishment, different energy generation technologies integrating more and more renewable energies and using control systems. Thus, ambitious standards can be reached going above the current regulation of the German and European legislation.

For the residential buildings in Karlsruhe-Rintheim (case 1), the project showed that a cost-effective retrofitting is possible even in the social housing sector. Information and communication between building operator and tenants may not only improve energy efficiency but also the atmosphere in the neighborhood. The application of a least- cost concept tool (DEROM) enabled the community owner to optimize demand and supply side investment and annual operating costs.

Analyses for the vocational colleges in Detmold (case 2) revealed from an energy point of view, already the first monitoring year can be described as a success. The plus energy target considering the primary energy demand could be achieved even when including user flow. However, from the occupants' perspective the intended high indoor environmental quality could not be provided, expectations of good indoor climate could not be fulfilled. This shows the need for an intensive optimization phase and integration of the building users once the refurbishment process is finished.

The campus of the University of Applied Sciences in Stuttgart finally (case 3) can be seen as a best-practice example for the modernization of inner-city campuses with partial heritage facades. Key findings from the analyses are that minimal-invasive measures like the installation of new and efficient LED lighting have large savings, provide excellent cost-benefit ratio and should therefore be prioritized (as also done in Detmold). Also, the combination with less cost-effective measures can be considered in order to improve the overall cost-effectiveness of an even more ambitious refurbishment program. Involving the different stakeholders in the case study of Stuttgart (all faculties at the university, students, neighbors and public administration) can expose challenges to the decision-making process.

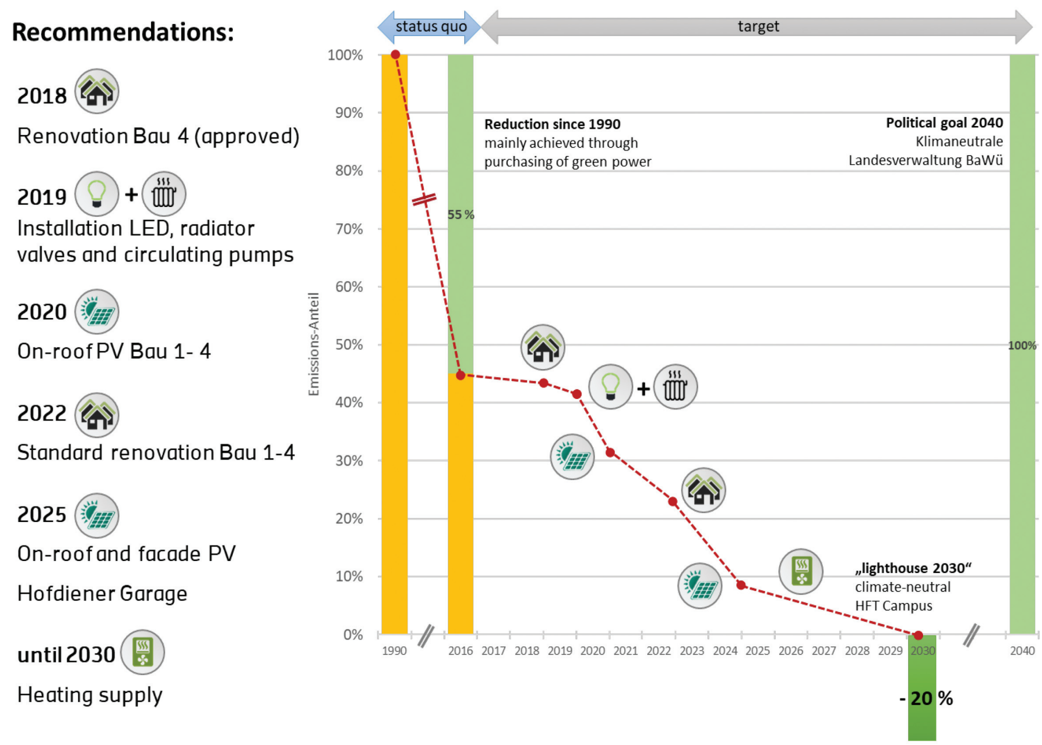

Figure 12 *Roadmap to 2030 for the campus of the University of Applied Sciences Stuttgart.*

Summarizing the first results from the projects it can be concluded that in order to improve the energy demand of existing communities, building refurbishment is mandatory. Deep retrofit projects (DER) are usually not cost-effective if only energy savings are considered. However, DER may reduce the primary energy balance to values as low as 40- 50 kWh/m^2yr (12.7- 15.8 $MBTU/ft^2yr$). The application of district heating scenarios helps to improve cost-effectiveness if highly effective energy supply architectures are considered. The heating system change largely depends on the goals of the concrete case study, e.g. energy autarky, CO_2 emission savings or costs.

Individual building simulations of different scenarios can show a good compromise between CO_2 and energy savings as well as economic goals.

Another important insight is the consideration of the users, their different roles (student, teacher, tenant, facility manager etc.) and the complexity of interaction between user and energy related environment when it comes to a good energy performance of a building. Appropriate information and tailor-made communication for the different target groups are the key words in order to increase acceptance of (new) technologies and to support the buildings' functions. The involvement of the users at an early stage of a project is of high relevance. The retrofitting of public buildings (such as the campus buildings in Detmold and Stuttgart) even offers the possibility of strengthening environmental awareness regarding energy issues.

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