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Linear Optimisation of a Settlement Towards the Energy-Plus House Standard

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Abstract: Future buildings will use technologies that are either well-known, innovative, or a combination thereof in order to be environmentally friendly and feasible at the same time. To evaluate and compare such systems through simulation, adaptive tools need to be available. This paper describes a conceived method for planning quarters and settlements. The novelty of this work emerges from the combination of a building simulation with a linear economic optimisation of the energy system, to achieve the energy-plus house standard for a settlement. Furthermore, the tools applied are adaptive or open source. In this article, a hypothetical basic example is given for a predefined idealised settlement, which consists of 132 single-family houses of one building type. The hourly demand for electrical energy and heat is established for three energy-efficiency classes for the building type with a dynamic simulation in MATLAB/SIMULINK using the CARNOT toolbox. This toolbox is also used to calculate the specific electrical energy production by photovoltaics. The components for the energy system of the settlement are implemented in the open source linear optimisation tool URBS. An economic optimum for the energy system of the settlement is found for each of the energy efficiency classes for an accumulated energy demand of the buildings. In this way, a lossless energy hub between the buildings is assumed. The results of the conducted simulations indicate that the optimal ratio of air/water to ground/water heat pumps shifts towards air/water heat pumps with more energy efficient houses. This is due to the lower specific investment costs, which outweigh the operational costs when less energy is required. The lowest costs for the entire energy system are for the one with the most energy efficient settlement. This is the case, as the costs for the higher energy standard of the buildings are not considered in the calculations. The behaviour of the optimisation is tested and discussed through a sensitivity analysis for one efficiency class. By presenting this simple, comprehensible example, an impression of the possible applications for this methodology is conveyed.

Keywords: efficiency; renewables; buildings; quarters; settlements; energy-plus house; simulation; optimisation

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1. Introduction

To continue its efforts considering climate protection and sustainability, the EU has set itself the following targets for the year 2030: Besides a 40% cut in greenhouse emissions compared with the levels of the year 1990, the EU aims for a share of renewable energy consumption of at least 27% and energy savings of at least 27% in comparison to a calculated business-as-usual scenario [1]. Furthermore, EU negotiators agreed upon even more ambitious targets only recently [2].

The residential sector is responsible for about 24% of the final EU energy consumption. It is the third largest sector after the transport and industry sectors [3]. The EU has introduced two main legislations to improve the energy performance of buildings, the Energy Performance of Buildings Directive and the Energy Efficiency Directive [4,5].

When building or energetically refurbishing houses, two potential measures can be taken to fulfil the goals of the EU. On the one hand, heat losses can be reduced to improve energy efficiency. On the other hand, the share of renewable energies can be increased. One concept, which aims towards an economic optimum between these two levers, is the energy-plus house standard. It mainly implies that the final and primary energy production in a specified system boundary for a building exceeds the total energy demand over the period of a year, including a user electricity consumption of 2500 kWh for a single-family house [6].

To achieve the energy-plus house standard, the use of photovoltaic (PV) systems and electric heat pumps is of major importance. This is due to the fact that electric power needs to be produced economically within the system boundaries, and because heat pumps have a high seasonal performance factor that can reach over 300%. Alternatively, energy systems, which use a variety of heat and electric power producers (e.g., decentralised combined heat and power plants and/or photovoltaic facades) could have economic and environmental benefits. This applies, as surface limitations for photovoltaic systems on roofs exist and heat pumps have technological limitations. The latter is particularly the case for certain buildings, for example, with a high heat demand per area or a need for high temperature levels for heating.

The energy-plus house standard could also be applied to the system boundary of an urban quarter or settlement. A focus on such boundaries yields synergy effects, and also, with respect to the power grid, as the behaviour of larger energy systems can be planned and controlled more easily [7].

This paper proposes a method for optimising the costs when planning quarters and settlements towards the energy-plus house standard. The tools applied for implementing the method aim at being adaptable, considering the technical and economic parameters. In this way, these tools enable the inclusion of innovative technologies into the simulations. In this article, a basic example is given for a predefined settlement, to test and comprehend the methodology and the tools used.

Measures to increase the energy efficiency and/or own consumption of electrical power have been studied in the past, mainly at the level of individual buildings. In this context, different building concepts, like zero-energy buildings [8], passive houses [9], self-sustaining buildings [10], and buildings with a high own generation like plus-energy houses [6], were examined, considering their planning and realisation. Additionally, research was undertaken to compare such building concepts with regard to their environmental impacts, through life cycle analysis [11]. Respective research projects in new built or retrofitting were accompanied by monitoring and further research measures [12] (e.g., case studies that examine detailed measures for energy renovation [13]); in some cases, the findings were documented in the form of guidelines [14]. Deviating from this, settlements and quarters are becoming increasingly important as an appropriate system boundary for new build and energetic refurbishment measures, which is attributable on the one hand to economies of scale and synergies, on the other hand, to climate protection plans and municipal energy concepts [7,15]. However, previous investigations mainly addressed constructional and urban planning issues [14,16]. Occasionally, research was conducted on individual quarters and settlements with energy efficient supply concepts and high local electricity production or plus energy settlements [17,18].

The impact on the electrical transmission and distribution networks when using energy systems with heat pumps as the main provider of heat has been partially analysed. To circumvent economic losses, peak shaving and load shifting technologies have to be considered when planning buildings and their energy systems [19].

In contrast to the tools that consider the optimisation of energy systems with detailed building models [13,20], this article focuses on the tools that make a compromise between the accurate calculations of the physical properties of one building, and the optimisation of these properties for multiple buildings and the components of their energy systems. Such tools that can optimise the energy system for a settlement or urban quarter are already available (e.g., RETScreen [21] and the tools developed by the passive house institute). However, the focus of the methodology developed is that it is highly adaptive and combines a dynamic simulation with linear optimisation. In this manner, the suggested methodology in this paper provides the opportunity to incorporate models of the described issues (e.g., low-ex district heating with decentralized heat pumps, PV-facades, and shadowing of buildings). However, only a fraction of the possible applications has been implemented so far. The advantages and limits of the methodology applied are listed in Table 1.

Table 1. Advantages and limits of the methodology applied

Advantages	Limits
Adaptable simulation environment and models (combination of CARNOT Toolbox for MATLAB/SIMULINK with open source tool URBS)	So far, the methodology presented has only been applied for energy systems with a few components. Further systems will need to be implemented in URBS.
Physical calculation of heat demand of single buildings with a tested single node model (CARNOT)	So far, the energy demand of several buildings is accumulated in URBS, and afterwards, the energy system is optimised.
Linear optimisation of multifarious energy systems towards minimal costs (URBS)	Further implementation will allow for the optimiser to additionally choose energy efficiency classes for each individual building of a settlement. Although costs for CO_2-emissions are implemented in URBS, they are not considered in this article.
Scale of simulation and optimisation can vary from single buildings to large quarters	The consequences for the calculation time of the optimisation might increase drastically with more degrees of freedom, which needs to be addressed with further implementations.

2. Materials and Methods

The methodology is shown in Figure 1. First, an urban quarter or settlement is defined. This is the basis for further steps considering the parameters and constraints. In the second step, the determined requirements lead to a categorization of building types, which will be simulated and shall represent the desired quarter or settlement. Afterwards, possible classes of energy efficiency are set for those building types. In the next step, the individual building types with their respective classes are simulated in MATLAB/SIMULINK (Version R2017b 9.3.0.713579/Version 9.0, MathWorks Inc., Natick, MA, USA) using the Toolbox CARNOT (Version 6.0, Solar-Institute Jülich of the FH Aachen, Jülich, Germany) [22]. This simulation environment has been chosen, as the blocks used in that model, the buildings and energy system have been validated in previous works [23]. The main results from this simulation are hourly values for the electrical and heat demand and supply. Finally, this data is used within the framework of the optimisation tool URBS (Version 0.7, Chair of Renewable and Sustainable Energy Systems of the Technical University of Munich, Germany), to determine the necessary optimal energy system configurations to achieve the desired targets [24].

In the following sections, each of the roughly described steps will be elaborated on.

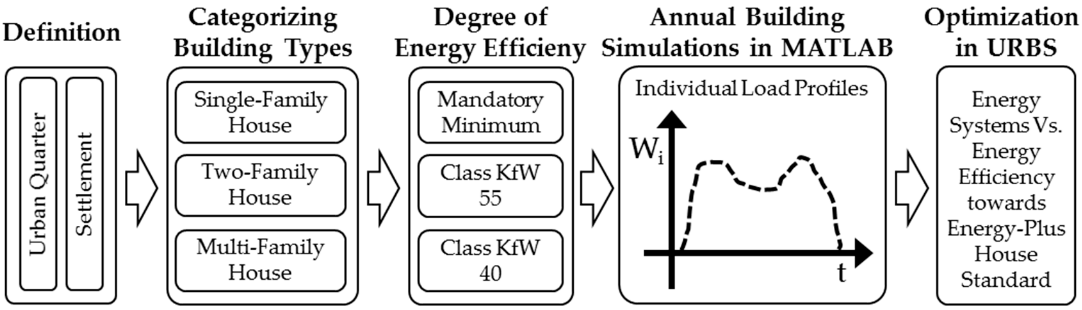

Figure 1. Methodology with exemplary sub items.

Definition: In the first step, the quarter or settlement is defined for the purpose of fitting into the methodology applied. It is assumed that the process of planning the quarter or settlement starts with an available site of a fixed area and location. Furthermore, the desired housing units, namely non-residential buildings with their respected utilisation, need to be established for the site. Basically, the information required at this point corresponds to the one included in a legally binding land-use plan. In the case presented in this paper, the defined settlement consists of 132 individual single-family houses in Potsdam, Germany. Potsdam has been chosen as an exemplary location, as it is adduced to calculate the building parameters for legal accreditations and to obtain certain funding (e.g., from the German government owned development bank Kreditbank für Wiederaufbau (KfW)). It is assumed that the houses themselves do not interact with each other. The surfaces for the installation of photovoltaic systems, in our example, are limited to the roofs of the buildings.

Categorizing building types: In this step, the defined requirements from the land-use plan are converted into specific building types. These represent the planned quarter or settlement. The number of different types of buildings varies with the requirements considering the accuracy of the predictions, as these models will be simulated afterwards with MATLAB/SIMULINK so as to determine their energy demand. Ideally, every variation of a building should be examined individually. However, this is time-consuming and simplifications need to be made where it is possible, considering the meaningfulness of the results. Therefore, this method can be best used for repetitive building types within a quarter or settlement.

In the simple example to validate this method, only one building type has been categorized so far, which is shown in Table 2. This building type is used to represent a settlement, which is planned in order to achieve the energy-plus house standard. As the basic model used is the single-family house 45 (SFH) model of the SHC Task 44, many of the parameters are predetermined or can be adjusted like internal gains through the occupational profile and electrical waste heat [23].

For the settlement calculated in this paper, only the SFH model is used. The geometrical data is adapted as shown in Table 2. The area of the roof equals the one of the ground floor. The electrical load profile is based on the VDI standard 4655 [25] and is set to 2500 kWh/a, as this is the limit for a SFH, which is supposed to fulfil the energy-plus house standard [6]. The hot water use is set to 2000 kWh/a, which is also derived from the VDI standard. The weather data used is from the German weather service (Deutscher Wetter Dienst) and represents a reference year in the climate of Potsdam in Germany (TRY Zone 4) [26].

Table 2. Exemplary parameters of the category single-family house.

Parameter	Ground Floor [m^2]	Floors	Housing Units	Length [m] (North/South)	Width [m] (East/West)	Height of Floors/ Rooms [m]	Window Area [%]
Single-Family House	70	2	1	10.7	7.7	3 / 2.6	20 south 5 north 7 east/west

Degree of energy efficiency: After the building types are chosen and the basic data for the models are determined, variations can be set up. This will be done in this step by defining the different degrees of energy efficiency for the building types. The variations applied in this paper are derived from the requirements of the KfW for funding. To achieve a certain standard of energy efficiency, specific targets considering the primary energy use and heat loss through transmittance have to be achieved, among other factors. In Table 3, the used thermal transmittance values are shown, which are recommended in order to achieve the desired class of energy efficiency [27]. For the classes KfW 55 and 40, the heat recovery ventilation is set to an efficiency of 80% and is assumed to have a constant power load of 75 W.

Table 3. Thermal transmittances of components of set efficiency classes.

Components [W/m^{2}K]	Mandatory Minimum	Class KfW 55	Class KfW 40
Outer Wall	0.28	0.22	0.15
Windows	1.30	0.90	0.70
Roof	0.20	0.14	0.11
Ground	0.35	0.25	0.22

Annual building simulations in MATLAB/SIMULINK using CARNOT: In this step, the data and parameters gathered beforehand are inserted into the CARNOT model simple house in the MATLAB/SIMULINK simulation environment, which is a single node model. If not otherwise mentioned, the standard parameters of this model are used [23,27]. The governing equation to calculate the energy demand in the building is as follows:

$$(\mathrm{m}\cdot\mathrm{c})_{\mathrm{house}}\ \mathrm{dT/dt} = \mathrm{solar}_{\mathrm{gain}} + \mathrm{internal}_{\mathrm{gain}} + \mathrm{heating}_{\mathrm{power}} + \mathrm{losses}_{\mathrm{to\_ambient}}, \tag{1}$$

with “m” as the mass and “c” as the capacity of the building. “dT/dt” stands for the change in temperature over time. Therefore, this side of the equation represents the change in energy in the single node. The other side represents the energy flux, which is represented as follows. “$\mathrm{solar}_{\mathrm{gain}}$” is the energy that is gained through irradiation. “$\mathrm{internal}_{\mathrm{gain}}$” incorporates the gains from the occupation of the building and the waste heat gains from the electrical equipment. “$\mathrm{heating}_{\mathrm{power}}$” stands for the energy that needs to be added to the system in order to retain a constant temperature, which is set to 20 °C in our simulations via the heat generator. Through “$\mathrm{losses}_{\mathrm{to\_ambient}}$”, the transmission heat losses through the surfaces are calculated. Hourly values are opted for in order to keep the calculation time low, as they are later used for the linear optimisation in URBS. Furthermore, much of the data applied is only available in this temporal resolution. In order to exemplify the different energy efficiency classes, the results for the yearly space heating demand divided by the net living area for two floors of 140 m^2 in total are shown in Table 4.

Table 4. Yearly space heating demand for different energy efficiency classes [kWh/m^{2}a].

Mandatory Minimum	Class KfW 55	Class KfW 40
45.6	24.0	16.1

The standard CARNOT model for a photovoltaic system, called PV Generator, with a collector slope of 30° facing south is used to determine the available power supply from a photovoltaic module for the simulations in URBS. The area for the electric power of 1 kW$_{\mathrm{peak}}$ of a PV-module is assumed to be 6.7 m^2. All of the other data for the calculations have been listed in the sections before.

In the next step, the linear optimisation tool URBS is used to determine the costs of the energy system. In the present case, this is done for the three different energy efficiency classes each, when a settlement of 132 housing units for a single-family house model is considered as a sum. The accumulation of the energy demand and supply can be construed as an idealised lossless energy hub.

URBS is a mixed integer linear programming model (MILP). It is meant to optimise a portfolio of technologies for a given demand. The model consists of three main tuples, the commodities (com), the processes (pro), and the storages (sto). The commodities describe the different energy demands and external energy sources. Table 5 lists the implemented commodities for our example [28]. CO_2-emissions are neglected in this paper.

Processes convert one commodity into another. They are defined by various parameters (e.g., input to output ratios, costs, and required area). Table 6 shows the different investigated processes [28].

Storage allows for the time shift of different forms of energies and commodities. In this study, a battery and a thermal energy storage (tank) are used.

Table 5. Commodities implemented in URBS.

Commodity	Com	Description
Solar energy	solar	solar irradiation
Electricity	elec	electricity demand of the building
Heat	heat	heat demand of the building
CO_2	CO_2	CO_2-emissions of the processes
Elec-buy	buy	electricity bought from the grid
Elec-sell	sell	electricity fed into the grid

The target function of URBS minimizes the total costs for an energy system, while matching the heat and electricity demand for every time step. In our example, we use the following function:

$$\min c = \sum_{\text{pro, sto}} \left[c^{\text{invest}}_{\text{pro, sto}} + c^{\text{var}}_{\text{pro, sto}} + c^{\text{fix}}_{\text{pro, sto}} + c^{\text{purchase}}_{\text{pro, sto}} - c^{\text{revenue}}_{\text{pro, sto}} \right], \tag{2}$$

in which the total costs are composed of investment "$c^{\text{invest}}_{\text{pro, sto}}$", variable "$c^{\text{var}}_{\text{pro, sto}}$" (related to the operation of the system), and fixed "$c^{\text{fix}}_{\text{pro, sto}}$" (independent from the operation of the system) costs, together with the purchase of electricity "$c^{\text{purchase}}_{\text{pro, sto}}$" and negative costs for the feed-in "$c^{\text{revenue}}_{\text{pro, sto}}$" [28].

Table 6. Portfolio of processes applied.

Process	pro	com_in		com_out
Photovoltaic (PV) system	photovoltaic	solar	→	elec
Air/water heat pump (HP)	a_heat-pump	elec	→	heat
Ground/water heat pump	g_heat-pump	elec	→	heat
Electrical grid	purchase	buy	→	elec
	feed-in	elec	→	sell

The applied parameters are shown in Table 7. Most are taken from the literature [28]. Only the ones for the ground/water heat pump (ground HP) are assumed. The second column shows the specific costs for investing in a process, depending on the power for the first three processes and the capacity for the fourth and fifth process. The buy and sell processes do not have investment costs. The variable costs depend on the amount of energy that is being transferred. The fixed costs depend directly on the investments costs. The purchase costs stand for either buying one kilowatt of electrical power or selling it. "η" is the efficiency of a process. The efficiency translates to the coefficient of performance for the heat pumps. For the energy storages battery (electric) and tank (heat), the efficiency stands for the energy left when a cycle of charging and discharging energy to the respective component is done. The efficiency of the PV-system is already included in the price for one kW_{peak}, and is therefore not further considered in the calculation of the processes. The cost of capital is set to 3% and the depreciation period is set to 20 years for the calculations.

Table 7. Cost parameters for the considered technologies.

Process	Invest. Costs	Variable Costs [€/kWh]	Fixed Costs [%-Invest.]	Purchase Costs [€/kWh]	η
PV	1440 €/kW_{peak}	0	1.5	0	-
Air HP	900 €/$kW_{electrical}$	0.005	2	0.29	2.7
Ground HP	1200 €/$kW_{electrical}$	0.005	2	0.29	3.5
Battery	1066 €/kWh	0.001	2	-	0.9
Tank	30 €/kWh	0.001	2	-	0.92
Buy	0	0	0	0.29	-
Sell	0	0	0	−0.123	-

3. Results and Discussion

The resulting installed capacities for the different energy efficiency classes are shown in Table 8. As the optimisation heads towards minimal costs and the photovoltaic systems reach a net profit with our constraints, the available surface will be used in every case.

Table 8. Installed optimal capacities for the given settlement for each class.

Installed Capacity	Mandatory Minimum	Class KfW 55	Class KfW 40
Photovoltaics [kW_{peak}]	1379.1	1379.1	1379.1
Heat storage [kWh]	98.7	86.8	86.3
Air heat pump [$kW_{thermal}$]	146.2	171.4	177.4
Ground heat pump [$kW_{thermal}$]	266.7	177.5	138.4
Ratio air to ground heat pumps	0.55	0.97	1.28

As the energy efficiency of the buildings improves, less heat pumps need to be installed in total. However, the ratio of air to ground heat pumps shifts further towards air heat pumps as the energy efficiency of the buildings improves. In this manner, the additional investment for the more efficient heat pump is only feasible for a high enough heat demand. The optimisation between air to ground heat pumps can be understood as a base to peak load issue (see Figure 2).

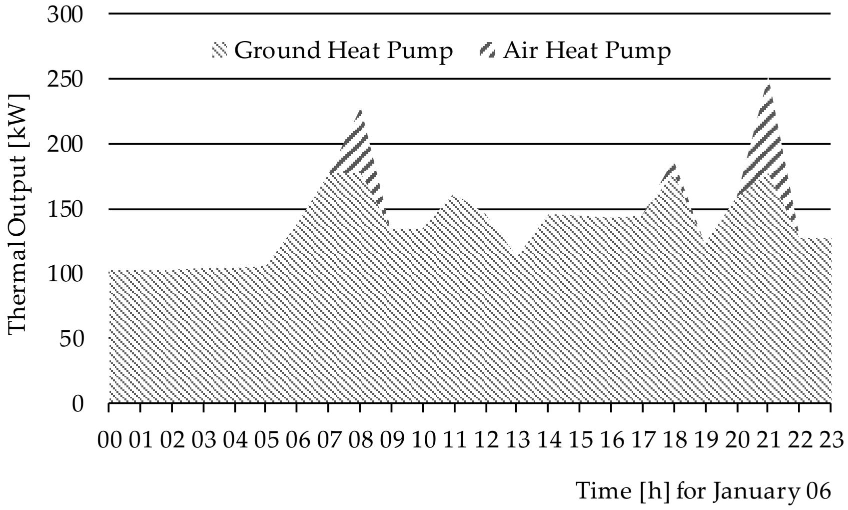

Figure 2. Behaviour of heat generators on a cold day for the class KfW 55.

In this fashion, the behaviour of the heat generators for a cold period is demonstrated. It has to be kept in mind that the simulation assumes a lossless energy hub between the buildings, as the energy demand for them is accumulated. In this way, the heat and power generators also transfer energy lossless between the buildings.

The electrical energy that is fed into (Sold) and purchased from the grid (Bought) in one year is presented in Table 9. All of the building classes accomplish a net positive energy balance for the energy-plus house standard. The electrical energy bought diminishes with an improved energy efficiency class, as expected. The relatively low amount of electrical energy sold for the class KfW 55 is due to the relatively low capacity of the thermal storage (see Table 8).

Table 9. Electrical energy fed into and purchased from the grid in one year.

Electrical Energy [MWh/a]	Mandatory Minimum	Class KfW 55	Class KfW 40
Bought	395.1	365.1	331.3
Sold	1434.7	1431.0	1439.4

The resulting annual costs in relation to the total floor area of 18,480 m^2 are shown in Table 10. In the applied implementation of URBS, only the investment costs are multiplied with the annuity factor to get the yearly costs. The results show that the energy systems of the simulated settlement of single-family houses with the energy efficiency class KfW 55 have total costs that are 0.95 €/m^2 lower than the ones of the energy system with the mandatory minimum energy efficiency. The optimal energy system for the KfW 40 class costs 1.76 €/m^2 less than the energy system for the class mandatory minimum.

Table 10. Resulting annual costs of the energy systems for the considered energy efficiency classes.

Costs [€/m^{2}a]	Mandatory Minimum	Class KfW 55	Class KfW 40
Invest	8.88	8.57	8.42
Variable	0.30	0.19	0.16
Purchase	6.14	5.67	5.15
Fixed	2.10	2.01	1.97
Revenue	-9.55	-9.52	-9.58
Sum	7.87	6.92	6.11

As the energy demand has been accumulated for the buildings, the results are, to a certain degree, less meaningful than if each building had been entered individually in URBS. However, implementing every building individually requires a great effort. In the version used, it needs to be done manually and comes along with longer calculation times, as more degrees of freedom are added to the optimisation.

A sensitivity analysis is conducted for the settlement with the efficiency class mandatory minimum (see Figure 3).

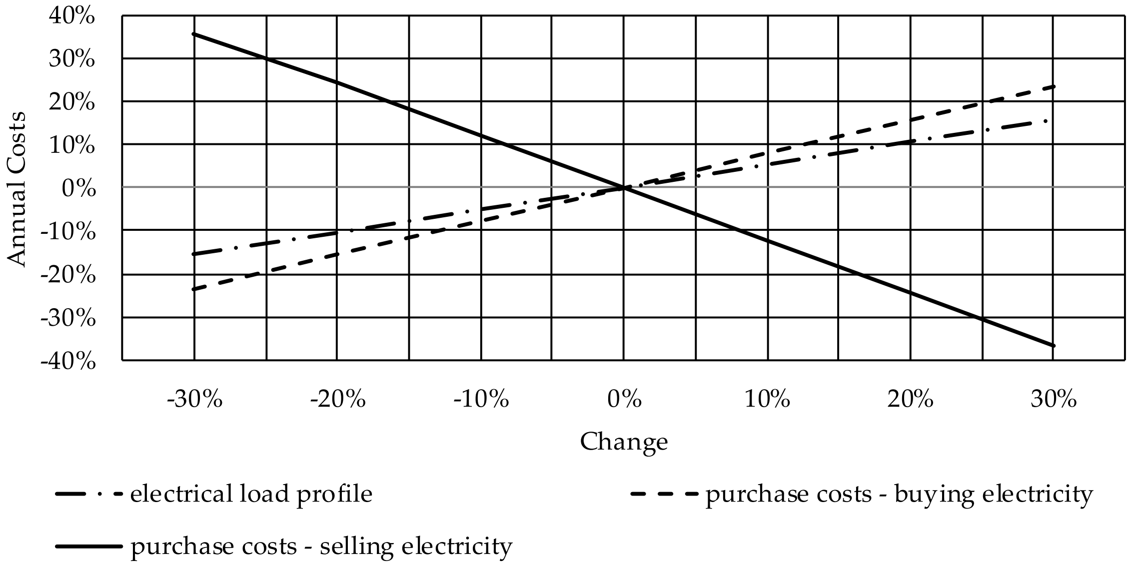

Figure 3. Sensitivity analysis for the settlement with buildings of efficiency class mandatory minimum.

The influence of three parameters on the resulting annual costs are examined—the hourly value of the electrical load profile and the purchase costs for buying and selling electrical power (see Table 7). Every parameter has been varied by up to plus and minus 30% of the original value, in 10% steps. The annual costs are nearly linearly dependent on the parameters examined, with a maximum deviation of 0.1%. The electrical load profile, which corresponds to the user behaviour when using electrical devices in the household, has the least impact on the results. The change in annual costs amounts to 5.2% per 10% change in the hourly values of the electrical load profile. However, the user behaviour can be very versatile and it affects the heating demand, too. These issues will need to be addressed in future studies with this methodology. The annual costs change by 7.8% for a 10% change in the purchase price for buying electricity. The price for buying electricity is usually known for a specific region, as well as the amount and power of electricity needed. However, the price for buying electricity can be subject to varying tariffs and can change over a longer time frame, and therefore contains uncertainties. For the operating points examined, the price for selling electricity has the highest influence on the annual costs in this sensitivity analysis. The costs change by -12.1% per 10% change in the price of electricity. This is due to the large number of PV-modules that have been installed in comparison to the power demand of the settlement. The uncertainty for this parameter is minimal, if a constant feed-in compensation can be assumed for the PV-system. However, further aspects as taxes for self-consumption will need to be accounted for in the simulation, in order to obtain results that are more realistic.

4. Conclusions

The conceived methodology for simulating and optimising the energy system for urban quarters and settlements has been presented and explained through the aid of a simple example. The tools, standard models, and data used, which provide the basis for the calculations, were portrayed in this article. The methodology was tested by providing a discussion about the results for the simple settlement of 132 single-family houses. For example, the installed capacities for the ground and air heat pumps were discussed when changing the energy efficiency standard of the buildings. A brief sensitivity analysis was conducted for the efficiency class mandatory minimum.

The calculations still bare many assumptions. For example, through accumulating the hourly energy demand for the 132 single-family houses, a lossless energy hub is implied. Furthermore, the energy system of each individual house of the settlement is not determined individually, but for the whole accumulated energy demand. Therefore, the goal for the future development of the methodology is to improve the tools by using more realistic assumptions and additional models. In this way, an adaptive tool for the optimisation of innovative energy systems will be created. To achieve this, the following objectives need to be accomplished specifically.

The optimisation in URBS aims at minimizing the overall costs through the application of annuities. This is why, without a restriction, it will always opt for the installation of as many photovoltaic modules as possible, as they are the net profit with our simplified constraints. More realistic constraints will need to be implemented into URBS so as to better reflect a realistic behaviour of the simulation. For example, within the German energy system, the power of photovoltaics needs to be sold via the electricity market when they reach a certain size.

Future studies will approach the described possible improvements for the implementation of individual buildings in URBS and investigate incorporating energy refurbishment measures into the applied methodology, as this topic affects the majority of buildings considering the goals of the EU. As URBS is an open source tool, it can be adjusted so as to also include different energy efficiency classes directly into the optimisation. This can lead to solutions in which a mix of energy efficiency classes is being used.

Additionally, several aspects towards more realistic calculations will be implemented in the resulting studies. First of all, other costs (e.g., for buildings, electric grids, and district heating) will be taken into account. In the presented article, only the costs for the energy system are considered. The amount of building models will be extended by a two-family and a multi-family house and will include a diversified user behaviour. This will be done in MATLAB using the CARNOT toolbox. Furthermore, the multifarious energy systems in URBS will be implemented in such a way that combinations of different heat producing technologies can be tested for the energy-plus house standard, in addition to heat pumps. The idealised energy-hub in this paper shall become subject to losses to become more realistic. Low-ex district heating options will also be implemented, as well as photovoltaics on facades. The validation of the characterized simulation model with data from an energy-plus settlement with ca. 300 housing units has been planned, which will be built in the region of Ingolstadt in Germany in the year 2019.

Considering the situation and development for different countries in the EU, future implementations for the tool are meant to incorporate a variety of constraints that are individual to different national economies, for which of course the parameters for the weather, costs, efficiency classes, and energy systems need to be adjusted. The commodity CO_2-emissions is implemented in the standard version of URBS. Therefore, the price for CO_2-emissions can be included and varied in the optimisation so as to determine adequate energy systems for future policies regarding costs for emissions. To achieve extended investigations into possible policies like subsidies [29] and tax exemptions, further implementations will be necessary.

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