The future of modernist housing estates: the “Replace vs Refurbish” dilemma in the context of future urban densification

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Abstract. The aim of this paper is to present a part of the research developed inside the author’s dissertation topic which deals with the future of large modernist housing estates. The central question of the dissertation investigates which of the currently dominating tendencies - their replacement or refurbishment - result in lower energy consumption and provides more sustainable use of natural resources within the context of future urban densification. The presented workflow combines actions contained in the first step of the research methodology built around the abovementioned dilemma. It explores the solar energy harvesting potential of various urban forms and densification scenarios, proposed inside the main “refurbishment” and “replacement” approaches, including both retain and demolition options of the existing building stock located in the Nordweststadt housing estate in Frankfurt, Germany. All scenarios are tested against maximal density rate which secures enough operational energy from on-site renewable energy sources for the achievement of the zero energy building (ZEB) standard. The expected outcome of this paper gives an insight which of the proposed densification scenarios from both approaches generate the highest density rate in respect to the given boundary conditions, and compares the energy balance between the best performing scenarios in both approaches at the same density level.

1. Introduction

A constant population growth catalyses densification of contemporary cities, triggering enormous energy consumption in the building sector [1] and putting additional pressure on already exhausted natural resources. These activities jeopardize the natural balance of our eco-system and cause serious climate changes. Carbon neutral buildings and cities represent globally adopted sustainability concepts to fight greenhouse gas emissions and put this climate change under control. In the EU, starting from January the 1st 2021, all new buildings should be nearly Zero Energy Buildings [1]. Numerous prototypes of such buildings and districts are already being constructed worldwide. [2]

The position of the existing building heritage, especially of buildings representing significant historical styles, in such a city is very sensitive and is not evaluated only upon energy performance criteria but also through its overall cultural contribution to the society. Therefore their refurbishment usually requires a balanced combination of methods and techniques which would not have a significant impact on their visual appearance. A special place in this context is reserved for the modernist housing estates, which currently due to high energy consumption and relatively bad public reputation, undergo massive transformation. Thanks to the relatively low plot-ratio which allows further densification, good position inside the existing urban transportation systems and connectivity to urban infrastructure grid of the plot, these housing estates are often challenged with the following dilemma regarding their further existence in the 21st century city.
concept: should they be maintained and densified or replaced by new urban development projects? Latest zero-energy retrofit examples of such residential buildings show that promising results can be expected also with existing buildings [3]. Thus, if a “zero” is already feasible, both by new and refurbished building typologies, comparison of overall energy balances associated within both of these approaches could have a significant impact on the final decision regarding the future of modernist housing estates.

2. Solar potential in the urban environment and its relationship to zero energy districts

Much research activity has already been invested in attempts to analyse and enhance the use of solar energy potential in the existing urban environment as well as to analyse and compare environmental performance of diverse urban configurations. Roof surfaces, thanks to the mostly unobstructed solar exposure, represent motors of urban renewable energy production. Nevertheless, in his research on zero energy building projects, Mussal [2] states that only buildings which need less than 0.9 m² of the roof PV system area per m² usable floor area have the possibility to achieve a zero energy balance. This criteria is usually met by 3-4 story high buildings, implicating a conclusion that zero balance is generally possible at low density rates. For the achievement of higher zero-energy density rates, activation and optimization of the façade areas for the BIPV application are crucial. Kanters and Wall [4] tested typical Swedish urban forms in a generic urban matrix layout against maximal zero energy density rates in Nordic climate conditions. Results show that analysed urban forms with density rates of up to 2.5 can realistically cover the total electricity demands and density rates of up to 1.5 the heating demand derived from Swedish energy efficiency standards with on-site BIPV energy production. Similar research was conducted in Switzerland [5] where the results showed that in the near future zero energy buildings will be able to go up to 40 stories high. Precondition for such development is the expected increase in PV system efficiency as well as further reduction of the energy demands through application of increasingly energy efficient building components and materials.

Most of the ongoing research activities are focused on exploring potentials of new build scenarios and generic urban developments. The aim of this paper is to explore the zero-energy balance potentials of the urban densification scenarios involving maximal reuse of the existing buildings in real urban conditions, and to compare their solar potential, energy performance and zero-energy density rates to the ones achievable by generic ones.

3. Research methodology

The methodology developed for this research consists of the following design and evaluation steps: definition of the densification scenarios for both refurbishment and replacement options; definition of the applicable renewable energy sources and on-site production levels; definition of the energy demands necessary for the zero energy balance calculation; comparison of the zero density rates among the typologies of the new-built and the existing stock densification scenarios; and finally the comparison of the energy production levels of best performing new-built scenarios on the zero energy density rate of the existing stock scenarios.

3.1. Case study

As a case study example an approximately 1-ha big plot located inside the Nordweststadt housing estate in Frankfurt, Germany was chosen (Figure 1). The selected plot, which represents a typical urban structure of the area, is created by a combination of four stripe buildings, varying in height and apartment typologies and surrounded with floating landscape and extensive greenery, which create an impression of a life in a green oasis. Due to structural similarity and conceptual consistency of the whole Nordweststadt masterplan, conclusions gained from this site could be transferred and applied to other lots inside of this housing estate.

Figure 1. Analyzed site in Nordweststadt, Frankfurt.
3.2. Definition of the densification scenarios
Densification scenarios are divided into two main approaches: replacement - “Tabula rasa” (TR) and refurbishment - “Existing stock densification” (ESD), each consisting of several sub-scenarios.

3.2.1. The “Tabula Rasa”. This densification approach assumes demolition of the existing buildings and greenery and testing of the analyzed plot with Martin and March’s generic urban form archetypes: Perimeter Block, Stripe, U-shaped block and Point House. Given the specific geometry of the selected plot these archetypes are used to create eight site-specific scenarios which maximize the built area and maintain two main existing building orientation axis: North–South (NS) and East–West (EW).

3.2.2. Existing stock densification. The main objective of this approach is the maximal reuse of existing buildings. The first two scenarios, the “minimal addition” (MA) and the “maximal extension” (EXT), represent interventions which respect the existing urban logic and the qualities of the estate. The aim was to increase the density by adding roof and side extensions analogue to the existing urban logic which would produce enough energy for the zero energy balance (decarbonisation). The main difference is that “MA” tests the minimal amount of necessary additions, while “EXT” explores the maximum density increase potential of the current urban logic. The presence and protection of the existing greenery limited applicable energy related actions to BIPV-equipped roof additions and façade retrofitting. The third scenario, called “selective preservation” (SP), allows evaluation and demolition of the existing stock and greenery and partial replacement by substitute buildings with the idea to re-create best performing scenarios from the “tabula rasa” approach using the maximum of suitable on-site buildings.

3.3. Definition of the “zero energy building” standard
The EU Commission defines a “zero energy building” as a building which produces at least the same amount of energy it consumes over a one-year period by on-site renewable energy sources. However, each member state is entitled to determine their own energy efficiency goals and standards [1]. Although Germany is still lacking official regulations which would define the standards for zero energy buildings and maximum allowed energy consumption per building typology, the “KfW Effizienzhaus 40” [7] and the “Passivhaus Plus” [8] can serve as an example where the nZEB definition could lead to. The Passivhaus institute defines a maximal energy demand of 45 kWh/m²a (treated floor area) as well as minimum 60 kWh/m²a of the on-site renewable energy production, as a precondition for the “Passivhaus plus” labelling. The “KfW Effizienzhaus 40” allows maximum 25 kWh/m²a for the heating demand.
3.4. Energy production

The on-site renewable energy sources are limited to the use of solar energy and geothermal energy. With an annual global irradiation gain of the roof surfaces of up to 1100 kWh/m² and up to 800 kWh/m² on the facades, the on-site solar energy is suitable for both photovoltaic and solar thermal systems. Geothermal energy, with a stable temperature range of 10-16 °C is ideal for the use of heat pump systems for heating and cooling. The application of wind energy for the energy production was not taken into consideration due to a few important disadvantages: the impact of the dynamic load on the construction system and the potential damage of the building as well as the visual impression on the installed roof systems on the tenants.

Solar energy production is calculated according to already scientifically proven thresholds [6] and market-conform photovoltaic panel efficiency of 15%. This means that only solar radiation above 400KWh/m²a was taken into consideration [6]. For the purposes of calculation simplification, total solar irradiation above this threshold value was converted to electricity. The roof area coverage by the PV is set to 90%, while the energy production of facades is simulated with 3 window-to-wall ratios: 30%, 50% and 60% assuming that the BIPV systems are mounted only on the non-glazed areas, satisfying the threshold-margins.

3.5. Energy demand calculation

The latest recommendation of the EU Commission is to use the Net ZEB Limited definition which includes energy demand for heating, cooling, hot-water production, ventilation, and auxiliary electricity for the zero energy balance calculation. In addition to that, the “Passivhaus Plus” [8] standard and SIA [9] consider also categories like household appliances and lighting, and propose maximum allowed values in each of these categories. These values are based on expected use of novel building systems and materials with increased energy performance and efficiency. Real energy demand used for this research is based on the data collected in several energy performance statistic reports. Specific energy demand benchmarks for each of the seven categories together with the adopted calculation values are presented in the Table 1 [10-15].

Table 1. Overview of the energy demand requirements.

| Specific energy demand (kWh/m²a) | Heating (thermal) | Cooling (thermal) | Hot Water (thermal) | Auxiliary Energy (electric) | Equipment (electric) | Ventilation (electric) | Lights (electric) | Total (electric) | COP |
|----------------------------------|------------------|------------------|--------------------|---------------------------|----------------------|-----------------------|-----------------|----------------|-----|
| SIA 2015:2024 - standard         | 19.4             | 6.6              | 19.8               | N/A                       | 14.2                 | 1.7                   | 4               | 33.24          | HW 3 |
| Passivhaus Institute             | 15               | 0-15             | 15                 | 3                         | 11                   | N/A                   | 0.8             | 27.84          | H 4  |
| Statistics [10-15]               | 15               | 5                | 28                 | 3.5                       | 31                   | 2                     | 6               | 53.14          | C 3.5|
| adopted values                   | 15               | 15               | 28                 | 3.5                       | 30                   | 2                     | 5               | 57.87          |     |

4. Results and discussion

In order to find the zero energy balance for the “Tabula Rasa” cases, proposed densification scenarios were simulated using DIVA [16] software and iterative step method against their solar potential for urban densities ranging from 1-10. The zero balance was calculated for three benchmarks of the final energy demand. The first one, amounting to around 27.85 kWh/m²a (Table 1) represents the “Passivhaus Plus” standard and at this benchmark, zero density rates start at 5.0 and end with over 10.0 rate achievable only by Point House typologies. Typologies with the lowest zero density rate are the Block-NS and Block EW configurations. The second benchmark is the energy demand created by reference values found in statistic reports. The average energy demand increased this way to 57.87 kWh/m²a, which dropped initial density rates to values between 1.1 and 2.15. At this point, highest density rates are reserved for U-Block EW, Stripe EW and Stripe NS typologies. It is interesting that the best performing typology varies not only for the two energy benchmarks but also at different density rates. For density rates of up to 1.8, the Stripe EW scenario generates the highest amount of solar energy surplus. In a range of 1.8-2.0 the best performing scenario is Stripe NS, but the highest zero energy density rate of 2.15 is achieved by the U-Block EW typology. This early classification of the results is based on a generic energy-demand assumption and does not consider the building orientation factor and its impact on the energy demand and therefore could lead
to wrong conclusions. For the final classification, a dynamic simulation of the selected building typologies using ARCHSIM [17] was conducted. The simulation models, which apply to German energy-efficiency standards, building codes and planning regulations, were built using density rates generated at the second benchmark assuming 6-7 story high buildings. With an estimated 3m story-height, these buildings do not cross the 22.5m limit of the German high-rise building regulation, which was important for the dimensioning of the communication areas and for the fire-escape planning. The share of apartment typologies was based on the author’s previous research conducted on the definition of the 21st century city living standards [18]. The thermal model for each building typology consists of two thermal zones: zone apartment and zone core. Zone definitions including occupancy schedules, load intensities and HVAC settings were created consulting SIA 2024:2015 [9]. Other relevant simulation inputs are presented in the Table 2. Simulation results revised the cooling and heating demand, ending up with a small density increase. Diagram No.1 shows a comparative overview of the zero energy density rates for all “Tabula Rasa” scenarios with 30% window-to-wall ratio, at three analyzed energy benchmark points.

Table 2. Overview of the simulation inputs and HVAC settings.

| Building skin | U-value | HVAC Settings | Winter | HVAC Settings | Summer |
|--------------|---------|---------------|--------|---------------|--------|
| facade wall  | 0.1     | heating setpoint | $T_{Room}=21°C$ (setback 18°C) | cooling setpoint | $T_{Room}=26°C$ |
| roof         | 0.1     | infiltration rate | 0.15 air changes per hour(ach) | infiltration rate | 0.15 air changes per hour(ach) |
| exterior slab| 0.1     | natural ventilation | scheduled (0.25 ach) | natural ventilation | scheduled up to 2 ach |
| openings     | 0.8     | mech. vent | off | shading on | $T_{out}=26°C$ and $I= 200 W/m²$ |

Diagram 1. “Tabula Rasa” approach (WWR 30%) – Overview of the zero energy density rates based on the “Passivhaus Plus”, statistical and simulation data.

In the case of refurbishment scenarios, if calculated with the statistical energy demand, the “roof addition” and the “extension” fail to perform a zero energy balance at any density rate. Yet according to the simulation results, lower cooling and heating demand in both scenarios can generate a zero energy density balance at a rate of 1.3 and 1.5 respectively. In this density range the Stripe NS configuration performed as the best suitable “tabula rasa” scenario and was re-created within the selective preservation (SP) scenario using existing north-south oriented buildings. This scenario allowed density rates of up to 2.2. Finally, the Diagram No. 2 presents zero energy balance margins for the existing stock scenarios and a comparison of all “Tabula Rasa” energy balances at these specific points.

Diagram 2. Left: Energy balance vs density rate for the existing stock densification scenarios. Right: Energy balance comparison of “Tabula Rasa” cases at the existing stock zero density rates.
5. Conclusion
The results of this research have shown that generally most of the new build typologies with the exception of the Point House (3) typology can outperform existing building stock, mainly due to preservation of the existing greenery and rigid densification rules. Yet a selective preservation scenario has shown that involving partial demolition could significantly increase density rates and reduce the energy balance gaps against the new scenarios. A further density increase for all scenarios could be possible only through additional heating demand reduction using mechanical ventilation with heat recovery. This option will be explored separately.

The results of this research will be used for the next research steps within the author’s dissertation which will focus on the life cycle assessment of the selected scenarios where the inclusion of the retained grey energy and choice of construction materials will give a final and more comprehensive response to the “refurbish vs replace” dilemma.

References
[1] European Parliament and Council of Europe, „Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings“, Off. J. Eur. Union, S. 23, Juni 2010.
[2] E. Musall, „Klimaneutrale Gebäude – Internationale Konzepte, Klimaneutrale Gebäude – Internationale Konzepte, Umsetzungsstrategien und Bewertungsverfahren für Null- und Plusenergiegebäude“, Dissertation, Wuppertal, September 2015
[3] A. Passer et al, „The impact of future scenarios on building refurbishment strategies towards plus energy buildings“, Energy Build., Bd. 124, S. 153–163, Juli 2016.
[4] J. Kanters und M. Wall, „The impact of urban design decisions on net zero energy solar buildings in Sweden“, Urban Plan. Transp. Res., Bd. 2, Nr. 1, S. 312–332, Jan. 2014.
[5] M. Hall, A. „Geissler Möglichkeiten und Grenzen von großen Nullenergiegebäuden“, Bauphysik 38, Heft 1, Februar 2016.
[6] M. Montavon, „Optimization of Urban Form by the Evaluation of the Solar Potential“, Dissertation, EPFL Lausanne, 2010
[7] KFW, „Anlage zum Merkblatt energieeffizient bauen“, online publication, 2018, retrieved from https://www.kfw.de on May, 2019
[8] Passivhaus Institut, „Kriterien für den Passivhaus-, EnerPHit- und PHI-Energiesparhaus-Standard“, online publication, 2016, retrieved from https://www.passiv.de on May, 2019
[9] SIA 2024:2015, „Raumnutzungsdaten für die Energie- und Gebäudetechnik“, Schweizerischer Ingenieur und Architektenverein, Zürich 2015
[10] Institut für Wohnbau und Umwelt, „Steps Towards NZEBs Exemplified for Different European Countries“, IWU, 2014, retrieved from www.episcope.eu on May 2019
[11] Entrane, “Heating and cooling energy demand and loads for building types in different of the EU“, online publication, 2014, retrieved from www.entrane.eu on May 2019
[12] BBSR, „Nutzenergiebedarf für Warmwasser in Wohngebäuden“, BBSR-Online-Publikation Nr. 17/2017, retrieved from www.bbsr.bund.de on May 2019
[13] A. Klemmer et al, „Datenbasis zur Bewertung von Energieeffizienzmaßnahmen in der Zeitreihe 2005 – 2014“, UBA, 2016, retrieved from www.umweltbundesamt.de, May 2019
[14] Schloßmann, B et al, „Energieverbrauch des Sektors Gewerbe, Handel, Dienstleistungen (GHD)“, ISL- Schriftenreihe „Innovationspotenziale“.Stuttgart: Fraunhofer Verlag, 2014
[15] A. Greml, „Komfortlüftungsinfo Nr.31: Komfortlüftung im Energieausweis“, online publication 2017, retrieved from www.komfortluftung.at May 2019
[16] Solemma LLC, DIVA for Grasshoper Version 4.0, 2018
[17] Solemma LLC, ARCHSIM for Grasshoper, 2018
[18] A. Tepavcevic, „Comparative analyses: urban quality, living standard, sustainability. Modernist housing estate vs 21st century city“, WSBE 2017, Proceedings WSBE17, Hong Kong, 2017