# Should we construct more skyscrapers? Scenario-based, energy performance assessment of plausible future urban densifications



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**Publication date:**
2025-11

**Permanent link:**
https://doi.org/https://doi.org/10.3929/ethz-c-000791233



**Originally published in:**
Journal of Physics: Conference Series 3140(6), https://doi.org/10.1088/1742-6596/3140/6/062017

Journal of Physics: Conference Series **3140** (2025) 062017 doi:10.1088/1742-6596/3140/6/062017

# Should we construct more skyscrapers? Scenario-based, energy performance assessment of plausible future urban densifications

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**Abstract.** Increases in Switzerland's population and the rate of urbanisation create the need for a better densification of its cities. This study assesses different urban developments in four plausible futures in Zurich and evaluates them through the perspectives of three energy performances: energy demands, emissions, and solar potentials. Scenario-based approaches are used to construct four futures with two axes: an ageing society that is either more or less productive, and with an urban spread that is either more centrally or decentrally planned. A parametric study is then conducted, with each future described with six parameters: new building typologies, occupancy rates, neighbourhood uses, residential schedule, commercial schedule, and existing building retrofitting. Through combinations of these parameters, 2,208 simulation cases are defined and simulated with City Energy Analyst (CEA). The methodology is applied and demonstrated in a case study at Altstetten Nord. The results suggest that skyscrapers are demand-efficient solutions, but at the expense of emissions and solar generation potential. The study explores trade-offs between different performance metrics for different block typologies. A design explorer is presented to summarise the best designs for different plausible futures.

## 1. Introduction

With Switzerland's population projected to reach over 10 million inhabitants by 2050, new constructions and densification in urban centres are expected to be more prevalent. Simultaneously, the Swiss Energy Strategy 2050 stipulates directives on the increase of building energy efficiency and reduction in overall emissions. Better insights on the interconnectedness of urban development strategies and their energy performances are needed to ensure the attainability of these two goals. One study [1] proposes an analytical approach to performance-oriented early decision-making in urban design. Using vernacular urban typologies in Singapore, [2] showcases a parametric approach to incorporating more solar energy use in an urban context. However, as urban design is heavily influenced by local and future contexts [3], a study specific to the Swiss contexts is still required.

This study proposes a scenario-based analysis of the effects of different plausible densified futures in Zurich on urban energy demands, emissions, and photovoltaic (PV) potentials. The proposed analysis is applied to a case study in one neighbourhood in Zurich. The results gathered answer three questions in regards to future densification: whether developing radically, such as with skyscrapers, is the best solution; what the trade-offs and consequences are between different

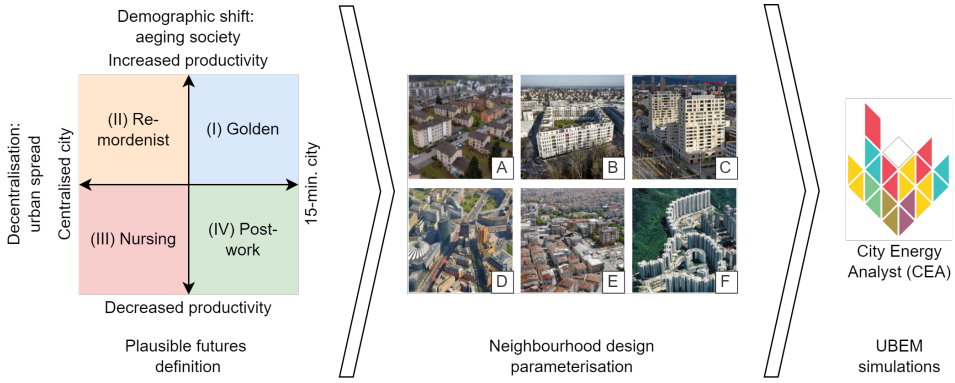


**Figure 1.** Workflow of assessing energy performances of plausible future densification.

building strategies; and which solutions provide the best balance between different performance criteria in each plausible future.

## 2. Methodology

In this study, densification is characterised in two ways: built and occupancy density. According to [4], two metrics are used to describe each, respectively: a higher floor area ratio (FAR) and a higher occupancy density. The study is performed in three parts: plausible future definitions, parameterisation, and urban-scale analyses, as summarised in Figure 1.

### *2.1. Plausible future definitions*

Future developments of the city are envisaged using a scenario-based method [5]. Two contemporary megatrends are identified: demographic shift and decentralisation [6]. For this study, the megatrends are further refined by taking into consideration local situations to the productivity of an ageing society [7] and urban geographical spread [8]. As shown in the first part of Figure 1, two axes depicting contrasting future outcomes and four resulting futures are defined. In the ageing society axis, the neighbourhood is projected to be either productive, where retirees are still active and producing beyond age 65, revitalising the local economy, or unproductive, where the opposites occur. In the urban spread axis, the neighbourhood is planned either in a decentralised manner, such as in a 15-minute city, where building use can vary in a neighbourhood, or a centralised manner, where one neighbourhood, one purpose applies. Following these trends, four future neighbourhoods are conceived in each quadrant: Golden (I), Re-modernist (II), Nursing (III), and Post-work (IV).

### *2.2. Parameterisation*

Six parameters are considered to describe the future scenarios, as summarised in Table 1. New development strategies are intended to represent how an empty site in a neighbourhood will be developed in the future. Block typologies are taken from three prevalent typologies in Zurich and one each from Berlin, Istanbul, and Hong Kong, as shown in Figure 1, which are row houses (A), blockrand (B), tower slab (C), diverse (D), dense quarters (E), and skyscraper (F). These typologies are selected for their high built density and well-accepted perceived density in their origins. These variants are grouped according to their respective similar floor area ratio (FAR). An option to not develop new buildings in the neighbourhood is also available for less productive neighbourhoods. Three different occupancy rates are projected for the neighbourhood: the current rate of 38 $m^2$/p, the Swiss-foreign mix rate of 35 $m^2$/p, and the foreign rate of 32 $m^2$/p [9]. Futures III and IV have a higher occupancy rate compared to Futures I and II.

**Table 1.** Summary of future parameters

| Parameter | | Value range |
|---|---|---|
| New development strategy | | None or 6 types of block typologies |
| Occupancy rate | | 32 - 38 $m^2$/person |
| Neighbourhood use (residential, commercial, offices) | | 75-100%, 0-15%, 0-15% |
| Residential schedule | | Increased or current |
| Commerical schedule | | Current or decreased |
| Existing building retrofit | Envelope | None, regular, or aggressive |
| | Energy system | Fossil or district |

Neighbourhood use types are categorised into three classes: residential; commercial, which includes retail, restaurants, food stores, gyms, and hotels; and offices. More diverse uses are expected in Futures I and IV with a 15-minute city concept. SIA 2024 [10] is used as the current schedule for both residential and commercial. Due to population ageing, the residential use pattern is foreseen to increase, with 40 % of occupants staying home during the workday at 9 AM-12 PM and 3 PM-5 PM. At the same period, the appliance schedule is increased to 20%. In a centralised city, it is expected that residents' commercial needs are not met solely inside the neighbourhood, which necessitates travel to the city centre. The retail schedules in these futures are assumed to decrease uniformly by 20%.

The retrofit strategy is intended for existing buildings in the neighbourhood, which will eventually be renovated in the future. Three options are possible for envelope retrofitting: none, regular, and aggressive. No retrofitting entails single-glazed windows, minimally insulated walls, and medium air-tightness. Regular retrofitting improves the insulation of the walls. Aggressive retrofitting improves wall insulation, double-glazed windows, and high air-tightness. For energy system retrofitting, the existing building either keeps the current fossil fuel-based systems or is retrofitted with district-based systems. All futures have the same options to retrofit their existing buildings. For new developments, the building conditions are assumed to be on par with aggressive retrofitted existing buildings and supplied by district-based systems. Emissions of these retrofits are accounted for in the future neighbourhood total emissions.

### *2.3. Urban-scale analyses*

City Energy Analyst (CEA) [11] is used to perform urban building energy modelling (UBEM). For the simulations, the Zurich weather at Kloten in 2010 [12] is morphed to a 2050 weather prediction using procedures taken from [13]. A total of 2,208 simulation cases are developed as a result of combinations of four possible futures and the values of the six future parameters.

Three key performance indices (KPI) are utilised for the energy assessment. First, the neighbourhood's space heating, space cooling, domestic hot water, and electricity demands are aggregated from individual buildings as total demand. The demand standard follows SIA 2024 [10]. Second, both embodied and operational life cycle analyses are performed, assuming a time horizon up to 2050. The emission database follows KBOB [14]. Lastly, solar potential metrics of self-sufficiency and self-consumption are analysed assuming a perfect spatial distribution of electricity generated, that is, energy generated at one building can be transferred to another within the same time step. Mono-Si PV modules and an annual solar threshold of 800 kWh/($m^2$.a) are assumed for the simulations.

## 3. Case study

The study methodology is applied in a case study involving a 200-m radius neighbourhood at Altstetten Nord. Figure 2 shows the selected site, its built conditions, and proposed new block

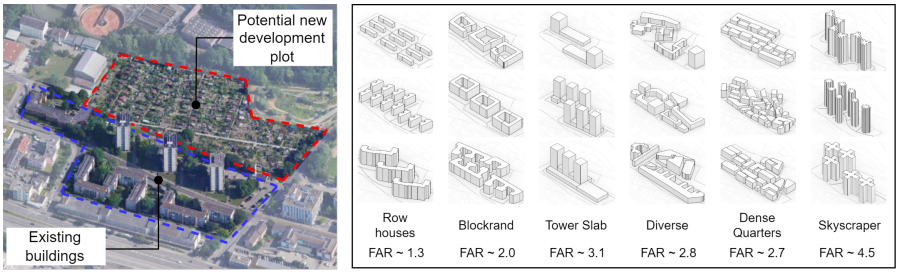


**Figure 2.** Case study site (a) and the potential new development block typologies (b).

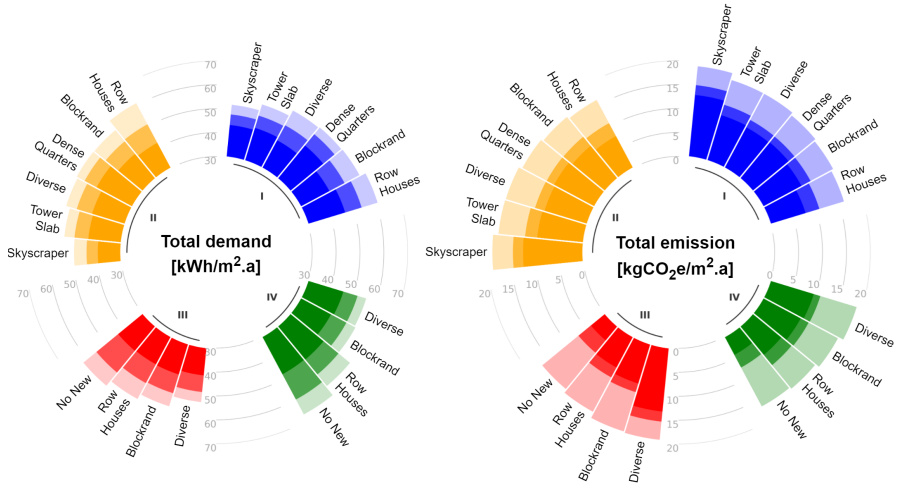


**Figure 3.** Total demands and emissions of plausible future neighbourhoods with different block typologies. The three levels of the bars represent minimum, median, and maximum values.

typologies for this study. The existing buildings were constructed between 1965 and 1976 and are assumed not to have been renovated since. For the potential new development plot, 18 new building typologies are created based on the six urban sprawl samples shown in the methodology. The average FAR of these typologies are also presented. To reflect the plausible, less productive, ageing society in Futures III and IV, having less future development, these futures have fewer options on new typologies: row houses, blockrand, and lower-FAR diverse. They also have the option not to develop at all. Futures I and II have all typology options, but without the option of no new development.

## 4. Results and discussion

The demand and emission performances of different Futures and their densification strategies are illustrated in Figure 3. For total demand, a lower FAR tends to result in a higher demand in all futures. Introducing higher FAR buildings reduces total demand due to the lower surface area to volume ratio, which reduces heat losses from the envelopes. An exception to the FAR-to-demand trend is noted for dense quarters typologies in their median values. The typologies' low-rise, separated volumes increase this compactness ratio even with a high FAR.

Total emission has an inverse relation with FAR. The amount of materials and, consequently, their high embodied emissions contribute heavily to this observation. Since new typologies are assumed to be built uniformly with relatively clean district-based energy systems, the effect of lower or higher operational emissions related to the total demand is negligible compared to the embodied emissions. It is also seen that the maximum emissions are less sensitive to the

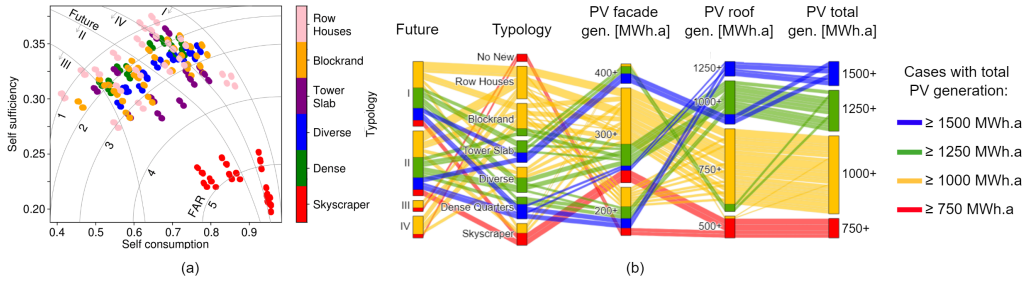


**Figure 4.** Solar generation performances of the neighbourhood for different futures and block typologies. (a) shows the solar performance metrics, and (b) shows the PV electricity generation.

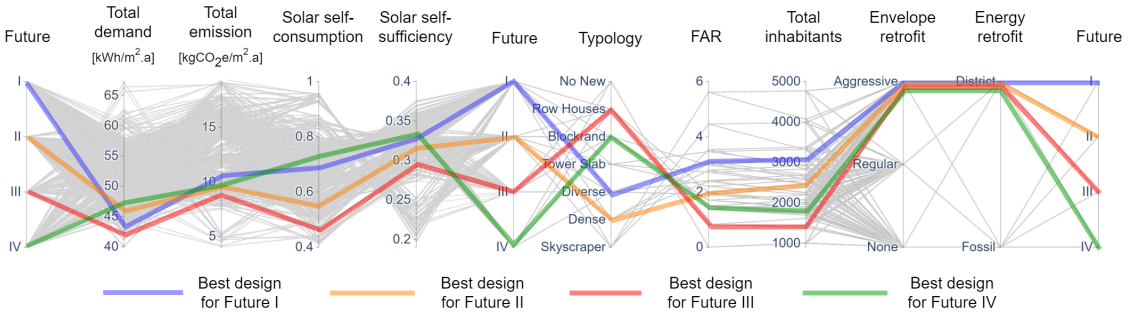


**Figure 5.** All design scenarios in the plausible futures. The highlighted lines represent the best designs for each future with a balanced demand-emission target.

densification strategies. There are scenarios when building new skyscrapers in the neighbourhood is roughly comparable to not constructing new buildings. This is due to the high influence of operational emissions of existing buildings if fossil fuel-based systems are still used there. The impact is also seen through the high discrepancy between median and maximum emissions in all scenarios. Therefore, planning for emission minimisation of a future neighbourhood with new energy-efficient buildings still requires retrofitting strategies for existing buildings.

Three trends shown in Figure 4(a) are observed from analysing different typologies and futures regarding solar generation potentials. First, neighbourhoods with skyscrapers are outliers with high self-consumption and low self-sufficiency. This finding is due to the neighbourhoods with skyscrapers consume more electricity without producing nearly as much as neighbourhoods with other typologies. Even when skyscrapers have larger unobstructed facades, the generation in these surfaces cannot compensate for the loss of potential on roofs, which skyscrapers lack. The situation is contrasted with tower and slab typology, whose flat roofs on its base complement the relatively small tower's roofs, as shown in Figure 4(b). Another observation is the FAR-to-PV metric trend. With a higher FAR, self-consumption tends to increase, and self-sufficiency tends to decrease. The phenomenon is explained similarly to the first observation. The third observation is the effects of different futures on solar potentials. The tendency noted is that the more varied a neighbourhood is in its use types, the higher the self-consumption is. In Future I and IV, whose futures are planned as 15-minute cities, commercial and office spaces are more prevalent. These spaces consume more electricity during the daytime as compared to typical residential areas, which is also shown in Figure 4(b). The magnitude and temporality of the electricity use in these futures result in more solar energy consumed directly on-site.

The three design questions posed in this study are answered as follows:

(i) Developing radically, such as skyscrapers, may not always be the best option. They provide more living spaces for future inhabitants with the most demand-efficient neighbourhoods.

However, they produce larger emissions and less solar generation potential.

(ii) Trade-offs between FAR, demand efficiency, emissions, and solar generation are observed. Generally, demand efficiency can be achieved by developing bigger and more compact structures. These goals often come with larger emissions and less solar generation.

(iii) Four best neighbourhoods for each plausible future are shown in Figure 5. The target is based on the lowest combinations of total demands and emissions. New developments with diverse, dense quarters, row houses, and blockrand typologies are selected respectively for Futures I to IV. Two of the highest FAR typologies, tower slab and skyscraper, are not preferred for this balanced target. For Futures III and IV, where the population is older and less productive, fewer new inhabitants are expected; hence, smaller FAR typologies are found to be sufficient. For exploring other design scenarios, a dynamic design explorer can be accessed here: `https://github.com/bnutr/plausible_future_UBEM`.

## 5. Conclusions

This study shows the impacts of future densification on urban energy performance for four plausible futures in Zurich. Skyscrapers, despite their higher densification with lower energy demands, produce higher embodied emissions that outweigh the savings in operational emissions. Furthermore, the loss of solar generation on its roofs is not compensated for on its facades. These trade-offs between the performances should be considered when densifying neighbourhoods for plausible futures. Lastly, renovating existing buildings plays a crucial role in minimising neighbourhood emissions, even with new energy-efficient developments. Future works include considerations on inter-neighbourhood and mobility impacts due to the densification strategies.

## 6. Acknowledgments

This study was conducted in the Integrated Design Project course by the Professorship of Architecture and Building Systems under Prof. Dr. Arno Schlueter. Special thanks to Dr. Michelle Yingying Jiang for her inputs and ETHZ LVML for the computational resources.

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