Bauhaus-Universität Weimar

Urban building energy modeling:

A sustainability & energy study analyzing design proposals of the Ecovillage Hannover competition

Master Thesis
Summer Semester 2019 / 20
Faculty of Architecture

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bauhaus ifex

IUDD Integrated Urban Development and Design

Bauhaus-Universität Weimar

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Master thesis submitted during summer semester 2019 / 2020

at the Bauhaus-University Weimar

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Study course Integrated Urban Development & Design

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Place, Date:	Weimar, 31. August 2020

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List of abbreviations

AEC	Effective catchment area
ASE	Annual sunlight exposure
BCR	Building coverage ratio
CHPP	Combined heat and power plant
EEA	European Environmental Agency
EnEV	Energieeinsparverordnung (Ger. - Energy Saving Ordinance)
EU	European Union
EUI	Energy use intensity
EVH	Ecovillage Hannover
FAR	Floor to Area Ratio
GFA	Gross floor area
GHG	Greenhouse gases
GHI	Global horizontal irradiance
HLFF	Heat loss form factor
NECP	National energy and climate plans
NZEB	Nearly zero-energy buildings
POA	Plane of array
PV	Photovoltaic
RQ	Research question
Q_h	Heating consumption
sDA	Spatial daylight autonomy
SI	Solar irradiation
SVR	Surface to volume ratio
tCO_2e	tons of carbon dioxide equivalent
UBEM	Urban building energy modelling
UTCI	Universal thermal comfort index

Abstract

The combination of new energy efficiency building standards and new technologies ultimately shape the building environment into a more sustainable one. However, after summarizing the current problems and partial solutions to the negative environmental impact of the building & construction sector it is clear that more has to be done to mitigate the already ongoing climate crisis. This thesis examines an emerging method for sustainable urban planning applicable in the earlier stages of the urban design process called UBEM - urban energy building modelling. The method consist of simulating energy demand of urban design proposals and with the help of other sustainable performance simulations it will be applied of the ongoing urban planning competition Ecovillage Hannover. The goal is to identify which of the enrolled seven urban design proposals at most fulfils the criteria of a sustainable urban design. From the various assessed criteria - heating energy consumption, solar power and rainwater harvest, thermal and daylight comforts the efficiency of the heating consumption proves to be the largest CO2 contributor, hence the most important criterion of sustainability. From the comparison of the seven urban design proposals, the 5th proposal (Jensen und Hultsch Architekten & Assmann Beraten + Planen) has proven to be the most energy efficient. The thesis also examines other existing studies and confirms the lack integration of tools using UBEM methods in the urban projects, which results in lack of sustainability's role in this field. On top of UBEM, another computational method of energy optimization has been acclaimed in this thesis as a prospective urban planning efficiency tool.

Foreword

For some people finding a concrete thesis topic can be as hard as writing a thesis. In my case, the selection of the field I wanted to focus on was pretty straightforward. It comes after recent years of accumulating my discord with the world's handling of the ongoing climate crisis, also being heavily influenced by the architecture business. It happened on my last internship, when I realized that our planet is not on the top of architects' priority list, as it was communicated from the recent global declaration of construction business (Constructions Declares, 2019).

I have completed a Master in Architecture, and was doubtful about my qualifications. The studies were long and hard, yet I was not feeling that I am prepared to enter the work environment. (we can get sucked and easily forget about the innovativeness and free thinking in school) I was not sure what exactly I wanted to do, so I decided to spend two more years in finding my distinct passion in the architecture field through another Master. With every university project I had an unsettling feeling, while forming my final defence argumentation. Not just of my own projects, but also the argumentation behind many others both from my fellow students and real projects being built around us. They started to appear to me as just lousy excuses for getting a project approval. What does it really mean, the playfulness of forms, nice gradation sexy minimalism? I found myself to be using these terms too. Who taught me this? Everybody in the business. These architectural terms are spreading around, and I caught up to them, but I did not believe in them contributing to a really prosperous design. Why were we not taught scientific arguments? Why are there not any subjects about climate engineering? What is the true defining quality of a design?

In my current studies there has been indications of methods with which we can in fact measure the quality of a design, rather than to evaluate them subjectively. Such quantifiable methods, are not always perfect or precise, because defining what quality means is tricky and often still subjective. But it is worth to try it and evolve our ancient discipline of architecture, with new technological tools. The previous century was full of inventions which also resulted in many new problems. In the current century we should aim to fix them.

I was provoked to study for two more years to find my aspiration in architecture and urbanism, and I think I did. It is time to change the perspective and put climate engineering on the top of what is considered "sexy" in the world of architecture.

1. Introduction

• Background

There are many techniques and technologies that can be used to reduce the ecological footprint of buildings. Systems like PV panels, insulation or heat pumps indeed remarkably reduce the amount of emissions required for the building's operation. Generally the bigger the investment, the more of the available technologies can be integrated into a building, resulting in a more effective performance. However, a properly efficient design should not simply try to implement as many sustainable technologies as possible, but also fulfil certain building shape conditions that also play a significant role in its energy consumption. Compact building shapes with smaller building envelopes generally reduce their heating demands.

This thesis focuses on ongoing (at the time of its writing) project called Ecovillage Hannover. After the initial process of settling what should the future urban quarter, located at the fringe of a city, offer for its future inhabitants an international competition was announced with seven participants taking part. As the term "ecovillage" implies, the project revolves around sufficiency and sustainability. Therefore, an energy performance of such project will be an important deciding criteria at the end of the competition. This thesis analyses the seven preliminary urban design proposals by simulating besides others, mainly their future energy performances. This method of designing is called urban building energy modelling (UBEM) and it can help to inform the designers about important thermal energy data, before any more detailed planning of the design process takes place in the second stage of the competition.

• Goal

The thesis acts as a sustainability and comparison study that examines following research question:

Which of the seven design proposals performs the best in accordance with sustainable principles?

The results can help inform the designers about how their designing principles influence the thermal energy performance, to know what needs to be further revised or if the designer should try a completely new design approach. The UBEM is showing great potential in designing sustainable cities in the times of global climate crisis at our doorstep. However, such methods of designing are still quite rare in the planning discipline. Therefore a second research question will examine:

What are the problems in implementing sustainable energy planning methods in urban projects?

It investigates the use of similar methods for analysing and planning such as the ones that are used in this thesis to evaluate Ecovillage Hannover.

• Methods

Firstly the thesis stresses out the relevance of the research with examining the impact of the building and construction sector on the climate crisis and what techniques are already being used for mitigating this impact. They include energy related goals and ordinances in Germany and the EU, and the urban design aspects. In the next, third chapter a more detailed look at the Ecovillage Hannover project is presented, in order to identify all the attributes that the winning design proposal should accomplish. To get an even better idea what qualities a successful ecovillage should possess, additional urban case studies are reviewed.

Based on the collected information from the research and from consultations with an energy experts working group from the EVH cooperative, in the fourth chapter the assessing criteria for the design proposals are selected. Usually for an urban project the quantifiable criteria consist of measures such as density, living area or number of stories. The assessed criteria in this thesis however, can only be measured after the appropriate interpretation of sustainable qualities such as accessibility, interconnectedness, climate-neutrality or sufficiency. Therefore an environmental-design related set of plugins called Ladybug tools is used to analyse the chosen assessment criteria.

Since most of the energy consumption of residential buildings comes from the heating demand, it is the most focused assessment criteria in this thesis. Basic principles for efficient heating demands are explored. The other assessment criteria include the potential use of solar energy, harvesting rainwater, outdoor comfort and daylight exposure, together making up the 'analysis toolbox'. For the analyses to be correct, the seven design proposals shall be remodelled in the Rhinoceros modelling environment with identical size parameters (such as floor height) for objectiveness.

• Results

The fifth chapter presents the individual results of the design proposals in a graphical form, where their weak spots can be identified. However, an evaluation with answers to the first research question are defined in the sixth chapter. The evaluation goes through each of the analysed criteria with explanation why a certain proposal performs better than the other in this aspect. A summary follows with determining the design proposal most in line with the sustainable urban planning principles. It can inform the designers which parameters are worth to adjust in order to gain better energy efficiency. Such comparison might be used on more competitions and projects, because it can reveal advantages of a design that might not be clear or visible from the first glance. The second research question is also answered in chapter six, with a closer look at the UBEM methods.

The advantage of competitions in architectural and urban projects is the possibility of examining already more than one design concept. However, the potential of almost infinite other alternatives still remains unexplored. Therefore lastly, in the seventh chapter Outlook, the thesis briefly explores the topic of energy optimization. Optimizing a design proposal can create new variations of the original one, whose performance may be improved, at least slightly. Even a 1% lower energy consumption during the whole lifespan of a building can return a substantial amount of tCO_2e not being released into the environment. There are many constraints when it comes to the structure of an urban plan such as structural modules of the buildings, minimum distances, daylight regulations that limit the area of parameters "fine-tuning". Therefore, only a simple modification of the building sizes was conducted to avoid interference with the original design's spatial concept.

- **Conclusion**

The ambition of this thesis is to contribute with an energy analysis to the already remarkably ambitious project of EVH. While focusing mainly on the urban planning aspect of the energy assessment, there are other technical and social criteria that make up a prosperous urban quarter.

2. State of the art

This chapter serves as an introduction to the importance of sustainability in the global building sector. EU's ambitions for the next decades are introduced as well as German energy performance measurements and certificates. The chapter also explores what are the current sustainability measures in both the architectural and urban scale, which also with the 3rd chapter leads then into the 4th chapter where the assessment methods will be later introduced.

2.1 Greenhouse gas emissions

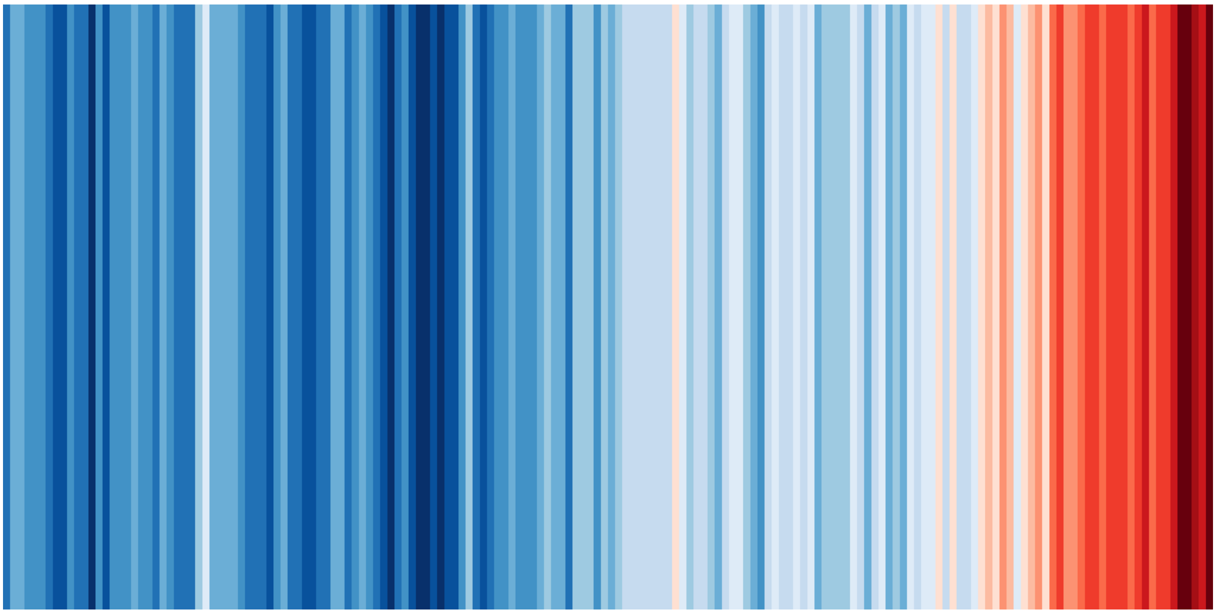


Figure 1: Warming stripes for globe from 1850 - 2019 (Hawkins, 2019)

In 2018 the first publication of the "Warming Stripes" graphic appeared. Developed by a climate scientist Ed Hawkins of the University of Reading, the stripes represent the change in temperature for each year in the period of 1850 – 2019. The pureness of the graphic, atypical for a graph without any labels, means to start conversation and bring awareness to the seriousness of the rising global temperatures (Hawkins, 2019).

Although still unacknowledged by some people or nations, reasons for the rising global temperatures include cutting down forests, farming livestock and mainly burning fossil fuels. These processes are releasing different gases such as CO_2, methane or nitrous oxide into the atmosphere, which then trap the sun's heat inside rather than releasing it back into space. Although these greenhouse gases (GHG) were always part of the global ecosystem, their increased presence is indeed due to human activity (European Commission, 2017a).

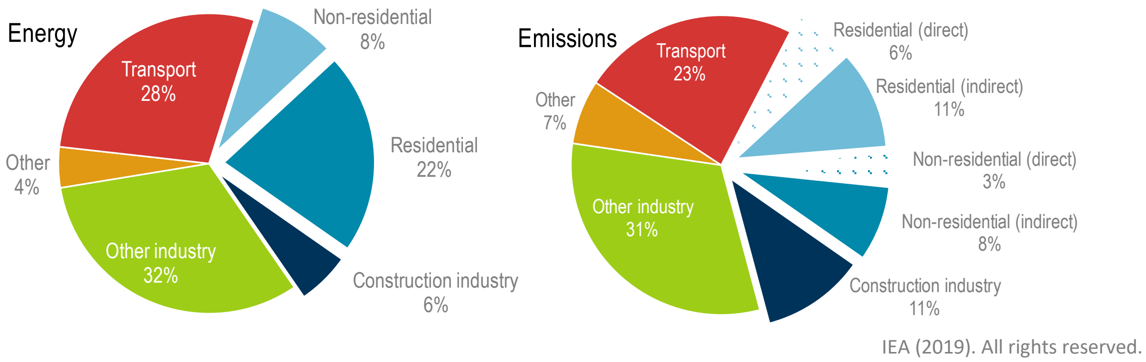


Figure 2: Changes in floor area, population, buildings sector energy use and energy-related emissions globally, 2010-18 (IEA, 2019)

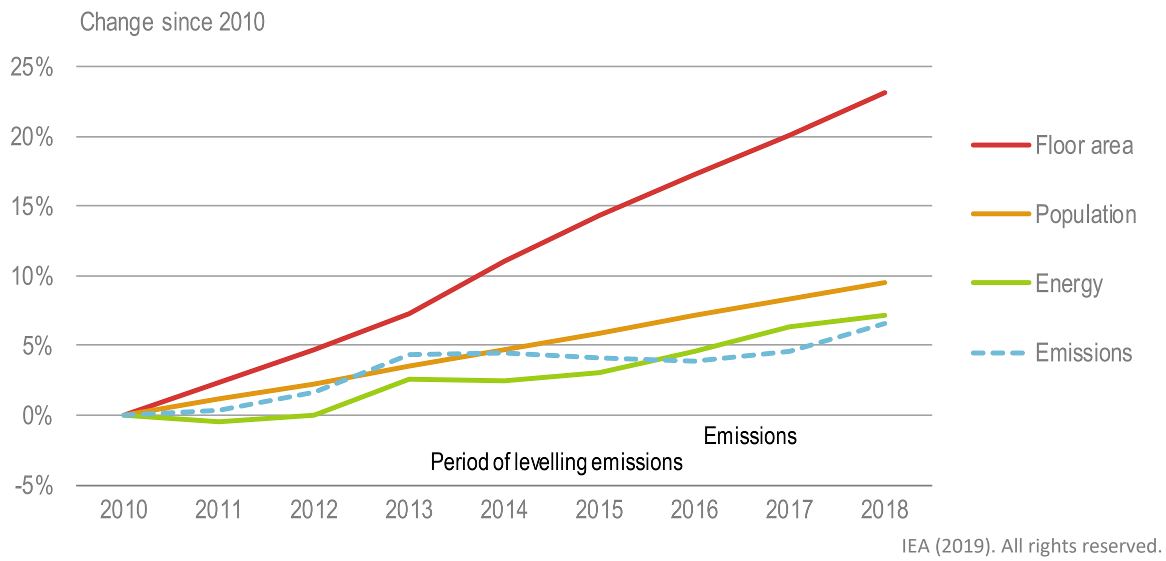


Figure 3: Global share of buildings and construction final energy and emissions, 2018 (IEA, 2019)

When it comes to comparison of the amount of global CO_2 emissions, the situation in the building and construction sector is alarming. According to International Energy Agency (IEA), this sector accounted for the largest shares of CO_2 emissions (39%) and of final energy use (36%) in 2018. Closer look at the data from 2010 – 2018 reveal following causes:

• both population and floor space demand have been increasing in the years 2010 - 2018

• despite higher demand, there has been an emission drop during 2013 – 2016 as a result of more energy efficient space heating (better building envelopes) and electricity consumption (shift towards LEDs)

• the subsequent emissions rise after 2016 is caused mainly by coal-based electricity generation from emerging economies

• as for the energy sources, renewables recorded the biggest increase in use of 21%, natural gas rose 8% and the slowly discontinuing coal dropped 10%

• generally space cooling is the only rising building sector's category in intensity, caused by its boost in the developing countries of the global south (IEA, 2019)

To sum up, there are visible improvements in the efficiency of the building and construction sector, but seemingly it is not enough. The offsets obtained with the improved efficiency measures are quickly drained by the growth of demand. Therefore, more efforts are being introduced to improve efficiency and new goals set for carbon-free economies. The Paris Agreement, Green New Deal or European Green Deal have all set ambitious goals. It is important to remember that the building and construction sector is the main emitter.

2.2 Short and long-term ambitions 2020-2050

In 2007 the EU set its first 'EU climate and energy targets' for the year 2020. These goals include a 20% improvement (from the 1990 levels) in these three categories:

• 20% cut in GHG emissions

• 20% of EU energy from renewables

• 20% improvement in energy efficiency

These goals however translate into individual national energy and climate plans (NECP), since not every country commences the energy shift from the same condition (European Commission, 2020a). According to the latest summarized data from 2017, the EU is on track in cutting the GHG emission with cut being already at 21.7%. The biggest drops however occurred in the 1990s as a result of phasing out of coal towards gas, after 2009 as a result of the economic crisis, but also because of shifts towards renewables and increased efficiencies. The EU is on track towards the goal of 20% renewables share, although the pace of transition has slowed down since 2014. On the positive side, the falling costs of solar installations and wind turbines will probably result in wider implementations (Eurostat, 2019).

In 2014 another 'climate & energy framework' was adopted for 2030 (targets increased in 2018) (European Commission, 2017b):

• at least 40% cut in GHG emissions

• at least 32% of EU energy from renewables

• at least 32.5% improvement in energy efficiency

The EU realizes the building sector's weight and has therefore set measures to improve both the existing building stock and the newly constructed buildings, such as: (European Commission, 2020b)

• Each country shall set their own renovation strategies aiming to decarbonize the older building stock by 2050

• from 31st December 2020 all newly constructed buildings must be at least of the nearly zero-energy buildings (NZEB) standard, however its definition varies throughout Europe (Ecofys, 2013).

These and other similar measures are in line with the newest growth strategy introduced in December 2019 – European Green Deal. The deal so far promises total investments of one trillion € and reaching full climate neutrality in Europe by 2050 where economic growth is no longer dependent on resource use. So far this is done via many leaflets stating vague measures in the building sector such as incentives for energy-efficiency, designing in line with the circular economy, increased digitalisation (European Commission, 2019). The member states and the EU are constantly facing criticism that the NECPs often allow for new developments associated with harvesting fossil fuels (Bankwatch Network, 2020). According to WWF, the new EU climate law shall put an immediate ban on all subsidies benefiting fossil fuels, increase the pace to reach climate neutrality by 2040 to comply with the Paris Agreement's limit on global warming at 1.5°C and create an independent scientific body for investigating EU's policies and actions (WWF, 2020).

2.3 Building energy performances

When it comes to building's energy efficiency, Germany's sustainable standards and measures has put the country on the leading positions in implementing change in the building and constructions sector. This subchapter examines the lawful energy performance certificate EnEV and the globally used Passive-house standard.

There are multiple units of measurement that describe the energy demands of the buildings. In order not to confuse different units of measurement and make clear, which one refers to which calculation, definitions from both European and national German sources were studied.

• **Heating consumption (Heizwärmebedarf)** Q_h represents the amount of thermal energy that is needed to heat up the living spaces of a building up to a designated temperature in order to comply with the human comfort (Brumme, 2018). The unit used in this thesis [kWh/(m²a)] specifically indicates the energy (kWh) needed to heat up 1 square meter (m²) of living space, annually (a).

• **Final energy consumption (Endenergiebedarf)** Q_E represents the amount of energy effectively used in the household itself. In other words, it is the energy that reaches the household, without including any energy losses caused during its generation or transport (Bosch Thermotechnik, 2018). Besides the thermal energy for heating, it also includes the energy used for water heating, ventilation, cooling and the electricity supply (Eurostat, 2018).

• **Primary energy consumption (Primärenergiebedarf)** Q_P represents the energy specified in the final energy consumption, including the energy consumption of the energy sector itself, which was needed for generation, transformation and distribution of the needed household's energy (Eurostat, 2018b). The amount depends on the energy sources and uses a **primary energy factor** e_p defining the energy-saving property of the source. Therefore, the factor is lower when using more renewable sources of energy.

Energy source	e_p
Renewables	0.0
Wood	0.2
Oil fuel	1.1
Natural gas	1.1

Table 1: Primary energy factors of different energy sources (Baunetz_Wissen, 2014)

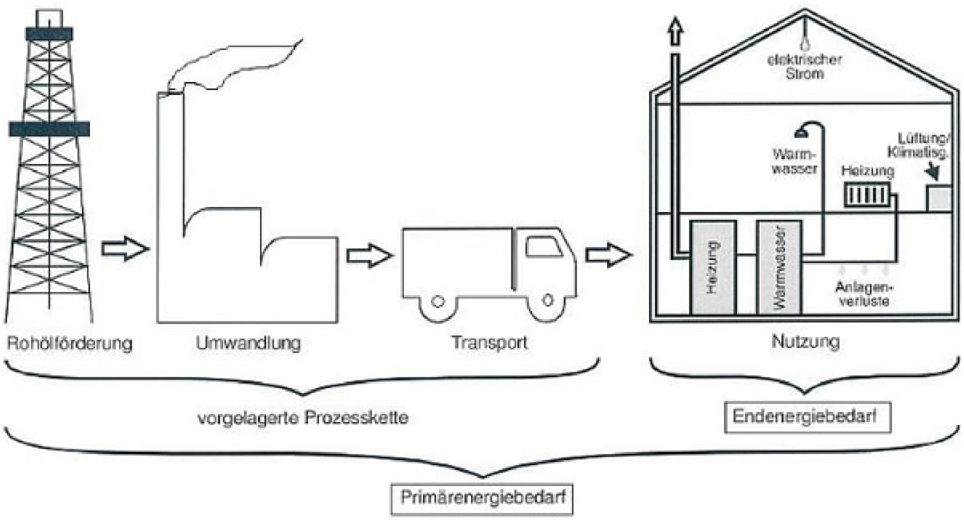


Figure 4: Distinction between primary energy consumption und final energy consumption (Bosch Thermotechnik, 2018)

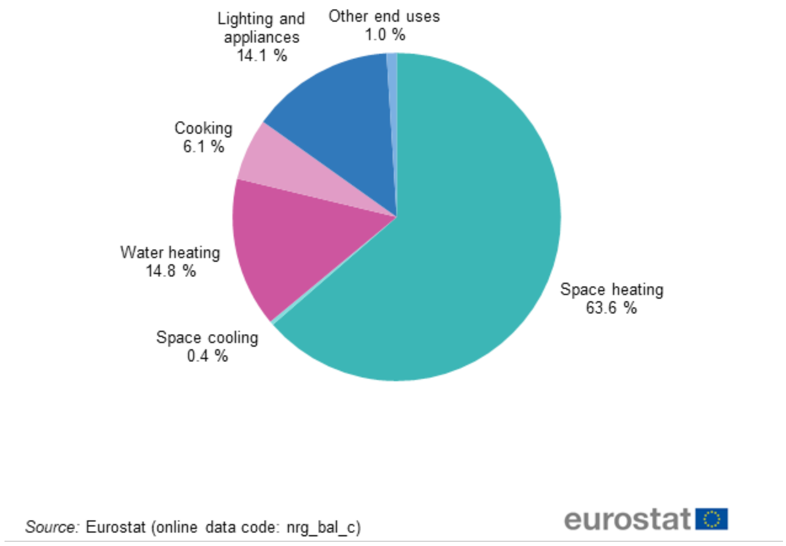


Figure 5: Final energy consumption in the residential sector by use, EU-27, 2018 (Eurostat, 2020)

As shown before, the building sector makes up a large portion of the global energy consumption. It is also clear as shown in Figure 5, that heating is the main cause of residential sector's high energy demand, in Germany it is around 66% (Eurostat, 2020). Therefore, any actions towards lowering the energy demand should focus primarily on heating consumption.

German Energy Saving Ordinance

The energy efficiency of buildings in Germany is documented with an energy performance certificate (Energieausweis), which is regulated by the Energy Saving Ordinance (Energieeinsparverordnung – EnEV). It distinguishes between residential buildings and non-residential buildings (Jungmann & Lambrecht, 2009).

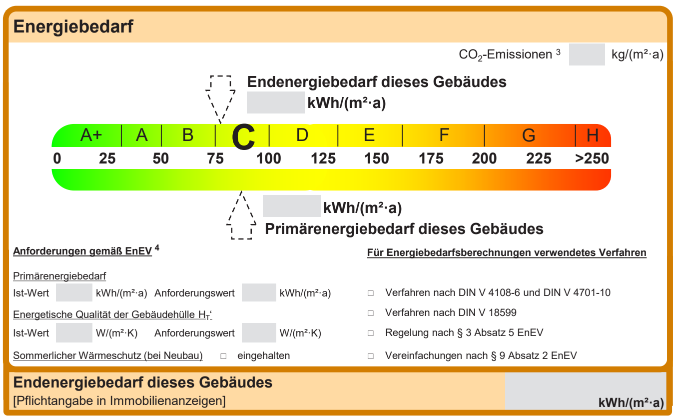


Figure 6: Model of the energy demand rating from EnEV (Jungmann & Lambrecht, 2009)

The documents state both the calculated yearly final/primary energy need and the recorded final/primary energy consumption of the previous year. As described earlier, the energy demand is measured in kilowatt-hour per square meter and year (kWh/(m²a)) unit, which are corresponding to an energy rating index. This way different buildings can be compared, which can help a potential buyer or a lodger to get a better idea about future energy costs. For this reason, a table stating different energy sources, their effectiveness and a sustainability factor is also part of the EnEV.

The biggest factor influencing the building's energy efficiency is its construction. The thermal insulation in the walls and roofs, windows or any part of the buildings that is in contact with the exterior will impact the heating demand. The standards for newer constructions are being regularly increased and the meaning of "energy-efficiency" is therefore constantly being challenged.

It should be noted however, that the energy demand also depends on the user's behavior. Because the daily routines of different occupants vary, also the amount of time spent at home can affect the need to heat up the rooms. Similarly, the size of the household or family can affect the energy or water demand *(Jungmann & Lambrecht, 2009)*.

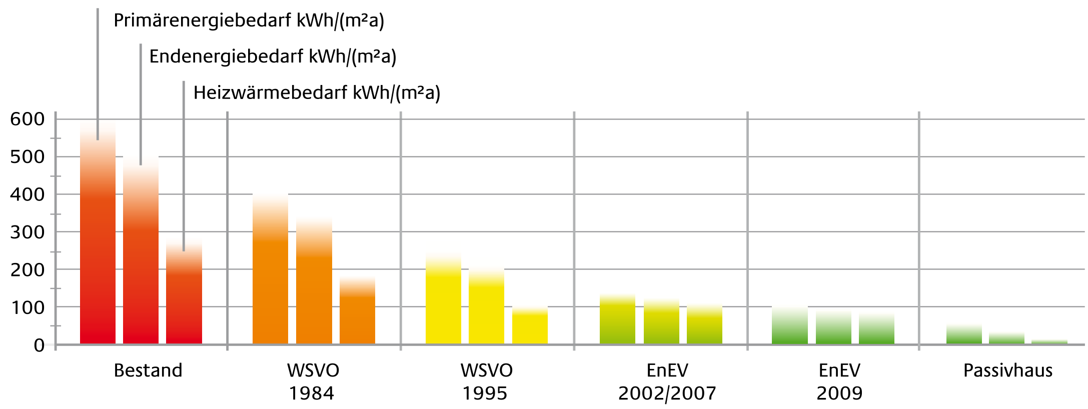


Figure 7: Comparison of different energy standards (Jungmann & Lambrecht, 2009)

The EVH competition strives to reach a high degree of ecological sustainability, therefore the energy demand is given a high importance. The future quarter will therefore continue the already set standard in the Hannover Kronsberg area and planning is assumed to develop the residential units in the passive-house standard.

Passive-house standard

The term Passive House does not represent a brand, but rather a building concept. According to the Passive House Institute, this standard allows for 90% of energy savings compared to typical building stock, or 75% compared to newer buildings, without any decreases on the human comfort (Passive House Institute, 2015). As the term suggests, it adopts mainly passive heating and cooling strategies like efficient use of the sun, shading or air supply. Such simple and capable techniques are economically affordable, however an efficient energy system requires also high-quality equipment such as well insulated building constructions and components. Additional economical savings become evident throughout the building's operation by noticeably lower energy bills. The current standard in Germany sets a passive house's heating consumption limit at 15 kWh/(m²a).

EVH aims for a specially promoted standard of passive houses, which can be partially financed by KfW *Kreditanstalt für Wiederaufbau* - the German Credit Institute for Redevelopment - by the means of funding. The "KfW-Effizienzhaus 40" which relates to a reference building stated in the EnEV 2009 (EnEV, 2009) should not exceed these two values:

• Yearly primary energy consumption (Q_p): 40 % of the reference building

• Transmission heat loss (HT): 55 % of the reference building (Wissen Wiki, 2013)

The energy standards in EnEV state the minimal physical requirements of the construction via the Heat transfer coefficient U [W/(m²K)]. These can be calculated based on the layers of materials in the constructions. The inputs used in the heating demand simulations of this thesis are the below shown layers of construction, without a heat transfer coefficient as an output. Therefore, the needed construction properties were approximately derived from an example construction of KfW-Effizienzhaus 55 (KfW, 2020) and the Construction Manual for passive houses (Fingerling et al., 200x).

2.4 Impact of energy-related aspects on urban design

As the case studies in the upcoming 3rd chapter indicate, energy related issues are getting proper attention when it comes to some urban-scale projects. However due to the subsequent disregarding of other social and urban planning issues, the projects main aspects (e.g. compact forms) can seem too often single-narrowed. That's why often urban planners rather avoid energy related issues, as they see a different perspective in the design approach than energy engineers (Yang & Yan, 2016).

Below are summed up different sets of actions, all urban planning principles useful for urban planners in their projects.

• **Density**
Density is a fundamental attribute with a big influence on projects, for the most part it is not in the hands of the planners but rather of the stakeholders. It directly effects energy consumption through the urban heat island (UHI) effect, which causes increase in

temperature of urban surfaces (Taha, 1997). Contrarily, it was also proved that the more the urban fabrics are clustered next to each other, the lower heat is emitted to the outside during the cold season (Ewing & Rong, 2008).

• Principles of compact buildings

Compactness of a building is often defined by how much of external faces (e.g. walls, roofs) a building has compared to its floor area. During the heating period when the difference between external and internal temperature is considerable the heat from inside escapes through these external faces to the outside. Therefore the less external faces a building has, the more energy efficient it is.

Recessions / setbacks – Although features such as balconies or recessed entrances are more a topic of architectural detailing, because they create additional external faces they also have a negative effect on the building's compactness.

Number of storeys – Higher number of storeys do not only make the building shape more compact, but because of the fact that heat rises it passes into neighbouring flats, which makes the higher located flats less dependent on their own heating energy. This effect can be occurring more likely in older building stock and it declines with four and more storeys (Kollárová, 2014) (Gonzalo & Rainer, 2014).

• Principles of solar urban design

The south orientation maximizes the solar gains, which then reduces the need for heating. It also increases the efficiency of PV panels and solar collectors.

Use of vegetation – By planting deciduous trees, the needed shading is achieved in summer, which is then unwanted and minimal in the winter when the trees shed their leaves.

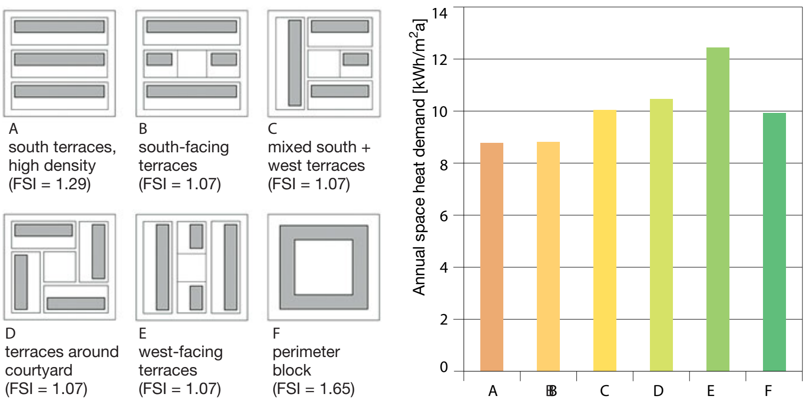


Figure 8: Influence of urban arrangements on the heating demand of apartments built in Passive-house standard (Gonzalo & Rainer, 2014)

• **They can results in conflicting situations such as:**
The south-facing orientation is not an element that can be achieved in every project. Often there are already existing obstructions concerning the given plot such as adjacent context or infrastructure, which may not allow for an uninterrupted southern orientation. The unobstructed orientation also conflicts with another principle of efficiency - high density. The compact shape requirement, which can have a form of a square building footprint can cause more conflicts when creating other than south oriented frontages.

Height and depth regulations can interfere with planning a more compact shaped buildings. While the height regulations are often specific for a site, the building's depth depends on the country's daylight regulations for different typologies (Gonzalo & Rainer, 2014).

3. Case studies

This chapter serves as an introduction to the importance of sustainability in the global building sector. The following examination of the case study of Ecovillage Hannover will present the project's goals and position among German sustainable urban projects, while also defining what ecovillages stand for. The chapter also explores what defines sustainability in both the architectural and urban scale, which then leads into the 4th chapter where the assessment methods will be later introduced.

3.1 Case of Ecovillage Hannover

The competition is based on a land-use plan (Ger. - Bebauungsplan) approved by the city of Hannover in 1996. Much of the Kronsberg site was developed already in the 1990s as a part of the Hannover 2000 EXPO. It aimed already at that time to showcase a sustainable approach to city planning. The municipality has set an energy standard for the new development in Kronsberg of a maximum energy demand of 50 kWh/m^2a, the EVH however, aims with its climate-neutral goals even higher (EVH e.G., 2020a). The EVH quarter shall be built on 3 parcels in the north part of Kronsberg, with the total size of about 5 ha. It should provide ca. 500 dwellings for about 900 people divided into three diverse typologies: 55% of apartment houses, 35% of module houses or smaller apartment houses and 10% of free-standing tiny houses (Transition Town Hannover, 2019).

The EVH Planning Process

The planning process of EVH is a contemporary example of a transparent and a bottom-up process. Throughout 2019 around 200 people and 16 working groups worked on a concept which eventually led to establishing the "Ecovillage Hannover Cooperative" in October 2019 (EVH e.G., 2020b).

At the start of the planning process a „production of wishes" was conducted through a number of workshops. This brought together perspective future inhabitants who had a chance to express their vision of living in such quarter and exchange opinions with others. Via a playful handling with physical models, collages and texts, first data in a form of numbers such as quantity of inhabitants and buildings density emerged (Amsel Kollektiv, 2019). Additionally, results from the work of different working groups such as Energy concept, Social life or Mobility concept were produced. All results were then collected in a „book of wishes", that served as a guideline for a cooperative urban planning competition, which was announced in January 2020.

The project has set some specific attributes, which all contribute to its sustainable fundamental:

• Sufficiency, which asks the questions how much space do we actually need in our homes and whether we can reduce it by including more sharable zones, without losing our private sphere.

• Sustainability, taking account its all three pillars – ecological, economical and social. It strives for 100% energy supply from renewable sources, car-free mobility and avoidance of polluting materials.

• Affordability, as living is one of the basic needs. A reachable goal that goes parallel with the reduction of the personal living area and the energy efficient measures. Pre-fabricated building modules is another prospective economical effort.

• Material circularity, as it is existing in nature. Possibly closed material loops are also planned for this future-proof quarter (EVH e.G., 2020b).

Ecovillage

What particularities does an ecovillage embodies and why there is such an interest in living there?

As it is known for every planner, the world population is constantly urbanizing and since 2007 there are more people living in cities then in rural areas (Ritchie & Roser, 2019). However, the high density and rushed life of the European cities eventually changes some people's minds and forces them to move back to the countryside – losing all the benefits of larger town like better job opportunities, easy access to a variety of functions, generally a certain modern lifestyle. But the Kronsberg area provided the people of Lower Saxony an alternative, balancing the advantages of both urban environments. While still in the city, being connected via the tram line its location on the city's margin has the aspects of a countryside.

Robert Gilman, a sustainability thinker and pioneer defined in 1991 what ecovillage should represent – a "human-scale full-featured settlement in which human activities are harmlessly integrated into the natural world in a way that is supportive of healthy human development, and can be successfully continued into the indefinite future" (Gilman, 1991). Indeed an ecovillage has more identifiable factors, mostly in a form of offered activities that people do seamlessly as a part of their everyday life.

The principles of an ecovillage can be best described with a real and successful example in Germany, the Ökodorf Sieben Linden, located in Saxony-Anhalt. Its location is of a different character than the one of Ecovillage Hannover, as it does not have such a close proximity to a larger urbanized area. However, the core message of an ecovillage applies to all and can be summed up as the synergy or co-living of people with nature, where ecological form of living is integrated in all scopes (Ökodorf Sieben Linden, 2015).

Ecology – the human impact on the natural capital can be measured by the means of an ecological (or carbon) footprint (Global Footprint Network, 2016). Although everybody can measure their personal footprint via a simple online calculator, in Ökodorf Sieben Linden two thorough studies were conducted by the Gesamthochschule Kassel (2004) and the Politecnico di Torino (2019) (Ökodorf Sieben Linden, 2020a). The more recent result uncovered that the ecovillage has an ecological footprint at 27% of the German average (excluding services), while the 2004 study measured 52% of the German average at that time (Bocco, A., & Gerace M., & Pollini, S., 2019). According to the residents, the result is due to the vegan and vegeterian diets, car-sharing, well isolated homes and avoidance of air travel. Additionaly natural practices as closing of material and water and energy cycles means that most of the natural capital consumed is self-yielded from the ecovillage's surroundings (Ökodorf Sieben Linden, 2020b).

Economy – the ecovillage functions as a cooperative (Ger. – Genossenschaft). Every inhabitant is part of this cooperative and via its shares it finances the cost concerning the grounds and infrastructure. The money that comes into the ecovillage is meant to circle between the different professions, before it leaves the village (Ökodorf Sieben Linden, 2020c).

Community – The third aspect is the social way of living. Since the inhabitants tend to practice many of their activities together, a community building is an important part of an ecovillage. Even daily activities like common dinners take place there, which results in smaller private area demand in the individual residential units.

3.2 Other case studies

The goal of the study is to get a clearer pictures about the aspects that are making a particular project ecological. The study can prove helpful to compose the Assessment toolbox. Additionally, the case studies may reveal, if it in fact is possible to reach 100% renewable energy supply and if not, what were the issues in the process.

- **Hannover-Kronsberg**

History: The idea of an ecovillage in the area of Kronsberg in Hannover does not come unforeseen. The first incentive for developing a sustainable quarter comes from the World Exhibition EXPO 2000 held in Hannover. The topic of the Expo 'Humankind-Nature-Technology' called for a flagship project, showcasing Germany's advanced urban-planning, ecological and social-planning standards in the 21st century (LHH, 2013). By the time of the EXPO, 2700 residential units were constructed in the Kronsberg area.

Urbanism: A tram line connecting the Kronsberg area with the Hannover center was extended to the site of the EXPO, and provides three tram stops parallel to the 1,5 km long site (Wikipedia, 2020a). The urban plan made from a grid of urban blocks with the size of approx. 120 x 120 meters is partitioned into three sections, each characterized by neighbourhood park in the middle covering one urban block. Generally, the western urban blocks closer to the tramline consist of higher four- to five-storey buildings with FAR 1.2, while also providing most of the social infrastructure as educational facilities, shops and community centers. The buildings on the eastern side are illustrating more the farmland character, usually two- to three-storey houses with FAR 0.7.

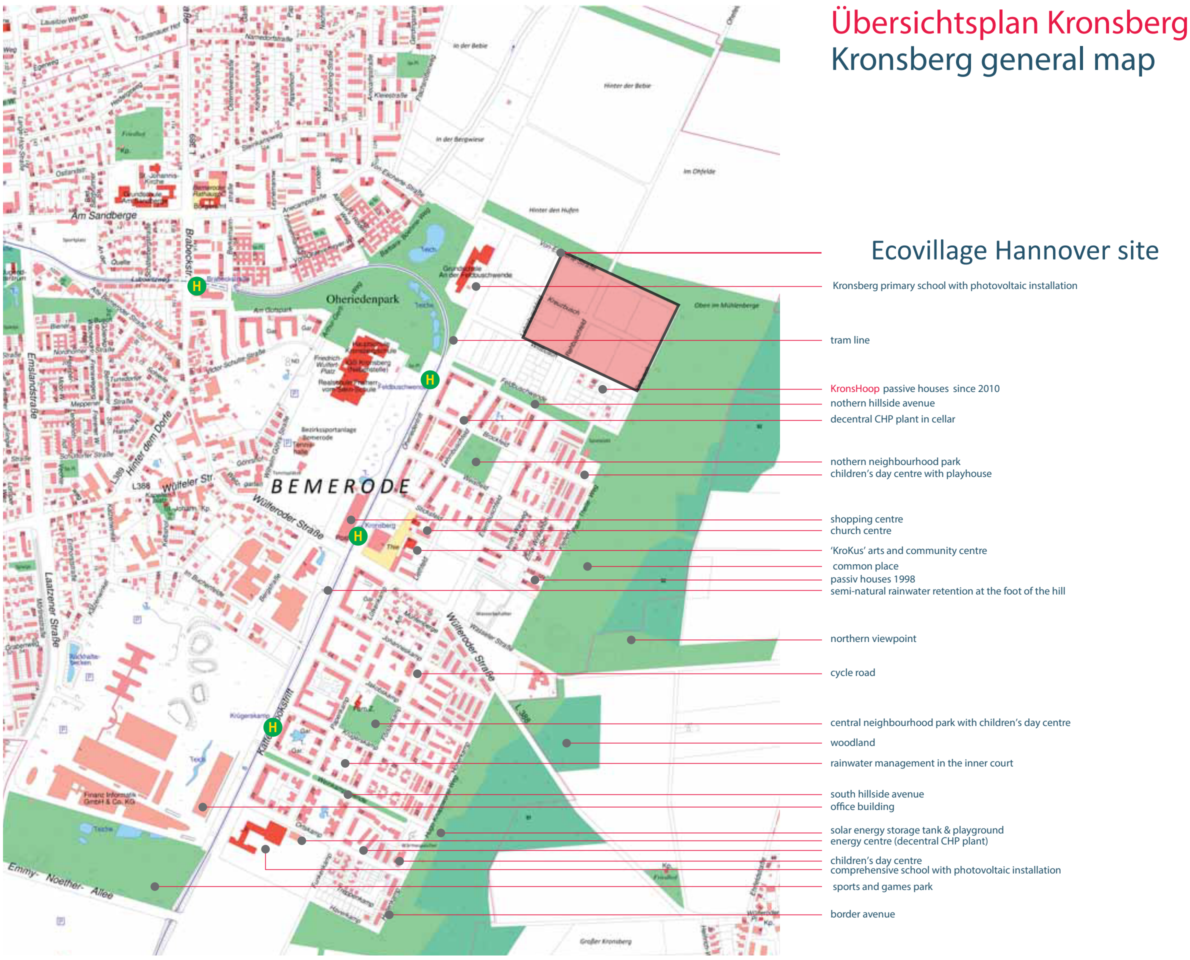


Figure 9: Kronsberg general plan (LHH, 2004)

Energy: The energy concept of the new area relied on low-energy consumption as a result of better insulation measures. This passive-house method was used even before the foundation of the Passivhaus Institute in 1996. For the energy source, two decentral combined heat & power plants (CHPP) were set up in the district. The rest of the electricity demands were covered by two large wind turbines located in the fields about 1.5 km away. The maximum heating energy requirement of 55 kWh/m²a was agreed on in 1995, which was about 30% of the conventional German new construction standard at the time (LHH, 2013).

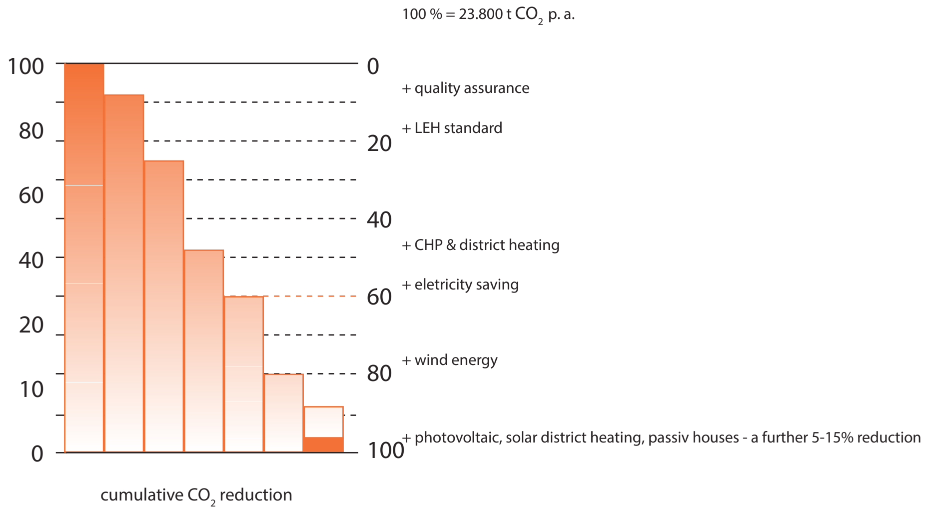


Figure 10: Reduction of CO_2 emissions at Kronsberg (LHH, 2004)

Water: The usual challenge with water management on new development sites is the change in natural water balance. All the newly built surfaces reduce the environment's imperviousness, which then results in decrease of rainwater ground infiltration and increases the surface runoff. Peak flows during storms can cause urban floods (Ruby, 2006). To avoid this, the water retention "Mulden-Rigolen-System" of hollow and trench concept was planned, which helps keeping the natural water balance with properties mostly identical to the natural situation (LHH, 2004). The water system is also integrated in private spaces and was essentially used as a design element in the whole quarter (LHH, 2013).

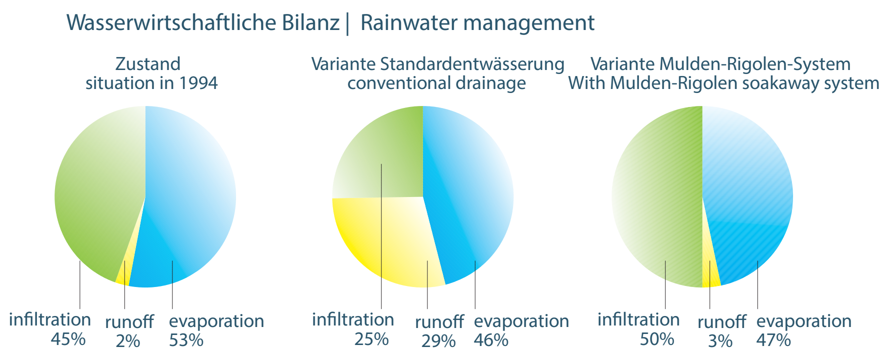


Figure 11: Rainwater management at Kronsberg (LHH, 2004)

Other ecological aspects of the Kronsberg quarter include: the ecological handling of soil, where the excavated land was primarily reused in a four-kilometre radius of the site, minimizing the ecological impact and the number of truck journeys; a waste concept prohibiting the use of hazardous building material and minimizing household waste (LHH, 2004); and a quality-assurance process where independent companies were testing if the technical performance specifications of the new buildings were met (LHH, 2013).

• zero:e park

The Hannover-Kronsberg project is considered as an ecological success. With the experience gained, the city of Hannover decided to continue the sustainable development by refurbishing the older housing stock and prioritizing those developers, who aim to construct a project with higher, passive-house standards. The new ambitions gained another possibility for a model project in south-west Hannover. A new project called zero:e park introduced an energy concept, that should not produce any CO_2 emissions, while covering the park's heating and energy needs. The park is of a smaller scale than Kronsberg, consisting of about 300 row, double and single family houses located on a 26 hectare site.

Clearly, the most eye-catching statement of this project is proclamation of being the biggest zero emissions quarter in Europe (LHH, 2013). However, this objective was not entirely achieved. The energy demand is significantly lower as a result of building the houses only in the Passive-house standard. Additional energy reductions using smart, energy-effective urban planning, active use of solar energy, efficient household appliances and the CHPP reduced the energy demand down to 25% of a standard new building at the time (2013) (LHH, 2016a). These remaining 25% of energy were meant to be compensated by to the project's „investors" – the city of Hannover, Niedersächsische Landsgesellschaft and the developer Meravis – by reactivating a nearby hydroelectric plant "Döhrener Wolle" back into operation. This however up until today, has still not happened (Stadtbezirk Ricklingen, 2016).

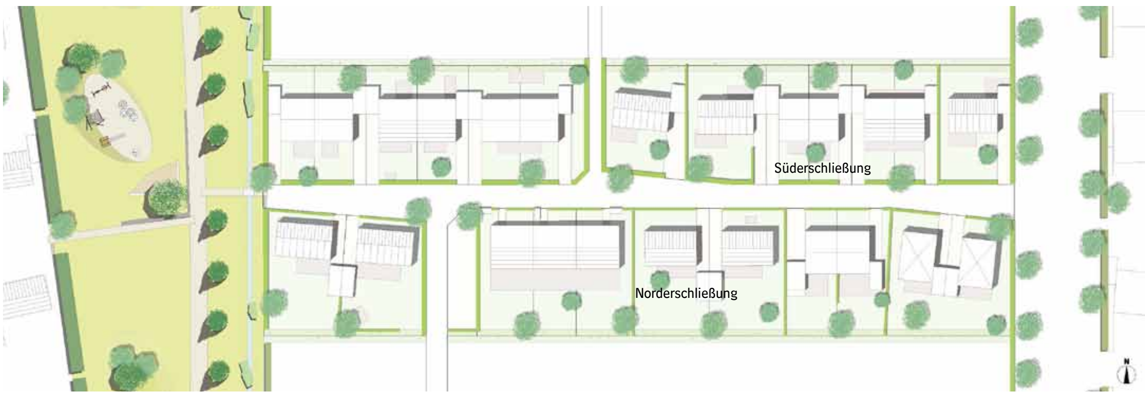


Figure 12: Section of a plan of zero:e park (LHH, 2012)

An element of sustainability that stands out in this project is the emphasis on shadow avoidance. The obscurity of light on the solar panels usually results in less energy being produced. Furthermore, the passive use of sunlight warms the house in the winter season, hence lowering its heating demands. The architects proposed an imaginary 'envelope curve' around the buildings, which illustrates the surface that should not be trespassed with the house's mass (LHH, 2016b). Additionally, a handbook for ecological garden organization recommends which type of vegetation will not grow too tall, also causing undesirable shadows (LHH, 2012).

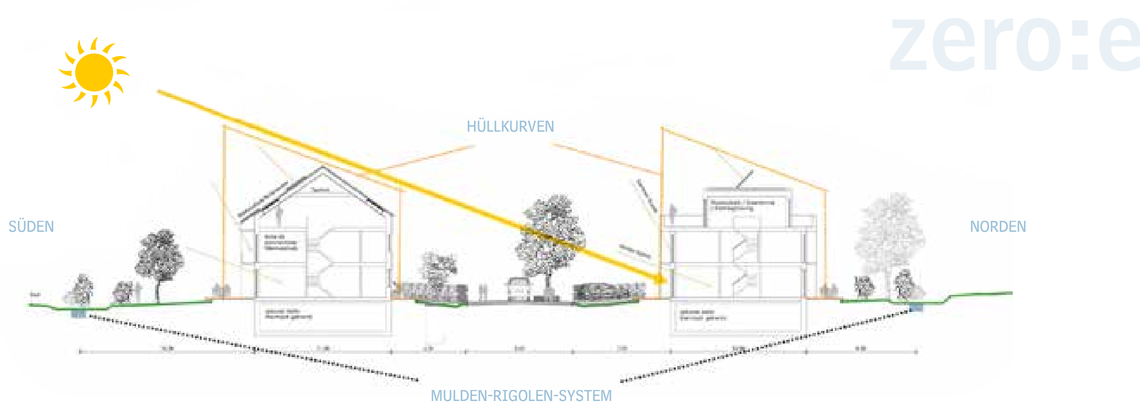


Figure 13: Section and the envelope curve of zero:e park (LHH, 2013)

4. Methodologies

In this chapter the detailed methods of the EVH design proposals' sustainability assessment and their conditions will be described. This includes mainly the logic behind different units of measurement. The chapter also includes the technical circumstances of the used software to conduct the needed simulations, for better interpretation of the results.

4.1 Assessment toolbox

The studies of the model projects uncovered the important criteria of sustainability in the built environment. The obtained information is now applied to establish the assessment criteria of the Assessment toolbox that will be prepared in the Rhino / GH environment to test the EVH proposals. The study revealed three main groups of criteria that revolve around sustainable projects: energy, resources and comfort.

CRITERIA - ENERGY	UNITS	NOTE
Heating demand	kWh/m^2a	For heating up building spaces
Solar irradiation (PV)	MWh/a	To generate electrical power or heat water

• Heating demand – heating being the major energy consumption share of the buildings sector in Germany, we simulate yearly energy demand for heating. Cooling demand is omitted, since the share of Final energy consumption (FEC) is only 0.2% (Eurostat, 2020). The value is simulated via the EnergyPlus engine that besides shape, also takes into account the orientation, glazing and construction of the building.

• Solar energy (PV) – measuring the solar irradiation received to potentially cover the electrical energy demands or the heated water demand using thermal collectors. The final value is also simulated via EnergyPlus and reflects the roofs' sizes, orientation and tilt angle.

CRITERIA - RESOURCES	UNITS	NOTE
Heating demand	kWh/m^2a	Building roofs as catchment areas

• Rainwater harvest – since with harvesting rainwater we can reduce the non-potable water consumption, calculation of amount of water can be gained from the roofs of the buildings. The final value represents the amount of harvested water available per person, annually.

CRITERIA - COMFORT	UNITS	NOTE
Outdoor comfort (UTCI)	°C	The 'feel' temperature on the 'Dorfplatz'
Annual sunlight exposure	%	Percentage of GFA lit with 50+ sunlight hrs
Soil sealing	%	Building coverage ratio

• Human centred outdoor comfort (Universal thermal comfort index UTCI) – Calculating the thermal comfort of the key public space in the ecovillage 'Dorfplatz'. Calculation derived from the size of soil-sealed areas, buildings and tree placements in the quarter on a grid of resolution 2x2 metres. The final measures are the average temperature and the maximum temperature (on the hottest day of the year).

• Annual sunlight exposure – measuring the average amount of each proposal's sun-lit spaces that receive at least 50 sunlight hours annually.

• Soil sealing – a percentage of all with buildings sealed surfaces in the quarter, also known as Building Coverage Ratio (BCR).

4.1.1 Heating consumption

The heating consumption Q_h unit (also often referred to as Energy use intensity EUI) was used to compare the different building typologies of the EVH design proposals. The final data results compare the final yearly heating consumption of the design proposals for their individual GFAs, but also a second comparison was conducted with the Q_h being remapped to one general GFA of 30 000 m^2 for all proposals. This way the differences in the design proportions do not affect the examined efficiency qualities in the proposals. A third comparison that excludes the typology of tiny houses was conducted, as it is unclear at this moment whether the tiny houses will be supplied by a selected company. In this case, the different dimensions and forms in the design proposals do not play a deciding role in the final heating consumption.

Below are the listed technical circumstances, by which the energy simulations were conducted:

Constructions

Four types of constructions were used for the setting up of thermal zones, shown throughout tables 2 - 5:

MATERIAL	THERMAL CONDUCTIVITY λ [W/(mK)]	THICKNESS [mm]
Outside plaster	0.35	15
Thermal insulation	0.06	200
Lime-sand brick	1.00	175
Inside plaster	0.70	10

Table 2: Exterior wall construction

MATERIAL	THERMAL CONDUCTIVITY λ [W/(mK)]	THICKNESS [mm]
Outside plaster	0.35	15
Reinforced concrete	1.60	200
Thermal insulation	0.06	200
Inside plaster	0.70	10

Table 3: Roof construction

MATERIAL	THERMAL CONDUCTIVITY λ [W/(mK)]	THICKNESS [mm]
Reinforced concrete	2.10	140
Thermal insulation	0.06	150
Floor finish	0.90	40

Table 4: Ground floor construction

TRIPLE GLAZED WINDOW	VALUE	UNIT
Heat transfer coefficient U	1.00	$W/(m^2K)$
Solar heat gain SHGC	0.5	factor
Visibility transmission VT	0.3	factor

Table 5: Window properties

Zone schedules

Besides the constructions, to properly simulate the heating consumption zone schedules have to be set. They inform the simulation engine about the type of building the zones represent. The type of the building determines when and how the building is used, defined by occupancy during a day and a heating set point, which in the end influences when throughout the day there is a need for heating. The data is set for all 8 760 hours in a year, for the purposes of this thesis, I used a pre-set zone program for a mid-rise apartment.

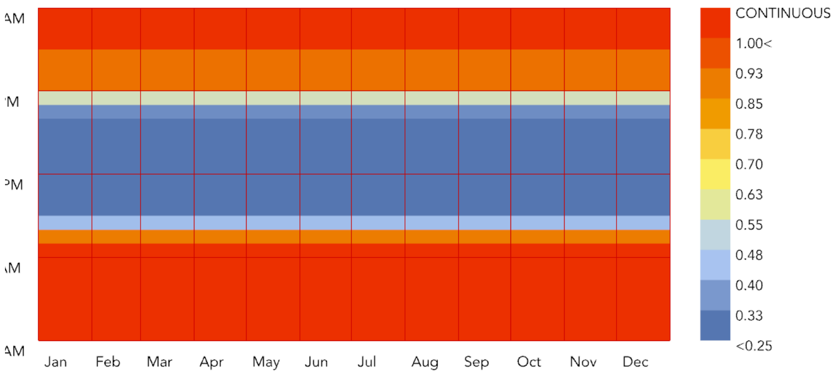


Figure 14: Occupancy schedule of a mid-rise apartment

The schedule shows full occupancy (1.00) in the night until about 7:00 AM. Then it starts to gradually change into the day, when only a quarter (0.25) of the dwellers occupy the house, until the evening when the buildings hosts again all dwellers.

The zone program also carries an information of the heating set point, which represents a level of inside temperature beneath which the heating starts to operate. This is set to 21.1 °C throughout the whole year.

Shadowing

The EnergyPlus simulation engine takes into account the casting of the shadows by the buildings, topography or other environment's context such as vegetation. The more detailed the modelled environment is, the more detailed are the final values. However, because the higher level of detail also greatly influences the needed computation time and because of the state of the EVH project being in its first phase of preliminary results (during the time of writing this thesis), most of the details were omitted. Because of great differences of urban forms in the design proposals, the omitted details presumably do not affect the final ranking position of the proposals, when it comes to the assessed heating consumption.

4.1.2 PV

The photovoltaic (PV) panels represent nowadays an integral part of the renewable technology systems. Although the technology of a solar cell was first implemented in small scales already in the 1950s, it sparked a greater interest after such energy related crises like the oil crisis, or the Chernobyl accident. Since the 1990s larger investments were being put into PV plants, with the capacities going up significantly from around 5 MWp, until nowadays currently largest PV plant in Bhadla, India with the capacity of 2 245 MWp.

For the purpose of comparing the different EVH design proposals, I chose to measure only the quality of conditions for the generation of energy, rather than the estimated energy output. The below explained units of measurements depend on preconditions such as location, building's orientation, weather conditions and context shading. I excluded the standard Specific yield or Nominal plant PV output measurements, because in their calculations they both also include the PV modules efficiency. The modules efficiency is rather an economic matter of which PV panels will be installed in the EVH quarter, however the focus of this thesis is purely the analysis of the proposed urban forms.

• **Global Horizontal Irradiance GHI** – represents how much light falls anually on the horizontal surface of the earth. Tha value differs in the world based on latitudes, in Hannover GHI stands at around 1 050 kWh/m^2. The average GHI in Germany is 1 088 kWh/

m^2. For the purpose of the simulations I used the weather file provided by the EnergyPlus website itself, which in fact refers to the location of Düsseldorf, being the nearest available city. Although there are other websites apart from EnergyPlus that provide weather files, using a file representing Hannover turned out to have much longer computation time. Therefore a GHI value observable on flat roofs stands at around 942.9 kWh/m^2, instead of the Hannover's specified 1 050 kWh/m^2. Nonetheless, for the purpose of comparison and ranking of the design proposals, the small deviation is not significantly influencing the outcome.

• **Incident POA Irradiation II** – As the GHI however only informs how much solar radiation falls on a flat surface, by tilting our solar panels – our "Plane of array" POA - by a 30° – 40° angle towards the south, we can increase the average incident irradiation from the average GHI of 1 088 kWh/m^2 to around 1 250 kWh/m^2 per year throughout Germany (p.45, Fraunhofer, 2020). Now although the roof surface rotation is taken into account, the unit remains as [kWh/m^2]. This unit of measurement quantifies how well were the individual buildings planned in accordance with the sun's location in the sky for the Hannover conditions.

• **Total Solar Irradiation Σ SI** – To accurately compare the fitness of the roofs for placing PV panels, the roofs with the best tilts had to be identified. If there were hypothetically 10 000 m^2 of PV panels available for EVH, they would be naturally placed first on the roofs facing the sun's path on the southern sky. This unit of measurement is the total sum of solar irradiation Σ SI received on these particular roofs. The proposals without any sloped roofs can have PV panels installed only on horizontal surfaces with solar irradiation of 942.9 kWh/m^2, therefore their result stands at
942.9 $kWh/m^2 \times 10\ 000\ m^2$ = 9 429 MWh anually.

4.1.3 Water harvest

A simple, but important calculation of potential rainwater harvest can reveal how much of usable water can be collected through the building roofs.
Potential: Given the average yearly precipitation in Hannover of 661.3 mm/a, rain with the volume of 661 litres falls on every 1 m^2 (Weather Atlas, 2020). This way, an average sized single-family house with a surface footprint of 105 m^2 can harvest about 70 000 litres of rainwater annually. A simple ratio of 'roof surfaces sum' to 'population' reveals how much of the water demand can be covered by rainwater harvesting. An average domestic water consumption in Germany in 2016 is approximately 123 litres/capita/day (Destatis, 2019). This includes both the potable water and the non-potable water. For a household of four people, that accounts for 219,150 litres annually, of which for example 27% - 59,170 litres is used just for toilet flushing, which could use the harvested rainwater instead of potable water (BDEW, 2016). The harvested 70 000 litres could cover the whole toilet demand, with some extra left that could be used for watering of vegetation.

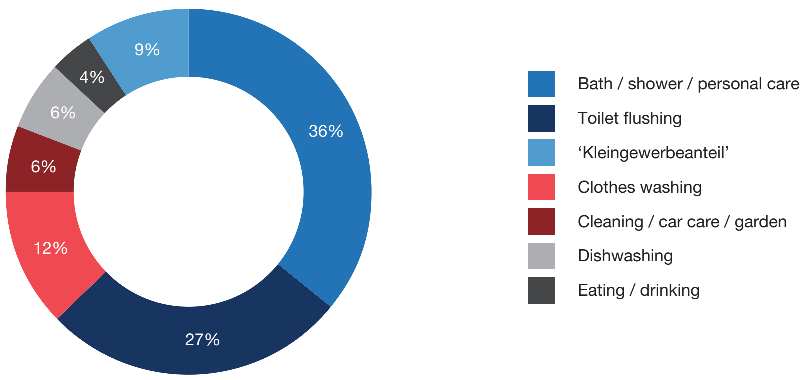


Figure 15: Drinkable water usage in households in 2015 (BDEW, 2016)

Calculation:
• **Effective Catchment Area AEC -** The amount of water able to be harvested from the buildings, depends not only on the rate of precipitation, but also on the building's roof harvesting system. Considering the smaller level of detail of the EVH urban plans, this thesis omits water harvesting attributes such as surface materials, collecting gutters and storage tanks and focuses only on the roof's size. The effective catchment area AEC of the buildings basically equals the roof's horizontal plan area.

• **Water Harvest WH -** After getting our building's AEC, calculating our potential amount of harvested water is a multiplication of the building's catchment area AEC times the average yearly precipitation P on the site. Precipitation is measured by the height (in millimetres) of accumulated water on a surface of one square meter, which is equivalent to kilogram per square meter (which is equivalent to the litres per square meter). The unit of the sum of harvested rainwater is litres per year [l/a].

$$WH = AEC \times P$$

• **Available Water -** Finally, we want to get the amount of harvested water that is available for a person, annually. Because of the different sizes of the design proposals, we estimate the number of inhabitants by allocating 35 m^2 of the heated space's GFA for each person. We divide the WH by the estimated inhabitants numbers and get a volume of harvested water available per person, annually [l/p/a].

4.1.4 Outdoor comfort

Everybody is familiar with the problem of the apparent outside air temperature that we usually observe on our thermometers does not really depict the true "feel" temperature of the outside our body gets in contact with. The Universal Thermal Climate Index (UTCI) was developed to truly assess the thermal environment and to reflect the human physiological reaction to the actual thermal condition. The UTCI value deviates from the air temperature with the effects of the actual air temperature and mean radiant temperature (Tmrt), wind speed (va) and humidity measured as vapour pressure (vp) (Błażejczyk et al., 2012). All the needed values can be found on the location's weather file.

$$UTCI = Ta + Offset\ (Ta; Tmrt; va; vp)$$

For the purpose of the simulation, specific conditions were picked to test the site for temperature extremes possibly occurring on the "Dorfplatz" (Ger. – village square) of each proposal. This area acting as a local center of the quarter has the highest potential to be the most paved part. Such large public spaces can be vulnerable in summer to extreme temperatures, as many cities acknowledge (Zölch et al., 2019). The simulation takes into account the shading of the nearby buildings, solar reflectance of the surrounding materials and the weather data of the hottest measured day throughout the year in Hannover (3rd of July).

For the purpose of the simulation, the landscape designs of the squares were taken into account, if visualized on the masterplan of the proposal. The differentiating parameter of the surface materials - the Solar Reflectivity (also referred to as Albedo) was set to 0.6 which portrays a rather more reflective concrete (Marceau & VanGeem, 2008). For comparison, a soil or grass surface has much smaller albedo value of around 0.25.

4.1.5 Shape Factors

In the chapter 2.4 the basics of building compactness were briefly examined. To measure the compactness, two units were used in this thesis:

• **Heat Loss Form Factor (HLFF)** –defined as the ratio between the building's envelope area (made up from its external faces – walls, roofs, openings) to its GFA (generally more accepted would be to use the net floor area, but considering this thesis deals only with GFA values, it is more suitable for an urban scale) (NHBC Foundation, 2016).

$$HLFF = A_{envelope} / GFA$$

	Type	Form Factor	Efficiency
	End mid-floor apartment	0.8	Most efficient
	Mid-terrace house	1.7	
	Semi-detached house	2.1	
	Detached house	2.5	
	Bungalow	3.0	Least efficient

Figure 16: The types of flats and their form factors (NHBC Foundation, 2016)

As the figure 16 shows, a flat with roughly the same floor area can have a different HLFF based on the housing typology. The heating consumption in the least efficient bungalow can be more than twice as large as in the end mid-floor apartment.

- **Surface to Volume Ratio (SVR)** – defined as the ratio between the building's envelope area to its volume.

$$SVR = A_{envelope} / V$$

The SVR is used as a definition in the German Energy Saving Ordinance, however it can start to be inaccurate when comparing buildings with different heights. If a building with the same footprint grows in height, its volume increases, hence the SVR indicates a more compact shape. In reality, the increased volume will results in higher energy demand, while the building's floor area remains constant.

4.1.6 Annual sunlight exposure

Annual sunlight exposure (ASE) is along with spatial daylight autonomy (sDA) are daylight performance metric, used to determine whether a building's interior space receives enough daylight to work or live comfortably in. They both use building geometry and a local climate data file (weather file) to simulate the amount of sunlight. While the sDA evaluates whether a standard horizontal work place receives enough daylight during operation hours, ASE examines space with excessive sunlight with high annual exposure, that may cause visual discomfort or overheating. With the help of optimization and simulation, ideal daylit spaces can be designed with window features such as blinds (Van Den Wymelenberg & Mahić, 2016).

While the heating consumption and the compactness act as the main indicators of building sustainability in the design proposals, reaching too efficient shape factors may create conflicts of interest with other qualities such as the daylight performance. Solar gains coming through the openings into the building do not contribute just to energy savings, but are also essential for human health, as it was stated already in the Athens charter (Themenportal Europäische Geschichte, 2009). Therefore, for the purpose of this thesis, an analysis similar to the sDA and ASE metrics was conducted to identify buildings that may be crossing a capability boundary behind which the extreme compactness is not worth the loss of daylight. This can occur when a building is planned with extensive depths, which will not receive enough daylight. It may be the case when higher buildings are built in front of smaller ones without insufficient spacing between them.

The method of assessment begins with first identifying the direct sunlight with a minimum illuminance of 1 000 lux. Then the assessed building floor surfaces are divided into illuminance grid cells of 1 x 1 meter sizes and each gets tested for how many annual sunlight hours are received. A threshold of 50 annual hours was set to determine how much of the building floor area (in percentage) and consequently of the whole design proposal receives sunlight of more than 50 annual hours.

4.2 Software

To conduct the simulation four different softwares were used, yet all under the hood of *Rhinoceros*. Rhinoceros is a 3D modelling software based on NURBS mathematical model, besides 3D modelling also used as a CAD tool. It comes equipped also with a visual scripting add-on *Grasshopper* which besides adding possibility of parametric and algorithm-based modelling also allows for simulations and performance analyses (Wikipedia, 2020c). A plugin for Grasshopper called *Ladybug tools* supports the environmental-design related features by bringing together several simulation engines. One of them is *EnergyPlus* which is an open-source building energy simulation engine developed by the U.S. Department of Energy. It is used in the building practice to simulate energy consumption in planned buildings or for evaluating conversions of buildings into more energy-efficient ones.

According to a study comparing four different UBEM tools, EnergyPlus resulted as the most accurate with the smallest deviation in the heating demand from the real, measured values. The EnergyPlus engine calculated the values with a -13% deviation, while the other engines IDA ICE, TRNSYS and VIP-Energy calculated with a +18%, +15% and -16% deviation, respectively (Johari, 2019).

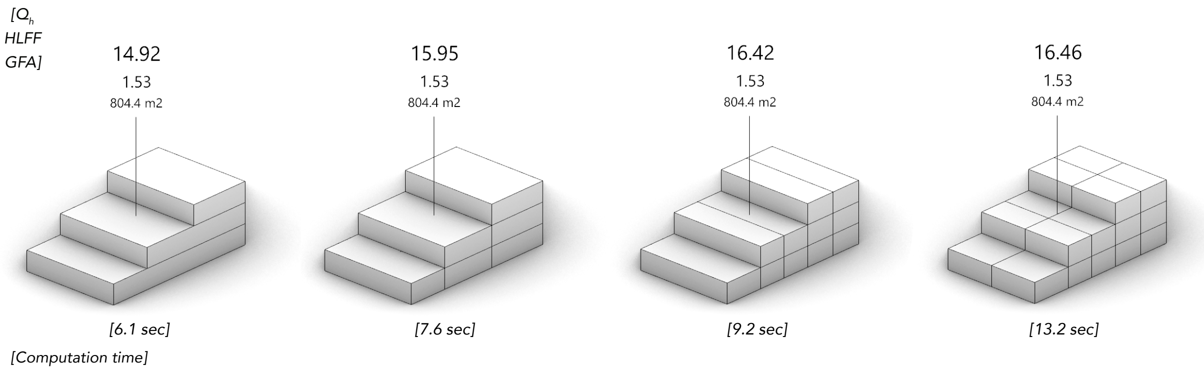
4.2.1 Pre-simulation tests

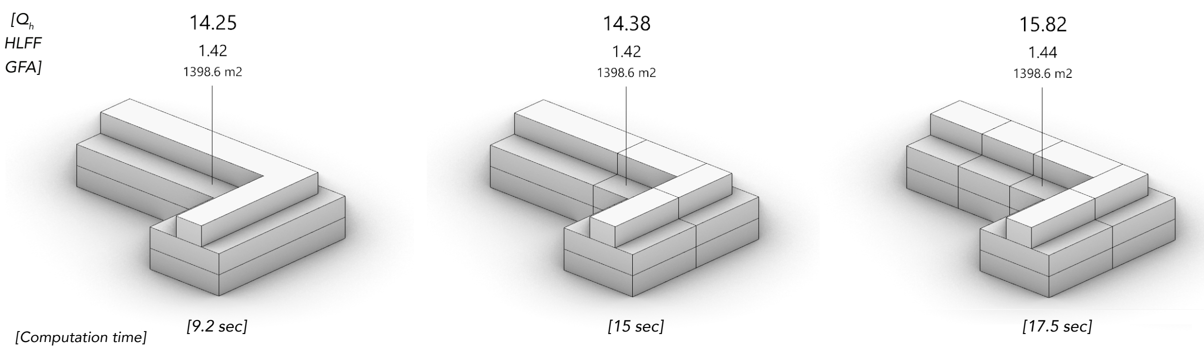
Before running the full urban quarter simulations, the optimal parameters for the simulation engine had to be set, to achieve the best balance between computation time and accuracy of the results. The most important element in the energy simulations is a thermal zone.

Thermal Zones - The thermal zones, also referred to as energy or HB (Honeybee) zones are used to build up the energy models. They are a set of closed, three dimensional boundary representations that can be understood in reality as closed-off rooms or microclimates of a building with uniform temperatures.

The Ladybug tools' primary use is meant for individual building energy calculations. The EnergyPlus simulation engine goes through every zone and calculates (besides others) the heating demand based on different factors like exterior temperature, constructions, adjacencies to other zones and shading geometries. Therefore, the more zones the simulated model has, the longer the computation time. In the case of an urban quarter, where there's a lack of detail, the modelled zones are representing whole floors, instead of closed-off rooms. This way, also the computation time is shortened significantly.

By simplifying the geometries of the climate zones there's a risk of getting inaccurate results of the heating demand as a consequence of huge unclosed spaces. In order to get a clearer picture of how does a set of simplified thermal zones compare to a more detailed set, few tests were conducted for different typologies. A balance between simple and not too massive zones was chosen.





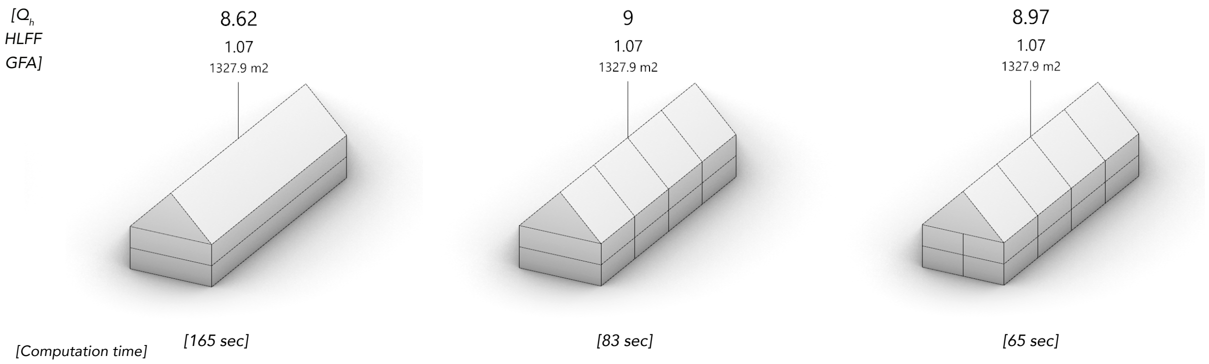


Figure 17: Example of three buildings showing different levels of detail of thermal zones

Most of the buildings show sizeable computational time savings, with heating demand deviations just around 10%. However, in the third example, the computation time actually decreases with more thermal zones included. The reason for this might be the pitched roof shape or the influence of the skylight windows on the calculation.

5. Data results

This chapter illustrates all the simulated data results in such graphical representations to most easily identify the weakest spots of the design proposals. In 5.1 firstly the individual proposals are assessed and in 5.2 the comparison of all proposals and criteria is conducted.

5.1 Individual results

The results can be found starting from the next page 34.

Proposal 1

Office: Studiomauer, Hannover
Cityförster architecture + urbanism, Hannover
GFA = 37 208 m^2 (36 868 m^2 heated spaces + 340 m^2 non-heated spaces)

Sealed area = 32.91 %
Q_h = 662.3 MWh/a
SI = 9431.6 MWh/a
sDA = 77%
AW = 10 187 l/p/a
$UTCI_{\varnothing}$ = 24.2°C
$UTCI_{max}$ = 40.9°C

Heating demand analyses:

Figure 18: Efficiency of the each buildings' heating demand of the 1st proposal

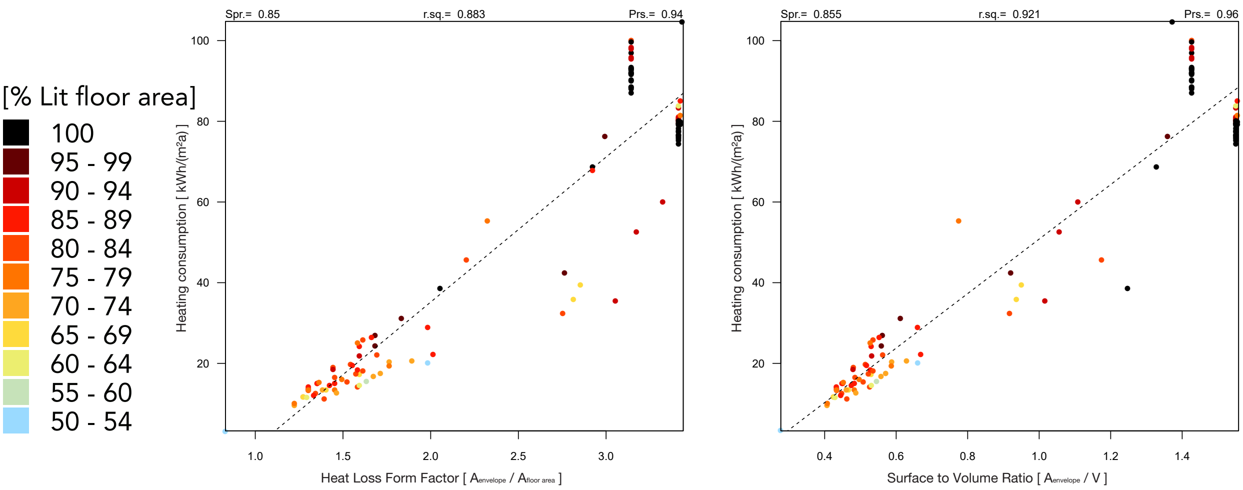


Figure 19: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 1st proposal

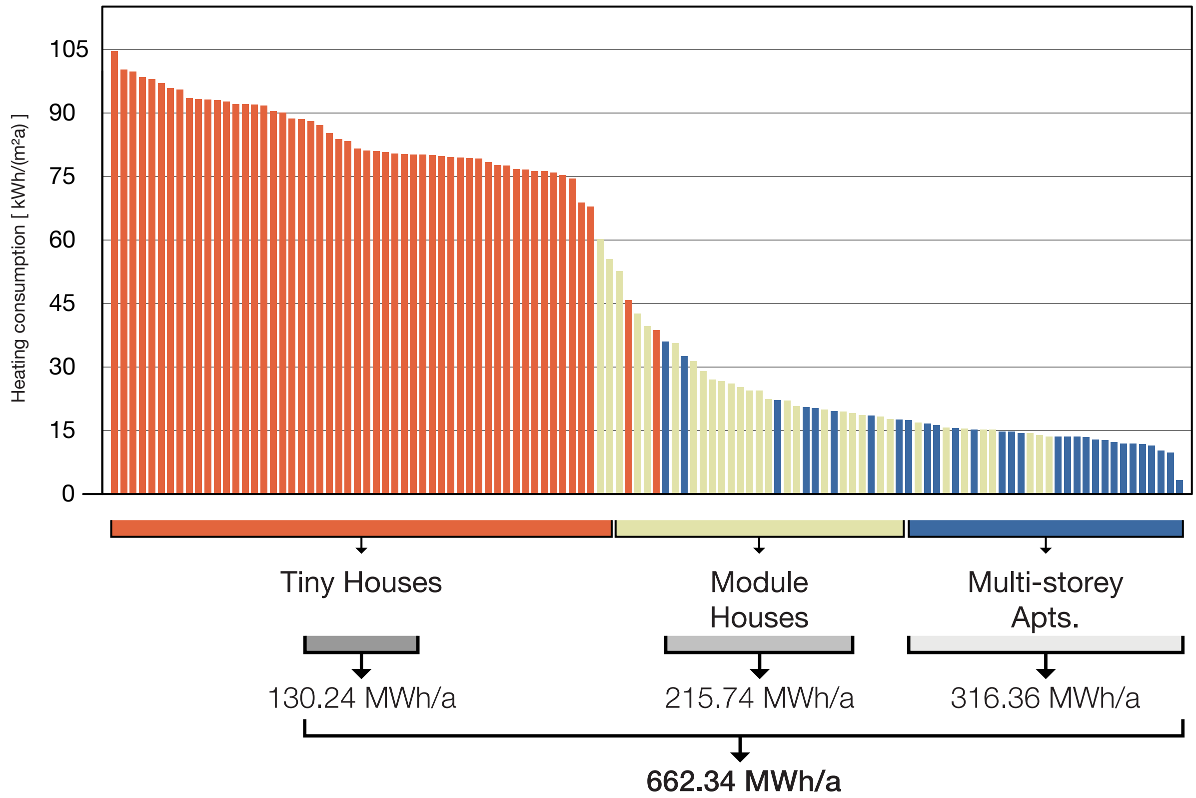


Figure 20: Bar chart of the buildings' heating demand efficiency of the 1st proposal

Remapping the heating demand for one general GFA of heating spaces:
Q_{h1}= 662.3 MWh/a
GFA_1= 36 868 m²
GFA_{gen}= 30 000 m²

Q_1= 662.3 MWh/a × (GFA_{gen} / GFA_1)
Q_1= 662.3 MWh/a × (30 000 m² / 36 868 m²)
Q_1= 662.3 MWh/a × (0.8137)
Q_1= 538.92 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h1'}$= 662.3 - 130.24 = 532.06 MWh/a
$GFA_{1'}$= 36 868 - 1 429 = 35 439 m²

$Q_{1'}$= 532.06 MWh/a × (GFA_{gen} / $GFA_{1'}$)
$Q_{1'}$= 532.06 MWh/a × (30 000 m² / 35 439 m²)
$Q_{1'}$= 532.06 MWh/a × (0.8465)
$Q_{1'}$= 450.4 MWh/a

For a GFA of 30 000 m² the 1st proposal would have a heating demand of 538.92 MWh anually, alternatively while excluding the tiny houses it would be 450.4 MWh anually.

Sunlight hours analysis:

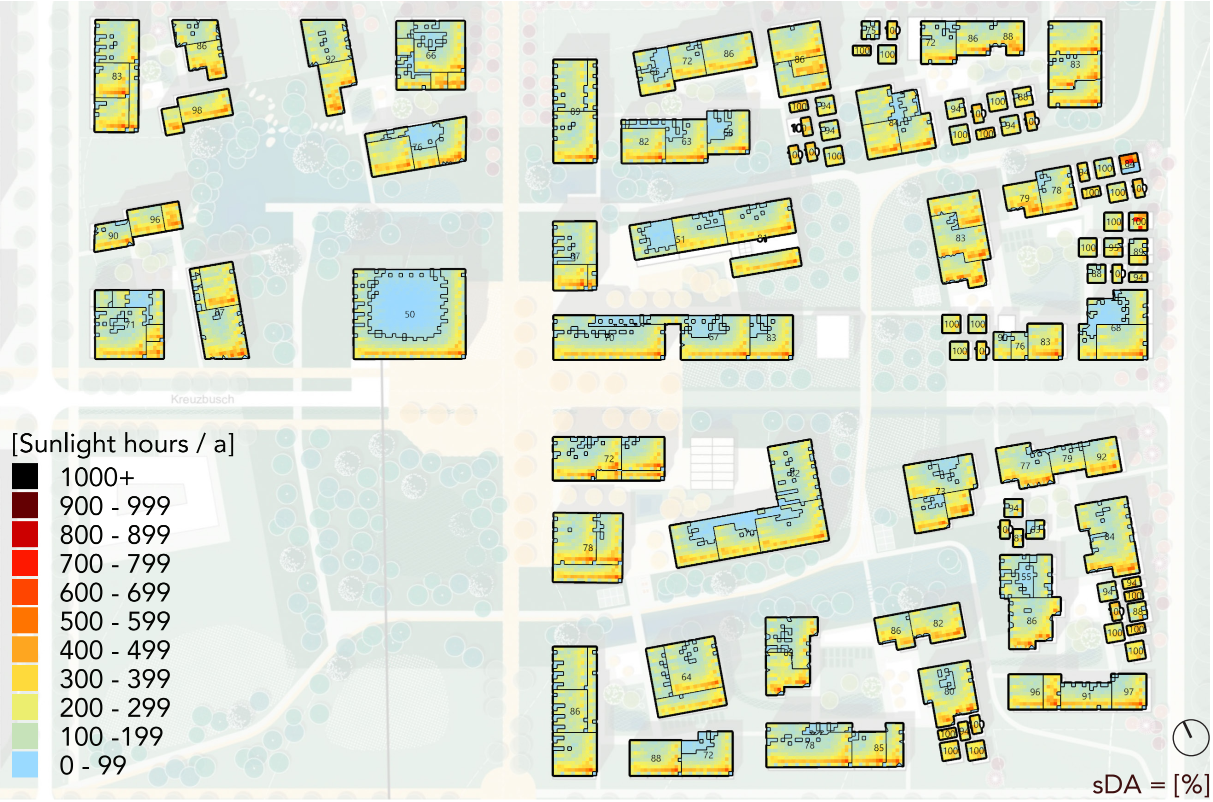


Figure 21: Percentage of floor area lit with 50+ sunlight hours annually is 77% for the 1st proposal

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Universal Thermal Comfort Index analysis:

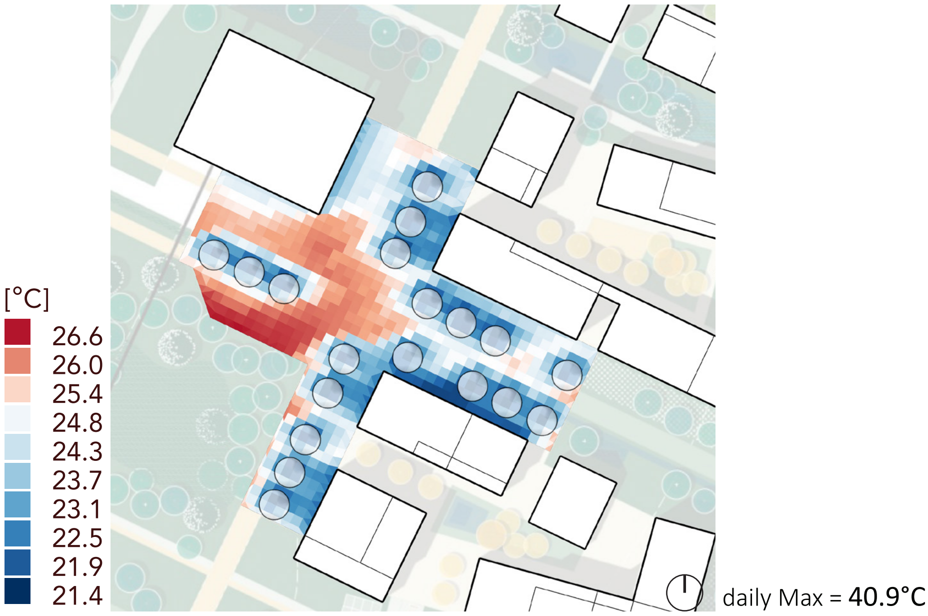

Figure 22: Average UTCI during the 03. July (the hottest day) on the village square of the 1st proposal

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PV potential analysis:

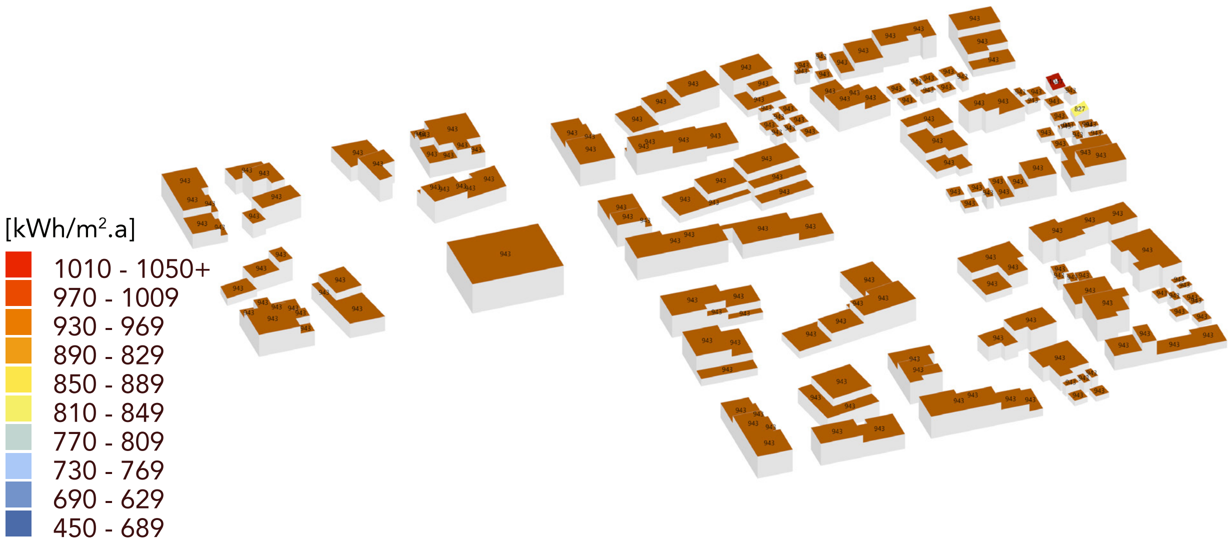

Figure 23: Incident POA irradiation of the roof surfaces of the 1st proposal

The total solar irradiance received from the sun on theoretical 10 000 m² of PV panels for the 1st proposal equals to 9 431.6 MWh/a.

Summary:

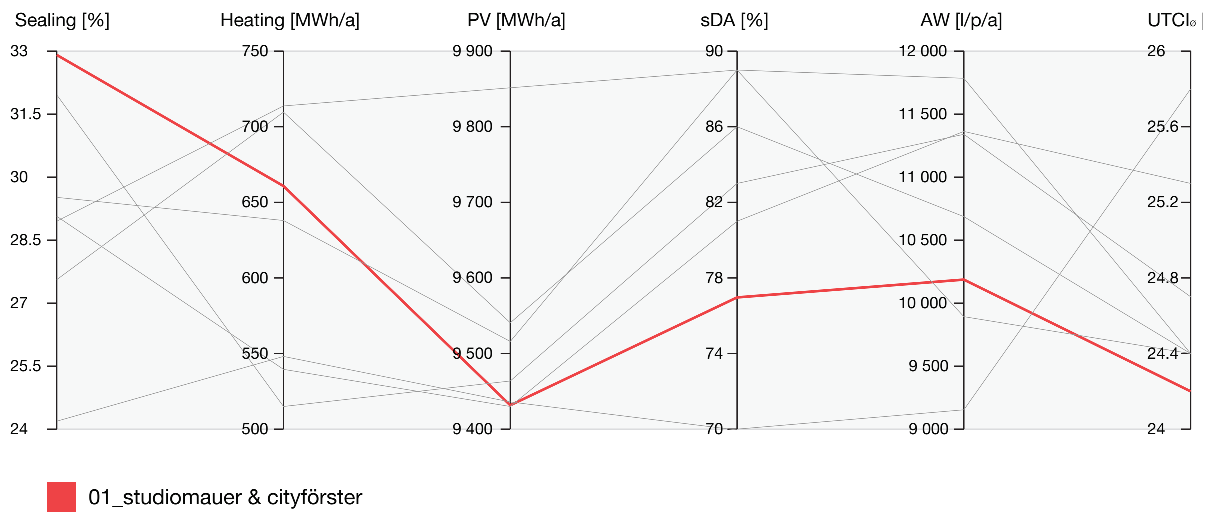

Figure 24: Performance of the 1st proposal visualized on a line graph

Proposal 2

Office: haascookzemmrich STUDIO2050, Stuttgart
Transsolar Energietechnik GmbH, Stuttgart
GFA = 33 898 m² (33 048 m² heated spaces + 844 m² non-heated spaces)

Sealed area = 28.65 %
Q_h = 713.76 MWh/a
SI = 9 851.5 MWh/a
sDA = 89%
AW: 9 893 l/p/a
$UTCI_{\varnothing}$: 24.4°C
$UTCI_{max}$: 40.4°C

Heating demand analyses:

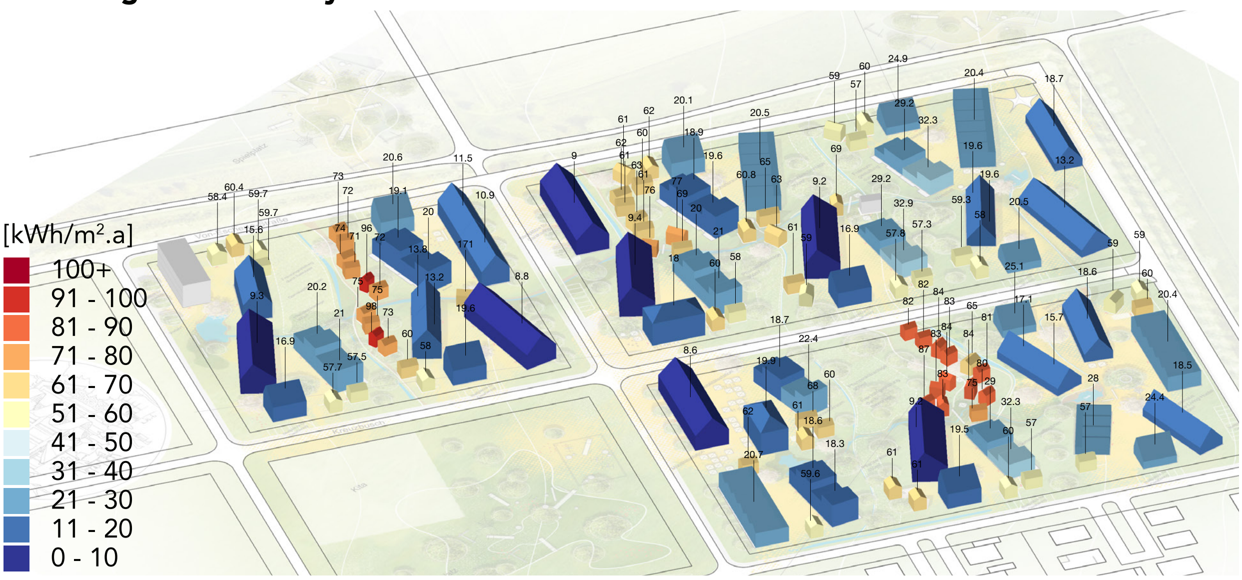

Figure 25: Efficiency of the each buildings' heating demand of the 2nd proposal

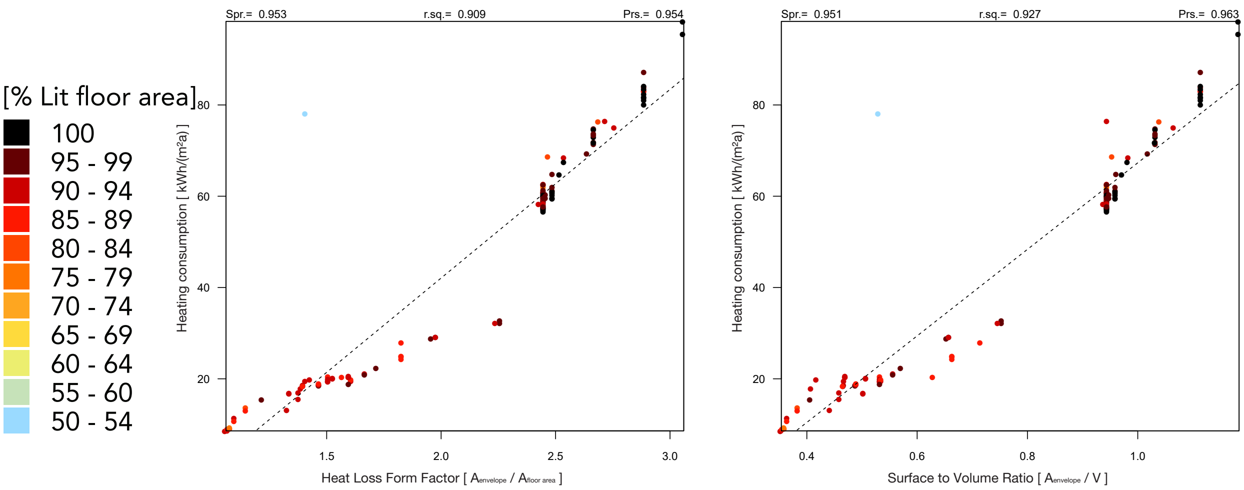

Figure 26: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 2nd proposal

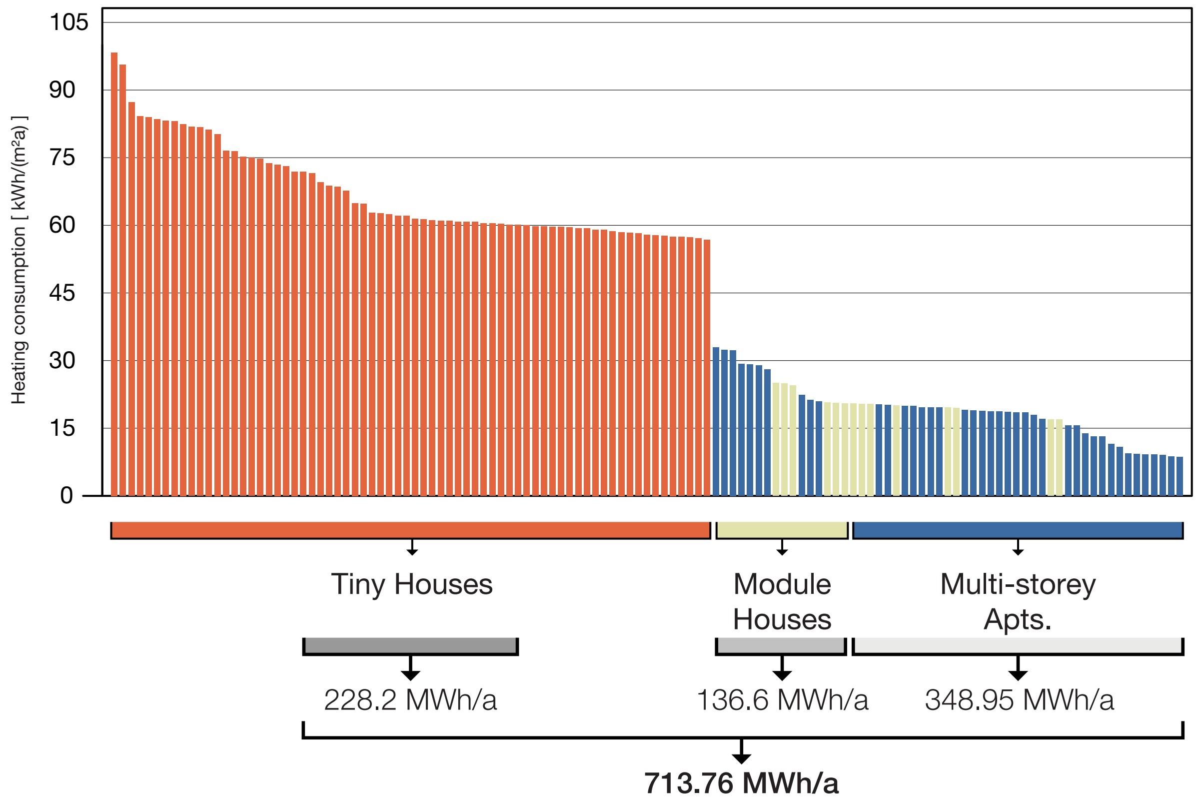

Figure 27: Bar chart of the buildings' heating demand efficiency of the 2nd proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h2}= 713.76 MWh/a
GFA_2= 33 048 m^2
GFA_{gen}= 30 000 m^2

Q_2= 713.76 MWh/a × (GFA_{gen} / GFA_2)
Q_2= 713.76 MWh/a × (30 000 m^2 / 33 048 m^2)
Q_2= 713.76 MWh/a × (0.9078)
Q_2= 647.79 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h2'}$= 713.76 - 228.2 = 485.56 MWh/a
$GFA_{2'}$= 33 048 - 3 487 = 29 561 m^2

$Q_{2'}$= 485.56 MWh/a × (GFA_{gen} / GFA)
$Q_{2'}$= 485.56 MWh/a × (30 000 m^2 / 29 561 m^2)
$Q_{2'}$= 485.56 MWh/a × (1.0149)
$Q_{2'}$= 492.77 MWh/a

For a GFA of 30 000 m^2 the 2nd proposal would have a heating demand of 647.79 MWh anually, alternatively while excluding the tiny houses it would be 492.77 MWh anually.

Sunlight hours analysis:

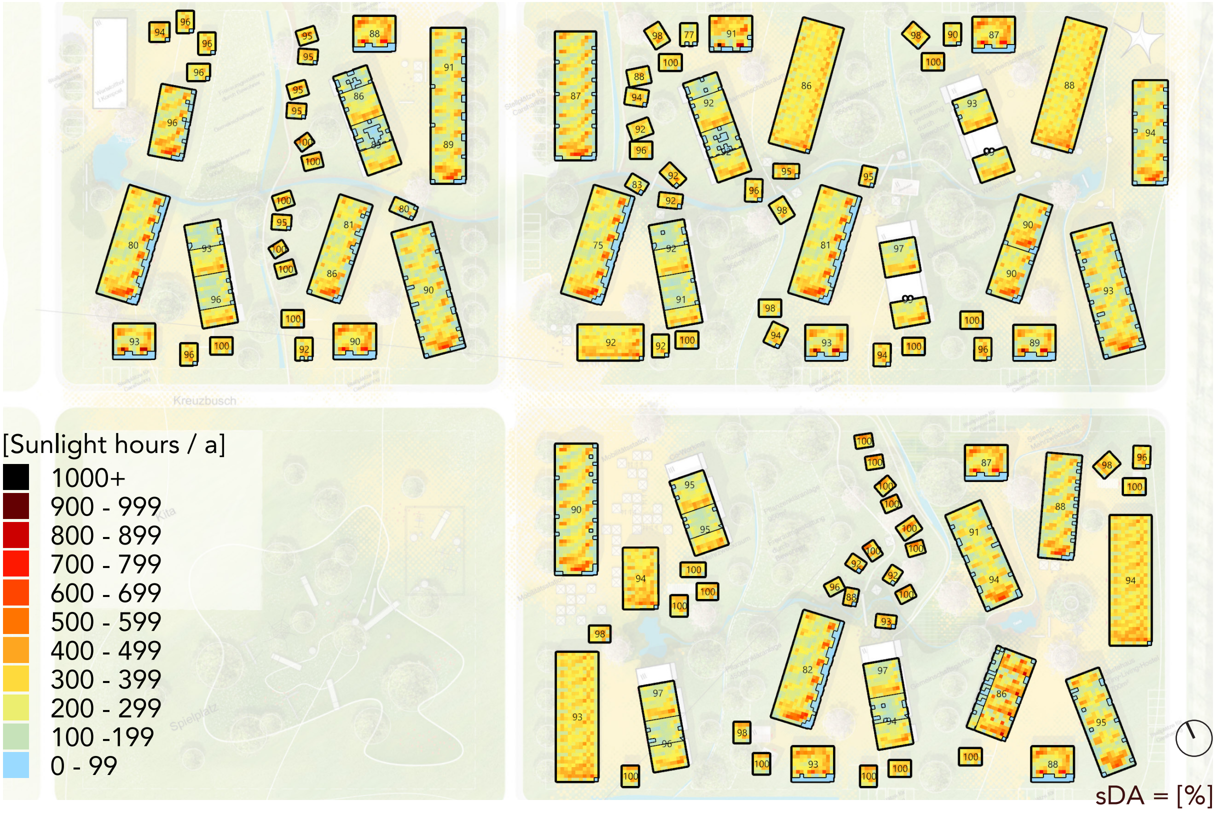

Figure 28: Percentage of floor area lit with 50+ sunlight hours annually is 89% for the 2nd proposal

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Universal Thermal Comfort Index analysis:

Figure 29: Average UTCI during the 03. July (the hottest day) on the village square of the 2nd proposal

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PV potential analysis:

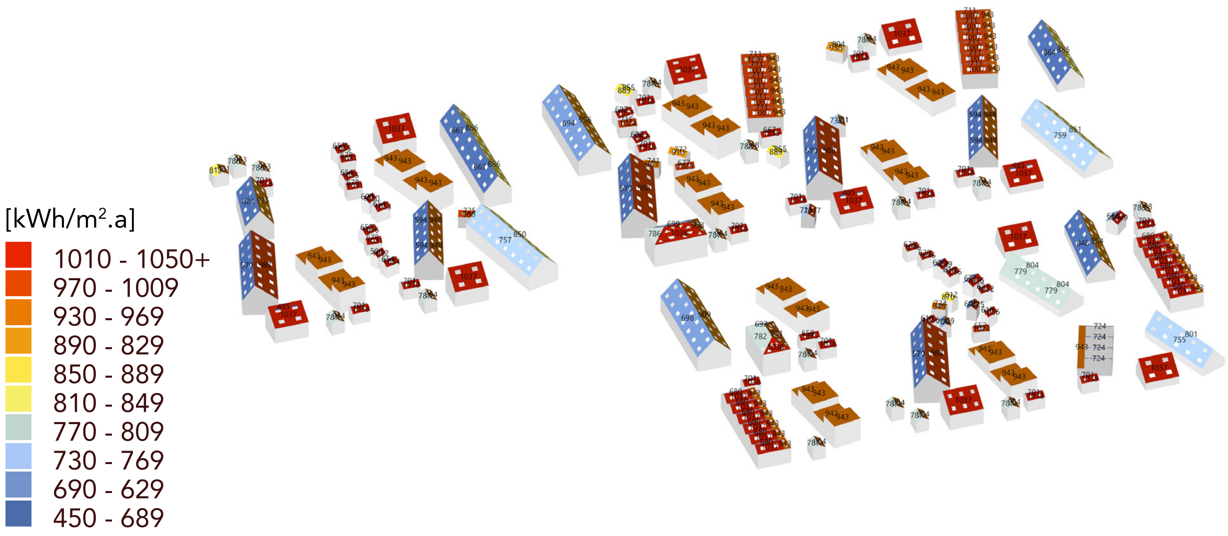

Figure 30: Incident POA irradiation of the roof surfaces of the 2nd proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 2nd proposal equals to 9 851.5 MWh/a.

Summary:

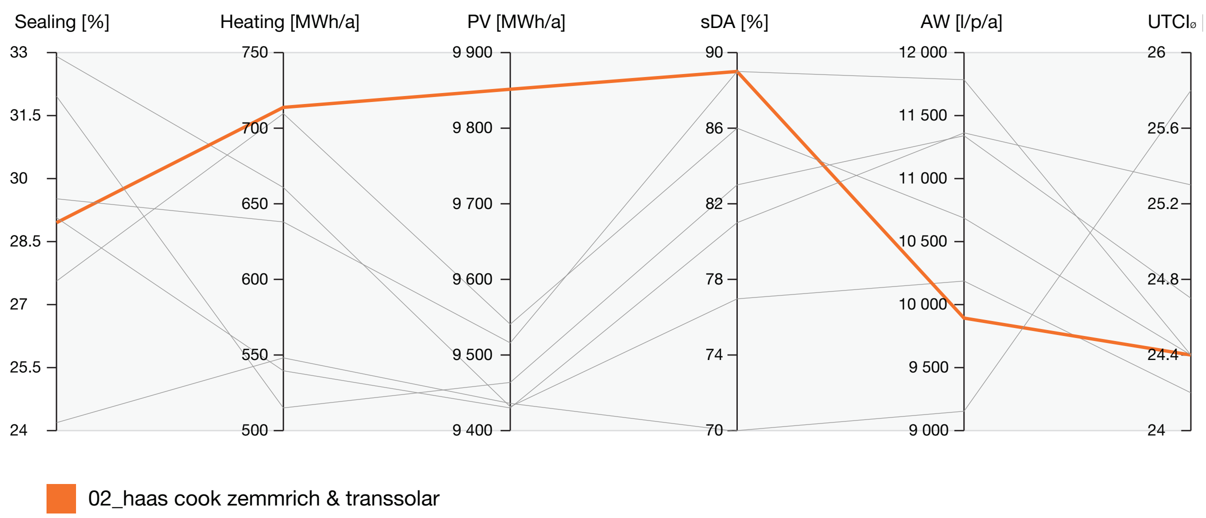

Figure 31: Performance of the 2nd proposal visualized on a line graph

Proposal 3

Office: ISSS research I architecture I urbanism
Sabatier Schwarz Architekten PartGmbB, Berlin
Plan Comun, Paris, France GFA = 31 443 m^2 (29 139 m^2 heated spaces + 2 304 m^2 non-heated spaces)

Sealed area = 28.69 %
Q_h = 539.55 MWh/a
SI = 9 430 MWh/a
sDA = 81%
AW = 11 363 l/p/a
$UTCI_{Ø}$ = 25.3°C
$UTCI_{max}$ = 40.8°C

Heating demand analyses:

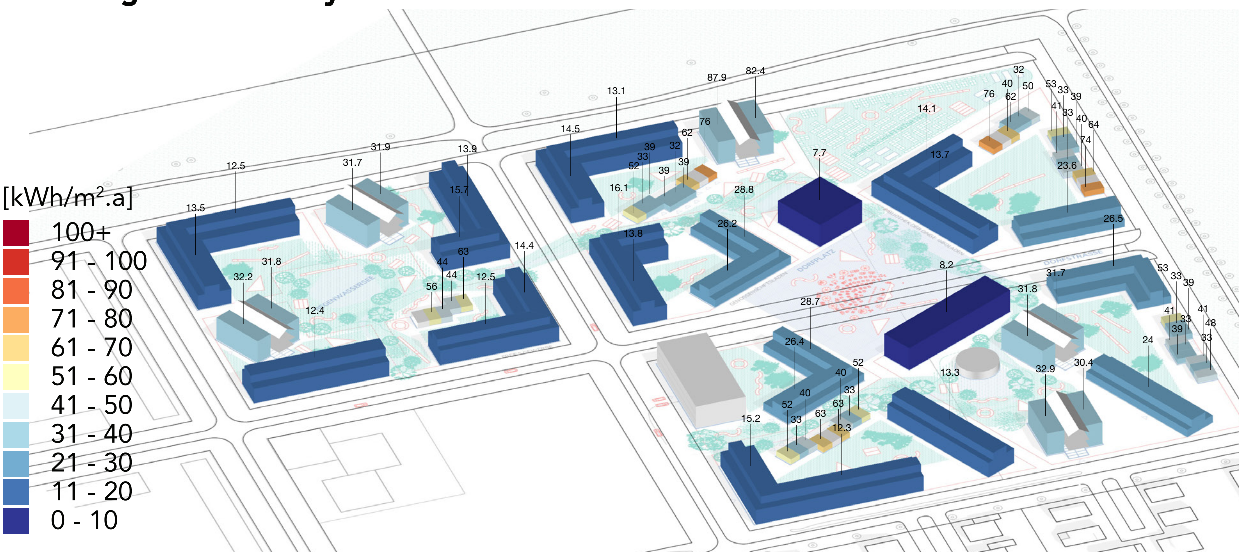

Figure 32: Efficiency of the each buildings' heating demand of the 3rd proposal

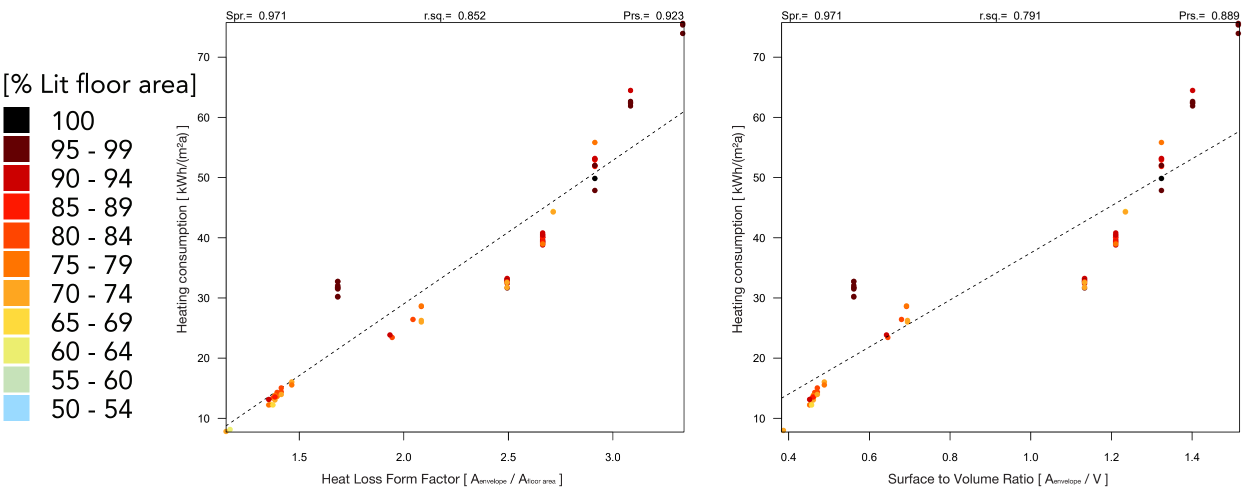

Figure 33: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 3rd proposal

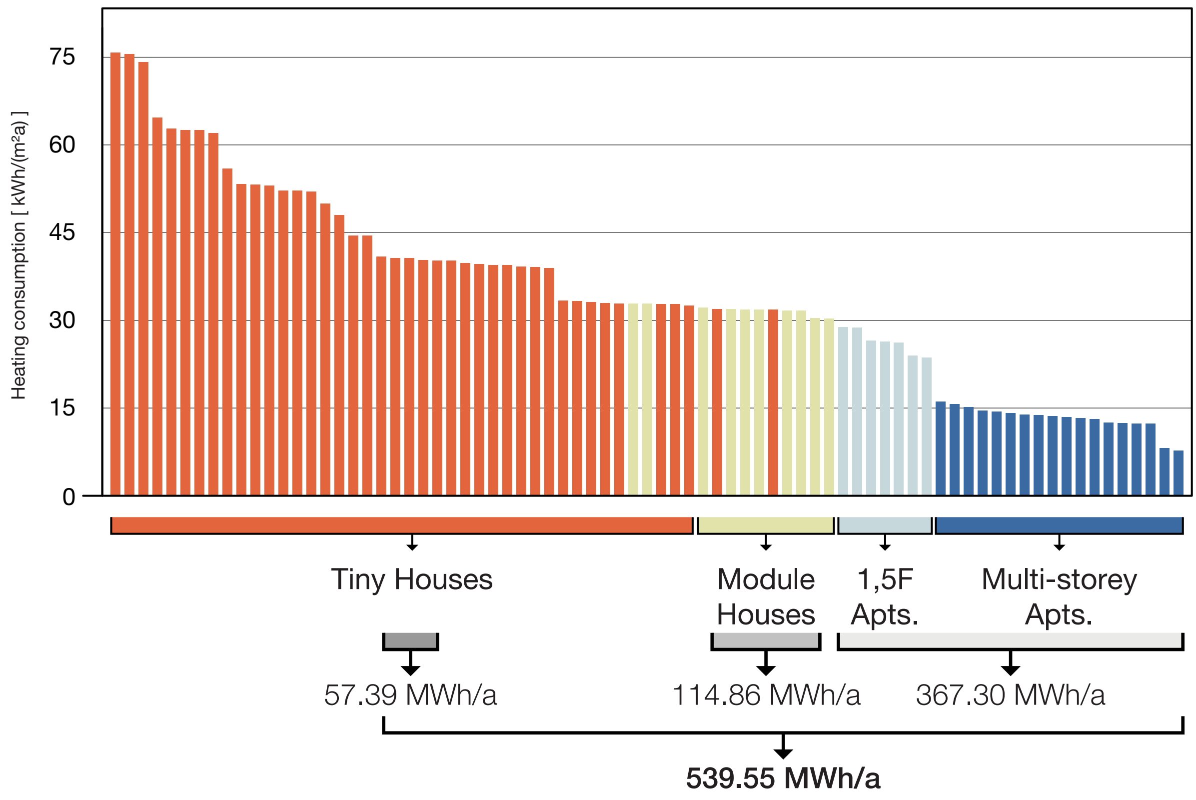

Figure 34: Bar chart of the buildings' heating demand efficiency of the 3rd proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h3} = 539.55 MWh/a
GFA_3 = 29 139 m^2
GFA_{gen} = 30 000 m^2

Q_3 = 539.55 MWh/a × (GFA_{gen} / GFA_3)
Q_3 = 539.55 MWh/a × (30 000 m^2 / 29 139 m^2)
Q_3 = 539.55 MWh/a × (1.0295)
Q_3 = 555.49 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h3'}$ = 539.55 - 57.39 = 482.16 MWh/a
$GFA_{3'}$ = 29 139 - 1 239 = 27 900 m^2

$Q_{3'}$ = 482.16 MWh/a × (GFA_{gen} / $GFA_{3'}$)
$Q_{3'}$ = 482.16 MWh/a × (30 000 m^2 / 27 900 m^2)
$Q_{3'}$ = 482.16 MWh/a × (1.0753)
$Q_{3'}$ = 518.45 MWh/a

For a GFA of 30 000 m^2 the 3rd proposal would have a heating demand of 555.49 MWh anually, alternatively while excluding the tiny houses it would be 518.45 MWh anually.

Sunlight hours analysis:

Figure 35: Percentage of floor area lit with 50+ sunlight hours annually is 81% for the 3rd proposal

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Universal Thermal Comfort Index analysis:

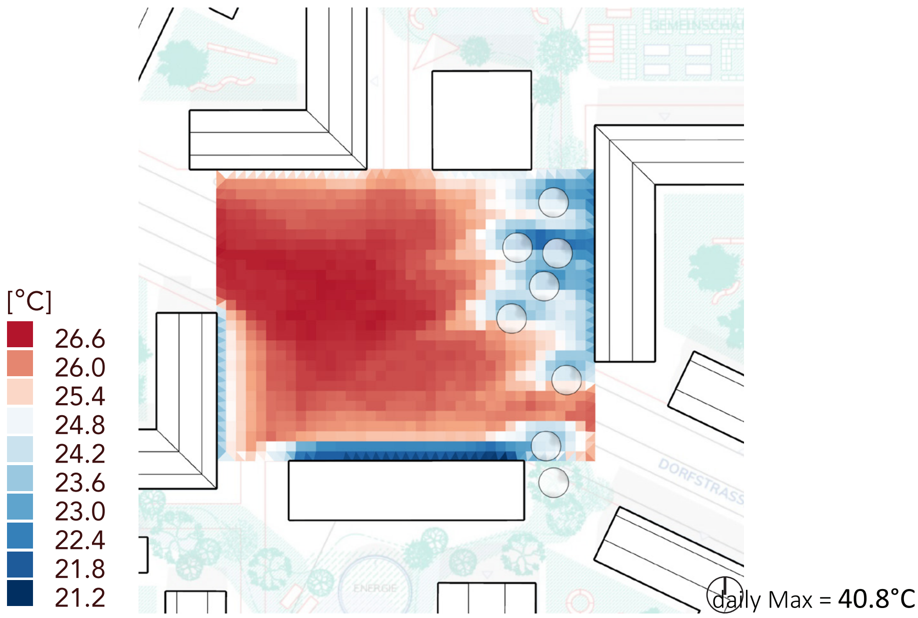

Figure 36: Average UTCI during the 03. July (the hottest day) on the village square of the 3rd proposal

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PV potential analysis:

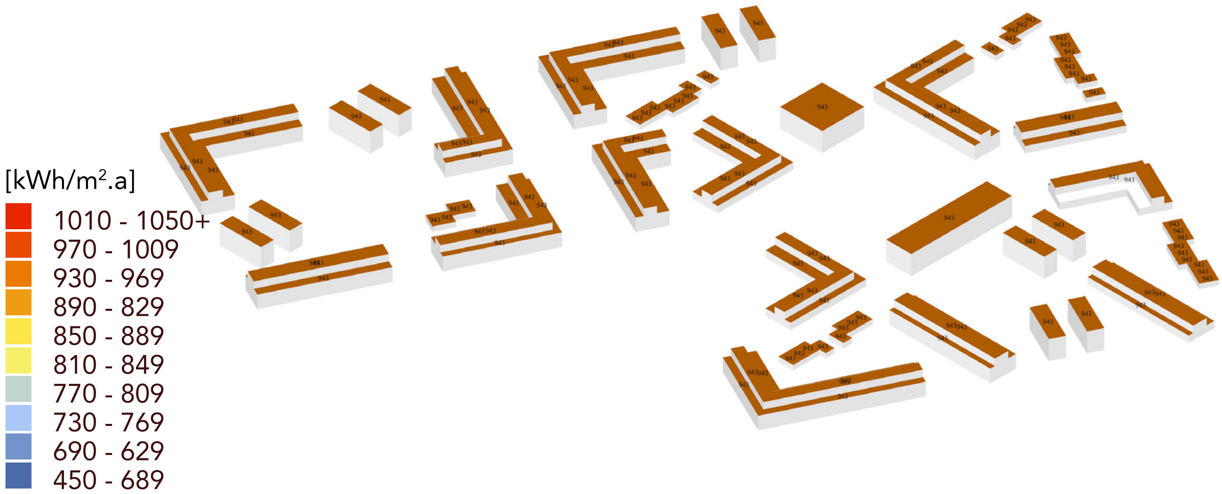

Figure 37: Incident POA irradiation of the roof surfaces of the 3rd proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 3rd proposal equals to 9 430 MWh/a.

Summary:

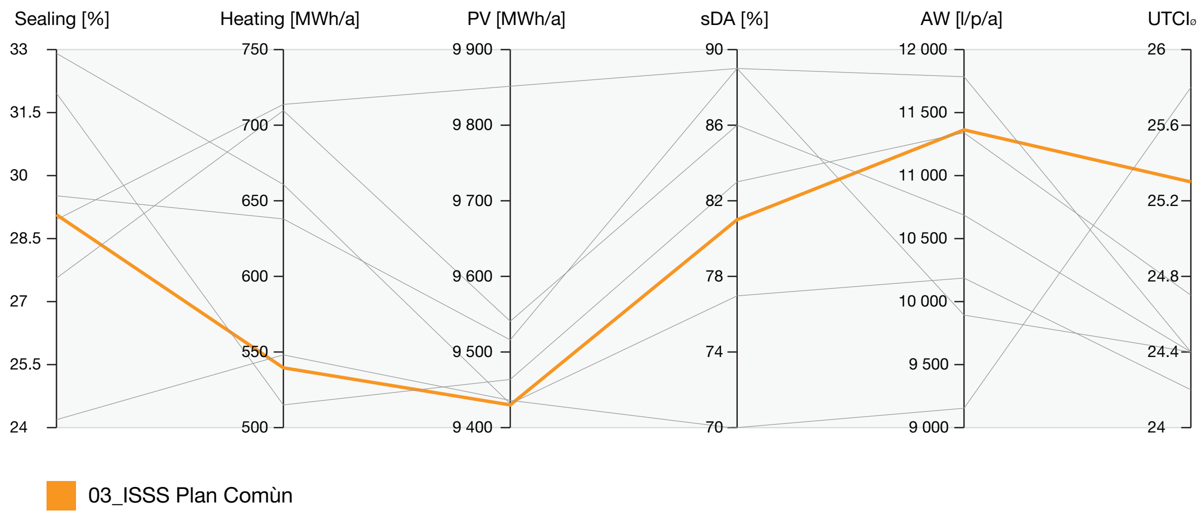

Figure 38: Performance of the 3rd proposal visualized on a line graph

Proposal 4

Office: Natrufied architecture, Bergen NH, Niederlande
GFA = 31 559 m² (30 226 m² heated spaces + 1 333 m² non-heated spaces)

Sealed area = 24.19 %
Q_h = 548.1 MWh/a
SI = 9 436 MWh/a
sDA = 70%
AW = 9 128 l/p/a
$UTCI_{Ø}$: 25.8°C
$UTCI_{max}$: 40.9°C

Heating demand analyses:

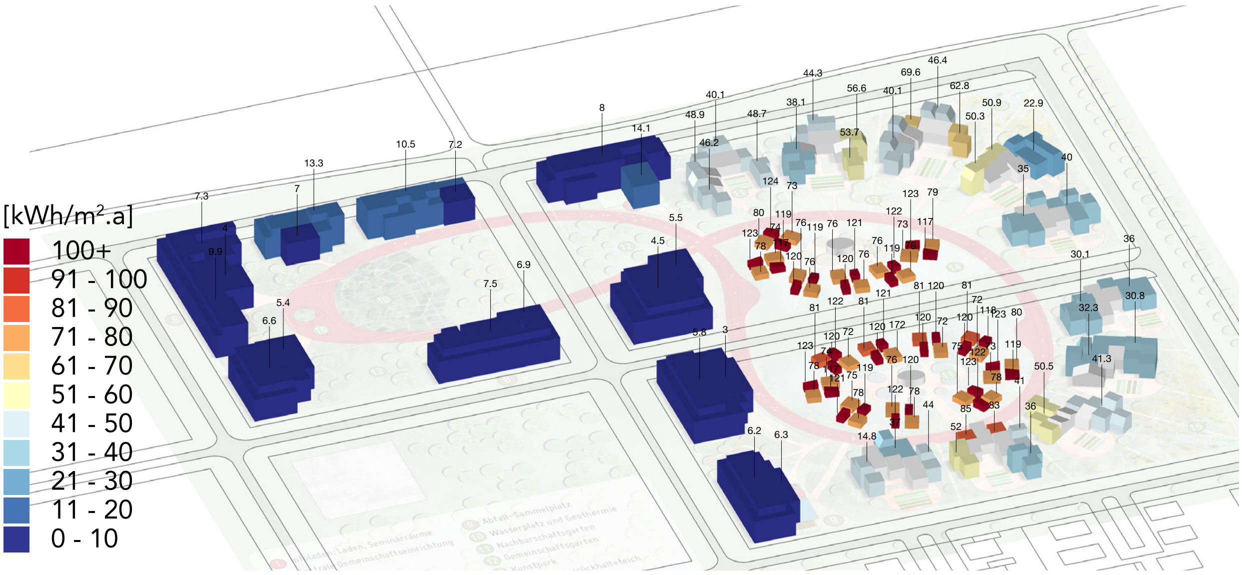

Figure 39: Efficiency of the each buildings' heating demand of the 4th proposal

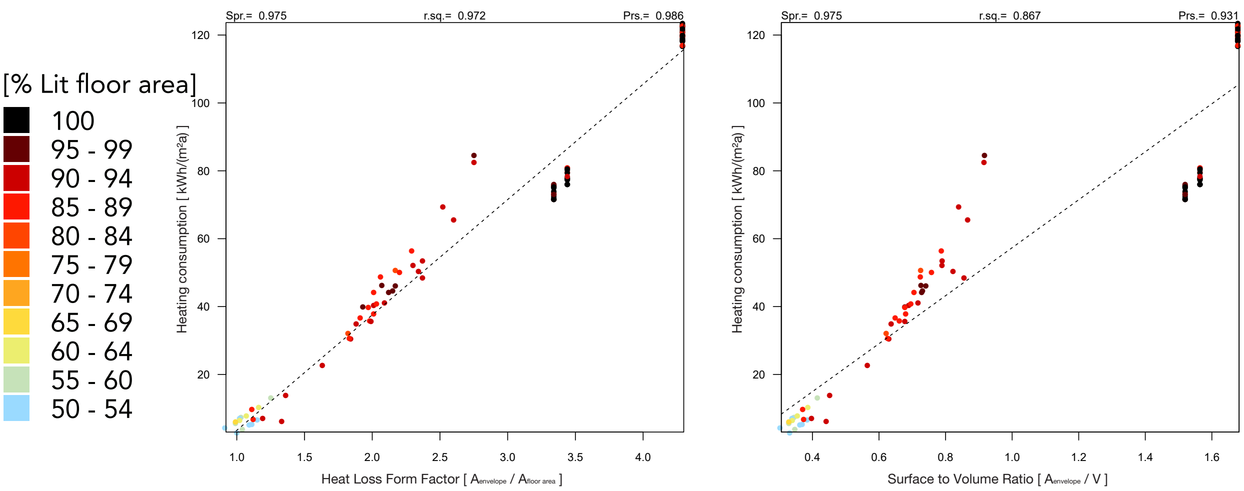

Figure 40: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 4th proposal

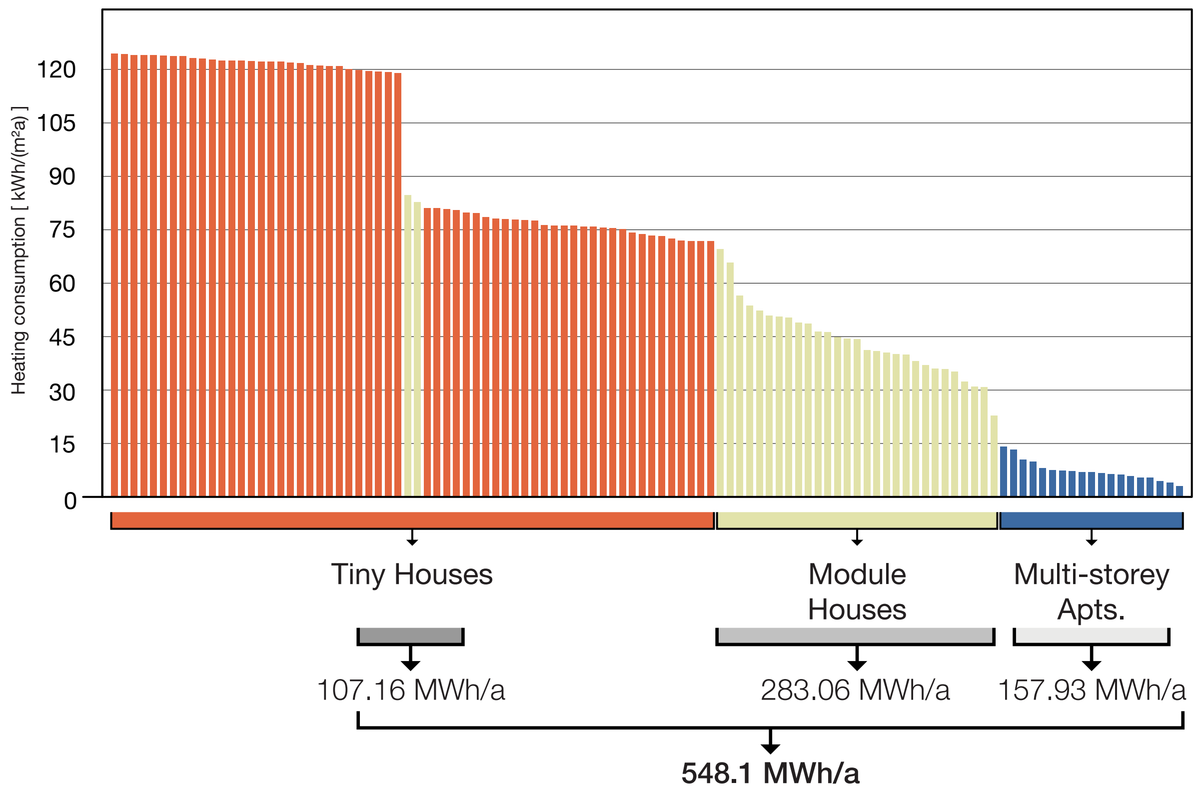

Figure 41: Bar chart of the buildings' heating demand efficiency of the 3rd proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h4}= 548.1 MWh/a
GFA_3= 30 226 m²
GFA_{gen}= 30 000 m²

Q_4= 548.1 MWh/a × (GFA_{gen} / GFA_4)
Q_4= 548.1 MWh/a × (30 000 m² / 30 226 m²)
Q_4= 548.1 MWh/a × (0.9925)
Q_4= 544 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h4'}$= 548.1 - 107.16 = 440.94 MWh/a
$GFA_{4'}$= 30 226 - 1 173 = 29 053 m²

$Q_{4'}$= 440.94 MWh/a × (GFA_{gen} / $GFA_{4'}$)
$Q_{4'}$= 440.94 MWh/a × (30 000 m² / 29 053 m²)
$Q_{4'}$= 440.94 MWh/a × (1.0326)
$Q_{4'}$= 455.31 MWh/a

For a GFA of 30 000 m² the 4th proposal would have a heating demand of 544 MWh anually, alternatively while excluding the tiny houses it would be 455.31 MWh anually.

Sunlight hours analysis:

Figure 42: Percentage of floor area lit with 50+ sunlight hours annually is 70% for the 4th proposal

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Universal Thermal Comfort Index analysis:

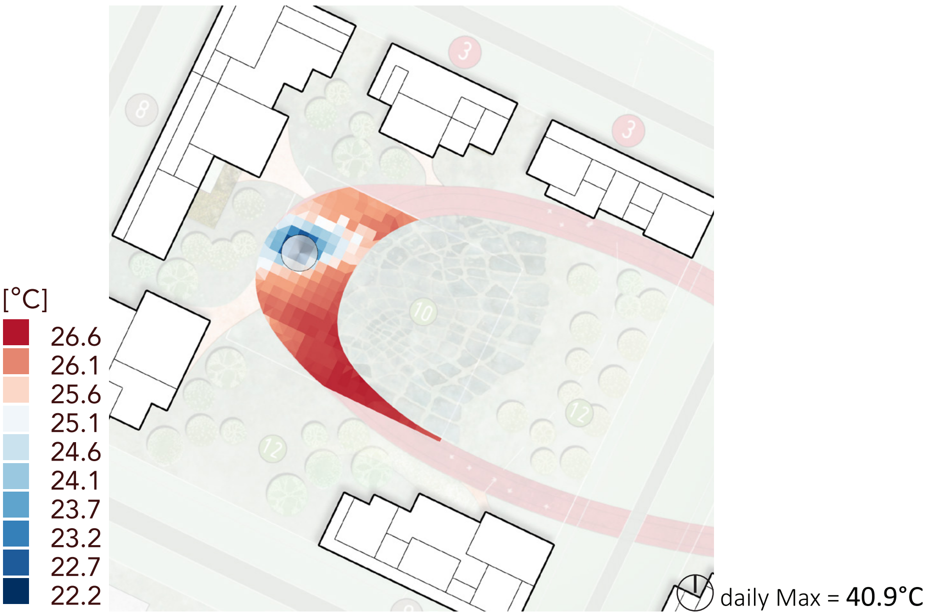

Figure 43: Average UTCI during the 03. July (the hottest day) on the village square of the 4th proposal

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PV potential analysis:

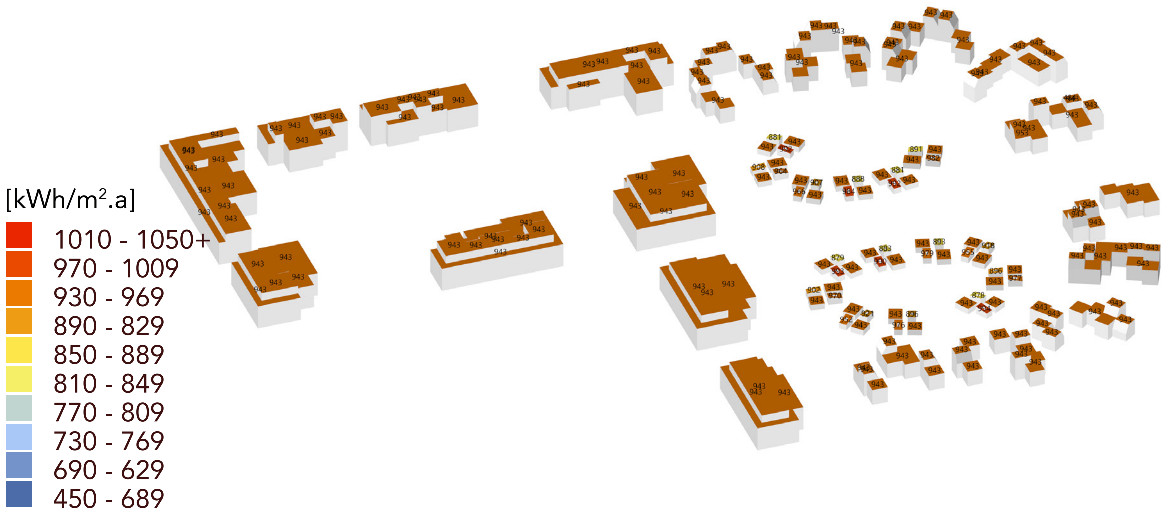

Figure 44: Incident POA irradiation of the roof surfaces of the 4th proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 4th proposal equals to 9 436 MWh/a.

Summary:

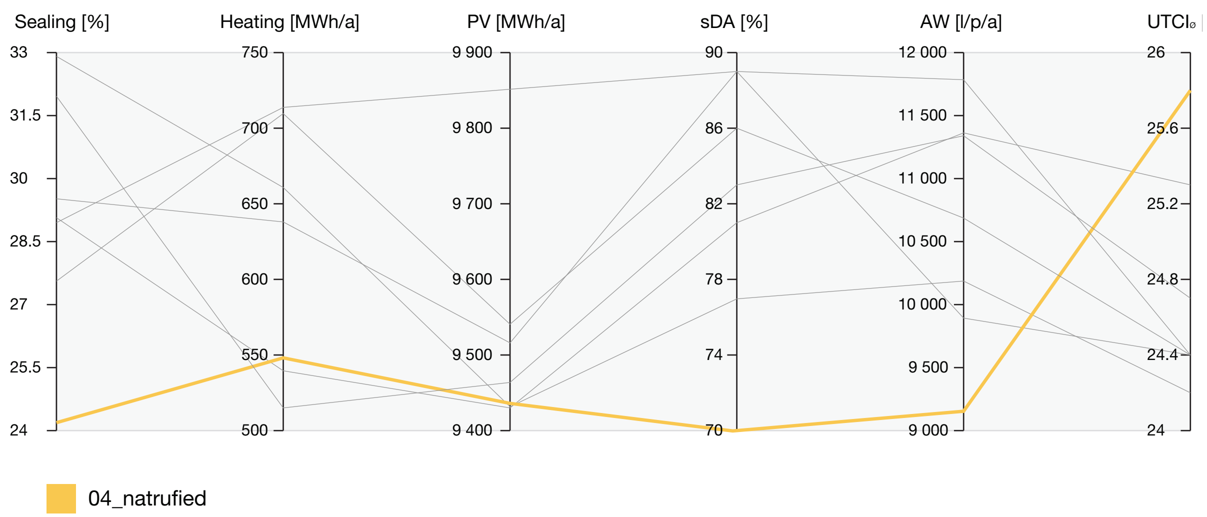

Figure 45: Performance of the 4th proposal visualized on a line graph

Proposal 5

Office: Jensen und Hultsch Architekten Part GmbB, Braunschweig
Assmann Beraten + Planen AG, Braunschweig
GFA = 32 776 m² (32 171 m² heated spaces + 2605 m² non-heated spaces)

Sealed area = 31.97 %
Q_h = 515 MWh/a
SI = 9 463.7 MWh/a
sDA = 83%
AW = 11 342 l/p/a
$UTCI_{Ø}$ = 24.7°C
$UTCI_{max}$ = 40.9°C

Heating demand analyses:

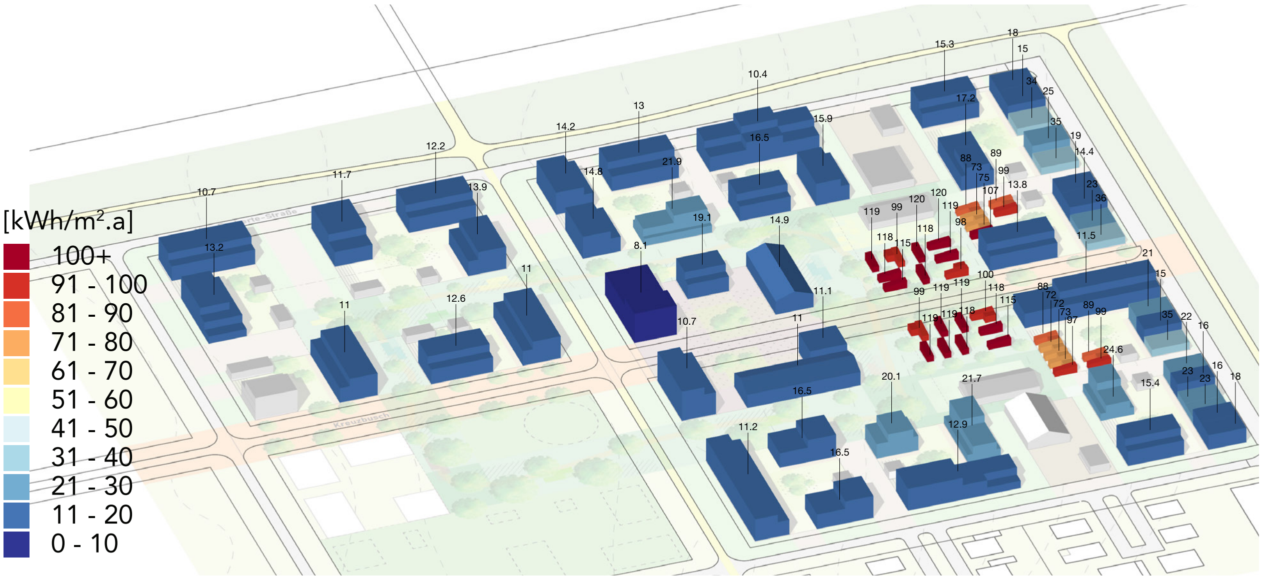

Figure 46: Efficiency of the each buildings' heating demand of the 5th proposal

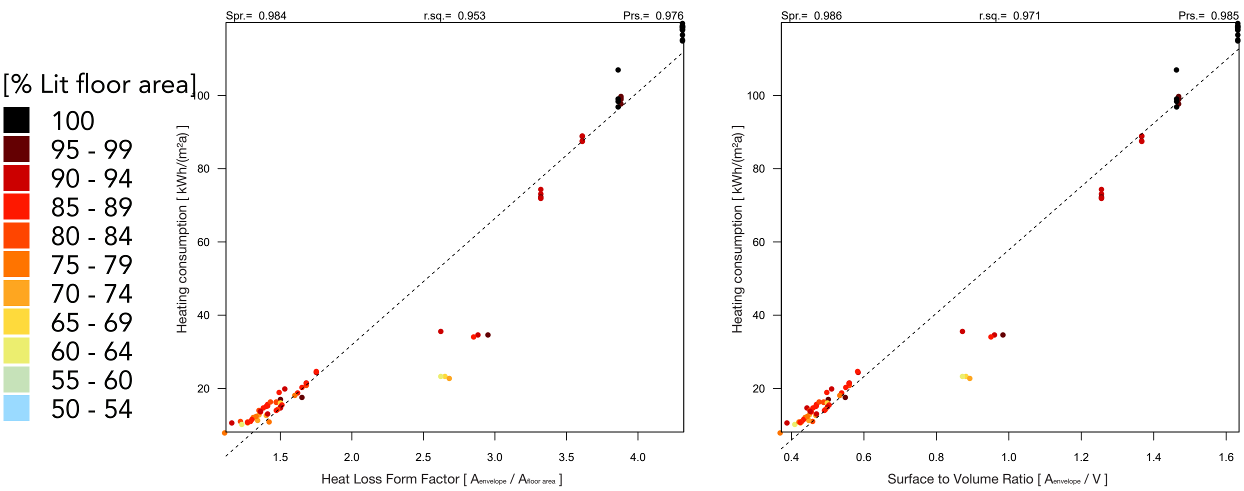

Figure 47: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 5th proposal

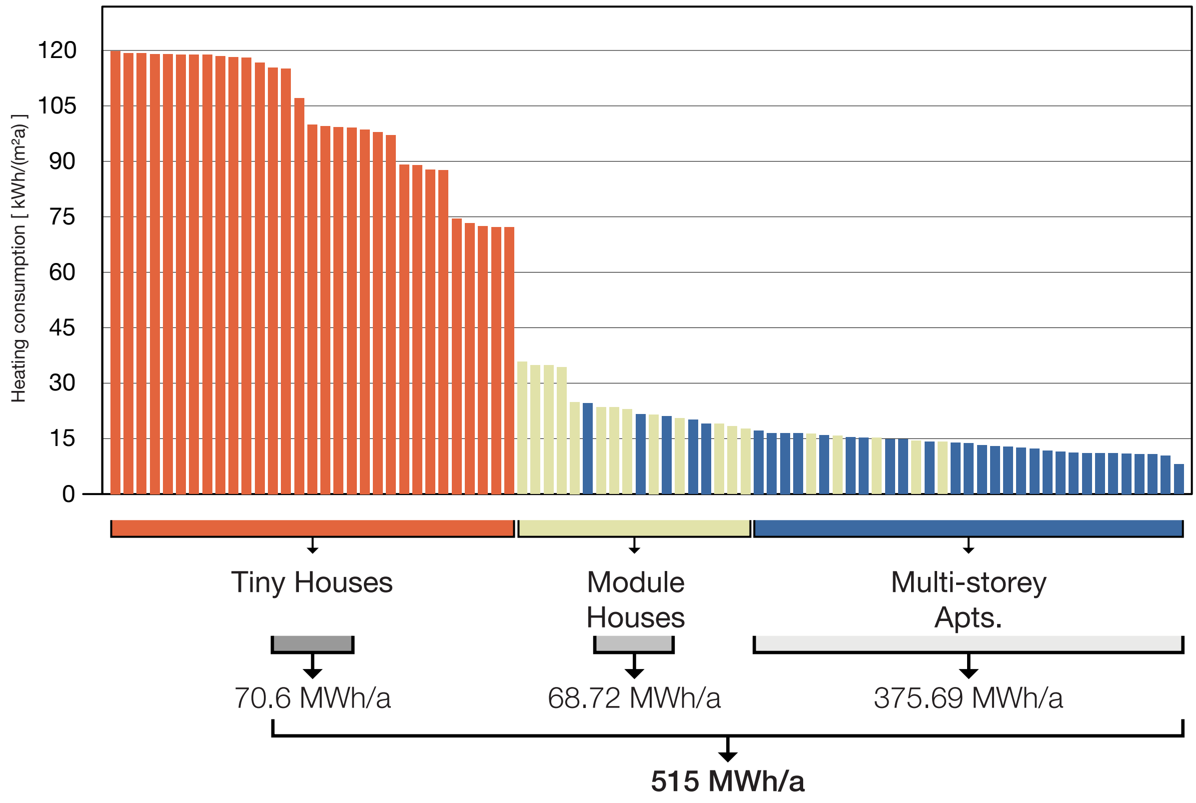

Figure 48: Bar chart of the buildings' heating demand efficiency of the 5th proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h5}= 515 MWh/a
GFA_5= 32 171 m^2
GFA_{gen}= 30 000 m^2

Q_5= 515 MWh/a × (GFA_{gen} / GFA_5)
Q_5= 515 MWh/a × (30 000 m^2 / 32 171 m^2)
Q_5= 515 MWh/a × (0.9325)
Q_5= 480.25 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h5'}$= 515 - 70.6 = 444.4 MWh/a
$GFA_{5'}$= 32 171 - 710 = 31 461 m^2

$Q_{5'}$= 444.4 MWh/a × (GFA_{gen} / $GFA_{5'}$)
$Q_{5'}$= 444.4 MWh/a × (30 000 m^2 / 31 461 m^2)
$Q_{5'}$= 444.4 MWh/a × (0.9536)
$Q_{5'}$= 423.76 MWh/a

For a GFA of 30 000 m^2 the 5th proposal would have a heating demand of 480.25 MWh anually, alternatively while excluding the tiny houses it would be 423.76 MWh anually.

Sunlight hours analysis:

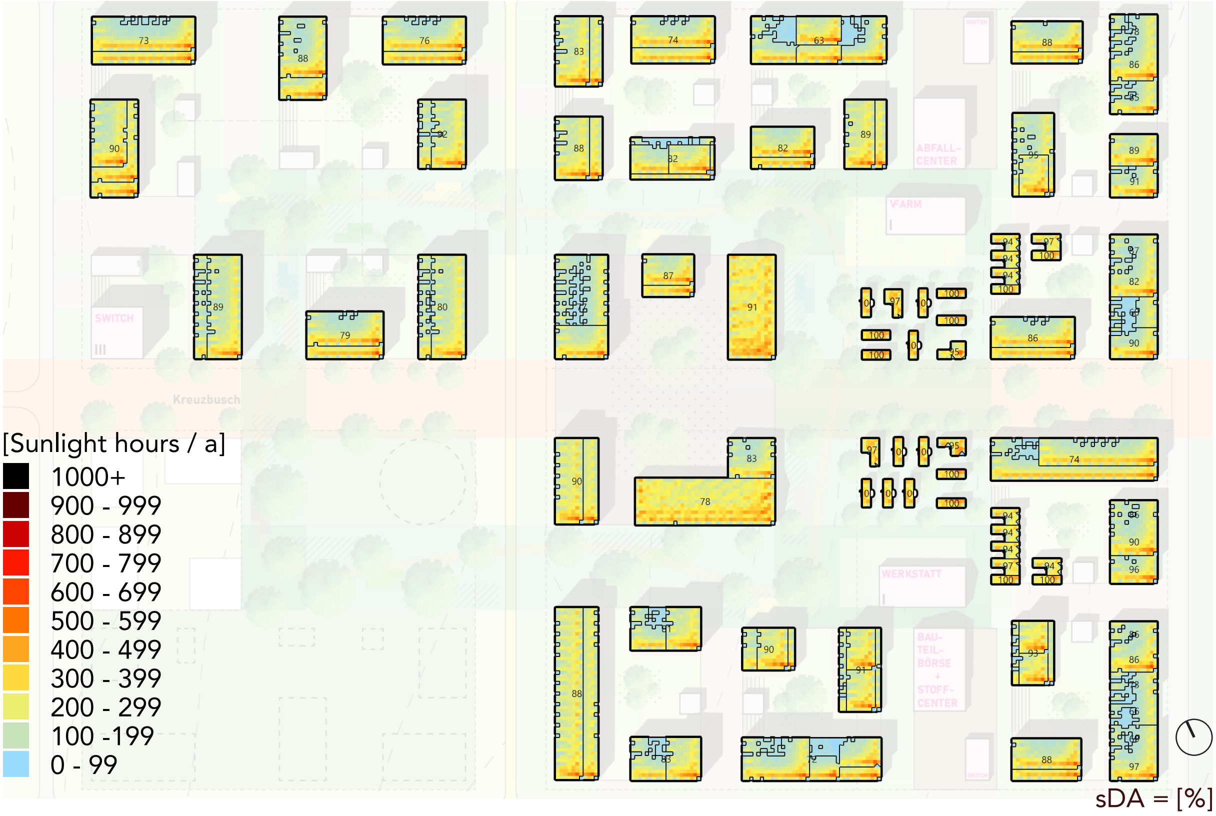

Figure 49: Percentage of floor area lit with 50+ sunlight hours annually is 83% for the 5th proposal

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Universal Thermal Comfort Index analysis:

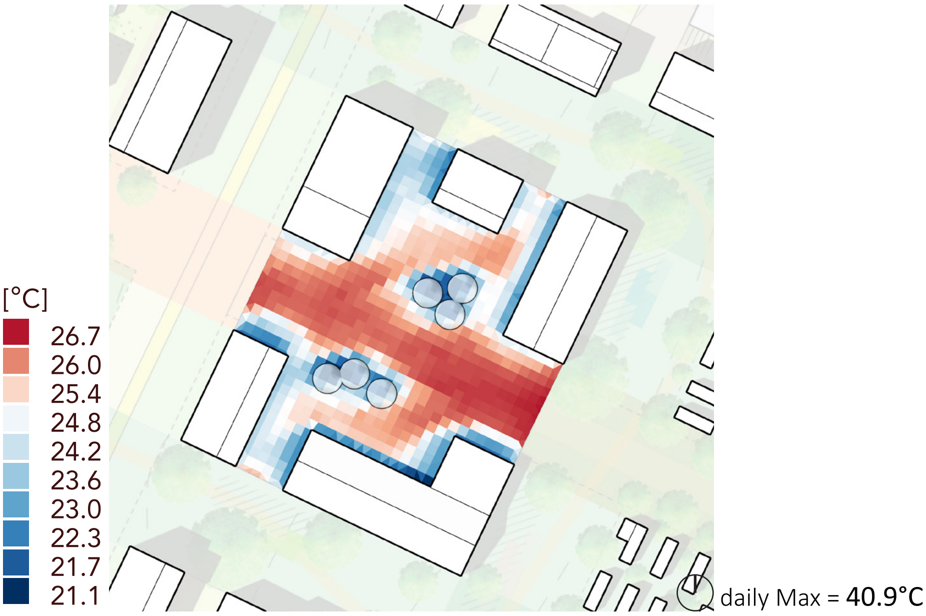

Figure 50: Average UTCI during the 03. July (the hottest day) on the village square of the 5th proposal

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PV potential analysis:

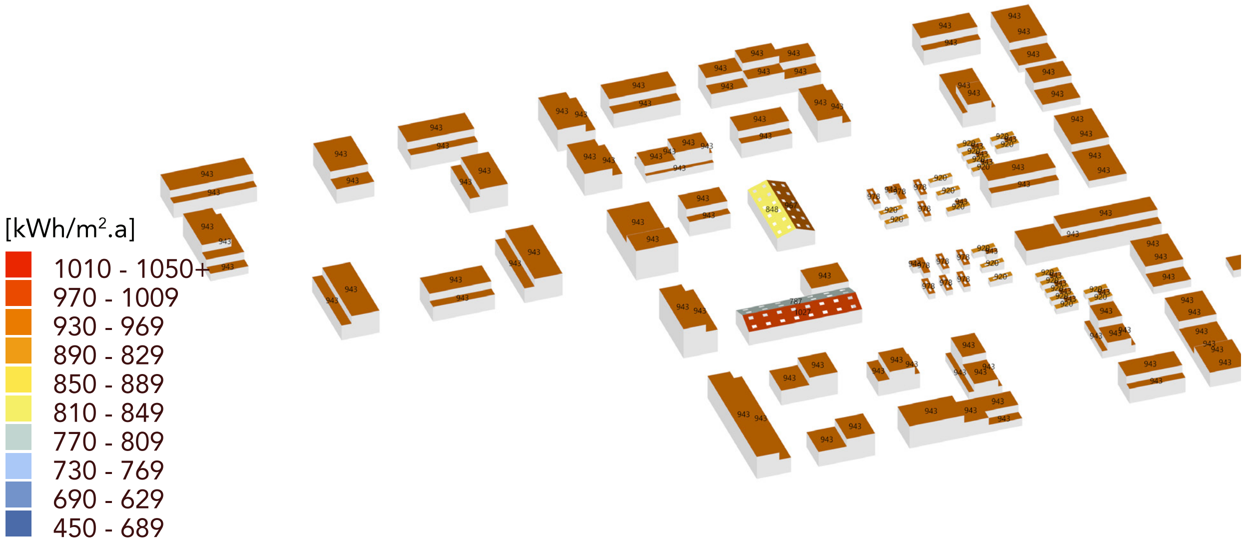

Figure 51: Incident POA irradiation of the roof surfaces of the 5th proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 5th proposal equals to 9 463.7 MWh/a.

Summary:

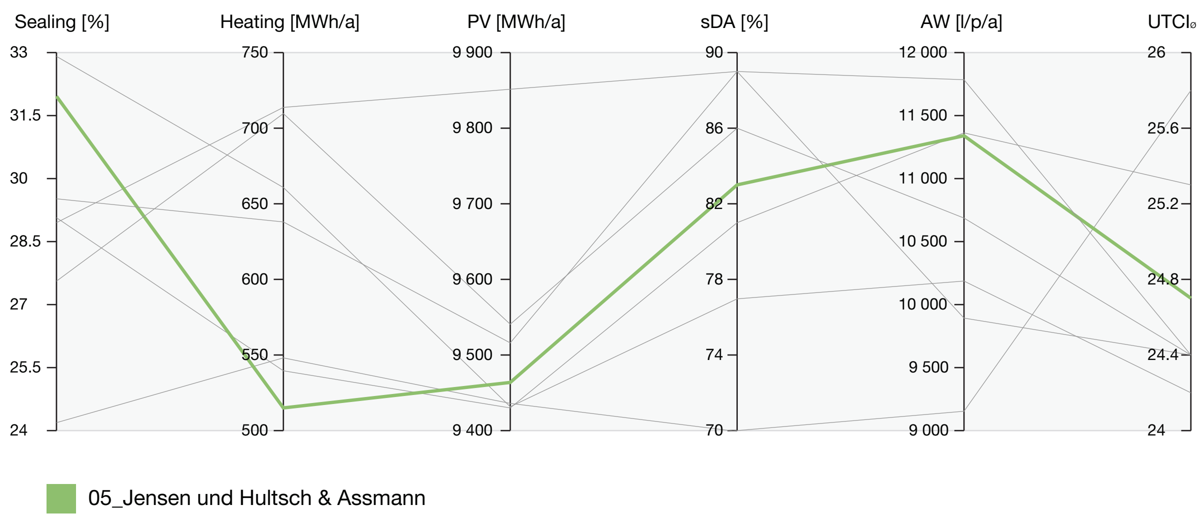

Figure 52: Performance of the 5th proposal visualized on a line graph

Proposal 6

Office: .bieker Nord GmbH, Hannover
GFA = 28 182 m² (all heated spaces)

Sealed area = 29.52 %
Q_h = 638 MWh/a
SI = 9 516 MWh/a
sDA = 89%
AW = 11 785 l/p/a
$UTCI_{\varnothing}$ = 24.4°C
$UTCI_{max}$ = 39.9°C

Heating demand analyses:

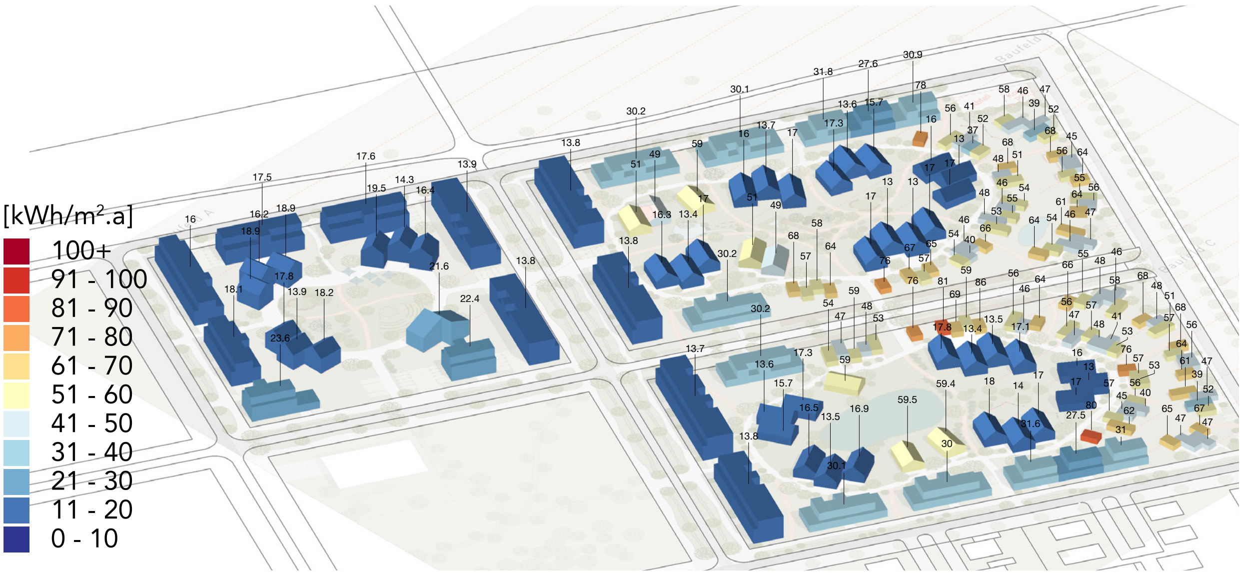

Figure 53: Efficiency of the each buildings' heating demand of the 6th proposal

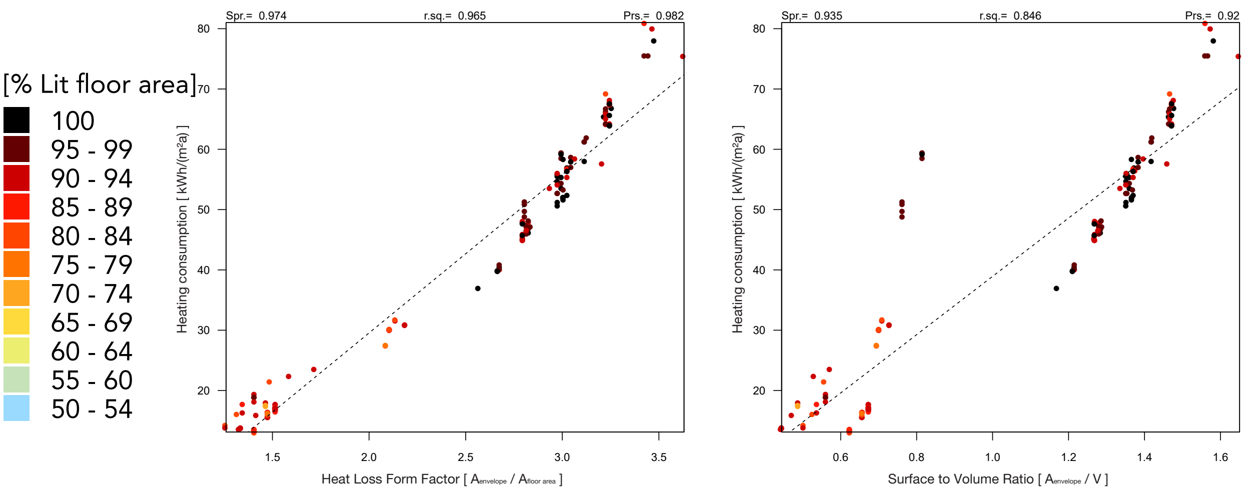

Figure 54: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 6th proposal

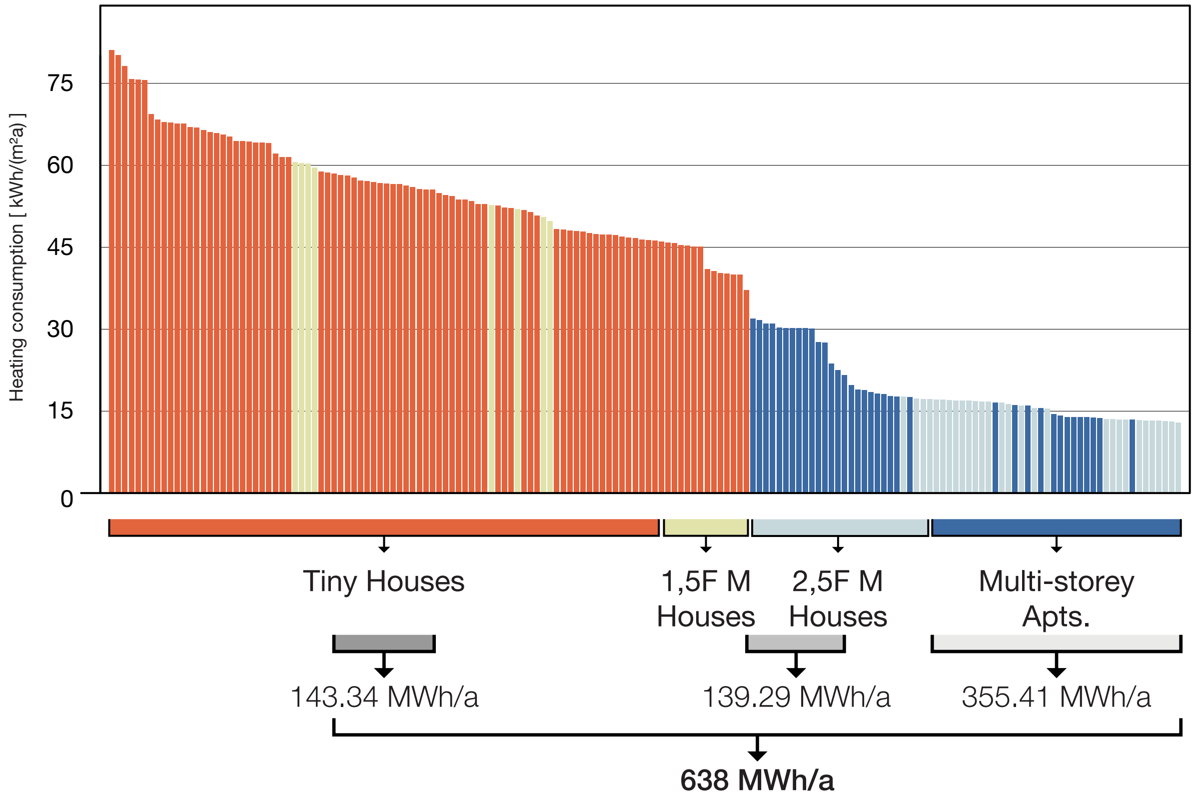

Figure 55: Bar chart of the buildings' heating demand efficiency of the 6th proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h6}= 638 MWh/a
GFA_6= 28 182 m²
GFA_{gen}= 30 000 m²

Q_6= 638 MWh/a × (GFA_{gen} / GFA_6)
Q_6= 638 MWh/a × (30 000 m² / 28 182 m²)
Q_6= 638 MWh/a × (1.0645)
Q_6= 679.16 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h6'}$= 638 - 143.34 = 494.66 MWh/a
$GFA_{6'}$= 28 182 - 2 619 = 25 563 m²

$Q_{6'}$= 494.66 MWh/a × (GFA_{gen} / $GFA_{6'}$)
$Q_{6'}$= 494.66 MWh/a × (30 000 m² / 25 563 m²)
$Q_{6'}$= 494.66 MWh/a × (1.1736)
$Q_{6'}$= 580.52 MWh/a

For a GFA of 30 000 m² the 6th proposal would have a heating demand of 679.16 MWh anually, alternatively while excluding the tiny houses it would be 580.52 MWh anually.

Sunlight hours analysis:

Figure 56: Percentage of floor area lit with 50+ sunlight hours annually is 89% for the 6th proposal

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Universal Thermal Comfort Index analysis:

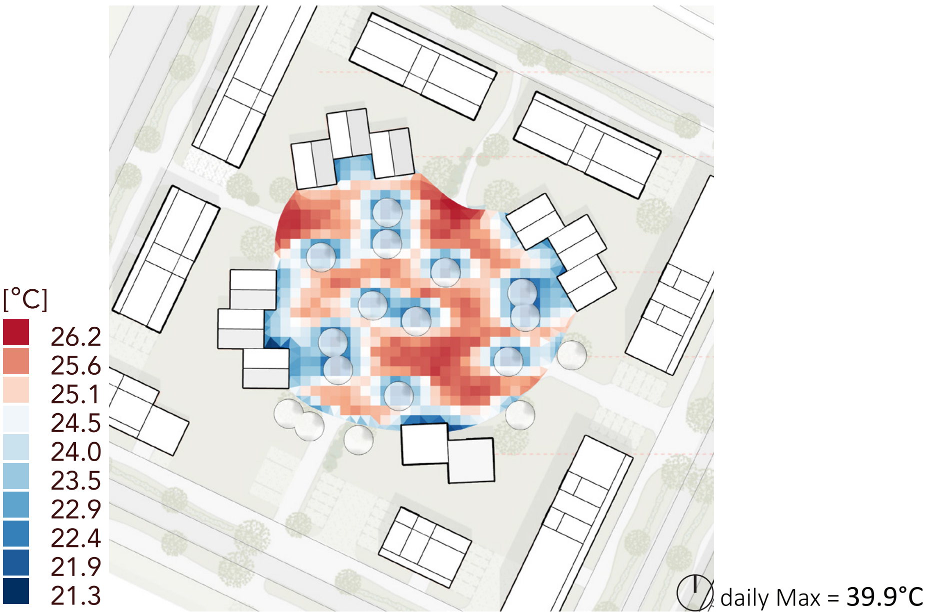

Figure 57: Average UTCI during the 03. July (the hottest day) on the village square of the 6th proposal

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PV potential analysis:

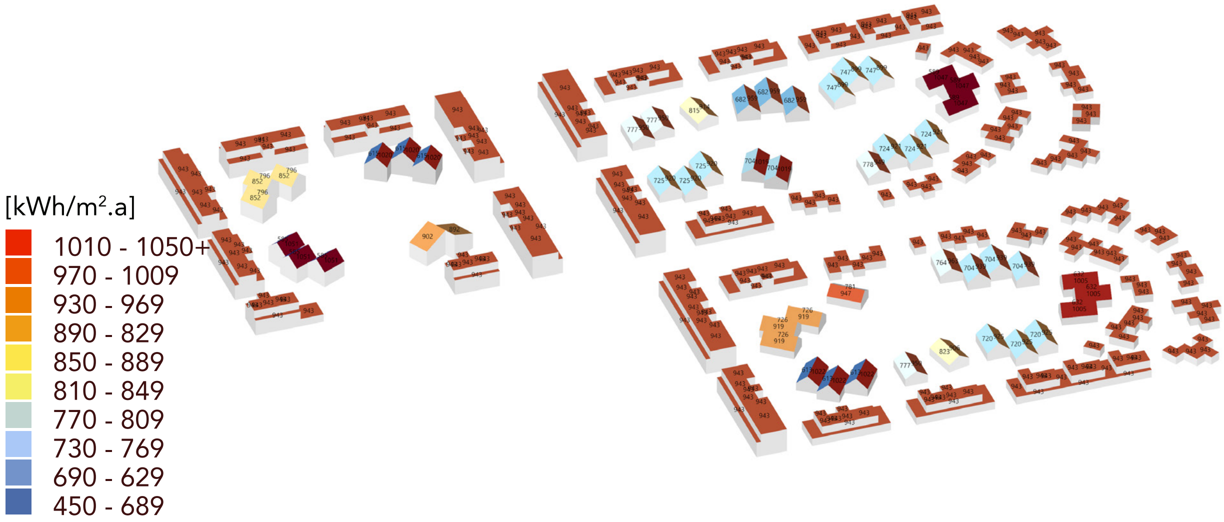

Figure 58: Incident POA irradiation of the roof surfaces of the 6th proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 6th proposal equals to 9 516 MWh/a

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Summary:

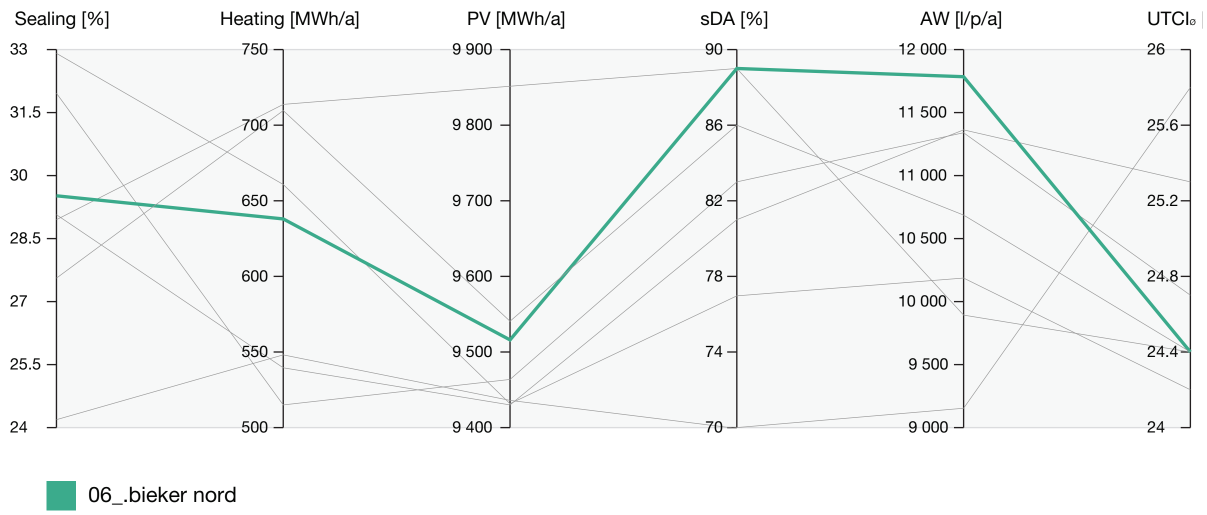

Figure 59: Performance of the 6th proposal visualized on a line graph

Proposal 7

Office: INORD Architects, Kopenhagen, Denmark

GFA = 28 775 m² (27 910 m² heated spaces + 865 m² non-heated spaces)

Sealed area = 27.56 %
Q_h = 709.7 MWh/a
SI = 9 540.7 MWh/a
sDA = 86%
AW = 11 274 l/p/a
$UTCI_{Ø}$ = 24.4°C
$UTCI_{max}$ = 40.8°C

Heating demand analyses:

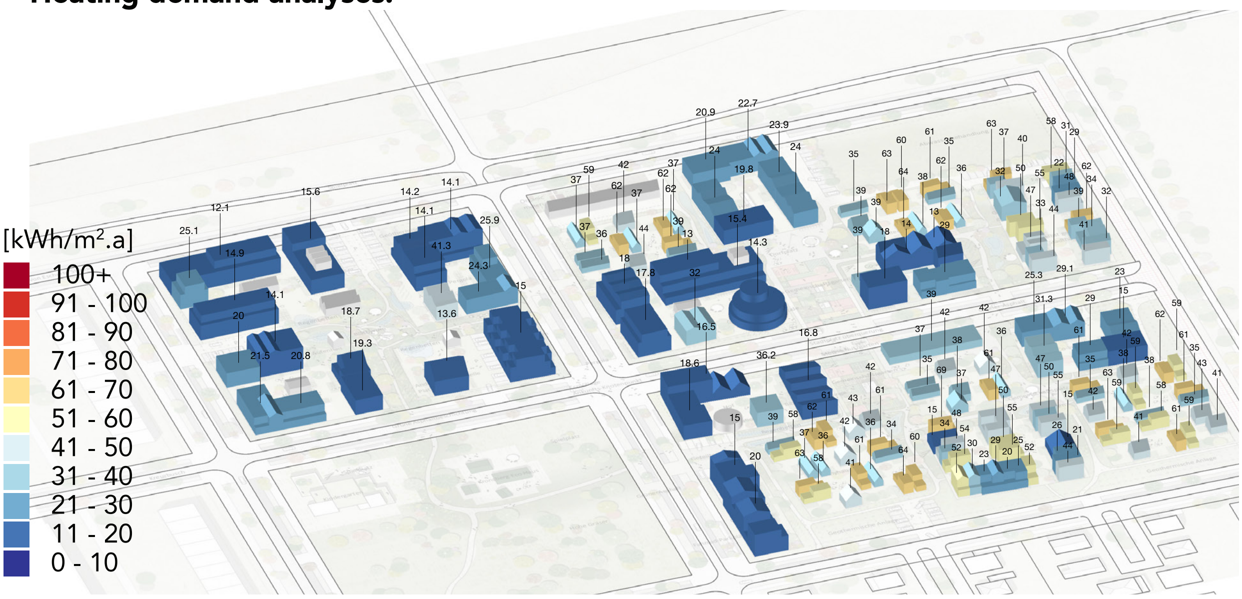

Figure 60: Efficiency of the each buildings' heating demand of the 7th proposal

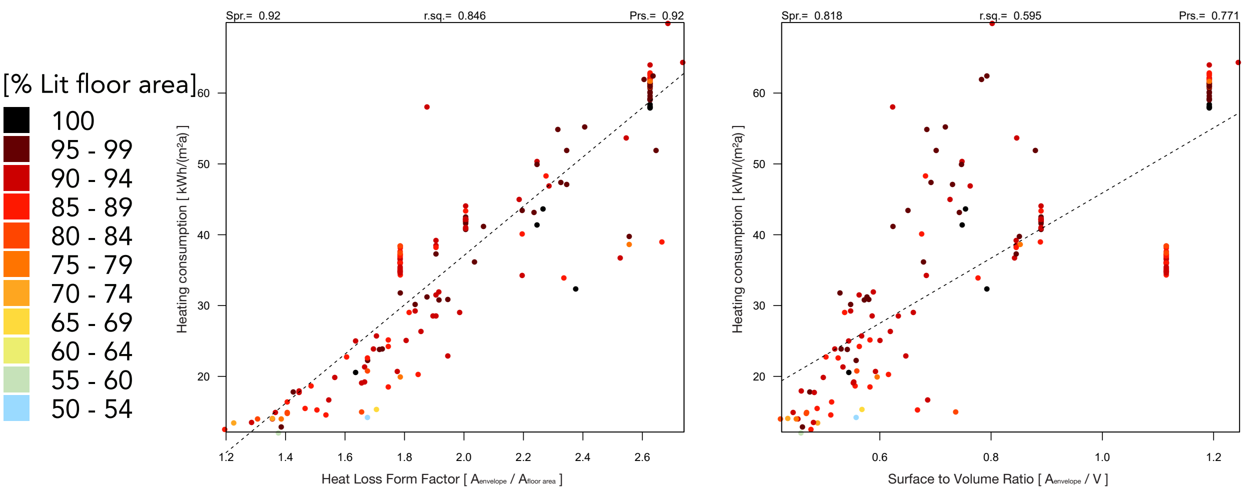

Figure 61: Scatter plots showing the relationship of heating demand to the buildings' compactness and the daylight analysis of the 7th proposal

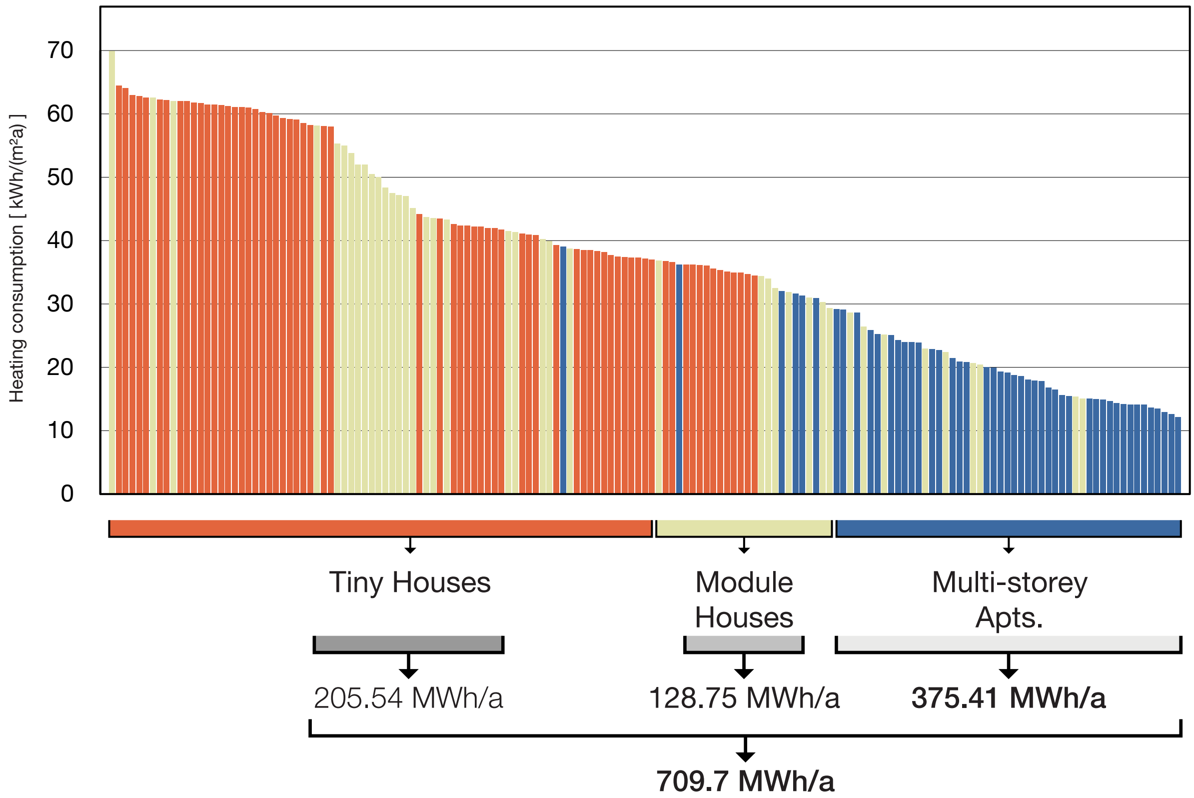

Figure 62: Bar chart of the buildings' heating demand efficiency of the 7th proposal

Remapping the heating demand for one general GFA of heating spaces:

Q_{h7}= 709.7 MWh/a
GFA_7= 27 775 m²
GFA_{gen}= 30 000 m²

Q_7= 709.7 MWh/a × (GFA_{gen} / GFA_7)
Q_7= 709.7 MWh/a × (30 000 m² / 27 775 m²)
Q_7= 709.7 MWh/a × (1.0801)
Q_7= 766.55 MWh/a

Remapping the heating demand for one general GFA of heating spaces while excluding the tiny houses:
$Q_{h7'}$= 709.7 - 205.54 = 504.16 MWh/a
$GFA_{7'}$= 27 775 - 4 320 = 23 455 m²

$Q_{7'}$= 504.16 MWh/a × (GFA_{gen} / $GFA_{7'}$)
$Q_{7'}$= 504.16 MWh/a × (30 000 m² / 23 455 m²)
$Q_{7'}$= 504.16 MWh/a × (1.279)
$Q_{7'}$= 644.84 MWh/a

For a GFA of 30 000 m² the 7th proposal would have a heating demand of 766.55 MWh anually, alternatively while excluding the tiny houses it would be 644.84 MWh anually.

Sunlight hours analysis:

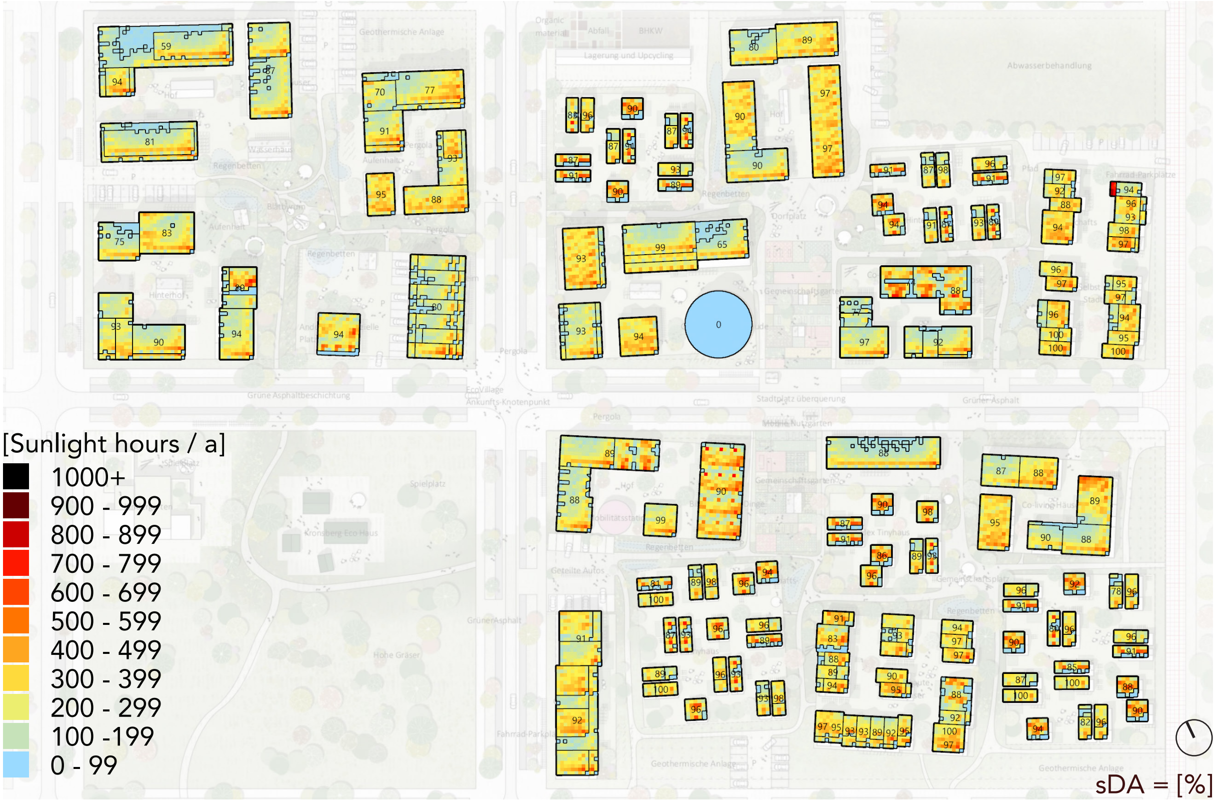

Figure 63: Percentage of floor area lit with 50+ sunlight hours annually is 86% for the 7th proposal

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Universal Thermal Comfort Index analysis:

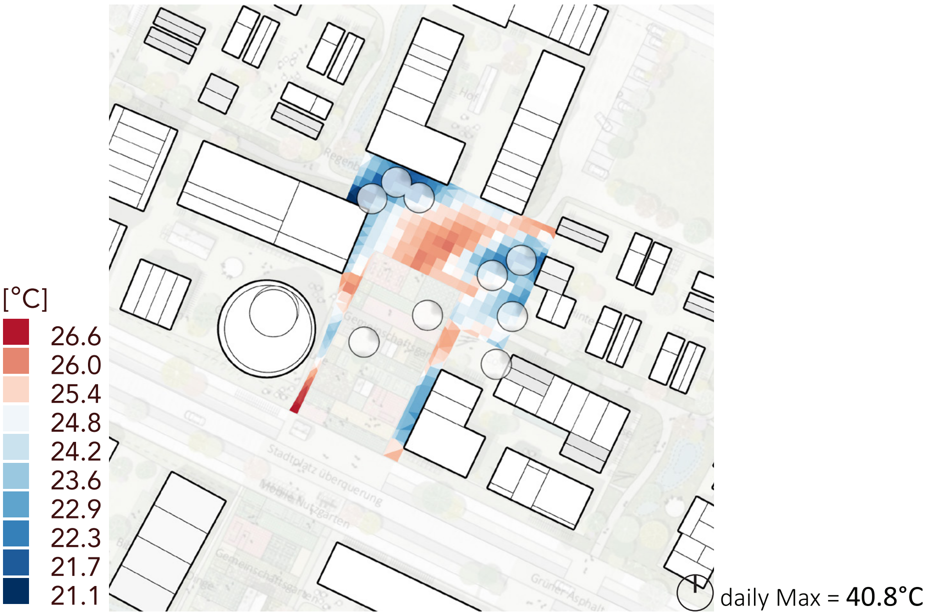

Figure 64: Average UTCI during the 03. July (the hottest day) on the village square of the 7th proposal

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PV potential analysis:

Figure 65: Incident POA irradiation of the roof surfaces of the 7th proposal

The total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels for the 7th proposal equals to 9 540.7 MWh/a.

Summary:

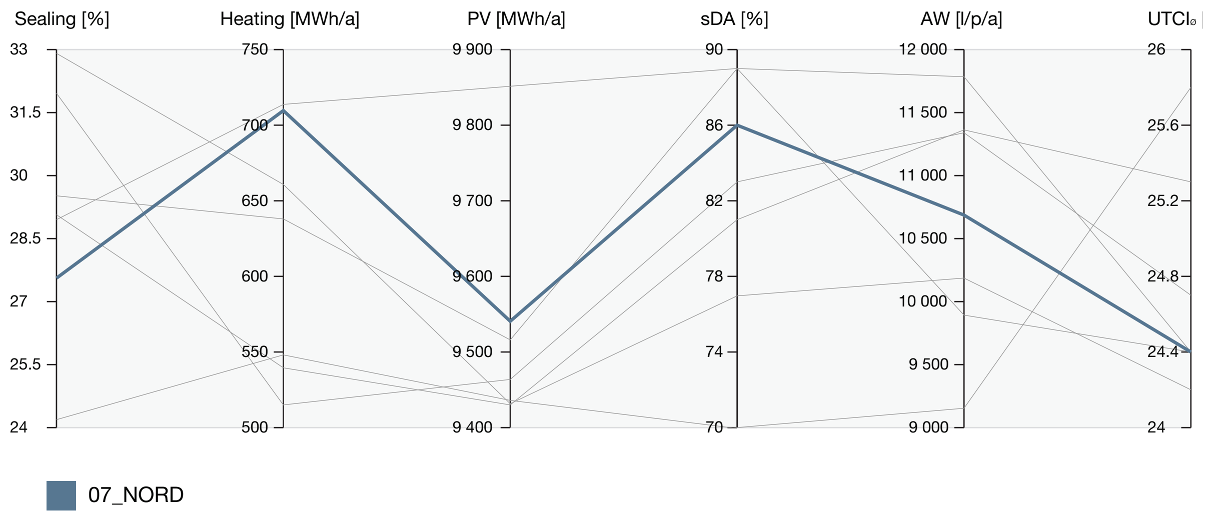

Figure 66: Performance of the 7th proposal visualized on a line graph

5.2 Comparison of performance

Now that all seven proposals have been individually evaluated in the selected criteria, following graphs will compare how different they perform between each other. Later in the Discussion chapter they will be examined with comments.

Heating demand:

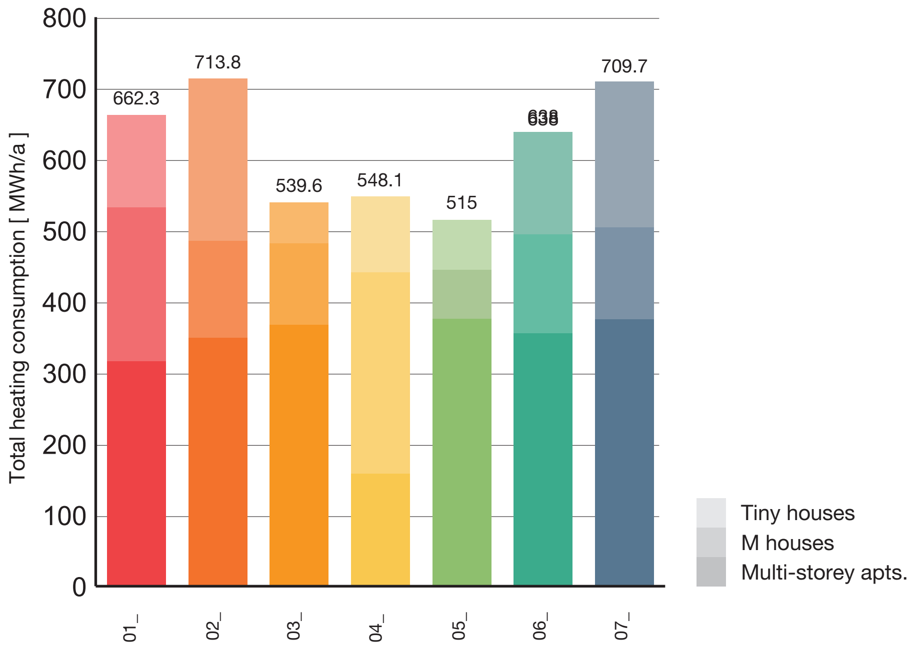

Figure 67: Final heating consumption for individual GFAs (without remapping)

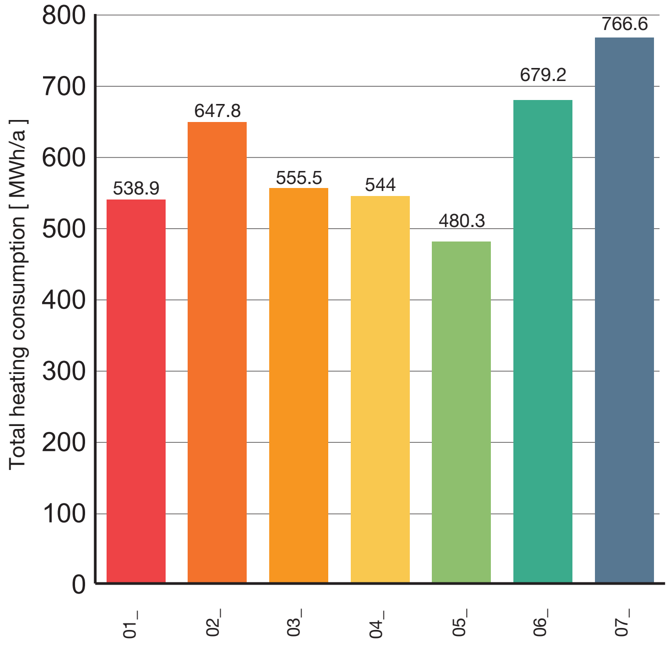

Figure 68: Final heating consumption remapped for general GFA of 30 000 m²

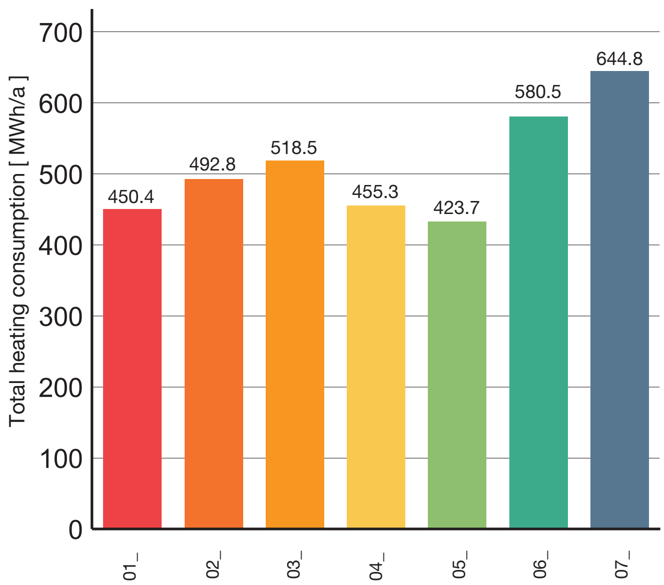

Figure 69: Final heating consumption remapped for general GFA of 30 000 m², with the exclusion of tiny houses typology

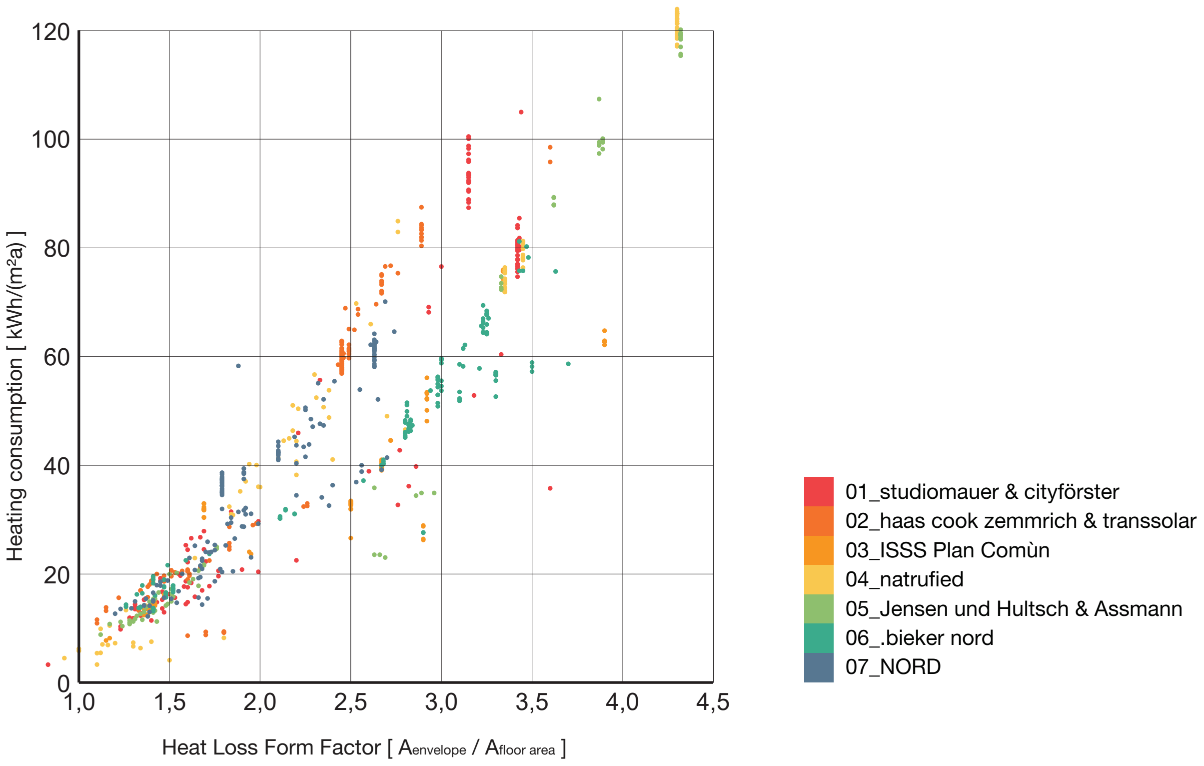

Figure 70: Scatter plot comparing all buildings' heating consumption to the heat loss form factor

PV potential:

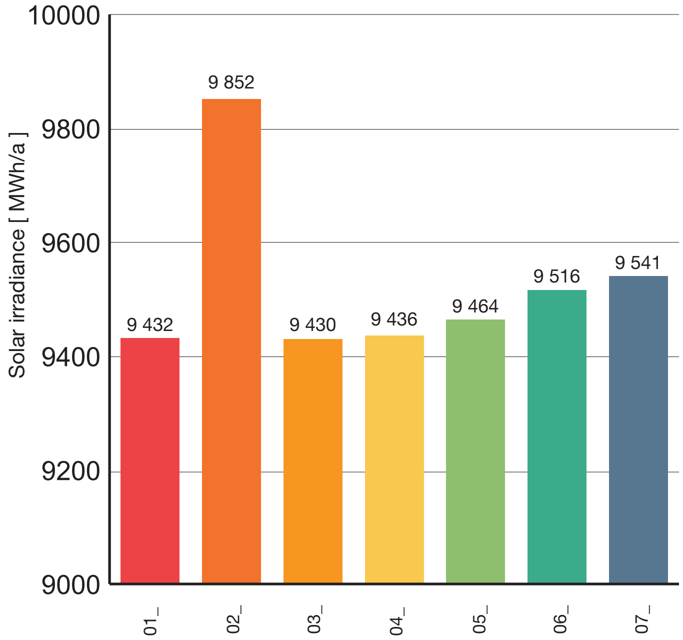

Figure 71: Comparison of total solar irradiance received from the Sun on theoretical 10 000 m² of PV panels

Sunlight hours analysis:

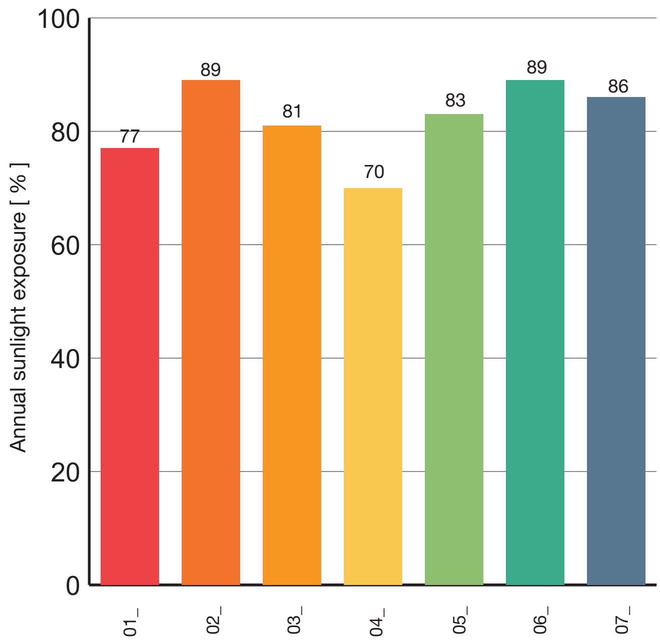

Figure 72: Comparison of percentage of floor area lit with 50+ sunlight hours annually

Available water:

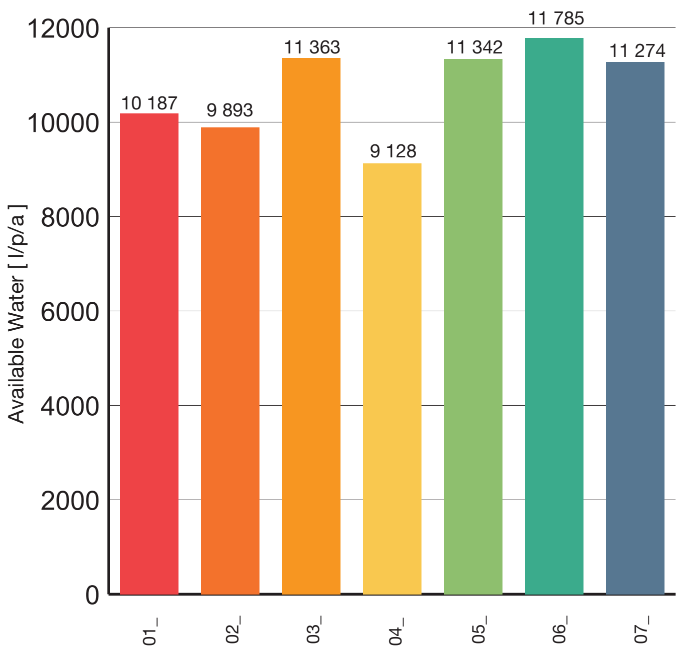

Figure 73: Comparison of available harvested water per person annually

Summary:

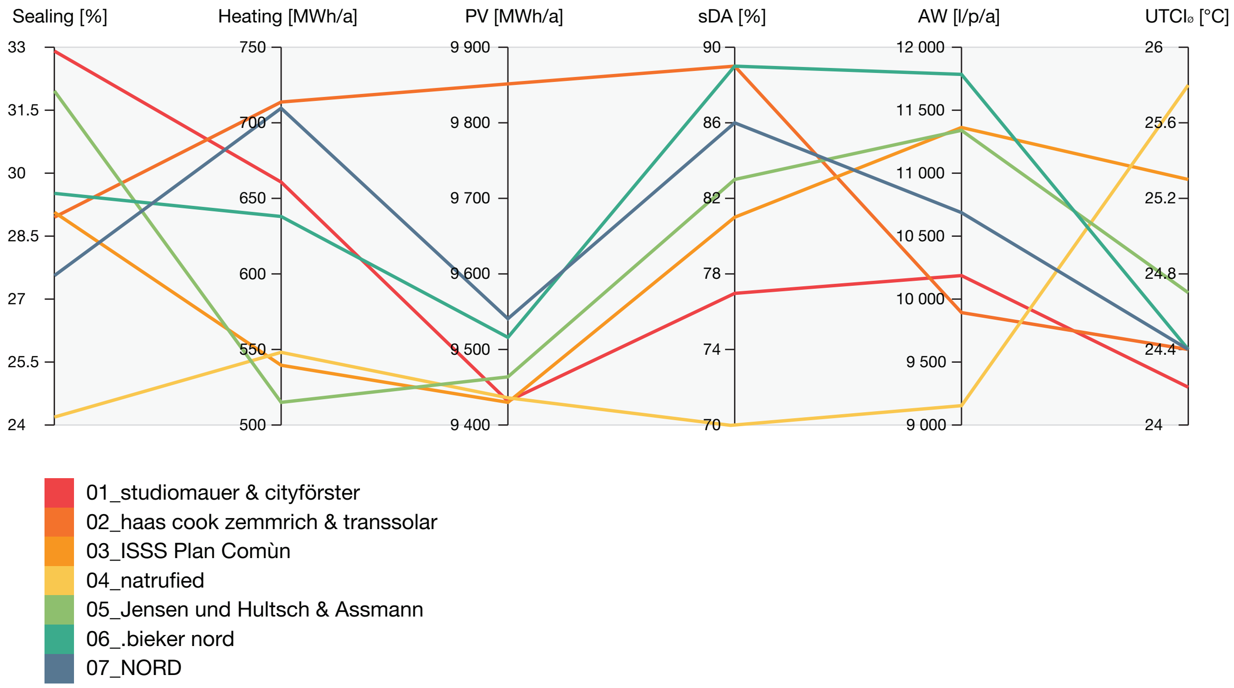

Figure 74: Performance of all proposals visualized on a line graph

6. Discussion

In this chapter the performance of the design proposals will be discussed, which associates with answering the stated research questions. Answering the first research question is done by inspecting the results of each performance criterion and determining the best performing design in that criterion. After a summarized comparison, the discussion proceeds to the second research question.

• RQ1: Which of the seven design proposals performs the best in accordance with sustainable principles?

As mentioned in the chapter 2, there are more principles that make up the aspiring sustainable quality of the design. This thesis deals for the most part with the energy performance and energy harvesting, therefore other than the considered topics shall not be judged. Also, because there is not much detailed information, for instance about the proposal's construction systems at this stage yet we will assume that the energy embodied in the production of the quarter is equal among all seven proposals. Therefore, the proposals have to be judged only by their operational energy, which examines the amount of energy needed for a building to fulfil its use throughout its life cycle. As stated earlier, the operation of buildings lies mainly in the heating demand, according to the Eurostat statistics the heating accounts for 66% of the residential sector energy consumption in Germany (Eurostat, 2020).

Q_h

If the question of this research would be which of the seven urban design proposals for the EVH competition requires least amount of operational energy, then the simple answer based on the information available during the writing of this thesis would be the 5th proposal by the office Jensen und Hultsch Architekten. The proposal manages to rank itself with the least amount of heating energy consumption in all three variations of the heating consumption charts.

Reasons:

The 5th proposal offers a diversity of building typologies. With most of the houses meant to be built in a modular principle, almost every one of them has an unique and compact shape. This can be observed also at the figure 47, showing the shape factors with most of the buildings possessing HLFF of around 1.5. The lower form factor compared to the other design proposals is caused also by the lack of sloped roofs, which cause higher heating consumption values. The 5th proposal has also the lowest amount of tiny houses in the masterplan, which are the least energy-efficient typology. However the 5th proposal manages to keep its top rank also on the chart comparing the proposals while excluding the tiny houses as seen on the figures 68 and 69.

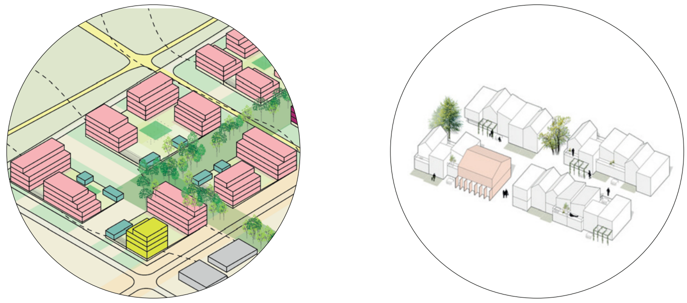

Figure 75: Difference in the level of detail between the design proposals 5 and 7

Another reason partly contributing to this result may also be the different level of detail between the design proposals. Although the designs were remodeled for the purpose of simulations with the same characteristics (handscript) the detailing of the urban masses such as setbacks, cantilevers or terraces was preserved. It is uncertain whether the 5th proposal urban masses stay as compact in the next stage of the EVH competition, nevertheless these architectural design features can also be provided without compromising the building's mass, as shown in figure 76. Therefore, we can estimate that these preliminary results are in fact, correct.

Figure 76: The recessed loggias worsen the building's form factor while the cantilevered terraces do not affect the form factor, nor create thermal bridges (Gonzalo & Rainer, 2014)

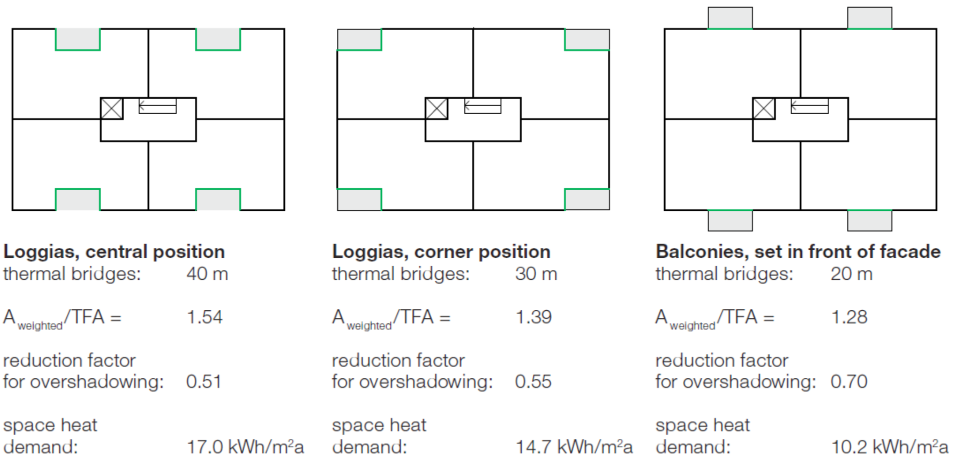

Figure 77: Effects of different incorporations of loggias (Gonzalo & Rainer, 2014)

Row houses:

Another reason behind the 5th proposal's efficiency is the typology of row houses. Placing the row houses close to each other further decreases the heating consumption by reducing the envelope area.

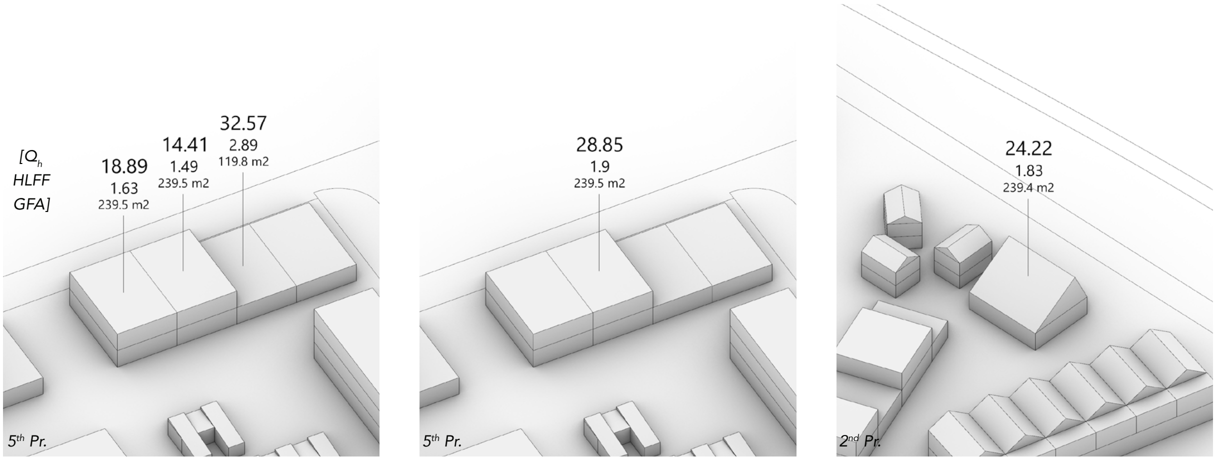

Figure 78: Row house example in the 5th and the 2nd design proposal

The figure 78 above proves the substantial impact the houses placement has on the heating demand. The 5th proposal's house while considered solo (middle image), has a Q_h of almost twice the amount, when considered with its neighbours (left image). This way two portions of the external walls are shared among the neighbour houses, lowering the house's HLFF from 1.9 to 1.49. The solo variation (right image) appears as the situation of the house in the 2nd proposal, with identical floor area and similar HLFF.

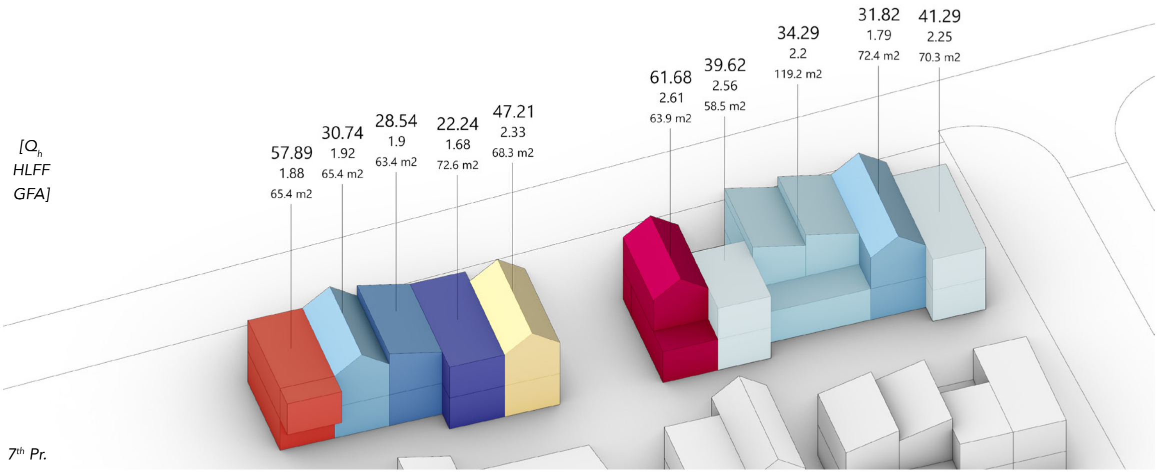

Figure 79: Row houses of the 7th design proposal

A closer looks at the row houses typology in the 7th proposal (figure 79) demonstrates how the Q_h differs for the buildings placed at the edges of a larger composition. Additionally, for the two houses visualized in red the setbacks are further hindered by setbacks in the form of cantilever and terrace (as indicated in the chapter 2.4).

Tiny houses: It is not hard to notice the fact that the tiny houses typology perform with poor energy efficiency values throughout all design proposals. Their often small, one-floor-only arrangements cause higher form factor values. However, by taking into consideration the nature of this typology of living on a very limited personal space, the final environmental impact might not be as negative as anticipated. The EnEV ordinance from 2016 defines different minimum U-values for homes with area smaller than 50 m^2 that reflect the worse energy efficiency preconditions (Tuschinski, 2015). However, according to one study, the tiny houses should have prescribed even more tailored rules when it comes to energy planning (Haupt, 2018). The author compares four different small house units and their heating energy demands: The results show that the annual Q_h of a 12 m^2 tiny house with only a 10 cm insulation layer is already lower (2 000 kWh/a) then the Q_h of a 45 m^2 bigger house (3 800 kWh/a) that fulfils the EnEV 2016 norms. The 12 m^2 tiny house although theoretically providing living area for the same amount of people (probably just one) has an almost twice larger EUI value of 167 kWh/m^2a compared to the bigger 45 m^2 house of 84 kWh/m^2a. The point the author was trying to communicate was not only that the tiny houses should have their specific EnEV norms, but also that for a proper promotion of energy efficient living standard the values of energy efficiency should be assessed with heating demand – besides per year, also per person.

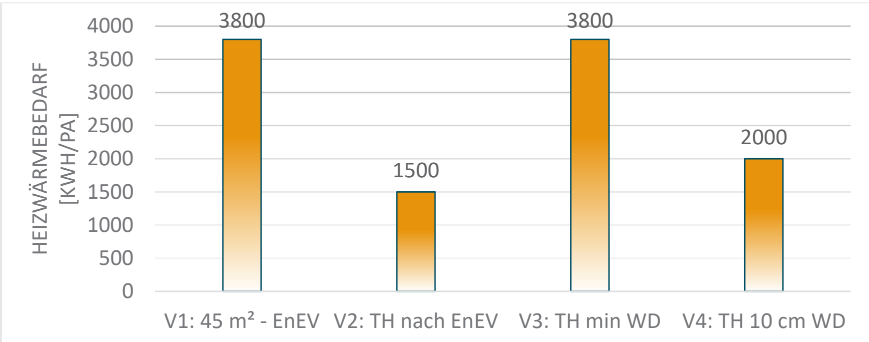

Figure 80: Comparison of yearly Q_h of different tiny houses

PV

There are other evaluation criteria of this thesis in the Assessment toolbox which might after their consideration alter the final comparison. Other than the heating demands, nearly all of the remnant residential sector energy demand in Germany (33% - water heating, cooking and lighting & appliances combined) could be covered by solar energy systems such as PV panels and thermal collectors. By looking into the fitness of the roofs to harvest this energy, we identified the 2nd proposal by the offices haascookzemmrich STUDIO2050 and Transsolar Energietechnik as evident leader in this criterion.

The prospect of rating the roof fitness is not straightforward. Although the roof tilt indicates the acquired solar radiation, the solar modules can be installed with a certain tilt, which can raise their efficiency. Choosing the correct solar modules tilt is notably more significant on the flat roof buildings, which are present in every of the design proposals.

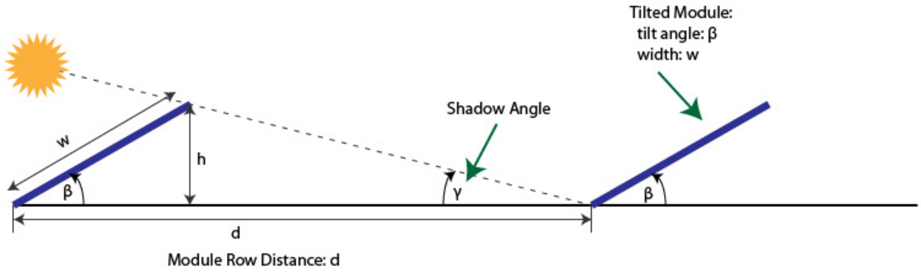

Figure 81: Parameters associated with self-shading of PV modules (Green Rhino Energy, 2016)

The optimization strategies changed over time as the prices of the PVs got more affordable. Around 20 years ago when PV modules were considerably more expensive as today the logical approach was to set up each panel to maximize its energy output, which is when the panel is facing the sun's average path as directly as possible (Grana, 2018). The tilt should then correspond to the latitude of the building's location, which in the case of Germany is around 50 degrees. With such steep tilt, the distances between the rows of the solar panels have to be larger in order to avoid a self-shading effect. This resulted in fewer solar panels able to fit on the limited area of a flat roof. However, with the prices of PVs being more affordable than before, the priority of maxing out every unit shifted to generating the biggest energy output as possible. This resulted in having more PV panels under smaller tilt, with partial shading on the lower parts of the unit. The final matter of tilt however still lies in the individual cases, where the question is whether the priority is on one hand the economics and a short investment payback time, or the maximal energy output on the other (Kanters & Davidsson, 2014).

In the referenced study "Mutual Shading of PV Modules on Flat Roofs" a parametric test revealed that for the maximal output of the flat roofs at the latitude of 55° in Lund, Sweden the ideal tilt is 0° without casting any self-shading effect (Kanters, 2014). The definite results of this assessment would require a more precise calculation, but generally the flat roofs solar systems require more space per generated energy unit then the sloped roof systems (Spirit Energy, 2020). Therefore the 2nd design proposal with its numerous sloped roof surfaces reaching incident POA irradiation values of 1 000+ kWh/m^{2}a.

AW

It may have been expected that the amount of available water will simply correlate with the BCR, as there is more roof area, the more water can be harvested. However as the calculation takes into account amount of water per person, the influencing factor is how densely is the quarter planned. Higher density, ergo higher FAR lowers the amount of harvested water, as more people are distributed under smaller roof areas.

Leading proposal in this criterion is the 6th proposal, with 11 785 harvested rainwater litres per person available annually. This amount could cover 103% of the average amount of water used for toilet flushing in the German households. However in the case of EVH, the working group K10 - Circular materials recommends the use of vacuum toilets, which use just 16.5% of the water a normal toilet uses. Therefore much of the harvested water could in that case be used for garden irrigation, after some water filtering also for other uses.

UTCI

The village squares located in between the community buildings offer a comfortable space with trees providing suitable shade mainly in the 2nd and 6th proposal.

The results of the average UTCI show fairly similar values among all design proposals. A reason for this are the equally set conditions of the simulation, such as the surface material properties or the glazing ratio of the surrounding buildings. Therefore the mainly distinguishing parameters are purely the enclosing geometries - buildings and planted trees. Also, the resulting arithmetic average merges the extreme values with the rest of the day (in the night hours), which might have almost identical temperature values throughout every proposal.

The results of this criterion are however more interesting considering the actual maps of the village square, showing the fragile spots known as thermal stresses. This can help the planners to re-evaluate the space and patch up the surfaces with extreme solar irradiation. The simplest solution of adding shading elements as trees is always possible after consulting the preliminary results with climate experts, however unnecessarily large open spaces prove to be more prone to higher thermal stresses as it is the case in the 3rd and the 4th proposal.

ASE

The measurement of the Annual sunlight exposure revealed the 2nd (haascookzemmrich STUDIO2050 + Transsolar Energietechnik) and 5th (Jensen und Hultsch Architekten + Assmann Beraten + Planen) proposals having the most sunlit building floor surfaces at 89% receiving at least 50 sunlight hours annually. The 2nd proposal's longitudinal shaped apartment buildings with southern orientation and many tiny houses produced good results. The 5th proposal with its prevailing typology of compact, medium-sized houses and reasonable distances in-between them delivered good shape factors and abundant amount of obtained sunlight, without any obstructions. Generally, all proposals perform well with the only exception of the 4th proposal with ASE reaching 70%. This result is caused by the nine substantially big apartment buildings with floorplan widths being as long as 25 metres.

Summary

After the individual assessments it is important to state certain facts:

• The assessed criteria are not equal.
• The assessed criteria were chosen from the reviewed case studies and from the EVH competition's qualitative focus.
• The Q_h does measure the majority of building's operational energy use but it does not measure the full embodied CO_2 output released throughout the building's life cycle.
• Even though Q_h is apparently the largest emission factor, determining the correct Q_h measurement (of the three variations) remains for the time being unresolved. Since the competition is still ongoing, the future steps concerning the deviations from the requested GFA and the possible pre-production of the tiny houses remain unknown.

The 3rd, 4th and 5th proposals feature a good heating energy performance, possibly also the 1st proposal. However, the 4th proposal scores well mainly because of its massive apartment buildings; the 1st scores poorly in other criteria besides UTCI; and the 3rd proposal scores generally well however with relative small GFA proves to be the least dense. By prioritizing other than Q_h assessment criteria, the 2nd proposal scores very well, but only manages to compete in the Q_h criteria after GFA remapping and excluding the energy-inefficient tiny houses. The 6th and 7th proposal with their higher form factors performs the worst in Q_h, but quite well in the other criteria. Thus, to attention come the following proposals:

As already examined, the 5th proposal dominantly succeeded in all variations of heating energy comparisons, while also scoring average in the other criteria (except higher BCR). The simplicity of the urban forms was touched upon earlier, however the design fulfils the necessary criteria for an urban design masterplan at this stage. More will be known after the handling of the design in the second half of the competition.

The 2nd proposal scored well in a lot of criteria (including heating assuming the remapped GFA values and with the exclusion of the tiny house typology). Its PV performance tells us that the roofs' orientation is well suited for solar energy harvesting, but in fact how much energy or resources are saved this way is unknown, since at this point we do not know if even the proposal with only flat roofs might have the capacity to supply the quarter with energy. The pitched roofs might actually have had a determining effect on the heating consumption because of the increased inside spaces volume. It is interesting to note that the office behind the 2nd proposal is known for consulting designers on climate engineering topics while using similar tools for energy based design, as were used in this thesis.

• RQ2 How well is the role of sustainability being implemented in urban projects with similar methods?

In the case of EVH competition there is no doubt about the emphasis on sustainable design. The planning procedure of EVH investigates every important aspect of a conscious planning through the different "working groups" as the Circularity of materials, Mobility or the Energy concept group. However, as one of the competing offices proclaims climate-focused planning is rare, nevertheless the EVH is a part of those few projects.

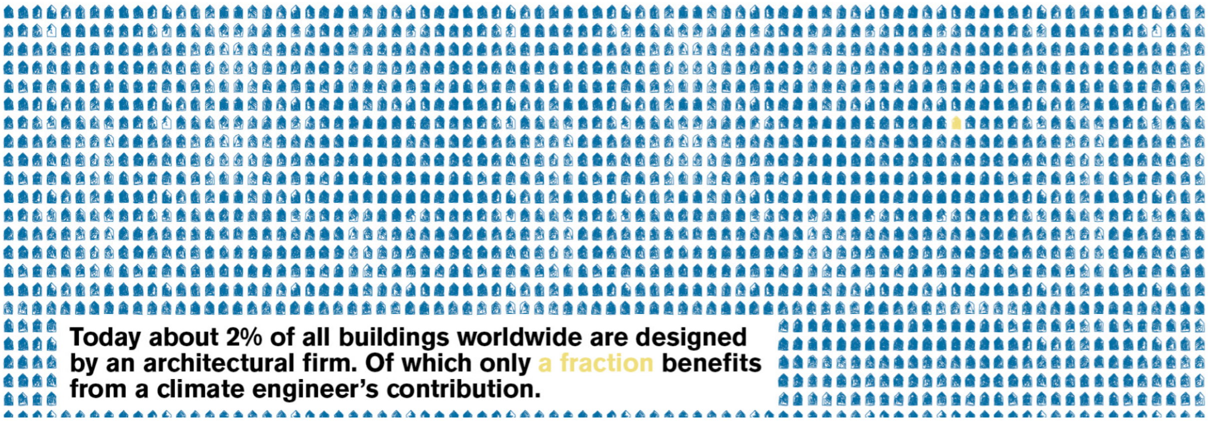

Figure 82: Contribution of climate engineering (Transsolar, 2020)

This thesis focuses on the software related sustainability methods, rather than the technological aspects. The question is what can be done during the planning process to achieve energy efficient construction. Despite the current beginning of a global climate crisis "an approach evaluating trade-offs between an urban energy balance and environmental quality considerations is lacking" (Natanian & Auer, 2020). In a study by Yang & Yan (2016) examining the problematic, this research gap is identified. It notes that the gap lies in the differences between how the urban designers and energy engineers define performance. While the goal of an urban designer in a search for urban forms that give people value and purpose (Lynch, 1981) which can be seen as rather vague, the goals of the energy engineers who optimize a high performance energy system is quite straightforward. Later the study suggests to bridge the gap of their common goal of designing a "high energy performance city" via a design framework consisting of Urban Design Computational Model (UDCM) and an Optimization Model of Energy Processes (OMEP). This one example of a proposition does no solve this disparity, but it examines differences and common ground of rationales, where the linkages yet have to be made (Yang & Yan, 2016).

UBEM can be still clarified as an emerging field. However, it can be defined as the bottom-up process of city energy modelling, which uses an accurate method of energy consumption calculations – physical models simulations. This approach stands in contrast with the top down approach where the building EUI is calculated only from statistical data of whole cities. With more available data and faster computations, the UBEM is becoming more widely available (Johari, 2019).

Another study examines the developed UBEM tools which might already be the answer for the above defined research gap. The paper looks at it from the Chinese perspective where the problem of fast paced development leaves no space for iterations of multiple design variants, and sees a better potential in the western countries where the urban development is focused on renovation and redevelopment. The paper also suggest a practical application of the UBEM tools using a base-case scenario. A base-case scenario would represent a model that fulfils all predetermined urban parameters of a project such as FAR, BCR or green space ratio. The base-case model would be a grid-like simple design with presumably good energy efficiency performance. Followed by using UBEM tools, variations of a liveable design can be proposed by urban planners, while always having base-case's efficient performance as a comparison (Yang & Jiang, 2019).

Currently, there is a lack of software aimed precisely for city-wide sustainable energy planning. That is why much of the used software developed originally for building assessment, is used (Johari et al, 2019). Prospectively, for a development of a truly comprehensive software more sustainability models such as climate comfort, energy systems and mobility will have to be included (Johari et al, 2020). Understanding the importance of the other sustainability criteria, this thesis pursued integration of those believed to be essential.

7. Outlook

In this last chapter, firstly the shortcomings of this thesis and its method are examined. Secondly, an additional method on top of UBEM is described, with an optimization test run on the 5th proposal's design. Lastly, concluding remarks summarize the results and the relevance of the research.

7.1 Shortcomings

• Problematic is the generalisation of the many parameters, such as window to wall ratio. For example in the case of the 4th proposal with substantially big buildings resulted in poor ASE performance, however the results may have been different if the simulated model was designed with more glazing. Therefore, the possibility of deviations shall not be forgotten. This just confirms the original thought of this assessment, that these assessment tools should be mainly used as a helping tools for designers to identify weak spots and not for strictly judging the proposals or selecting a winner.

• One factor that was not implemented in the simulations is the morphology of the site. The quarter sits on a slightly hilly terrain, which places buildings on different elevations. The elevations affect the shading casted by the buildings and if taken into account, it would result in slightly different energy consumption values.

• What might be also interesting in the future is to have a closer examination at how the arrangement of the buildings influence their heating demands. This might be done with a simple comparison of the individual buildings' performance within their current spatial arrangements to the performance as solo-standing structures.

7.2 Energy optimization

An initial inspiration for this thesis was a study "Computational optimization of housing complexes forms to enhance energy efficiency" (Derazgisou et al., 2018) which conducted an optimization test on three different planning scales: villa, complex of seven villas and a masterplan of six apartment buildings. However, the proper assessment of the EVH design proposals proved to be enough to fulfil the scope of a master thesis, therefore this method is touched upon only in this subchapter.

The principle of energy optimization, similar as in the 2018 study, would be to generate multiple design variations of the original proposal, all of which would be assessed for at least one sustainability criterion – in this case for the heating demand. The generation of the design variations results from changing chosen parameters of a design model.

Choosing which parameters to modify can be tricky, as the goal is to retain the original design concept of the proposal. For the urban examples, the mentioned study parametrized the centre points of the villas (effectively their location of the masterplan), which with each iteration altered the EUIs of the assessed buildings.

However for a more complex optimization process, possible other optimization parameters are:

- roof shape
- number of floors (while keeping the prescribed GFAs within the competition rules)
- rotation of the smaller individual housing units
- window to wall ratio

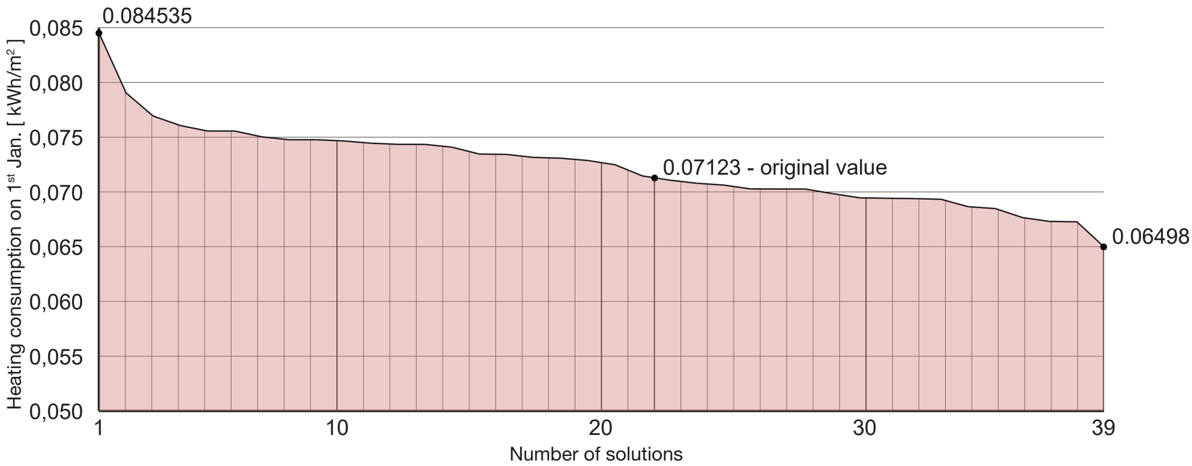

Figure 83 : Evolutionary solver showing the solutions of the test

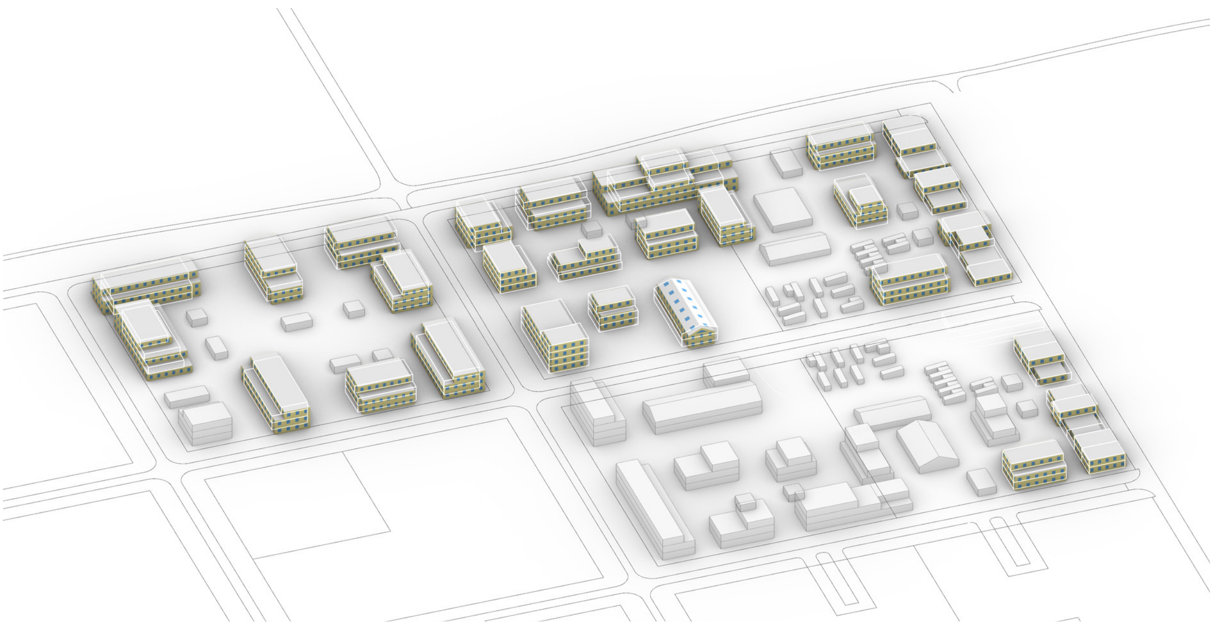

Figure 84 : Optimized buildings with a wireframe overlay of the original shapes

For the purpose of a test the 5th proposal's buildings, a scaling ratio between 0.7 – 1.3 was set for each building's width and length dimension to test how to optimization engine will respond to the objective. The testing period of the Q_h simulation was shortened from yearly demand (resembling 8 760 hours) to just 1st of January (24 hours) in order to speed up the computation time.

Proposal 5 original Q_h values for 1st of January:
1 535 kWh / 21 549 m² = ***0,07123 kWh/m²***

Proposal 5 optimized Q_h values for 1st of January:
1 564.7 kWh / 24 081 m² = ***0,06498 kWh/m²***

The results reveal an improvement in the EUI of the tested 40 buildings. However, the improved efficiency is an outcome of higher floor area. The optimization managed to increase the floor area by 11.7% at the cost of Q_h increase only by 1.93%, ergo increasing the efficiency. The alteration of the floor area could be avoided with the mechanism of multi-objective evolutionary algorithms, in which the second objective would be keeping the difference between original and optimized floor area at minimum.

7.3 Conclusion

UBEM represents an effective set of sustainable assessment methods, mainly for the circumstances like the EVH competition, since the preliminary analyses can prove useful for designers. They can either inform what to fix in the second stage, or identify if a proposal should try a different design approach. For the second case it may already be late, which just stresses the importance of such analyses to be integrated into the earlier conceptual design stage (Tian et al., 2015).

The EVH project with its working group of individual experts that contribute their time to develop an efficient city quarter are a positive example of progress in the urban sustainable field. This thesis sought to contribute with an energy analysis related to the urban scope, however there are other technical aspects that will ultimately decide the energy efficiency of the design. For instance, the working group's objective is to decide for a viable energy and heat source for the quarter whose specifications vary in price, funding and GHG emissions. In that sense, urban planning is not the main deciding factor of sustainability, but rather the one that was never fully considered as important, but is getting its attention now.

It is important to not forget that the problem of building energy efficiency although being a major one, is only one of many that the building sector has to face, which negatively influences the climate change. Flawed urban planning also directly affects the transportation sector, with sprawling urban fabrics demanding more individual transport resulting in even more GHG emissions. Also, the faster we are building, the more land is being taken from nature. Between the years 2012 – 2018, only in the EU28 itself 539 km^2 was built upon, annually (EEA, 2019). Problems of other manners include social, political, hygienic issues or unavailability of resources. However, the ongoing change of climate has an effect on all urbanized parts of the world.

There are many targets, incentives, technologies and methods for reducing building and construction related emissions. However, us as planners should try and push beyond the boundaries which separate the bare minimum to pass certain building requirements. Learning new skills and techniques in order to improve energy efficiency will not just pay off for us personally by our own self-growth, but will contribute positively to the biggest global challenge yet.

8 Endmatter

8.1 Literature

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8.2 List of figures

8.3 List of tables

8.4 Statutory Declaration

I hereby affirm that the Master thesis at hand is my own written work and that I have used no other sources and aids other than those indicated. All passages, which are quoted from publications or paraphrased from these sources, are indicated as such, i.e. cited, attributed.

This thesis was not submitted in the same or in a substantially similar version, not even partially, to another examination board and was not published elsewhere.

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Place, Date Signature (First name and Surname)

Finally, I would like to express gratitude to everybody who helped me throughout the process of writing this master thesis, namely my supervisors Reinhard König and Sven Schneider, the people associated with the Ecovillage Hannover Hermann Hussen and Lidewij Tummers-Mueller and my family and closest. Thank you.

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Place, Date Signature (First name and Surname)