MASTER

Energy efficient design
comparing energy efficient houses designed with or without the use of a building energy simulation program

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Energy efficient design

* Comparing energy efficient houses designed with or without the use of a building energy simulation program *

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Preface

This research is the result of my interest in ‘green architecture’ and follows my specialisation in building physics and services, and the specialisation in architecture. In the engineering of building physics, simulation tools are often used to simulate a variety of building aspects such as the amount of daylight entering the building, the energy consumption of the building or the airflow in and around buildings. In architecture, digital programs are primarily used to draw plans, section designs or 3D images. With this research, I attempted to gain further insight into the interaction of the disciplines building physics and architecture. The interaction between these two work fields and the fact that I graduate in the studio ‘digital architecture’ led me to investigate the use of building energy simulation programs during the design process of architects.

I would like to thank my graduation committee, which consists of prof. dr. ir. B. De Vries, prof. dr. ir. J.L.M. Hensen, ir. M.H.P.M. Willems and dr. ir. M.G.L.C. Loomans, for their commitment, knowledge and helpfulness.
Summary
In 2020, all new buildings in The Netherlands must be net zero energy buildings. A net zero energy building is a building that uses renewable sources to produce as much energy as the building uses, usually measured in a timeframe of one year. To reach this goal, all architects are bound to design energy efficient houses. In this research, it was assumed that architects will use two different design processes in the future to design net zero energy buildings. These two design processes are using guidelines or using a building energy simulation program. This thesis researches whether using a building energy simulation program results in buildings with a better score on energy use, comfort and overall architecture. The following question that will be answered in this research:

If architects use building energy simulation programs in the early phases of the design process, does it result in more efficient designs in the field of energy reduction of residential buildings?

The main conclusion that can be drawn from this research is that, the influence of a building energy simulation program in the design process can be judged as positive. This was researched by creating 26 designs using two different design processes of an energy efficient house. The first group used guidelines from Trias energetica and passive house. The second group used Sefaira, a building energy simulation program. The design assignment was to design a house for a family in Shenzhen, South China.

All designs were compared on passive and active energy use, comfort and overall architecture. The energy use of the designs and the level of daylight in the designs were simulated with Sefaira. The designs were judged on overall architecture by two tutors of architecture. To answer the research question, the designs were compared on a total score that consists of the individual scores for passive energy use, architecture and comfort. These individual scores were ranked from zero to ten and then incorporated into a total score. Passive energy counted for 40% of the total score and architecture and daylight both counted for 30%.

The research showed that the average total score of designs made with Sefaira is 1.11 points higher than the average total score of designs made with guidelines. While designing, Sefaira simulates daylight and energy consumption of the design and displays it in real-time. This enables architects to adjust the results of Sefaira into design decisions and design an energy efficient building with more ease. The research showed that it is well worth the effort to further investigate in the use of a building energy simulation program during the early phase of a design process of energy efficient houses.
**Samenvatting**

Vanaf 2020 moeten alle nieuw te bouwen woningen in Nederland een EPC score van nul halen. Door deze lage EPC score, worden architecten gedwongen om energie zuinige woningen te ontwerpen. In dit onderzoek is ervan uitgegaan dat architecten in de toekomst twee ontwerpprocessen hanteren om energie zuinige woningen te ontwerpen. Namelijk met behulp van richtlijnen of met behulp van een bouwfysisch simulatieprogramma. In dit onderzoek is onderzocht of ontwerpen met behulp van een bouwfysisch simulatieprogramma beter scoren op het gebied van energieverbruik, daglicht en architectuur. Dit is onderzocht met de volgende onderzoeks vraag:

Kunnen ontwerpen energiezuiniger gemaakt worden als architecten een bouwfysisch simulatieprogramma gebruiken tijdens de eerste fase van het ontwerpproces?

De voornaamste conclusie die uit het onderzoek kan worden getrokken is: de invloed van een bouwfysisch simulatieprogramma in het ontwerpproces kan als positief worden beschouwd. Om dit te onderzoeken zijn 26 ontwerpen met behulp van twee verschillende ontwerpprocessen voor energiezuinige huizen gemaakt. Richtlijnen van Trias Energetica en passief huis zijn gebruikt als leidraad om energiezuinig te bouwen bij het ontwerpproces met richtlijnen. De tweede groep heeft Sefaira een bouwfysisch simulatieprogramma gebruikt. De ontwerpopdracht was het ontwerpen van een woning voor een gezin in Shenzhen, zuid China.

De ontwerpen zijn vergeleken op passief en actief energieverbruik, comfort en architectuur. Het energieverbruik van de ontwerpen en de hoeveelheid daglicht dat in het ontwerp aanwezig is, is gesimuleerd met Sefaira. De ontwerpen zijn op architectuur beoordeeld door twee docenten van architectuur. De ontwerpen zijn ook beoordeeld met een totaalscore. De totaalscore is opgebouwd uit de onderlinge scores voor passief energieverbruik, comfort en architectuur. De scores voor deze onderdelen zijn gerankt van 0 tot 10 en daarna verwerkt in de totaal score. Passief energie verbruik telt voor 40 % mee en daglicht en architectuur tellen beide voor 30 % mee.

Het onderzoek laat zien dat het gemiddelde van de totaalscore van de ontwerpen gemaakt met Sefaira 1.11 hoger is dan de ontwerpen gemaakt met richtlijnen. Tijdens het ontwerpen simuleert Sefaira daglicht en energieverbruik en geeft dit overzichtelijk weer. Hierdoor kunnen architecten de ontwerpbeslissingen afstellen op de resultaten van Sefaira en zo energiezuinige woningen ontwerpen. Het onderzoek toont aan dat het de moeite waard is de toepassing van een bouwfysisch simulatieprogramma in het ontwerpproces verder te onderzoeken.
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1. Introduction

Digital architecture
Almost all facets of our lives are being influenced by the digitalization of today’s world and building engineering is no exception. We write emails instead of writing letters, increasingly we draw technical drawings with the computer and simulation tools save us from hours of mental arithmetic. Are these tools used to their full potential or are there further benefits to be gained? For example, can architects design houses more energy efficient when they use simulation tools during the design process? This is a relevant question, since energy efficient constructions will become more important in the future.

This research is realized within the studio ‘digital architecture’. Within this studio the theme digital architecture is interpreted in different ways and used in different phases of a design process. An example of digital architecture after the building is made is, a building that changes through the influence of digital data. An example of digital architecture in the latest phase of the design process is architecture that can be created using a 3D printer. The 3D printer can build a building faster with less construction workers. Digital architecture can also be used in an earlier phase of the design process. BIM (building information modelling) is an example of using digital architecture in an earlier phase of the design process. In a BIM model, different disciplines within the building engineering can work together.

In this research, the theme digital architecture is interpreted as the use of a digital simulation program that can be used in the first phase of the design process of architects of energy efficient houses.

Scientific relevance
There are (international) standards set for newly constructed buildings. Already, since January 2015 all new constructed buildings in The Netherlands have to reach an EPC (Energy Performance Coefficient) of 0.4. But in 2020 this will change. This is due to the goal set by the European and Dutch government policies that all new constructed buildings have to be net zero-energy in 2020. [RVO,2014] Besides the quota of 2020, many large organizations worldwide have signed on to reach the 2030 challenge. The 2030 challenge lays out a path to reduce the contribution to climate change. The 2030 challenge is asking the global architecture and building community to adopt the following targets:

“All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70% below the regional (or country) average/ median for that building type.” [architecture2030,2014]

Structure of the report
This research focuses on the design process of architects to design net zero-energy buildings. The next paragraph 1.1 describes the design process of architects and which design decisions are taken in the early design phase. In paragraph 1.2 the research question and some sub questions are formulated.
Chapter 2 describes the method used in this research. Paragraph 2.2 and 2.3 give more information about the two different design processes that are used conducting this research. Paragraph 2.4 gives more information about the designs.
Chapter 3 describes the results of this research by comparing the different design processes. The results are discussed in chapter 4 and the research question will be answered in chapter 5. Recommendations on further research will be given in chapter 6.
1.1 Design process of architects for energy efficient residential buildings

A building uses energy during its life. The total energy use of a building can be split in two kinds. The first kind is part of the material used in the building and consists of energy used during the construction of the building. The second kind is the energy use of the building during the utilisation phase. Research from [Verbeeck, 2007] shows that within the life cycle of a building, the energy use is the largest in the operational phase. “Particularly, in a comparison between embodied energy and energy during the utilisation phase for dwellings, shows that compared to the energy use during the utilisation phase, the embodied energy constitutes a relative small contribution, and concludes that:’ effort should be made to the reduction of the energy consumption during the utilisation phase, as this phase still has the largest potential for improvement’.” [Weytjens, 2013] The role of architects is important, since they are the ones creating a building in the first place. This means that they can design a building in such a way that it uses less energy during the operational phase. They can do this by taking in and applying building physics at the start of the design process and keep using them all the way through to the end product.

“Architects’ complete reliance on engineers and energy analysts has hurt our understanding of how building design affects energy use. With an integrated design team and current software, architects can begin to engage in design simulation, re-learning how to achieve performance through passive design. While engineers will do most of the detailed modelling, architects who learn to simulate can begin to understand and design for energy performance. They can also more easily communicate with engineers and energy analysts, resulting in a more integrated decision-making process that helps achieve low-energy goals.” [Anderson, 2014]

The basic design process of architects is represented in the diagram below. (Figure 1.1)

![Early design phases diagram](image)

Figure. 1.1 Design process

Traditionally, a building delivery process has been a discrete and sequential set of activities. Designers start with rules of thumb to create a design, then an engineer makes a model to verify its compliance with the performance goals. If the design does not meet the performance goals, the architect will restart with the design process. This tedious trial and error approach continues until the design meets the performance goals. However, the ‘net zero’ objective is an energy performance design goal that embraces the integration of energy performance goals early in the design process. Architects are forced to expand their scope of responsibility beyond function and aesthetics. The design process of small scale net zero energy buildings, with no energy specialist involved, shows that the design is not intuitive and energy performance requirements must be determined in the early design stages. 20% of the design decisions that are taken in the early design phase influence 80% of all design decisions. [Attia et al, 2012]

The diagram describes the basic design process of architects, but this is a general overview as all architects have their own preferred methods and habits as well. According to the earlier mentioned conclusion that the early design phase has such a big influence on the later design decisions. Two popular methods used by architects in this early phase of design are mentioned. Those two methods are form finding and space planning.

In the research of Bron [2014] nine architects are interviewed about their design process for energy efficient buildings. Almost all interviewed architects start with a program of
requirements. After the program of requirements, they start sketching. All interviewed architects answered that the design process is an interaction between the methods space planning and form finding. For the space planning the architects can make a spot plan. By making this spot plan questions will be answered like; where in the plan should zones/rooms be placed? Which view is desirable for a zone/room? For form finding, the volume and facades of the building are designed and within the volume the functions will be placed. Some of the interviewed architects use sun- and daylight studies during the early phases of the design process to create a comfortable indoor climate and make design decisions. After the sun- and daylight study the orientation is defined and the building envelope is sketched. The building envelope consists of windows, walls, roofs, overhangs and sun shading. During the construction design phase the building physics advisor makes simulations and calculations. In this phase of the design process, almost all decisions are taken and the technical drawings are made.

Decisions taken in an earlier phase of the design process have a bigger impact on the building performance than measures taken later in the design phases or during building operation. [Hensen, 2004] Early geometries are rarely compared for energy use, daylight, shading or airflow potential, since there are many other issues for architects to consider, such as the wishes of the clients and the adjusting on the location. [Anderson, 2014] To make an energy efficient design, it is important for the architect to consider decisions that may influence the energy use of the building, in an early phase of the design process.

Architects use sun studies to make decisions about the orientation of the building, let sunshine enter the building in winter times and block sunshine in summer time to protect the inside temperature from overheating. The sun and daylight study can be used to define the amount of glazing, set the window to wall ratio and define the glazing orientation. Daylight simulation can also be used to see the architectural effect of daylight inside the building.

“Designing the right quantity, location, orientation, and type of glazing is the most important aspect of energy use on most projects, affecting comfort, solar loads, daylight, natural ventilation and overall energy use.” [Anderson, 2014]

“Facades design becomes a balance between light, views, orientation for pleasant breezes, and reducing unwanted solar gain.” [Anderson, 2014]

Architects design the building and facades in the early design phase. Besides orientation and the influence of the facade other decisions have to be taken as well. Such as: size, massing, function, geometry/shape, envelope materiality/ resistance, window to wall ratio, interior spaces, natural ventilation, thermal mass, daylight, renewable energy and infiltration [Hemsath, 2013]

In a research from Attia [2012] different parameters are divided into two themes, passive and active design. Parameters for the passive design are; climate analysis, form, massing, orientation, aspect ratio, thermal zoning, day lighting, natural ventilation, solar access, opening, window wall ratio, shading, insulation, U-value and thermal mass. Active design parameters are; Mechanical Ventilation, HVAC, Photovoltaic and solar thermal energy. [Attia et al 2012]

Attia et al [2011] describe the different interpretations of important parameters of building energy simulation programs for architects and engineers. Two online surveys were held and the findings are based on an inter-group comparison between architects and engineers. Both groups were asked to classify and rank 15 design parameters. There was an agreement from both groups that the energy consumption is the most important parameter. The results are shown in figure 1.2.

There is a big difference in ranking the parameters between architects and engineers. Architects ranked passive strategies higher than the engineers. The engineers ranked most active systems higher. The conclusion of the research of [Baba et al, 2013] shows similar
results. Within the design process, architects are more concerned with design issues (such as geometry, orientation, aesthetic, natural ventilation and day lighting), while engineers are more concerned with mechanical systems and control.

Within the early design phases, a schematic design is made. During the construction design phase a complex energy simulation will be made. If the decisions that were made within the early design phase change, the modeller may require a complete rebuild of the model in design development. Specific design options that cannot be easily changed later, are: building siting and orientation, exterior envelope constructions, glazing size and location, thermal zone and space configuration, shading and day lighting strategies, system features that impact floor or ceiling space (e.g. bigger ducts) and HVAC system type options. [Tupper, 2011] Most of the decisions that are difficult to change in a developed energy-modelling model consist of passive parameters.

These passive parameters can be simulated in the early design phase. An early simulation allows for a very quick simulation of the performance of the building design in the preliminary design phase. The consequences of design variants are immediately visible. After the first phase, the building design chosen can then be transferred to the advisor for further simulation development. [Vabi, 2014]

The design decision of the architect consists mainly of passive parameters. The architect can choose to use building physical knowledge or a building energy simulation program during this early design phase to make the design decisions. After the early design phase an advisor can make simulations and calculations when most decisions are made. The aim is to prevent rebuilding/redesigning of the designs. In case of a small building, it is also possible that the architect finishes the design without intervention of an advisor.

Nowadays architects design houses which meet the building requirements with the EPC score of 0.4. Architects who design houses with a lower EPC score than 0.4 are sparse. Broadly, architects can use three design processes to design an energy neutral building:
- They hire a building physics advisor;
- Use guidelines;
- Use a building energy simulation program.

Usually architects who design energy neutral houses hire a building physics advisor. But in this research it is proposed that if all architects have to design net zero-energy buildings, they will not all hire a building physics advisor. So two design processes remain: using guidelines or a simulation program. The architects who design energy neutral buildings nowadays primarily use guidelines and hire a building physics advisor during the early design phase to help making design decisions.
1.2 Research question

Taking into account the 2020 goals, the fact that decisions taken in an earlier phase of the design process have a huge impact on the energy efficiency of the final product and the scattered use of architects of two possible design processes to design energy neutral buildings leads to the following research question:

If architects use building energy simulation programs in the early phases of the design process, does it result in more efficient designs in the field of energy reduction of residential buildings?

To answer the research question, two different design processes of energy efficient houses will be compared. A design process with building physical knowledge (guidelines), which is most common among architects nowadays, will be compared with a design process with the use of a building simulation program. The overview of the research is organized in a scheme. See figure 1.3

Secondary questions

To answer the research question, a simulation program has to be selected. This is done by researching which simulation program is the preferred choice to use during the early phase of a design process. After the designs are made and there is a distinction between the two different design processes, it is interesting to know whether architects or building physics students can distinguish which design is made with which design process. And whether there is one parameter that has more influence on the score of energy use than the other parameters? The focus of this research is on passive parameters, but students can choose to incorporate solar panels into their designs as an active system to contribute to the energy efficiency. So, another question is whether there is a distinction in the designs that incorporate solar panels, but were created using different design processes.

Target Group

This research is aimed at all architects who already design energy efficient houses and for all architects who are going to design energy efficient houses in the future. Since, from 2020 on all architects are required to design energy efficient houses, it is relevant for all architects. This research may also be interesting for people from other disciplines of building engineering who want to know more about the design process of architects for energy efficient houses.

Boundaries

This research is about the design process of architects for energy efficient houses. Utility buildings are disregarded from this research, because, the integration of the different disciplines in the design requires more knowledge from every discipline. Only two design processes will be compared in this research. It is assumed that in the future these are, or will be the two most common design processes of energy efficient designs. Master students of architecture make the designs that are used to compare the two design processes. The designs are made with software that is on the market and guidelines that are used by architects at the time of this research. The final comparison of the designs uses simulation software that is used by architects at the moment.
2. Method

The research question is about the design process of an energy efficient house. As mentioned in the introduction, the design process can be carried out in several ways. In addition, the design can also be assessed at various points. The method has an important function in this study, so the following methodic questions are used to define the method of this research.

1. How many designs would be needed in order to obtain a significant result?
2. What guidelines do architects use during the design of energy efficient buildings?
3. Which program is preferred to use during the design process?
4. What is the design assignment?
5. Which components of the designs have to be reviewed?

2.1 Numbers of designs needed

This research compared two design processes. The designs that were made with the different design processes will be compared to see whether one of the processes results in more efficient designs in the field of energy reduction of residential buildings. The first design process used in this research was a design process where architects used guidelines in the early design phase to help making design decisions. In the second design process architects used a building energy simulation program to help to make design decisions during the early phase of the design process. But in order to obtain a significant and reliable result, the researcher needed to know how many designs were needed. This prevented too many or not enough designs.

The program G-Power 3.1 was used to estimate the number of designs needed in order to obtain a significant result for this research. The program compared the two different design processes so the T-test is used for the calculation. The following assumptions were made to make the calculation. The most important assumption was the Effect size. This is the main value used by the program G-Power 3.1 to calculate the required group size (number of designs needed). 0.5 was used for the effect size, as this is a much used assumption for the medium value. For the type 1 error $\alpha$ was set to 0.10. This means that if the same research is done 100 times, in 90% of the cases the result will be the same. The last assumption was the type 2 error. The power was set to 0.8, which meant that $\beta$ was set to 0.2. The chance accepts the null hypothesis when it is correct. With a power of 0.8, the researcher has a chance of four out of five to detect an existing difference in the real population. With these assumptions, the program calculated that a group size of 21 designs in total was enough to see the assumed effect between the two design processes.
2.2 Guidelines
Research from Bron [2014], shows that architects think about the energy efficiency of a building when designing it, but they do not use simulation programs to research it. Instead, most of the architects follow the Trias Energetica or guidelines for a passive house to optimize the building envelope and design an energy efficient building. One guideline of a passive house is, all opaque building components of the exterior envelope of the house must be very well insulated.

Trias Energetica is a guide for entrepreneurs in the Netherlands to build energy efficient to reach the European guideline of 2020. In accordance with European policy from 2020 only nearly zero energy buildings may be built. The Trias Energetica, previously known as Trias Energica was developed in 1979 by the Urban Design Study and Environmental at TU Delft, led by Kees Duijvenstein and published in the journal BOUW. Erik Lysen from the Dutch Agency for Energy and Environment (Novem) introduced the three-step strategy in 1996 internationally fig. 2.2. [AgentschapNL,2013]

Recently, the method was transformed into the new steps strategy inspired by the cradle to cradle concept of Mc Donough & Braungart fig. 2.3. [Yanovshtchinsky et al, 2012]

Step one requires a passive, smart and bio-climatic design. It starts with the optimization of planning measures, such as terrain classification, taking into account the surrounding buildings, vegetation, orientation of the building and so on. Regarding the optimization of the architectural design, the design of the facades, orientation, layout, compactness, glass surface, building mass, insulation, natural ventilation opportunities and passive climate adaptive elements are involved.

Step two involves the use of waste heat, but also waste water or waste material in the energy chain, with the aim to create closed circuits. In addition, waste from one stream can feed another stream.

In step three (a), the remaining energy - which, if step 1 and 2 are applied properly, is considerably reduced - on the in side is supplemented with energy from renewable energy sources. Step three (b) concerns the still remaining waste (in the case of energy, there is low-grade waste heat), which no longer can be disruptive for the environment or can be food for the environment.

In the fourth step ‘monitoring, learn and inspire’ can be added. A durable design does not end with the completion of the building. [Yanovshtchinsky et al, 2012]

The guidelines came from Trias Energetica and the passive house concept. The guidelines are primarily aimed at reducing the heating and cooling demand of the building. For example by adding shading devices or changing the orientation of the building. The guidelines were used by the first group to make design decisions in the early phase of the design process. The second group used a simulation program. The guidelines used in this research are mentioned in the document ‘Guidelines’ see is attachment (1.).
2.3 Simulation program

The second design process was using a simulation program. In this research the program Sefaira was used. This program was selected using an extensive elimination process. In this paragraph, the selection process is briefly described. For information that is more detailed, see attachment (2).

The simulation programs that were researched were mentioned in one of the interviews held for the pre-research of this project or they were mentioned in other research about energy efficient designs. For the first selection criteria the simulation programs were selected based on their usability in a cold climate like Eindhoven and whether the simulation programs were usable in the early design phase with less known parameters. The second selection criteria were the parameters, which the simulation program needs to make a simulation, and which simulation results the program generates.

After these two selection rounds five simulation programs remained. With these simulation programs case studies were made to explore whether the programs are usable in the early design phase. The simulation programs were compared on five criteria, these five criteria were based on a research of Attia [2011e]; usability, intelligence, interoperability of building modelling, process adaptability and accuracy of tools.

After the third selection round, Sefaira and Design Builder had the best scores. Both tools had advantages as well as disadvantages. An advantage of Sefaira was that the architect directly sees the influence on the energy use of the building of his changes in the design. In addition, Sefaira is a plug-in of SketchUp and SketchUp is already used widely by architects in the early phase of the design process. For the second design process the simulation program Sefaira was used to help the architect by making decisions in the design process.

![Figure 2.4 Scores of the simulation programs](image-url)
2.4 The designs

Twenty-six designs made with two different design processes were compared with each other to answer the research question. Six designs were made by the researcher, a second year master student of architecture and building physics, the other 20 designs were made by first or second year master students of architecture. The designs were made by architecture students, because it was assumed that professional architects don’t have enough time to participate in research.

The making of the designs for this research was a small assignment within the master project of the students, so they only had 60 hours to work on the assignment. The assignment and the usable time for the designs of the students were equal to the designs of the researcher. Each master student made one design as a small assignment within his or her master project. The students were designing a master plan of Shenzhen, the location of the designs was in Shenzhen, and so the students could use the designs in their master plan as well. The simulation program used making thirteen designs was already researched. The simulation program is also usable in a hot humid climate, so the same simulation program could be used.

The twenty students were split into two groups and the ratio male/ female and international/ Dutch was mixed. Ten students received the assignment document and a special document with guidelines to design an energy efficient building in a hot humid climate. The other students received the same assignment document but instead of guidelines, they received a document with information about how to work with Sefaira. The simulation program they would use during the design process. The students were not allowed to talk with students from the other group about the designs. The researcher made three designs with the same guidelines as the students and three designs with the simulation program Sefaira.

For the comparison it was important that the houses had some common parameters, so that the designs are only compared on design solutions instead of other energy efficient techniques. The program of requirements was the same for all the designs.

The assignment was to design an energy efficient house for a family with three kids. The house should have: One living room, a dining room/ a kitchen, three children bedrooms, one master bedroom, one bathroom, one separate toilet, an entrance and a work room. The total floor space is about 150 m². The complete program of requirements can be found in assignment students 2014, (attachment 3.). The documents from the separate groups on how to work with Sefaira and their guidelines can be found in attachment (4.).

After the students made their designs, they completed a questionnaire with questions about the materials and U-values of their design, how many hours they have used to make the designs, which options they have tried with Sefaira and more basic questions about their building physics knowledge, design process and the applied program. Besides the questionnaire, the students who have designed with Sefaira invited the researcher in Sefaira so that some parts of their design process within Sefaira were visible for the researcher.
2.5 The comparison

The different designs were compared to answer the research question. The designs were reviewed on three parts. The energy demand, the architectural quality of the design and finally the designs were compared on comfort. The energy use of the design is important for this research, but it is possible to design a very energy efficient house which is uncomfortable to live in and with a low architectural quality. That is why comfort and architecture were also reviewed.

Energy

Sefaira calculated the energy use of the building. All designs were simulated as if they are built on ground floor level with no surrounded buildings. The energy demand and generation of the design will be accessed separately. The expectation was that the designs score better on energy use than a passive house. For this comparison a passive house in Japan that was built in 2009 is taken as basis to compare. Details of the passive house can be found in attachment (S.). The energy use of the passive house (128 kWh/m²) is ranked with a 5.5, all designs which use less energy than the passive house, received a score above 5.5 and all designs which used more energy than the passive house, received a score lower than 5.5. The score is calculated using this formula: 5.5 + ((energy use passive house - energy use design)/20). This formula is used twice: First for the passive energy usage of the designs, so without active systems and the second time for the active energy usage of the designs, including the energy generated by the solar panels.

The design was created for the climate of Shenzhen (China) that has a sub tropical climate. The heating set point was set to 21 degrees Celsius and the cooling set point was set to 28 degrees Celsius based on a research of [Peeters,2011] and PMV calculations. The warm season in Shenzhen lasts from May 14 to October 15 with an average daily high temperature above 30 degrees Celsius. The cold season lasts from December 14 to February 24 with an average daily high temperature below 21 degrees Celsius. The daily high and low temperature is shown in figure 2.5 with the heating and cooling set point.

![Figure 2.5 Daily high and low temperature with heating and cooling set point](image)

The designs were compared on design solutions and not on system efficiency. The basic values for the heating, cooling and ventilation system were taken from Sefaira. The heating system had a COP (Coefficient of Performance) of 0.85. The cooling system had a COP of 3 and the ventilation rate was 1L/m²s. The U-value and infiltration rate were equal for each design. Some students did not answer the question in the questionnaire about the U-value and infiltration rate and some students choose values, which are not yet within reach. So the U-value for roof and facade were set to 0.12 W/m²K, for the floor was set to 0.20 W/m²K, for the windows was set to 0.64 W/m²K and the infiltration rate was set to 1.0 m³/m²h. These values are normal values for a passive house.
Comfort
The definition of comfort is: A state of physical ease and freedom from pain or constraint. [Oxford]

Heating, cooling, daylight, sound and ventilation can influence the comfort of a building. The program Sefaira was used for the building energy simulation of the building. The program also allowed simulations of daylight. A fixed value for the heating, cooling and ventilation systems was entered in Sefaira to make the calculations. So, heating, cooling and ventilation were excluded from the comparison of comfort, because active systems with a fixed value are used instead of passive techniques like natural ventilation and solar heat. Sound was also not taken into account because the location was unknown. The designed building can be placed at different locations, which means different sound levels. The amount of daylight can be influenced by design decisions, so daylight was taken into account at the reviewing of comfort.

Daylight:
Daylight is split into two categories, the amount of daylight inside the building and the visual discomfort (glare). Both are visible within the design process in SketchUp with the plug-in of Sefaira. The definitions of Sefaira [Sefaira, 2014] for glare and daylight are:
SDA:
Spatial daylight autonomy (sDA). The sDA describes how much of a space receives satisfactory daylight. Spatial daylight autonomy is a standard requiring 50% of occupied hours during the year are adequately lit in the project. Adequately day lit is between the 300 and 3000 lux.
ASE:
The glare in the building is the Annual Sunlight Exposure (ASE). ASE describes how much of space receives too much direct sunlight. This can cause visual discomfort or increase cooling loads. The maximum ASE is 10%. The calculation of the ASE is based on LEED v4.

LEED v4 requires that illuminance values of 1000 lux and above must not exceed 250 occupied hours during the year, and must not exist in more than 10% of the occupied floor area. [Idibozeman, 2014]

The daylight of the designs is made visible in a circle diagram, see figure 2.6. The different designs were ranked by the values given in this circle diagram. A design received a score of ten when the building was 100% well lit or when the building was equal or more than 90% well lit and had equal or less than 10 % glare.

<table>
<thead>
<tr>
<th>Glare</th>
<th>X &lt; 11% = x points</th>
<th>X &gt; 11% = max 10 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well lit</td>
<td>= all points</td>
<td>well lit = 69 points</td>
</tr>
<tr>
<td>Under lit</td>
<td>= zero points</td>
<td>Under lit = 0 points</td>
</tr>
</tbody>
</table>

Total score / 10 is end score

End score = 7.9

Architecture
The designs were reviewed on the following different components of architecture by two tutors of architecture. The designs received one end mark between 1 and 10.
- Interpretation of the assignment (taking into account the wishes of the family)
- Energy (integrating energy systems into the design)
- Concept and vision (argumentation why decisions are made)
- Relation with the context (implementation of the building on the locations/ interaction with surrounded buildings)
- Functional quality (can the building be used to live in)
- Spatial quality (would it be a comfortable building to live in)
- Manipulability (can the building be build)
Calculation the total score
For this research the designs were reviewed separately on the three parts (passive energy use, comfort and architecture) and given a total score. The scores of each part were given a score from zero to ten. Zero for the worst and 10 for the best score of the designs. To calculate a balanced total score, a sensitivity analysis was made. The sensitivity analysis makes it possible to compare the individual scores in proportion to the total score. The sensitivity analysis can be found in attachment 6. The sensitivity analysis was made with values between 20, 30, 50 and 33, 33, 33. Wider ranges were not chosen because none of the three values can be overvalued. The most desirable distribution is 33 % for each part. The focus of this research was the energy efficiency of the designs, so this part was given a higher value than the other parts. With a distribution of 40% for energy and 30 % for architecture and daylight, the energy part had more influence on the total score but was not overvalued.

Graphs were made using the Total score and with the individual scores on architecture, passive energy use and daylight. These graphs gave a visual impression on whether there was any difference between designs which were made with a building energy simulation program and designs that were made with guidelines. In the graphs the mean score of the two design processes is shown with a line. Whether the difference between the two design processes is significant, was calculated with the T-test. The results are two independent samples and it has been assumed for the t-test calculation that the two population variances are equal. The hypothesis were:

\[ H_0 : \mu_x = \mu_y \] and \[ H_1 : \mu_x < \mu_y \]

\( H_0 \): samples are taken from identical populations
\( H_1 \): Samples are not taken from identical populations, the two averages are different.

The used formula for the student t-distribution:

\[ T = \frac{X - \mu}{s \sqrt{\frac{1}{n} + \frac{1}{m}}} \]

The hypothesis \( H_0 \) is rejected if \( p < 5\% \quad \text{P}= P(T \leq t ; H_0) \)

The student t-distribution table 10.2 from statistical compendium [Berkum,2010] is used to find the value of \( p \).

As a double check, the significance is calculated with the Mann-Whitney U test because the sample size is below the 30 for each group and it cannot be proven that the distribution for an entire population will be normally distributed. The Mann-Whitney U test is used to calculate the significance of the scores of passive energy use, architecture and daylight.

Mann-Whitney U test, Test criteria 5% two tailed m and n. The table ‘critical value of the mann-whitney u’ [ocw,2015] is used to find the critical value.

The hypothesis \( H_0 \) is rejected if \( T \leq \text{Cv} \)

The same hypothesis as used at the t-test was used for this calculation.

The scores for passive energy use, architecture or daylight, were ranked and the ranks were add separately for each sample. The U-value was calculated with the formula:

\[ U = T - \frac{1}{2} n(n + 1) \]

Besides the total scores, graphs were made that showed whether one of the parameters had more influence on the total score or on the individual scores for architecture, passive energy use or daylight. The total score of one of the individual scores were plotted against, floor area (m²), volume (m³), perimeter (m¹), window to wall ratio, orientation of the largest window area, sort of sun shading for the windows, sort of sun shading for the facade, the angle of the roof and the roof area.

The correlation between a parameter and the total score or the score on passive energy use, architecture or daylight was calculated using the spearman’s rho.
Spearman’s rho:  
\[ \rho = 1 - \frac{6 \sum d_i^2}{n(n^2-1)} \]

\( \rho \) 0 is no correlation  \( \text{range } 1 \text{to} -1 \) 0.00 \( \langle \) 0.30 no correlation  
\( \rho \) 1 is strong correlation  0.30 \( \langle \) 0.50 low correlation  
\( \rho \) -1 is strong negative correlation  0.50 \( \langle \) 0.70 moderate correlation  
0.70 \( \langle \) 0.90 high correlation

**Questionnaire**

After the students finished the designs, a questionnaire was filled out. This questionnaire was developed to investigate whether architects and building engineering professionals can distinguish the difference in design processes only by looking at the finished designs. The questionnaire was distributed among architects, architecture students and graduating/graduated bps students. None of the respondents had prior knowledge or participated in the project. In this questionnaire, pictures of the 26 designs were shown accompanied by this question whether the design is made with a building energy simulation program or with guidelines for energy efficient designs and why they think the design is made with that design process. An example of one of the questions is shown in figure 2.7.

The results of the questionnaire were used to determine whether architects and bps students can distinguish which design process was used to create a design. Per design, it was counted how many answers each design process was given. These numbers were put into a graph which shows per design what the given answers were from the respondents next to the correct answer. The results of the two groups were split to determine whether architects or bps students had the correct choice in more cases. The textual answers were used to achieve where the architects or bps students have based their choice on.

![Example question of the questionnaire](image)

**Figure. 2.7** Example question of the questionnaire
3. Results
The following chapter will show the six designs made by the researcher. The designs are made with the simulation program or with the guidelines which were described in the previous chapter. The results of the comparison of the designs will be shown in the second part of this chapter. The results will be discussed in the next chapter.

3.1 Designs
Content designs:
Design one made with guidelines
Design two made with guidelines
Design three made with guidelines
Design one made with Sefaira
Design two made with Sefaira
Design three made with Sefaira
Designs of the students,
Personal reflection of the designs
3.2 Comparison

All designs are compared on ground level with no surrounding buildings and with the same U-values for floor, roof, facades and windows. The U-value of the different designs is equalized because the U-value influences the energy use of the design and lowering the U-value does not have to change the appearance of the design. The students have answered a question in the questionnaire about the U-value of the design and there is little difference in the choice of U-value between students who have worked with Sefaira and those who have worked with guidelines. The students who worked with Sefaira looked slightly more to the U-value and presented on average lower value. From the students who worked with Sefaira, 6 students included the U-value in the design process, two of which have maintained the basic value of Sefaira. From the students who worked with guidelines, 5 students adapted the U-value in the design process of which two students used values above 1.0 W/m²K. The table with the values can be found in attachment (7.).

The different designs are compared on the three aspects and a total score is defined for each design. These aspects are plotted against each other in the graphs of figure 3.1 till 3.8 but to interpret the graphs correctly the following information is necessary.

<table>
<thead>
<tr>
<th>Passive energy</th>
<th>Energy use of the building without the generation of solar panels (kwh/m² ranked from 1 to 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active energy</td>
<td>Energy use of the building with the generation of solar panels (kwh/m² ranked from 1 to 10)</td>
</tr>
<tr>
<td>Generation</td>
<td>Only the energy generated with solar panels (kwh/m² ranked from 1 to 10)</td>
</tr>
<tr>
<td>Triangle</td>
<td>Designs made with Sefaira</td>
</tr>
<tr>
<td>Circle</td>
<td>Designs made with Guidelines</td>
</tr>
</tbody>
</table>

Figure 3.1 Passive energy/ daylight
Figure: 3.2 Passive energy/ generation

Figure: 3.3 Architecture/ daylight

Legend:
- Sefaira
- Guidelines

Figure: 3.4 Passive energy/ architecture
The figures 3.5 till 3.7 and 3.9 show the score on architecture, passive energy, daylight and the total score for the designs made with Sefaira and guidelines. The black lines are the means of all designs made with either Sefaira or guidelines.

All graphs show that the mean score of Sefaira is higher than the mean score of guidelines, figure 3.8 shows the intermediate differences.

<table>
<thead>
<tr>
<th>Intermediate difference</th>
<th>Total score</th>
<th>Passive energy</th>
<th>Architecture</th>
<th>Daylight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.11</td>
<td>0.49</td>
<td>0.81</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Legend:
- Sefaira
- Guidelines

<table>
<thead>
<tr>
<th></th>
<th>Sefaira</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (black line)</td>
<td>6.83</td>
<td>5.733</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.07</td>
<td>1.59</td>
</tr>
<tr>
<td>Average SD</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td>Variation</td>
<td>1.15</td>
<td>2.53</td>
</tr>
<tr>
<td>Effect size</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>(\alpha) err prob</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Power (1-(\beta) err prob)</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Total sample size</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Figure: 3.5 Passive energy
Figure: 3.6 Architecture
Figure: 3.7 Daylight
Figure: 3.8 Intermediate difference
Figure: 3.9 total score
Figure: 3.10 Statistical values
Student T-distribution

\[ S = \sqrt{\frac{12\cdot1.15+12\cdot2.53}{24}} = 1.35 \]

\[ T = \frac{\bar{X} - \bar{Y}}{S\sqrt{\frac{1}{n} + \frac{1}{m}}} \]

Student t-distribution \( P(T_{24} \geq 2.064) = 0.025 \)

\( T_{24} = 2.05 \) which is smaller than 2.064 so \( P \) is smaller than 0.025.

Mann-Whitney U-test

The individual scores for Sefaira and designs made with guidelines are ranked from low to high. The lowest score receives the number 1 and the highest score receives the number 26. All the ranked numbers are added separately for each sample. The total score of the designs made with Sefaira is 215 and the total score of the designs made with guidelines is 136.

\[ Us = 215 - \frac{1}{2} \cdot 13 \cdot (13 + 1) \]
\[ Ug = 136 - \frac{1}{2} \cdot 13 \cdot (13 + 1) \]

Us = 124 Ug=45

For a two-tailed test, the test statistic \( T_s \) is the smaller of the two \( U \)-values. In this cases \( T_s = 45 \).

Test criteria 5% two tailed with \( m = 13 \) and \( n = 13 \)

From the table, the Critical Value is 45.

If \( T_s \leq CV \) reject \( H_0 \)

| Calculations of these values can be found in attachment (8.) |
The scores of architecture, passive energy use and the total scores are plotted against, floor area (m²), volume (m³), perimeter (m'), window to wall ratio, orientation of the largest window area, sort of sun shading for the windows, sort of sun shading for the facade, the angle of the roof and the roof area. In figure 3.14 till 3.17 the graphs in which a possible trend is visible are shown. The possible trend will be further explained in the next chapter (Discussion). The graphs with no possible trend visible can be found in attachment [9].

![Graph: 3.14 Passive/ Volume](image1)

![Graph: 3.15 Passive/ Angle of the roof](image2)

![Graph: 3.16 Daylight/ window area](image3)

![Graph: 3.17 Passive/ window area](image4)

<table>
<thead>
<tr>
<th>Spearman's rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive/ volume</td>
</tr>
<tr>
<td>Passive/ roof angle</td>
</tr>
<tr>
<td>Passive / window area</td>
</tr>
<tr>
<td>Daylight/ window area</td>
</tr>
</tbody>
</table>

range 1 to -1

0.00 < r < 0.30 is no correlation
0.30 < r < 0.50 low correlation
0.50 < r < 0.70 moderate correlation
0.70 < r < 0.90 high correlation
0.90 < r < 1.00 very high correlation
After the designs were made, a questionnaire was developed to investigate whether architects and building engineering professionals can distinguish the different design processes only by looking at the finished designs. The questionnaire has been completed 24 times. Twelve times by an architect and twelve times by a graduate / graduated bps student. In figure 3.18, On X axis show which is made with simulation and which one with guidelines. The first thirteen designs are made with a simulation program and the designs 14 to 26 are made with guidelines.

![Figure 3.18 Questionnaire design process of the designs](image)

![Figure 3.19 Percentage of correct answers](image)

In 3.5 percent of the cases, the architects are more likely to be right as regards the choice of the design process of the shown image. But in most cases, half of the architects as well as half of the bps students selected the correct process. Figure 3.20 and 3.21, the two wordle figures, describes the words which are most used when asked to motivate their choice. All reactions of the questionnaire can be found in attachment (10).

![Figure 3.20 Why chosen for guidelines?](image)

![Figure 3.21 Why chosen for simulation program?](image)
Figure 3.22 Designs with a distinct choice

Figure 3.22 represents the designs with a clear distinction between the two different design processes.
4. Discussion

In the previous chapter, the designs and results of the comparison are shown. The scores of the designs on different parameters are visualized in graphs. In this chapter these results will be discussed.

4.1 main question

The main question of the research was whether the designs of energy efficient houses could be improved when architects use a building energy simulation program in the early phase of the design process. To answer this question, two calculations were used to calculate whether there was a significance difference between the total score of designs made with Sefaira and the total score of designs made with guidelines. The significance is calculated with the T-test and controlled with the Mann-Whitney U-test. The hypothesis $H_0$: Samples are taken from identical populations. $H_0$ is rejected if: $t$-test: $P \leq 5\%$ Mann-Whitney: $T_s \leq Cv$

The score of $P$ is 0.025 which is equal to 2.5% so $H_0$ is rejected with the t-test $T_s$ and $Cv$ are both 45 so $H_0$ is also rejected with the mann-Whitney U-test. This means that hypothesis $H_1$ is accepted.

$H_1$: Samples are not taken from identical populations, the two averages are different.

The research question can be answered with yes, the designs made with a simulation program have an overall better score than the designs made using guidelines.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$T_s$</th>
<th>$Cv$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total score</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Passive energy use</td>
<td>78.5</td>
<td>45</td>
</tr>
<tr>
<td>Architecture</td>
<td>67.5</td>
<td>45</td>
</tr>
<tr>
<td>Daylight</td>
<td>39</td>
<td>45</td>
</tr>
</tbody>
</table>

The Mann-Whitney U-test was also used to calculate the significance of the difference for the scores on passive energy use, architecture and daylight. By architecture and passive energy use the difference between the two mean scores as can be seen in figure 3.5 and 3.6 cannot be proven to be significant. The difference between the scores for daylight made with Sefaira or guidelines is significant. So, with high probability it can be said that the score for daylight most influences the significance of the total score.

In this research, master architecture students made the designs. The students represent a group of architects to answer the research question. Figure 4.1 shows the total score of the designs again, but using different colours to score the different designs. These different colours where applied because the design process of some designs could not be compared to the design process of architects. If architects work with a building energy simulation program during the design process in the future, it may be assumed that they already understand the simulation program and devote sufficient time to make the design. The designs created by the students cannot be compared one to one with designs created by architects so it would be interesting to do the same research with architects instead of architecture student to confirm the result of this research.

All designs are used in this research, but it could be interesting to make a selection within the designs. The distribution of the circles and triangles in figure 4.1 are based on the number of hours worked on the design (for the designs made with guidelines) and how the students have worked with the program (for the designs made with Sefaira). The expectation is that the designs could have been improved if the students had more time to design the designs or used Sefaira in a correct way.

The red triangles in the results of Sefaira, are not used during the design process because of incorrect interpretation of the given results of the program on the energy use of the imported design. There is a slight difference between the orange and light green triangle. The orange
triangle represents the designs where the program was not optimally used and the light green triangle represent designs where Sefaira generally speaking is used in a correct way but stopped doing so, because of bugs of the program that the students could not solve. So, the start of these designs was good but they would be further improved if the student would have been able to solve the bugs in the program. The green triangles describe designs where Sefaira is used in a correct way and with 60 or more design hours. Information about the design process and the bugs which occurred by some students can be found in the table of the values which can be found in attachment (7.). The information for this weighting comes from information students answered in the questionnaire and the researcher could see the changes students made on the internet page of Sefaira.

<table>
<thead>
<tr>
<th>Total score</th>
<th>Passive energy</th>
<th>Architecture</th>
<th>Daylight</th>
</tr>
</thead>
<tbody>
<tr>
<td>All designs</td>
<td>1.11</td>
<td>0.49</td>
<td>0.81</td>
</tr>
<tr>
<td>Exemplary designs</td>
<td>1.16</td>
<td>0.55</td>
<td>0.80</td>
</tr>
</tbody>
</table>

The higher scores for daylight can be explained because, while designing, Sefaira gives insight in the effect on the daylight score of taken decisions.

There is a small difference between the mean scores of passive energy use and architecture for designs designed with Sefaira and designs designed with guidelines. The difference has increased in the comparison of passive energy use between all designs and the exemplary design. But, this increased difference is still not significant. It would be interesting to research whether the scores on passive energy and architecture is also influenced by the use of Sefaira.

Further investigation with a second group of students who have experience with Sefaira and are willing to design the given time or with architects would have to confirm this.
4.2 Secondary questions

1. Which program is preferred to use during the design process?

Sefaira is selected after an elimination process. One of the reasons that Sefaira was selected was that architects can make a simulation with a few parameters. Also, the simulation program is a plug-in of SketchUp, which is a program that architects use regularly during the design process. After intensive use of the simulation program, a few drawbacks were detected. Sefaira is a good program to use in the early phase of a design process to support taking design decisions. But detailed daylight or energy simulations can better be simulated with complex programs. For example: it is not possible to change the daylight level per room, so all designs are simulated for daylight without interior walls. Sefaira requires the same daylight level in a closet, toilet or living room. In most designs the closet and toilet have fewer windows than living areas, so the requirement of Sefaira’s daylight level could not be reached with interior walls.

For designing, the program SketchUp is used. Thereafter, the design can be optimized by changing some parameters on an internet page. One of the changeable parameters is the use of brise soleil. The use of brise soleil affects the energy use of the building in a positive way, but also influences the daylight. The daylight simulation is made with the model made in SketchUp, so the brise soleil should be drawn in this model. With most designs it was not possible to draw the brise soleil for the daylight calculation because Sefaira could only simulate a model in SketchUp which has less than 1500 planes.

A bug in Sefaira is that the program automatically changes planes below 500 mm from ground floor level into floors. So shading in front of a low window is automatically changed to the entity type floor and also calculated as floor. This influences the energy use and daylight calculation. More floor area means more transmission losses and the floor area is also calculated as percentage of floor area that receives enough daylight.

The program is updated regularly, but the industry of sustainable design solutions is changing at a higher speed. So, the program cannot always simulate the most recent developments.

In this study Sefaira is not fully utilized by all students. This has most likely to do with a combination of the program, building physical knowledge of the students and the limited time of the assignment. The use of Sefaira could be improved in almost all design processes of this research. This was the first time the students worked with Sefaira. The level of skills to work with the program can be developed by working frequently with the program. The results should be different if the research was done with students or architects who are experienced users of Sefaira.

2. Is it visible in the final design which design process is used?

The response of the questionnaire shows that in most cases it is not visible. Figure 3.18 shows that at the majority of the designs, both design processes are almost equally selected. On only nine out of the 26 designs respondents clearly chose one design process. On three out of these nine designs, the respondents thought the design was created with a different design process than it was actually created with. The thought and the actual design process are given in figure 3.22.

Besides the respondents of the questionnaire, two architects responded by mail. They said that they had to guess with which designs process a design was created because they could not see it. The designs are not judged on design solutions by the respondents but rather on their look. A traditional, usual simple design, which could be calculated easily by hand, is in most cases judged as made with guidelines. The use of an overhang or facades with too much glass is also a trigger to choose for the guidelines as design process. Designs with a complex shape and/or an unusual design are in most times judged as to be designed with a
simulation program. The use of a specific roof system or facade system, are also triggers to choose the use of a simulation program as being the design process. The use of shading was a given guideline, but students who have worked with Sefaira also used overhangs to create shadowing. The choices are not clearly based on a guideline or a direction the simulation program could give, the choices are mostly based on the look of the designs, simple or complex.

3. Does one of the parameters have a high influence on the different scores?
The students have made the designs and answered a questionnaire about the designs and their design process. One of the questions was about the U-value of the windows, walls, roofs and floors. Not all students have responded to this question, some students choose a value above the 1.0 W/m²K and some students choose a value that was so low that it is not on the market yet. All designs are compared with the different U-values but it turned out that the U-value has a high influence on the score for passive energy use. Because some students had not responded to the question, the U-value of these designs was set to 0.12, which is a basic value for passive house buildings. It was decided to compare all designs with an equal U-value of 0.12 for the walls and roofs, 0.20 for the floor and 0.64 for the windows. The change of the U-value can be done without changing the appearance of the design.

Besides the U-value, there are some other parameters that may have an influence on the total score. Figure 4.3 shows the ratio between the passive energy use of a design and the volume of that design. There is a low correlation between the volume of the building and the score on passive energy use. Buildings with a larger volume area use more passive energy than smaller buildings. This could be due to the energy required to heat or cool the larger quantity of air in the building. This decrease of energy use for smaller volumes is not visible in figures with the floor area or perimeter while these parameters also influence the size of the building.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spearman’s rank</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive/ volume</td>
<td>0.39</td>
<td>Low correlation</td>
</tr>
<tr>
<td>Passive/ roof angle</td>
<td>0.03</td>
<td>No correlation</td>
</tr>
<tr>
<td>Passive / window area</td>
<td>0.92</td>
<td>Very high correlation</td>
</tr>
<tr>
<td>Daylight/ window area</td>
<td>0.10</td>
<td>No correlation</td>
</tr>
</tbody>
</table>

Figure: 4.2 Spearman’s rho, correlation

All parameters that are based on design changes and could influence the scores on passive energy, architecture or daylight are plotted against these parameters (including volume, angle of the roof and window area). From the graph of figure 4.4 it could be thought that designs with a high score on passive energy use have a roof angle between zero and thirty. But this is an incorrect interpretation of the results because there is no correlation. The use of roof angles between zero and thirty can cause because, the optimum tilt angle for solar panels in Shenzhen is between the zero and thirty degrees. In many designs these solar panels
are integrated on the roof, making it more common to use a slope between the zero and thirty than a higher slope in low energy buildings.

In figure 4.5, the passive energy use of the designs was plotted against the window area. The trend line in this graph shows that there is a visible relationship between the energy use and the window area. With a correlation rank of 0.92 this is confirmed. A logical explanation for this decrease of energy use by less window area is the difference in insulation value of a window and a façade. In all designs the insulation value of a window is lower than the insulation value of a closed façade. This means that a window leads to more transmission losses than through a closed façade. It is notable that there is no correlation between the lower window area and the score on daylight, which is shown in figure 4.6. The score on passive energy use can be decreased by lowering the window area, while there is still enough daylight in the building, but this leaves out the influence of daylight on architectural quality.

4. Is there a difference in the use of solar panels between the two design processes?
Solar panels are integrated in all designs designed with Sefaira. Two designs which are made with guidelines do not have solar panels and five designs integrate just a small amount of solar panels. The integration of solar panels has a positive influence on the active energy use. Active energy use is the energy the design needs to supplement the energy generated with solar panels. The designs made with Sefaira have on average a higher score than designs made with guidelines. The differences between Sefaira and guidelines are significant for generation as well as for the active energy use.

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<td>Generation</td>
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The assignment was to design a house, which was as efficient as possible, almost a net zero energy building. Students who have designed with Sefaira could see the energy use of the design while designing and see the influence of the use of energy generated by solar panels. So they could try to reach the zero energy limit. Students who have designed with guidelines had not such insight in the energy use of the building they designed. So they did not know whether they had designed a net zero energy building or not. This possibly explains the difference in the use of active systems by the integration of solar panels.
4.3 Method

Some critical notes can be made on the method of this research. Shenzhen has a hot humid climate, so the average temperature outside is higher than the desired temperature in the building. This means that the simulation program almost solely focuses on cooling strategies. The use of a simulation program is different for designs in a cold climate. The Netherlands has a cold climate, which means that the houses use energy for heating during winter and energy for cooling during summer. For designs in The Netherlands, Sefaira could simulate the optimum of designs solutions affecting the energy use for heating as well as for cooling instead of only focussing on cooling strategies. It would also be interesting to research the effect of the use of a simulation program for designs in a cold climate.

The designed houses did not reach the net zero energy goal. The climate in which the designs were situated for this research may be one of the causes. Another reason may be the omission of natural ventilation, especially in a hot humid climate, natural ventilation is often used to cool the building. In addition, the active systems are also not adapted to the designs.

Another remark is that the researcher also made six designs that were used for the comparison. Although it should be mentioned that there is a small change that previous designs made with guidelines have influenced the designs made with Sefaira and the other way around, therefore the researcher has made the designs for Sefaira and guidelines alternately.

Nevertheless, even with the warm climate and without the adjustment of active systems, the influence of a building energy simulation program in the design process, in this case Sefaira can be judged as positive. However, it would be difficult to carry out the same research again in ten years because passive techniques and simulation programs are developing quickly.
5. Conclusion

Architects have to design net zero energy buildings in 2020. Designing with guidelines or with a building energy simulation program are assumed to be the two design methods architects will use to design energy efficient buildings. The hypothesis that designing a building with an energy simulation program results in more efficient designs was answered in this research.

Research question

If architects use building energy simulation programs in the early phases of the design process, does it result in more efficient designs in the field of energy reduction of residential buildings?

The research question can be answered positive, yes it does. One small remark, the designs in this research were conducted by students and not by architects. However, the hypothesis is that the answer will be the same if the research will be repeated with architects.

Secondary questions

Can architects or building engineering professionals distinguish which design is made with which design process? Based on the response of the questionnaire, this is not visible in most of the designs. The common reaction why the respondents voted for guidelines was because the designs looks simple, has a traditional shape and could easily be calculated by hand. The use of an overhang or facades with too much glass were also triggers to choose for guidelines as design process. Designs with a complex shape and an unusual design were often judged as to be designed with a simulation program. The use of a specific roof system or facade system, were also triggers to choose the use of a simulation program as being the assumed design process.

Does one of the parameters have a high influence on the different scores? Yes, the parameter window area has a high influence on the score of passive energy use. The score on passive energy use can be decreased by lowering the window area. Another parameters that highly influences the energy use is the U-value. The U-value can be decreased without changing the appearance of the designs.

Is there a difference in the use of solar panels between the two design processes? Yes there is, in the designs that were designed with a simulation program, solar panels were more often integrated in the designs. The average total score of designs that were designed with Sefaira is significantly higher on energy use including the generation of the solar panels than designs that were designed with guidelines.

There is a significant difference between the total score of designs made with guidelines and designs made with a simulation program, in which the designs made with the simulation program score better overall. So it can be concluded that the use of a building energy simulation program has a positive influence on the design outcome.
6. Recommendations

The conducted research and results lead to a number of recommendations. Since the designs for this research were conducted by students, the first recommendation is to repeat the research but asking architects to design for the research instead of students. The time, which is used to make the designs, could also have influenced the results of this research, so with a follow-up research, the designs should be made with more time. The influence of the use of a building energy simulation program by architects in later phases of the design process of houses would be interesting to research as well.

The simulation program that was used, was the best simulation program to use for this research, at the time it was conducted. In the discussion of this research some small remarks about the simulation program are mentioned. For a follow-up research, if the program is improved it is interesting to see what the results are. Besides the development of Sefaira, other simulation programs are also being developed and new simulation programs are designed and released, so with a follow-up research the best simulation program for that research should be selected again.

Continuing on the simulation program, it could be interesting to research which parts of the simulation program the architects often use in the design process, which elements architects miss and how the simulation program could be improved to make it even more suitable to fit into the design process of architects.

This research only focuses on passive strategies, but of course there are other possibilities as well to build energy efficient houses. As shown, the use of solar panels has a positive influence on the total energy use of the design. Natural ventilation and active systems influence the energy use of the building and could be integrated in the early phase of the design process of architects. For a follow-up research the use of passive and active strategies should be combined and natural ventilation should also be part of the designs especially in warm climates.

The last recommendation for further research is to change the location. As mentioned in the discussion, the designs mainly focus on shadowing. In a colder climate the simulation program could have more influence in finding an optimal design for winter and summer situations, which could result in more difference between the designs.
7. References

**Images**

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## Appendices

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