Living in a greenhouse
Exploring the effects of integrating greenhouses and dwellings.
Abstract

This paper describes the research on the contributions a greenhouse can make to dwellings. The results will be used in a design for elderly cohousing. This way elderly people can both have social interaction and spend time outdoors in nature throughout the year. The research is mainly done by case studies on existing greenhouse buildings, expert meetings and site visits. The results show that greenhouses contribute to dwellings on an architectural, climatological and technical level by creating a buffer and transition zone. The results also show lessons that should be taken into account when wanting to design with greenhouses.
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Introduction

The Dutch population is aging. Research shows that as the baby boom generation is reaching the age of 65+, in the year 2040 21% to 33% of the population will consist of elderly people (Mulder, 2010) (Figure 1). These elderly are often lonely, newspapers report that an increasing amount of elderly people pay others to keep them company (Huisman, 2014). Other research shows elderly people spend up to 95% of their time indoors, mostly because of the outside weather (Oei & Bergs, 2007, p30). The image of elderly people sitting in their homes being lonely is one that nobody wants for their parents or future selves.

Combining elderly cohousing with greenhouse architecture offers a solution to both problems. Cohousing offers private rooms as well as communal rooms and areas for the residents to come together and enjoy each other’s company. By covering (parts of) the outside areas with greenhouses, these areas can be used throughout at least large parts of the year, decreasing the threshold for residents to leave their homes and go ‘outside’. The combination of the two principles will create a place in which elderly can spend their old days Mediterranean style: by being outside in the company of others.

In order to design such a building the following design question has to be answered:

How can greenhouses contribute to a design for senior cohousing?

Since there are no examples (to my knowledge) of the combination of senior cohousing and the use of greenhouses in architecture the research is split in two.

One part focusses on the typology of senior cohousing. The other part focusses on the way greenhouses can contribute to the architecture of dwellings. This part of the research is described in this paper. The technical research question leading to this research is:

How can greenhouses contribute to the design of residential buildings?

In order to answer the technical research question, the question is divided into sub questions. The first sub question has the aim to gain basic knowledge on greenhouses:

How do greenhouses work and how are they built?

The rest of the research questions focus on the different aspects in which a greenhouse can contribute to the design of residential buildings: Architecture, climate design and technique.

How can a greenhouse contribute to the architectural qualities of dwellings? This research will focus on the functions housed in greenhouses, the way greenhouses affect privacy zoning and the atmosphere inside the greenhouse.
How can a greenhouse contribute to the indoor climate and sustainability of dwellings?
For this question the focus will be on the different techniques that can be used to condition a greenhouse and the connected architecture. It is also interesting to look at the way a greenhouse can react to the different seasons. The last focus of this question will be on the orientation of the greenhouse.

How can a greenhouse contribute to the technical detailing of dwellings?
The greenhouse has an effect on the way the buildings is materialised and detailed. These two aspects will be the focus for this question.

Figure 2 shows the structure of the research as described so far.

The combination of architecture with greenhouses seems to be a very beneficial one. It is however not often used, especially in residential buildings. By researching and structuring the many possibilities and benefits of using greenhouses in architecture, this sustainable combination will hopefully pique the interest of more architects and clients. This can lead to an increase in the implementation of this concept.

Now that the reasons for doing this research and the research structure have been explained, the methods, results and conclusions will be described.

A greenhouse dwelling?
During this research I talk a lot about greenhouse dwellings. With this I mean that dwellings (volumes) are connected, sheltered or bordered by a glass façade (skin). This skin can cover (a part of) the volume and its surroundings. This cover which shelters the volume from wind and rain makes for a different living experience as areas outside of the volume can still be used to live in.
Methods

In order to answer the questions mentioned in the previous chapter multiple research methods were used.

Case studies

A large part of the research has been done by case studies on buildings that contain greenhouses. Suitable projects were found by reading about excursions of ‘Bouwen met groen en glas’ (an organisation promoting the use of glass and greenery in architecture), internet findings, own knowledge and suggestions of others. From 28 found projects the following projects were chosen for the case study:

- Christian Agricultural School by BDG Architects
- Crystal Court by Tangram Architects
- Cubity by TU Darmstadt
- ‘Kaswoning’ from KWSA Architects
- FinanzIT by Hascher Jehle Architects
- ‘Het Rode Dorp’ by Braaksma & Roos Architects
- Lumen by Behnisch, Behnisch & partners
- Pyjama Garden by MVRDV
- Mont Cenis Academy by Jourda Perraudin
- Prêt à Loger by TU Delft
- Zonneterp by Innovatienetwerk Groene Ruimte and Agrocluster

The choice was made on the basis of a few factors. The availability of information was one as was the wish to have examples of multiple types of greenhouses and functions. There are relatively more case studies done on dwellings and ‘multiple volumes covered’ (Figure 3). These were particularly interesting because of the expectation that these two directions will offer potential solutions for the design goal of senior cohousing.

The buildings are analysed according to a template. The template (shown in Figure 4) shows basic information, representative photos of the project, explanatory text and the subjects mentioned in the sub questions: Architectural qualities, climate concept and technology.
Figure 3: Chosen case studies ordered by type and function
Figure 4: Template Case Studies
Architectural qualities
The research on architectural qualities is divided in use, zoning and atmosphere. Atmosphere is represented by a photograph which captures the ambience of being inside the greenhouse. The study of use and zoning is combined in an analysis of the floor plans and sections. Areas in the schematic representations of the plans and sections are coloured according to the amount of privacy that one has when in the area. A darker colour represents relatively more privacy. After this the use of the greenhouse is analysed which is shown in the same figure by adding symbols to the used areas. Information for this analysis is gained from analysing floor plans and reading publications on the projects. An example and legend are shown in Figure 6 and Figure 5. This analysis is done to gain knowledge on the distribution of privacy in a greenhouse, so how are the most private areas placed in relation to the more public areas. It also creates insight in what type of activities and functions can take place in the greenhouse area. By comparing these analyses different ordering types can be discovered and connected to different ways of using the greenhouse area.

Climate concept
Greenhouses are in essence designed to grow plants. Humans however have different demands when it comes to the indoor climate. This makes it necessary to learn about controlling the climate within a greenhouse. For this reason the case study researches the climate concepts of the projects. This is done by making a schematic representation in

Figure 6: Example of Use and Zoning analysis (Crystal Court Amsterdam)

Figure 5: Legend to Use and Zoning analysis
which air flows, installations and other ways of controlling the indoor climate are showed. This information comes from books and magazine articles on the projects. Elements that can’t be shown in the scheme are described in the explanatory text. An example of a climate scheme can be seen in Figure 7.

Technology
The fact that a greenhouse is integrated in the design can have an effect on how the volumes inside the greenhouse are detailed and materialized. Besides this there are multiple ways of constructing the greenhouse itself and connecting it to other volumes. These subjects are researched by looking into detailed drawings of the designs. By comparing the different solutions, connections can be made to the types of climate concepts and/or ways of implementing the greenhouses.

Explanatory text
The explanatory text summarizes the most important aspects of the design and addresses elements of the climate concept that couldn’t well be displayed in the scheme. This way information won’t get lost.

Literature research
Literature has been used for multiple reasons. First it is used to gain general knowledge about greenhouses and designing with greenhouses for architecture. Literature also provided interesting projects for the case study and has been used to gain information on the case study projects. Books from architects and magazine articles often provided information about the climate concept, detailing and floor plans.

Online research
A lot of information, in particular on the case studies, can be found online. Architects publish a lot on their own websites and often refer to publications on their designs.

Expert meetings and site visits
Meeting with experts in different fields is a quick way to gain information and inspiration. Site visits make it possible to see for yourself how things work. For this research meetings and site visits were held with Peter Wienberg from KWSA who designed and lives in a ‘kaswoning’, Roel Bakker who is the owner of Bakker Westland tomato greenhouses, Batist Westland who builds greenhouses and private glass houses and Christian Wiegel who is currently doing his PhD with Solarlux on wintergardens.

In depth research
From the case studies, four cases were chosen for a more in depth analysis. These projects all have something special that, when further researched, could be of value when wanting to design with greenhouses. The in depth research of the KWSA ‘Kaswoningen’ focuses on how the glass shelter influences the use and perception of different areas in and around the home (Figure 8). The areas were analysed to find out what it is that brings quality to them (Figure 8).
Studying the Crystal Court focusses on how privacy can be created in and around a communal greenhouse. It is especially interesting to look into how the stacking of the volumes is used to create privacy. The third study, Cubity, focusses on how the position of volumes in a greenhouse can influence zoning.

Doing the research as has been described throughout this chapter led to many interesting results which will be discussed in the next chapter. The actual case studies are not shown in the results but can be seen in the annex.
Results

By applying the methods described in the previous chapter the earlier stated sub questions can be answered.

How do greenhouses work and how are they built?

Greenhouses have a history of simplicity and optimisation. More light entering the greenhouse means more profit; this has resulted in very thin detailing of the frames and construction. According to Peter Wienberg, architect of greenhouse dwellings, the aesthetical qualities of these thin frames is a mere side effect (2014). The same urge for simplicity results in a clear steel construction (Figure 10) with single glazing. Nowadays greenhouses are controlled by computers. The computer measures the wind direction and velocity, the indoor temperature and the humidity (Figure 11). According to these data glass panels in the roof can be opened. Windows in the direction of the wind are opened less to avoid draught. In winters the sun is not always enough heating so additional heating is necessary. In these cases the windows are opened as less as possible. Another way to avoid heat loss is to span sheets beneath the roof. These sheets keep the warm air inside the greenhouse. This is often used on winter nights. Figure 12 shows a simplified representation of an ordinary greenhouse.

In the world of greenhouses, research is done to make greenhouses more sustainable and lower the costs. Instead of letting the warm air escape through the roof windows, the heat can be harvested via heat exchangers and stored underground. This way there is no need for fossil fuels to heat the greenhouse in winter.
How can a greenhouse contribute to the architectural qualities of dwellings?

According to the case studies a division can be made in private and communal use of greenhouses. The fact that a greenhouse is private or communal has a large influence on the use.

The private greenhouse

Private greenhouses like Prêt à Loger and the KWSA ‘Kaswoningen’ become an integrated part of the dwelling. The greenhouse has a large influence on the way the dwelling is used. Because it shelters outside areas from wind and rain, these areas can be used throughout the year instead of only for a few months. This influences the type of activities taking place in these locations. A visit to Peter Wienbergs ‘kaswoning’ showed how the roof terrace is used as a study and gym and that the garden terrace functions as dining room with overhanging grape vines (Figure 13). These areas receive an abundance of natural light and have a clear view on the aesthetic greenhouse construction and surrounding landscape.

Areas inside the dwelling volume can also benefit from the glass cover. Windows and doors can for example be opened throughout the night for ventilation. Large opening façade elements can create open connections between rooms inside the volume and the greenhouse areas and its greenery.

Depending on the temperature fluctuations (that will be described in the section on the climate concept) the use of the greenhouse can vary throughout the seasons. This happens in both the KWSA ‘kaswoning’ and in the Prêt à Loger. In summer the greenhouses are open and become a sheltered part of the garden. In winters the greenhouse is cool but can still be used when wearing for example a sweater. In spring and autumn the greenhouse is a full part of the home and can be used as such.

Positioning the greenhouse

The way the volumes and greenhouse are positioned determines the use of areas that are created between building volume and glass façade. Large areas can become full functioning rooms. Smaller narrow areas are more likely to be used as storage.

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The communal greenhouse

When a greenhouse is a communal area it is mainly used as a circulation area. The often green atmosphere and natural light of the greenhouse offers a welcome contrast to the rest of the building. Besides circulation the areas are also used for people to get together for small meetings or to go on breaks. The Pyjama Garden (Figure 17), for example, is a place people can go to get a break from the clinical atmosphere of the hospital. They can walk around or sit down at the restaurant. When comparing the zoning analyses of the case studies a division can be made into categories based on the way volumes are placed in relation to the greenhouse.

![Figure 15: The inner courtyard of Crystal Court. Source: Funda](image)

The extent to which the volumes dominate the greenhouse influences the way the greenhouse is experienced. The 4 categories range from volumes placed around the greenhouse to volumes dominating the greenhouse, they are shown in Figure 16. The positioning of the volumes influences the privacy zoning of the greenhouse.

In ‘Het Rode Dorp’ and Lumen the greenhouse is fitted in the void between volumes. The greenhouse is therefore one large open and communal area (Figure 16, type 1). In the second type volumes break through the skin of the greenhouse. These volumes divide parts of the areas near to the facades. There is however still one clear shared open area in the middle (Figure 16, type 2). An example of this type is Crystal Court (Figure 15). In type 3 all volumes are

![Figure 16: How the position and domination of volumes in and around a greenhouse creates areas and zones.](image)

![Figure 17: In the PyjamaGarden, trees in the greenhouse offer a welcome break from the clinical hospital atmosphere. Source: http://www.mvrdv.nl](image)
situated in the greenhouse. They are situated near the edges which divides the greenhouse in a large communal area and smaller more private areas near the edges of the greenhouse. An examples of this type is Cubity (Figure 19).

In the fourth type the volumes are placed in a way that doesn’t create one large open area but multiple small ones. The positions of the volumes can create several smaller squares and circulation walkways. An example of type 4 is the Pyjama Garden from MVRDV (Figure 17). The several different small squares have a more private atmosphere because of their scale.

Creating privacy in a communal greenhouse
As just described, volumes can be placed in and around a greenhouse in different ways. The way in which this happens plays a large role in the notion of privacy and its zoning. This zoning is especially important when the volumes contain private functions like dwellings.

In addition to the position of the volumes in the greenhouse, their position relative to each other can also be used to create zoning. The horizontal and vertical position of volumes can create secluded areas and voids. In Crystal Court (Figure 15) the stacked volumes create overhangs over private terraces of dwellings.

The balconies in Crystal Court are placed in such a way that they are often enclosed on two or three sides. The sight on these balconies is also blocked by the thick dimensioned columns (Figure 20).

The indoor nature atmosphere that can be created in a greenhouse can also be used to create zoning. Strategically placed water and greenery can be used to create a distance between private and communal areas and to create zoning of the greenhouse area as can be seen in Lumen (Figure 18).

Conclusion
Private greenhouses are an integrated part of the dwelling and bring nature into the home. The greenhouse changes the way the different areas in and around the dwelling are used by allowing use of outside areas throughout the year. These areas receive an

Figure 19: The volumes in Cubity create a large inner court and smaller more private areas in between. Source: http://www.solardecathlon.tudarmstadt.de

Figure 18: Greenery and water divide the atria of Lumen in different zones. Source: http://www.myeducation.bg

Figure 20: Balconies at Crystal Court are partially shielded off by thick construction elements. Source: HoutWereld 2009 nr 3 page 16
abundance of natural light which creates an atmosphere of being outside while at the same time being shielded from wind and rain. In communal greenhouses the border between greenhouse and volumes is more clear. The area is used like a garden in which people can walk and sit for a while. Because of the covering the garden can be used throughout the year.

How can a greenhouse contribute to the indoor climate and sustainability of dwellings?

In general it can be concluded that the biggest contribution of a greenhouse to the climate concept of a building is its function as a buffer zone. The heat from air escaping from the volumes can be collected in the greenhouse. The other way around, cold air can be preheating in the greenhouse before entering the volumes.

The biggest issue when working with a greenhouse is the risk of overheating in summer. The regulation of the temperature is there for the biggest challenge. The case studies showed different ways of dealing with this temperature regulation. The main tool is however the same in every design: ventilation. This happens by opening parts of the glass façade and mainly the roof. The opening of the glass is often regulated by computers which measure the indoor temperature (and CO2 level).

An exception is the ‘Zonneterp’. In this concept hot air is cooled by extracting its heat and storing it in underground aquifers. This happens via fawahex (fine wire heatexchanger) systems. This system hardly provides fresh air, making it not suitable for a housing function. It is however an option to let warm air run past heat exchangers before leaving the building as is done in ‘Prêt à Loger’.

Besides ventilation there are many other aspects that influence the temperature of the greenhouse. Peter Wienberg talks about a difference between high-tech and low-tech greenhouses (2014). In a low-tech greenhouse the temperature will fluctuate a lot as a result of differences in the outside weather conditions. This means that during a cloudy winter day people will want to wear a sweater or coat when being in the greenhouse. In a high-tech greenhouse the temperature will experience less influence from the outside conditions. An extreme example of a high-tech greenhouse are tropical winter gardens to house butterflies in a zoo.

The extent to which the temperature fluctuates is the result of many aspects. The most important ones will now be described. These represent some important choices an architect needs to make when incorporating greenhouses in a design.

The greenhouse façade is dominated by glass, therefore the type of glass has an enormous impact on the inside temperature. Single glazing, as is used in ordinary greenhouses is not well insulating in comparison with double glazing. The insulating properties of double glazing can be enforced by special coatings or prints on the glass. Prints can be placed at strategic places like at FinanzIT where only the top part of the glass is printed.

When the façade is made out of double glazing, ordinary greenhouse frames will become thermal bridges. For this reason...
Insulating (aluminium) profiles should be used when choosing double glazing.

Shading can not only be used to prevent the sun from overheating the greenhouse, it can in a way also be used to prevent the warm air from cooling in winter nights. Adjustable shading such as used in the Christian Agricultural School can be used only when necessary. FinanzIT has integrated fixed shading on strategic locations blocking sun in summer and letting it in in winter.

When analysing the case studies a difference can be seen in the way the volumes are ventilated.

The Christian Agricultural School in Dronten has an, as the architects call it, backwards ventilation. Instead of entering the volumes directly, the fresh ventilation air enters the greenhouse at ground level near the facades of the volumes. The fresh air preheats in the greenhouse and enters the volume via grills that users can open at will (Figure 21). Another option is to warm ventilation air via heat exchangers before letting it enter the volumes.

The choice of the level of high- or low-tech solutions depends on your goals as a designer. The constant temperature of high-tech greenhouse might sound preferable at first. The costs however exceed the costs of a low-tech greenhouse. A choice has to be made up to what level temperature fluctuations are acceptable. Peter Wienberg prefers low-tech. This allows residents to experience and live with the seasons. He refers to the book Grüne Archen from Log ID which describes how living with the incentives of changing seasons has a positive effect on residents. (2014)

When designing with greenhouses, the orientation of the greenhouse plays a large role. Greenhouses oriented towards the north will mainly loose warmth instead of gaining it. Greenhouses oriented towards the south benefit from the sun's energy the most. It is however the opinion of Christian Wiegel, PhD candidate at Solarlux, that south isn't the optimal orientation. In a south oriented greenhouse the most heat is gained during midday. This is however not the moment a buildings needs it most. In a south-east orientation the building gets warmed in the morning and in a south-west orientation it gets warmed in the afternoon for a warm evening. These are according to Wiegel the most efficient orientations. (Wiegel, 2014)

When designing a greenhouse, the use of greenery seems a natural choice. But besides aesthetic qualities, greenery also provides climatological qualities. Just as water, greenery cools warm air in summer by evaporation. Mont Cenis Academy shows how trees can also be used as smart shading. In summer the leaves block the sun while in winter the absence of leaves allows the sun to warm the greenhouse.

Conclusion

In short, greenhouses contribute to the climate concept by being a buffer zone. The biggest climate related challenge is to control the temperature in the greenhouse. Depending on the set acceptable temperature fluctuation choices have to be made about the type of glass, frames, shading and ventilation. The same goes for orientation of the greenhouse, this depends on the moment of the day the particular greenhouse needs to warm up the most.

How can a greenhouse contribute to the technical detailing of dwellings?

As discussed at the climatological benefits, the choice between an ordinary greenhouse construction or a more elaborated façade depends on the chosen climate concept. Fact is however that building regulations for dwellings are more strict than for ordinary greenhouses. This results in larger dimensions for the construction and the use of safety glass. Wienberg believes this is detracting from the aesthetical thin greenhouse construction (2014). Designs for the Zonneterp and Mont Cenis however show an aesthetical solution by using wood for the main construction (Figure 23). The materialisation when building with greenhouses can be described as a durable skin with a sustainable core. The skin in this description is the greenhouse made from steel or aluminium and glass which are low
maintenance. The core inside the skin can be of any material, many designs from the case study are made of (untreated) wood like the Christian Agricultural School (Figure 22). But not only wood is a solution, Wienberg talks about how the core can be made of materials like clay as well (2014). A large advantage of the skin is that the core does no longer have to be water and windproof. This can reduce the material costs. The wooden window frames of the ‘kaswoningen’ from KWSA aren’t painted and the Christian Agricultural School doesn’t have window frames at all. The windows are just placed directly in the façade. Though the core doesn’t have to be water and wind tight, it should have enough mass to insulate the core in winter as well as in summer. It is important that both elements, skin and core, can move free from one another. When the volume pops through the skin like at Crystal Court and the KWSA ‘kaswoningen’ the connection must be able to absorb the differences in for example thermal movement.

Conclusion
The biggest benefit of the greenhouse on a technical level is its protective properties. Volumes inside the greenhouse are not exposed to wind and rain which makes for a more simple detailing and material use. The core should however have enough mass to stay cool in summer and warm in winter. When the core pops through the skin, attention should be paid to the connection as both materials should be able to move independent from each other.

The results that derived from the research contain lessons one should take into account when wanting to integrate a greenhouse in a design. These lessons will be described in the next chapter.
Conclusion & discussion

The research question posed at the beginning of this research was: How can greenhouses contribute to the design of residential buildings? In order to answer this question research was done into the architectural, climatological and technical benefits of designing with greenhouses. Case studies, literature and online research, meetings with experts and site visits have provided answers and valuable lessons that should be taken into account when designing with greenhouses.

Although the focus during the research has been on dwellings, this research derived from the goal to design elderly cohousing. For this function there are also some specific lessons that are to be taken in consideration during the design semester.

How can greenhouses contribute to the design of residential buildings?
The biggest contribution of a greenhouse in architecture is its function as a buffer zone in many ways.
On a technical level the glass shelters the building and its outside areas from wind and rain which allows for a detailing and materialisation of the building (volume) that doesn’t need to be wind or water tight. It should however have enough mass for (sound) insulation. In the case of dwellings it is however the question if it is desirable to enclose the entire volume in the protective greenhouse. Residents want to be able to open windows to let in fresh outside air. When the greenhouse is private they can open the greenhouse windows for ventilation. But what if the greenhouse is communal and part of a larger climate concept? In this case it must be considered to let parts of the dwellings pop out of the greenhouse to create a direct connection with the outside.
On a climate level the greenhouse also creates a buffer zone. Heat from the greenhouse can be used to pre heat ventilation air and at the same time the greenhouse captures heat escaping from the dwellings. The biggest issue will be overheating. The case studies however show there are many ways to prevent this varying from shading and smart ventilation to underground heat storage.
Besides a technical and climate buffer, the greenhouse also creates an interesting architectural buffer, a transition between dwelling and nature and between inside and outside. Adding an extra link in these transitions results in very interesting architectural areas in the dwelling in which living and nature can merge.

Lessons for designing greenhouse dwellings
Another conclusion of this research is that there are some important decisions to be made by architects who want to design with greenhouses.

Private or communal
Whether (part of) a greenhouse is private or communal has a large impact on the use of it. Where a communal greenhouse seems to be used as a covered outside area for circulation and short meetings, the private greenhouse becomes part of the dwelling. The private greenhouse makes it possible to use areas like a roof terrace as a full part of the dwelling since they can be used throughout the year. The private greenhouse houses living functions in a combination with greenery and an abundance of natural light create an experience of living in and with nature.

Positioning of volumes
The position of volumes relative to the greenhouse and each other can create different areas in the greenhouse. In a large communal greenhouse the positioning can
be used to create different zones with different levels of privacy. The way in which volumes are positioned next to and on top of each other can create setbacks, overhangs, secluded areas, large open areas etc. In a smaller private greenhouse the way the volume and greenhouse are positioned creates areas on and around the volume. Bigger areas can become rooms while smaller areas are more often used for storage.

Temperature fluctuations
An important choice for a designer is to which degree temperature fluctuations in the greenhouse are acceptable. Will residents have to wear sweaters and jackets when using the greenhouse on cold winter days or will the greenhouse always have a comfortable temperature? This decision will affect many aspects of the greenhouse like the type of glass, frames, climate installations, ventilation principles and costs.

Additional lessons
Besides the described choices a designer needs to make, the research provided the following lessons on designing greenhouse dwellings:
- Hot air rises, this also happens in the greenhouse. By creating roof top terraces residents can get to this warm air on colder days.
- Besides overheating, acoustics are also a potential problem when working with large glass surfaces. Greenery and strategic materialisation of the volumes can help solve this problem.
- The core (volume) and skin should be able to move separately from one another. When volumes pop out of the skin the connections should be able to absorb the differences in movement.
- Ordinary greenhouse constructions don’t meet building regulations for dwellings. Therefore the dimensions of the main construction will be bigger.
- North oriented greenhouses loose heat more than they generate. Glass facades with a south-east and south-west orientation are preferable since the morning and late afternoon are the hours on which the greenhouse needs the sun’s warmth most.
- Ventilation is not only important for fresh air and getting rid of excess heat. It is also needed to avoid high moisture levels in the air which will result in condensed windows.
- The glass cover can also be used to help block outside noise when for example building next to busy roads and railroads.

How can greenhouses contribute to a design for senior cohousing?
The question that triggered this research was: How can greenhouses contribute to a design for senior cohousing? With elderly cohousing in mind some lessons can be formulated for this specific function.
- Since the dwellings will be inhabited by elderly, extreme temperature fluctuations in private greenhouses are not preferable.
- Many greenhouses have communal gardens. At least a part of this garden can be sheltered with a greenhouse. In this communal greenhouse garden temperature fluctuations are acceptable.
- Elderly apartment will be single floored apartments. If these apartments will have private greenhouses they will also be one story high. Creating the characteristic glass roofs in every one of these greenhouses can prove to be a challenge.
- Since it is preferable that the apartments have a direct connection with the outside (and fresh air) their volumes will have to pop through the glass skin. Volumes housing communal functions can however be placed inside the greenhouse.
- Volumes will have to be placed in the greenhouse in such a way that different zones are created with different levels of privacy. This way residents can use the communal greenhouse when they want contact with other residents but also when they want some more privacy.
Reflection

During this research many insight has been created in the world of designing with greenhouses. Though many examples could be found of greenhouses being used in public and office buildings, this was not the case for dwellings. Especially not when looking for realised projects. It seems that the concept of the greenhouse dwelling has been getting more attention since there are multiple examples of concept plans for these type of dwellings (Marc Koehler architects, KasCo). It is however the question if these concepts will ever be built. According to Peter Wienberg people are still reserved when it comes to greenhouses because of the fear of overheating. Besides this, living in a greenhouse is not for everyone. Especially living with the seasons in a low-tech greenhouse with fluctuating temperatures asks for a certain attitude.

This research has made me believe even more in the greenhouse dwelling concept. The fact that adding a greenhouse improves not only the technical and climatological properties but also makes for interesting architectural zones and uses its very inspiring. With my graduation project I hope to proof the high value of integrating greenhouses in architecture. In my opinion it is a concept that could and should be used more.

Throughout this research it hasn’t been possible to quantify the climatological effects of the greenhouse. Though multiple ways of controlling the temperature were described, it is not yet clear what temperatures and fluctuations in temperature will be the consequences of the different options. This has proven to be very difficult since the temperature depends on many different factors that were too complicated for the time available for this research. In order to convince more people that greenhouses are an asset to architecture hard numbers will be of great value.

Because the design goal of my graduation is to design a new dwelling complex, the focus of this research has been on new buildings. Greenhouses can however also have a positive effect on the existing building stock.

At the start of the research the goal was to make a toolkit of different types of greenhouses and their properties. These types were defined by the size and shape of the greenhouses in relation to the volumes. This way it would be easy to pick a certain type of greenhouse suiting the demands of the design. The research however showed that although the size of a greenhouse can often be linked to it being private or communal (which has an effect on the use), there are no direct links to the climatological performances. The indoor climate is mainly regulated by the materials of the greenhouse, the way of ventilating and use of installations. Because this made it hard to create a useable toolbox I’ve decided not to. By writing down all the lessons I learned throughout this research I hope to have created an clear overview of the consequences and opportunities that rise when designing with a greenhouses. I will use the results as guidelines for my design and hope others will find it as useful as I do.
References

Not all the sources on this list are mentioned in this report. Many of them were however used in the case studies and thus contributed to the knowledge presented in this paper.

Literature


*Bauwelt, jg. 89* (no. 27 17 juli), 1564-1567.


Websites
These websites were all visited between October and December 2014
www.bdgarchitecten.nl
www.behnisch.com
www.braaksma-roos.nl
www.duurzaamgehouwd.nl
www.hascherjehe.de
www.kwsa.nl
www.mvrdv.nl
www.perraudinarchitectes.com
www.pretaloger.nl
www.rodedorpdenhaag.nl
www.solardecahon.tu-darmstadt.de
www.tangramarchitekten.nl
www.zonneterp.nl
Annex

Case studies
- Christian Agricultural School by BDG Architects
- Crystal Court by Tangram Architects
- Cubity by TU Darmstadt
- ‘Kaswoning’ from KWSA Architects
- FinanzIT by Hascher Jehle Architects
- ‘Het Rode Dorp’ by Braaksma & Roos Architects
- Lumen by Behnisch, Behnisch & partners
- Pyjama Garden by MVRDV
- Mont Cenis Academy by Jourda Perroudin
- Prêt à Loger by TU Delft
- Zonneterp by Innovatie netwerk Groene Ruimte and Agrocluster

In depth research
- New areas or areas with another use because of the greenhouse (KWSA ‘Kaswoning’)
- Areas who gain extra qualities from the greenhouse (KWSA ‘Kaswoning’)
- Privacy zoning in a communal greenhouse (Cubity)
- Privacy zoning in a communal greenhouse (Crystal Court)
The greenhouse covers the two volumes (6), connected through a bridge (1) creating a meeting area in between (2). The hardened single glass has prints at some places. Layered glass replaces the lowest single glass panels for safety reasons. Sheets underneath the roof and at the facades can be used to block the sun. Ventilation air is inserted into the wintergarden at ground level near the facades of the volumes. Underpressure in the volumes causes the ventilation air that is pre heated by the wintergarden to enter the volumes through natural ventilation. This reversed ventilation prevents condens on the glass. Green facades improve the air quality and trees outside of the greenhouse create shade. The roofs of the volumes can also be used for meeting one another. The stairs that lead to the middle square can be used for lectures.

Crystal Court luxury apartments  
Tangram Architects  
2009  
Amsterdam  
http://www.tangramarchitekten.nl/ht-docs/project.php?fase_id=1&project_id=27

Climate concept: low tech with permanent openings  

Technique: scaffolding, prefab concrete, infra+floor, western red cedar wood  

Atmosphere: Water and platforms  

Crystal Court houses 36 luxury apartments stacked to create FSI of 4 (1). To create space for a communal wintergarden (2) the density intensifies towards the upper floors. All apartments have balconies and/or logias in the wintergarden and on the outside. The wintergarden functions as a central entrance and transition zone for the residents. Water creates a distance between the groundfloor dwellings and the path. The wintergarden also provides privacy, social security and a climate buffer. To create a connection with nature, the outside water flows underneath the glass facade into the wintergarden. The glass facade has permanent openings for ventilation. There is no balanced ventilation because the freedom of opening a window was prioritized. The facades have safetyglass, the roof has insulation glass and can be opened to get rid of heat (and smoke in case of a fire).

Use & Zoning: Circulation, security, ‘outside’ areas

Cubity
TU Darmstadt
2014


Cubity is concept of compact student housing. The minimal private spaces (4) allow for a large variety of communal areas like the kitchen (2) and living area (8) on the groundfloor. The way the living cells are placed create the different areas for these functions. On the upper floor the walkways come together in a larger balcony like living area (7). The whole is covered (1), this way a village inside a building is created.


Climate concept

Use & zoning
The curved glass roof covers most of the terraced office wings (1, 2) creating lush terraced gardens in which employees can meet and relax (6). The roof is printed in such a way that most of the direct sun is blocked in summer but enters the building in winters. The garden never needs to be heated by other ways than the sun. Offices border direct to the garden (3) creating the experience of working in nature.
The ‘kaswoningen’ in Culemborg are covered with a greenhouse (1). This greenhouse is similar to ordinary greenhouses except for a heavier main construction. The greenhouse makes it possible to use the garden terrace (3,4) and roof terrace (2) throughout the year.

The climate system is low tech. Residents can choose 3 ventilation modes. A computer opens and closes the glass facade elements. Residents experience and live with the seasons. In the winter the glass and the dwelling windows remain closed. The greenhouse becomes a thermal buffer. The higher balcony is comfortably warm to use in winters. In autumn and spring the greenhouse stays closed, the windows of the dwelling can be opened to let the pre heated air inside. In summer the greenhouse can be opened but the dwelling remains closed as to not loose the cool air. At night the windows can be opened to cool to the night air.

Wienberg, P. (2014, 21-10). [Visit and interview with Peter Wienberg]
Het Rode Dorp (the red village) consists of 19th century worker homes which are renovated into student housing. By placing a greenhouse roof over the former back gardens (1), a workshop is created for students who live here and study at the art academy. The workshop is directly accessible from the dwellings who seem to claim parts of it by placing benches and chairs in front of their doors (5). The workshop is also accessible from outside by doors in the short sides. Sheets under the roof can be used to block the sun (4).

Lumen houses a research institute of the Wageningen University. The large atriums (5) function as climate buffers. Except for specific areas like kitchen and library, the building is ventilated naturally. The atriums are useable throughout the year. In summer the planted and water areas provide shade and cooling (5). Opaque heat exchangers can be used as blinds. Heat can leave the atriums through openings in the single glazed roof and vertical louvres and openable doors in the glass façade. There is no need for mechanical cooling. The temperature in the atriums will reach a maximum of 28 degrees. The buildings cools at night. In winters the blinds can be used to prevent warm air from leaving the atrium. Ventilation air is led though the underground spaces before entering the building. Heating is only nescessary in the main functional areas. The temperature won’t be under 0 degrees and will never be below 5 degrees for more than 100 hours. Bridges connect the different “fingers” on the higher levels (5) overviewing the indoor gardens in which employees can meet.

In contrast to the typical hospital hallways, the Pyjamagarden is a natural lighted area with open squares and trees covered with a greenhouse (1). Functions that need privacy are located in little pavilions (5) whose roofs are also used (3). The positioning of the pavilions create a route(2) connecting open squares (5). In summer the doors of the greenhouse can be opened, patients can then literally go outside. The glass is covered with a craquelé of two kinds of paint which are dried in different ways on different locations. This is done to lower the amount of sun entering the greenhouse.

Mont Cenis Academy
Jourda Perraudin
1999
Herny, Germany
http://www.perraudinarchitectes.com/projets/herne_allemande/herne_allemande.htm

The Mont Cenis Academy is a wood and metal constructed greenhouse with multiple volumes ordered in two lines, creating a communal area in the middle of them. This area is divided by water and plants. The greenhouse creates a mediterranean buffer zone. The volumes can be built independent from the greenhouse construction. In summer cool air is ventilated into the greenhouse from shaded facades and through an underground airduct. In winter the air in the greenhouse is heated by the sun and heatloss from the volumes inside the greenhouse.

http://www.perraudinarchitectes.com/projets/herne_allemande/herne_allemande.htm
Prêt à Loger is the entree of the TU Delft in the Solar Decathlon. The concept is to wrap existing row houses (1, 2, 3) in order to become energy neutral. The wrap creates a special extra room: the wintergarden. The wintergarden adapts to the seasons which results in a different way of use. In winter it functions as a buffer zone in which plants can grow and heat can be harvested, it can be used but you will need a coat (5). In autumn and spring it becomes part of the dwelling, warming up the house. In summer it becomes a shaded part of the garden (6). The wintergarden is also used to collect rain water and house pv cells and solar collectors. Collected heat can be stored in PCM underneath the dwelling. Ventilation occurs via the chimney.

www.pretaloger.nl
The zonneterp is a concept and feasibility study to combine greenhouses with dwellings in order to close loops and become self sufficient. 

(a) Heat cannot escape from the greenhouse because there are no openings. Instead it is used to warm the surrounding buildings and underground storage. The aquifer doesn’t need a heat pump. The dwellings are designed for low temperature heating (25 degrees).

(b) Black waste water and greenhouse waste can be used to create biogas which can be used in turbines to create electricity and heat. CO2 can be used for the greenhouse.

(c) Grey water can be used to water the plants. It will be fertilized with the residual form the biogas production. The water evaporates and condensates against the glass. This water can be collected and purified in order to be used as drinking water.

The concept has not been realized yet.

The greenhouse is connected to dwellings with other glasshouses. One of them functions as an indoor street (5) between the greenhouse and the gardens of the dwellings which are also situated in a greenhouse with an open connection to the circulation greenhouse (3).

New areas or areas with an other use because of the greenhouse: ‘Kaswoningen’

Roof terrace
Qualities:
- Free view to the sky and surroundings
- Warm in winter due to rising heat
- Free from rain and wind
- Useable throughout the year
- Visible greenhouse structure
- View onto lower green living areas

Use:
- Gym
- Kids play area
- Study

Ground floor terrace
Qualities:
- High area connected to other terraces
- Indoor nature
- Close connection with garden
- Close connection with living room
- Free from wind and rain
- Visible greenhouse construction
- Warmed by the sun

Use:
- Dining room
- Kids playground

Attic
Qualities:
- Large flat area
- Free from wind and rain

Use:
- Storage for wooden plates etc.

Hallway
Qualities:
- Bufferzone between front door and living room
- Free from wind and rain

Use:
- Entrance to dwelling
- Covered bike storage
- Storage

First floor
Second floor
Section AA'
Section BB’
Areas who gain extra qualities from the greenhouse: ‘Kaswoningen’

Living Room
Qualities:
- Possibility to open large parts of the facades towards the wintergarden
- Close connection with nature in wintergarden

Use:
Living room

Use:
- Bedroom
- Study
Privacy zoning in a communal greenhouse: Cubity

Central living area
Qualities:
- height
- lots of natural light
- curtains can be used for more privacy (and better indoor climate)

Sitting area
Qualities:
- privacy because of height
- view on construction
- connection with central living area
- sheltered by bedroom volumes
- more intimate because of limited height

Hallways
Qualities:
- more privacy
- wide enough to create small sitting areas

Kitchen
Qualities:
- lots of natural light
- connection with outside terrace
- connection with central living area
- sheltered by bedroom volumes
- intimate because of limited hight

Crystal Court

Crystal Court houses several luxury apartment connected by a communal greenhouse. Privacy is created in several ways. First of all, the glass creates a barrier between the inner court and the outside world. With the court water creates a distance between the walkways and the apartments. The private outside areas (both on the outside and on the court side) gain privacy from being set back. The thick dimensioned construction creates more privacy by blocking more view. The way the volumes are stacked contribute to the visual quality of the court but also create overhangs which give privacy to some of the ground floor terraces.