THE AFFORDABILITY AND FLEXIBILITY OF CLIMATE SYSTEMS FOR MODULAR ENERGY NEUTRAL BUILDINGS IN THE NETHERLANDS

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ABSTRACT

This paper addresses the possibilities of making currently used climate systems within the Netherlands more affordable and effective for modular, energy neutral buildings. Climate systems are often not integrated within the architecture, which reduces their effectivity. This paper proposes a new method and catalog that will help architects design an effective and integrated climate system. Two active and two passive climate systems case studies and two innovative elements have been analyzed, based on purpose, effectiveness, affordability and flexibility. The conclusion is that the most affordable, effective and flexible climate system can be achieved for energy neutral modular buildings by first optimizing the insulation of a habitation with the use of passive elements and afterward by adding the necessary most effective active elements.

KEYWORDS: *Climate systems, Modularity, Energy neutral, Affordability, Flexibility*

I. INTRODUCTION

In a country like the Netherlands, where one million new homes before 2035 are needed (ABF Research, 2018), it is important to consider the influence of these new habitations on the local environment. In previous decades, new habitations ran on gas, and were built without considering the effects a poorly insulated house would have on the environment. Today, as we can observe these effects, we realize the need to change the way we build new dwellings and the systems they run on. One of the possible ways of intervention is by changing new homes climate systems and developing energy neutral buildings. To be energy neutral, a building tries to keep its energy requirements as low as possible while, at the same time, provides for the additional energy in a sustainable way, for example through wind or solar energy (Milieu Centraal, n.d.). The climate systems of these buildings can work in a passive or active way, which not only reduces the emissions, but also improves the indoor comfort of a building. When an active system is applied to your house it adapts the indoor climate to your needs, while, with the application of a passive system, you have to adapt to the indoor climate created by the house. The use of these energy neutral systems influences the price of these houses, which are put on the market at a price that is not affordable (Appendix A) for the lower, middle class, who are most struggling to finding a house nowadays (Springco Urban Analytics, 2021). Therefore, the need to make these energy neutral habitations more affordable for these classes arises. Over the years we have seen that pre-fabricated elements and modular houses (Appendix A) did affect the housing market and made owner-occupied houses more affordable for the lower classes (Klusvakman.nl, 2021). This research tries to find a way to combine the use of modular architecture and energy neutral climate systems, to make an habitation as affordable as possible, leading to the thematic research question: *How can the design of climate systems for modular strategies decrease the purchase price of new energy neutral buildings in the Netherlands?* The following questions will help answer the research question: *What kind of climate systems are used in the Netherlands? What elements can compose a climate system for modular architecture? How can we make currently used climate systems more affordable?* In chapter 2 the methodology of this research is defined, chapter 3 introduces the results and chapter 4 answers the research question.

II. METHOD

This study is based on findings from different case studies, researched between November 2021 and January 2022. The goal of this research is not to find new ways to climatize buildings, but to map different climate systems that are currently used within the built environment and to analyze in which way we can create an energy neutral climate system that is as affordable as possible in order to improve its purchase attractiveness. The results of this research will be categorized into a catalog (Appendix E) that can be used as a reference in the design of effective climate system for new energy neutral buildings. The method is mostly based on case studies of currently used systems to dive deeper into the practical and effective use of climate systems more than their theoretical use. The following methodology was adopted: (1) Research the Dutch climate; (2) Analyze two active and two passive climate system case studies; (3) Analyze new innovative climate system elements; (4) Categorize climate system elements based on flexibility (Appendix A) to be fitted into modular architecture; and (5) Research ways to make climate systems elements more affordable.

After listing the elements of this research, it is necessary to identify its limitations. As this research mainly focusses on four case studies and the difference between active and passive climate systems, not every existing climate system element is included in this research. This was deliberately done in order to focus on specific, real life issues and depart from an academic literature study. Furthermore, this research does not focus on the technical parts within an element, but on the interaction between the elements and how they work as a system. This means that this study does not focus on the fundamentals behind a technique, but on the application of the technique. Lastly, it is important to state that no diagram was published online about the case studies. The climate system diagrams were achieved through written information, calculations and interviews with some of the architects and by further reflections upon this information.

2.1. Research the Dutch Climate

As climate does not change a lot within the Netherlands, it was decided to focus this study on a location in the center of the country, Den Bilt, which is also used as the reference point of the weather in the Netherlands. In this way it is possible to have an average climate situation in the country.

The information about the average Dutch Climate is retrieved from an online repository of climate data (Climate.onebuilding.org, n.d.) and is processed through the program *Climate Consultant*. By looking at some specific output, it becomes visible which elements are important to consider for the design of a climate system in the Netherlands. What kind of outputs are important, are based on the *Trias Energetica*, which has been used in the Netherlands since the nineties to design climate systems (Yanovshtchinsky, Huijbers and van den Dobbelsteen, 2013, pp.45). This method involves a four-step procedure: (1) Reducing the energy demand; (2) Reuse of residual flows; (3) Solve the remaining energy demand in a sustainable way; and (4) Using energy waste as nutrition. The outputs from *Climate Consultant* that are relevant to solve these steps are the temperature range (heating/cooling), sky cover range (heating/cooling/energy), wind wheel (energy/ventilation), sun chart (heating/cooling) and the psychrometric chart of interventions that influence the indoor comfort (heating/cooling/ventilation/indoor comfort). These outputs helped decide which element typologies are needed in a climate system for buildings in the Netherlands.

2.2. Analyze Two Active and Two Passive Climate System Case Studies

To analyze currently used climate systems in the Netherlands, four case studies have been selected. These case studies needed to be built in the last 5 years, had to be possibly energy neutral and in the Netherlands. As there are active and passive techniques within climate systems, two active and two passive case studies have been used: M'DAM (NL) and Park Avenue (NL) being the active case studies and Veldhuis (NL) and Agar Grove (England) being the passive case studies. M'DAM is an apartment complex in Monnickendam (NL). The building, built in 2021, is an energy neutral and modular building with 62 social rent, social owner-occupied and private owner-occupied units (Finch Buildings, n.d.). Park Avenue is an apartment complex in Utrecht (NL). This building is also energy neutral, with 55 private owner-occupied units and was built in 2020 (VORM, n.d.). Veldhuis is a residential care center in Apeldoorn (NL). Even though this building was not part of the new energy neutral regulation in the Netherlands, which states that every building built from 2021 needs to be nearly energy neutral (Rijksdienst voor Ondernemend Nederland, 2021), the building is energy neutral, thanks to the *Passivhaus* principle (Appendix A), a set of criteria for building in a passive way (Etude and Levitt Bernstein People Design, n.d.) (Troelstra, 2021). Lastly, as it was difficult to find another passive apartment complex built in the Netherlands in the last 5 years, the fourth case study is a neighbourhood in London (England), Agar Grove. It has different apartment complex with 493 social rent and private owner-occupied units (Max Fordham, n.d.). The neighbourhood is not energy neutral, but has won the UK Passivhaus award 2021 (Passivhaus Trust, n.d.).

The documentation of the four case studies, including the calculation sheets for the energy performance coefficient (EPC) for M'DAM and Park Avenue, interviews with the architects of Park Avenue and Agar Grove, and further reflection upon the received information, were the elements that helped set up the climate principle schemes of the four case studies. Afterward, to understand the effectiveness and the affordability of these elements, all the elements have been analyzed individually, based on purchase and usage price (Appendix A), purpose and effectiveness, based on the following criteria. The purchase and usage price of an element was determined with a research on the prices of stores that sell these elements and information about the elements. The purpose of an element will also be determined through a research about that element. However, the effectiveness of an element is not as straightforward as a price or purpose. The effectiveness can be judged in different ways. For this research the effectiveness of an element stands for the influence that an element has on the indoor climate. The more the indoor climate is affected by the element, the more effectiveness an element has. For every typology there are different considerations that need to be made: (1) Heating/Cooling: Does the element heat/cool in an active or passive way? (Yanovshtchinsky, Huijbers and van den Dobbelsteen, 2013, pp.60–65); (2) (Warm)Water: What is the capacity to heat water? (ZBG, 2016); (3) Ventilation: Is the unit ventilation type A,B,C or D? (Ventilatieland, n.d.); (4) Electricity: What is the capacity to generate energy? (Yanovshtchinsky, Huijbers and van den Dobbelsteen, 2013, pp. 232–234); and (5) Indoor Comfort: What is the difference between the indoor climate with and without the element? (Yanovshtchinsky, Huijbers and van den Dobbelsteen, 2013, pp. 72–79)

The results of this analysis were added to the catalog.

2.3. Analyze New Innovative Climate System Elements

Next to the currently used climate systems, this research looks into new innovative climate system elements which are not yet applied in large numbers. However, as some of these elements are not yet on the market, there is no information available yet about the price of these elements. Because of this, the elements are not considered within the catalog and conclusion as current possible solutions for an energy neutral climate system, but by estimating a price direction and researching the purpose and the effectiveness like the previous case studies, these elements were considered in the catalog and conclusion as possible future solutions for new climate systems.

2.4. Categorize Climate System Elements Based on Flexibility

To assess which elements would function best within a modular strategy it is important to see how flexible these climate systems are. Flexibility can be assigned to the climate systems in different ways, namely based on the system as a whole or based on the specific elements. While analyzing the four case studies, different used criteria emerged that seem to influence the flexibility of a system or element. Within a climate system as a whole there were two questions that came up: (1) Is it more flexible to have 1 climate system for each habitation or to have all the habitations connected to 1 climate system? (2) Is it more flexible to have all the different typologies of climate elements connected to each other in 1 climate system or to separate the typologies and have more little systems for each typology? Which criteria is more flexible, can be suggested by looking at the way they were applied within the case studies (Appendix C). When looking at climate system elements by themselves, there were three additional questions that came up: (1) Is it more flexible to have 1 element for each habitations or to connect different habitations to 1 element? (2) What elements take as less room as possible? (3) How can the position of the elements influence the length of the pipes? The flexibility of these criteria, can also be suggested by looking at the way they were applied within the case studies. The results of the flexibility of each element were added to the catalog.

2.5. Research Ways to Make Climate Systems Elements More Affordable

This research focusses on ways in which these elements are applied to make them more affordable. In this research the affordability of an element is based on an average between the purchase price and the usage price. A lower usage price can compensate a higher purchase price and vice versa. The two price elements compensate each other, but the goal is to achieve the lowest price as possible. Further improvements may be achieved through the ad-hoc application of the selected elements. There are a few solutions that can be looked at for each element: (1) Can the element be divided between more than 1 habitation to split the costs? (2) Can the elements be rented by an organization to the inhabitants of the units so they do not have to buy it? (3) How far can we go with passive solutions, to reduce the use of active machines to the maximum of their capacities?

III. RESULTS

3.1. The Average Dutch Climate

The output of the climate analysis of Den Bilt in *Climate Consultant* shows different graphics about the average climate situation in the Netherlands based on the *Trias Energetica*. The different graphics are shown in Appendix B.
The *temperature range* in Den Bilt shows an annual range between -8 ˚C in the winter and 28 ˚C in the summer. This large yearly temperature fluctuation requires different climate approaches. As shown in the graphic (Appendix B1), the comfort zone is between 20 and 24 ˚C, which is much higher than the average temperature during most of the year. As the *sky cover range* influences the amount of sunlight that shines through that day, this theme influences the heating/cooling of a building and also its energy. As is visible in the graphic (Appendix B2), the sky coverage is quite volatile. For example, the range of sky coverage in July goes from 9 to 99%. This instability shows how the sun in the Netherlands is unreliable for heating, however, as solar panels work more efficiently when the sky is clouded, since white clouds reflect extra sun light (Schenk, 2020), the Netherlands is an efficient country to generate energy through solar panels. The *sun chart* (Appendix B3,B4) shows that, for most of the year the sun does not provide a comfortable temperature, and that heating is needed for almost the whole year, while cooling is only requested in some limited situations. The *wind wheel* (Appendix B5) shows the strength and direction of the wind. In the Netherlands, the wind does mostly come from south west with speed peeks of 12 m/s. The wind speed and strength influence the ventilation within a building when natural ventilation is used as a ventilation system. Furthermore, wind can be used to generate energy. Even though wind energy is not used as much as solar energy in the Netherlands, this aspect can be considered for future climate systems. Lastly, with the input data, Climate Consultant creates a *psychrometric chart*, which shows intervention that influence the indoor comfort (Appendix B6,B7). These interventions together create a comfortable indoor comfort at every temperature and humidity rate. Appendix B7 shows that removing heating lowers the amount of comfortable situations by 52%. Other interventions do not influence the indoor comfort as much as the elimination of heating. The information about the Dutch climate does mostly highlight the necessity of a heating system to create a comfortable indoor climate.

3.2. The Case Studies

The four case studies help create an image of the currently used climate systems. The climate systems and the passive elements of every case study have been reported in a diagram. Appendix C has all the information and diagrams of the climate systems and its elements.

3.2.1. M'DAM (Active System)

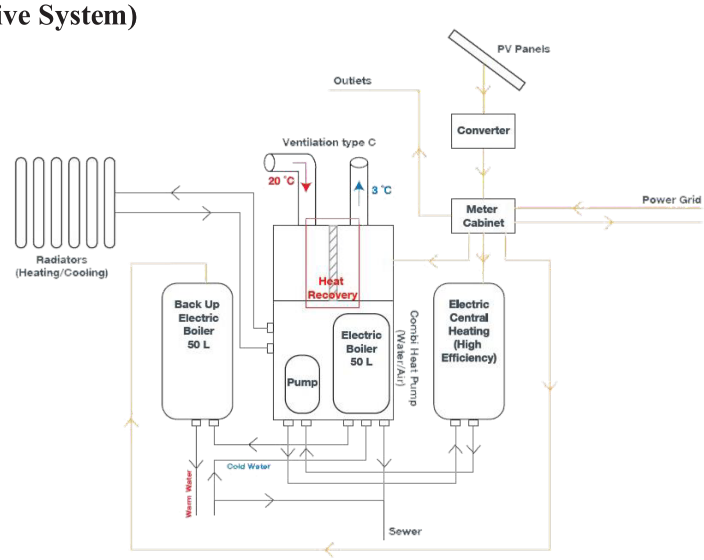

Figure 1. Climate Principle Diagram M'DAM (Appendix C1)

M'DAM is a modular apartment building. Figure 1 shows the climate principle diagram for the building. Unique to this climate system is the use of a combination of heat pump and ventilation system. The use of both systems in one element does eliminate the need for a second machine. The system is all-electric, with an extra boiler in case the heat pump does not manage to boil enough hot water. The RC values of the building are: RC roof 6,00 m^2K/W, RC facade 5,00 m^2K/W and RC floor 6,00 m^2K/W. The whole building has HR++ glass and an airtightness of 0,25 dm^3/sm^2.

Every unit in this building has its own climate system. Heating and cooling is achieved through the combi air heat pump and ventilation unit. This element recovers heat from return air through the pump. The heat is used to warm up the place through the radiators and to heat the water in the boiler. The energy is generated through PV panels which powers the pump and the boilers.

3.2.2. Park Avenue (Active System)

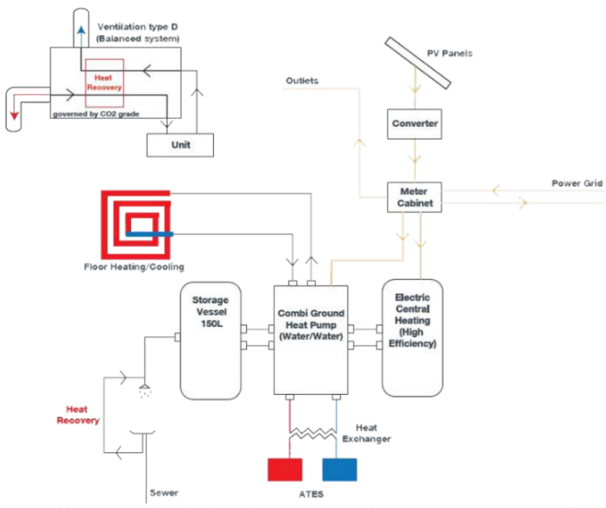

Figure 2. Climate Principle Diagram Park Avenue (Appendix C2)

Park Avenue is an apartment complex. Figure 2 shows the climate principle diagram of this building. Differently from the other case study, the ventilation unit and the heat pump are separated and not connected with each other. The system is all-electric with an extra electronic central heating unit, in case the heat pump does not produce enough heat. Unique to this system, is the fact that the climate system is rented out and not owned by the inhabitants of the building. Maintenance is done by the company that rents the systems. The RC-values of the building are: RC roof 6,00 m^2K/W, RC facade 4,50 m^2K/W, RC floor outside 6,00 m^2K/W, and RC ground floor 4,50 m^2K/W. The building has HR++ glass and an airtightness of 0,25 dm^3/sm^2.

Like M'DAM, every unit has its own climate system. Every habitation has a water heat pump with ATES and a ventilation unit. The heating and cooling is done through the heat pump and the floor heating. Heat recovery is done through the showers. The ventilation system works by itself, with its own heat recovery from return air. The energy is generated through PV panels which power the pump and the central heating.

3.2.3. Veldhuis (Passive System)

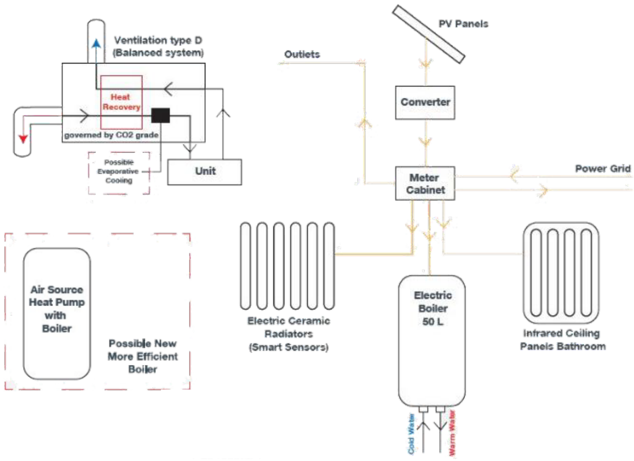

Figure 3. Climate Principle Diagram Veldhuis (Appendix C3)

Veldhuis differs from the other case studies. The building is an apartment complex, but for residential care. The building is one of the few passive complexes in the Netherlands. Figure 3 shows the Climate Principle Diagram of the building. Because the building is extremely well insulated, thanks to the *Passivhaus* method, it does not need a lot of heating. As a consequence, the climate system only has an electrical boiler for warm water and electric radiators and panels to heat the apartments up if needed. A passive, natural ventilation is not as effective as a mechanical ventilation system, therefore an active ventilation unit is added. The system only ventilates and does not cool the building. Everything is powered by the PV panels. For the future, the addition of an air source heat pump is being considered to make the building even more effective. Every apartment has its own boiler, but it is not known if every apartment has its own ventilation unit. The RC-values of the building are: RC roof 7,00 m^2K/W, RC facade 8,50 m^2K/W and RC floor 5,00 m^2K/W. The building has triple glazed HR+++ glass and an airtightness of 0,15 dm^3/sm^2.

3.2.4. Agar Grove (Passive System)

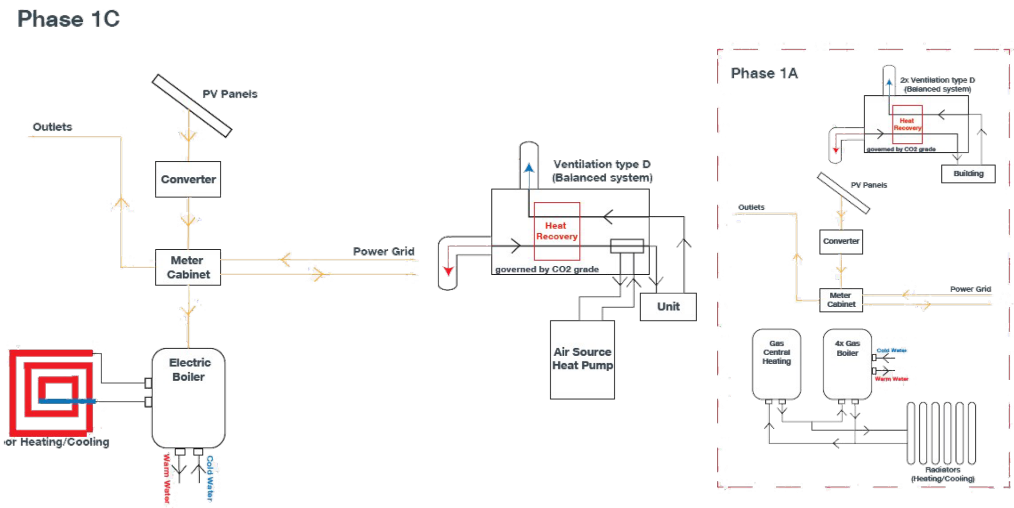

Figure 4. Climate Principle Diagram Agar Grove (Appendix C4)

Agar Grove differs from the other case studies as it is the only one outside of the Netherlands, in England. As England has a few different regulations than the Netherlands, there are some differences within the climate system, which are not extremely significant as they are mostly within phase 1a. Agar Grove is a neighbourhood with different apartment complexes. As the neighbourhood has been built in different phases, there are different climate systems for each phase. This research focusses on phase 1c, which is free from the use of gas, unlike phase 1a. The climate system is different than the others (Figure 4). For instance the air heat pump is connected to the ventilation system but not to the floor heating. The ventilation unit and air heat pump are used to heat and cool the air within the building. Because the building is very well insulated thanks to the *Passivhaus* strategy, the building does not need a lot of heating. The needed floor heating is controlled by an electric boiler, which is fed through the PV panels, but mostly the power grid, as this neighbourhood does not have enough PV panels to be energy neutral. In this system, every unit has its own ventilation unit, heat pump and electric boiler. In the previous phase, there were only 2 bigger ventilation units for the whole building. The RC-values of the building are: RC roof ~9,14 m^2K/W, RC green roof ~8,86 m^2K/W, RC façade ~7,14 m^2K/W and RC floor ~5,71 m^2K/W. The building has triple glazed HR+++ glass and an airtightness lower than 0,6 dm^3/sm^2.

3.2.5. Purchase and Usage Prices

All elements of the climate systems listed in the previous paragraphs are described in Appendix C. The schemes show the purchase price and how the usage price changes when these elements are used. From these schemes it appears that the heat pumps and the ventilation units are the major expenses within the systems, but every case study tackles these elements in different ways. M'DAM uses some innovative elements. For example, the heat pump and ventilation unit are combined in a single system. Combining the elements, reduces the need for another machine, so even though the price seems elevated (~€ 4.000), it actually is not that expensive. Furthermore, this element has a high energy label (A+++), does not use gas and uses the energy generated through the PV panels, which ensures a low usage price. The other heating elements are also relatively efficient, but the used electric boiler is not, which means it can lead to a higher usage price. The PV panels, the HR++ glass and the insulation do not have any usage price, but they drastically lower the usage prices of the other elements. This applies to all 4 case studies. Park Avenue uses many different elements. To heat the building, a ground heat pump is used, which uses an ATES as its source. A pump like this costs ~€ 6.000, excluding the costs that are needed to install the ATES. However, as this pump is very sustainable, it does ensure a low usage price. The backup elements have a reasonable price and are efficient which reduces the usage price further. Park Avenue has a separated ventilation unit type D. The unit costs ~€ 2.500, but has a low usage price. Thanks to the *Passivhaus* strategy, Veldhuis is extremely well insulated so it hardly needs heating. The radiators and infrared panels are not major expenses, and they are fully powered through the PV panels, which lowers the usage price. The major expense is the ventilation unit, which costs ~€ 2.500, with a low usage price. Agar Grove is also very well insulated, but employs extra machines within the climate system. The system combines an air heat pump and a ventilation unit which together can cost up to ~€ 5.500. The elements are very sustainable (Energy Label A+++ and A+), but as the buildings do not have enough PV panels to supply all the machines, the usage price rises a lot due to the need for electricity unlike the other case studies.

3.2.6. Effectiveness

The effectiveness is based on the influence of an element on the indoor comfort of a building. The schemes within Appendix C show a specific trend. Without looking at the energy labels, which indicate the technical efficiency of an element, elements that are part of the active system affect the indoor climate more directly. This explains why most of the times within a passive system, a mechanical system is still used to ventilate the buildings. The effectiveness of an active system beats the passive concept. However, passive solutions that are used to insulate a building are extremely effective in another way. The use of these elements (mineral wool insulation, HR+++ glass, etc.) decreases the need for active elements so much, that in some occasions they become unnecessary. Active and passive elements are effective in different ways.

3.3. New Innovative Climate System Elements

Innovative climate system elements show the trends for future climate systems. Over the last years, new solutions have been suggested for climate systems and four of these systems are illustrated in Appendix D.
The Smartty Air Clean is a passive ventilation system which purifies the air within a room and creates natural humidity. Thanks to an element of 1,5 m^2, the air is filtered through water and plants. A system like this is not as effective as active ventilation would be, but on a smaller scale, it gets the job done. The price of this system has not been announced yet, but as a passive system, probably it will not be a major expense.
The Modul-AIR Blue is a new heat pump with ventilation system (type C or D) and boiler combination. It is the first all-electric system that actively cools, heats, warms up water and ventilates a habitation. The element does not need an outdoor unit. As an active system, this element is extremely effective. However, as this system is completely active and groundbreaking, this element will probably be very expensive.
The Multi Air Supply System is an active ventilation system without supply routes. The unit blows air into the main hall, which will afterward spread in the habitation through the door slits. The system then aspirates and recovers the heat from the return air. As this system is completely active, it affects the indoor climate directly. This system does not need materials for the supply routes, it is flexible and small, making it look like it will be an affordable element.
Karbonic heating foil is an easy applicable, flexible foil which can be used as floor heating. The foil is thin and converts 100% electricity into heat, which makes it look like an extremely effective system. Furthermore, the system has been advertised as an inexpensive solution.

3.4. Flexibility

When the climate systems of the case studies are looked at in their entirety, different approaches become visible. In every case study, every unit has its own climate system. The fact that every habitation has its own heat pump and ventilation system makes this solution a flexible one. There are no long pipes that need to be pulled through a building, which makes every habitation a self-standing element that can be placed somewhere independently. Another visible approach is the differentiation between connecting every typology together in a singular circuit and separating the climate system in smaller circuits. M'DAM's climate system has one circuit which focalizes around the heat pump and Agar Grove's climate system is divided in two circuits, one focalized around the electric boiler and the other around the ventilation unit. A single circuit system has more elements than those of a two circuit system. This makes it more difficult to find room for one bigger system than a few smaller systems, which makes the few smaller systems more flexible.
Also on an element specific level, there are different approaches within the case studies. As previously mentioned, in these case studies, every unit has its own climate system. This means there is only one habitation connected to, for example, one ventilation unit. However, in phase 1a of Agar Grove there was more than one habitation connected to each ventilation unit. From a flexibility point of view, it is better to have only one habitation connected to each element in order to reduce the length of the pipes. However, this may not be the case if we consider its affordability. Maybe by connecting two houses to each unit, the two houses together become a self-standing element to keep the flexibility, but by sharing the ventilation unit, the climate systems becomes more affordable. Another element that affects the flexibility is the room that an element takes within a building. By looking at the different elements, it becomes visible that the passive elements are the ones that take less space and the active machines those that take the most. To create a flexible climate system, it is best to use as many passive solutions as possible before using the active machines. When the system shifts to active solutions, it is best to start with smaller active machines and machines without long piping. The last element that influences the flexibility of a climate system is the way the pipes are approached, mainly in an apartment complex. As previously mentioned, long piping lowers the flexibility rate of a system. Short distances between the machines and the habitation are preferable, but it is also important to consider the shafts for the piping on a vertical level. Even when the machines are all nearby the habitation, there is always piping

connected to the machines that needs to go down. This means that, when designing a flexible climate system on different levels, the position of the machines becomes crucial. To have shorter piping, and a more flexible system, the machines need to be on the same place on every level.

3.5. Affordability

One of the goals of this research is to find ways to make the application of climate systems more affordable. The case studies show that the most expensive elements within a climate systems are mainly the heat pump and the ventilation unit. There are a few interventions that can be done to make them more affordable. Elements can be split between different habitations. Some elements, like a heat pump, are difficult to share, as the heat pump would need a much higher capacity than normal to be split between habitations, but a ventilation unit or PV panels can be split between inhabitants. By splitting the machines, the costs would be shared as well, which would make the system more affordable. Furthermore, like in Park Avenue, some climate system machines can be rented by a company to the inhabitants of the building. Through a monthly subscription, different climate systems are installed in your house and are maintained by the company. On the long term, this will probably not be the most affordable solution; however, if buyers cannot afford to spend thousands of euros in one solution, this could be a way to temporary make climate systems more affordable. Lastly, climate systems can be made as affordable as possible by eliminating as many machines as possible. As machines are the largest expense, by focusing first on the passive solutions and by adding active machines only when the insulation is optimized, the amount of machines can be reduced, that will contribute to a more affordable climate system.

IV. Conclusion

This paper addressed the current situation around climate systems in the Netherlands. By separating the climate systems in single elements and analyzing the elements individually, this research aimed to create a better view on how to use different elements within a system and how to design an affordable, energy neutral and flexible climate system for a modular building. To achieve these results, the climate systems of four case studies and four innovative techniques have been analyzed based on purpose, affordability, effectiveness and flexibility.

The research on the Dutch climate situation shows the different climatological elements that influence the indoor climate of a building. From these elements it can be concluded that outside temperature and sun light affect the indoor climate most. These elements influence the heating and cooling (including warm water), ventilation, electricity and indoor comfort of a building. The results show that, in the Netherlands, heating results to be the most important one.

Subsequently, this paper focused on the climate systems of the four case studies, based on the previously mentioned interventions. Every case study approached similar elements in different ways by either focusing more on the insulation (passive systems) or on the machines (active systems). Since every case study is functional and effective, the question arose on which properties of these climate systems would work better for an affordable, energy neutral and flexible climate system. Appendix E contains a catalog with every element of the case studies' climate systems categorized on purpose, effectiveness, average price and flexibility. Generally, from these case studies, it can be concluded that when a system is designed on a passive system, a climate system will need less elements. This makes passive systems more flexible and affordable than an active system. Flexibility can be achieved by giving every habitation its own climate system, by making smaller circuits within a climate system, by making a climate system as compact as possible and by always placing the machines on the same place to reduce the piping. Active systems can absolutely be integrated into a flexible climate system as long as they fall within the previous rules. In comparison with passive elements, active elements affect the indoor climate more directly, which can hint that active elements are more effective. However, some passive elements, like application of additional insulation, lower the need for active elements so much that they indirectly have a great influence on their effectiveness. The affordability of the elements can be addressed in different ways. When looking at the purchase and usage price, it can be concluded that the usage price will be much lower if the elements are efficient, as long as there are enough PV panels to

generate enough energy for the system. However, as electrical heating needs a great deal of electricity, these elements become extremely expensive. There are ways to lower the purchase price of the systems. On one hand, the more effective way is focusing on passive solutions first, and adding active machines only when the insulation is optimized. This way the amount of machines will be reduced, which will make for a more affordable climate system. On the other hand, if one would not be able to pay the full climate system, it would still be possible to rent the elements from a company or splitting the few machines that can be shared, like a ventilation system. However, especially the first one would only be a temporary solution, since someone would end up paying more in the long run.
This conclusion also includes the innovative climate systems. However, it is interesting to note, that each developer of these systems tried to make an efficient system which is as small and flexible as possible. This is in line with the climate systems future trends, where systems will need to be as small, flexible and affordable as possible.
The research question asked how changes within climate systems for modular strategies can decrease the purchase price of new energy neutral buildings in the Netherlands. In general, by first optimizing the building by using passive solutions, like insulation, orientation, wall to window ratio, compactness, etc., and afterward by adding the necessary effective active elements, a most affordable, effective and flexible climate system can be achieved for energy neutral modular buildings. The catalog (Appendix E) helps deciding which elements to use for a new climate system. An example of a climate system for a modular building was designed for this paper to show the possibilities with currently used and innovative elements (Appendix F) by using the catalog.

At a first glance, a passive solution seems to be the most effective one, but the results of this research demonstrate that what matters is the integration of the climate system elements within the architecture of a building, e.g. the position of the elements and the piping. Nowadays, the climate systems are not well integrated within the architecture of a building. Climate systems are added at the end of a design process, which results into non-effective building performances which lead to non-affordable buildings where the implementation of climate systems only becomes a burden. By using this new method, to develop a climate design together with an architectural design at the beginning of a process and integrate them together, an architect can achieve an integrated and effective design. As these results are based on the Dutch climate, this method and catalog can be used by all the architects in the Netherlands and countries with similar climates.

The adopted method for this research was based on the use of case studies. This was done to focus on the application of climate systems. As literature mainly focusses on the technical aspects of a climate system and its elements, this would not have been appropriate for this kind of study. Case studies helped to gain understanding of this application, which makes it an appropriate method for this kind of research. This methodology has some limitations: (1) By focusing on only four case studies, other techniques and climate system elements could have been excluded from this research; (2) By focusing on the entire climate system, it was not possible to dive into the fundamentals behind a technique within this research; and (3) Information about some case studies was difficult to retrieve, which meant that some elements needed to be reasoned through background knowledge. Further research could look more into literature, and elaborate more on the techniques or look more into innovative techniques and develop new climate system elements in collaboration with a climate system company.

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APPENDIXES

APPENDIX A

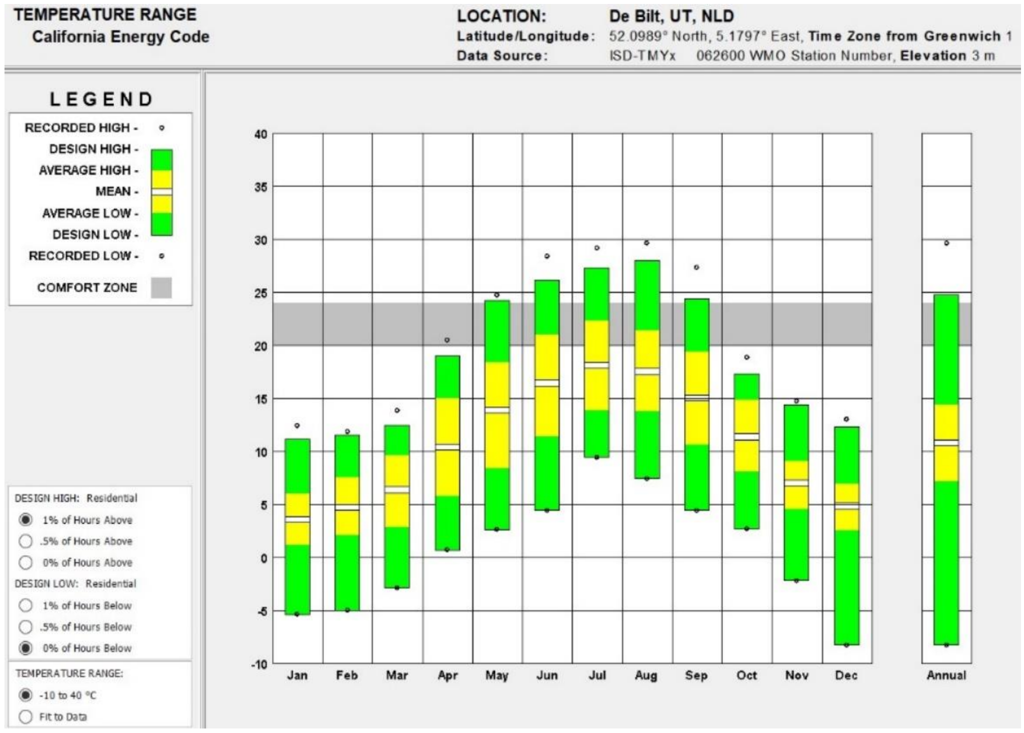
Definition of the Key Terms

Affordable Housing	The term affordable owner-occupied home is often used for households with a middle income that is so high that they are no longer eligible for social housing, but at the same time earn too little to be able to afford an expensive (owner) home on the free market. (Springco Urban Analytics, 2021)
Modular Architecture	Modular Architecture is a construction technique in which modules are linked or stacked to create a building. The modules are produced in a factory, are brought to the site ready for use and are installed on site using a crane. (Portakabin, n.d.)
Flexibility	In this study flexibility stands for the ability of a climate system element to not interfere with the building. An interference would be long piping that need to be pulled through a building. This means that if an element can affect the indoor climate by taking the least amount of space possible and could be placed everywhere in a habitation, it would be considered flexible.
Passivhaus	Passivhaus is a technique developed to design comfortable, highly energy and efficient buildings with set performance targets and to achieve a net zero operational carbon building. Good Passivhaus design is based on free heat in winter, simple building form, high levels of insulation, extremely airtight building, reducing of thermal bridges, triple glazed windows, natural purge ventilation, background mechanical ventilation with heat recovery and an accurately predicted energy use. (Etude and Levitt Bernstein People Design, n.d.)
Purchase Price	The purchase price is the initial price that needs to be paid to install a climate system element.
Usage Price	The usage price includes the costs of the electricity that is needed to power a climate system element and the costs of water.

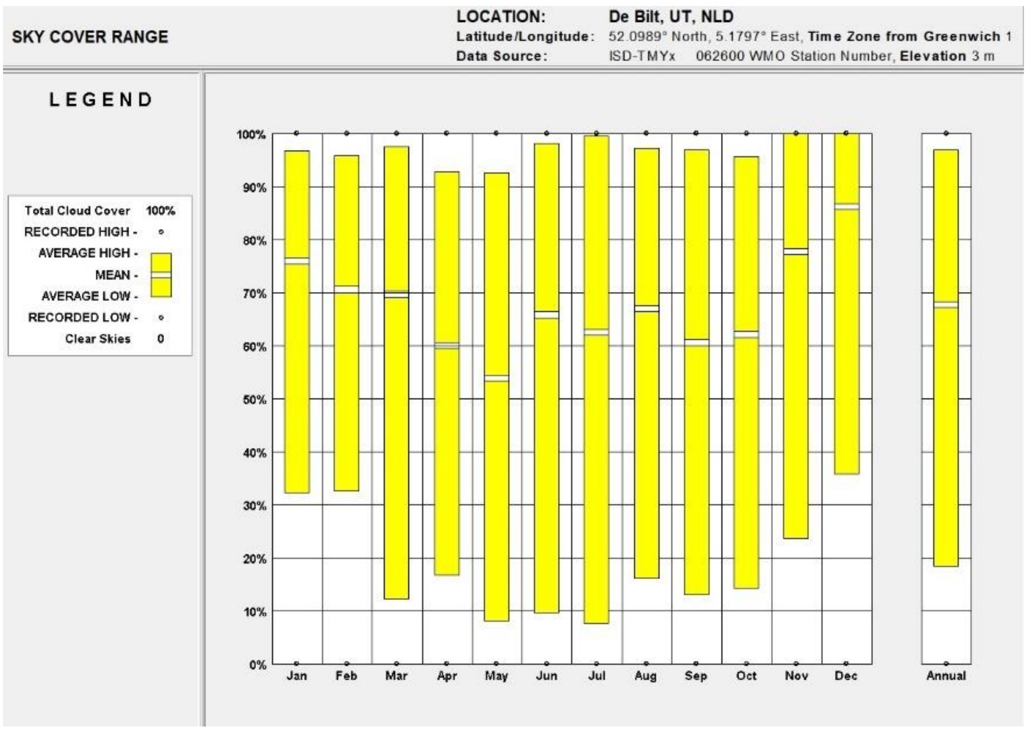
Appendix A. Definition of the Key Terms

Appendix B

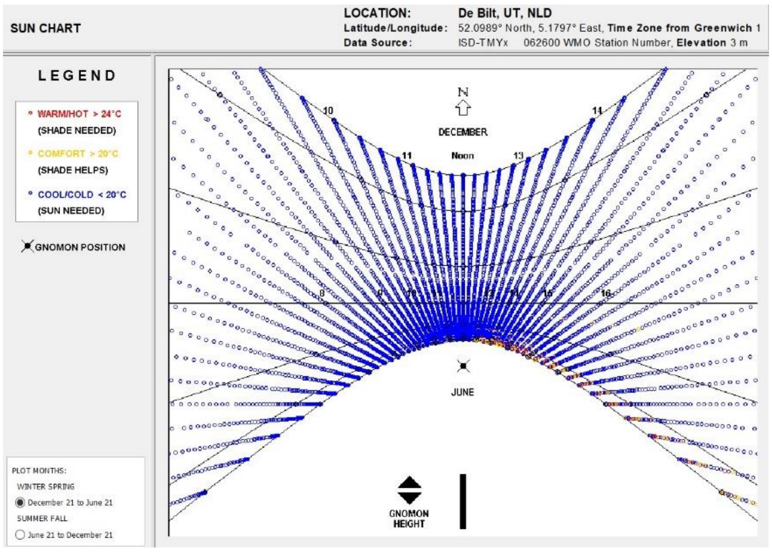
Output Climate Situation Den Bilt (The Netherlands) from *Climate Consultant*



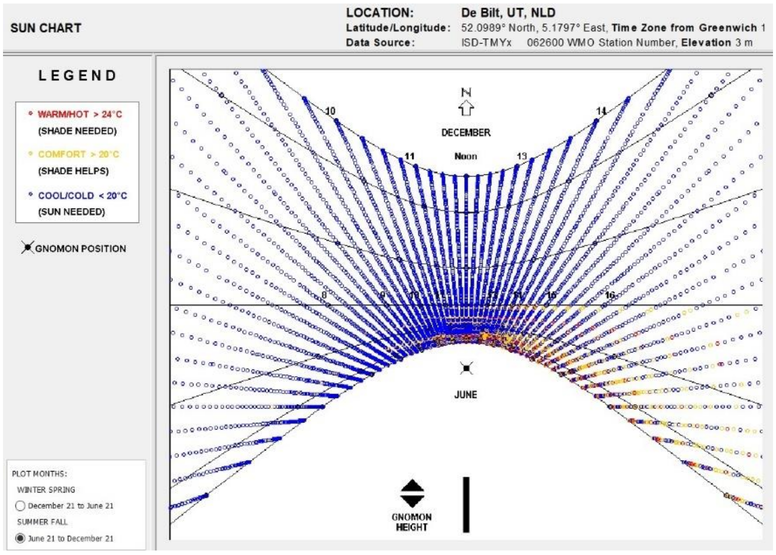
Appendix B1. Annual Temperature Range (Climate Consultant)



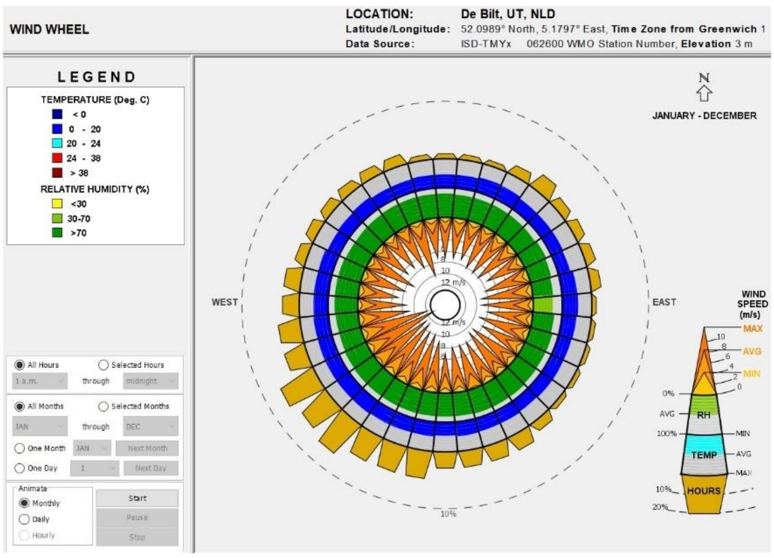
Appendix B2. Annual Sky Cover Range (Climate Consultant)



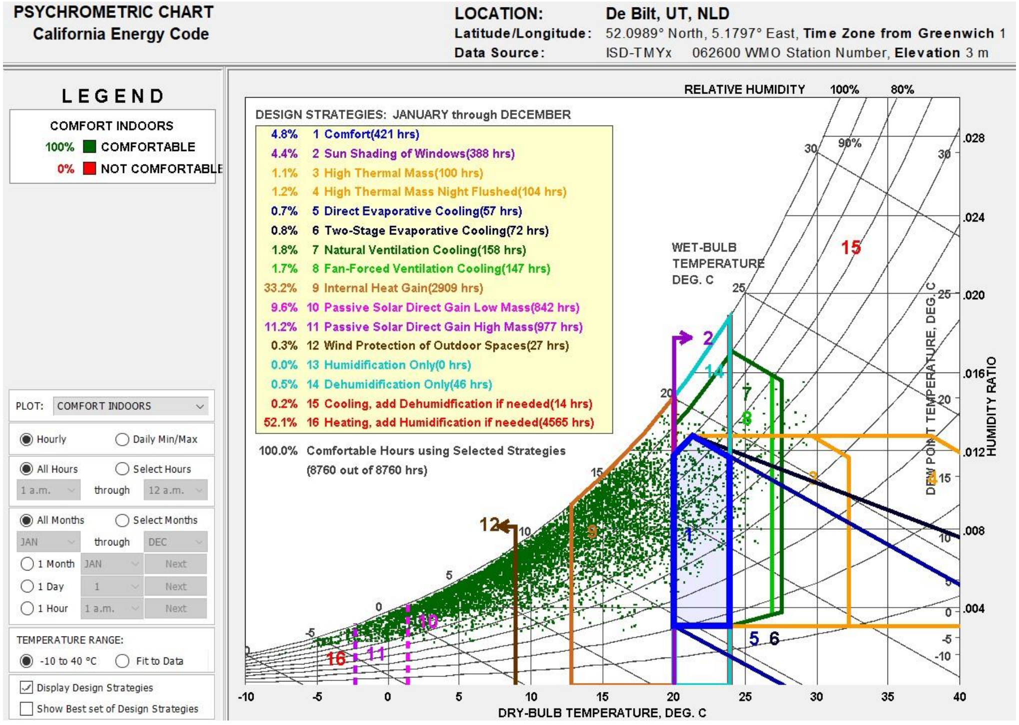
Appendix B3. Sun Chart December to June (Climate Consultant)



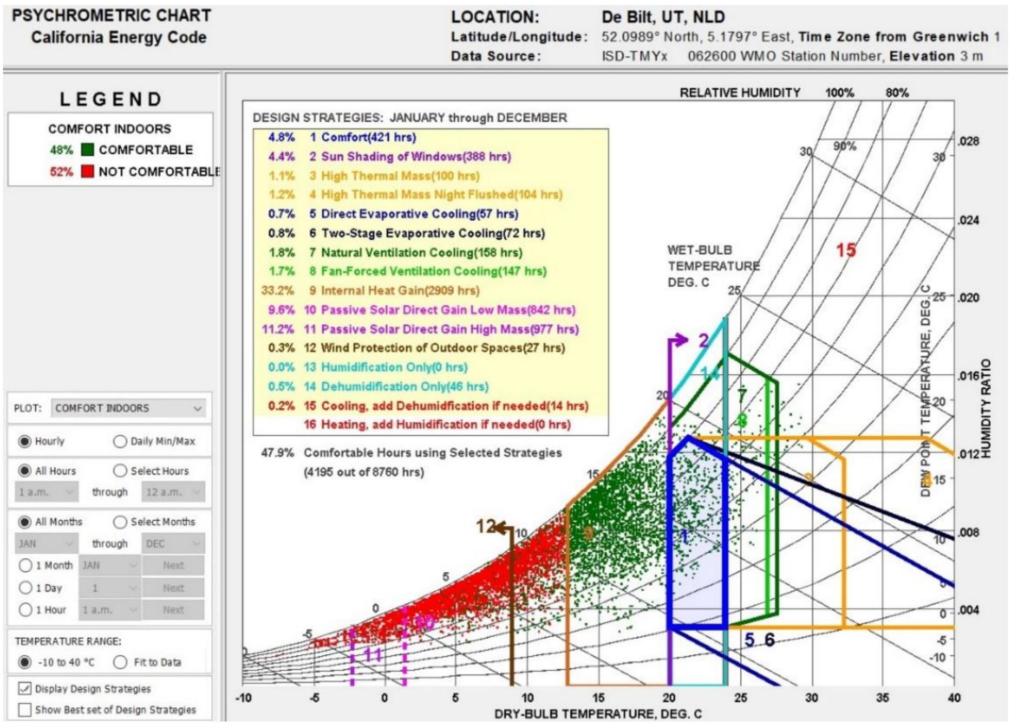
Appendix B4. Sun Chart June to December (Climate Consultant)



Appendix B5. Wind Wheel (Climate Consultant)



Appendix B6. Influence Design Strategies on Indoor Comfort (Climate Consultant)



Appendix B7. Influence Design Strategies on Indoor Comfort Without Heating (Climate Consultant)

APPENDIX C

Information about the Case Studies

M'DAM

General Information

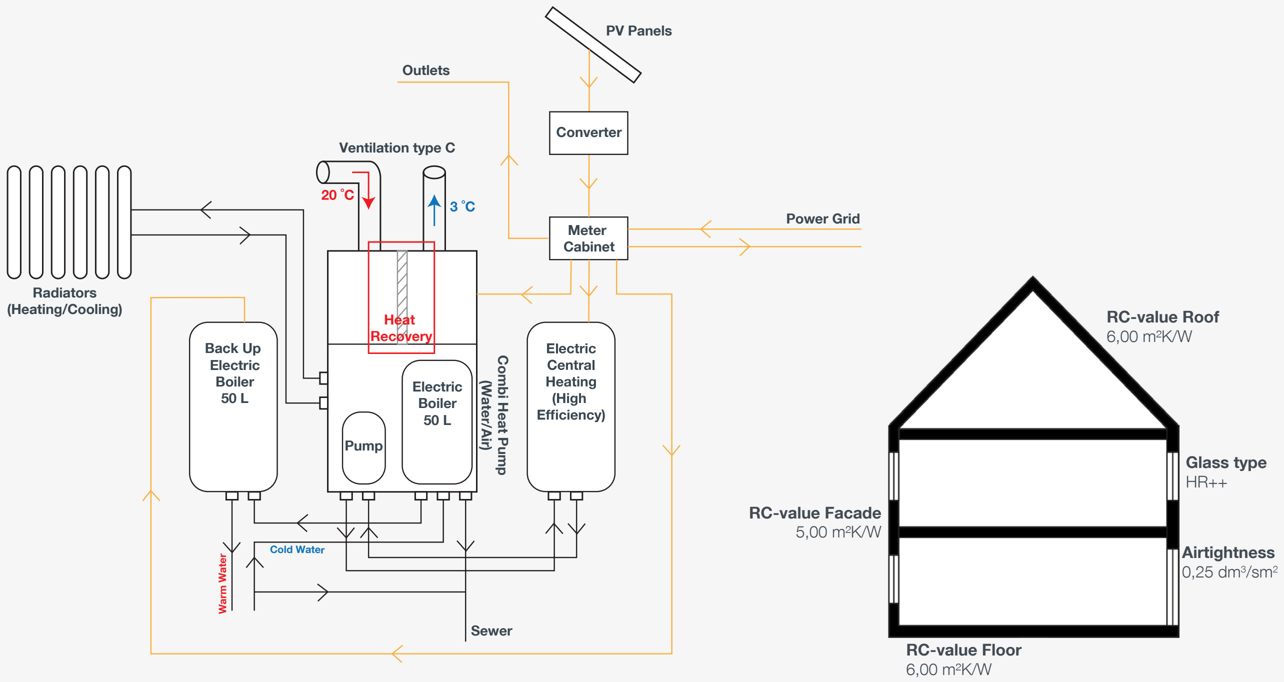
Architect	Finch Buildings
Location	Monnickendam, The Netherlands
Climate Principle	Active System
Typology	Modular Apartment Complex (50,65,76,110 m²)
Function	Dwelling (Social Rent, Social Owner-Occupied, Private Owner-Occupied)
Number Units	62
Year	2021

Source (Finch Buildings, n.d.)

Impressions Building

Source (Finch Buildings, n.d.)

Climate Principle Scheme



Source (Inventum, 2017) (Loohuis Energie & Installatie Advies B.V, 2018a) (Loohuis Energie & Installatie Advies B.V, 2018b)

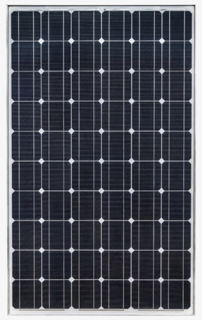
Climate Elements

Element	Combi Air Heat Pump and Ventilation Unit Type C
Name	Inventum Ecolution Combi 50 All Electric
System	Active System
Typology	Heating/Cooling + Ventilation + (Warm) Water
Purpose	Heat recovery of ventilation system is the heating source. Connected to a back up boiler and electric central heating to compensate in case of over consumption.
Effectiveness	As an active system the element does affect the indoor climate directly (Energy Label A+++), Vent Type C is less effective than D. Fully mechanic system affects more directly.
Purchase Price	~€4.000 per pump
Usage Price	High Energy label, no gas, energy from PV panels: low usage price

Element	Electric Central Heating (CH)
Name	-
System	Active System
Typology	Heating/Cooling
Purpose	Heating system to compensate in case of over consumption. All kind of CH can be connected to the HP.
Effectiveness	Active system affects indoor climate directly (High Efficiency)
Purchase Price	~€1.000 per CH
Usage Price	On 100m², €2.000 consumption costs, but with energy PV panels, it will be lower

Element	Electric Boiler
Name	Inventum EDR 50
System	Active System
Typology	(Warm) Water
Purpose	Boiler to compensate in case of warm water over consumption.
Effectiveness	Lower capacity (Energy Label C)
Purchase Price	~€900 per Boiler
Usage Price	Energy Label C, not very efficient in costs

Element	Radiators
Name	Jaga Low H20 Tempo Omkasting
System	Active System
Typology	Heating/Cooling
Purpose	Heat emissions in the building
Effectiveness	Active system that heats in a passive way through radiation and convection. Highest EPC and saving up until 16% (Most efficient radiator in the Netherlands)
Purchase Price	~€400-600 per Radiator
Usage Price	Saves op 16% of energy use, but with energy PV panels, it will have a low usage price



Element	PV Panels (530 units)
Name	-
System	Active System
Typology	Electricity
Purpose	Generating energy
Effectiveness	Peak capacity of 365 Wp/panel
Purchase Price	~€150 per Panel
Usage Price	No usage price, lowers price of other elements

Element	HR++ Glass
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	Lower Heat Transfer Coefficient, less heat is transferred through the glass, more efficient (1,65 W/m²K)
Purchase Price	~€80 per m²
Usage Price	No usage price, lowers price of other elements

Element	EPS Insulation
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	High Insulation Value 030 – 0.040 W/mK
Purchase Price	~€10 per m²
Usage Price	No usage price, lowers price of other elements

Sources (Inventum, 2017) (Sanispecials, n.d.) (Verwarminginfo, n.d.) (Jaga, n.d.) (Solar Outlet, n.d.) (Dubbelglasstunter, n.d.) (Isolatie-info, n.d.)

Appendix C1. Climate System M'DAM

PARK AVENUE

General Information

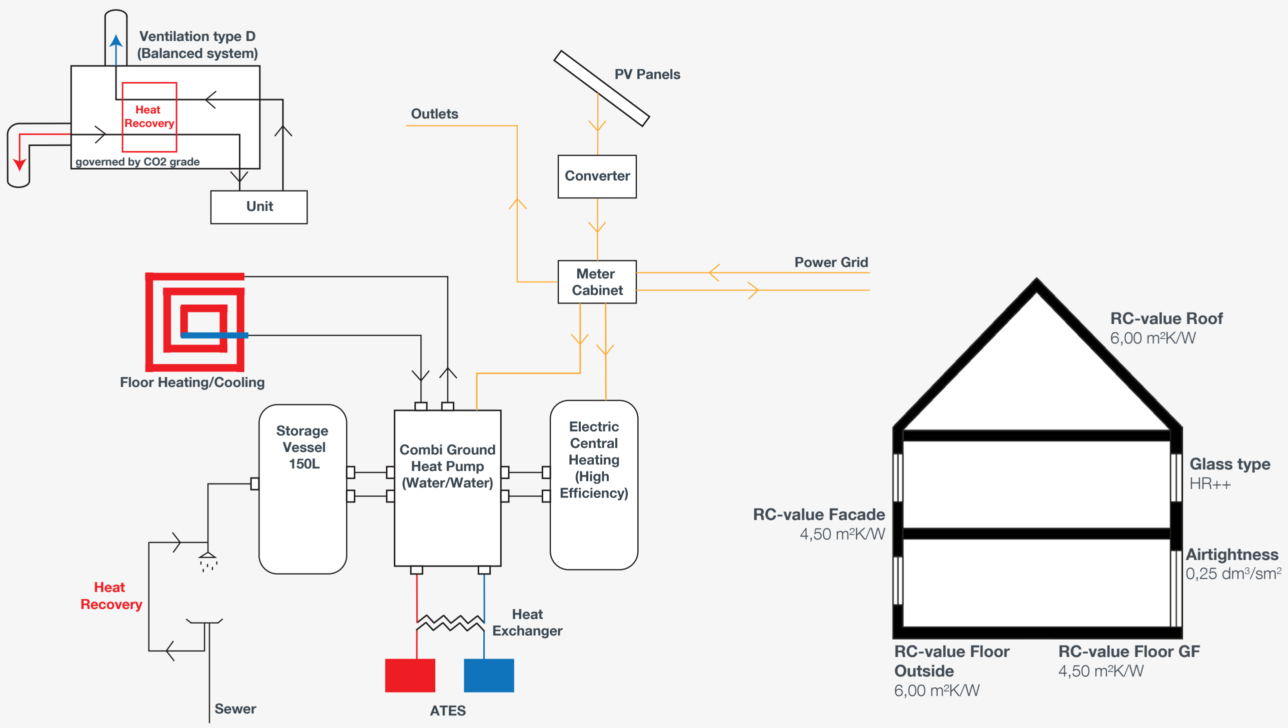
Architect	Klunder Architecten
Location	Utrecht, The Netherlands
Climate Principle	Active System
Typology	Apartment Complex (Lofts, Apartments, Penthouses - 77-198 m²)
Function	Dwelling (Private Owner-Occupied)
Number Units	55
Year	2020

Source (VORM, n.d.)

Impressions Building

Source (Klunder Architecten, 2018)

Climate Principle Scheme



Source (Klimaatgarant, n.d.) (Buro Bouwfysica, 2020a) (Buro Bouwfysica, 2020b)

Climate Elements

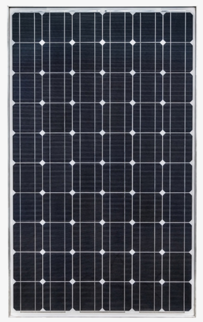
Element Combi Ground Heat Pump (Water/Water)
Name Itho Daalderop WPU 55 5G
System Active System
Typology Heating/Cooling
Purpose Heating source is Aquifer Thermal Energy Storage (ATES). Connected to Storage Vessel and a back up Central Heating System.
Effectiveness As an active system the element does affect the indoor climate directly (Energy Label A+++)
Purchase Price ~€6.000 per pump + ATES
Usage Price High Energy label, no gas, energy from PV panels: low usage price

Element Electric Central Heating (CH)
Name -
System Active System
Typology Heating/Cooling
Purpose Heating system to compensate in case of over consumption. All kind of CH can be connected to the HP.
Effectiveness Active system affects indoor climate directly (High Efficiency)
Purchase Price ~€1.000 per CH
Usage Price On 100m², €2.000 consumption costs, but with energy PV panels, it will be lower

Element Storage Vessel 150L
Name WPV150
System Active System
Typology (Warm) Water
Purpose To prepare and store warm water.
Effectiveness Efficient thanks to direct connection with heat pump (Energy Label A+)
Purchase Price ~€950 per Vessel
Usage Price High Energy label, no gas, energy from PV panels: low usage price

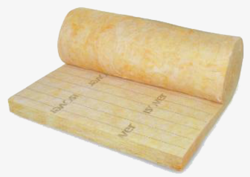
Element Ventilation Unit Type D - Balanced System
Name Itho Daalderop HRU ECO 300 DUO Zone
System Active System
Typology Ventilation
Purpose Mechanical balanced system, governed by CO_2 grade. Ventilation system for fresh air supply, no cooling system.
Effectiveness Fully mechanical system affects indoor climate directly (Energy Label A+)
Purchase Price ~€2.500 per Unit
Usage Price High Energy label, no gas, energy from PV panels: low usage price

Element Low Temperature Floor Heating
Name -
System Active System
Typology Heating/Cooling
Purpose Heat emissions in the building
Effectiveness Active system that heats in a passive way through radiation
Purchase Price ~€40-100 per m²
Usage Price Energy from PV panels



Element PV Panels (463 units)
Name -
System Active System
Typology Electricity
Purpose Generating energy
Effectiveness Peak capacity of 370 Wp/panel
Purchase Price ~€180 per Panel
Usage Price No usage price, lowers price of other elements

Element HR++ Glass
Name -
System Passive System
Typology Indoor Comfort
Purpose Insulating
Effectiveness Lower Heat Transfer Coefficient, less heat is transferred through the glass, more efficient (1,65 W/m²K)
Purchase Price ~€80 per m²
Usage Price No usage price, lowers price of other elements



Element Mineral Wool Insulation
Name -
System Passive System
Typology Indoor Comfort
Purpose Insulating
Effectiveness High Insulation Value 0.032-0.041 W/mK
Purchase Price ~€15-20 per m²
Usage Price No usage price, lowers price of other elements

Sources (Solar Outlet, n.d.) (Dubbelglasstunter, n.d.) (Itho Daalderop, 2020) (Verwarminginfo, n.d.) (Itho Daalderop, 2021a) (Itho Daalderop, 2021b) (Isolatie-info, n.d.) (Vloerverwarming Direct, n.d.)

Appendix C2. Climate System Park Avenue

VELDHUIS

General Information

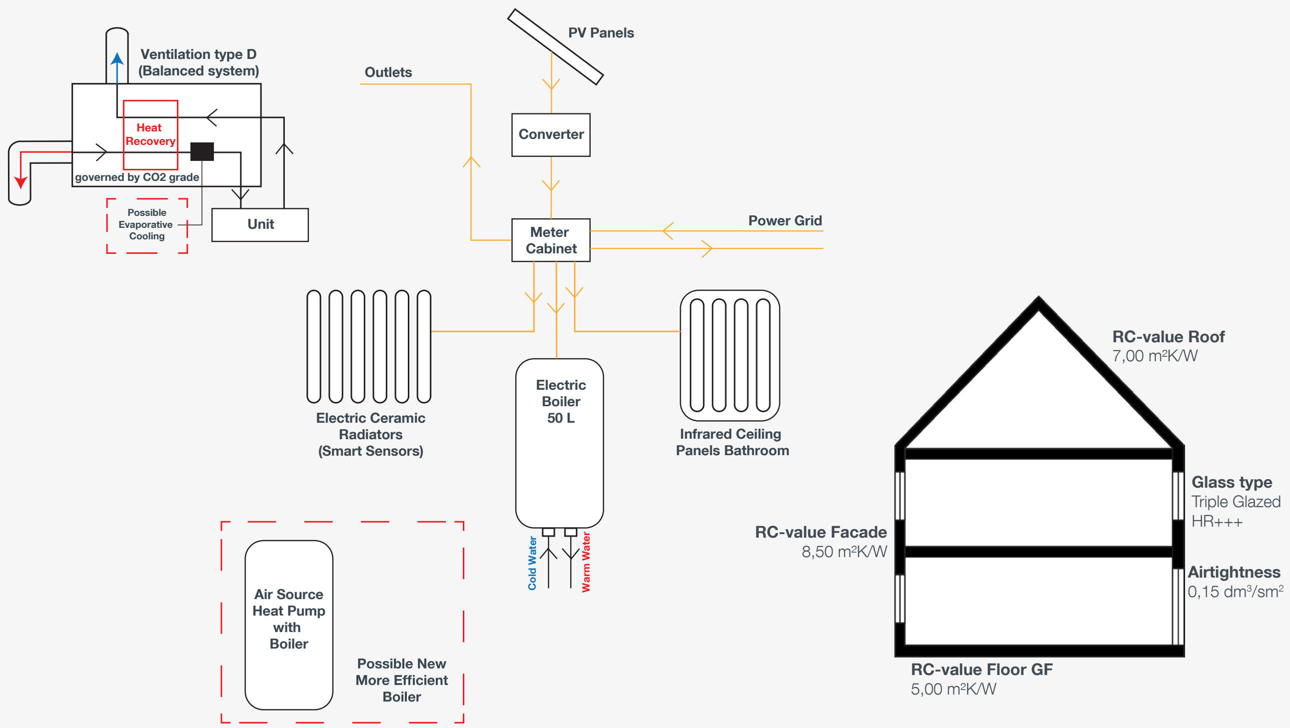
Architect	FAME Groep B.V.
Location	Apeldoorn, The Netherlands
Climate Principle	Passive System
Typology	Apartment Complex (2 Room Apartments)
Function	Residential Care Center (Inpatient Nursing Care, Private Rent)
Number Units	86 (7.537 m²)
Year	2019

Source (Troelstra, 2021)

Impressions Building

Source (Klokgroep.nl, n.d.)

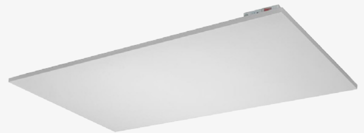
Climate Principle Scheme



Source (Troelstra, 2021)

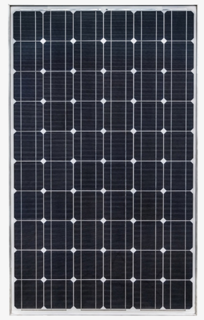
Climate Elements

Element	Electric Ceramic Radiators
Name	-
System	Active System
Typology	Heating/Cooling
Purpose	Heat emissions in the building (No need for much heating, building very efficiently insulated)
Effectiveness	Not very energy efficient, Active system that heats in a passive way through radiation and convection
Purchase Price	~€20-100 per Radiator
Usage Price	Energy from PV panels



Element	Infrared Ceiling Panels
Name	-
System	Active System
Typology	Heating/Cooling
Purpose	Heat emissions in the building (No need for much heating, building very efficiently insulated)
Effectiveness	Energy efficient, Active system that heats in a passive way through radiation and convection
Purchase Price	~€350-1000 per Panel
Usage Price	Energy from PV panels

Element	Electric Boiler 50L
Name	-
System	Active System
Typology	(Warm) Water
Purpose	To prepare and store warm water.
Effectiveness	Medium capacity (Energy Label B)
Purchase Price	~€700 per Boiler
Usage Price	Saves 10% more than normal electric boilers



Element	PV Panels
Name	-
System	Active System
Typology	Electricity
Purpose	Generating energy
Effectiveness	Peak capacity not specifically mentioned
Purchase Price	~€- per Panel
Usage Price	No usage price, lowers price of other elements

Element	Ventilation Unit Type D - Balanced System
Name	-
System	Active System
Typology	Ventilation
Purpose	Mechanical balanced system, governed by CO_2 grade. Ventilation system for fresh air supply, no cooling system.
Effectiveness	Fully mechanical system affects indoor climate directly (Energy Label A+)
Purchase Price	~€2.500 per Unit
Usage Price	High Energy label, no gas, energy from PV panels: low usage price

Element	HR+++ Glass
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	Lower Heat Transfer Coefficient, less heat is transferred through the glass, more efficient (0,5-0,9 W/m²K)
Purchase Price	~€120-150 per m²
Usage Price	No usage price, lowers price of other elements

Element	Insulation
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	Insulation Value not known as insulation material is not mentioned
Purchase Price	~€- per m²
Usage Price	No usage price, lowers price of other elements

Source (Itho Daalderop, 2020) (Dubbelglasstunter, n.d.) (Warmteservice, n.d.) (Elektrische Radiatoren, n.d.) (Verwarminginfo, n.d.)

Appendix C3. Climate System Veldhuis

AGAR GROVE

General Information

Architect	Hawkins\Brown with Mae
Location	London, England
Climate Principle	Passive System
Typology	Apartment Complexes (Maisonettes, 1-2-3 Bedroom Apartments)
Function	Dwelling (Social Rent, Private Owner-Occupied), Commercial
Number Units	493
Year	2018-tbd

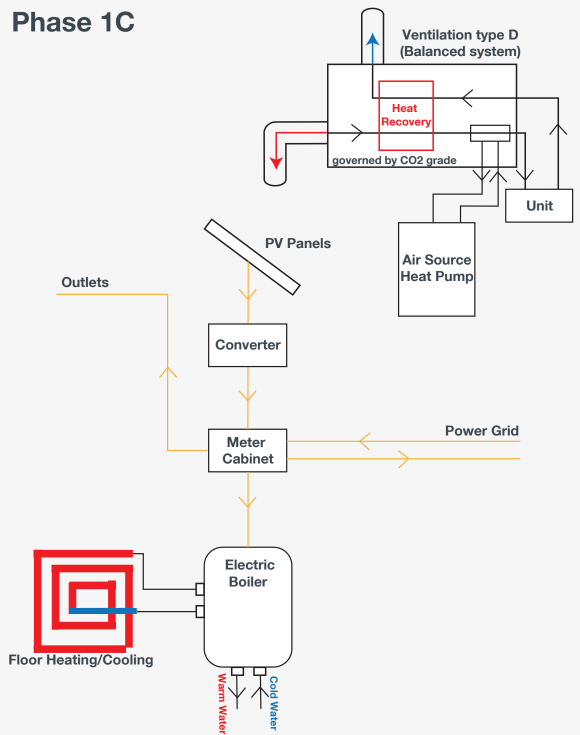
Source (Max Fordham, n.d.) (Camden, 2019)

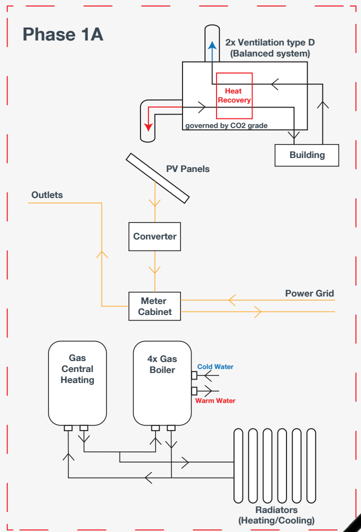
Impressions Building

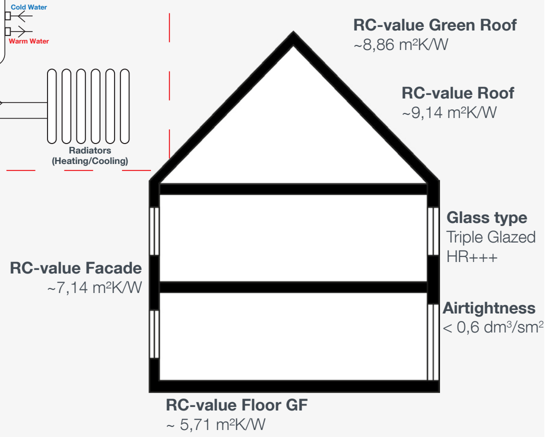
Source (Hawkins\Brown, n.d.)

Climate Principle Scheme

Phase 1C





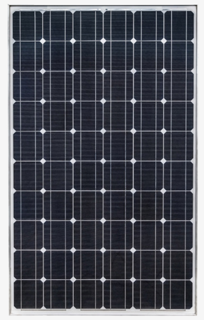


Source (Max Fordham, n.d.) (Etude and Levitt Bernstein People Design, n.d.) (Hawkins\Brown, n.d.)

Climate Elements

Element	Air Source Heat Pump (Air/Air)
Name	-
System	Active System
Typology	Heating/Cooling
Purpose	Heating and Cooling the building through air and the MVHR.
Effectiveness	As an active system the element does affect the indoor climate directly (Energy Label A+++)
Purchase Price	~€1.500-3.000 per pump
Usage Price	High Energy label, no gas, but not enough PV to generate enough energy: higher usage price

Element	Electric Boiler
Name	-
System	Active System
Typology	(Warm) Water
Purpose	To prepare and store warm water.
Effectiveness	No specific boiler has been mentioned, capacity may vary
Purchase Price	~€- per Boiler
Usage Price	Not enough PV to generate enough energy: higher usage price



Element	PV Panels
Name	-
System	Active System
Typology	Electricity
Purpose	Generating energy
Effectiveness	Peak capacity not specifically mentioned
Purchase Price	~€- per Panel
Usage Price	No usage price, lowers price of other elements

Element	Ventilation Unit Type D - Balanced System
Name	-
System	Active System
Typology	Ventilation
Purpose	Mechanical balanced system, governed by CO_2 grade. Ventilation system for fresh air supply, no cooling system.
Effectiveness	Fully mechanical system affects indoor climate directly (Energy Label A+)
Purchase Price	~€2.500 per Unit
Usage Price	High Energy label, no gas, energy from PV panels: low usage price

Element	Floor Heating
Name	-
System	Active System
Typology	Heating/Cooling
Purpose	Heat emissions in the building
Effectiveness	Active system that heats in a passive way through radiation
Purchase Price	~€40-100 per m²
Usage Price	Not enough PV to generate enough energy: higher usage price

Element	Air Tightness Tape
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Keeps building air tight
Effectiveness	Extra air tightness
Purchase Price	~€40 per roll
Usage Price	No usage price, lowers price of other elements

Element	HR+++ Glass
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	Lower Heat Transfer Coefficient, less heat is transferred through the glass, more efficient (0,5-0,9 W/m²K)
Purchase Price	~€120-150 per m²
Usage Price	No usage price, lowers price of other elements

Element	Mineral Wool Insulation
Name	-
System	Passive System
Typology	Indoor Comfort
Purpose	Insulating
Effectiveness	High Insulation Value 0.032-0.041 W/mK
Purchase Price	~€15-20 per m²
Usage Price	No usage price, lowers price of other elements

Source (Isolatie-info, n.d.) (Dubbelglasstunter, n.d.) (Vloerverwarming Direct, n.d.) (Itho Daalderop, 2020) (Isolatienoord, n.d.) (SPRSUN, n.d.)

Appendix C4. Climate System Agar Grove

APPENDIX D

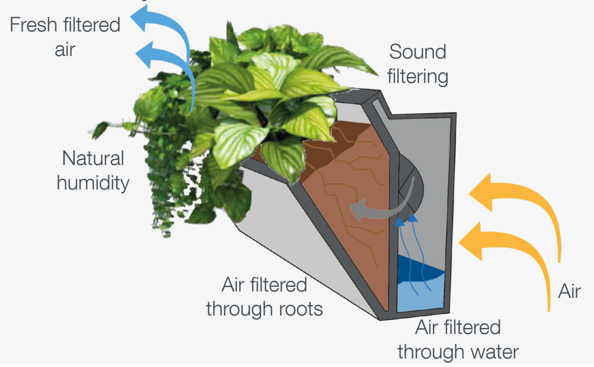
Innovative Techniques

INNOVATIVE TECHNIQUES

General Information

Element Passive Ventilation Unit
Name Smartty Air Clean
System Passive System
Typology Ventilation
Purpose Passive way to ventilate a habitation
Effectiveness Passive, less effective than active ventilation, this system only needs to ventilate a few rooms, plants filter air and sound, creates natural humidity
Purchase Price -
Usage Price -

Climate Principle Scheme



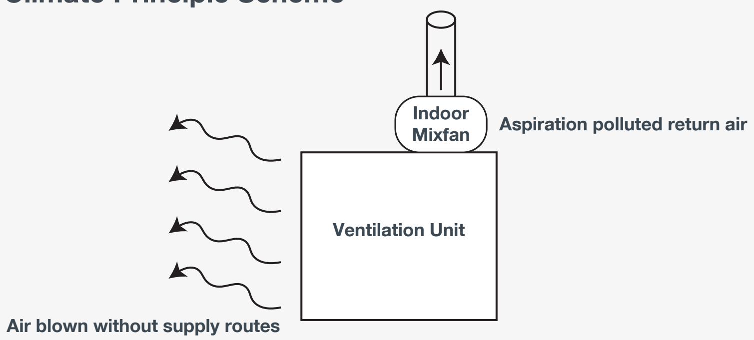
Climate Element

Source (Smartty, n.d.)

General Information

Element Ventilation Unit with Heat Recovery without Supply Routes
Name Multi Air Supply System
System Active System
Typology Ventilation
Purpose Flexible ventilation unit, without supply routes, air is blown into the main hall, and spreads through the door cracks, Indoor Mixfan aspirates polluted return air.
Effectiveness Heat Recovery can be regulated, Type D effective
Purchase Price -
Usage Price -

Climate Principle Scheme



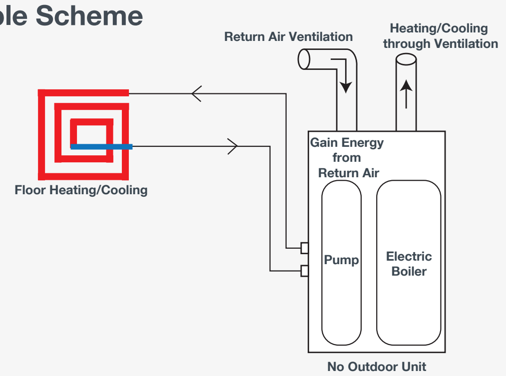
Climate Element

Source (Brink, n.d.)

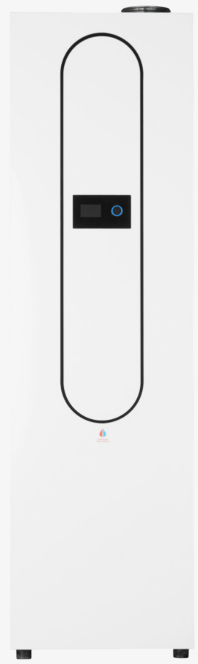
General Information

Element Combi Air Heat Pump, Ventilation and Boiler
Name Modul-AIR Blue
System Active System
Typology Heating/Cooling, (Warm) Water, Ventilation
Purpose First all-electric air heat pump that actively cools and heats, warms water and ventilates the habitation
Effectiveness Active systems heats directly (A+++), Type C and D possible, D more effective but need for an extra element
Purchase Price -
Usage Price -

Climate Principle Scheme



Climate Element

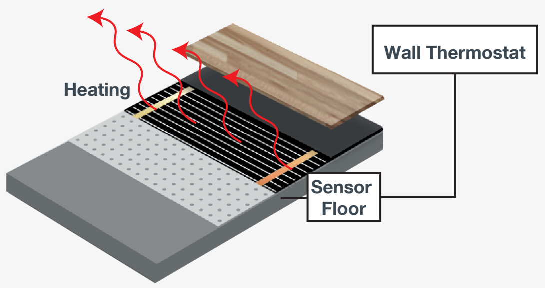


Source (Inventum, n.d.)

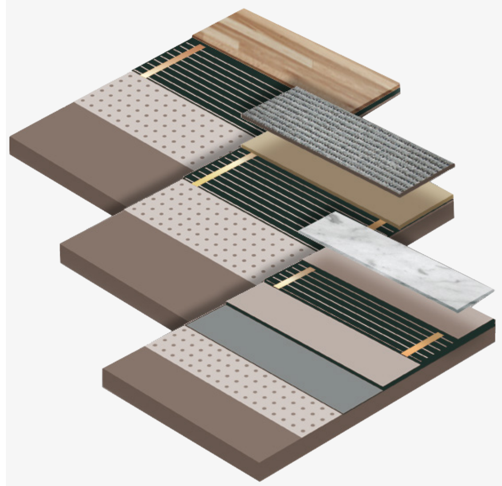
General Information

Element Heating Floor Foil
Name Karbonic Heating Foil
System Active System
Typology Heating
Purpose Easy applicable, flexible and cheap floor heating
Effectiveness Conversion electricity to heat 100%,12 % energy saving, Active system that heats in a passive way through radiation
Purchase Price -
Usage Price -

Climate Principle Scheme



Climate Element



Source (Karbonik, n.d.)

Appendix D. Innovative Climate System Elements

APPENDIX E

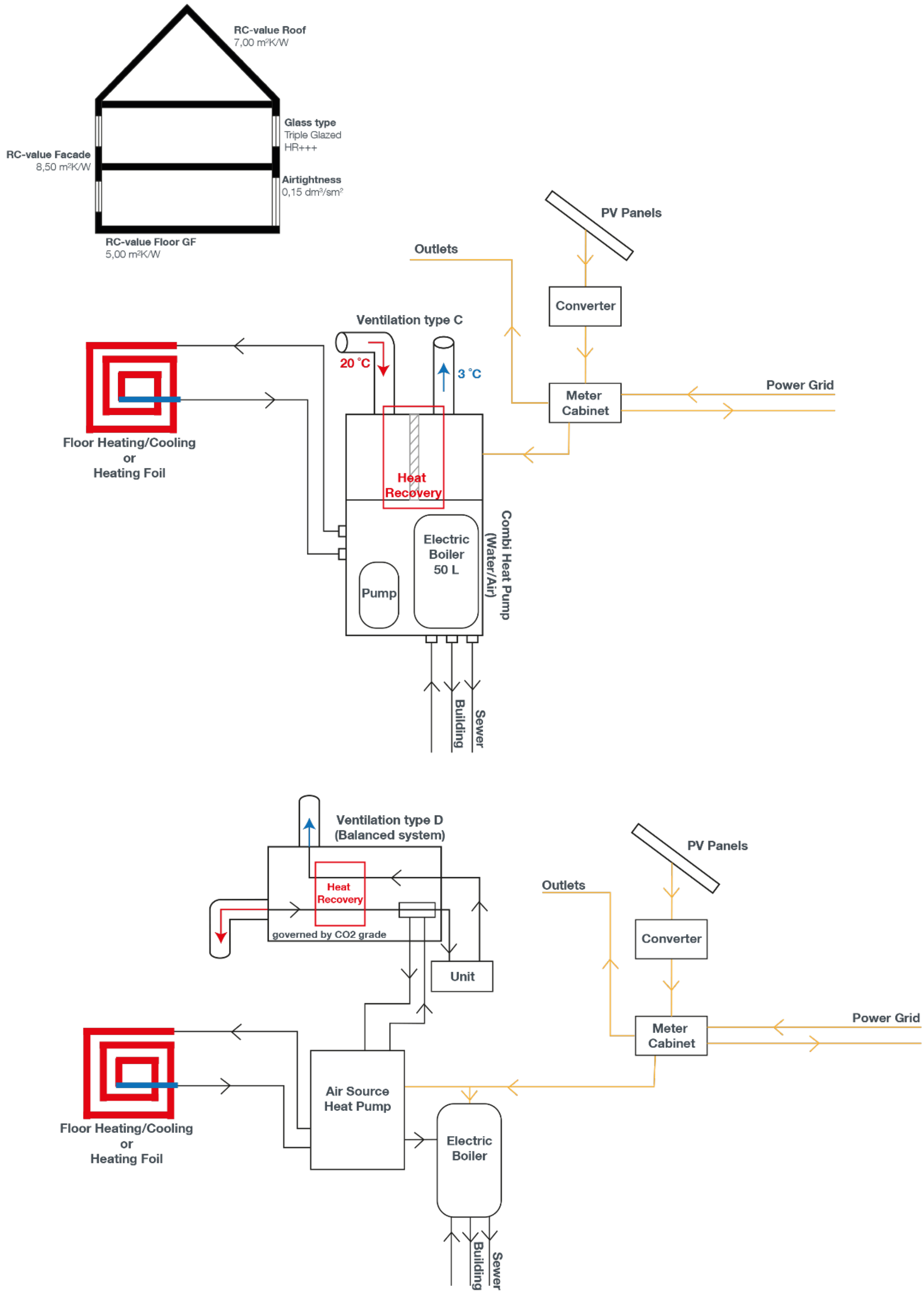
Catalog

	Element	Active | Passive	Purpose	Effectiveness	Average Price	Flexibility
Heating/Cooling	Combi Air Heat Pump and Ventilation Unit Type C	**Active** | Passive	Heating, cooling and ventilation with back-up boiler and central heating, all-electric	●●●●◐	●●●○○	●●●○○
	Electric Central Heating	**Active** | Passive	Heating system, not as effective as heat pump so can be used as back up or when small amounts of heat are needed	●●●○○	●●○○○	●●●○○
	Radiators	**Active** | Passive	Heat emissions in the building controlled by heat pump	●●●○○	●●●○○	●●●○○
	Ground Heat Pump	**Active** | Passive	Heating and cooling with back up electric central heating with ATES	●●●●○	●●●●○	●●○○○
	(Low Temperature) Floor Heating	**Active** | Passive	Heat emissions in the building controlled by heat pump	●●●○○	●●○○○	●●●●○
	Electric Radiators	**Active** | Passive	Heat emissions in the building controlled by heat pump, all-electric	●●○○○	●●●●○	●●●○○
	Infrared Ceiling Panels	**Active** | Passive	Heat emissions in the building controlled by heat pump, all-electric	●●●○○	●●●●○	●●●○○
	Air Heat Pump	**Active** | Passive	Heating and cooling through air, can be connected to MVHR	●●●●○	●●●○○	●●●○○
(Warm) Water	Electric Boiler 50 L	**Active** | Passive	Boiler for warm water, can be used as back up in case of over consumption	●●○○○	●●○○○	●●●○○
	Storage Vessel 150 L	**Active** | Passive	Boiler to warm water and storage	●●●○○	●●○○○	●●●○○
Electricity	PV panels 365 Wp	**Active** | Passive	Generates energy for the building and to supply the climate system	●●●○○	●●●○○	●●○○○
	PV panels 370 Wp	**Active** | Passive	Generates energy for the building and to supply the climate system	●●●○○	●●●○○	●●○○○
Ventilation	Combi Air Heat Pump and Ventilation Unit Type C	**Active** | Passive	Heating, cooling and ventilation with back-up boiler and central heating, all-electric	●●●●◐	●●●○○	●●●○○
	Ventilation Unit Type D	**Active** | Passive	Mechanical ventilation system for fresh air supply, governed by CO_2	●●●●○	●●●○○	●●●○○
Indoor Comfort	HR ++ Glass	Active | **Passive**	Insulating	●●●●○	●●○○○	●●●●●
	HR +++ Glass	Active | **Passive**	Insulating	●●●●●	●●●○○	●●●●●
	Mineral Wool Insulation	Active | **Passive**	Insulating	●●●●○	●○○○○	●●●●●
	EPS Insulation	Active | **Passive**	Insulting	●●●●○	●○○○○	●●●●●
	Air Tightness Tape	Active | **Passive**	Keeps building air tight	●●●○○	●○○○○	●●●●●
Innovative Elements	Smartty Air Clean	Active | **Passive**	Passive ventilation unit, filters air and creates natural humidity	●●●○○	●●○○○	●●●●○
	Modul-AIR Blue	**Active** | Passive	All-electric air heat pump that actively cools and heats, ventilates (C/D) and warms water	●●●●◐	●●●●●	●●●●○
	Multi Air Supply System	**Active** | Passive	Ventilation unit without supply routes (Type D)	●●●○○	●●○○○	●●●●○
	Karbonic Heating Foil	**Active** | Passive	Easy applicable foil for floor heating, heat emissions in the building	●●●●○	●○○○○	●●●●●

Appendix E. Climate System Elements Catalog

APPENDIX F

Possible Climate Systems for Modular Buildings



Appendix F. Possible Options for Climate Systems for Modular Buildings